

LITHOPROBE

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

and

CORDILLERAN TECTONICS WORKSHOP

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LITHOPROBE SLAVE/NORTHERN CORDILLERA LITHOSPHERIC EVOLUTION WORKSHOP

and

CORDILLERAN TECTONICS WORKSHOP

University of Calgary, March 1-3, 1996

SATURDAY, March 2, 1996

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Chairman: F. A. Cook

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ABSTRACTS of ORAL PRESENTATIONS

Preface

This volume includes the abstracts and short articles submitted for the 1996 LITHOPROBE Slave-Northern Cordillera Lithospheric Evolution (SNORCLE) and Cordilleran Tectonics Workshop. These meetings were held concurrently on March 1-3 at the University of Calgary in order to facilitate travel and minimize overlap. Accordingly, although this is the 4th LITHOPROBE SNORCLE transect report, it includes several contributions (both oral and poster) from work in the southern Canadian Cordillera. We thank Phil Simony for assisting in the organization of the meeting.

Frederick A. Cook and Philippe Erdmer

The Deep Crust of the Western Slave Province - Geological Mapping and U-Pb Geochronology of the Forked Lake Area

Thomas Chacko, Matthew Perks, Robert A. Creaser, and Karlis Muehlenbachs.

Department of Earth and Atmospheric Sciences
University of Alberta, Edmonton, Alberta, Canada T6G 2E3

The shallow level of erosion that characterizes much of the Slave Province (SP) generally precludes direct study of the rocks present at mid- and lower-crustal levels. These deeper level rocks are, however, important for understanding the mechanisms by which this ancient craton formed and stabilized. To obtain this information, we have undertaken a detailed petrologic and isotopic study of the high-grade terrane south of Ghost Lake, one of the few known, regionally extensive exposures of deeper-level rocks in the SP. The main goals of the study are to: 1) document the mineral assemblages and metamorphic grade of the metasedimentary and metaigneous rocks within this terrane; 2) determine the pressure-temperature conditions experienced by the terrane; and 3) examine the temporal and genetic relationship between metamorphism and granitoid magmatism using field observations, radiometric dating and stable isotope studies. The data obtained in this study will provide a better understanding of the metamorphic, magmatic and tectonic processes responsible for forming the Slave Craton. These data, in conjunction with data on crustal xenoliths found in SP diatremes (concurrent studies by W.J. Davis -GSC and D. Canil - U. Victoria), will also provide valuable constraints for the modeling of deep-crustal geophysical data obtained in the SNORCLE Transect

The high-grade rocks that are the focus of this study are found in the so-called Ghost Domain (Henderson and Schaan, 1993), which is located south of Ghost Lake approximately 100-150 km NNW of Yellowknife (Fig. 1). The northern part of this domain (Wijninedi Lake map sheet) has recently been mapped on a 1:50000 scale by J.B. Henderson and co-workers (1993; 1994). The southern part of the domain was effectively unmapped before the present study. Henderson and Schaan (1993) and Henderson (1994) documented a southward increase in metamorphic grade within the domain from upper amphibolite to granulite facies. Furthermore, on the basis of a distinctive aeromagnetic signature, they proposed that the high-grade rocks extend for at least 40 km south of the Wijninedi Lake map sheet. Reconnaissance field work during the 1994 season confirmed this proposal as granulite-facies mineral assemblages were found across the entire north-south length of the aeromagnetic anomaly (Henderson and Chacko, 1995). Specific assemblages indicative of granulite-facies conditions include orthopyroxene (and locally clinopyroxene) in orthogneiss bulk compositions, garnet-cordierite $\pm$ K-feldspar and locally garnet-orthopyroxene and garnet-cordierite-orthopyroxene $\pm$ K-feldspar in the pelitic composition metaturbidites and quartz-plagioclase-orthopyroxene $\pm$ biotite in the psammitic metaturbidites. Orthopyroxene, likely of magmatic origin, is also sporadically present in the post-tectonic, K-rich granitoids of the region. Initial thermobarometric estimates from the northern part of the the Ghost Domain made on the basis of the garnet-orthopyroxene-plagioclase-quartz assemblage indicate pressures of 6-7 kbar and temperatures of 825-900°C without any apparent regional variations (Chacko et al., 1995). The high temperature estimates are consistent with field observations indicating extensive partial melting in the pelites related to biotite breakdown.

The primary goal of the 1995 fieldwork was to map a representative section of the poorly studied area south of the Wijninedi Lake map sheet (Fig. 1). The aeromagnetic map of this region shows that it is characterized by steep magnetic gradients which are arranged in a series of bulls-eyes (Fig. 2). One of these aeromagnetic bulls-eyes, the Forked Lake area, was targeted for mapping as part of the M.Sc. thesis research of Matthew Perks. His geological map is shown in Fig. 3. The three major lithologic units in the area in decreasing order of abundance are granitoid composition orthogneiss, migmatized, turbiditic metasediment, and K-feldspar megacrystic granite. The orthogneiss unit can be subdivided on a textural basis into a strongly layered (granitoid gneiss) and more massive varieties (foliated granite, massive granitoid and tonalite). The rock units found in the Forked Lake area are very similar in type and proportion to

those documented by Henderson near Ghost Lake. The orthogneiss unit is a particularly abundant lithology and may represent a major constituent of the middle and lower crust, here and perhaps elsewhere in the SP. There is no apparent variation in metamorphic grade across the map area as granulite-facies assemblages have been found throughout.

The units described above are arranged in a circular map pattern which mimics the circular aspect of the local aeromagnetic anomaly and the arcuate shape of the lakes in the region (Fig. 3). At the core of this feature is a lithologically complex unit consisting dominantly of K-feldspar megacrystic (locally orthopyroxene-bearing) granite along with lesser amounts of metasedimentary enclaves, leucogranite and pegmatite. A related unit, an opx-bearing (locally K-feldspar megacrystic) granite, occurs as a sill- or sheet-like intrusive body concordant with the regional stratigraphy. The metamorphic foliation dips away from the core in all directions suggesting that the circular feature is a structural dome. It is not entirely clear at this stage whether the dome formed in response to the diapiric intrusion of the central granite body or as a result of regional-scale cross folding. Throughout the field area, however, we have noted the occurrence of decimeter- to meter-scale ductile shears, showing an extensional sense of movement. These shears clearly formed at high grade and may reflect extension related to an intrusive doming process. Alternatively, both shearing and granite intrusion may be related to late-stage, regional extension as has been proposed for other parts of the central and southern SP (e.g., Davis et al., 1994; Stubbley, 1994).

Perks is presently processing samples of granite, tonalite and metasediment from the map area for zircon and monazite U-Pb geochronology. The goal of this work is to establish the relative (and absolute) timing of magmatism and high-grade metamorphism. In particular, we are examining the question of whether intrusion of voluminous high-temperature (opx-bearing) magmas into the middle crust provided the heat necessary for granulite-grade metamorphism.

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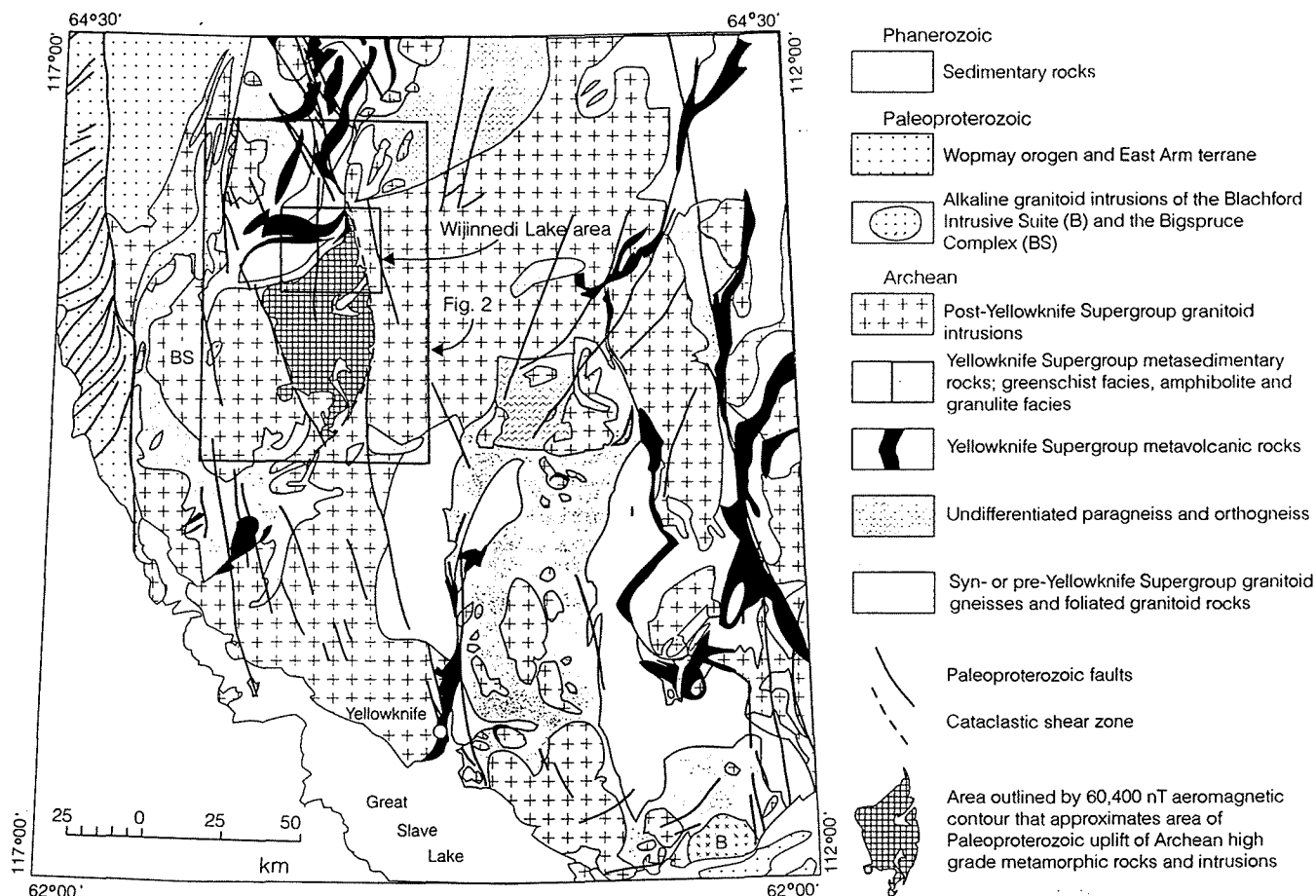


Fig. 1. Map of the southwestern Slave Province showing the location of the high-grade Ghost Domain (cross-hatched pattern) (from Henderson and Chacko, 1995). The Wijinnedi Lake map sheet has been mapped at the 1:50000 scale by J.B. Henderson whereas the region to the south was effectively unmapped before the present study.

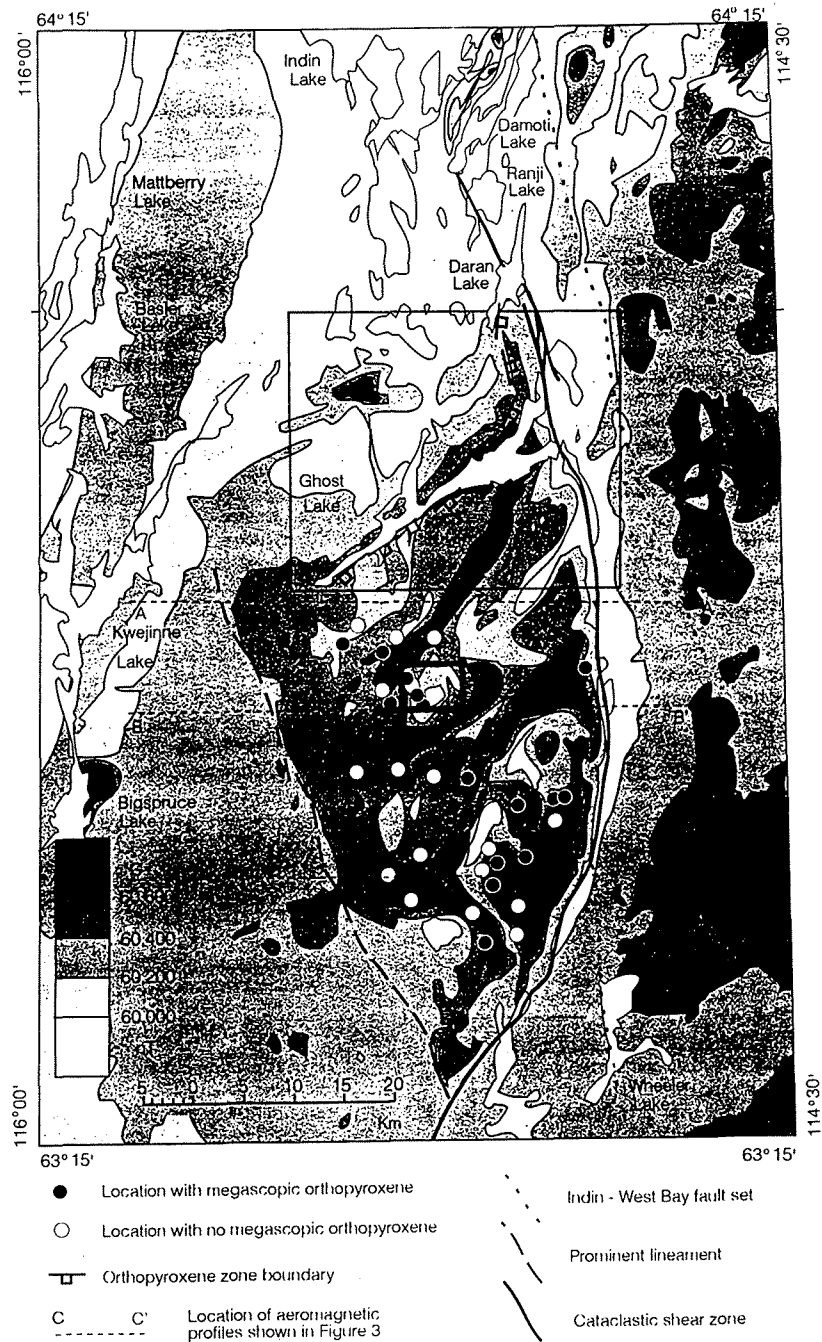


Fig. 2. Aeromagnetic map of the Ghost Lake area (from Henderson and Chacko, 1995). The triangular-shaped region showing high magnetic gradients is the zone of high-grade rocks. The dots represent localities visited during our reconnaissance field work in 1994. The outlined area (Forked Lake) was the focus of detailed mapping in the 1995 field season by M.Sc. student Matt Perks.

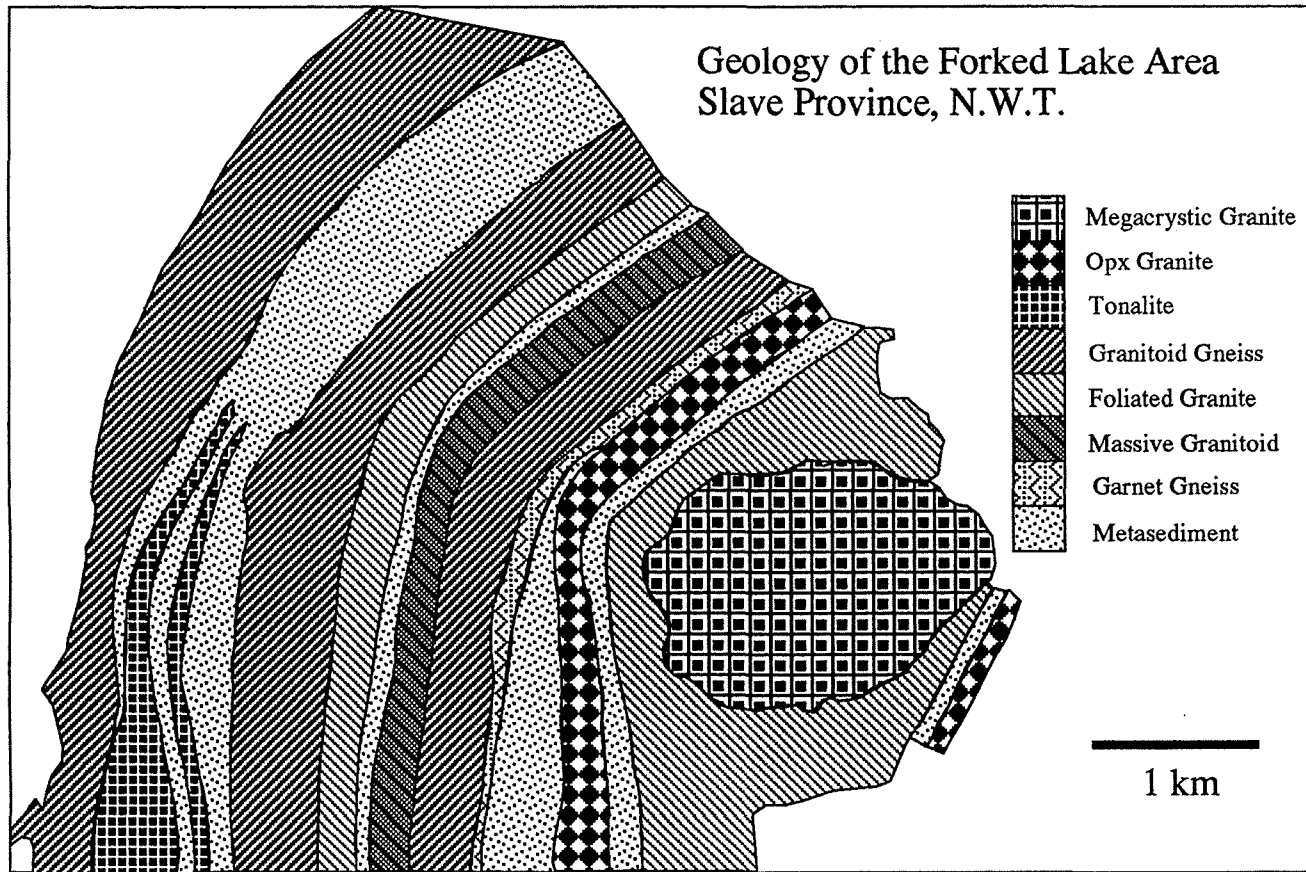


Fig. 3. Geological map of the Forked Lake region. The major lithological units are megacrystic granite, migmatized metasediment and several varieties of granitoid composition orthogneiss. The circular distribution of lithologic units mimics the circular nature of the local aeromagnetic pattern. The granite at the core of the feature is an aeromagnetic low.

SOURCE OF SEDIMENTS IN THE CORDILLERAN MIOGEOCLINE: A Nd ISOTOPIC STUDY

GARZIONE, Carmala N., and PATCHETT, P. Jonathan, Dept. of Geosciences, Univ. of Arizona, Tucson, AZ 85721, U.S.A.; ROSS, Gerald M., Inst. of Sedimentary and Petroleum Geology, 3303 33rd St. N. W., Calgary, Alberta T21 2A7; NELSON, JoAnne, Ministry of Energy, Mines, and Petroleum Resources, 1910 Blanshard St., Victoria, B.C V8V 1X4.

Nd isotopes in sediments of Yukon, northern British Columbia, and southern Alberta are used to examine the source of sediments in the Canadian Cordilleran miogeocline. Boghossian et al. (in press) determined that sediments of Neoproterozoic to Upper Ordovician age in southern Alberta have ϵ_{Nd} values which reflect Canadian Shield sources ($\epsilon_{Nd} = -14$ to -22), whereas a shift to a more juvenile source ($\epsilon_{Nd} = -6$ to -9) occurs by Late Devonian time. One suggestion is that these more juvenile sediments were derived from the Innuitian Orogen in the Canadian Arctic. Deformation occurred in the Innuitian region between Late Devonian and Early Carboniferous time, resulting in a large southwestward prograding sediment wedge which probably contributed significant sediment to the miogeocline.

In Yukon and northern British Columbia, the shift to more juvenile Nd isotopic values occurs by Middle Ordovician time, predating the Ellesmerian (Innuitian) orogenesis by more than 80 million years. This suggests that the shift to more juvenile values is not due solely to the influx of Innuitian sediments following Devonian deformation. Cambrian and older sediments have ϵ_{Nd} values of -13 to -21 consistent with derivation from Canadian Shield sources. Middle Ordovician through Permian age sediments in Yukon /Northwest Territories, including Late Devonian Innuitian-derived strata (Imperial Assemblage), have ϵ_{Nd} values of -5 to -11 . This represents a wider range than observed in sediments of comparable age in southern Alberta but still records a distinct shift to juvenile values. In northern British Columbia (Kechika Trough), the shift to a more juvenile source is less well-developed with ϵ_{Nd} values in Middle Ordovician through Late Devonian sediments ranging from -7 to -14 , suggesting continued input from Canadian Shield sources. Figure 1 contains a summary of the data.

Differences in Paleozoic tectonic setting may explain the different times of appearance of the juvenile signature in Yukon, British Columbia, and Alberta sequences. In the Kechika Trough, quartzites derived from the emergent Peace River Arch (cratonal North America) are present in the Paleozoic section, suggesting the continued importance of this source region. This must be balanced with the potential contribution from ultrapotassic volcanic sources which are widespread but volumetrically minor throughout the Selwyn Basin and Kechika Trough. The Middle Ordovician onset of juvenile sediment sources in the northern Cordillera represents a fascinating puzzle.

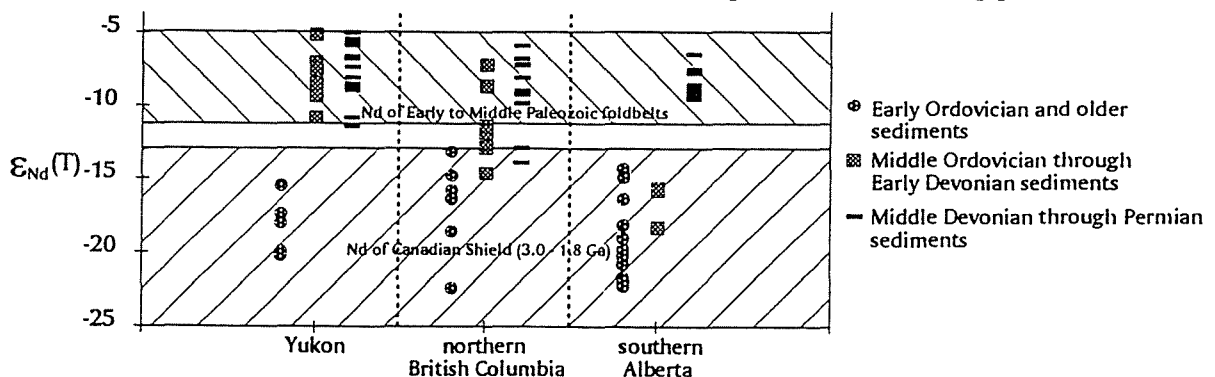


Figure 1. Plot of ϵ_{Nd} at time of deposition vs. location. For each location, sedimentary units have been broken into three time periods based on timing of significant shifts in Nd signatures of source rocks. A complete shift to a more juvenile source occurs by Middle Ordovician time in Yukon but not until Late Devonian time in southern Alberta. The first juvenile signature in northern British Columbia appears in Middle Ordovician time. However, involvement of Canadian Shield sources continues until at least Late Devonian time.

Stratigraphy and correlation of the early Neoproterozoic sedimentary sequence of the northern Cordillera and Amundsen Basin

Rainbird, Robert H., Consultant, 1725 Grasmere Crescent, Ottawa, Ontario.
K1V 7V1

The Proterozoic stratigraphic record of northwestern Canada and Alaska includes three, unconformity-bounded sedimentary sequences which are termed from oldest to youngest: A, B and C. Recent and ongoing stratigraphic studies of Sequence B, along with improved geochronology, allow extension and refinement of existing correlation schemes for northwestern Canada and Alaska. Sequence B strata include the Shaler Supergroup of Amundsen Basin and the Mackenzie Mountains supergroup, Pinguicula group, Fifteenmile group, and the lower Tindir Group of the northern Cordillera. The framework for regional lithostratigraphic correlation of Sequence B is built on recognition of four distinctive sedimentary assemblages; two thick stromatolitic platformal carbonate assemblages, separated by two largely subaerial siliciclastic assemblages. Pairing of these assemblages defines two large-scale transgressive-regressive cycles that can be correlated not only within North America but with contemporary assemblages on other continents such as Australia and Siberia. These continents are considered to be primary building blocks of a supercontinent that amalgamated with the culmination of the Grenvillian orogeny (ca. 1000 Ma). In northwestern Canada, paleogeographic information from Sequence B rocks indicates a northwest-trending promontory (Amundsen-Ogilvie-Mackenzie platform) on the margin an intracratonic basin. The platform margin marks the approximate site of subsequent rifting, which signaled the initiation of the break-up of the supercontinent ca. 750 Ma. Sequence B therefore records a cycle of similar scale, duration and origin to the first-order supercontinent cycle of the Phanerozoic that records the assembly and break-up of Pangea.

GEOCHRONOLOGY OF STRANGER STONES IN NEOPROTEROZOIC DIAMICTITES, (NORTHERN AND CENTRAL CANADIAN CORDILLERA)

Gerald M. Ross, G.S.C.-Calgary, 3303 33rd Street N.W., Calgary, AB T2L 2A7
Mike Villeneuve, G.S.C.-Ottawa, 601 Booth Street, Ottawa, ONT., K1A 0E8

The Neoproterozoic sedimentary record in western Canada is represented by the Windermere Supergroup which is widespread in the Canadian Cordillera. The Windermere contains evidence for two glacial episodes, a signature of Neoproterozoic sedimentation globally. The first Windermere glacial interval is the Toby Formation in the southern Cordillera and the Rapitan Group in the northern Cordillera and the second Windermere glacial interval is the Ice Brook Formation in the northern Cordillera and the Mount Vreeland Formation in the central Cordillera. Diamictites (muddy conglomerates) are common rock types in all of these occurrences and were deposited mostly from resedimentation of glaciogene tills. Most of the clasts in the diamictites are of sedimentary origin with local provenance; a very small percentage of clasts are composed of undeformed igneous crystalline rock types of uncertain provenance ("stranger stones"). We present the results of the U-Pb zircon dating of crystalline clasts from the Rapitan Group and Mount Vreeland Formation as a means to constrain the ages of source areas and possibly detect the presence syndepositional magmatic activity.

The Rapitan Group consists of a lower unit of bedded clastic dolomite with dropstones (Sayunei Formation) overlain by a thick-bedded diamictite unit, the Shezal Formation. Only 3 stranger stones have been recognized in the Rapitan in spite of years of mapping and stratigraphic study. A dropstone from the Sayunei Formation, composed of undeformed leucogranite, gives a U-Pb zircon date of 755 ± 18 Ma (single grain analysis; 0.53% discordant) and provides a maximum depositional age for the Rapitan Group. Two stones from the Shezal diamictites are both undeformed and comprise a biotite gabbro and a biotite syenogranite. Each gave nearly concordant zircon ages of 1857 ± 3 Ma and 1860 ± 1 Ma, respectively.

The Mount Vreeland Formation is a very thick sequence of diamictite that occurs in the central Cordillera (ca. 55°N). In contrast to the Rapitan glacials, it sits well above the base of the Windermere and can be mapped into the widespread grits characteristic of the Windermere in the southern Cordillera. Hence it is interpreted as correlative with the second Windermere glacial interval (=Ice Brook Formation). The diamictites of the Mount Vreeland Formation attain a thickness of more than 1000m and although most clasts are composed of sedimentary rock or diabase, a significant number are composed of undeformed felsic plutonic and extrusive rocks suggesting derivation from an undeformed volcano-plutonic terrane. A total of 5 boulders of felsic composition were dated. All were undeformed and included a tonalite, two syenogranites, a Kspar megacrystic granite and a dacite porphyry. Four of the boulders gave dates of 1863-1867 Ma and the fifth gave a date of 1842.9 ± 4 Ma. The narrow range of ages suggests that the dated boulders are all derived from a restricted source area and may be related magmatically.

The sources of the crystalline boulders in the Rapitan Group are enigmatic. Regional isopach maps show that crystalline basement to the east of the Cordillera is covered by pre-Windermere strata (Mackenzie Mountains Supergroup and Hornby Bay-Dismal Lakes

groups) and therefore crystalline basement could not have been a source for the Windermere stones. The association of ca. 1860 Ma and ca. 755 Ma plutonic rocks is similar to an association seen in intra-Cordilleran basement occurrences such as the Sifton-Deserters ranges, Malton Gneiss and Monashee basement. We tentatively suggest an intra-Cordilleran source for the Rapitan stones perhaps reflecting the age of basement outboard of the present North American Cordilleran margin that was uplifted and exposed during the Windermere rift event.

The composition and restricted suite of ages for the boulders from the Mount Vreeland Formation suggest derivation from an undeformed volcano-plutonic belt and the most likely candidate is the Fort Simpson High, an aeromagnetic domain in the subsurface of northeastern British Columbia. This is consistent with previous studies of the distribution of the Mount Vreeland diamictites which suggested derivation from the northeast. The age of the Fort Simpson High is constrained as 1845 Ma, on the basis of two granites recovered in drill core, which only matches the age of one of the boulders from the Mount Vreeland. However, detrital zircons from Paleozoic sandstones derived from the Peace River Arch (which includes the southern extension of the Fort Simpson High) suggests that the local basement could range from 1831-1888 Ma. We thus suggest that the Mount Vreeland diamictites were derived from basement rocks of the western Peace River Arch-Fort Simpson High in northeastern British Columbia.

THE EARLY POST-RIFT NATURE OF THE NORTHERN LAURENTIAN MARGIN: PRELIMINARY LITHOSTRATIGRAPHIC AND CONODONT BIOSTRATIGRAPHIC DATA FROM THE KECHIKA TROUGH AND CASSIAR TERRANE

Leanne J. Pyle and Christopher R. Barnes, School of Earth and Ocean Sciences, University of Victoria, P.O. Box 3055, Victoria, B.C. V8W 3P6

Stratigraphic and conodont biostratigraphic and paleoecological studies have recently been initiated in northern British Columbia to understand the nature of the early post-rift phase of the northern margin of Laurentia. This study complements work in progress for the southern Cordillera and earlier work on the southern Laurentian margin in the Newfoundland Appalachians. The line of transect for the sections studied approximates to part of Line 2 of the SNORCLE/ LITHOPROBE Transect. The two principal stratigraphic units examined are the Kechika Group (Upper Cambrian-Lower Ordovician) and the Road River Group (Lower Ordovician to Lower Devonian).

The western edge of the MacDonald Platform, transitional to the outer miogeocline and upper slope facies, was studied at Grey Peak, Kwadacha Wilderness Park, where shallow-water Cambrian carbonates are overlain abruptly by deeper basinal shales and thin carbonates of the Kechika Group, 1.4km thick; another abrupt lithological change occurs at the base of the overlying Road River Group where black basinal shales are interbedded in the lower part of the 500m sequence by slope carbonate breccia flows. To the northeast, within the Kechika Trough, sections at Driftpile Creek and Bluff Creek represent condensed basinal packages of both the Kechika and the Road River groups, together commonly being less than 400m thick. In other thrust panels of the Trough, thicker sequences are developed, such as at Gataga Mountain, where the Kechika appears to be up to 1km thick, possibly reflecting a positive tectonic element on the western side of the Kechika Trough. Sections were also measured and sampled on the east and west sides of the pericratonic Cassiar Terrane, west of the Trough, at Moodie Creek and Cassiar, respectively.

From these sections, over 250 3kg conodont samples were collected. These are presently being processed and picked for conodonts and other microfossils.

Most of the sections are deformed and other fossil material is extremely rare; conodont recovery is modest to date with conodont Colour Alteration Index (CAI) values of 5 indicating burial temperatures in the range of 300-400 degrees C. The Kechika-Road River contact approximates to the base of the Arenig Series.

From the preliminary data and that from earlier mapping in the region, thick platform carbonates and/or clastics of Early to at least Middle Cambrian age occur throughout much of the area and evidence for early to syn-rift deposits (Late Proterozoic-Early Cambrian) is limited to narrow belts. The Kechika Trough appears to subside more regionally in the Late Cambrian, marked by the onset of Kechika Group sedimentation. A further phase of extension appears to occur within the Early Ordovician (basal Arenig) with the development of thin anoxic basinal shales of the Road River Group. Early extensional phases are characterized by slope carbonate breccias shed from the steepened platform margin in late Early to early Middle Ordovician time. The deeper basinal facies extends as a largely condensed sequence into the Devonian when a magmatic arc develops, and further rifting and black shale deposition lead to the generation of several important mineral deposits along the Kechika Trough (e.g. Driftpile, Cirque, Akie).

In the summer 1996 field season, it is planned to examine sections in the central part of the Cassiar Terrane and especially in the MacDonald Platform to the east (Ware and Trutch map-areas, British Mountains), in order to complete the full transect from the platform, through the slope and basin/trough, and across the Cassiar Terrane.

PALEO-HYDROGEOLOGY OF THE NAHANNI RIVER REGION, NORTHWEST TERRITORIES: INITIAL RESULTS.

Morris, George A., Nesbitt, Bruce E., Muehlenbachs, K., and Fraser, S., Department of Earth & Atmospheric Sciences, University of Alberta, Edmonton, Alberta, T6G 2E3, Canada.

Field, mineralogical and geochemical studies have been used to examine paleo-fluid flow in the Nahanni River region, Northwest Territories. Four major fluid events have been identified. 1- The first event produced syngenetic Ordovician sulphide mineralisation. 2- This was followed by widespread diagenetic dolomitisation producing fine-grained gray mosaic dolomite. Lower and middle Devonian strata are host to the broadly stratiform, and regionally developed Manetoe Facies, an extensive body of megacrystalline white sparry dolomite (Morrow et al., 1990). 3- Lower in the stratigraphic sequence and postdating the gray dolomites, a dolomitisation event consisting of dolomite/calcite vugs and veins associated with occasional minor pyrite occurs. This event clearly predates Laramide deformation. 4- The final fluid event was associated with Laramide orogenic activity. This event can be subdivided into two distinct but related phases, consisting of earlier, thrust fault related, calcite/quartz veining, cross-cut by later high angle calcite/quartz/sulphide veins. The final Laramide phase is related to quartz vein hosted lead-zinc-silver mineralisation.

Fieldwork consisting of a traverse of the Nahanni River Corridor, as well as visits to specific localities on the Nahanni River, the Ram Plateau and along the Alaska Highway between Dawson Creek and Liard Hotsprings has produced in excess of 300 samples. These are currently being analysed for stable isotope (C, O and D), fluid inclusion data and U-Pb radiogenic isotopes at Univ. of Alberta. Preliminary results are as follows:

Gray mosaic dolomites from the Wittaker Formation return isotopic values of $22.0 \pm 1.4\text{‰}$ ($\delta^{18}\text{O}$ SMOW) and $-0.5 \pm 0.5\text{‰}$ ($\delta^{13}\text{C}$ PDB), slightly depleted from the normal Ordovician dolomite $\delta^{18}\text{O}$ values of 23 - 27‰ (Fraser, 1996). Samples of Manetoe Facies dolomite vary in $\delta^{18}\text{O}$ from 12 to 20‰ (SMOW) and in $\delta^{13}\text{C}$, from -2 to 2‰ (PDB) (Morrow *et al.*, 1990). Extracted inclusion fluids from these dolomites return δD values of - 80 to -12‰ (SMOW). The later calcite/dolomite event shows a clear gradient in $\delta^{18}\text{O}$ (SMOW) along the Nahanni River corridor for both the calcite (22.1‰ - 2.8‰ west to east) and dolomite (20.5‰ $\rightarrow$ 14.6‰ west to east). This gradient is mirrored by changes in $\delta^{13}\text{C}$ (PDB: calcite, -0.1‰ $\rightarrow$ -3.4‰; dolomite, 0.3‰ $\rightarrow$ -2.9‰) and δD (SMOW: - 184‰ $\rightarrow$ -136‰ from inclusion fluids) values. Variations in isotopic values appear to be related mainly to changes in host stratigraphy and, to a lesser extent, structural complexity.

By comparison, the Laramide fluid event shows a strong correlation with structural complexity, returning high $\delta^{18}\text{O}$ and $\delta^{13}\text{C}$ values from calcite (19‰ $\rightarrow$ 22‰, SMOW, and -0.4‰ $\rightarrow$ 1.1‰, PDB, respectively) where the rock is unfolded to weakly folded at the western and eastern ends of the traverse, suggesting a low fluid to rock ratio. lower values ($\delta^{18}\text{O}$, 10‰ $\rightarrow$ 13‰ and $\delta^{13}\text{C}$, -4.9 $\rightarrow$ -3.3‰) are reported for areas where the rock has undergone a high degree of deformation towards the center of the Nahanni River traverse, suggesting, much higher fluid to rock ratios were tectonic events have created pathways.

Fluid inclusion data from the megacrystalline Manetoe dolomites return a homogenisation temperature of ~160°C and salinity values of >20 eq.wt.%. The Laramide quartz/calcite/sulphide veins consistently show salinities of 16 - 18 eq.wt.%. Homogenisation temperatures of the unmineralised Laramide veins are in the range 180 - 200°C, while the sulphide bearing veins return lower values of 140 - 160°C.

Unit	mineral	$\delta^{18}\text{O}$ (‰)		$\delta^{13}\text{C}$ (‰)		δD (‰)
Wittaker Fmn.	Dolomite	22.0±1.4		-0.5±0.5		
Manetoe Facies	dolomite	12.0 - 20.0		-2.0 - 2.0		-80 - -12
Calc/Dolo Vugs	calcite	east	west	east	west	-184 - -136
	dolomite	9.7	22.1	-3.4	-0.1	
		14.6	20.5	-2.9	0.3	
Laramide	calcite	undeformed	deformed	undeformed	deformed	
		19.7 - 22.5	10.4 - 13.2	-0.4 - 1.1	-4.9 - -3.3	

Table 1. Summary of preliminary results from paleo-fluid flow studies in the Nahanni River region.

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THE ISAAC LAKE FAULT: EVIDENCE FOR TRANSTENSION IN THE NORTHWESTERN CARIBOO MOUNTAINS, BRITISH COLUMBIA

Reid, Leslie, Department of Geology and Geophysics, University of Calgary, Calgary, Alberta, T2N 1N4.

The Isaac Lake Synclinorium is a structural depression in the Omineca Crystalline Belt that preserves much of the Neoproterozoic Windermere Supergroup at a high structural levels. The synclinorium is bound to the west by the Isaac Lake Fault Zone which is a northwest-trending dextral oblique-slip fault with minimum displacement calculated to be four kilometres. The eastern boundary is also structural, and consists of a northwest-trending dextral oblique west-verging thrust fault. Displacement along this fault appears to die out to the northwest.

The main regional structures (D_2 structures) of the Isaac Lake Synclinorium are southwest-verging overturned folds which formed during the Columbian Orogeny. Associated with these folds is a regional penetrative axial planar cleavage (S_2) which crenulates an earlier cleavage that is sub-parallel to bedding (S_1). These structures are subsequently cut and deformed by the Isaac Lake Fault Zone and associated structures which include east-west-trending upright, en-echelon F_3 folds and northeast-trending extensional faults. An axial planar cleavage to these F_3 folds is well developed in the hinges and crenulates the earlier S_2 cleavage. The angular relationship between the Isaac Lake Fault Zone, F_3 folds and extensional faults corresponds to that which is expected in a right lateral shear couple implying that all of these structures could be co-genetic D_3 structures.

The development and intensity of deformational fabrics has been affected strongly by the rheologic properties of the sedimentary succession. In particular the Neoproterozoic Cunningham Formation, a thick-bedded limestone unit, and the Cambrian(?) Yanks Peak Formation quartzites form rigid beams within ductile pelite-rich Neoproterozoic rocks of the Kaza and Cariboo Groups. D_2 folds that are tight and overturned in incompetent Isaac Formation pelites are accommodated by broad flexures in the overlying Cunningham Formation. En-echelon D_3 folds appear to be spatially restricted to regions within the Cunningham and Yanks Peak Formations perhaps suggesting these units generated buckling instabilities during D_3 .

The presence of the Isaac Lake Fault Zone demonstrates evidence of a significant transtensive event in the southern Cariboo Mountains. Determining the age of formation of the Isaac Lake Fault Zone will be critical in order to ascertain its tectonic implications in the southern Canadian Cordillera, and to potentially link these structures to similar transtensive structures in the northern Canadian Cordillera.

TITLE: Isograd compression from strike-slip deformation: metamorphism and structural evolution of Penfold Creek area, Cariboo Mountains, British Columbia.

Michael A. Cooley
Ray A. Price
Dugald M. Carmichael } Department of Geological sciences, Queen's University, Kingston, Ontario K7L 3N6
Gerald M. Ross } Geological Survey of Canada, 3303-33rd Street NW. Calgary, Alberta T2L 2A7

Fletcher (1973) described an anomalous zone of closely spaced and steeply dipping isograds (2.4 km separate the biotite and sillimanite isograds), known informally as Campbell's Line (Campbell 1963), which parallels the regional structural trend along the northeast flank of the Shuswap Complex in the valley of Penfold Creek. The NE side of Campbell's Line is characterized by garnet and lower grade metasedimentary rocks of the Kaza Group whereas the high-grade, SW side is characterized by upper staurolite zone (and higher) paragneisses and schists of uncertain stratigraphic parentage. The apparent compression of the isograds has been attributed to a locally high geothermal gradient driven by an unidentified igneous source (Fletcher, 1973). However, the spatial coincidence between the zone of isograd compression and the Matthew Fault, a significant dextral strike-slip fault of uncertain age, was suspicious. The purpose of this study was to investigate the cause of close spacing of isograds by concentrating structural-kinematic studies in three critical areas that straddle this zone.

The discovery of garnet on the low-grade side of the biotite zone as mapped by Fletcher (1973) indicates that isograds are more widely spaced NE of Penfold Creek than originally perceived. This study places the garnet and biotite isograds 1 km and 2 km further NE respectively than previously mapped isograds. Chlorite pseudomorphs after biotite and partially chloritized (and difficult to recognize) garnets suggest retrograde overprinting of higher grade assemblages. Retrogression may be synchronous with dextral deformation; greenschist-grade shear bands with dextral asymmetry are widespread in phyllitic lithologies up to 3 km away from Matthew Fault. These shear bands cut previous metamorphic fabrics and are associated with chlorite growing along shear planes.

Metamorphic grade is not continuous across Penfold Creek; from NE to SW metamorphic grade increases from garnet to kyanite-staurolite, omitting the staurolite-in zone. Absence of a staurolite-in isograd may be due to an improper bulk composition of the rocks but is most likely the result of dextral strike-slip along Matthew Fault. Dextral shear bands and asymmetric pull-aparts of quartz+kyanite veins and pegmatites are ubiquitous within a wide zone of high-grade rocks adjacent to Penfold Creek. These brittle/ductile shear fabrics are syn-to post-metamorphic and occur in at least kyanite stability field.

Seventeen kilometers NW of the Penfold Creek area a staurolite zone can be found at Mount Mitchell where there is a sharp increase in metamorphic grade from biotite to staurolite across Matthew Fault. A minimum offset of 17 km may be inferred if the high-grade side of the fault at Mount Mitchell is Penfold Creek's missing staurolite zone. 10 km SE of the Penfold Creek area metamorphic evidence for dextral strike slip is not found. Across the fault in this area metamorphic grade goes from kyanite to sillimanite in an apparently continuous sequence (Engi, 1984). This implies that Matthew Fault does not cut through a metamorphic zone in this area and that isograds are parallel to the fault.

Consideration of the regional kinematics of the Matthew Fault suggests that the high-grade rocks of Campbell's Line are displaced from equivalents in the western Premier Range. This represents part of a regional dextral deformation event in the northwest Cariboo Mountains. Geochronologic studies are underway to constrain the timing of this deformation.

Isotopic, geochemical, and kinematic studies of the Yukon Tanana terrane in the Money Klippe, SE Yukon.

Steven Grant, Robert Creaser, & Philippe Erdmer

*Department of Earth and Atmospheric Sciences, University of Alberta, Edmonton, Alberta, T6E 2E3
Canada.*

The Yukon Tanana Terrane (YTT) is a complex assemblage of metamorphic and plutonic rocks of mid-Paleozoic age or older which occupies a position between rocks of the ancient North American Continental Margin (NACM) and rocks which are accreted (Fig. 1). Much of the YTT northeast of the Tintina Fault in southeastern Yukon is underlain by a deformed metasedimentary package called the Nisutlin assemblage. The deformation state of the metasedimentary Nisutlin assemblage reaches mylonitization in areas, destroying stratigraphy and making correlation between areas difficult. The YTT also contains structurally higher tabular bodies interpreted as shear-bound slices of plutonic and volcanic rock. These include a package containing gabbro and sheared mafic volcanic rock, called the Anvil Allochthon by Templeman-Kluit (1979) and, of lesser areal extent, felsic plutonic rocks, identified as the Simpson Allochthon by Templeman-Kluit (1979). Intrusive relationships are obscured by shear between plutonic units. The area around the Money Klippe was chosen by the authors as a site to examine structural and intrusive relationships and obtain samples of the various rock units for geochemistry and isotope analysis. The Nisutlin assemblage outcropping around the base of the Money Klippe was scrutinized for microstructures in order to determine the mode of emplacement of the terrane. Geochemical and isotopic analyses of Nisutlin assemblage samples were performed in order to gain insight into the tectonic affinity of the source material. Zircon U-Pb geochronology of the plutonic units was undertaken in an attempt to constrain the time of emplacement and to discover relationships between the units. Geochemistry and Nd isotopes on Nisutlin assemblage rocks reveal that the sediment includes both ancient upper crust (possibly from the NACM) and juvenile mafic material. U-Pb zircon ages in the 340 to 360 Ma range were determined for all igneous rocks in the klippe, including zircon from a gabbroic sample of the Anvil Allochthon. These results, in conjunction with noted intrusive relationships, suggest that all igneous rocks of the Money "Klippe" may have formed during a limited time span.

The metasedimentary Nisutlin assemblage, which compares with the "lower unit" and possibly "middle unit" of Mortensen and Jilson (1985), surrounds the klippe and consists largely of mica-quartz schist and mylonite, although in some localities amphibole-bearing schist or graphite-bearing schist predominates. Shear-sense indicators, such as C'planes (asymmetrical extensional shear bands) and rotated porphyroclasts, reveal two distinct directions of shear in the Nisutlin Assemblage schists and mylonites around the perimeter of the Money Klippe. Mylonites to the west and south of the klippe have an over-all shear-sense of top-to-the-east-southeast. Foliation planes in mica-quartz mylonite north and north-east of the klippe are shallow and variable in dip-direction but contain a constant north-south trending lineation. Most shear-sense indicators record top-to-the-south shear but several suggest top-to-the-north.

SiO₂ contents of the mica-quartz schists ranges from 72.5 to 95.8 %; amphibole-bearing schists have lower SiO₂ contents of 52.8 to 58.6%. The SiO₂ /Al₂O₃ ratio for the schists is quite constant at 5.5

except for two graphitic samples which also have SiO_2 contents of ~90% and very high $\text{K}_2\text{O}/\text{Na}_2\text{O}$ ratios. The graphite seems to be locally concentrated in thin wispy stylolitic layers.

Some trace elements, such as REE, Y, Th, Sc (Taylor and McLennan 1985), Ti, Zr, Hf (Bhatia and Crook, 1986) are retained by detritus during erosion and sedimentation, thus quantitatively preserving geochemical patterns of their source rocks. The authors have employed these trace elements in an attempt to probe the tectonic provenance of the Nisutlin metasediments. Several samples show relatively flat, slightly LREE-enriched plots ($\text{La}_\text{N}/\text{Sm}_\text{N} = 2.2$ to 2.6) with slight negative europium anomalies ($\text{Eu}/\text{Eu}^* = 0.89$ to 0.93), indicating that these samples have undergone little differentiation and are therefore geochemically primitive. This group of rocks with chemically primitive signatures are termed Group 1. All remaining samples, assigned to Group 2 and Group 3 (see below), have higher LREE enrichment ($\text{La}_\text{N}/\text{Sm}_\text{N} = 3.2$ to 5.2) and overall show signs of more chemically-evolved crust. The degree of europium depletion was used to further subdivide these samples. Samples with LREE enrichment which have Eu/Eu^* ratios in the range: 0.15 to 0.38 constitute Group 3. Group 2 is defined by LREE-enriched samples which have less pronounced Eu anomalies ($\text{Eu}/\text{Eu}^* = 0.54$ to 0.68). Several samples have somewhat anomalous REE patterns which defied classification by REE patterns alone; other trace-element criteria helped group these samples.

Further trace-element analyses support the REE-defined trend indicating that Group 1 represents material weathered from a mafic, chemically immature source, Group 3 represents mature felsic material, and Group 2 is intermediate between Groups 1 and 3. For example, Th-Sc-Zr/10, La-Th-Sc, and Ti/Zr-La/Sc plots show that Group 3 largely coincides with the “passive margin” and possible “active continental” fields of Bhatia and Crook (1986), Group 1 overlaps the “active ocean” field, and Group 2 largely occupies an intermediate position, which is nominally the “continental island arc” field. An examination which includes only trace elements suggests that Group 2 may represent a mix of the two different provenances represented by Group 1 and Group 3; Nd isotopes indicate that the provenance may be more complicated (see below).

Metasedimentary rocks of the Nisutlin assemblage from the Money Klippe area show a considerable range in Sm-Nd characteristics ($\epsilon\text{Nd}_0 = -19.2$ to $+1.87$, $\epsilon\text{Nd}_{360} = -15.4$ to $+5.0$). While the calculated T_{DM} model ages (2.2Ga to 0.8Ga) probably have no real age significance due to mixing of sediment, it is clear that the Nisutlin assemblage includes material weathered from crust of at least Proterozoic age and material weathered from rock of much shorter crustal residence (Paleozoic?). A plot of $\epsilon\text{Nd}_\text{T}$ vs. Th/Sc can be helpful to further explore provenance because it couples a felsic-mafic index (Th/Sc) with the age discrimination power of Nd isotopes (McLennan et al. 1990). Creaser et al. (submitted) used the $\epsilon\text{Nd}_\text{T}$ vs. Th/Sc plot to show that YTT metasediments from the Teslin tectonic zone (TTZ) trend from juvenile mantle-derived material (low Th/Sc, high ϵNd) to a highly evolved upper crust (high Th/Sc, low ϵNd). Intermediate rocks (“type II” from that study) are interpreted as a mix of the two end-members. Metasediments from the Money Klippe (Fig. 2) area show similar trends except that the most ancient material belongs to the geochemically intermediate Group 2 ($\epsilon\text{Nd}_{360} = -13$ to -15). Group 3, the most indicative of passive margin settings, has intermediate, yet still relatively low ϵNd_{360} values ($\epsilon\text{Nd}_{360} = -7.2$ to -7.6). This may suggest a more complex sedimentary provenance for the Money Klippe samples (ie. more than two end-member sources). It may be that such discriminations are outside the resolution power of this chemical system; regardless, it is clear that evolved upper crust provided sedimentary input into these rocks. It is possible that the North American continental margin (NACM) acted as a source for geochemically evolved sediment to the Nisutlin assemblage. Younger, more mafic material implied by Group 1 metasediments may have been derived from a Paleozoic arc.

The upper portions of the Money Klippe contains quartz-porphyritic granite and hornblende granodiorite of the Simpson Range Plutonic Suite and an undeformed volcanic plug which contains rock ranging from flow-banded rhyolite to hornblende-andesite. The lower portion of the Money Klippe contains largely undeformed gabbro-diorite and sheared mafic metavolcanics assigned to the Anvil Allochthon by Templeman-Kluit (1979), but linked to the Slide Mountain Terrane by others (eg. Mortensen and Jilson 1985). The plutonic units (granite, granodiorite, gabbro) show little sign of deformation except for within 1-2 meters on either side of contacts between units, where weak deformation includes small anastomosing chloritized shears, fractured grains, and slickensided surfaces. Intrusive contacts are clearly present as well; for instance, a ~1-2 m sill of quartz-porphyritic granite intrudes the gabbro and diabase dikes intrude the granite and granodiorite. In addition to the plutonic units of the klippe, a foliated granodiorite outcrops south of the Money Klippe in contact with the Nisutlin assemblage. Nd isotopes for the felsic igneous units of the Money klippe area range from $\epsilon\text{Nd}_0 = -17.1$ to -11.8 ($\epsilon\text{Nd}_{360} = -12.6$ to -7.86) with T_{DM} model ages ranging from 1.7 Ga to 2.1 Ga. These T_{DM} model ages in excess of their U-Pb crystallization ages indicates that old crustal material was an important component of their source region(s); this interpretation is consistent with inheritance patterns noted in U-Pb zircon analysis from several Money Klippe igneous units (see below).

Figure 3 displays U-Pb analyses of zircon fractions from the Money Klippe igneous units. Ages of ~346 Ma were obtained for two nearly concordant zircon fractions from the quartz-porphyry granite. A regression line through three slightly discordant granodiorite zircon fractions has a lower intercept of $345.2 \pm 1.9/-1.9$ Ma and an upper intercept of $1809 \pm 90/-82$ Ma. Two discordant zircon fractions from a quartz-porphyry volcanic rock from the undeformed volcanic plug yield a regression with a lower intercept of $356.5 \pm 3.4/-4.0$ Ma and a poorly constrained upper intercept of $1682 \pm 486/-361$ Ma. For both the granodiorite and the quartz-porphyry the lower intercept is interpreted as the crystallization age and the upper intercept provides insight into inheritance. The U-Pb zircon ages from the quartz porphyry volcanic plug obtained in this study are similar to U-Pb zircon ages of 360.5 ± 1.9 Ma obtained by Mortensen (1992) on nearby andesite porphyry, possibly from the same volcanic plug. Three zircon fractions (two single-grain analyses) from the foliated granodiorite to the south of the Money Klippe yielded an upper intercept of $357.4 \pm 21.2/-17.2$ Ma, which is interpreted as the age of crystallization; discordance in this fraction is attributed to lead loss. A small zircon fraction from a pegmatitic phase of a gabbro (from the Anvil assemblage of Templeman-Kluit 1979) was ~5% discordant and plotted near a cluster of zircon analyses from the quartz-porphyry granite, hornblende granodiorite and sheared granodiorite. This indicates that the gabbro may be broadly contemporaneous with the felsic magmatism of ~350 Ma, although further analyses of zircon from the gabbro would better constrain the result. Other U-Pb ages for the Slide Mountain Terrane of SE Yukon include U-Pb zircon ages of 365-370 Ma (Mortensen 1983) and 274.3 ± 0.5 Ma (Mortensen 1992), both from plagiogranite associated with greenstone. The U-Pb ages determined for the Simpson Range Plutonic Suite outcropped at the Money Klippe (quartz-porphyry granite, hb-granodiorite and sheared granodiorite) are similar to results obtained by Mortensen (1983) on the Simpson Range Plutonic Suite (349-359 Ma), although the age results of the present study range a little younger.

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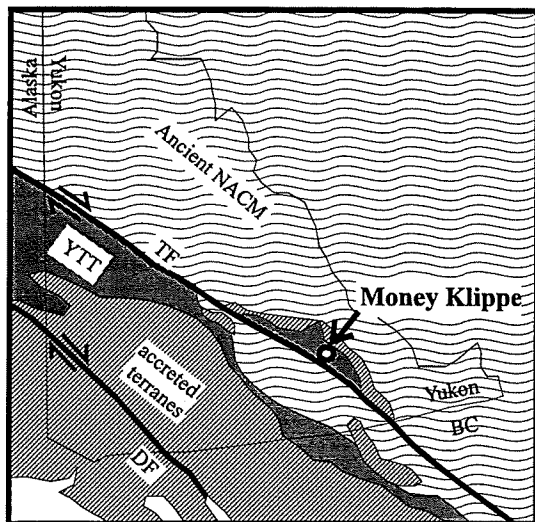


Figure 1. General map of the Yukon Cordillera, showing the location of Money Klippe in relation to the ancient North American continental margin (NACM) (wavy lines), the YTT (stippled grey), and accreted terranes (vertical stripes). TF= Tintina Fault and DF = Denali Fault. Modified from Mortensen and Jilson (1985) Mortensen (1992), and Creaser et al (submitted).

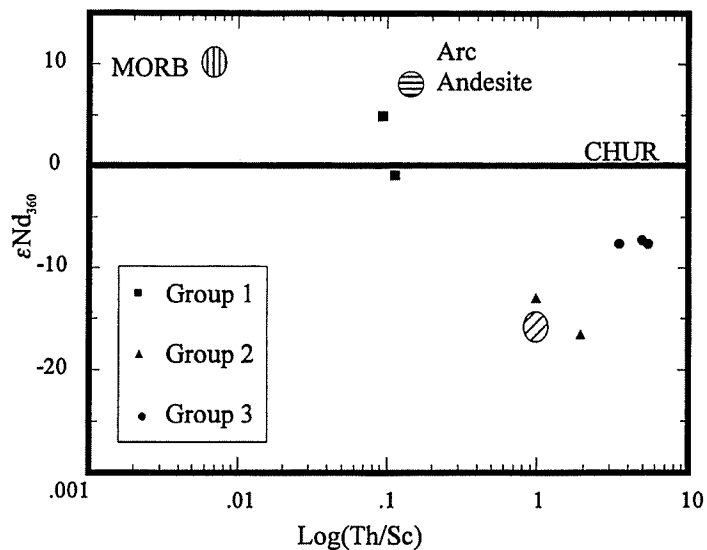


Figure 2. ϵNd_{360} vs. Th/Sc. The fields of MORB, Arc Andesite, and Upper Crust from Taylor and McLennan (1985). Note that Group 3 schists, which contain the most geochemically evolved material, do not have the most ancient ϵNd signature.

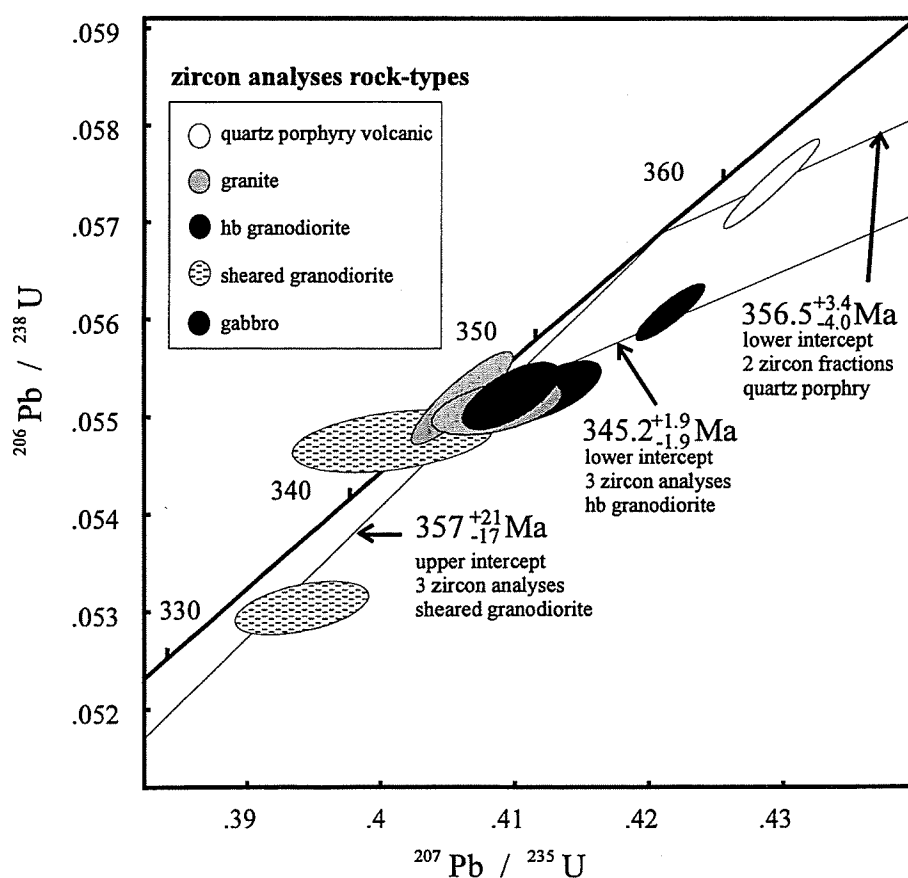


Figure 3. U-Pb concordia diagram showing zircon analyses from Money Klippe igneous units. Ages and uncertainties are labelled for various regression lines. All errors are reported at 2σ .

VARIATIONS IN WHITE MICA $^{40}\text{Ar}/^{39}\text{Ar}$ COOLING AGES AND CALCITE *e*-TWIN TYPES: IMPLICATIONS FOR SUBDUCTION ZONE POLARITY

OLIVER, Douglas H., HANSEN, Vicki L., Department of Geological Sciences, Southern Methodist University, Dallas, TX 75275; and HEIZLER, Matthew T., New Mexico Bureau of Mines and Mineral Resources, Socorro, NM, 87805.

Subtle yet systematic variations in white mica $^{40}\text{Ar}/^{39}\text{Ar}$ cooling ages and calcite *e*-twin type distribution are found at Little Salmon Lake, Yukon Territory, and constitute evidence for subduction zone polarity. Structural analysis delineated three distinct deformation events within this part of the Teslin suture zone: (1) subduction-related ductile shear recorded in normal and reverse dip-slip tectonites; (2) top-to-the-NW ductile strike-slip shear that partially overprinted earlier dip-slip fabrics; and (3) folding of the composite tectonite assemblage during NE-vergent contraction.

With the tectonites restored to their pre-folding configuration, white mica $^{40}\text{Ar}/^{39}\text{Ar}$ cooling ages young both downward and to the southwest. Possible explanations include: (1) variations in white mica closure temperature related to differences in composition and/or diffusion radii; (2) progressive exhumation of the tectonite assemblage through the white mica closure isotherm during folding; and (3) static cooling of a SW-dipping tectonite assemblage below the white mica closure temperature prior to folding.

XRD analysis of white mica b_0 and $d_{(002)}$ spacings do not indicate systematic compositional variations among the samples, nor is there any correlation between grain size and cooling age. The distribution of calcite *e*-twin types—which undergo several temperature-dependent changes in morphology from ~150 to >250°C—indicate that most, if not all, of the tectonite assemblage had cooled below the white mica closure temperature prior to folding with the lowest temperature *e*-twin types occurring to the northeast. We infer that the spatial distribution of white mica $^{40}\text{Ar}/^{39}\text{Ar}$ cooling ages at Little Salmon Lake is the result of slow cooling (<5°C/Ma) after ductile shearing but prior to folding. Our results are consistent with models that interpret the Teslin suture zone as the product of dextral transpression related to SW-dipping subduction, and provide timing constraints for the inception of NE-vergent contraction.

Progress in Structural Mapping in the Teslin Suture Zone, Big Salmon Range, Central Yukon Territory

James L. Harvey, Richard L. Brown, and Sharron.D. Carr

Ottawa-Carleton Geoscience Centre and Department of Earth Sciences, Carleton University, Ottawa, Ontario, K1S 5B6.

Introduction

The Teslin Suture Zone (TSZ) delineates the boundary between North American continental margin rocks to the east and accreted terranes to the west (Figure 1). Several workers (Templeman-Kluit, 1979; Erdmer, 1985; Hansen, 1989, 1992a,b; Hansen and others, 1991) have argued that the TSZ formed as a subduction-mélange complex on the western margin of North America during the early Mesozoic. The primary arguments for a subduction zone origin for the TSZ include: (1) the presence of eclogitic rocks within the TSZ (Templeman-Kluit, 1979; Erdmer and Helmstaedt, 1983; Erdmer, 1985); (2) the discontinuous nature of lithologic units in the field (Erdmer, 1985); (3) the presence of "cataclastic" fabrics in the supracrustal rocks (Templeman-Kluit, 1979; Erdmer, 1985; Hansen, 1989); (4) thermobarometry from supracrustal rocks suggesting a high-pressure origin (Hansen, 1992b); and (5) southwesterly plunging (down-dip) stretching lineations and top-to-the-east kinematics in supracrustal rocks consistent with eastward thrusting of accreted terranes over North America (Hansen, 1989; 1992b). Alternatively, Stevens (1994) and Stevens and others (1995) suggested that the TSZ represents a zone of complex transpressional deformation. These workers cited: (1) thermobarometry suggesting moderate pressure and temperature conditions in supracrustal rocks; (2) apparently random variations in the orientation of structural features among different structural domains; and (3) west-verging thrust structures to the west, and east-verging thrust structures to the east of the TSZ, suggesting that material was extruded from the TSZ. These discrepancies show that data regarding the geometry and timing of deformation, metamorphic setting, and kinematic significance of structural features within the TSZ are currently insufficient to develop well constrained tectonic models.

Purpose

The current project has a number of important goals. First, we undertake detailed mapping in the TSZ itself, North American rocks east of the TSZ, and the klippen that overlie the North American rocks. Detailed mapping is aimed at establishing the sequence of fabric development and the structural geometry of both the Yukon Tanana and Slide Mountain terranes, in both the TSZ and the klippen to the east of the TSZ, and at ascertaining the relative timing of juxtaposition of the Yukon Tanana and the Slide Mountain within the TSZ. Secondly, we will use these data to determine the timing, number, and peak P-T conditions of the metamorphic and deformational events that have affected the rocks in each of the areas. Finally, these data will be used to establish a tectonic model for the evolution of the TSZ and the Northern Cordillera.

The field area was briefly examined by R. L. Brown, S. Carr and P. Williams in the summer of 1994. This paper presents the results of a full summer of detailed mapping, carried out by J. Harvey in the summer of 1995.

Regional Geology

The Teslin Suture Zone (TSZ) is a zone of steeply dipping, NNW-striking rocks in central Yukon Territory and Northern British Columbia (Figure 1), which separate autochthonous North American rocks to the east from accreted terranes to the west. It is thought to be the southern extent of the Yukon Tanana terrane, an apparently composite terrane that overlies North America as a thin tectonic flap in northern Yukon Territory and eastern Alaska (Mortensen and Jilson, 1985; Hansen, 1989; Mortensen, 1992).

The TSZ is composed of several distinct lithologic packages. These include supracrustal sedimentary and volcanic rocks equivalent to those in the Yukon Tanana terrane, oceanic crustal rocks correlated with the Slide Mountain terrane, and three plutonic suites, including Devonian-Mississippian peraluminous granites, and both Permian and Late Triassic to Early Jurassic I-type granitoids. Both the Devonian-Mississippian peraluminous suite and the Permian intrusive suite are deformed, while Late Triassic to Early Jurassic plutons are undeformed, thereby constraining the age of deformation and metamorphism to between Late Permian and Late Triassic (Mortensen, 1992). Supracrustal rocks throughout the Yukon Tanana terrane range in age from Devonian to Permian (Mortensen, 1992), and this approximate age range is tentatively adopted for similar rocks in the TSZ. Following deformation and cooling (Mortensen, 1992; Templeman-Kluit, 1979) of the supracrustal and plutonic rocks, oceanic crustal rocks of the Slide Mountain terrane (Anvil allochthon of Templeman-Kluit, 1979; Teslin-Taylor Mountain terrane of Hansen, 1989) were emplaced over Yukon Tanana terrane rocks along low-angle, post-metamorphic faults (Mortensen, 1990, 1992; Templeman-Kluit, 1979).

In the Big Salmon Range of central Yukon Territory, the TSZ is about 20 km wide. It is separated from North American rocks (to the east) by the D'abbadie fault and from accreted terranes (to the west) by an apparently steeply dipping normal fault. In the TSZ, Slide Mountain and Yukon Tanana rocks both contain steeply dipping fabrics, unlike their counterparts throughout the rest of Yukon and Alaska. The nature of the contact between these two terranes has not been established for the TSZ. East of the TSZ, thin slices of both Slide Mountain and Yukon Tanana terranes overlie North American autochthonous strata, up to 200 km away from the TSZ, along sub-horizontal thrust faults. Structural fabrics in the klippen are typically subhorizontal, unlike those in the TSZ.

Progress

Introduction

Mapping in the summer of 1995 focused on the eastern TSZ, between Last Peak and Dycer Creek, where there is extensive exposure both along and across strike. The continuous exposure allowed detailed mapping of both supracrustal rocks and plutonic rocks within the TSZ and of some rocks immediately east of the TSZ, with the main focus on understanding fabric relationships and regional structural geometry of the TSZ.

Lithologic Packages and Field Relationships

Three distinct, NNW-striking lithologic packages occur in the area (Figure 2). From east to west, these include (a) along the margin of the TSZ, a sequence of mylonitic orthogneisses; (b) a diverse package of metasediments, referred to herein as the eastern supracrustal package (ESP), including carbonates, chlorite-amphibole and chlorite-biotite, quartz-muscovite, and graphitic schists; (c) a homogeneous package of calcareous and/or graphitic quartz-muscovite schists, referred to herein as the western supracrustal package (WSP). On one cross-strike traverse, a sequence similar to the ESP was encountered west of the WSP. The WSP and ESP roughly correspond with the Nisutlin and Anvil allochthons as mapped by Templeman-Kluit (1984).

Mylonitic Orthogneisses. Within the mylonitic orthogneiss suite, three lithologies occur. These include, from east to west, muscovite-porphyroblastic mylonite, granitic protomylonite, and granitic porphyroclastic mylonite (Figure 2). Each of these is characterized by near-vertical mylonitic or protomylonitic foliation and by subhorizontal stretching lineations, which plunge either NNW or SSE.

The easternmost of these, which defines the margin of the TSZ, is a fine-grained mylonite with coarse muscovite porphyroblasts, which are late synkinematic. Shear sense was determined in the field from well-developed S-C fabrics and is exclusively dextral. The unit crops out for at least 20 km along strike, from Dycer Creek to the Big Salmon River, and is of approximately the same thickness for the entire strike length (about 250 m).

Granitic protomylonite occurs immediately west of the muscovite mylonite. This unit is characterized by large (cm scale), euhedral K-feldspar porphyroblasts and weakly deformed, nearly square, porphyroclasts, in a medium- to fine-grained matrix. Quartz rods define a moderately developed stretching lineation, and shear sense, also exclusively dextral, was determined in the field from weakly to moderately developed S-C fabrics. K-feldspar porphyroclasts rarely have well-developed tails. The contact with muscovite mylonite appears to be abrupt.

Porphyroclastic mylonite lies on the westernmost edge of the orthogneiss package, between granitic protomylonite and the supracrustal package. This unit is characterized by cm-scale rounded K-feldspar porphyroclasts in a fine- to very fine-grained matrix, with fine-grained biotite. A well-developed stretching lineation is defined by both quartz rods and streaks of biotite. Dextral shear sense was determined in the field by well-developed S-C fabrics, shear bands, and both sigma and delta porphyroclasts.

Contact relationships between the granitic mylonite and protomylonite vary from south to north. In the southern part of the area, the distinction between the two bodies is not clear. There, the rocks bear moderately rounded porphyroclasts in a fine-grained matrix, a texture that is intermediate between the two distinctive textures farther north. Within a few km north of Dycer Creek, however, the two bodies become distinct, with an easily mappable contact. A few km south of the Big Salmon River, the contact between the two units is well exposed, and there is a thin (perhaps 25 m) mylonitic margin in the protomylonitic body. Also in this region, small dykes of undeformed granite cross-cut the foliation in the porphyroclastic mylonite. These relationships suggest that the protomylonite is somewhat younger than the porphyroclastic mylonite, although they may be very close in age.

Immediately south of the Big Salmon River, the porphyroclastic mylonite is not present, and the protomylonite is juxtaposed against the supracrustal sequence. A well-exposed contact between the supracrustal sequence and protomylonite at this location reveals that the protomylonite is entirely post-kinematic with respect to regional deformation. Immediately along the contact, supracrustal rocks are folded into relatively shallowly dipping orientations, which are cut by the vertical pluton margin. A thin metamorphic aureole is present in the country rocks.

The contact between the granitic mylonite and the supracrustal sequence is not exposed, but is everywhere parallel to the strike of the supracrustal rocks. In some locations, the supracrustal sequence is slightly hornfelsed near the contact.

Eastern Supracrustal Package. The eastern supracrustal package (ESP) is characterized by diversity of lithology, minor fold plunges that are bi-directional, and three penetrative generations of planar fabrics. Characteristic lithologies include marbles, chlorite-amphibole and chlorite-biotite, quartz-muscovite, and graphitic schists. Units on either side of this package are mappable for over 20 km parallel to strike, while those in the middle of the package occur in discontinuous outcrop patterns. Carbonate units are rarely continuous for more than a few km along strike, but often several bodies occur along the same strike. Other units crop out in patterns that geometrically resemble en-echelon arrays.

Structurally, this package is characterized by three generations of planar fabrics (discussed in detail below). The most recent of these fabrics is a steeply dipping, penetrative cleavage, everywhere except for within a few meters of the contact with the protomylonitic gneiss. Minor folds plunge gently or moderately either to the NNW or SSE.

A single traverse encountered lithologies similar to the eastern supracrustal package on the western margin of the area (in the centre of the TSZ). Detailed mapping of these rocks was limited by the available exposure.

Western Supracrustal Package. The western supracrustal package (WSP) is characterized lithologically by a sequence of graphitic and/or calcareous quartz-muscovite schists. Lithologic variations in this package are generally gradational, and few individual units can be mapped.

Three generations of planar fabrics are present in this package. The most recent of these (S_2) is a variably developed cleavage, which is axial-planar to latest minor folds. Earlier fabrics probably represent one or more transposition cycles (see below). In this package, virtually all minor folds and intersection lineations plunge moderately to gently NNW. Outcrop patterns, S_2 minor folds, and S_1 - S_2 cleavage relationships define a regional, shallowly NNW plunging antiform with steeply dipping limbs, which occurs in the center of the WSP (Figure 2).

Fabric Relationships in Supracrustal Rocks

As alluded to above, fabric relationships in the supracrustal rocks differ for each of the two lithologic packages. Both packages clearly contain three generations of planar fabrics, the earliest of which (referred to herein as S_0) is either bedding or transposed bedding. Refolded F_1 isoclinal folds have been clearly identified in each package. Commonly, the most recent fabric in each package is a cleavage, parallel to the axial planes of the latest folds. The principal differences between the ESP and WSP lie in the form and degree of penetrativeness of S_1 and S_2 , the orientations of minor fold axes and intersection lineations, and the development of folds subsequent to F_2 .

The ESP is characterized by a penetrative S_2 surface, which is usually nearly vertical. The surface may be present either as a tightly spaced cleavage (<5 mm) parallel to the axial planes of F_2 folds, a penetrative grain-shape foliation (defined by micas) and compositional layering, or both. Where S_2 is a penetrative cleavage, F_2 is usually preserved as symmetric or asymmetric isoclinal folds, which may be rootless, or as tight fold trains with steeply dipping form surfaces. Occasionally, S_2 is non penetrative at the scale of a small outcrop, and the hinges of F_1 isoclinal folds are clearly preserved. These outcrops preserve type 2 and 3 interference patterns. A post F_2/S_2 folding event (F_3) is nonpenetrative. F_3 folds are asymmetric and open to tight, with the interlimb angles that decrease along the axial planes perpendicular to the hinge lines until the folds die out, usually within a few meters or less.

WSP rocks are characterized by large variations in the development of the S_2 cleavage, which is tightly to widely spaced and parallel to F_2 axial planes. The degree to which this cleavage is penetrative is directly related to the density and tightness of F_2 folds, which range from gentle, asymmetric warps in the S_1 foliation, with widely spaced axial-planar cleavages, to tight or rarely isoclinal asymmetric folds with tightly spaced cleavages. S_1 is usually easy to identify between S_2 cleavage surfaces, and varies from sigmoidal domains to tight, symmetric folds, which may or may not be rootless. Where tight folds are present, inter- S_2 domains may alternate from synformal to antiformal across S_2 surfaces. Compositional layering (S_0) parallel to S_1 is often continuous across S_2 surfaces in both sigmoidally and symmetrically folded domains. Where S_2 is weak or not present, S_1 forms steeply dipping foliations, usually defined by compositional layering.

In some outcrops, thin discrete carbonate layers are preserved; where S_2 and S_1 are both relatively weak, these layers are continuous, and can be traced through the closures of rare F_1 folds. Where S_1 is penetrative and S_2 is weak, the carbonate layers occur as boudins with axes parallel to the S_1 foliation. Where S_1 is penetrative and S_2 is strong, trains of boudins parallel to S_1 define the limbs of F_2 folds, and are folded in the hinges of the F_2 folds. These observations suggest that the boudins result from limb attenuation and isolation of F_1 fold hinges during transposition.

Geochronology

Current geochronological investigations focus on the ages of the mylonitic rocks on the eastern margin of the TSZ. These rocks were included in the Anvil allochthon by Templeman-Kluit (1984), and mapped as "peraluminous orthogneiss assemblage", implying their equivalence with the Devonian-Mississippian orthogneiss assemblage, by Hansen (1989). However, our detailed mapping shows that contacts of the granitic protomylonite cross-cut deformation fabrics in the TSZ, indicating that these bodies are post-kinematic with respect to deformation in the TSZ. Weak contact aureoles, which overprint the regional metamorphic fabric of the TSZ, are locally developed along the margins of all of the mylonitic rocks, indicating that all of the bodies post-date regional metamorphism in the TSZ. Contact relationships among the various mylonites are ambiguous.

Two samples each from both the porphyroclastic mylonite and the protomylonite were collected during the summer of 1995 (Figure 2). Sample BS107 was collected near the well-exposed contact of the granitic protomylonite with the ESP. To date, three fractions of zircon and two of monazite have been selected for analyses, which are in progress. Zircon is generally quite small, with one fraction of clear, bluish, inclusion-free grains being obtained from each of

the 105-149 μ , and 74-105 μ fractions. Another fraction of clear, colorless to bluish grains, with a small number of inclusions, was obtained from the 105-149 μ fraction. One of the monazite fractions comprises two grains of >149 μ , and the other includes 5 grains from the 105-149 μ fraction. Sample BS082 was collected from the porphyroclastic mylonite. Two fractions of clear, colorless to blueish, inclusion-free zircons were obtained from the 105-149 and 74-105 μ grain size ranges. Data from these samples will be available in the spring.

Current data bearing on the ages of the mylonitic rocks come from several sources. On a regional scale, Mortensen (1992) has dated post-kinematic plutons as old as latest Triassic (212 Ma) in eastern Alaska. However, the oldest post-kinematic plutons in the TSZ itself are approximately late Jurassic (188 Ma; Stevens and others, 1994). The later age is roughly consistent with $^{40}\text{Ar}/^{39}\text{Ar}$ white mica ages of 190-195 Ma, which were obtained from metamorphosed supracrustal rocks in the TSZ and were interpreted as metamorphic cooling ages by Hansen and others (1991). We expect the maximum ages obtained from these plutons to be about 188 Ma, or possibly as old as 212 Ma. However, concordant white mica and biotite ages of 97 Ma were obtained on the porphyroclastic mylonite by Hansen and others (1991). The concordance of these ages, as well as the presence of numerous Cretaceous plutons in the region with similar cooling ages and U-Pb ages (Mortensen and Hansen, 1992) strongly suggests a middle Cretaceous age, at least for the granitic protomylonite.

Metamorphic History

We have not yet compiled detailed information on the metamorphic history of the map area, but our field observations can be used to provide some constraints. Important assemblages observed in the field include muscovite + biotite + chlorite, muscovite + biotite, chlorite + biotite, and chlorite + actinolite. Garnet was observed in only one location, and this location appears to be part of the contact aureole of the granitic protomylonite. No distinctive variation of mineral assemblages along strike was observed in any of the units. These observations lead us to tentatively suggest that maximum metamorphic grade reached in the area was in the greenschist facies.

Preliminary Conclusions

- 1) The intrusion and subsequent mylonitization of granitic protomylonite on the eastern margin of the TSZ post-date deformation in the TSZ itself. The age of the protolith of this body is unknown, but it must be post-Late Triassic, the age of the oldest undeformed plutons intruding the Yukon Tanana terrane. Contact relationships for porphyroclastic mylonite are equivocal, and no minimum or maximum age can be determined from field relationships. U-Pb geochronological studies are currently in progress for both bodies.
- 2) Two distinct packages of supracrustal rocks are defined for the eastern TSZ. The boundary between these packages roughly corresponds to that defined by Templeman-Kluit (1979) for the Nisutlin and Anvil allochthons. Structural data suggest that the two packages have differing deformational histories. The nature of the boundary between the two packages is not known.

- 3) Fabrics in both supracrustal packages show that these rocks have experienced at least one transposition cycle. Rocks of the eastern supracrustal package appear to have experienced a second, nearly complete transposition. In both packages, rotation of F_1/S_1 fabrics into near-parallelism with F_2 axial planes and the development of strong axial planar cleavages parallel to the F_2 axial planes produce the strong, NNW-trending foliation in the TSZ.
- 4) The identification of both a major antiform in the western supracrustal package and units with along-strike continuity in the eastern supracrustal package suggests that a coherent structural geometry exists and is tractable in the TSZ.

Future Work

Work during the summer of 1995 established the presence of a coherent structural geometry, the fundamental rock units, and the nature of structures in the eastern part of the TSZ. Mapping during the coming summer will be focused between Dycer Creek and the South Big Salmon River. This region offers good exposure both along and across strike and is known to have exposures of ultramafic and mafic rocks correlative with the Slide Mountain terrane as well as rocks correlative with the Yukon Tanana terrane. Furthermore, region offers good access to North American rocks and a major klippe overlying them east of the D'abbadie fault, potential exposures of the fault itself, as well as good exposure of plutons that have been mapped as both Cretaceous and Devonian. Specific objectives include:

1. Continuing current mapping in Yukon Tanana rocks southward;
2. Mapping structural geometry in rocks correlative with the Slide Mountain terrane and establishing the nature of the contact between Yukon Tanana and Slide Mountain rocks within the TSZ;
3. Establishing structural styles in both North American rocks and a klippe of Yukon-Tanana rocks east of, and for comparison with, the TSZ;
4. Establishing with certainty the age, contact relationships, and deformational history of plutonic rocks in the area;
5. Collecting appropriate specimens in all terranes which can be used to determine the metamorphic age (via U-Pb geochronology) and/or peak conditions and P-T histories.
6. Investigation of strain partitioning during Cretaceous strike-slip deformation, via mapping of mylonitic fabrics associated with Cretaceous plutons.
7. Construction of a crustal-scale cross section through the TSZ region and, through the use of geochronologic, metamorphic, and structural data, development of a more tightly constrained model of the evolution of the TSZ and related rocks.

Acknowledgements

The research presented herein is supported by LITHOPROBE and NSERC grants to R.L. Brown and NSERC grants to S.D. Carr. Special thanks to Martin DeKiejer and Paul Williams for beneficial discussions during fieldwork. We gratefully acknowledge P. Erdmer for his help in getting us started in the Yukon, and for his help with logistics. J. Harvey thanks Chris Boyko for a timely arrival in the field!

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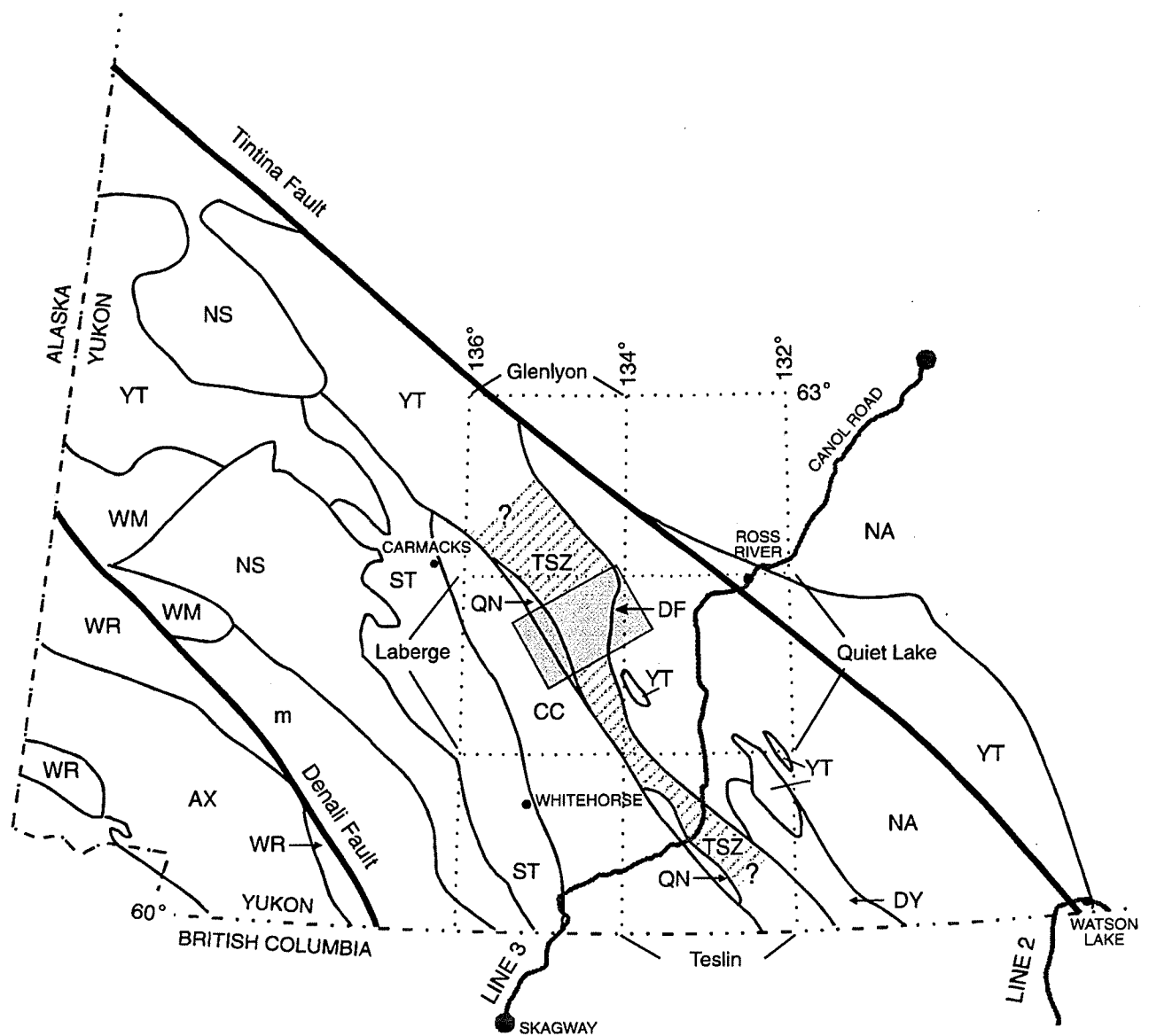


Figure 1. Terrane map of the Yukon, highlighting the Yukon Tanana Terrane and Teslin suture zone and showing the location of the study area (shaded box) and Lithoprobe Line 1 (also part of Line 2). The main map areas in which the Teslin suture zone is exposed are also shown (Teslin, Quiet Lake, Laberge, Glenlyon). Terranes are: NA = North America, YT = Yukon Tanana, TSZ = Teslin suture zone, NS = Nisling, DY = Dorsey, QN = Quesnellia, CC = Cache Creek, ST = Stikinia, WM = Windy McKinley, m = undivided metamorphics, AX = Alexander, WR = Wrangellia. DF = D'Abbadie fault. Modified from Wheeler and McFeely, 1991, and Stevens et al., 1993.

LEGEND

Lithologic Units

m	Calcite marble, usually with volumetrically minor quartz-rich layers
qm	Quartz mica schist; most commonly muscovite+chlorite, but also with biotite
g	Graphitic schist; fine-grained graphitic schist, often with pyrite porphyroblasts
cgs	Calcareous graphitic schist; orange to grey weathering, most commonly with muscovite + quartz + calcite; in several locations, contains discontinuous carbonate layers; often graphitic.
gpm	Granitic protomylonite; weakly-developed S-C fabric and stretching lineation, with weakly deformed K-feldspar porphyroclasts and minor muscovite
pm	Porphyroclastic mylonite; strongly deformed K-feldspar porphyroclasts in a fine-grained matrix, sometimes with visible biotite; quartz rods and biotite define stretching lineation; commonly with S-C fabrics and shear bands
ESP	Eastern Supracrustal Package (see text)
WSP	Western Supracrustal Package (see text)

Map Symbols

	Mylonitic foliation; inclined, vertical		Minor fold axes with vergence; F1, F2
	S2 cleavage; inclined, vertical		Lithologic contact, dashed where inferred
	S1 foliation; inclined, vertical		Shear zone, dashed where inferred
	Stretching lineation		Axial surface trace of major antiform, dashed where inferred
	S1-S2 intersection lineation		Geochronology sample location and number
		BS107	

Figure 2. Geologic map of the eastern TSZ between Last Peak and Dycer Creek, mapping during the summer of 1995.

STRUCTURAL ANALYSIS IN THE TESLIN TECTONIC ZONE, SOUTH-CENTRAL YUKON

Martin de Keijzer and Paul F. Williams,
Department of Geology, University of New Brunswick, Fredericton, N.B., E3B 5A3

INTRODUCTION

It is generally accepted that the Teslin tectonic zone (TTZ) (cf. Stevens 1994) in south-central Yukon forms the boundary between (par)autochthonous rocks of the Middle to Late Paleozoic continental margin of North America to the east and accreted terranes of the Intermontane Belt to the west. The TTZ forms the southern extension of the Yukon-Tanana terrane (Tempelman-Kluit 1979; Hansen 1989) and comprises a 10-20 km wide NNW-trending belt of generally steeply dipping ductilely deformed metasedimentary, metavolcanic and metaplutonic rocks.

A tectonic model for the Teslin tectonic zone was first proposed by Tempelman-Kluit (1979) and involved the formation of a W-dipping subduction complex in Permo-Triassic time. In this model, metasedimentary rocks in the TTZ (Nisutlin Allochthon; Tempelman-Kluit 1979), are believed to be a tectonic melange of trench and fore-arc sediments formed during subduction. Nisutlin terrane and Nisutlin assemblage are frequently used names in more recent publications and include rocks assigned to Nisutlin Allochthon. 'Nisutlin Assemblage' is favoured herein. This model was supported by Erdmer & Helmsteadt (1983) and Erdmer (1985) and was refined by Hansen (e.g. 1988, 1989, 1990) with the suggestion that Early Mesozoic subduction involved oblique plate convergence with dip-slip movements (normal and reverse) and right-lateral margin-parallel translation along subduction-related strike-slip faults.

On the other hand, primary contact relationships and intrusive contacts indicate that at least part of the Nisutlin assemblage in the Teslin map area has a pré-Early Mississippian depositional age, and that these rocks may have formed a regionally extensive continental crustal terrane which had formed by the mid-Mississippian (Mortensen and Jilson 1985; Stevens 1994; Stevens et al. *in press*). If this is correct, the Nisutlin Assemblage cannot have formed as a Late Paleozoic - Early Mesozoic

subduction zone melange. Stevens (1994) proposed an alternative scenario in which the structure of the TTZ is represented by a doubly-vergent transpressive shear zone with the characteristics of the lower portion of a flower-structure, rather than a more genetic tectonic model involving subduction-related deformation.

A reconnaissance study in 1994 by Brown, Carr and Williams resulted in the tentative conclusion by Brown et al. (1995) that the TTZ need not represent a (crustal scale) suture zone; the zone displays intense deformation, but features characteristic of subduction-related deformation were not observed; the type of chaos typical in melange formation, whether sedimentary or tectonic, was not recognized. Despite intense transposition a 'mappable' stratigraphy seems to be preserved in the metasedimentary rocks (Stevens 1994; Brown et al. 1995; Stevens et al. *in press*). These observations are in agreement with those of Mortensen and Jilson (1985) who recognize that rocks mapped as the Nisutlin Allochthon E of the Tintina fault are "highly tectonized but internally relatively coherent".

The difference of opinions regarding the tectonic evolution of the TTZ and related units, as described above, indicates that the present state of knowledge of the process of terrane accretion in this part of the Cordillera is still inadequate. This is predominantly due to insufficient structural, metamorphic and geochronologic data. The main objective of the present study is to establish the geometry and style of deformation of the TTZ, including along-strike variations, and of adjacent rocks of the 'North American continental margin' (Cassiar terrane). Structural mapping was carried out in the summer of 1995 near Last Peak in the Lake Laberge map area (Fig.1), in collaboration with Harvey, Brown and Carr from Carleton University.

STRUCTURAL OBSERVATIONS

Four generations of structures, including previously unrecognized structures, are recorded in the metasedimentary rocks in the TTZ.

Pré-F3 structures comprise a transposed primary layering (S1) and a penetrative metamorphic foliation S1 axial planar to F1 isoclinal. The maximum of S0/S1 orientations plots approximately to the W with dips of 45-75°. There is a spread, however, between

horizontal and vertical dips and dip-directions between SW and ENE. This pattern can be satisfactorily explained by the subsequent folding events described below. At two locations where F1 isoclinal hinges are well developed, an older generation of (cm-scale) isoclinal hinges is refolded by F1.

Occasionally, F1 isoclinal hinges are refolded by open to tight dm-scale F2 folds. Where determined, the vergence of F1 and F2 folds is dominantly easterly. The recognition of F2 structures is limited, i.e. unequivocal overprinting relationships are only found in few outcrops, and the importance of F2 in the structural geometry of the area is unknown at this stage. The observations suggest that the 'early' transposition involved the formation of more than one generation of folds, possibly in a progressive deformation regime.

The above structures are overprinted by a third, regionally important and complex folding event which gave rise to conjugate S3 surfaces (S3' and S3'') and related open to tight F3 folds, symmetrical about S0/S1. Locally, F3 folds are isoclinal. They are observed at scales up to 500 m and plunge gently to the N-NW. A number of F3 conjugate folds and axial planar S3 cleavages have been observed in outcrop. S3' and S3'' are not seen to overprint each other, i.e. there is no evidence of one cleavage being folded by the other. In general, S3' varies in dip from gentle to moderate and in dip direction from W to N, whereas S3'' is steeply E/NE-, vertical or W-dipping. Domains are identified, in outcrop and at map scale, in which one of the conjugate S3 cleavages is dominant (Fig. 2). When viewed N-NW, S3' is generally associated with open to tight S-folds and S3'' with open to tight Z-folds (Fig. 2). In both cases, however, opposed vergences are also observed.

The conjugate nature of F3 structures has not been documented before. The recognition of the fact that F3 structures define a regional scale N-NW plunging structure, at least in the study area, implies that different structural levels, and thus probably different styles of deformation related to F3, are exposed along-strike in the TTZ. To the S in southern Lake Laberge and Teslin map areas the style of F3 structures and the coaxial / non-coaxial character of F3 deformation may differ.

Evidence for post-F3 folding includes a) systematic variations in S3' orientation

on a m- to km-scale from N to WNW near Last Peak in the TTZ, and b) 100-500m scale chevron-type folds in the NE part of the study area (Fig. 2). The latter forms the transition zone between the relatively steeply dipping transposition fabrics of the TTZ and more flat-lying fabrics characteristic of the 'North American' rocks to the E.

SOME NOTES ON THE KINEMATICS

The fact that a) probably more than 1 generation of folds (pre-F1?, F1, F2) contributed to the transposition, and b) where determined, the asymmetry of these folds is dominantly E-verging, indicates a strongly non-coaxial strain path. However, the conjugate nature of F3 structures, symmetrical about S1, is indicative of a dominantly coaxial strain path. Thus there is a change in the kinematic frame between the formation of pré-F3 structures and F3 structures and the relationship between the two has to be considered an overprinting relationship. A change in the kinematic frame implies that the structural fabrics are the result of non-steady progressive deformation or of two (or more) distinct deformation events.

Several authors interpreted the structures in the metasedimentary rocks to have formed in one progressive deformation event (e.g. Gordey 1981; Hansen 1989; Stevens 1994). Gordey (1981) and Stevens (1994) recognize that the early penetrative fabrics (transposition fabrics with the formation of isoclinal folds; F1/S1 this study) and subsequent folding and related cleavage development (F3/S3 this study) are sequential. According to Gordey (1981) the folds, including open E-verging third generation folds, are the endmembers of continuous deformation and "do not represent two distinct folding episodes".

Hansen (1989) shows a block-diagram with the structural fabrics of the TTZ which include a "mylonitic to neoblastic metamorphic foliation, locally comprised of a composite S-C foliation (preserved in the motion plane)" and open to tight folds with axial planes parallel to "shear planes" and axes parallel to a mineral elongation lineation. It is argued by Hansen (1989) that these folds "must have formed synchronously with on-going penetrative, non-coaxial ductile deformation, and apparently nucleated as open-style folds with colinear axes and L (mineral elongation lineation)".

We correlate the penetrative cleavage (S-planes) with S0/S1 (this study) and the spaced cleavage (C-planes / shear planes) with the S3 cleavage (this study), axial-planar to our F3 folds. Our field observations conflict with the scenario of S-C fabric development as indicated in the block-diagram. First, the conjugate nature of F3 structures, symmetrical about S1, is geometrically different to an S-C fabric. Second, the tightness of some F3 folds makes them morphologically different to an S-C fabric. Furthermore, given the change in kinematic frame between the formation of S1 and S3 cleavages as described above, we favour a scenario of superposition of the structures in a genetically 'unrelated' fashion (i.e. true overprinting relationship), rather than the formation of genetically related S- and C-fabrics formed "during the same non-coaxial deformation" (Hansen 1989).

According to Hansen (1989) the open to tight folds with axial planes parallel to the shear planes (C-planes), and colinear axes and mineral elongation lineation, are confined to a number of discrete 1-3 km wide strike slip zones (Lss tectonites) (sub)parallel to the trend of the TTZ. If the above correlation with our F3 folds is correct then this observation is not supported by our results; F3 folds are developed throughout the study area and are not confined to discrete zones.

Lss fabrics are believed to predominantly post-date Lds fabrics (dip-slip fabrics) (Hansen 1989). Furthermore, Hansen (1987) documents P/T conditions of 425-550 °C and 5-8 kbar for Lss tectonites (i.e. supposedly where F3 structures are developed) and significantly higher P/T conditions (575-675 °C and 8-16 kbar) for dip-slip tectonites (Lds) elsewhere in the TTZ. Also, distinct amphibole compositions for Lds and Lss domains is interpreted as reflecting different metamorphic conditions (Hansen 1992). Taken these results into consideration, it is suggested by Hansen (e.g. 1987, 1989) that penetrative dip-slip fabrics evolved into discrete strike-slip zones in one progressive non-coaxial deformation.

Our present dataset, which consists of geometrical relationships only, does not allow the distinction between non-steady progressive deformation or distinct deformation episodes. Positive evidence is needed from metamorphism and/or absolute dating to

differentiate between the two options. Whichever of the options applies, it will reveal important new insights into the kinematic evolution of the TTZ. Furthermore, the present results show the complexity of the regional structure and also show that the present knowledge of the structure and kinematics of the TTZ is still incomplete. Structural mapping adjacent to the 1995 study area will be continued in the summer of 1996 in order to more completely determine the structural framework of the TTZ. In recognizing the different sets of structures, a high degree of structural (and stratigraphic?) continuity seems to be preserved in the study area. This is different from the chaotically mixed and fragmented rocks ('block-in-matrix' fabric) on several scales that are expected to some extent in subduction zone melanges.

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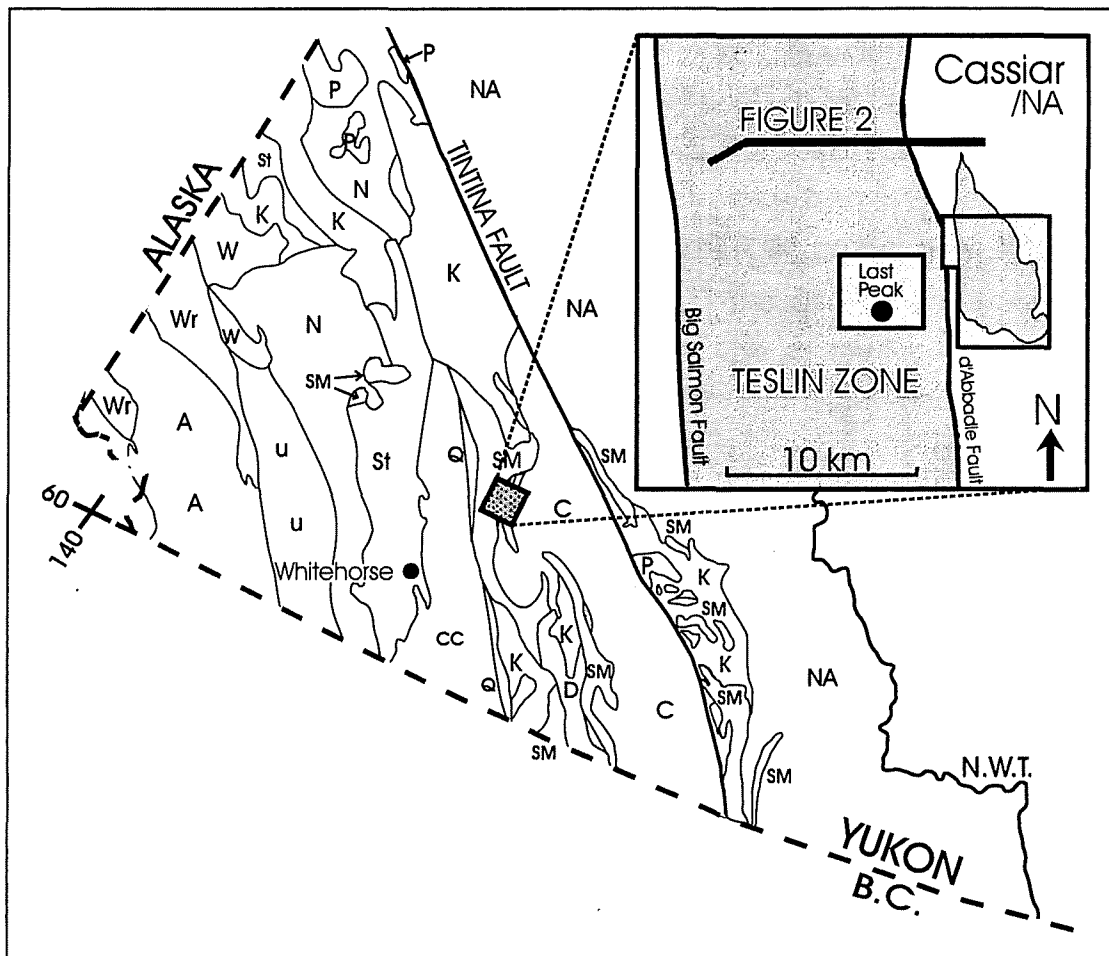


Fig. 1. Simplified terrane map of Yukon Territory. Study area is enlarged in the upper right corner. Ancestral North America (NA); displaced North America - Cassiar (C); pericratonic terranes - Kootenay (K), Nisling (N), Pelly Gneiss (P); accreted terranes - Dorsey (D) Slide Mountain (SM), Quesnellia (Q), Stikinia (St), Cache Creek (CC), Windey McKinley (W), undevided metamorphics (u), Wrangellia (W), Alexander (A). Modified from Wheeler & McFeely, 1991, Map 1712A.

NORTH OF TERAKTU CREEK, LAST PEAK AREA, SE YUKON

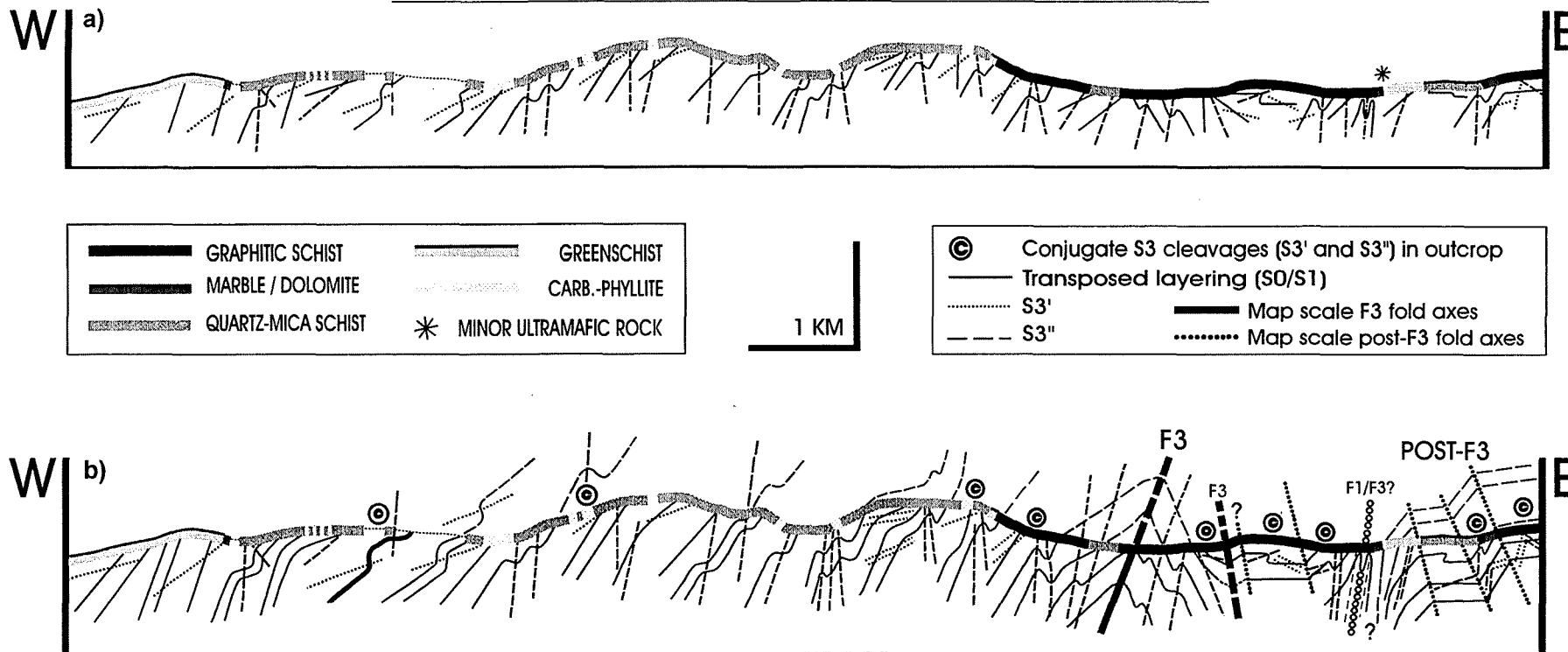


Fig. 2. Schematic representation in profile of the structural fabrics in area 95-2, a) observations, b) partial interpretation. Asymmetric folds as shown in the profiles are dominantly outcrop scale (< 5m) and are enlarged here for clarity. See text for a more detailed explanation.

Detrital Zircon U-Pb Constraints on the Evolution of the Teslin Tectonic Zone, Yukon

L.M. Heaman and P. Erdmer

Department of Earth and Atmospheric Sciences, University of Alberta, Edmonton, Alberta, Canada. T6G 2E3.

INTRODUCTION AND GEOLOGICAL SETTING

Although the potential tectonic significance of the Yukon-Tanana Terrane (YTT) in Cordilleran orogenesis has been long recognized, the terrane's origin and evolution have remained enigmatic. The YTT is located along a fundamental divide of the

orogen (Fig. 1), between parautochthonous assemblages of the North American continental margin (e.g. Cassiar Terrane) and allochthonous terranes to the west accreted in Mesozoic time (e.g. Cache Creek Terrane). Stratigraphic differences between the YTT and the Paleozoic North American continental margin are evident (Mortensen and Jilson 1985), but whether the YTT is in part or entirely

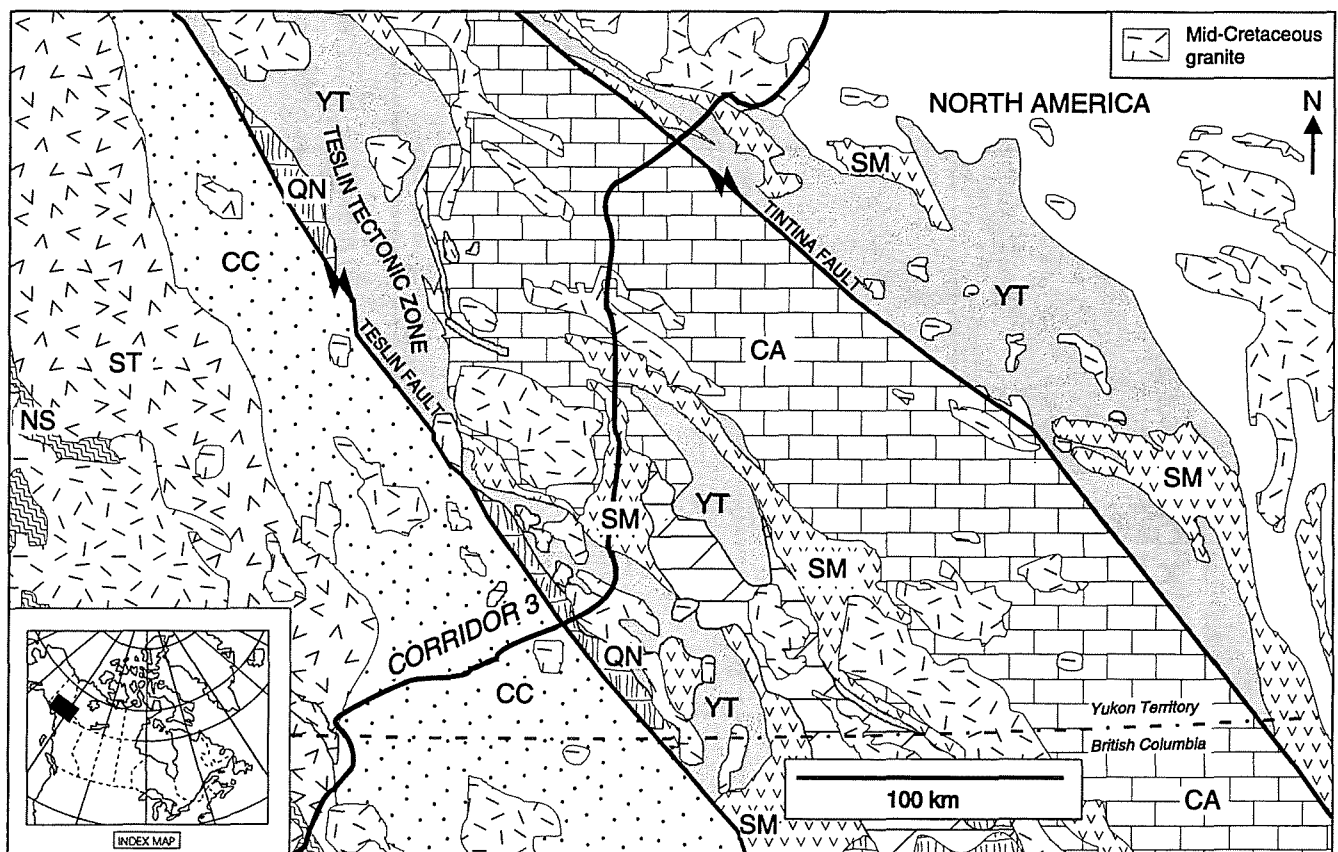


Figure 1. Terrane map of part of the northern Canadian Cordillera, modified from Wheeler et al. (1991). Terrane abbreviations: YT= Yukon-Tanana, CA= Cassiar, SM= Slide Mountain, QN= Quesnellia, CC= Cache Creek, ST= Stikinia, NS= Nisling, North America= Proterozoic-Paleozoic miogeocline of North America. Corridor 3 is the planned seismic acquisition route.

allochthonous is a topic of much debate (e.g. Tempelman-Kluit, 1979; Mortensen and Jilson, 1985; Wheeler and McFeely, 1991).

The pre-Mesozoic rocks of YTT consist predominantly of clastic metasedimentary rocks of continental margin affinity with subordinate metavolcanic assemblages, intruded by a variety of granitoid plutons ranging in age from Devonian to Permian (Mortensen, 1992). The depositional age of the supracrustal rocks is unknown. Single detrital zircon age studies of the Nasina quartzite west of Dawson indicate Paleoproterozoic (1.8-2.3 Ga) and Archean (2.6-2.8 Ga) provenance ages for pre-Devonian supracrustal units in at least part of the YTT (Mortensen, 1990).

The distribution of pre-Mesozoic supracrustal units in a portion of the Teslin tectonic zone (TTZ), a part of YTT, is shown in Figure 2. In this region, the supracrustal rocks are intruded by a number of Devonian to Jurassic granitoids that yielded U-Pb zircon ages of 351.2 ± 1.4 , 348.4 ± 0.8 , 341 ± 5 -17, and 188 ± 3 -5 Ma (Stevens, 1994), demonstrating that the supracrustal units are older than early Mississippian.

A tentative stratigraphic column (Fig. 2) indicates that the supracrustal rocks can be subdivided into three lithological assemblages; 1) a lowermost siliceous schist and quartzite unit, 2) a middle graphitic phyllite unit and 3) an upper unit of greenstone and metagabbro. These pre-Mesozoic rocks were deformed and metamorphosed to amphibolite grade and are characterized by mylonitic and protomylonitic fabrics in many places (Stevens *et al.* 1996). Compositional layering, interpreted to reflect primary bedding, is preserved in the lowermost quartzite unit north of the Boswell River (Fig. 2).

The supracrustal rocks of the TTZ record a more than 20 epsilon-Nd decrease upward in the proposed stratigraphic section (Creaser *et al.*, submitted), with distinctly juvenile Nd signatures (positive epsilon-Nd values) recorded in some units. This change in Nd isotopic signature is accompanied by systematic changes in trace element geochemistry (e.g. Th/Sc ratios also decrease up-section), and indicates a significant ancient crustal component in the lowermost units and a dominantly chemically

juvenile component higher in the stratigraphic section. The Nd isotopic and geochemical patterns in these supracrustal rocks is significant because it provides evidence of juvenile provenance in parts of the pre-Devonian sedimentary record that could reflect the influence of previously unknown, pre-Devonian magmatic arc.

U-PB STUDY

The focus of the present project is to investigate U-Pb single-grain detrital zircon ages in metasedimentary units that have markedly different Nd isotopic signatures. As a starting point, U-Pb detrital zircon age profiles are being determined for metasedimentary units that have the largest disparity in Nd isotopic signatures.

The first sample processed (RS91-415; see sample locations on Fig. 2) is from the lowermost quartzite unit (epsilon-Nd signature of -28 epsilon units) and contains abundant detrital zircon grains. The zircon grains in this sample span a range of colours from colourless to purple and a range of original grain morphology preservation, from round spheres to well-faceted prisms. A high proportion of turbid grains is characteristic.

The second sample (RS91-296) is higher in the inferred stratigraphic section and has an epsilon-Nd signature of -1 epsilon units. The zircon yield from this sample was extremely low and the grains recovered are < 60 microns in diameter. Both of these observations are consistent with derivation from a mafic to intermediate, dominantly volcanic source. There may be two zircon populations in this sample: (1) round, equant, colourless grains and (2) elliptical grains with slight colouration. Single grain analysis of both varieties is in progress.

U-Pb results are not available at the time of writing, and our initial single grain analyses will be presented at the transect meeting. We are expecting that the samples with Nd isotopic signatures indicating a significant ancient crustal component may yield a detrital zircon age profile similar to North American continental margin sedimentary strata (cf. Mortensen 1990), while samples with a juvenile Nd isotopic signature may have an age profile diagnostic

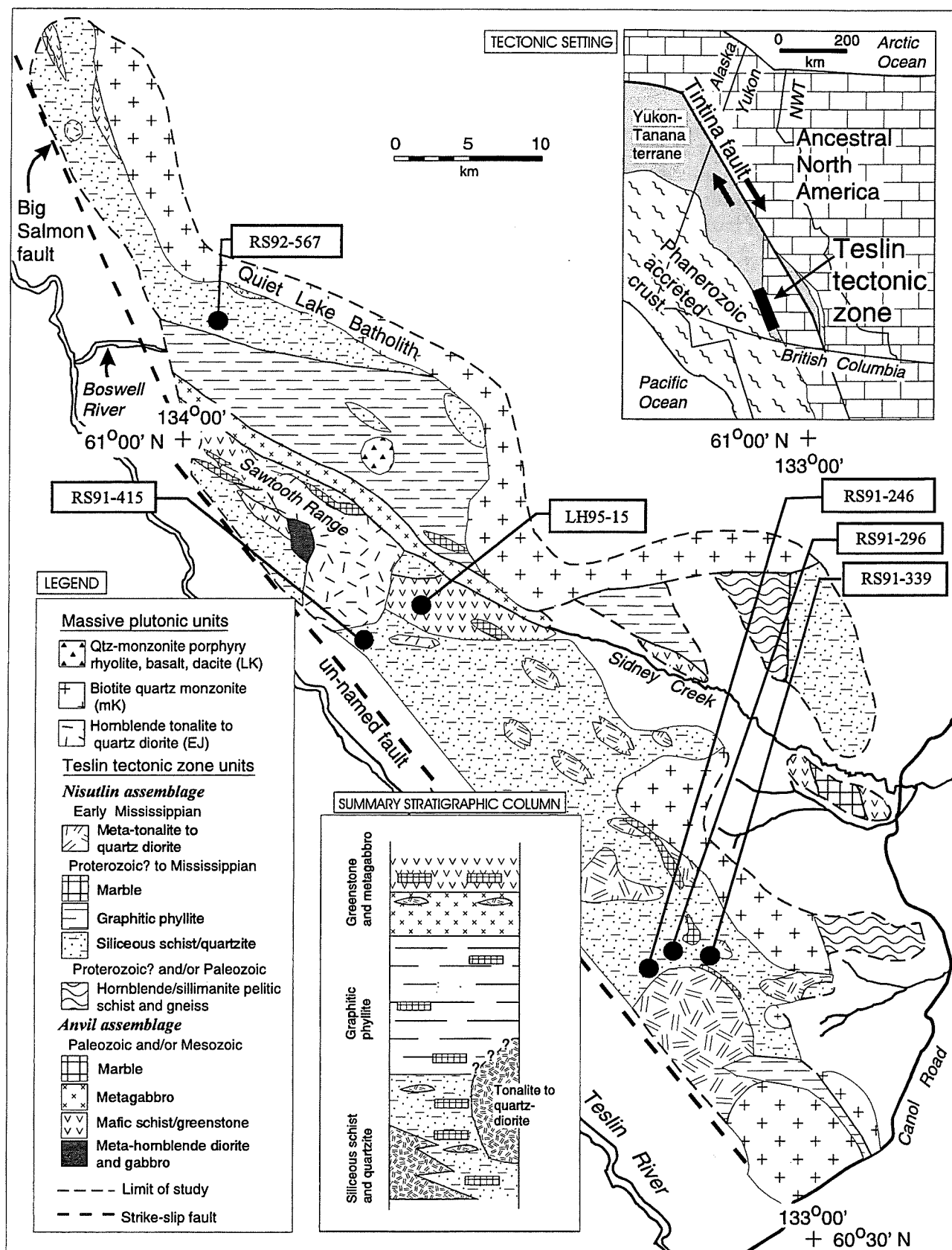


Figure 2. Geology of part of the Teslin tectonic zone and location of samples collected for U-Pb analysis of detrital zircon (black dots). After Stevens et al. (1996).

of a magmatic arc.

Confirmation of the juvenile component would be particularly intriguing because it would strongly support the existence of a relatively old, previously unrecognized (pre-Devonian) magmatic arc. Knowledge of the nature of poorly known early Paleozoic crust later accreted to the North American continental margin is lacking in the northern Cordillera at present. An understanding of the tectonic affinity of Paleozoic basement(?) rocks would help answer the question of whether the accreted portion of the orogen is thick- or thin-skinned at this latitude.

During field collection of samples for the detrital zircon study, we also searched for felsic to intermediate volcanic rocks within the upper greenstone assemblage that would be amenable to U-Pb dating. Establishing the timing of volcanism would provide a direct age constraint for the deposition of the supracrustal rocks. Although no felsic or intermediate volcanic rocks were identified, one sample was collected from a coarse-grained hornblendite (LH95-15) in a greenstone horizon, and was considered to have slight potential for U-Pb geochronology. Unfortunately, thin section examination did not reveal the presence of any U-bearing phases such as zircon or baddeleyite and the sample is considered to be barren from a U-Pb perspective.

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U-Pb zircon dating of eclogite from the Teslin tectonic zone: Constraints for the age of high-pressure metamorphism in the Yukon-Tanana terrane.

Robert A. Creaser, Larry M. Heaman, Philippe Erdmer.

Department of Earth and Atmospheric Sciences, University of Alberta, Edmonton AB T6G 2E3.

High-pressure metamorphic rocks of the Yukon-Tanana terrane extend from southern Yukon to Alaska, and constitute one of the best-preserved belts of Paleozoic high-pressure rocks known (Erdmer, 1992; see Fig. 1 of Erdmer *et al.*, this volume). The belt, comprising numerous localities of eclogites and blueschists, records subduction-zone processes that occurred in Late Paleozoic time prior to the accretion of these rocks to the continental margin of western North America in the early Mesozoic. The high-pressure metamorphic rocks have been linked, through a common subduction process, to widespread Late Permian calc-alkaline volcanism of the Yukon-Tanana terrane (Mortensen, 1992) but much fundamental information is still lacking. For example, it is not known whether all rocks record high-pressure metamorphism of a single age. The connection to the Late Permian calc-alkaline volcanism is made solely on the basis of a few mica Rb-Sr cooling ages.

In order to better constrain the timing of high-pressure metamorphism in the YTT, we have initiated a detailed U-Pb, Sm-Nd and Rb-Sr isotope research program of the YTT eclogites and blueschists. This research is an extension of the P-T-t evolution study in progress by Erdmer *et al.* (this volume), and the initial isotopic results are presented here. The study forms part of a wider isotopic and geochemical research program addressing the crustal evolution, tectonic setting and origin of the Yukon-Tanana terrane prior to its accretion to North America.

One eclogite sample from the Last Peak area (Big Salmon River, location 1 in Fig. 1 of Erdmer *et al.*, this volume) has yielded abundant zircon, titanite and rutile from the heavy mineral fraction. The zircons are water-clear, equant and poorly-faceted (Fig. 2 A-B). U-Pb isotopic results for 5 fractions of zircon are shown on a concordia diagram in Figure 1. Importantly, all isotopic analyses show extremely low Th/U ratios (0.012 - 0.016). Primary magmatic zircons from mafic rocks typically have Th/U > 1, whereas high-grade metamorphic zircons from mafic protoliths typically have Th/U < 0.3 (Heaman *et al.*, 1990; Heaman and Le Cheminant, 1993). These chemical features, together with morphological characteristics, are indicative of a metamorphic origin for the zircons. All analyses are near-concordant and yield a mean weighted concordia intercept age of 268.8 ± 1.5 Ma (1σ). We have also conducted preliminary U-Pb analyses on titanite and rutile (Fig. 2C). Both minerals have very low U contents (< 2 ppm) and considerable common Pb, and meaningful ages can not be obtained from a concordia projection. However, we are continuing isotopic analysis using the ^{238}U - ^{206}Pb isochron approach in an attempt to define a U-Pb based cooling history for this sample. Another eclogite sample from the Ross River area yielded neither zircon nor titanite in the heavy mineral fraction.

The U-Pb isotopic data provide clear evidence of the formation of metamorphic zircon in the Last Peak eclogite at 269 Ma, which we interpret to date the peak of eclogite facies metamorphism. The geothermometric data for the Last Peak eclogite record temperature estimates of up to 625°C (Erdmer *et al.*, this volume) indicating that metamorphic zircon likely grew well below its closure temperature for Pb diffusion ($> \approx 900^\circ\text{C}$). Thus, although the timing of zircon growth is well-constrained chronologically, the timing of metamorphic zircon growth relative to the eclogite's total P-T-t metamorphic path is not yet known. Nevertheless, these U-Pb data do provide a key chronologic "pin" in the Paleozoic history of the Yukon-Tanana terrane because together with $^{40}\text{Ar}/^{39}\text{Ar}$ mica cooling ages of 260 - 270 Ma from YTT eclogites and blueschists (Erdmer *et al.*, this volume), they indicate that the high-pressure metamorphism associated with Late Paleozoic subduction had ceased, and the rocks had been uplifted and cooled by 260 Ma. This conflicts with several tectonic models for the Late Paleozoic to Early Mesozoic evolution of the northern Cordillera, which suggest continual subduction in the YTT over this period (see Erdmer *et al.*, this volume).

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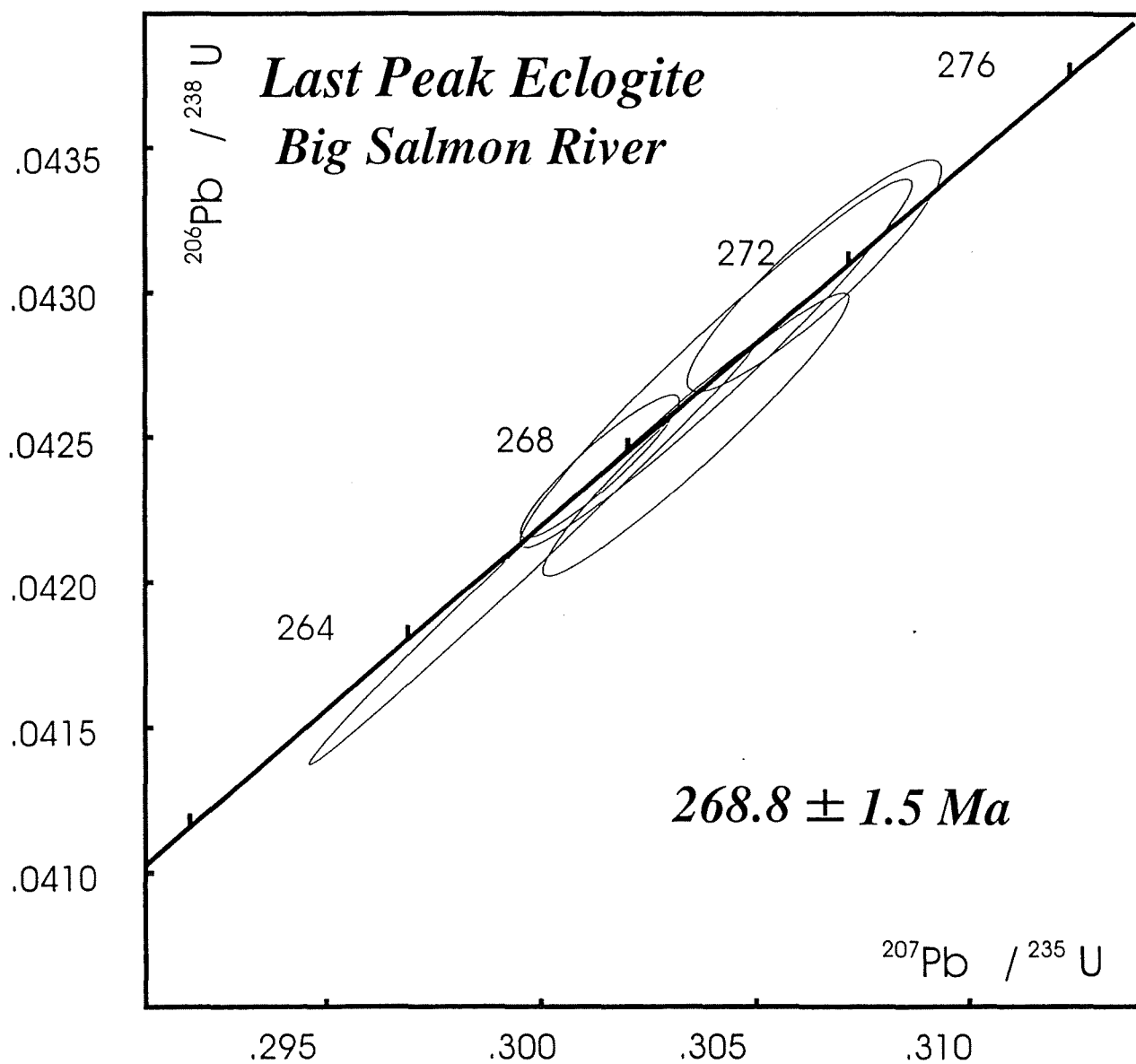


Figure 1. U-Pb concordia diagram showing 5 zircon analyses from the Last Peak eclogite, Teslin tectonic zone. These data yield a mean weighted concordia intercept age of $268.8 \pm 1.5 \text{ Ma}$ (1σ).

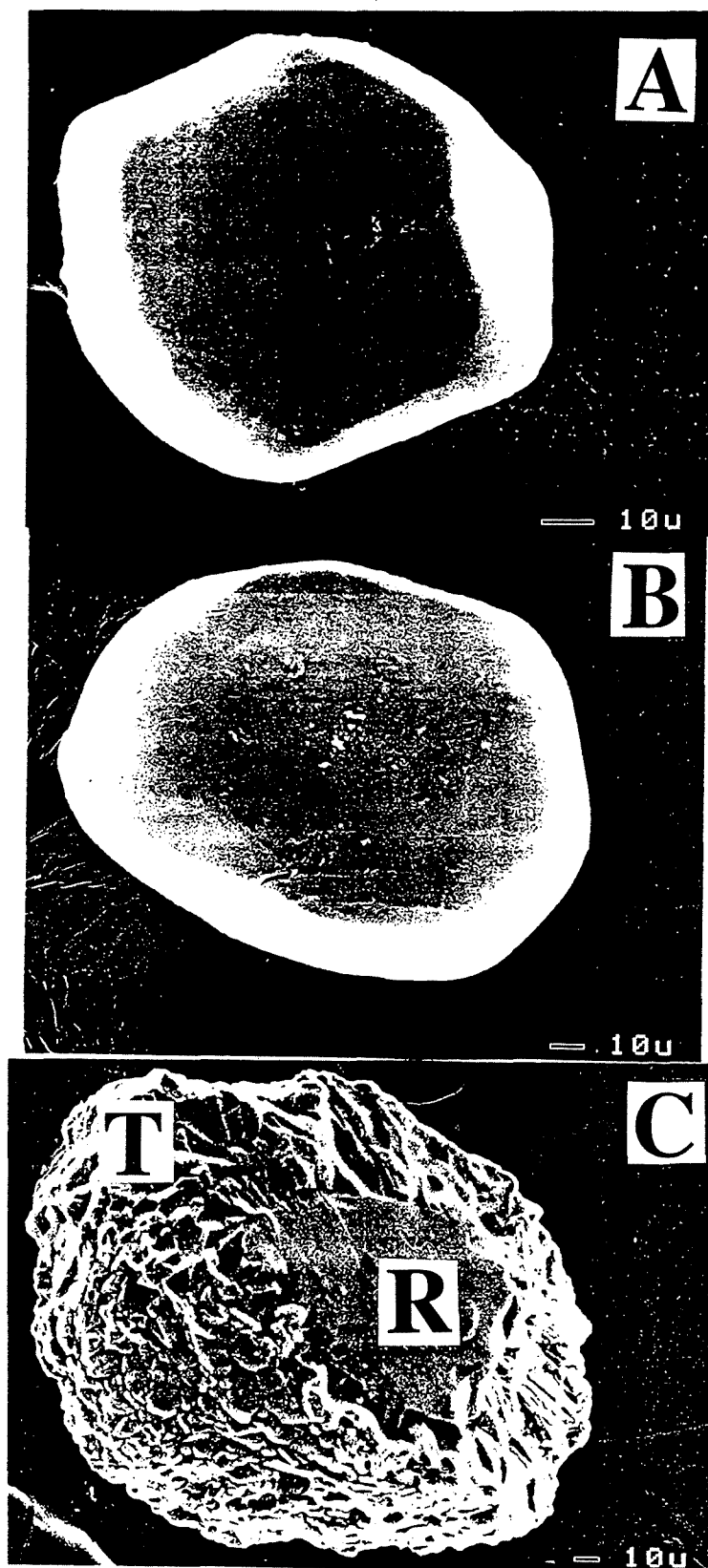


Figure 2. Scanning Electron Microscope images of zircon, titanite and rutile from the Last Peak eclogite, Teslin tectonic zone. A, B: zircon images showing poorly-faceted, equant morphology. C: polycrystalline titanite (T) overgrowth on rutile (R). All scale bars are 10 microns.

High-pressure metamorphism in the Yukon-Tanana terrane - physical conditions, timing and tectonic implications

Philippe Erdmer

Department of Earth and Atmospheric Sciences, University of Alberta, Edmonton, Alberta T6G 2E3

Edward D. Ghent

Department of Geology and Geophysics, University of Calgary, Calgary, Alberta T2N 1N4

Douglas A. Archibald

Department of Geological Sciences, Queen's University, Kingston, Ontario K7L 3N6

Mavis Z. Stout

Department of Geology and Geophysics, University of Calgary, Calgary, Alberta T2N 1N4

Abstract

Permian-Triassic eclogite and blueschist which occur from the Yukon to Alaska preserve a partial record of Late Paleozoic subduction and subsequent unroofing. Previously known high-pressure metamorphic rocks in the Yukon-Tanana terrane were reexamined, one new occurrence was discovered and the best-exposed localities were resampled for analysis. Eclogites typically occur as metre-sized or larger inclusions in greenschist and blueschist rocks. They contain garnet-clinopyroxene-rutile-quartz with additional epidote, micas and amphiboles. They are commonly mylonitized and the degree of retrogression is variable. Garnets locally have Fe-rich cores and Mg-rich rims (~35 mol % pyrope). For rocks near Faro, Fe-Mg exchange between garnet and clinopyroxene suggests temperatures in the 400-500 °C range. Jadeite (~40 mol %) + quartz with no stable albite suggest minimum pressures of 11 to 13 kbar at 400-500 °C. The assemblage clinopyroxene-garnet-epidote-quartz suggests pressures near 15 kbar (for $P_{H_2O} = P_s$). Rocks near Last Peak yielded estimates of pressure and temperature as high as 625 °C with a minimum pressure of 14 kbar. Rocks from Ross River yielded temperatures near 525 °C and a minimum pressure near 13 kbar. Subsequent metamorphism under greenschist to blueschist facies conditions is likely related to incorporation of tectonic slivers of eclogite into the country rocks. Isotopic age determinations on a small sample set indicate that eclogite metamorphism peaked at about 270 Ma (U-Pb zircon) near Last Peak and the rocks cooled to 350 °C in several localities at 270 - 260 Ma ($^{40}\text{Ar}/^{39}\text{Ar}$), with possible overprinting in the Early Jurassic. The pressure-temperature results, isotopic ages and inferred unroofing history cast doubt on the continuation of subduction through Late Triassic or Early Jurassic time proposed or implicit in existing evolutionary models.

INTRODUCTION

Among the numerous tectonic assemblages involved in the Mesozoic accretion of arc rocks to the former continental margin in the northern Canadian Cordillera, only the high-pressure rocks of

the Yukon-Tanana terrane (YTT) provide direct physical evidence of the subduction of former oceanic crust. The eclogites and blueschists of YTT represent unambiguous pressure, temperature and time pins in the vertical displacement history of the crust at the western margin of Paleozoic-Mesozoic North America.

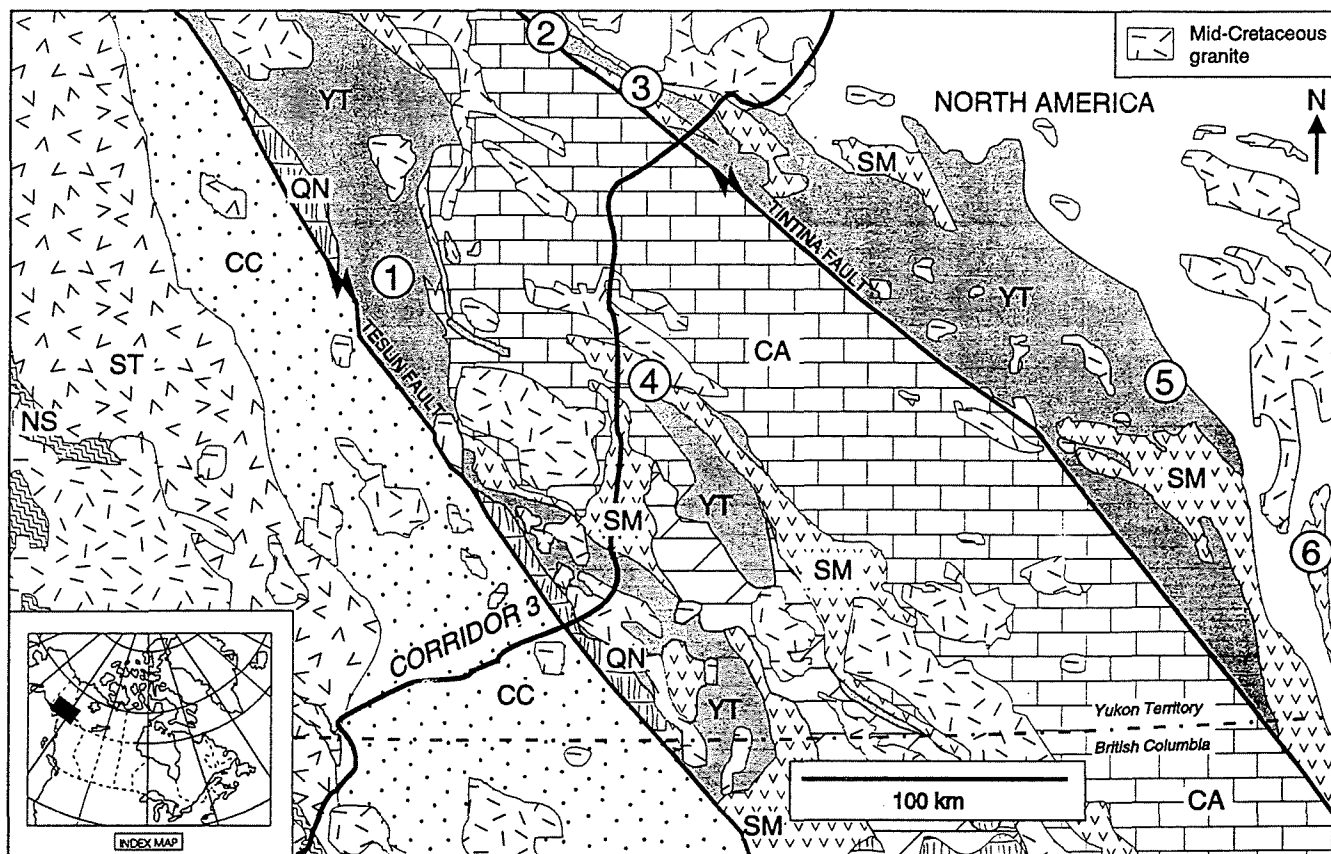


Figure 1. Location of high-pressure rocks (circled numbers) studied in the Yukon-Tanana terrane, shown on a terrane map of part of the northern Cordillera modified from Wheeler et al. (1991). Key to occurrences: 1= Last Peak, 2= Faro, 3= Ross River, 4= St. Cyr klippe, 5= Simpson Range, 6= Stewart Lake. Terrane abbreviations: YT= Yukon-Tanana, CA= Cassiar, SM= Slide Mountain, QN= Quesnellia, CC= Cache Creek, ST= Stikinia, NS= Nisling, North America= Proterozoic-Paleozoic miogeocline of North America. Corridor 3 is the planned seismic acquisition route.

Our previous knowledge of the petrology and P-T history of the high-pressure rocks was the result of reconnaissance work and was based on geothermobarometers which have undergone significant refinement. The timing of metamorphism and deformation, on which much weight was placed in tectonic modelling, was imprecise because only minimum estimates of the age of high-pressure metamorphism were available until now from sparse K-Ar and Rb-Sr data and indirectly from field relationships.

Our objective was to advance the understanding of the physical conditions and timing of metamorphism and deformation in the Yukon-Tanana high-pressure belt crossed by Corridor 3 of the SNORCLE transect (Fig. 1). It was unclear whether all high-pressure mineral assemblages

record the same history, or whether the high-pressure metamorphism is of a single age. We completed a critical reappraisal of previously studied exposures and carried out study of new localities, in which we tested details of the inferred metamorphic history in the best exposed occurrences to confirm the age of protoliths and tectonism.

We have presented previously an outline of the gap in knowledge about these rocks, of the detailed reasons for their study and of previous work in a previous report (Erdmer and Ghent, 1995). We present here the highlights of new metamorphic and isotopic age data. Our study is not completed at the time of writing. Interpretations are to be considered preliminary and may require adjusting as additional data from analyses in progress become available. A separate, related report on the U-Pb dating of zircon

and other minerals from one of the eclogites near Last Peak complements the data presented here (see Creaser *et al.*, this volume).

RESULTS

Previously known high-pressure metamorphic rock exposures were reexamined (Fig. 1). One new occurrence was discovered in the St. Cyr klippe; a second one (K. Fallas, personal communication, 1995), is being confirmed through petrographic study. The field setting of the first new occurrence is similar to that of previously reported occurrences in the Yukon-Tanana terrane (cf. Tempelman-Kluit 1970, Erdmer and Helmstaedt 1983, Erdmer 1987, 1992, Brown and Forbes 1986).

For metamorphic study, samples from the most promising localities were selected on the basis of lack of retrogression of the peak assemblages and presence of the largest number of mineral phases within the rock. For $^{40}\text{Ar}/^{39}\text{Ar}$ analysis, samples were selected on the basis of visible white mica in either hand sample or thin section.

The eclogites typically occur as metre-sized or larger (tectonic?) inclusions in greenschist and blueschist rocks. They host garnet-clinopyroxene-rutile-quartz assemblages with additional epidote, micas and amphiboles. They are commonly mylonitized and retrograded and are now largely schistose and compositionally layered S- and L-S tectonites. The degree of retrogression is variable. Garnets locally have Fe-rich cores and Mg-rich rims (~35 mol % pyrope). This zoning is interpreted to record prograde growth to peak pressure and temperature (cf. Erdmer and Helmstaedt 1983).

Newly derived estimates of P-T conditions

P-T results are reported for five eclogites in four localities (Fig. 2). For rocks near Faro in the part of the Yukon-Tanana terrane northeast of the Tintina fault (samples Faro 4-1, 5-1; Fig. 2), Fe-Mg exchange between garnet and clinopyroxene suggests temperatures in the 400-500 °C range.

Jadeite (~40 mol %) + quartz with no stable albite suggest minimum pressures of 11 to 13 kbar at 400-500 °C. The assemblage clinopyroxene-garnet-epidote-quartz suggests pressures near 15 kbar (for $P_{\text{H}_2\text{O}} = P_{\text{s}}$).

Eclogite 10 km west of Last Peak, in the Teslin tectonic zone (cf. Stevens *et al.* 1996), yielded estimates of garnet-rim temperature as high as 625 °C with a minimum pressure of 14 kbar (sample BSR - 1, Fig. 2). The intersection of the equilibrium curves $\text{an} + \text{di} = \text{grs} + \text{prp} + \text{qtz}$ and $\text{ab} = \text{jd} + \text{qtz}$ on Figure 2 is inconsistent with the results of garnet-clinopyroxene geothermometry, suggesting that oligoclase is not in equilibrium with garnet, clinopyroxene and quartz.

The newly discovered eclogite in the St. Cyr klippe (Fig. 1) yielded minimum estimates of garnet-rim temperature of 460 °C at a minimum pressure of 12 kbar.

Rocks from Ross River yielded garnet-rim temperatures near 525 °C and a minimum pressure near 13 kbar.

Subsequent metamorphism under greenschist to blueschist facies conditions overprinted most eclogites. This metamorphism is synkinematic with respect to the mylonitic fabrics. The high-pressure minerals are pre-kinematic: clinopyroxene is commonly recrystallized as elongate euhedra into the main foliation and (or) stretching lineation; garnet porphyroblasts are draped by the foliation and have elongate pressure shadow tails parallel to the stretching lineation visible on foliation planes. We interpret the overprinting greenschist to blueschist metamorphism to be related to the incorporation of tectonic slivers of eclogite into country rocks, i.e., to the collision and uplift of the accreted rocks to a crustal depth at or above the ductile-brittle transition.

The field occurrence of the Yukon eclogites is similar to the Type C rocks of Coleman *et al.* (1965). Some of the temperature estimates, e.g. near Last Peak, are similar to some estimates from Type B eclogites.

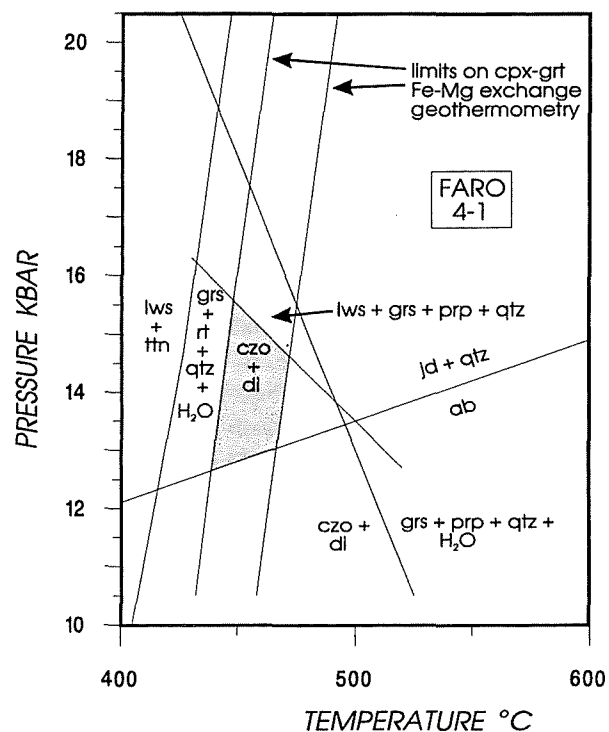
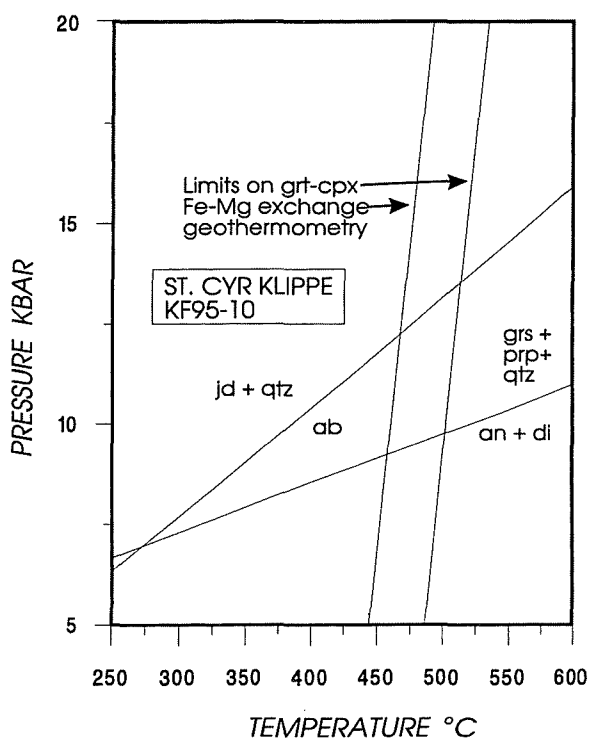
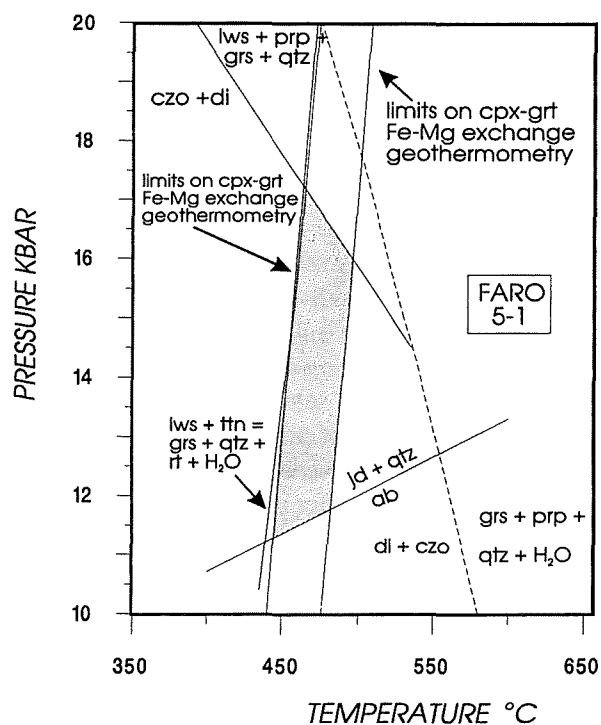
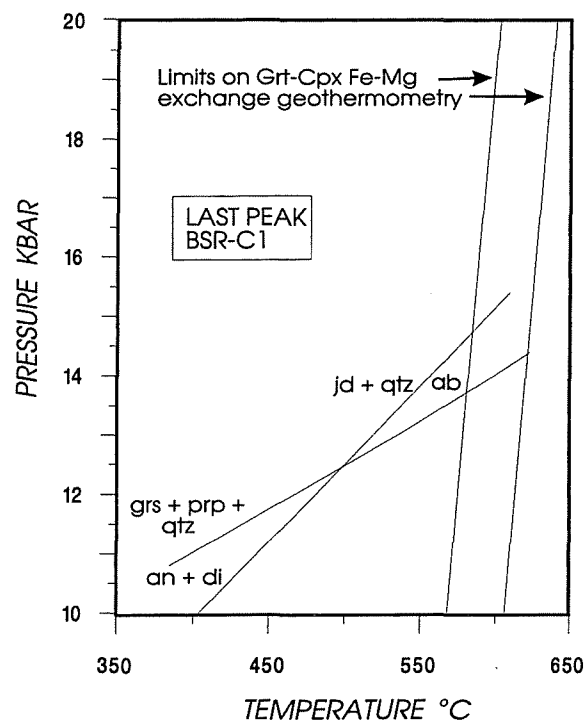


Figure 2. Pressure-temperature constraints for five eclogites from the Yukon-Tanana terrane. Lines are equilibrium curves for phases listed. Shaded areas are limits on P and T for Faro samples. Abbreviations: ab= albite, an= anorthite, cpx= clinopyroxene, czo= clinozoisite, di= diopside, grs= grossular,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

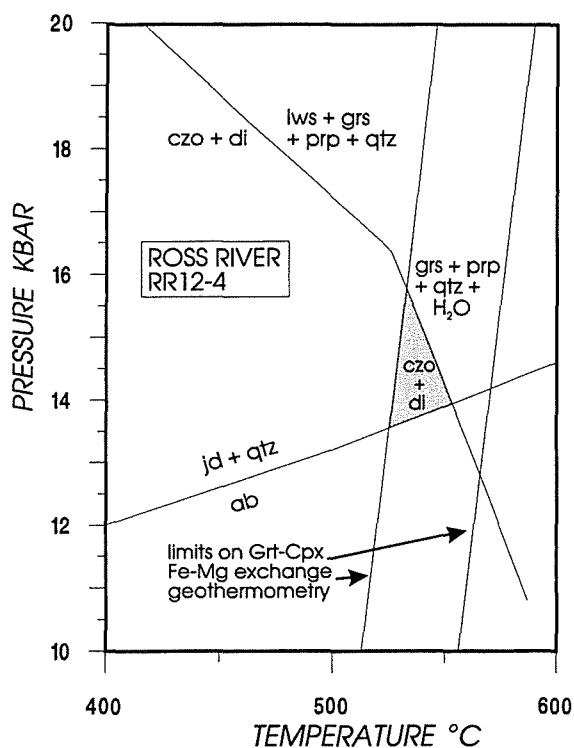


Figure 2. (Continued from previous page).

New age determinations

Existing data consisted of concordant Rb-Sr dates at approximately 246 Ma on both whole rock and muscovite in one blueschist at Ross River, an indicated 344 Ma whole rock age for the same rock (Erdmer and Armstrong 1989) and a K-Ar age of 258 Ma for one eclogite at Faro (Wanless *et al.*, 1978; recalculated from the reported age of 255 Ma using new constants).

New age determinations indicate that eclogite metamorphism peaked at about 270 Ma (U-Pb zircon; see Creaser *et al.*, this volume) and that the rocks cooled through 350 °C at about 270 - 260 Ma, with possible overprinting in the Early Jurassic. $^{40}\text{Ar}/^{39}\text{Ar}$ spectra for one blueschist and two eclogites are presented in Fig. 3.

The Ross River blueschist (sample PE85-25-1) yielded a good plateau segment at 272.7 Ma and an integrated age of 272.3 Ma. A correlation plot of $^{39}\text{Ar}/^{40}\text{Ar}$ against $^{36}\text{Ar}/^{40}\text{Ar}$ suggests the presence of a minor component of excess argon and the

correlation age (97.7%) of 268.6 $\pm$ 5.4 Ma is similar to a K-Ar date for the same sample locality (cf. Erdmer and Armstrong 1989). A correlation age close to the plateau and integrated ages precludes the possibility that the white mica records an age that is markedly "too old" because of excess argon.

The Ross River eclogite sample (PE85-21-10) yielded a somewhat more disturbed spectrum but for which the 267 Ma dates in the mid-temperature range are likely significant. The older integrated age of 274 Ma may result from minor excess argon. A $^{39}\text{Ar}/^{40}\text{Ar}$ vs. $^{36}\text{Ar}/^{40}\text{Ar}$ plot shows a poorer correlation than in the blueschist, which indirectly supports that interpretation. The data are interpreted to indicate that the eclogite and blueschist cooled at the same time in this locality.

The Faro eclogite sample (PE80 - F3) yielded a well-defined plateau segment at 260 Ma and an integrated age of 255 Ma. It may have been slightly overprinted in early Jurassic time. The cause of this overprint is unclear. No Cretaceous disturbance is recorded, which shows that heat from the nearby 100 Ma Anvil batholith (cf. Pigage and Anderson 1985) did not affect the eclogites. The batholith's aureole provides evidence that the rocks at Faro have been within 1 km of the surface since mid-Cretaceous time (Smith and Erdmer 1990).

DISCUSSION

The refined pressure and temperature constraints and minimum estimates confirm the previous inference that all eclogites were likely metamorphosed at depths 40 km (cf. Erdmer 1987, Erdmer and Helmstaedt 1983). The results from the Faro samples suggest a specific depth range of 40 to 50 km. As the eclogites originated as upper crustal rocks, the new constraints confirm that they underwent subduction followed by rapid uplift through the blueschist field.

The concordant zircon age from eclogite near Last Peak dates the peak of high-pressure metamorphism. This peak can be taken either as a minimum age for the initiation of subduction, or an age somewhere between the initiation and the cessation of subduction, or the age of cessation of

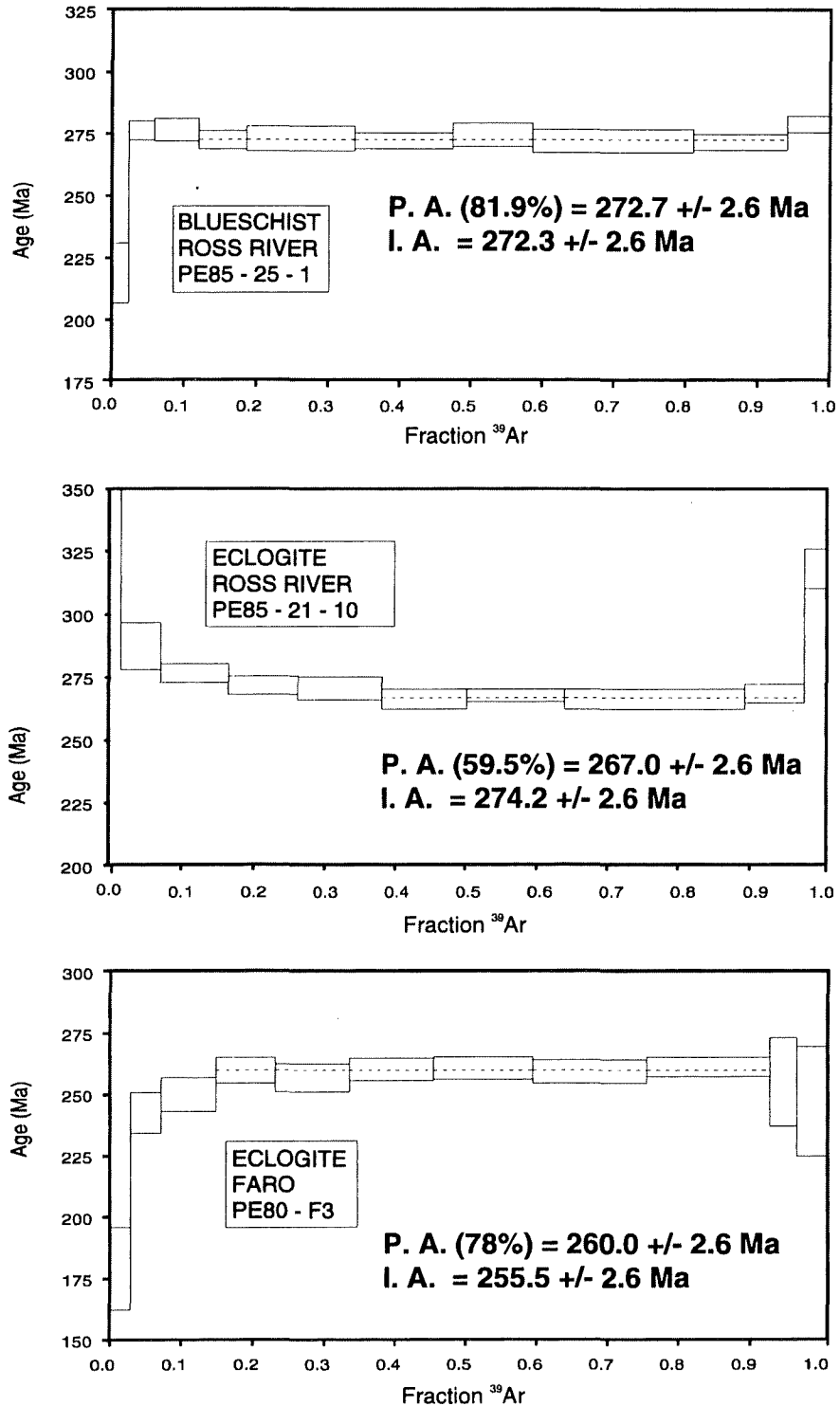


Figure 3. Age spectra for two eclogites and one blueschist from the Yukon-Tanana terrane. Errors indicated are at the two-sigma level. Dashed line indicates the steps included in the plateau age. The Faro F-3 sample locality is adjacent to sample Faro 5-1 (see Fig. 2).

subduction prior to uplift. The significant and rapid uplift implied by the only slightly younger cooling ages favour the third interpretation. This hypothesis is being tested by the $^{40}\text{Ar}/^{39}\text{Ar}$ analysis of muscovite in the Last Peak eclogite. It will also be tested by attempts to find and date zircon in several of the eclogites for which $^{40}\text{Ar}/^{39}\text{Ar}$ data are reported here or are in progress. Not all of the eclogites contain zircon, as indicated by at least one barren sample processed from the Ross River occurrence.

The K-Ar, Rb-Sr and Ar-Ar data unambiguously indicate cooling of fabric-defining white mica below about 350 °C in early to middle Permian time. The synkinematic metamorphism shows that the ductile fabrics in these rocks were imposed before final emplacement as thrust slices onto the continental margin. The ductile mylonitic fabrics are interpreted to be of early to mid-Permian age.

This has important implications, and in particular requires a revision of the assumption of continued subduction through Late Triassic or Early Jurassic time, an assumption proposed or implicit in a number of evolutionary models for the northern Cordillera (e.g. Tempelman-Kluit 1979, Hansen 1992, Dusel-Bacon *et al.*, 1995).

WORK IN PROGRESS

The $^{40}\text{Ar}/^{39}\text{Ar}$ analysis of white mica samples from additional localities including Last Peak, St. Cyr klippe, Simpson Range and Stewart Lake (Fig. 1) is in progress.

Additional isotopic investigations of a range of rocks collected in this study are underway in collaboration with R. Creaser and T. Chacko (University of Alberta). To shed further light on the timing of metamorphism and cooling, samples of eclogite are being analyzed for Sm-Nd mineral ages of garnet and pyroxene and muscovite separates are being dissolved for Rb-Sr analysis.

Rutile has been picked from selected eclogites and will be used in the application of garnet-rutile-quartz geothermometry.

The tectonic affinity of the protoliths of the high-pressure rocks is an objective of additional study: were the eclogites slices of Paleozoic oceanic crust and associated sediments, or mafic intrusions or flows added to a passive margin or accretionary prism succession? Whole rock and minor and trace element geochemistry is planned to address this question.

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THE STRUCTURAL AND METAMORPHIC EVOLUTION OF THE ST. CYR KLIPPE, SOUTH-CENTRAL YUKON: A PROGRESS REPORT.

Karen M. Fallas : Dept. of Earth and Atmospheric Sciences, University of Alberta, Edmonton, Alberta, T6G 2E3.

The St. Cyr klippe is a slice of the Anvil allochthon, which has been regionally correlated with the Slide Mountain Terrane, and of the Nisutlin allochthon. The klippe is located in south-central Yukon between the Tintina fault on the northeast and the Teslin Tectonic Zone on the southwest. The klippe exposes a contact between parautochthonous rocks of the Cassiar Platform and the obducted Slide Mountain Terrane. The northeast side of the klippe is intruded by the mid-Cretaceous, post-kinematic Nisutlin Batholith. Previous work in the area includes regional mapping (1:250 000) by Tempelman-Kluit, and reconnaissance work by Erdmer.

Detailed mapping (1:50 000) during the summer of 1995 focussed on the northwest end of the klippe where the Anvil allochthon is in direct thrust contact with the North American platformal rocks. The Anvil allochthon comprises peridotite, serpentized peridotite, gabbro, amphibolite, and metavolcanics interpreted as ocean crust and is metamorphosed to greenschist and lower amphibolite grade with local lenses of eclogite. Most exposures of the Anvil allochthon are well developed S and L-S tectonites, but massive exposures are also present. Analysis of the mylonitic foliation reveals a preferential dip to the southwest, and the orientations are scattered by open non-cylindrical folding about a NW-SE axis, which is compatible with NE vergent mesoscopic open folds observed in the field. Extension lineations and fold axes cluster in the NW and SE, with minor scatter due to the folding of the mylonitic foliation. Previous studies have suggested that the allochthonous rocks were thrust to the NE over the North American rocks. Since the lineations do not record this motion, the lineations as well as the mylonitic foliation are interpreted to predate the emplacement of the thrust sheet. The folding of the mylonitic foliation is most likely associated with the NE-directed emplacement of the allochthon.

Geothermobarometry results are forthcoming on Gt-Bt pairs found in siliceous compositions of the Anvil, as well as Gt-Px pairs found in two new eclogite locations. Two eclogite locations within the St. Cyr klippe were studied previously by Erdmer, but did not yield plausible results. Andalusite in the contact aureole of the Nisutlin Batholith indicates that the rocks of the St. Cyr klippe were intruded along with the rocks of the Cassiar Platform while at shallow crustal levels.

Dorsey Assemblage: pre-mid-Permian high temperature and pressure metamorphic rocks in the Dorsey Range, southern Yukon Territory.

R.A. Stevens, Department of Geological Sciences, Queen's University, Kingston, ON, K7L 3N6, stevens@geol.queensu.ca

Introduction

Rocks underlying the Dorsey Range have been assigned to the Dorsey Terrane (Wheeler and McFeely, 1991), which is considered to be a distinct succession of upper paleozoic sedimentary rocks that overlies rocks assigned to the Slide Mountain terrane (Monger et al., 1991). Recent mapping throughout the Dorsey Terrane (Gordey and Stevens 1994a,b; Harms, 1992; Harms and Stevens, 1995, this volume; Stevens and Harms, 1995, this volume) has shown that rocks assigned to it can be subdivided into a number of different assemblages, each with distinct stratigraphies and structural and metamorphic characteristics. These assemblages have correlatives with rocks in other terranes in the Canadian Cordillera suggesting that the Dorsey Terrane may not exist as a separate and distinct terrane.

The Dorsey assemblage occurs along the northeastern edge of the Dorsey Range, in the central part of the area assigned to the Dorsey terrane (Fig. 1). It averages 4 to 5 km wide and over 50 km in length and is fault bound to the northeast and southwest (Fig. 2).

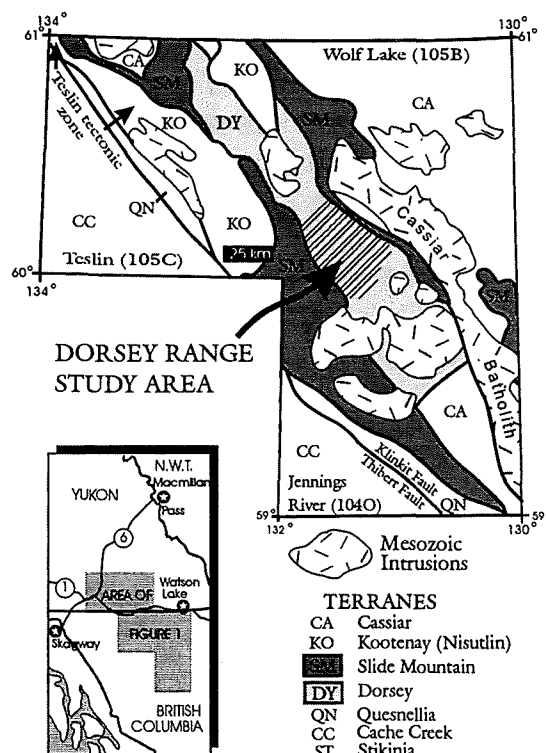


Fig 1. Location map and tectonic framework of the project area

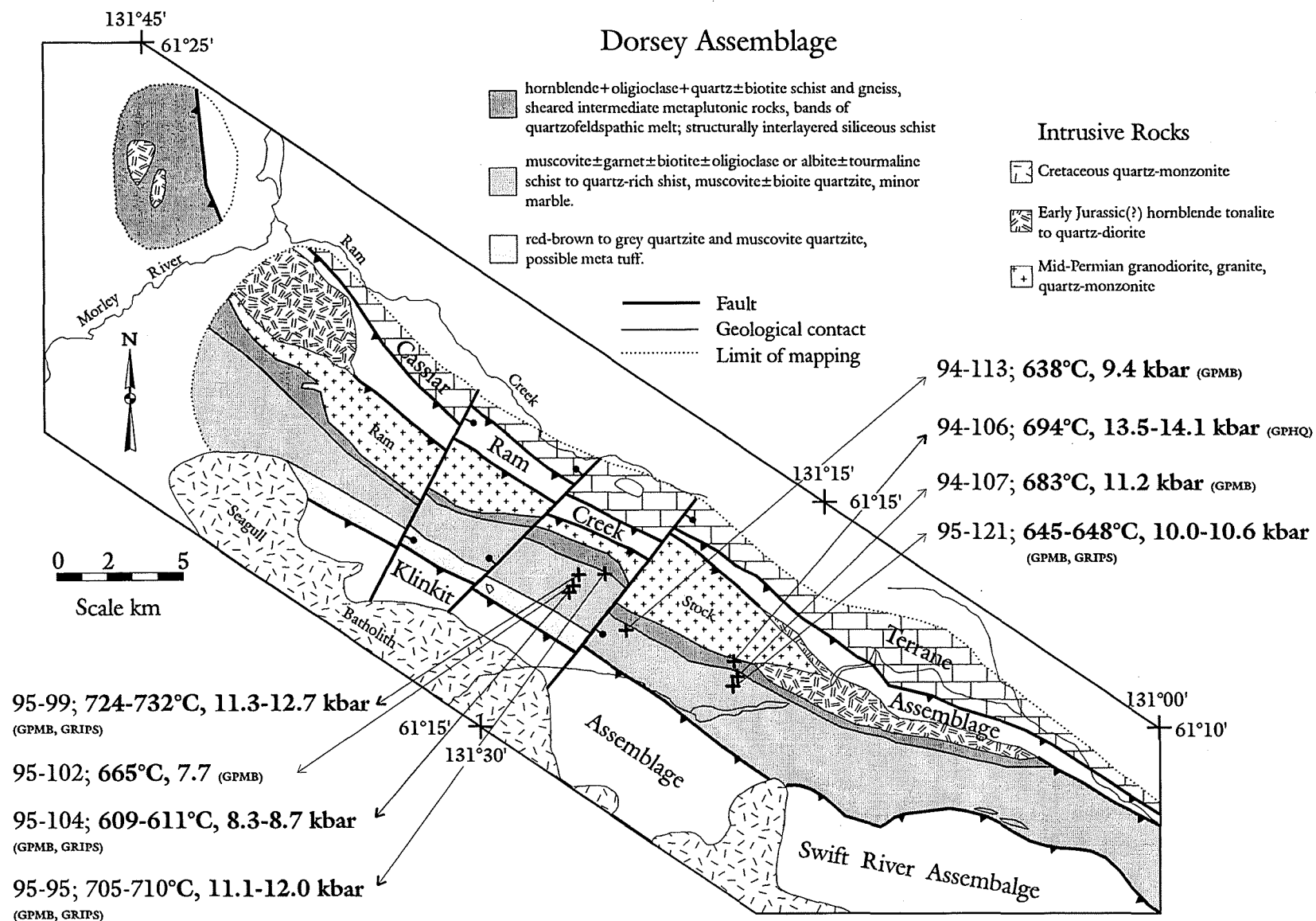


Fig 2. Simplified geology of the Dorsey assemblage (see Stevens and Harms, this volume for more details and for description of the Klinkit, Swift River and Ram Creek assemblages). Temperature and pressure estimates are preliminary. Mineral assemblages are: GPMB - garnet-plagioclase-muscovite-biotite; GRIPS - garnet-rutile-ilmenite-plagioclase-quartz; GPHQ - garnet-plagioclase-hornblende-quartz (see text for references).

Lithology

Three units have been identified within the Dorsey assemblage (Fig. 2). To the northeast, the structurally lowest unit comprises hornblende-rich mafic schist and gneiss, sheared intermediated metaplutonic rocks and structurally interlayered siliceous schist and quartzite. Bands of quartzofeldspathic melt from < 1 cm to 1 m wide are common in the northwestern half of the unit. The middle unit comprises muscovite±garnet±biotite±plagioclase±tourmaline schist to quartz-rich schist, muscovite±biotite quartzite and minor marble. The upper unit, which is confined to a small area in the central part of the assemblage comprises quartzite, muscovite quartzite, minor marble and possible metatuff. The contacts between the units are structural and gradational. The Dorsey assemblage has been intruded by plutonic bodies of three different ages. The oldest is the mid-Permian (259±2 Ma; zircon date; J.K Mortensen, pers. comm., 1994) granodiorite, granite and quartzmonzonitic Ram Stock. The intrusive nature of this contact is demonstrated by the occurrence of inclusions of foliated rock of the Dorsey assemblage within massive rock of the Ram Stock, and by dykes and offshoots of massive rock of the Ram Stock cutting foliated rock of the Dorsey assemblage. This intrusive contact indicates that youngest penetrative deformation and metamorphism in the Dorsey assemblage was pre-mid-Permian. The Dorsey assemblage is also cut by Early Jurassic(?) hornblende tonalite to quartz-diorite, and Cretaceous quartz-monzonite of the Seagull and Hake batholiths.

Structure

The Dorsey assemblage is characterized by strong, ductile, S- and L-S tectonite fabrics. The S-fabric is schistosity or mylonitic foliation defined by micas, amphibole and tabular quartz grains, and the L-fabric is a mineral lineation defined by elongate grains of the same minerals. The foliation dominantly strikes northwest-southeast and dips moderately to steeply southwest. Mineral lineations typically plunge moderately to steeply southwest, but their orientation varies locally. Isoclinal folds from the hand-specimen to outcrop scale are well developed and common in the northwestern half of the assemblage. The axes of these folds tend to be parallel to local mineral lineations.

Metamorphism

The common metamorphic mineral assemblages in the Dorsey assemblage are muscovite±garnet±biotite-oligoclase±albite±tourmaline±ilmenite±rutile in siliceous schist, and hornblende-oligoclase-quartz±sphene±biotite±garnet±albite±actinolite in mafic schist. These mineral assemblages and the presences of small interlayered bands of melt suggest rocks of the Dorsey assemblage were metamorphosed under amphibolite facies. Chloritization of biotite and garnet, and seritization of plagioclase indicate at least one phase of retrograde metamorphism.

Pressures and temperatures of metamorphism in the Dorsey assemblages have been estimated for eight samples of garnet-bearing schist (Fig. 2). The thermodynamic data of Berman (1988, 1990) and the computer program TWEEQU (Berman, 1991)

were used to estimate temperatures and pressures for samples with the assemblages garnet-plagioclase-muscovite-biotite and garnet-rutile-ilmenite-plagioclase-quartz. This program uses the solution model of Berman (1990) for garnet, McMullin et al. (1991) for biotite, Chatterjee and Froese (1975) for muscovite and Fuhrman and Lindsley (1988) for plagioclase. For sample 94-106 (see Fig. 2) the garnet-hornblende thermometer of Graham and Powell (1984), and the garnet-hornblende-plagioclase-quartz barometer of Kohn and Spear (1990) were used. The P-T estimates range from 609-732°C and 7.7-14.1 kbar (Fig. 2). The relatively narrow range in temperature estimates for most samples using the garnet-biotite thermometer (see Fig. 2) suggests that chemical equilibrium exist between garnet-rims and matrix biotite in the samples analyzed. The pressure estimates however show a much greater range in values using the garnet-plagioclase-muscovite-biotite barometer. This suggests that chemical disequilibrium may exist in some samples. Plagioclase in the peristerite gap or disequilibrium plagioclase may be the cause of the apparent disequilibrium, as it shows a fair bit of compositional variation in some samples. For example, sample 95-102 contains both oligoclase (An_{24}) and albite (An_3). Microprobe and textural analysis will be used to further evaluate compositional variations in plagioclase and other minerals.

Implications

Metamorphic mineral assemblages, the presence of partial melts, and thermobarometry suggest the Dorsey assemblage was metamorphosed in the amphibolite and likely upper amphibolite facies. Pressure estimates show a fair degree of variability, but suggest reasonably high pressures in the order of 9-13 kbar. The age of the intrusive Ram Stock demonstrates that this metamorphism was pre-mid-Permian in age. Lithologically, rocks of the Dorsey assemblage are similar to rocks of the Yukon-Tanana terrane (YTT) that are exposed to the north and west of the Dorsey Range. However the locally well developed gneissic character and the presence of partial melts in the Dorsey assemblage is a feature that the author has not observed in the YTT. The pre-mid-Permian constraint on deformation and the apparent high-pressure metamorphism in the Dorsey assemblage also has a possible correlative in the YTT in the form of isolated structural slices of Permian age eclogite and blueschist (Erdmer and Armstrong, 1988; Erdmer, pers. comm. 1995). However schists in the YTT typically give Early Jurassic or younger cooling ages (Hansen et al., 1991), and deformation is thought to extend into the Late Triassic or Early Jurassic (Mortensen, 1992; Hansen et al., 1991; Stevens, 1994). It is possible that the Dorsey assemblage preserves part of a Permian high-grade metamorphic or subduction deformation event that is also recorded by the eclogite, and that it has not seen a younger Triassic to Early Jurassic metamorphism and deformation that has apparently affected most of the YTT. This possibility and others are currently being investigated in order to establish the tectonic significance of the pre-mid-Permian high grade metamorphism in the Dorsey assemblage.

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Structural evolution and rock types of the Slide Mountain and Yukon-Tanana terranes in the Campbell Range, southeastern Yukon¹

Heather E. Plint and Terence M. Gordon, *Department of Geology and Geophysics University of Calgary, Calgary, Alberta T2N 1N4. Plint@geo.ucalgary.ca; tmg@geo.ucalgary.ca*

1. Modified from Plint, H.E. and Gordon, T.M. 1996. Current Research 1996-A, Geological Survey of Canada Paper, in press.

ABSTRACT

The Finlayson Lake fault zone forms the boundary between autochthonous north American strata and the accreted Slide Mountain and Yukon-Tanana terranes. Field mapping at 1:50 000 scale in the Campbell Range, Yukon was carried out to examine the kinematics of the Finlayson Lake fault zone and the rock types of the Slide Mountain and Yukon-Tanana terranes. Map units identified are: DT_p chlorite-actinolite phyllite, DT_a argillite, DT_c metachert and slate, DPS_c and DPS_p metachert, argillite, and phyllite, DPS_g greenstone, breccia, metagabbro, metadiorite, metachert and argillite, DPS_{lg} leucogabbro, and DPS_s serpentinite, and DME_c metachert and argillite, and DME_s sandstone, siltstone and shale. Units DT_p, DT_a and DT_c are correlated with the Yukon-Tanana terrane. Units DPS_c, DPS_g, DPS_{lg} and DPS_s are correlated with the Slide Mountain terrane. Units DME_c and DME_s are tentatively correlated with the Devonian-Mississippian Earn Group.

Unit DPS_g is thrust over DT_p and DT_a in the west and DPS_c in the east. The map pattern of DT_c suggests that it is a klippe preserved from erosion by normal faulting along its southern boundary. These structures are interpreted to be an originally east-directed thrust sequence disrupted by west-directed back thrusts with continued shortening.

INTRODUCTION

In the northern Cordillera, Late Devonian to Late Triassic, massive greenstone, mafic to ultramafic plutonic rocks and sedimentary rocks of the Slide Mountain terrane are faulted between autochthonous North American strata and the Yukon-Tanana terrane. In southeastern Yukon, the boundary between the North American rocks and accreted rocks is the Finlayson Lake fault zone (Fig. 1, FLFZ). The fault zone is interpreted to be the displaced northern extension of the Teslin structural zone of south-central Yukon, that has been offset 450 km to the southeast along the mid-Cretaceous to Tertiary dextral strike-slip Tintina fault (e.g., Tempelman-Kluit, 1979).

The FLFZ incorporates and deforms rocks of the Slide Mountain terrane and

Yukon-Tanana terrane and locally contains eclogitic rocks. The timing and nature of motion along the fault zone is poorly understood. At its northern end, it is marked by north-northwest-trending, anastomosing, steeply dipping faults interpreted to have mainly strike-slip displacement (e.g., Tempelman-Kluit, 1972). Farther south, in the northern Campbell Range, the fault zone comprises north-northwest trending faults, some of which are thrust faults that place Slide Mountain terrane over rocks of Yukon-Tanana terrane in the west and other rocks of the Slide Mountain terrane to the east (Plint, 1995). The fault zone is thought to be a transpressive zone (Mortensen and Jilson, 1985) although the details of its structural evolution remain unknown. Our geological mapping in the Campbell Range,

southeastern Yukon (Fig. 2), is part of an ongoing study of the depositional setting of the Slide Mountain terrane and the structural evolution of the fault zone.

LOCATION AND ACCESS

The study area is located 175 km north of Watson Lake, Yukon between the Campbell Highway to the east and Wolverine Lake to the west (Fig. 2). Mapping at 1:50 000 scale covering parts of NTS sheets 105G/8/9 and 105H/5/12, was carried out for 6 weeks during the 1995 field season from helicopter-supported fly camps and the Campbell Highway. Outcrop is excellent to sporadic above treeline (ca. 1600 m), moderate to absent on mountain slopes and locally present along creeks.

TECTONIC SETTING AND PREVIOUS WORK

The rocks underlying the map area have been assigned to the Slide Mountain and Yukon-Tanana terranes (e.g., Wheeler and McFeely, 1991). The Slide Mountain terrane in southeastern Yukon consists of greenstone, ultramafic and mafic plutonic rocks, ribbon chert and minor marble (Mortensen, 1992a,b). The Yukon-Tanana is a pericratonic terrane of polydeformed and metamorphosed rocks derived from pre-Devonian to Upper Triassic sedimentary, volcanic and plutonic protoliths (e.g., Hansen, 1990). The Slide Mountain terrane is interpreted to be the remnants of oceanic crust that separated the Yukon-Tanana terrane from North America (e.g., Nelson, 1993). The Yukon-Tanana terrane may be a distal equivalent of North America or an unrelated allochthonous terrane (e.g., Hansen, 1990; Hansen et al., 1991).

Early geological mapping by the Geological Survey of Canada reported greenstone, metadiorite, minor serpentinite and minor amphibolite throughout most of the map area (Wheeler et al., 1960; Roots et

al., 1966). Regional mapping in the study area by Mortensen and Jilson (1985) defined the "Campbell Range belt" as consisting of a unit of greenstone, serpentinite, chert, minor diabase and minor gabbro structurally interleaved with units of grey chert and metachert and of massive carbonate. Age determinations indicate that the rocks of the Campbell Range belt range from latest Devonian to Early Permian age (Mortensen and Jilson, 1985; Mortensen, 1992a). The greenstone unit is correlated with the Slide Mountain terrane (Monger, 1984; Plint, 1995). Plint and Gordon (1995) interpreted the greenstone unit to have formed in a deep submarine environment with some terrigenous influx based on the presence of radiolarian chert, serpentinite, breccias containing pillow fragments, altered glass shards and dendritic pyroxene microphenocrysts, and quartz-chert greywacke layers containing detrital epidote, plagioclase, tourmaline and rare volcanic clasts.

The regional correlation of the carbonate and chert/metachert units is uncertain. Correlations of the chert/metachert unit with Devonian-Mississippian North American stratigraphy, mid-Paleozoic units of the Yukon-Tanana terrane and the Late Devonian to Late Triassic Slide Mountain terrane have been suggested (J.K. Mortensen, pers. comm., 1994). Plint (1995) divided the chert/metachert unit into two units, at least one of which was interpreted to be part of the Slide Mountain terrane.

Mortensen and Jilson (1985, their Fig. 2) interpreted the Finlayson Lake fault zone as a zone of steep faults developed in the chert/metachert unit and truncated by a folded thrust fault at the base of a klippe of greenstone. Plint (1995) reported that the base of the greenstone is marked by diverging thrust faults and included them, along with inferred steep, north-northwest-trending faults, as part of the fault zone.

MAP UNITS

Five map units (units 1 to 5) were identified and described by Plint (1995) from the 1994 field season. Mapping in 1995 has revealed the presence of thin, distinctive lithological units at the top of the former unit 1 and structurally below unit 3, and identified 4 new units. The units have been renamed to reflect their inferred depositional age. The terminology from Plint (1995) is given in brackets:

- DT_p chloritic phyllite and schist (unit 1)
- DT_a grey argillite and metasiltstone (new unit)
- DT_c metachert and grey slate (unit 2)
- DPS_c tan to yellow weathering metachert and maroon siliceous and argillaceous metasiltstone and argillite (unit 3)
- DPS_p pink, orange or tan weathering metachert and tan or grey argillite and phyllite (new unit)
- DPS_g greenstone (unit 4)
- DPS_{lg} leucogabbro (new unit)
- DPS_s serpentinite (unit 5)
- DME_c black metachert and argillite (new unit)
- DME_s sandstone, siltstone and shale (new unit)

Unit DPS_g is thrust to the southwest over units DT_p and DT_a and to the northeast over unit DPS_c (Plint, 1995). Faults, one of which is interpreted to be a normal fault, are inferred to bound unit DT_c. Serpentinite is exposed as small slivers in unit DPS_g and is structurally interleaved with rocks in unit DT_c. It is designated as a separate unit due to its varied mode of occurrence, although it rarely forms map-scale bodies.

Chlorite-actinolite phyllite and schist (DT_p)

This unit has been correlated with the Yukon-Tanana terrane (Mortensen, 1992a) and the middle unit of the "layered

metamorphic suite" of Mortensen and Jilson (1985). The unit is renamed "chlorite-actinolite phyllite and schist" to better reflect the abundance of actinolite in many samples. Mariposite is present locally. The chlorite-actinolite phyllite commonly contains subhedral plagioclase porphyroclasts and calcite-filled amygdules. Its protolith is interpreted to be a mafic metavolcanic rock. In addition to the muscovite-quartz-chlorite phyllite (felsic metavolcanic rock), black carbonaceous argillite and minor metachert described in Plint (1995), the unit is expanded to include white quartzite, with or without grey argillaceous partings. The quartzite is exposed in scattered outcrops along the western edge of the ridge east of Wolverine Lake.

Two sub-map scale bodies of feldspar porphyry are present as structural lenses in unit DT_p. The northern porphyry is approximately 150 m thick and 200 m long. The rock is light grey or white, resistant weathering, and poorly to strongly foliated. It contains subhedral potassium-feldspar phenocrysts up to 1 cm in the longest dimension and minor, embayed quartz microphenocrysts in a microcrystalline quartzofeldspathic matrix. The porphyry grades downwards into a phyllite. The porphyry differs from those in unit DT_c in that it lacks plagioclase phenocrysts, contains quartz microphenocrysts and has a microcrystalline, rather than fine grained, matrix. Its protolith is interpreted to be a phyrlic felsic volcanic flow.

The southern porphyry is exposed as a boulder train approximately 200 m wide and 500 m long between units DT_p and DT_a. The rock is weakly to moderately foliated and contains clinopyroxene phenocrysts strongly altered to actinolite and subhedral plagioclase in a very fine grained quartzofeldspathic matrix. It is similar to porphyries in unit DT_c in containing plagioclase and mafic phenocrysts but unlike

those in unit DT_c, it contains no potassium feldspar in the matrix. Its protolith is interpreted to be a high-level intrusive rock.

Grey argillite and metasiltstone (DT_a)

A unit of rusty brown or grey weathering, grey or greyish-brown argillite and minor metasiltstone is differentiated from unit DT_p. It is exposed directly below the western thrust fault. Well exposed sections indicate this unit is up to 60 m thick; it was traced over a strike length of at least 9 km.

Metachert and slate (DT_c)

This unit is included in the chert/metachert unit of Mortensen and Jilson (1985). Plint (1995) hypothesized it may correlate with the lower division of the Slide Mountain terrane as defined in the Sylvester Allochthon (e.g., Nelson, 1993). The unit consists predominantly of grey, white and black laminated metachert, grey siliceous metasiltstone and rusty brown to grey weathering, grey to black carbonaceous slate or argillite, structurally interleaved with serpentinite, hornblende-plagioclase and plagioclase-potassium feldspar porphyry, muscovite-quartz-chloritephyllite, quartz-eye muscovite-chlorite phyllitic schist, chloritic schist and minor grey, calcareous metacarbonate and greyish green metachert. Subhedral feldspar and less common, embayed quartz porphyroclasts are present in the phyllites and schists. Their protoliths are interpreted to be felsic to mafic phyric flows.

Tan to yellow weathering metachert and maroon siliceous and argillaceous metasiltstone and argillite (DPS_c) and pink, orange or tan weathering metachert and tan or grey argillite and phyllite (DPS_p)

These units are included in the chert/metachert unit by Mortensen and Jilson (1985) and correlated with the Slide Mountain terrane by Plint (1995). Unit DPS_c consists of massive or thinly to moderately

bedded, rusty brown, yellow, tan and maroon weathering metachert, commonly with manganese staining along joints and fracture surfaces, and is rhythmically interbedded with grey, tan and maroon metasiltstone and argillite. Its exposed thickness is approximately 650 m, although it is likely thickened by thrust faults and folding. The metachert locally contains recrystallized radiolaria. One 15 m thick bed of massive chert-quartz conglomerate containing minor, rounded fine grained argillaceous and gabbroic clasts, was observed in unit DPS_c.

Unit DPS_c is structurally underlain by a newly recognized unit (DPS_p) approximately 375 m thick of pink, orange, tan, white or rarely greenish-grey metachert with argillaceous partings or thinly to moderately interbedded with tan or grey argillite and phyllite. Bedding is commonly planar or slightly undulating and locally, lentic. Dolomite-quartz veins, up to 1 cm thick and associated with copper?-bearing minerals in one outcrop of unit DPS_p, suggest localized hydrothermal alteration.

Greenstone (DPS_g) and Serpentinite (DPS_s)

Units DPS_g and DPS_s are correlative with the upper divisions of the Slide Mountain terrane (Plint, 1995). Unit DPS_g comprises massive to moderately foliated greenstone, greenstone breccia, pillow breccia, heterolithic breccia, maroon metasiltstone or argillite and minor maroon, grey, green, pink and white metachert, metagabbro, metadiorite and metagreywacke. Greenstone is commonly aphyric in outcrop but contains microphenocrysts of augite, plagioclase and rare brown amphibole. Intrusive contacts between metadiorite and metachert are well exposed locally.

Two, rusty weathering alteration zones with associated copper-staining were observed in the greenstone. The altered rock, exposed over an area of less than 20 m², is

brecciated, highly calcareous and cut by calcite veins. These zones are interpreted to have formed by seafloor hydrothermal alteration.

Another localized, rusty weathering zone was examined in pillowed to massive greenstone at the "Money showing" in the southern part of the map area (Fig. 2). The zone is less than 10 m thick and disappears ca. 100 m along strike. Sulphide mineralization is developed in foliation concordant, siliceous lenses in a very fine grained, well foliated, rusty weathering dark green rock composed of chlorite, muscovite, quartz and sphene. The rock contains minor subhedral, microscopic quartz crystals and is interpreted as a tuffaceous lens in the greenstone.

Leucogabbro (DPS_{lg})

Massive, coarse grained, ophitic leucogabbro underlies most of one mountain in the northeastern part of the map area. The rock consists of approximately equal parts plagioclase and clinopyroxene, with plagioclase typically enclosing subhedral pyroxene.

The map pattern suggests that the leucogabbro intrudes the greenstone (Fig. 2). An intrusive relationship is further supported by both the common occurrence of fine grained phases in an otherwise coarse grained leucogabbro near its inferred contact and by basaltic xenoliths and metre-scale blocks locally in the leucogabbro.

North of the leucogabbro and near a zone of hydrothermal alteration, the greenstone contains an 8 m thick, 100 m long slice of highly fractured and altered leucogabbro juxtaposed against a submap scale body of serpentinite (Fig. 2). Although no kinematic indicators are present, the density of northwest-trending, vertical fractures in the leucogabbro increase towards the contact with the serpentinite, suggesting the leucogabbro is fault-bounded. An outcrop

of fish-scale serpentinite is exposed also in the main leucogabbro body (Fig. 2). These observations suggest that the leucogabbro is tectonically disrupted and probably intruded the greenstone prior to their thrust emplacement onto unit DPS_c.

Black Metachert and Argillite (DME_c)

This unit is included by Mortensen and Jilson (1985) in the chert/metachert unit and is tentatively correlated here with the Earn Group (see below). Contacts with other units are not exposed.

The unit consists of black, grey, rusty brown, tan or white weathering, dark grey to black, massive to thinly bedded, locally laminated, radiolarian-bearing metachert with argillaceous partings or interbedded with rusty weathering, dark grey to black argillite. Quartz veins cut bedding and intrude along joint surfaces. One 50 cm bed of medium- to coarse-grained quartz-chert sandstone with angular to subrounded grains was observed in the black metachert. Quartz grains are polycrystalline and in some, the quartz subgrains define a foliation suggesting a tectonized, continental(?) detrital source.

Minor chloritic phyllite is interlayered on the centimetre- to metre-scale with argillite. Foliation in argillite and phyllite is parallel to bedding in metachert. An outcrop of massive, tan-coloured, silty (meta)limestone, ca. 15 m thick (horizontal distance) is exposed in this unit near its western boundary (Fig. 2). The limestone exhibits a weak northwest-striking, steeply southwest-dipping spaced cleavage.

Sandstone, Siltstone and Shale (DME_s)

This unit is included by Mortensen and Jilson (1985) in the chert/metachert unit. It may correlate with the Devonian-Mississippian Earn Group (see below).

Five outcrops in unit DME_s were examined; its contacts are not exposed. The unit consists of well sorted, very fine

grained, laminated grey sandstone to siltstone and black fissile shale.

WHOLE ROCK GEOCHEMISTRY

Whole rock XRF analyses for major and trace elements were carried out on 21 samples of greenstone and one gabbro (unit DPS_g) and 6 samples of chlorite-actinolite phyllite (unit DT_p) to characterize the nature of their basaltic protoliths and to see if the units differed geochemically. Figure 4 shows that both the greenstone and chlorite-actinolite phyllite are ocean floor basalts and can not be differentiated geochemically. An ocean floor basalt geochemical signature for greenstone of unit DPS_g is consistent with the predominance of massive, aphyric greenstone (=flows) and only localized development (along fault scarps?) of pillow and greenstone breccias with deep water granulation and quench textures (Plint and Gordon, 1995). Geochemically, greenstone of unit DPS_g is identical to greenstones correlated with the structurally upper parts of the Slide Mountain terrane exposed in British Columbia (e.g., Nina Creek Group - Ferri and Melville, 1994; Division II of the Sylvester Allochthon - Nelson and Bradford, 1993).

An ocean floor basalt geochemical signature for chlorite-actinolite phyllite of unit DT_p is consistent with the occurrences of the Wolverine volcanogenic hosted massive sulphide deposit in this volcanic-sedimentary sequence (Mining Review, 1995).

REGIONAL CORRELATIONS

Without age control, regional correlation of map units depends upon matching lithologic associations. The documentation of metaplutonic rock (porphyry) in unit DT_p further supports its correlation with the Yukon-Tanana terrane (cf. Mortensen, 1992a). Plint (1995) hypothesized that unit DT_c may be correlated with the lower

division of the Slide Mountain terrane as documented in the Sylvester Allochthon (e.g., Nelson, 1993). However, the absence of calc-arenite and *radiolarian* chert and the presence of mafic and felsic metavolcanic rocks and feldspar-hornblende porphyry in unit DT_c suggest that it is more probably correlative with the Yukon-Tanana terrane.

Unit DPS_g is geochemically identical to, and units DPS_c , DPS_p , DPS_g , DPS_{lg} and DPS_s are lithologically identical to, the upper divisions of the Slide Mountain terrane in British Columbia (e.g., Nelson, 1993; Ferri and Melville, 1994) and are thus correlated with the Slide Mountain terrane (Plint, 1995). Unit DME_c is similar lithologically to the lower Devonian-Mississippian Earn Group whereas unit DME_s could correlate with either division of the Earn Group (e.g., Gordey et al., 1982).

STRUCTURAL GEOLOGY

Macroscopic structures consist of (a) thrust faults at the base of the greenstone unit, (b) inferred northwest- and east-striking faults that bound unit DT_c and northwest-plunging folds in unit DT_c and (c) folds and faults in unit DME_c .

Thrust Faults

A top-to-the-southwest thrust fault separates units DT_p and DT_a from greenstone along the western margin of the map area. The fault is exposed in the head wall of an northeasterly trending valley near the southerly mapped extent of unit DT_a (Fig. 2). Here, the thrust at the base of the massive, fractured greenstone is subparallel to the cleavage in grey to rusty brown weathering argillite (unit DT_a).

Evidence for top-to-the-southwest thrust displacement appears in many outcrops of chlorite-actinolite phyllite where the steeply northeast dipping cleavage is cut and deflected in a dextral sense by a subparallel, low-angle cleavage (see Plint, 1994, Fig. 8).

Evidence is also found at the northern plagioclase porphyry in unit DT_p . The argillite, structurally overlying the porphyry contain tight to isoclinal intrafolial folds of compositional layering suggesting dip-parallel transposition along the foliation. The porphyry is not lineated but is increasing foliated towards its base. Quartzofeldspathic layers in argillite directly below the porphyry are isoclinally folded into northwest-trending, southwest-verging folds whose axial surfaces are truncated and dextrally deflected into sigmoidal forms by a low-angle cleavage. These structures record top-to-the-southwest shear at the porphyry margins.

A top-to-the-northeast thrust fault, that places greenstone over unit DPS_c in the eastern part of the map area, has been refined. The serpentinite thought to lie along the thrust fault is now interpreted to mark another submap scale, top-to-the-northeast thrust fault (untraceable along strike) in the greenstone unit (see Plint, 1995, Fig. 9). The regional thrust fault and unit DPS_c that forms the footwall are exposed farther to the east than originally interpreted. Outcrop-scale, listric, top-to-the-west back thrusts associated with the regional thrust fault are well exposed in river canyons that transect unit DPS_c (see Plint, 1995, Fig. 9).

The contact between units DPS_p and DME_c is interpreted to be a thrust fault because its inferred trace is subparallel to the thrust fault between units DPS_c and DPS_g and because small scale, top-to-the-northeast reverse faults are observed in argillite in unit DME_c (see below).

Faults and Folds in unit DT_c

The paucity of exposure in areas of inferred contacts of unit DT_c hinders structural interpretations. However, small scale structures are relatively well developed in unit DT_c and yield some clues as to the nature of the contacts.

Moderately, easterly plunging, upright, gentle folds to tight crenulations deform the cleavage in slate in unit DT_c . Quartz rodding in metachert and in foliation-parallel quartz veins in slate have a similar orientation and may have developed synchronously with the easterly plunging folds.

Foliation parallel or subparallel, northeast or southwest-dipping faults truncate the easterly plunging folds and juxtapose massive hornblende-plagioclase or potassium feldspar-plagioclase porphyry, serpentinite, slate and metachert. At one outcrop, massive serpentinite becomes strongly foliated towards the unexposed contact with slate suggesting a faulted contact. Kinematic indicators are lacking for these faults. They are probably thrust faults however, as they imbricate a wide variety of rock types on a scale of metres.

Northwest-trending, horizontal to moderately north-plunging, commonly upright to steeply inclined folds, deform the foliation on the outcrop and regional scale (Fig. 3). Towards the western margin of unit DT_c , the folds vary from upright to northeast-verging. The timing of folding about northwest-trending axes relative to foliation-parallel faults and easterly plunging folds is unclear. However, because evidence for foliation parallel faulting is found along both northeast- and southwest-dipping foliation surfaces, it is probable that the faults are folded by the northwest-trending folds.

The east-striking fault that forms the southern contact is interpreted to be a north-side down normal fault because the map pattern (Fig. 2) requires a sharp contact at a high angle to the regional foliation. Similarly oriented normal faults are common in the region (e.g., Tempelman-Kluit, 1979; Mortensen, 1992a) and small scale, top-down-to-north normal faults and shear bands occur locally in unit DT_c .

Faults and Folds in Unit DME_c

West- and northwest-trending, moderately plunging, open to tight folds deform the bedding on a regional and outcrop scale in unit DME_c. The regional significance of these folds is unclear. Locally, outcrop scale, northwest striking, southwest-dipping, reverse faults are exposed in argillite in the unit. The cleavage is deflected or folded and truncated across the fault surfaces in a sinistral shear sense. Localized dip-parallel (southwest-plunging) rodding on foliation surfaces observed in metachert is inferred to result from foliation-parallel thrusting within unit DME_c.

METAMORPHISM

Metamorphic grade increases from subgreenschist prehnite-pumpellyite facies in the east through pumpellyite-actinolite facies to greenschist epidote-actinolite facies in the west. Foliation in subgreenschist facies greenstone is defined by a planar parting visible in outcrop but rarely in thin section. Synmetamorphic epidote veins are common along foliation surfaces and, in well foliated samples of greenstone breccia, foliation is defined by flattened glass shards now replaced predominately by chlorite, quartz and pumpellyite. Foliation in chlorite-actinolite phyllite of unit DT_p is defined by actinolite, chlorite and flattened relict amygdulites. This foliation wraps around epidote porphyroblasts containing chlorite-filled extensional fractures (Plint and Gordon, 1995) suggesting that metamorphism was syn- to post-tectonic with respect to the foliation in the region. Therefore, the metamorphic assemblages are interpreted to result from regional, rather than sea floor, metamorphism. This is further supported by the widespread development of the assemblage pumpellyite-quartz-chlorite which would be unstable, or only stable over a narrow depth range, under the high geothermal gradients associated with sea

floor alteration (e.g., Liou et al., 1987).

No metamorphic grade change can be determined across the eastern regional thrust fault or the boundaries of unit DT_c due to differences in rock type. The western regional thrust fault juxtaposes rocks of the same (epidote-actinolite) facies. Either it is a post-metamorphic fault that fortuitously juxtaposes rocks of the same grade or it is a pre- or syn-metamorphic fault. A syn-metamorphic fault is most probable because structures in unit DT_p that formed during regional thrusting caused ductile deformation of pre-existing fabrics.

DISCUSSION

Regional mapping by Mortensen and Jilson (1985) reveals an abundance of both easterly and westerly dipping thrust faulted contacts in the Campbell Range. Some of these are interpreted to be klippe folded about northwest-trending axes. The exposure of unit DT_c in the map area was interpreted to represent the core of one of these synformally folded klippe of greenstone (Mortensen and Jilson, 1985, p. 807). Mortensen and Jilson (1985) evoked steep (strike-slip?) faults underlying and truncated by the basal thrust to account for the discontinuity of units beneath the klippe.

Our data indicate that the base of the greenstone unit is marked by northwest-striking, moderate to shallowly dipping thrust faults with hanging wall displacements to the southwest and northeast. No evidence for steep, northerly trending faults is found in the footwall rocks. This contradicts the folded thrust fault and klippe interpretation. However, the map pattern of unit DT_c is most readily explained as a klippe preserved from erosion by normal faulting along its southern boundary (Fig. 2, 3). Given that northwest-trending thrust faults characterize the regional structure and that northwest-trending folds are widespread in unit DT_c, it is reasonable to assume that the northwest-

trending boundaries of unit DT_c are also reverse faults. Whether they are diverging faults or a single synformally folded thrust fault is indeterminate (Fig. 3).

We propose the following hypothesis to explain our observations: The divergently dipping thrust faults record an originally east-vergent thrust sequence in which continued shortening was accommodated by west-directed back-thrusts. In this scenario, we envisage both sinistral reactivation of the western (east-dipping) limbs of the klippen in addition to the generation of new, west-directed thrusts. This back-thrusting may simply be the consequence of continued shortening in the upper crust. Alternatively, it may reflect larger scale processes such as "tectonic wedging" of Yukon-Tanana terrane under Slide Mountain terrane. Such a scenario has been proposed for the boundary between paleo-North America and accreted terranes in British Columbia (e.g., Bellefontaine, 1990; Price, 1986). However, tectonic wedging requires a wedge-shaped basement geometry for which there are no constraints in the map area. Either case, shortening on the small scale or crustal scale, can account for the folded klippen documented by Mortensen and Jilson (1985) and the divergent thrust faults at the base of unit DPS_g, northwest-trending folds in unit DT_c and general map pattern documented in this study.

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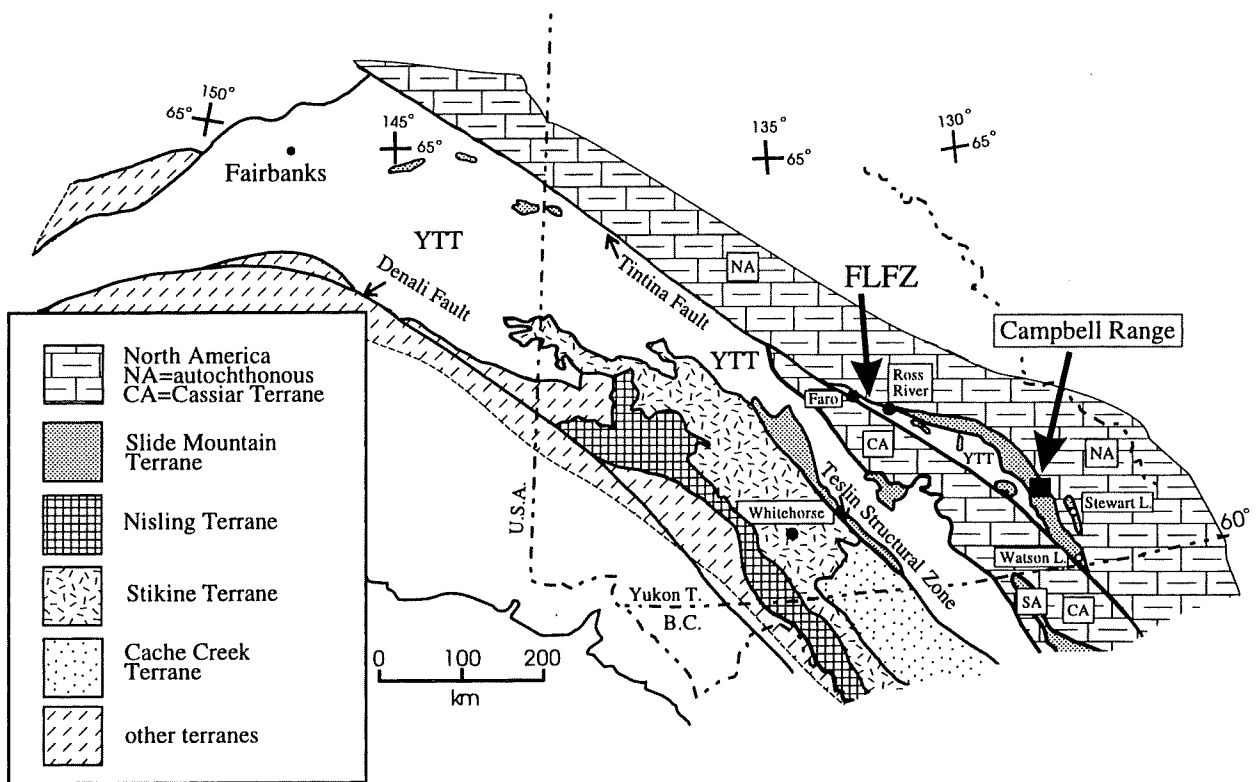
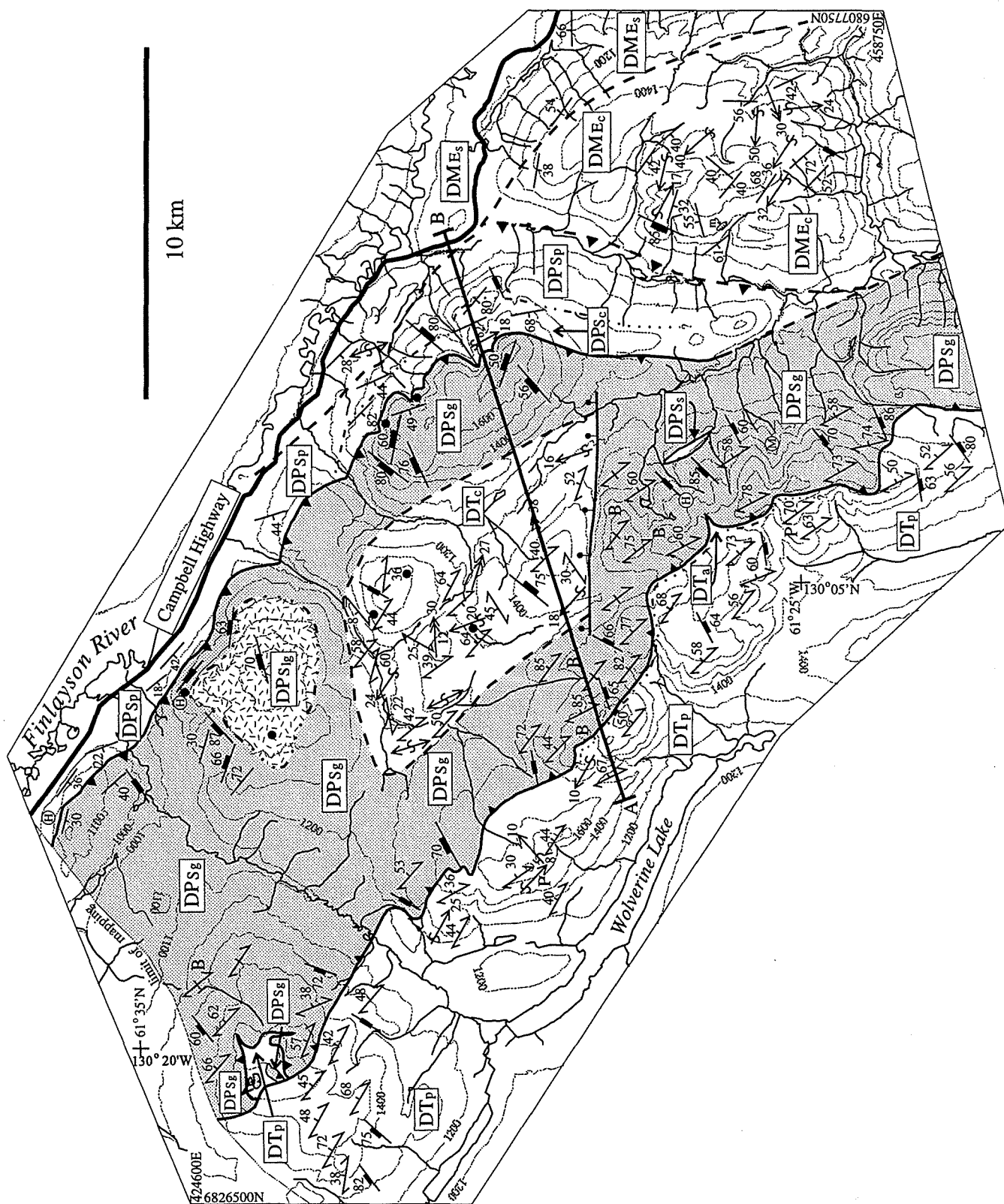


Figure 1: Terranes of the northern Cordillera. NA is autochthonous North American strata; CA is allochthonous North American strata (= Cassiar terrane); YTT is Yukon-Tanana terrane, FLFZ is the Finlayson Lake fault zone. SA = Sylvester Allochthon. Modified from Mortensen (1992b).



DEVONIAN-MISSISSIPPIAN EARN GROUP?

DME_s	Sandstone, siltstone and shale: Well sorted, very fine-grained, sandstone, laminated siltstone and black, fissile shale.
DME_c	Metachert and argillite: Grey, rusty, tan or white weathering, dark grey to black, massive to thinly bedded, radiolarian metachert with argillaceous partings or interbedded with argillite. Minor quartz-chert sandstone and chlorite phyllite.

DEVONIAN-PERMIAN SLIDE MOUNTAIN TERRANE

DPS_s	Serpentinite: green to black, magnetic, locally brecciated; massive, sugary textured to well foliated; locally contains grey metacarbonate and maroon metasiltstone.
DPS_g	Greenstone: massive to foliated greenstone, greenstone and pillow breccia, heterolithic breccia, metasiltstone, metachert, metadiorite, metagabbro and metagreywacke.
DPS_{lg}	Leucogabbro: plagioclase-pyroxene, coarse grained, ophitic gabbro, some fine grained and pegmatitic phases and fine grained mafic enclaves.
DPS_c	Metachert and metasiltstone/argillite: ribbon to massive, tan, yellow, or maroon weathering, tan, grey, maroon or green metachert, interbedded with metasiltstone/argillite; minor chert breccia and chert-quartz conglomerate.
DPS_p	Metachert and phyllite: pink, orange, tan, white or green-grey metachert with argillaceous partings or with argillite or phyllite interbeds.

PRE-DEVONIAN - UPPER TRIASSIC? YUKON-TANANA TERRANE

DT_c	Metachert and slate: Grey, white and black laminated metachert interfoliated with black slate and siliceous metasiltstone; structurally interleaved with serpentinite, feldspar - hornblende porphyry, muscovite-chlorite-quartz phyllite and metacarbonate.
DT_p	Actinolite-chlorite schist and phyllite, interfoliated with muscovite-quartz-chlorite phyllite, black slate, white quartzite (some with argillaceous partings) and minor grey, white and tan metachert.
DT_a	Rusty brown or grey weathering, grey or grey-brown argillite (some phyllitic) and metasiltstone.

SYMBOLS

●	sub-map scale serpentinite bodies
P	porphyry in unit DT _p
B	breccia in unit DPS _g
m	silty marble in unit DME _c
⊕	hydrothermal alteration zone
Ⓜ	Money sulphide showing

	cleavage or schistosity: inclined, vertical
	joint: inclined, vertical
	rodding
	mesoscopic folds and crenulations
	inferred fault (displacement unknown)
	thrust fault: defined, inferred (symbol on upper plate)
	normal fault: defined, inferred (symbol on down-dropped block)
	geological boundary, defined
	geological boundary, approximate
	elevation contour (c.i. = 100 m)
	drainage

Figure 2. Geology of the study area. In the legend, age assignments are from Mortensen (1992a,b) and terrane assignments are discussed in the text.

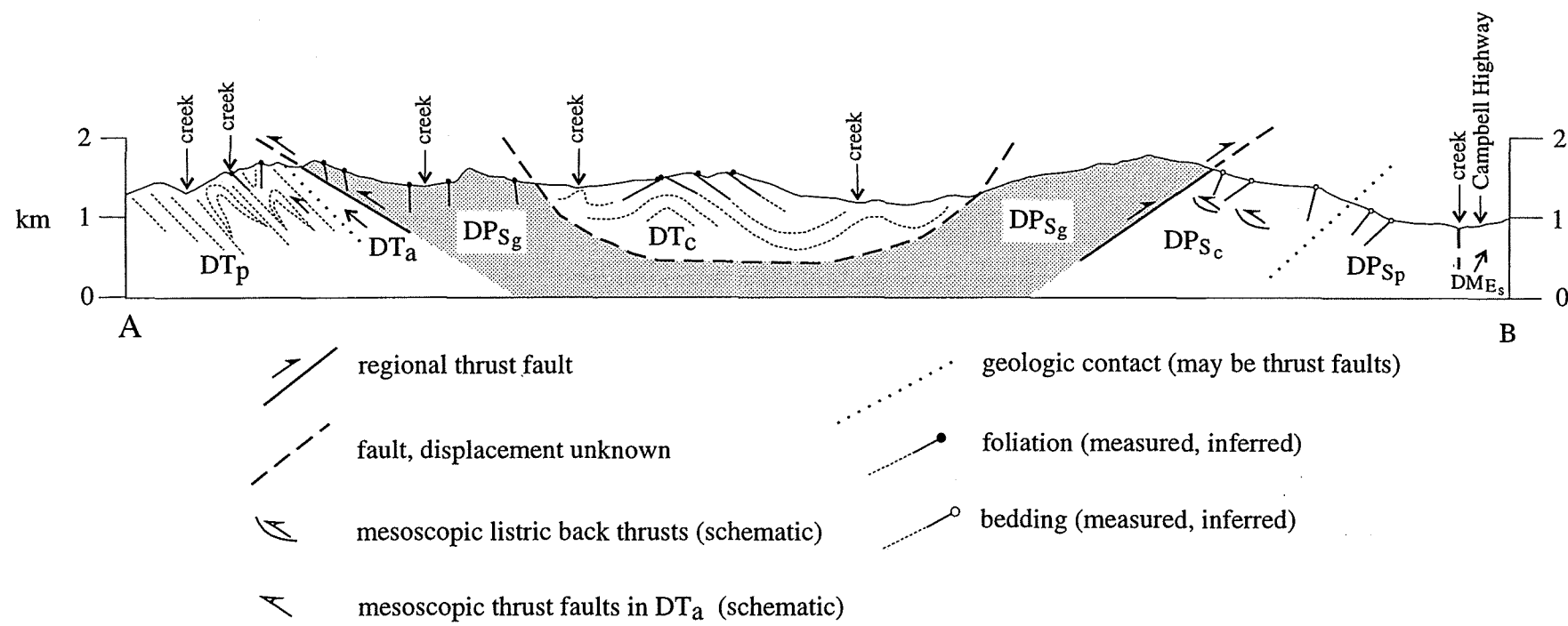


Figure 3. Geologic cross-section through line A-B shown on Figure 2.

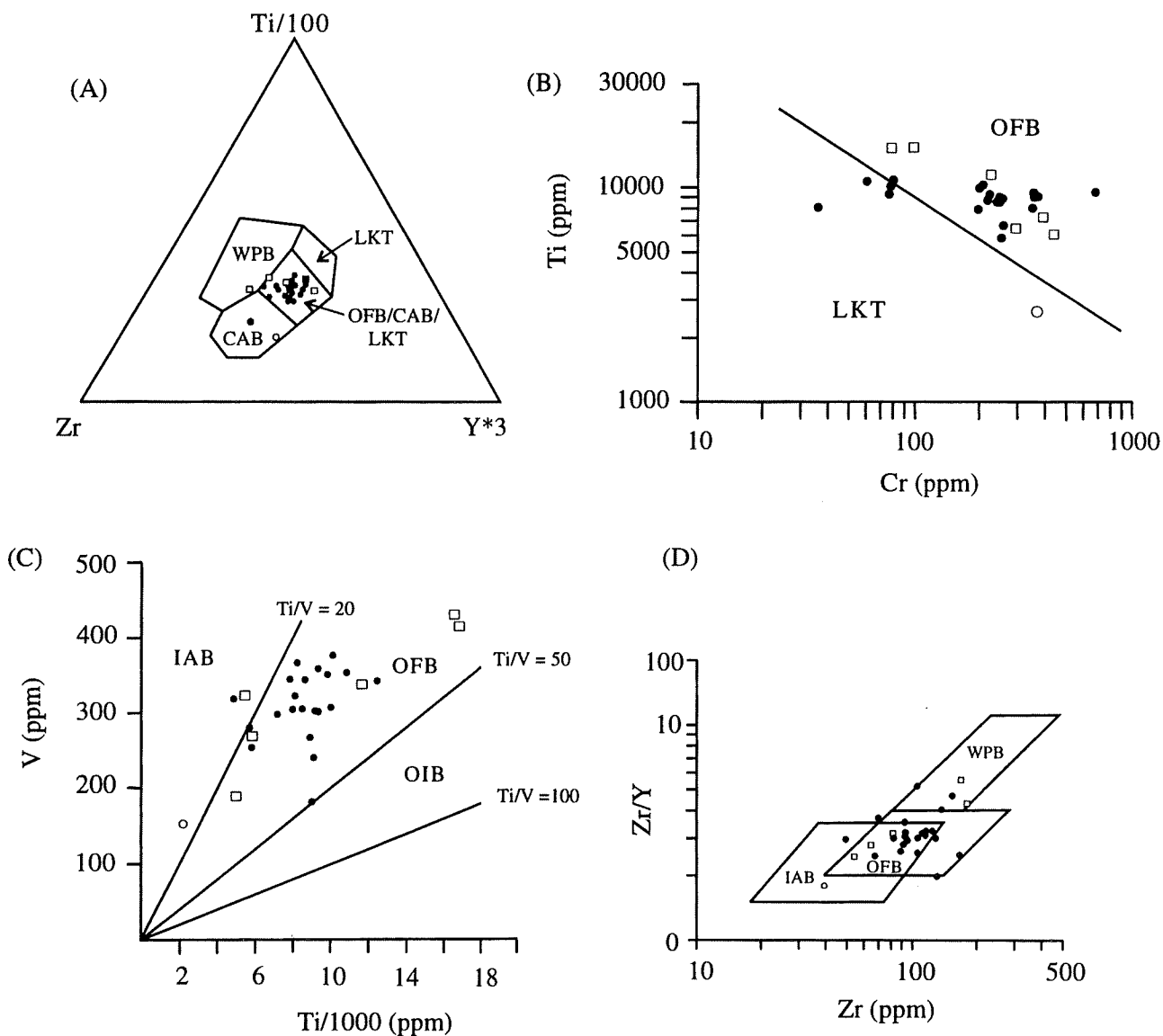


Figure 4: Tectonic discrimination diagrams for SMT greenstone (solid circles) and gabbro (open circle) and for YTT chlorite-actinolite phyllite (open squares). LKT = low K tholeiite, WPB = within-plate basalt, CAB = calc-alkali basalt, IAB = island arc basalt, OFB = ocean floor basalt, OIB = oceanic island basalt. Fields from (A) Pearce and Cann, 1973, (B) Pearce, 1975, (C) Shervais, 1982, and (D) Pearce and Norry, 1979.

The Vanderhoof Metamorphic Complex, Vanderhoof, B.C.

S. Wetherup, Department of Earth and Atmospheric Sciences, University of
Alberta, Edmonton, AB, T6G 2E3

Vanderhoof Metamorphic Complex rocks are a suite of paragneisses and orthogneisses outcropping south and southeast of Vanderhoof, British Columbia (93F/9, 16 and 93G/5, 6, 12, 13). Mapping of the area at 1:50,000 scale began during the 1995 field season as part of the Geological Survey of Canada's, Nechako NATMAP Project.

The Vanderhoof Gneisses are in fault contact with structurally overlying Cache Creek Group rocks, along a shallowly eastward dipping detachment. Motion along this detachment appears to have displaced the Cache Creek rocks in approximately a southeastward direction. Paragneisses within the complex are composed of psammitic, semi-pelitic, and calcic units interpreted to represent fine grained clastic rocks, limestones, marls and possibly basalt protoliths. Metamorphic grade of these paragneisses is indeterminate from field evidence. Orthogneisses of the complex are in spatial proximity to the detachment that separates the gneisses and Cache Creek rocks. These orthogneisses are mostly biotite granite and granodiorite in composition, grading into non-deformed granitoid sills, dykes and plutonic masses with distance from the detachment. At their most southerly extent, the rocks of the metamorphic complex are intruded and overlain by felsic to intermediate volcanic and intrusive rocks, probably of Tertiary age.

Presently, lab work is being done to establish the deformational and uplift history of the Vanderhoof complex and possibly the terrane to which it belongs. This work will be essential in helping to understand the Vanderhoof Metamorphic Complex, and may be able to determine whether the complex is another example of an extensional core complex, in the Canadian Cordillera.

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STIKINE TERRANE STRATIGRAPHY ALONG THE NORTHWESTERN MARGIN OF THE BOWSER BASIN

Chris Ash, British Columbia Geological Survey, Victoria.

Richard Friedman, Department of Geological Sciences, UBC, Vancouver.

Fabrice Cordey, Radiolarian Biostratigraphy, Vancouver.

Howard Tipper, Geological Survey of Canada, Vancouver.

Mesozoic Stikine arc volcanic rocks crop out along the northwestern margin of the Bowser Basin, in an area bisected by Highway 37 along the proposed SNORCLE transect line. A program of systematic 1:20,000 scale mapping of these rocks and associated mineral deposits was initiated in 1994 and will be completed in 1996. We report on preliminary results of this mapping.

East of Highway 37, a well preserved Lower Jurassic, southwest-facing, bimodal basalt-rhyolite succession is exposed immediately below and north of the Bowser Lake Group on the southwest end of the Todagin Plateau. This is characterized by a lower sequence of Pliensbachian layered, massive and pillowed flows and breccias of augite-phyric mafic volcanic rocks with lesser volcanic sediments and an upper layered rhyolitic volcanic flow or flow dome complex that varies upward from massive to banded to brecciated. Preliminary U-Pb isotopic data suggests that the rhyolitic volcanic rocks are Toarcian in age (*ca.* 181Ma). Further to the southwest, in the area of Kinaskan Lake, similar bimodal volcanic rocks are overlain by a thick sequence of related Lower Jurassic epiclastic rocks with intervals of laminated black siltstone. The Lower Jurassic bimodal volcanic succession here forms part of the uppermost Hazelton Group, intermittently exposed around the northern margin of the Bowser Basin. Interestingly, the age of the bimodal volcanics in this area fall between the age of the Cold Fish volcanics (*ca.* 194 Ma) to the east and Eskay Creek bimodal volcanics to the southwest (*ca.* 174 Ma).

West of Highway 37 this bimodal volcanic succession overlies a sequence of north-facing siliciclastic sedimentary rocks that include chert, siliceous mudstone, siltstone and medium-grained volcanic wacke. Three samples of siliceous or cherty material collected from this sequence contain radiolarian fauna indicating that the sequence is Middle(?) to Late Triassic (Ladinian(?)-Carnian-Norian) in age. Further north these Triassic sediments are overlain by massive andesitic volcanic breccias.

East of Highway 37, Upper Triassic and possibly Lower Jurassic feldspathic volcanic wacke and siltstone with lesser, discontinuous intervals of augite-phyric mafic volcanic rocks predominate. These are overlain by a sequence of massive andesitic volcanic breccias with intervals of derived volcanic conglomerate and lithic wacke.

All of the Mesozoic volcanic rocks (apart from the bimodal suite) are intruded by a variably mineralized suite of Early Jurassic hornblende quartz diorite to monzonite high-level dikes and stocks. The age of this suite has been constrained by U-Pb isotopic dating of three separate samples at *ca.* 200-205 Ma. Dated samples contain zircon fractions suggesting the presence of Early Paleozoic inheritance.

Post-Late Cretaceous, northeast-trending, high-angle fault zones comprise several major structures that cross the entire map area. Detailed structural analysis in the central Kinaskan area indicate that movement along one of these structures, the Ealue Lake Fault, is primarily dextral strike-slip.

A WORKING HYPOTHESIS FOR THE TECTONOSTRATIGRAPHIC AFFINITY OF THE STIKINE RANGES AND A PORTION OF THE DORSEY TERRANE

Tekla A. Harms

Department of Geology, Amherst College, Amherst MA 01002 USA

Robert A. Stevens

Department of Geological Sciences, Queen's University, Kingston, ON, K7L 3N6

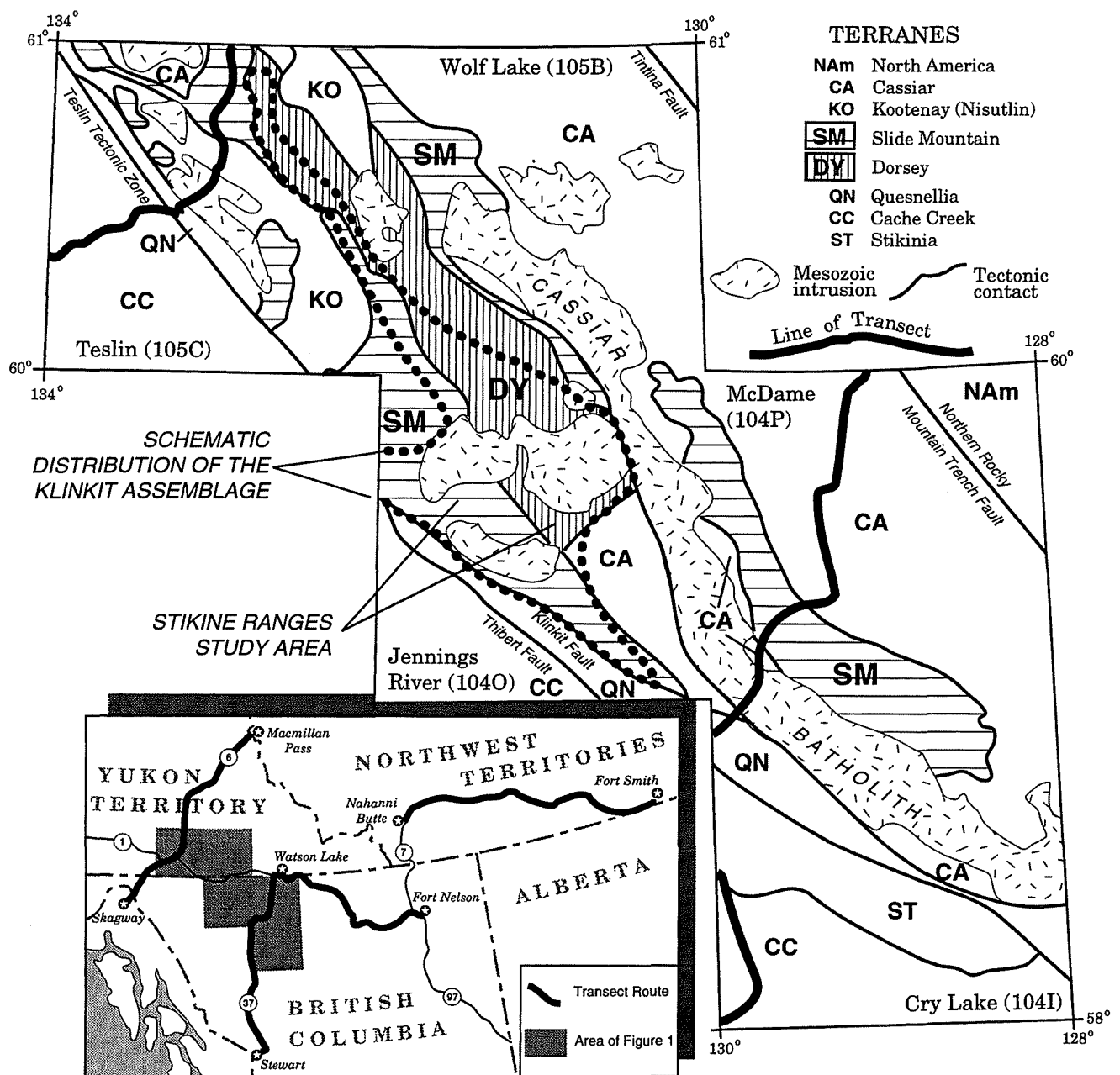
ABSTRACT

Recent field studies in the Dorsey and Slide Mountain terranes in northern British Columbia and southern Yukon (Figure 1) show that this area can be characterized by a number of lithologically and structurally distinct, and at least partly coeval assemblages (Harms and Stevens, this volume). Rocks in the Stikine Ranges (corresponding to unit 11 of Gabrielse [1970]) characterize the informally-named "Klinkit Assemblage", which also includes rocks of the "Upper and Middle Assemblages" of Stevens and Harms (1995) in the Dorsey Range, and Units Mv and Ml of Gordey and Stevens (1994) or "Sequences A and B" of Harms (1992) in the Thirtymile Range. Mapping completed in 1995 demonstrates that marker beds within the Klinkit Assemblage can be traced from ESE to WNW through the Stikine Ranges and cross, without significant offset, the inferred location of the "Slide Mountain/Dorsey terrane" contact as drawn by Wheeler and McFeely (1991). The Klinkit Assemblage is unlike Slide Mountain terrane as characterized to the east of the Stikine Ranges (Harms, 1986; Nelson, 1993), and does not correspond readily to other assemblages defined in the Dorsey Range. It constitutes a single distinct geologic entity that is neither Slide Mountain terrane nor Dorsey terrane.

Units within the Klinkit Assemblage in the Stikine Ranges change character and thickness along strike, and have been subjected to map-scale deformation subsequent to their deposition. Defining a single through-going stratigraphy has been elusive. Nevertheless, the assemblage characteristically consists of: (i) thick, massive, clean quartz sandstone, commonly black or purply-grey, or interbedded siliciclastic, shale, and chert that may or may not be a facies equivalent of the quartz sandstone. The latter has yielded Triassic conodonts (M. Orchard, personal communication); (ii) an equally thick or thicker heterogeneous volcanic unit that includes both fine and very coarse volcanoclastic accumulations and mafic flows; and (iii) one or more carbonate horizons at least, in part, Pennsylvanian in age (Gabrielse, 1970; Abbott, 1981; M. Orchard, personal communication). These lithologies suggest mafic to intermediate volcanism in a marine setting with a continental influence.

Facies changes that occur along strike within the Klinkit Assemblage are consistent with the nature of a volcanic environment, but render direct, unit-by-unit correlations between this assemblage and other sequences tenuous. In general, however, the late Paleozoic mixed arc and continental character of the Klinkit Assemblage is similar to the basement of Quesnellia in southern British Columbia (Harper Ranch and Okanagan subterrane of Monger et al. [1991]; Roback and Walker, 1995), and the McCloud belt in the western United States (Miller, 1987). While McCloud faunal affinity is defined on the basis of Permian forms - and no Permian strata have been identified within the Klinkit Assemblage - Pennsylvanian fusulinids reported from the Klinkit Assemblage, by genus, are consistent with those that characterize Carboniferous Sonomia and the rest of the McCloud belt and differ from miogeocline fauna in the United States (Carter, et al., 1991; Ross and Ross, 1983).

Figure 1: Terrane map of southern Yukon Territory and northern British Columbia in the vicinity of the Dorsey terrane and the SNORCLE transect (adapted from Wheeler and McFeely, 1991). Dotted line encircles the schematic distribution of the Klinkit Assemblage. Inset map shows the SNORCLE transect route.



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AN OVERVIEW OF THE NATURE, DISTRIBUTION AND TECTONIC SIGNIFICANCE OF XENOLITHS FROM THE STIKINE VOLCANIC BELT, NORTHERN CORDILLERA

B. R. Edwards and J.K. Russell

INTRODUCTION

Ultramafic and feldspathic xenoliths are found throughout the northern Cordillera in magmatic centres of the Stikine Volcanic Belt (SVB), which is a broad zone of Neogene to Recent, extension/plume-related magmatism 1200 km in length (Souther & Yorath, 1991; Francis & Ludden, 1995) (see figure). The xenoliths comprise samples from several different depths of the continental lithosphere and as such contain important information about the composition and evolution of the northern Cordillera lithosphere. The purpose of this paper is to briefly review the nature and distribution of the xenoliths and to outline their importance for constraining tectonic models for the evolution of the northern Cordillera.

NATURE AND DISTRIBUTION OF XENOLITHS

A variety of xenoliths occur in centres throughout the length of the Stikine Volcanic Belt (figure). The xenoliths can be grouped into three broad categories: 1. ultramafic xenoliths, 2. feldspathic xenoliths and 3. xenocrysts. In addition to the xenoliths/xenocrysts, cognate inclusions are also found at many of the centres and range in composition from gabbro to syenite. The xenoliths and inclusions are commonly found in crater tephra, lava flows, vent breccias and high level plugs. Detailed studies of the xenoliths have been completed for only a limited number of locations including Fort Selkirk (Sinclair et al., 1978; Prescott, 1983; Ross, 1983; Francis & Ludden, 1990), Alligator Lake (Francis, 1987), Atlin (Ruby Mountain, Nicholls et al., 1982) and Castle Rock (Littlejohn & Greenwood, 1974; Prescott, 1983; Ross, 1983). However, information on the geology and petrology of many of the xenolith-bearing centres is available (table).

Ultramafic Xenoliths

Published reports of ultramafic xenoliths from the SVB describe a broad range of rock types including 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; Ross, 1983; Higgins & Allen, 1985; Francis, 1987). Two of the most detailed studies, of Fort Selkirk and Castle Rock by Ross (1983) and of Alligator Lake by Francis (1987), found both geochemically depleted and undepleted ultramafic xenolith populations. At Alligator Lake, Francis (1987) determined that all peridotite xenoliths were Type I (Cr-rich clinopyroxene). These studies also found both tectonized and non-tectonized mineral fabrics.

Ultramafic xenoliths have been collected from at least 15 different centres covering over two-thirds of the length of the Stikine Volcanic Belt (refer to figure and table). Their distribution is skewed towards the northern half of the SVB as well as the Yukon-Tanana and Cache Creek terranes. Ultramafic xenoliths are found in the majority of centres located in Yukon-Tanana, approximately one-half of the centres in Cache Creek, but only in a few of the centres within the Stikine terrane. No ultramafic xenoliths are known from SVB centres within the Cassiar terrane or east of the Tintina Fault.

Feldspathic Xenoliths

The feldspathic xenoliths include sedimentary, plutonic and metamorphic rocks and are extremely common throughout the SVB. The most common types are granitic plutonic rocks, whose sources are commonly exposed in surficial outcrops. In contrast, samples of gneissic, high-grade metamorphic rocks have only been well documented at two centres: Prindle in Alaska (Foster et al., 1967) and Iskut River in west-central British Columbia (Nicholls et al., 1982). However, they may also be present at Sixty Mile, Alligator Lake and Castle Rock (T.S. Hamilton, per. comm.; Hamilton et al., in prep). At Prindle several different varieties of gneisses have been identified as belonging to the granulite facies (Foster et al., 1967).

Many of the upper lithospheric xenoliths exhibit reaction textures with the surrounding magma and some have been partly melted and contain glass. These xenoliths have been studied in detail at Alligator Lake (Eiche et al., 1987; Carignan et al., 1994), Ash Mountain (De P. Watson & Mathews, 1948), and the Iskut-Unuk

rivers centres (Hauksdottir, 1994; Hauksdottir et al., 1994; Hauksdottir & Russell, 1994). However, even though many of the feldspathic xenoliths found in the SVB are partly melted and have reacted with the surrounding host magmas, only rarely does the geochemical signature of these contaminants appear to be reflected in the bulk chemistry or isotopic signatures of the host magmas. At Ash Mountain and South Tuya, Moore et al. (1995) could detect no chemical evidence for contamination even though both centres contain partly melted crustal xenoliths. Similarly, Eiche et al. (1987) and Carignan et al. (1994) did not find significant chemical contamination at Alligator Lake, although they did not totally discount it as a possible source of chemical variation. However, at the southern end of the SVB in the Iskut River area Hauksdottir (1994) and Cousens and Bevier (1995) both documented variations in geochemistry due to assimilation of upper lithospheric material.

Xenocrysts

Xenocrysts have been reported in most of the SVB centres that are xenolith-bearing (table). Most of the xenocrysts obviously were liberated into the surrounding magma as their parent xenoliths disaggregated. However, three very interesting groups of xenocrysts have somewhat less obvious origins: kaersutite amphibole xenocrysts from Llangorse Mountain (Higgins & Allen, 1985), clear, glassy plagioclase megacrysts from the Iskut-Unuk rivers centres, Little Bear mountain and Aiyansh (Hauksdottir, 1994; Edwards & Russell, in prep.), and an as yet little-studied population of large, black, glassy clinopyroxene megacrysts. The plagioclase and clinopyroxene have in common with the feldspathic xenoliths obvious signs of reaction with the host magma including sieve-texture cores and irregular, resorbed and embayed outer margins. The plagioclase megacrysts also exhibit complex growth and dissolution features (Hauksdottir, 1994).

Like xenoliths in general the xenocrysts are distributed throughout the length of the SVB. For xenocrysts obviously derived from xenoliths this is an obvious relationship. However, both the plagioclase and clinopyroxene megacrysts have unique distributions. The plagioclase megacrysts appear to be limited to the southern half of the SVB and the Stikine terrane. However, the clinopyroxene megacrysts have a broader distribution than any of the other xenocrysts or

xenoliths. They are found throughout the Yukon-Tanana, Cache Creek and Stikine terranes from Prindle and the West Dawson area to the Iskut-Unuk rivers.

Cognate Inclusions

Cognate inclusions include troctolite from Ash Mountain (Moore et al., 1995), a suite of plagioclase-dominated inclusions from Level Mountain (Hamilton, 1981), gabbroic inclusions from Little Bear mountain and Mt. Edziza (Souther, 1992), and syenitic inclusions from Hoodoo Mountain. These inclusions are confined to the larger volcanic centres in the central and southern SVB which is within the Stikine terrane, with the exception of Ash Mountain, which is near the boundary between the southern Yukon-Tanana and Cassiar terranes.

RELEVANCE TO NORTHERN CORDILLERAN TECTONICS

The xenoliths and cognate inclusions provide insights and constraints for the tectonic development of the northern Cordillera as do other physical and chemical characteristics of the Stikine Volcanic Belt. The xenoliths are critically important because they provide samples of the inaccessible parts of the Cordilleran lithosphere in at least five different lithostratigraphic terranes including: Yukon-Tanana, Stikine, Cache Creek, Cassiar and the Coast Plutonic Complex (table). Temperature estimates and preserved textures in ultramafic xenoliths provide important information for the composition and structure of the lithosphere and can be used to create feasible stratigraphic columns for the lower lithosphere (Ross, 1983). Two different studies have emphasized the fact that the lower lithosphere beneath the northern Cordillera is distinctly different from that underneath the southern Cordillera (Nicholls et al, 1982; Francis, 1987). Mitchell (1987) pointed out the wide diversity in mineral chemistry found throughout the entire Canadian Cordillera, and noted that the endmembers of the chemical diversity were Fort Selkirk and Castle Rock, both within the SVB. Detailed geochemical and isotopic studies have further defined geochemically distinct segments of lower lithosphere and upper asthenosphere within the northern Cordillera (Carignan et al, 1994; Cousens & Bevier, 1995).

Feldspathic xenoliths also help to constrain the composition and nature of the lithosphere. In at least three areas of the SVB feldspathic xenoliths provide

information about the lithologies directly beneath volcanic centres. At Prindle, the occurrence of mafic, gneissic metamorphic xenoliths demonstrates that granulite facies rocks underlie the predominantly amphibolite and greenschist facies assemblages exposed at the surface near the volcano. Xenoliths from the Edziza Formation show that granitic plutons occur somewhere beneath the extensive Edziza complex. The presence of coarse-grained, pyroxene-bearing feldspathic xenoliths dissimilar to units exposed around the edges of Little Bear mountain also provide new insight into the composition of the upper lithosphere in the Iskut River area of the Stikine terrane.

Important evidence for the depth and significance of lithospheric scale structures can also be gleaned from the variations in distribution of magmatism within the Stikine Volcanic Belt. Several of the centres (Fort Selkirk, Mount Edziza, Level Mountain, Llangorse Mountain) are aligned along major fault zones which may have provided pathways for ascent of asthenospheric melts (Francis & Ludden, 1990, 1995; Souther, 1992; Hamilton, 1981; Souther & Yorath, 1991). One study in particular detected changes in the geochemical characteristics of magma source regions across the Tintina Trench (Hasik et al., 1993). Detailed comparisons of major and trace element chemistry between centres erupted through different terranes may further help to define distinct geochemical domains within the lower lithosphere and upper asthenosphere of the northern Cordillera (Carignan et al., 1994).

The distribution of cognate inclusions and of the large, polygenetic volcanic complexes in the SVB may also be related to differences in the lithospheric structure and thickness between different terranes. The Stikine terrane hosts all of the largest magmatic centres in the Stikine Volcanic Belt (Level Mountain, Heart Peaks, Mount Edziza, Hoodoo Mountain), which are also the only centres with voluminous, chemically evolved lavas. One explanation for this spatial arrangement has been suggested by Carignan et al. (1994) and Francis and Ludden (1995): that the long-lived magmatism at Level Mountain and Edziza may be due to a mantle plume. Alternatively, the structure of the Stikine terrane may be such that it inhibits the rapid rise of magmas directly from their source regions to the surface and favors formation of crustal magma chambers.

SUMMARY

The magmatic products of the Stikine Volcanic Belt commonly host a variety of xenoliths, xenocrysts and cognate inclusions. These materials provide direct samples of the northern Cordilleran continental lithosphere and are amenable to petrochemical analysis and interpretation. Combined with geochemical signatures and spatial distributions of SVB magmatism, the information provided by xenoliths helps to reconstruct a petrological picture of the inaccessible regions of the northern Cordilleran lithosphere and will be a significant benefit to subsequent geophysical and tectonic studies of the northern Cordillera.

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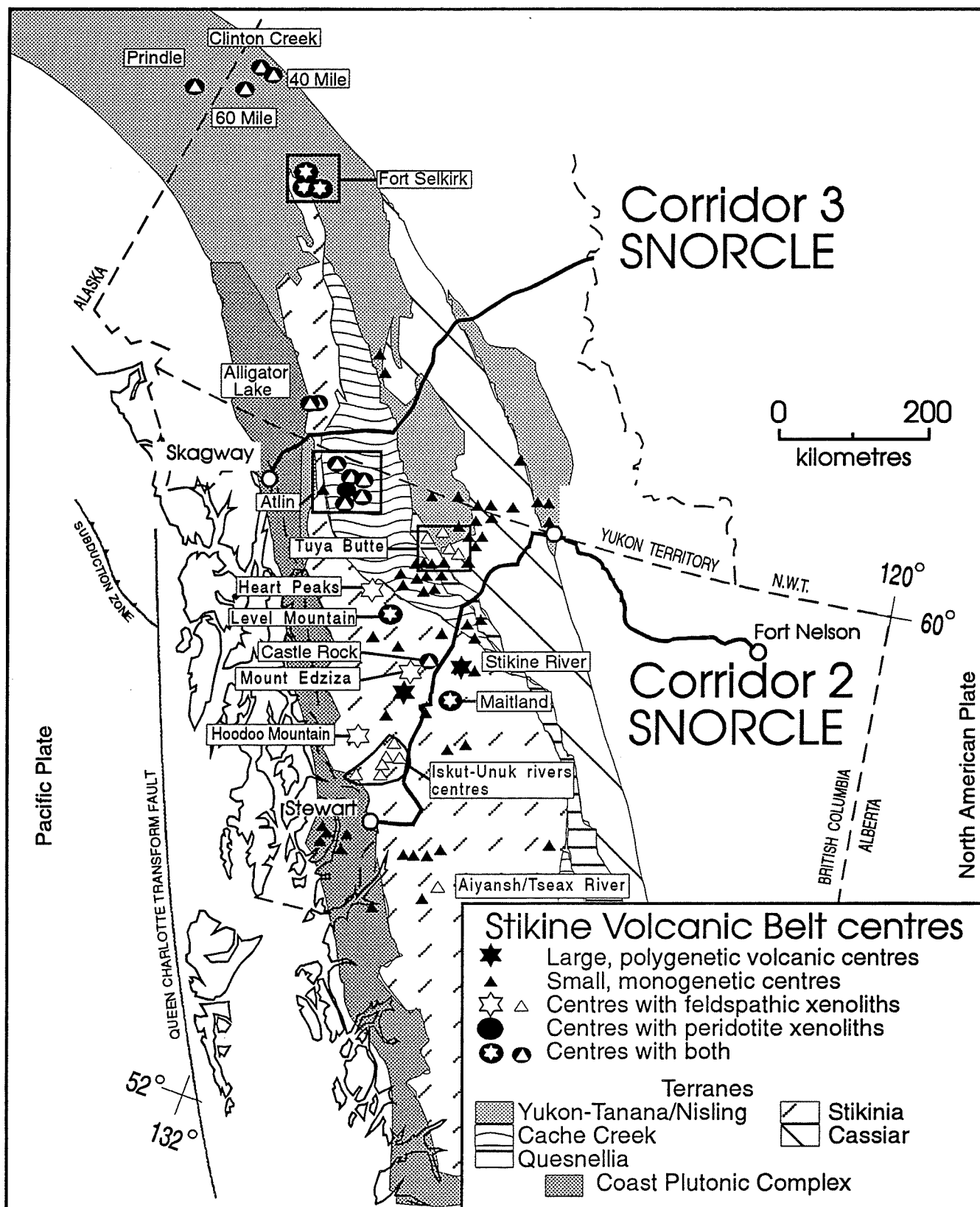
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Location of xenolith-bearing and non-xenolith-bearing volcanic centres of the Stikine Volcanic Belt (modified from Hickson, 1991). Corridors 2 and 3 for the SNORCLE Transect are shown in bold lines.

Summary of Xenolith-bearing magmatic centres in the Stikine Volcanic Belt.

Volcanic centre	Terrane	Types of xenoliths/inclusions	References
Prindle	Yukon-Tanana	spinel lherzolite, spinel harzburgite, spinel wehrlite, granulite, clinopyroxene xenocrysts	Foster et al. (1966); Hamilton et al. (in prep.)
60 Mile	Yukon-Tanana	peridotite, sedimentary rocks, granite	Mortensen & Roddick (1989); Hamilton et al. (in prep.)
Clinton Creek	Yukon-Tanana	peridotite, granite	Mortensen & Roddick (1989); Hamilton et al. (in prep.)
40 Mile	Yukon-Tanana	peridotite, granite	Mortensen & Roddick (1989); Hamilton et al. (in prep.)
Fort Selkirk (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)	Sinclair et al. (1978); Prescott (1983); Ross (1983); Jackson (1989); Francis & Ludden (1990); Francis (1991); Trupia & Nicholls (in press)
Alligator Lake	northern Coast Plutonic Complex	spinel lherzolite, spinel harzburgite, granite	Eiche et al. (1987); Francis (1987); Hamilton et al. (in prep.)
Atlin (including 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	Aitken (1959); Nicholls et al. (1982); Higgins & Allen (1985); Francis & Ludden (1995); Edwards et al. (1996)
Tuya Butte area (including Ash Mountain, 3 Caribou tuya, Mathew's tuya, South tuya)	Cache Creek/Cassiar	granite, granodiorite, troctolite	Mathews (1947); de P. Watson & Mathews (1948); Allen et al. (1982) Allen (1991); Moore et al. (1995); Hamilton et al. (in prep.)
Kawdy Mountain	Cache Creek	granite	Hamilton (pers. comm.); Hickson (pers. comm.)
Heart Peaks	northern Stikinia	possible xenocrysts	Jones (1980)
Level Mountain	northern Stikinia	spinel lherzolite, garnet wehrlite, gabbro, granitic gneiss, sedimentary rocks, clinopyroxene xenocrysts	Hamilton (1981); Hamilton (1991)
Castle Rock	northern Stikinia	spinel lherzolite, granite, gneiss	Littlejohn & Greenwood (1974); Prescott (1983); Ross (1983); Hamilton (pers. comm.)
Edziza	northern Stikinia	hornblende biotite granite, gabbro	Souther & Hickson (1984); Souther et al. (1984); Souther (1991b); Souther (1992)
Maitland	northern Stikinia	peridotite, feldspathic xenoliths	Souther (1991e); Hamilton (per. comm.), Evenchick (per. comm.)
Hoodoo Mountain (including Little Bear mountain)	northwestern Stikinia	granite and syenite; clinopyroxene xenocrysts	Kerr (1948); Souther (1991c); Edwards & Russell (1994; 1995; in prep)
Iskut-Unuk rivers centres (including Lava Fork, Iskut River, Snippaker Creek, King Creek, Cone Glacier)	northwestern Stikinia	granitic gneiss and schist; plagioclase & clinopyroxene xenocrysts	Kerr (1948); Nicholls et al. (1982), Grove (1986); Hauksdottir (1994); Hauksdottir et al. (1994); Cousens & Bevier (1995)
Aiyansh/Tseax River flows	west-central Stikinia	quartzite (?)	Southerland-Brown (1969); Nicholls et al. (1982); Hamilton et al. (in prep.)

A Chemo - Isotopic Transect of the Lithospheric Upper Mantle across the Northern Canadian Cordillera

Francis, D., Abraham, A.C., Rowins, S., & Shi, L., Earth & Planet. Sci., McGill Un.,
Carignan, J., GEOTOP, Université de Québec à Montréal, and
Ludden, J., CRPG, Vandoeuvre-les-Nancy, France

The chemical and isotopic character of recent alkaline volcanics and their mantle xenoliths across the northern Canadian Cordillera carry important information about the lithospheric mantle beneath its disparate tectonic elements.

The lavas of recent alkaline volcanic centres within the Coast Plutonic Belt or along its eastern margin within the Intermontane Belt are characterized by elevated $^{87}\text{Sr}/^{86}\text{Sr}$ and Rb/Zr ratios and bimodal mantle xenolith populations consisting of harzburgites and lherzolites. The harzburgite xenoliths appear to represent depleted mantle that has experienced a pervasive metasomatic event that has elevated their $^{87}\text{Sr}/^{86}\text{Sr}$ and $^{206}\text{Pb}/^{204}\text{Pb}$ ratios and incompatible element contents relative to the lherzolite xenoliths. Recent seismic evidence of a pronounced mantle reflector at approximately 50 km depth beneath the Coast Plutonic belt along the U.S. Accrete Transect and higher estimated temperatures for the harzburgites suggest that the latter may represent anomalous lower lithospheric mantle which appears only beneath the westernmost Intermontane and Coast Plutonic Belts. Similar trace element and isotopic enrichment in alkaline volcanics west of Dawson suggest that the anomalously enriched mantle beneath the Coast Plutonic Belt may extend northward into Alaska.

Volcanic centres further to the East within the Intramontane Belt and the western portion of the Omenica Belt are characterized by lavas with the lowest $^{87}\text{Sr}/^{86}\text{Sr}$ and Rb/Zr ratios and unimodal mantle xenolith suites comprised of relatively unmetasomatized lherzolites. In the volcanic data collected to date, there is no apparent change from the Stikine to Cache Creek terranes, nor across the Teslin suture into the western portion the Omenica Belt. Within the Omenica Belt itself, however, there is an eastward increase in $^{87}\text{Sr}/^{86}\text{Sr}$, $^{206}\text{Pb}/^{204}\text{Pb}$ and Rb/Zr ratios in recent alkaline lavas across the Cassiar fault.

An abrupt increase in Zr, Ca, and degree of heavy rare-earth depletion, but decrease in $^{87}\text{Sr}/^{86}\text{Sr}$ ratio occur in alkaline lavas across the Tintina Fault, separating the Omenica Belt from ancestral North America. These changes suggest a greater proportion of garnet in their mantle source and/or a thicker lithosphere to the East of the Tintina Fault, and require that, contrary to some recent suggestions, the Tintina Fault is a high angle structure which penetrates the lithospheric mantle.

Further to the East, the recent alkaline volcanics in the Beaver River area, at the eastern limit of the Stikine Volcanic Belt, are characterized by extremely elevated Ba, Sr, and Nb contents and $^{87}\text{Sr}/^{86}\text{Sr}$, and $^{206}\text{Pb}/^{204}\text{Pb}$ ratios, in striking contrast to coeval alkaline lavas of the accreted terranes to the West. These features indicate that the lithospheric mantle changes abruptly about 100 km to the East of the Tintina Fault and may mark the transition to the cratonic mantle root of North America.

Basaltic Lava Flows and Enclosed Xenoliths as Samples of the Lithosphere and Low Velocity Zone beneath Northern British Columbia, A Progress Report

J. Nicholls and M.Z. Stout. Department of Geology & Geophysics, University of Calgary, Calgary, Alberta T2N 1N4.

Introduction

Studies of volcanic rocks from the Cordillera have the potential of delimiting depths of country rock incorporation, magma storage, fractionation, and assimilation. These processes probably occur where there are physical changes, such as changes in rock type in the lithosphere. The depth estimated with petrologic studies can be compared to changes in geophysical properties. In addition, the chemistry of the volcanic products can help detect and constrain interpretations of lateral chemical variations in the low velocity zone.

Four different field areas are the focus of this study. Edwards, *et al.* (1996) describe the details of the field relations of the volcanic centres near Atlin Lake:

The Thumb and near-by volcanic rocks in central B.C.
Nisga'a Memorial Lava Bed Park (Aiyansh Lava Flows) near Terrace, B.C.
Mount Llangorse near Atlin Lake, northern B.C.
Ruby Mountain near Atlin Lake, northern B.C.

The Thumb

Basaltic lava flows, cinder cones and volcanic breccia near McConnell Creek rest on a Tertiary post-Sustut Group erosion surface. Many flows have been dissected by glaciers and the rocks may be Tertiary and/or Quaternary (Richards, 1976).

The Thumb is a map unit of basanite and volcanic breccia, in the Connelly range. Lord (1948) called the Thumb itself a volcanic neck, a description also used by Souther (1990). However, the body may be the remnant of a lava flow that filled an old valley cirque. At the southern end of the outcrops of volcanic rock, the volcanic breccia forms scattered erosional remnants at topographic positions where, prior to erosion, the breccia could have underlain the basaltic rocks of the Thumb. The basanite that forms the Thumb itself is underlain, at least in part, by the Sustut Group. The body consists of a basal blocky jointed zone overlain by a zone of columnar jointing.

Blocks in the volcanic breccia consist of sandstone from the Sustut Group, glassy basalt, and mafic cumulates. The latter are most probably from a layered igneous body like

the Skaergaard or Muskox intrusions. The mineral assemblage consists of olivine, orthopyroxene (En₈₈), plagioclase (An₇₄), clinopyroxene, and opaque minerals.

The basanite forming the Thumb contains more than 15% olivine, approximately 37% diopside and augite, 42% plagioclase, and 5% opaque minerals with very minor apatite. Xenocrysts or glomerocrysts of partly digested pyroxene and olivine, and megacrysts of black spinel occur in the basanite. Most glomerocrysts show some alteration at their margins. The augite and diopside xenocrysts are unlikely extracts of the layered gabbro sampled by the volcanic breccia because the fragment of layered gabbro contains orthopyroxene, not clinopyroxene, as the dominant pyroxene.

One glomerocryst approximately 5 mm across is dominantly pyroxene, diopside and augite, accompanied by one smaller crystal of olivine. The pyroxene in this glomerocryst is zoned over a larger range in MgO contents than the pyroxene in the host rock. The core of one glomerocrystic pyroxene is the most MgO rich at 15.3 wt% compared to MgO contents of less than 12 wt% in pyroxenes forming small clusters and pyroxenes in the groundmass of the rock. However, MgO concentrations in the olivine associated with the high MgO pyroxene is not as high as that in the rock, Fo_{67.4} compared to Fo_{73.4} in the core of an olivine phenocryst approximately 500 μ across.

A single black spinel, larger than 500 μ across, is also present in the rock although the rest of the opaque minerals, magnetite solid solutions, are groundmass size. The spinel contains 55% Al₂O₃, 32% FeO, and 8% MgO.

Most plagioclase is less than 300 μ across and many crystals show textural features of partial resorption. The most CaO rich plagioclase microphenocryst has a composition of An₆₅. Groundmass plagioclase content reaches a maximum value of An₄₃ and much of the feldspar groundmass has Or contents of 3-6 mol%. Sanidine with celsian contents near 1.3 mol% also occurs in the groundmass.

The basanite from the Thumb has an unusual mineral assemblage compared to assemblages in rocks from Atlin, the Itcha Mountains (Nicholls, *et al.* 1982) and the Quesnel Lake region (Fiesinger and Nicholls, 1977) where basanites lack large crystals of augite. Nor does the basanite from the Thumb match the description of basanites from the Fort Selkirk series (Francis and Ludden, 1990). The Fort Selkirk basanites contain augite phenocrysts but they are unlikely to be xenocrysts because they are not described as partly resorbed (Francis and Ludden, 1990).

Two other centres in the McConnell Creek map area consist of lava flows and cinder cones. There are one or two cones approximately 5 km north of the Thumb and perhaps half a dozen cinder cones at the centre 15 km northeast of the Thumb. The rock types at these other two centres have not been sampled or described. Both mantle and crustal xenoliths may be present. If samples of the layered gabbroic body are present at the other volcanic complexes, we may be able to delimit the size of the layered intrusion.

Nisga'a Memorial Lava Bed Park (Aiyansh Lava Flows)

This Recent flow is approximately 22 km long and has a volume of approximately 0.5 km³. The rock is a high iron basalt with ~14% total iron as FeO. ⁸⁷Sr/⁸⁶Sr is equal to 0.7032 ± 0.00015 and d ¹⁸O is equal to 6.2 suggesting a mantle source region. The Aiyansh lava flow formed from one of the last volcanic eruptions in the Canadian Cordillera according to accounts by native peoples, radiocarbon dates (1700 AD, Southerland Brown, 1969; 1700 and 1325 AD, Wuorinen, 1978), and paleomagnetic dates (1650 AD, Symons, 1975). Wuorinen (1978) postulates at least two eruptions, separated by 375 years, because of the different radiocarbon dates.

There are pronounced variations in modal mineral amounts and some trace elements with minor textural variations from vent to toe of the flow. Modal amounts of small pyrrhotite nuggets vary by two orders of magnitude from 0.002 to 0.02 volume percent over the length of the flow. Olivine, feldspar and pyroxene differ by 10-15 volume percent and the Fe-Ti oxides by six volume percent between samples. In contrast, the major and minor element variations are small. For example TiO₂ contents throughout the flow range between 3.60 wt% and 3.72 wt%.

The rocks are almost wholly crystalline. Although few phenocrysts of olivine and plagioclase are as large as 1 mm, pyroxene and plagioclase megacrysts up to 10 mm occur sporadically throughout the flow and occur more commonly near the cone.

The results of Pearce element ratio analysis indicate that some of the chemical variations are consistent with sorting of olivine, plagioclase and pyroxene. Preliminary thermodynamic modeling shows that the magmas that formed the lava flows were saturated with the three phases, olivine, plagioclase and clinopyroxene at pressures near 0.5 GPa. (Nicholls and Stout, 1994).

Thermodynamic modeling predicts temperature-composition paths at set pressures and QFM values. Analyses of zoning in phenocrysts (> 500 μ) and microphenocrysts

(< 500 μ) show close agreement with predicted compositions along the crystallization path calculated at 0.35 GPa and one log unit below QFM for a sample from approximately 5 km down the flow from the upper end at the cone.

Mount Llangorse

Mount Llangorse is approximately 60 km ESE of Atlin, B.C. Aitken (1959) mapped three areas of olivine basalt south of the summit on Mount Llangorse.

The lava flow described here is a valley fill on Coast Range plutons. On the east side, the flow is in contact with granitic sand derived from the underlying pluton. The flow is fine grained and vesicular at the contact. One small ultramafic xenolith was found in the flow at this contact. Above the contact the flow is columnar jointed and coarse grained.

On the west edge of the basaltic body, the base of the flow is dense and chilled. A vesicular zone, approximately 1 m thick, occurs above approximately 1 m of chilled lava flow. The flow is resting on granitic sand with large granite cobbles. The elongated cobbles are about 0.1-0.5 m long, are well rounded and supported by the enclosing, bedded sand. The chilled zone contains ultramafic xenoliths up to 6 cm across. Two fresh xenoliths were found resting on the sandstone and are probably from the flow. More weathered xenoliths occur within the upper metre of the bedded sand.

A xenolith included in the basalt near the base of the flow on the west edge of the rock body differs from a xenolith found on the east edge. Although both contain olivine, pyroxene, and spinel, the composition of the minerals are different. Olivine ranges from Fo_{89.5} to Fo_{89.9} in one xenolith and from Fo_{91.4} to Fo_{91.8} in the other. Both xenoliths have brown spinel but the spinel from the west edge of the body has higher Al₂O₃ (55 to 58%), FeO (12 to 18%), and MgO (18 to 20%) with pronounced zoning from core to rim. Spinel in the other xenolith has a large amount of Cr₂O₃ and almost no zoning in Al₂O₃ (31.4 to 32.5%), FeO (12.6 to 13%) and MgO (15.4 to 15.7%). Enstatite is present in both xenoliths but in the xenolith from the west edge of the body, the enstatite is less magnesian (34 vs 36%), more iron rich (6.5 vs 5%) and has more aluminum (4.5 vs 2.2%) than the xenolith from the east edge. In addition, the xenolith from the west edge has only orthopyroxene whereas the other xenolith contains one diopside crystal, 300 μ x 100 μ , as well as enstatite. The presence of two different xenoliths implies a difference in source rock composition and/or source depth.

Several large olivine crystals, approximately 1 mm in diameter, in the basalt have compositions similar to those of xenolith olivine, Fo_{89.3} to Fo_{89.9}. Other smaller crystals of olivine in the rock range from Fo₈₀-Fo₈₅ in phenocrysts larger than 500 μ , Fo₆₃-Fo₇₉ in microphenocrysts less than 500 μ across, and from Fo₅₆-Fo₇₄ in the groundmass. All pyroxene is high calcium clinopyroxene and has pronounced zoning. For example, TiO₂ ranges from 1.5% to greater than 5%. Feldspar is approximately An₅₀ and both magnetite and ilmenite occur in the groundmass. Upon completion of chemical analyses of the rock, thermodynamic modeling will be applied to obtain estimates of pressure, temperature and mineral compositions of first crystallization.

Ruby Mountain

Rock and mineral analyses of basanites from Ruby Mountain were reported by Nicholls, *et al.* (1982). Temperature and pressure estimates of equilibration of minerals from one of the lherzolite xenoliths, based on the thermodynamic values derived by Ghiorso and Sack (1995), are 6.5-7.0 GPa at 1000°-1040°C.

Summary

Preliminary work shows that a variety of mantle samples are present in the volcanic rocks extruded at these widely spaced sites. Differences in rock types, xenoliths, and xenocrysts/megacrysts occur both between and within sites. This supports the conclusion that the wide variety of Quaternary rock types imply that the source region for mantle derived rocks, the low velocity zone, beneath B.C. was chemically heterogeneous (Nicholls, *et al.*, 1982). Similarly, Frances and Ludden (1993) and Hasik and Frances (1993) interpreted trace element contents of the lava flows to conclude that there was an E-W difference across the Tintina Fault in the composition of the source rocks for Late Tertiary magmas that erupted in the Yukon.

The agreement between thermodynamically predicted mineral compositions at approximately 0.35 GPa and the measured mineral compositions in the Nisga'a lava flow provide an estimate of the depth of magma storage at this volcanic centre. Depths at which the lava flows from the 1968 eruption in Hawaii fractionated have been estimated with similar techniques (Nicholls and Stout, 1988). The petrologic interpretations were consistent with the seismically determined depth of the Kilauea magma chamber (Klein, *et al.*, 1987), providing confidence that the estimate for the British Columbia centre is accurate. Estimates of depths at which volcanic processes occur constrain interpretations

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of vertical variations in lithospheric structure and knowledge of the chemistry of the volcanic products constrain interpretations of lateral chemical variations in the low velocity zone. Combining petrologic interpretations with the results from geophysical mapping of the lithosphere-to-asthenosphere transition has the potential of providing more detailed information about the nature of the lithosphere beneath Northern British Columbia.

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Early Jurassic tectonism in north-central British Columbia
H. Gabrielse

Collision between Stikinia and the Cache Creek Terrane in north-central British Columbia was heralded by a significant change in tectonic regime in latest Triassic or earliest Jurassic time followed by marked instability of northern Stikinia during Early Jurassic time. The change in tectonic behavior is documented by 1) the regionally continuous belts of Upper Triassic volcanics as opposed to the localized occurrences of Lower Jurassic volcanics, 2) the common pervasive foliation in Late Triassic (ca. 215-225 Ma) plutons and the general lack of foliation in Early Jurassic (ca. 185-195 Ma) plutons, 3) uplift in earliest Jurassic time resulting in regional unconformity and 4) west-northwest elongation of Late Triassic plutons defining the Stikine Arch and northeasterly elongation of Early Jurassic plutons which parallels a set of faults bounding blocks of markedly contrasting Lower Jurassic stratigraphy. Subduction, probably southwest directed, must have occurred under northern Stikinia until Middle Jurassic time. Northerly directed subduction under Quesnellia may have ceased in Early Jurassic time.

The Whitehorse Hotspot: The Late Cretaceous Carmacks Group

Stephen T. Johnston*, Canada-Yukon Geoscience Office, Box 2703 (F-3),
Whitehorse, Yukon Y1A 2C6, Canada

P. Jane Wynne*, Pacific Geoscience Centre, 9860 West Saanich Road, P.O. Box
6000, Sidney, British Columbia V8L 4B2, Canada

Don Francis*, Earth and Planetary Sciences, McGill University, Montreal, Quebec
H3A 2A7, Canada

Craig J.R. Hart, Canada-Yukon Geoscience Office, Box 2703 (F-3), Whitehorse,
Yukon, Y1A 2C6, Canada

Randolph J. Enkin, Pacific Geoscience Centre, 9860 West Saanich Road, P.O.
Box 6000, Sidney, British Columbia V8L 4B2, Canada

David C. Engebretson, Department of Geology, Western Washington University,
Bellingham, Washington 98225, U.S.A.

The Late Cretaceous Carmacks Group, a thick subaerial volcanic succession that once covered much of southwest Yukon, was deposited on an uplifted terrain and is divisible into a lower fragmental unit and an upper flood basalt unit. Coeval hydrothermal activity resulted in remagnetization of pre-Cretaceous formations, widespread alteration and gold mineralization. The lavas are shoshonites, enriched in LIL and LRE elements, but depleted in HFS elements. Ankaramitic absarokite flows of the upper Carmacks range up to 15 wt.% MgO, requiring a high liquidus temperature (1400 degrees C at 1 atm, dry). High K₂O contents (>3%) indicate that this potassic character was established in the mantle. Though previously interpreted as subduction-related, the Carmacks Group was erupted during a Cordilleran-wide magmatic lull, and lacks coeval calc-alkaline batholiths. The lavas are petrologically similar to plume-related Miocene to Pliocene potassic lavas of the western U.S.

New paleomagnetic collections combined with previous work place the Carmacks Group 17.1 +/- 6.5 degrees south (1900 +/- 700 km) of its present position during deposition, near the paleolocation of the Yellowstone hotspot. The spatial coincidence, tectonic setting and lithological similarity of the Carmacks Group rocks with the Yellowstone hotspot suggests that the Carmacks Group is the 70 Ma effusion of the hotspot. Subsequent northward transfer of the Carmacks Group was facilitated by coupling with the Kula Plate. Correlation of the Carmacks Group with the Yellowstone hotspot fixes the paleolatitude and the paleolongitude of the northern Intermontane Belt at 70 Ma.

PALEOMAGNETIC DETERMINATION OF THE GEOTECTONIC DISPLACEMENT OF THE NORTHERN INTERMONTANE, YUKON: PROGRESS REPORT AND PRELIMINARY RESULTS FROM THE WHITEHORSE PLUTON

D.T.A. Symons¹, M.J. Harris², W.H. Blackburn¹, C.J.R. Hart³

A:PROGRESS REPORT

During the summer of 1995, one partial and three full collections were made for paleomagnetic study. They were: 1) 26 sites from the 103 Ma Cassiar batholith outside the eastern boundary of the Intermontane superterrane in the pericratonic Cassiar terrane; 2) 34 sites from the 172 Ma Fourth of July plutonic complex and associated lamprophyre dykes of the Cache Creek terrane in the Intermontane; 3) 32 sites from near-vertical Eocene (?) mafic dykes and host rocks of the easternmost Coast Plutonic Complex next to the Intermontane; and, 4) 7 sites from the circular 185 Ma Teslin Crossing granitic pluton in the Stikinia terrane of the Intermontane (Figure 1). A total of ~1080 specimens have been prepared for paleomagnetic measurement. Progress was made also on the 109 Ma Whitehorse pluton and slightly younger Mount McIntyre pluton collections. Preliminary analysis has been completed on the remanence data. Thin sections were prepared and described from specimens from each of the 48 sites, and microprobe measurements on feldspars and hornblendes have been made on polished thin-sections from many of these sites for geobarometric determinations to test for tilt in the plutons.

¹Department of Earth Sciences, University of Windsor, Windsor, ON, N9B 3P4

²Department of Earth Sciences, University of Western Ontario, London, ON, N6A 5B7

³Canada/Yukon Geoscience Office, Department of Economic Development, Box 2703,
Whitehorse, YT, Y1A 2C6

B:PRELIMINARY RESULTS FOR THE WHITEHORSE PLUTON

Introduction

The Whitehorse pluton outcrops just west of the city of Whitehorse in the Yukon (Figure 1). The pluton is intruded into rocks of the Whitehorse trough in the Stikine terrane. This terrane is one of four large terranes that form the bulk of the Intermontane superterrane [Gabrielse *et al.*, 1991]. The superterrane is allochthonous, being bounded on its northeastern side by pericratonic terranes and the North American craton, and on its southwestern side by the Coast Plutonic Complex and other outboard allochthonous terranes. Marquis and Globberman [1988] estimated that the superterrane was translated northward by 1500 ± 950 km and rotated clockwise by $10^\circ \pm 21^\circ$ between ~ 70 and ~ 50 Ma from the paleomagnetic analysis of the Carmacks volcanics, the only such study done to date in the northern Intermontane. This study aims to check their result which suggested both greater and more rapid northward translation for the Intermontane than comparable data from two studies in the Intermontane of southern British Columbia.

Geology

The Whitehorse pluton outcrops over an area of ~ 160 km² (Figure 2). It intrudes strata of the Hancock and Mandanna members of the Late Triassic Lewes River Group along the north, west and south margins. The Hancock member is an ~ 600 m thick unit comprising dominantly limestones and minor siltstones. The Mandanna member is composed of crystal-rich, volcanogenic lithic greywackes and shales with minor red bioturbated siltstones and pebble conglomerates [Hart and Radloff, 1990]. The Whitehorse pluton also intrudes the conglomerate unit of the Early Jurassic Laberge Group along the southern margin. It is a polymictic cobble conglomerate that is intercalated with thin arenite and greywacke layers [Hart and Pelletier, 1989]. Drilling and aeromagnetic survey results suggest that the pluton has near-vertical contacts

on its eastern and western sides predicated near-vertical emplacement without subsequent tilt. The pluton is calc-alkaline, ranging from diorite on the periphery to granodiorite at its core [Hart, 1995]. It has given a 116 ± 2 Ma Rb-Sr isochron [Morrison *et al.*, 1979], minimum ages ranging between 108 ± 5 Ma and 116 ± 4 Ma from K-Ar dates on hornblende and biotite pairs [Hart and Pelletier, 1989], and a minimum age of 109.0 ± 0.6 Ma by U-Pb zircon on a cross-cutting granite [Hart and Radloff, 1990]. Ore deposits in bounding skarns have yielded ~\$500 million worth of Cu-Au-Ag production. A few mafic dykes of uncertain age cut the pluton at its southern end. The pluton is nonconformably overlain by thin remnants of the undeformed Miocene-Pliocene Miles Canyon basalts and by unconsolidated Quaternary alluvium.

Sampling

A total of 290 specimens were obtained for paleomagnetic study from cores drilled at 27 sites that were distributed across the pluton (Figure 2). The sites represent the range of rock types and several were collected to provide paleomagnetic contact tests for remanence stability between the pluton and its host rocks, between a late granodiorite dyke from the pluton and the host rocks, and between a late mafic dyke and the pluton.

Paleomagnetic Measurements

The natural remanent magnetization (NRM) of the specimens were measured using an automated CTF DRM-420 cryogenic magnetometer inside a three-layer steel magnetically-shielded room. Alternating-field (AF) demagnetization was done on most specimens in five to 10 steps up to 130 mT using a Sapphire Instruments SI-4 AF demagnetizer. Nearly all of these specimens show the initial removal up to about 20 mT of a viscous remanence component that is often in the direction of the present Earth's magnetic field, and thereafter isolate a characteristic remanent magnetization (ChRM) that is directed steeply-downwards towards the north (Figure

3a). In addition at least two specimens from each site were thermally demagnetized in 11 steps up to 600°C using a Magnetic Measurements MMTD demagnetizer. Most of these specimens similarly show the initial removal of a viscous remanence up to about 200°C and thereafter the isolation of the same ChRM (Figure 3b). Their thermal unblocking temperature spectra indicate that magnetite is the dominant ChRM carrier (Figure 3c) with pyrrhotite as a minor carrier in some specimens (Figure 3d). For some specimens, first AF and then thermal step demagnetization were used to isolate the ChRM. The ChRM directions were obtained using the Kirschvink [1980] method, requiring that the maximum angular deviation be $<15^\circ$ but with most $<10^\circ$. Also saturation isothermal remanent magnetization (SIRM) analyses were done on 14 representative specimens. They show that the ChRM is carried by both pseudosingle and multidomain magnetite (Figure 4). Overall, only 14 specimens failed to give accepted ChRM directions. Also all sites give site mean ChRM directions with radii for their cones of 95% confidence of $<10^\circ$ [Fisher, 1953] except for three sites collected for contact tests which have two component directions. The contact tests indicate that the Whitehorse pluton carries a primary ChRM. Averaging the 21 site mean directions from the pluton gives a preliminary unit mean of declination 15° , inclination 76.5° , and radius of 95% confidence of 3° (Figure 5).

Geobarometric Measurements

Ten polished sections were prepared from 10 sites across the pluton which appeared most promising from thin section examination. Analyses of hornblende and plagioclase crystal contacts were performed on a JEOL JXA-8600 Superprobe. Plagioclase was analyzed for SiO_2 , Al_2O_3 , Fe_2O_3 , CaO , Na_2O , and K_2O , and hornblende for SiO_2 , Al_2O_3 , TiO_2 , Cr_2O_3 , FeO , MnO , MgO , CaO , Na_2O , K_2O , F and Cl . For each section, two crystals were analyzed with at least three analyses per crystal. Using the geobarometer of Hollister *et al.* [1987] which is accurate to within

± 1 kbar, all analyses gave values < 3.1 kbar. The average values for the north and south halves of the pluton are statistically the same indicating no tilt (Figure 6). The values indicate that the present exposure surface of the pluton records only about 4.4 km of uplift.

Geotectonics

The preliminary unit mean ChRM direction for the Whitehorse pluton corresponds to a pole position at 280°E , 82°N ($\alpha_{95}=5.5^{\circ}$). This pole is compared to the Early Cretaceous reference pole for the North American craton of Van der Voo [1993] that is located at 194°E , 69°N ($\alpha_{95}=5.0^{\circ}$) (Figure 7). Using these poles and their 95% confidence limits provides an initial estimate for the increase of paleolatitude of $9.5^{\circ} \pm 5^{\circ}$. This corresponds to a poleward or northward translation of 1050 ± 550 km. There also is a clockwise terrane rotation of $60^{\circ} \pm 15^{\circ}$.

The 1050 ± 550 km estimate is notably less than the 1500 ± 950 km estimate obtained by Marquis and Globerman [1988] from the 70 Ma Carmacks volcanics. Perhaps more significantly and assuming that relative northward translation with accretion ended at 50 Ma in Eocene time [Symons and Welling, 1989; Bardoux and Irving, 1989; Vandall and Palmer, 1990], the Carmacks volcanics estimate corresponds to a high but tenable minimum velocity for the northern Intermontane of 7.5 cm/a. In contrast the Whitehorse pluton result provides a minimum rate of 1.6 cm/a that is a typical "average" rate for plate motion. In addition, when compared to data from the southern Intermontane, the Whitehorse displacement of 1050 ± 550 km is: 1) virtually identical to the very reliable 1100 ± 600 km estimate obtained by Irving *et al.* [1995] for the nearly-coeval middle Cretaceous Spences Bridge volcanics; 2) statistically the same and close to the 1300 ± 800 km estimate of Monger and Irving [1980] for the coeval middle Cretaceous Axelgold mafic pluton; and, 3) allowing for continued northward motion at about the same rate, closely matches the reliable 1500 ± 200 km estimate obtained by Symons [1983] for the end-Jurassic

Francois Lake plutons. From these comparisons, it appears that the estimate for the Carmacks volcanics is too large both in terms of absolute poleward displacement and rate of displacement.

The significance of the $60^{\circ} \pm 15^{\circ}$ clockwise rotation is less obvious. Because each of the paleomagnetic collections analyzed to date from the Intermontane has given a different value for rotation, we prefer to wait for additional data from other collections in the northern Intermontane before discussion.

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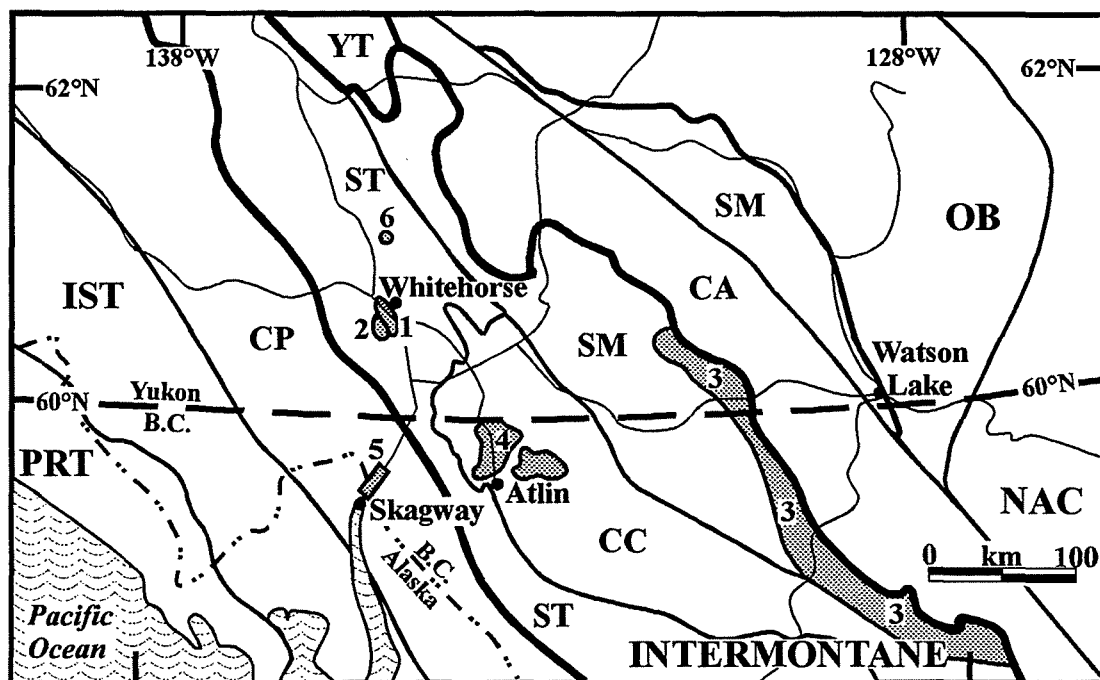


Figure 1 - Tectonic subdivisions of the northern Cordillera. Abbreviations: North American craton (NAC); Omineca fold belt (OB); Cassiar terrane (CA), displaced craton; Yukon-Tanana terrane (YT); Intermontane superterrane includes Slide Mountain (SM), Cache Creek (CC) and Stikinia (ST) terranes; Coast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

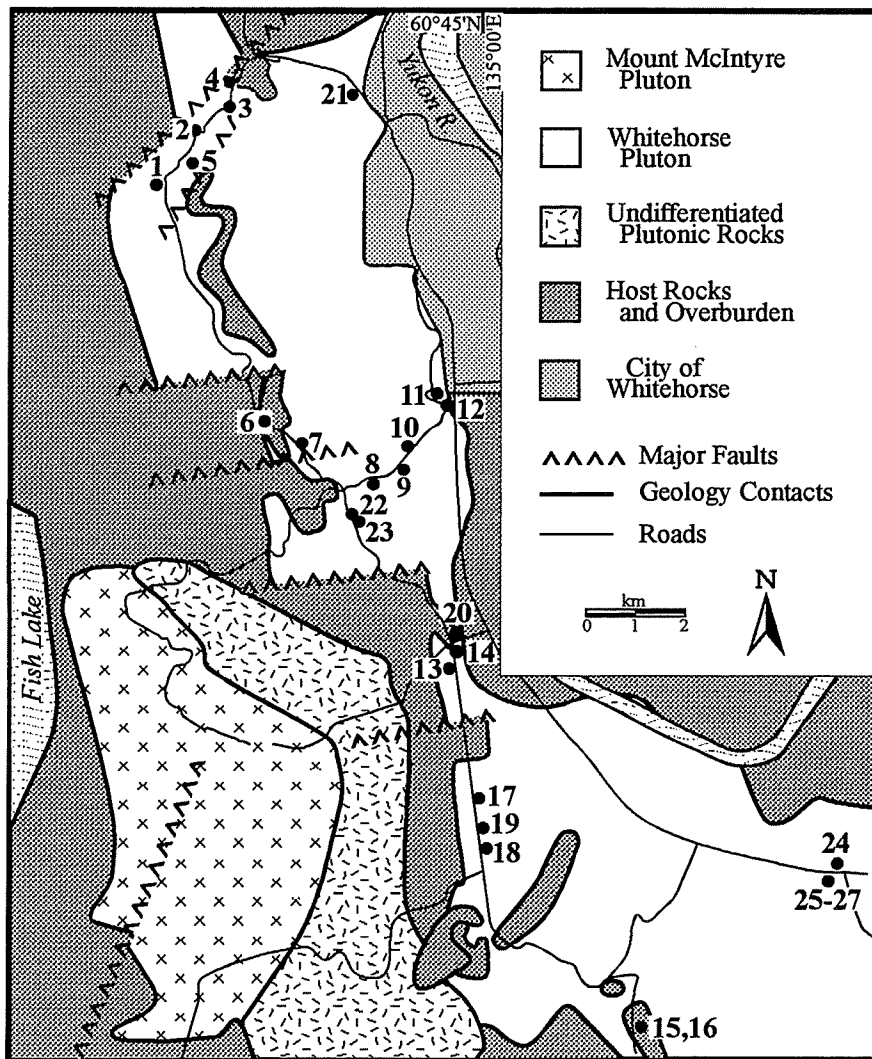


Figure 2 - Geology of the Whitehorse pluton after Hart and Pelletier [1989] with sampling sites.

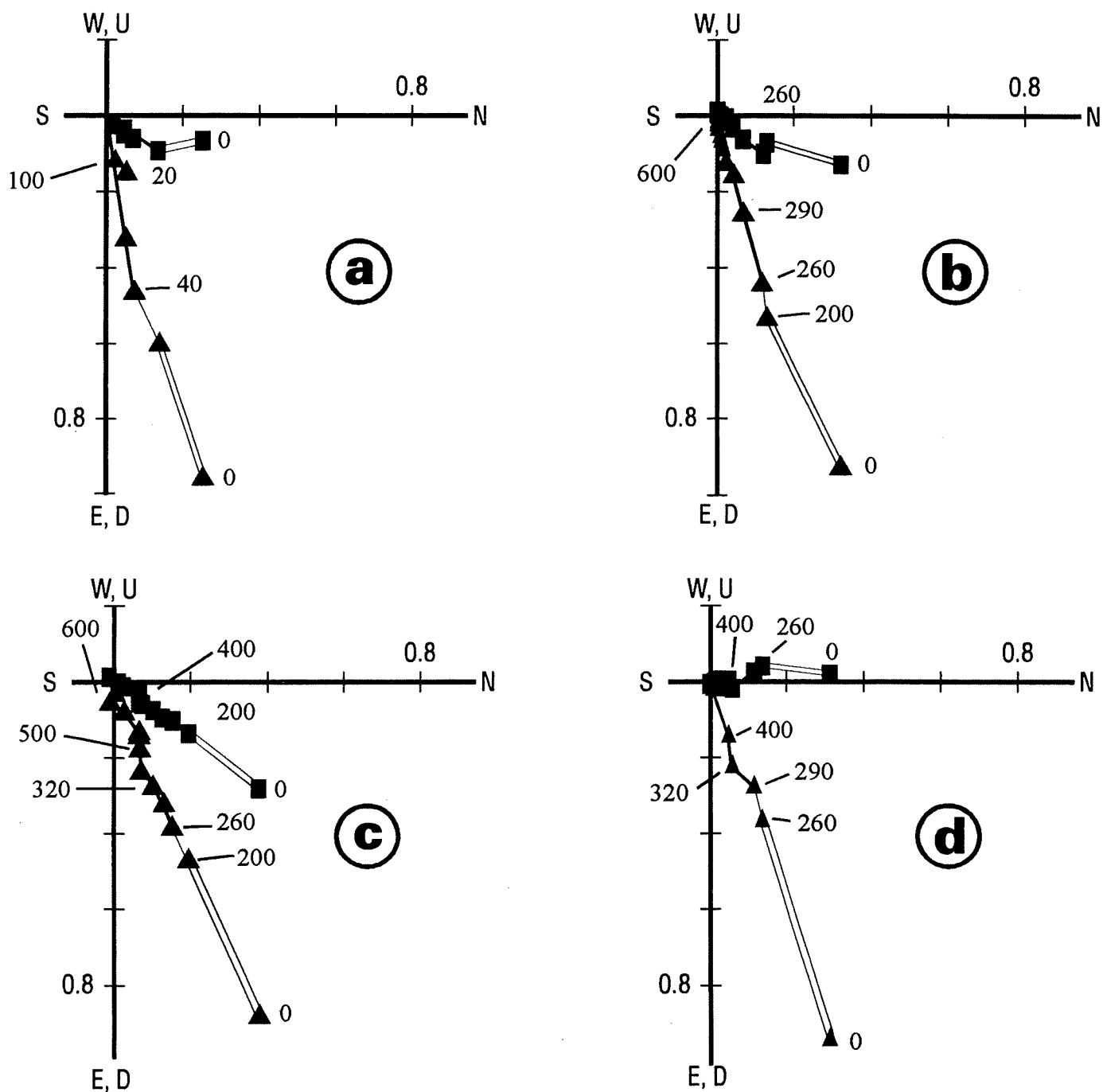


Figure 3 - Orthogonal step demagnetization plots: (a) AF demagnetized; (b-d) thermally demagnetized. Squares are projections in the N-E-S-W plane. Triangles are projections in the Up-N-Down-S plane. Double lines indicate the VRM component; thick lines denote ChRM component.

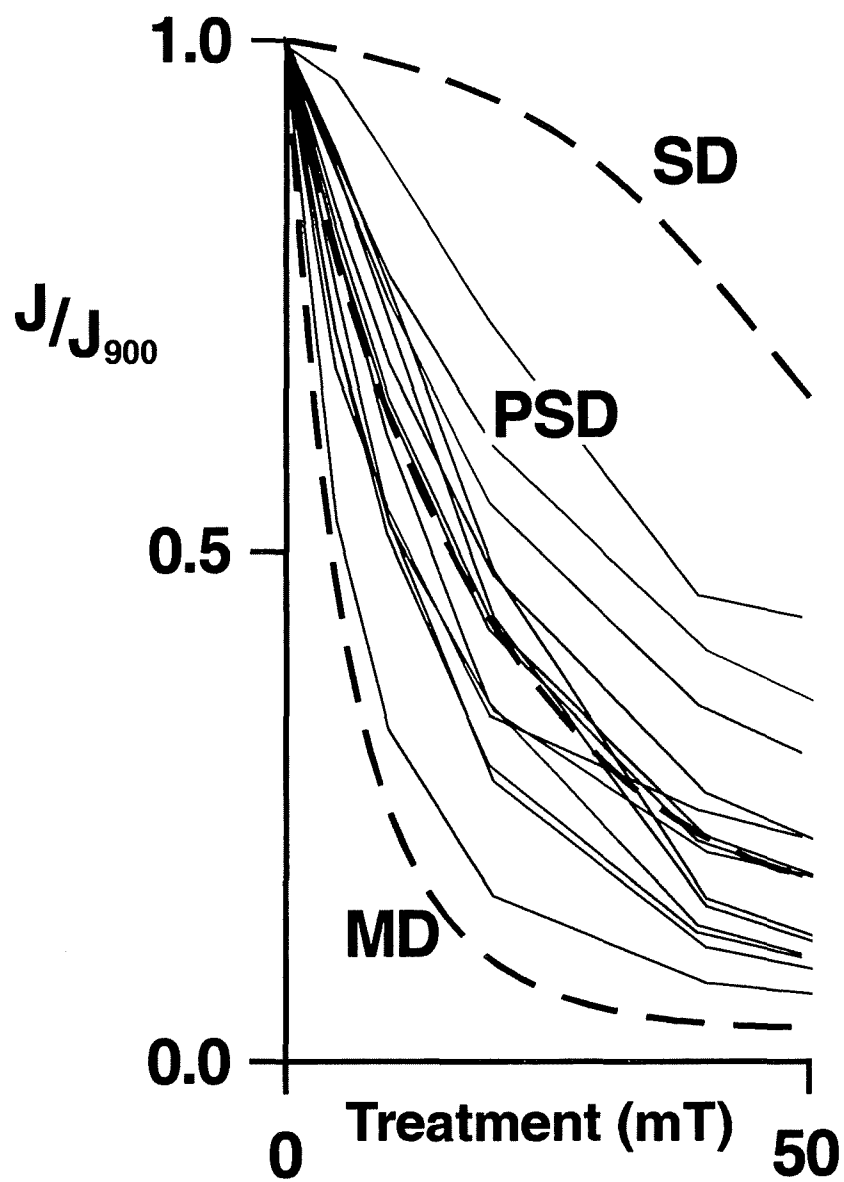


Figure 4 - Standard decay curves from saturation isothermal remanence magnetization tests. Treatment field in milliTesla (mT).

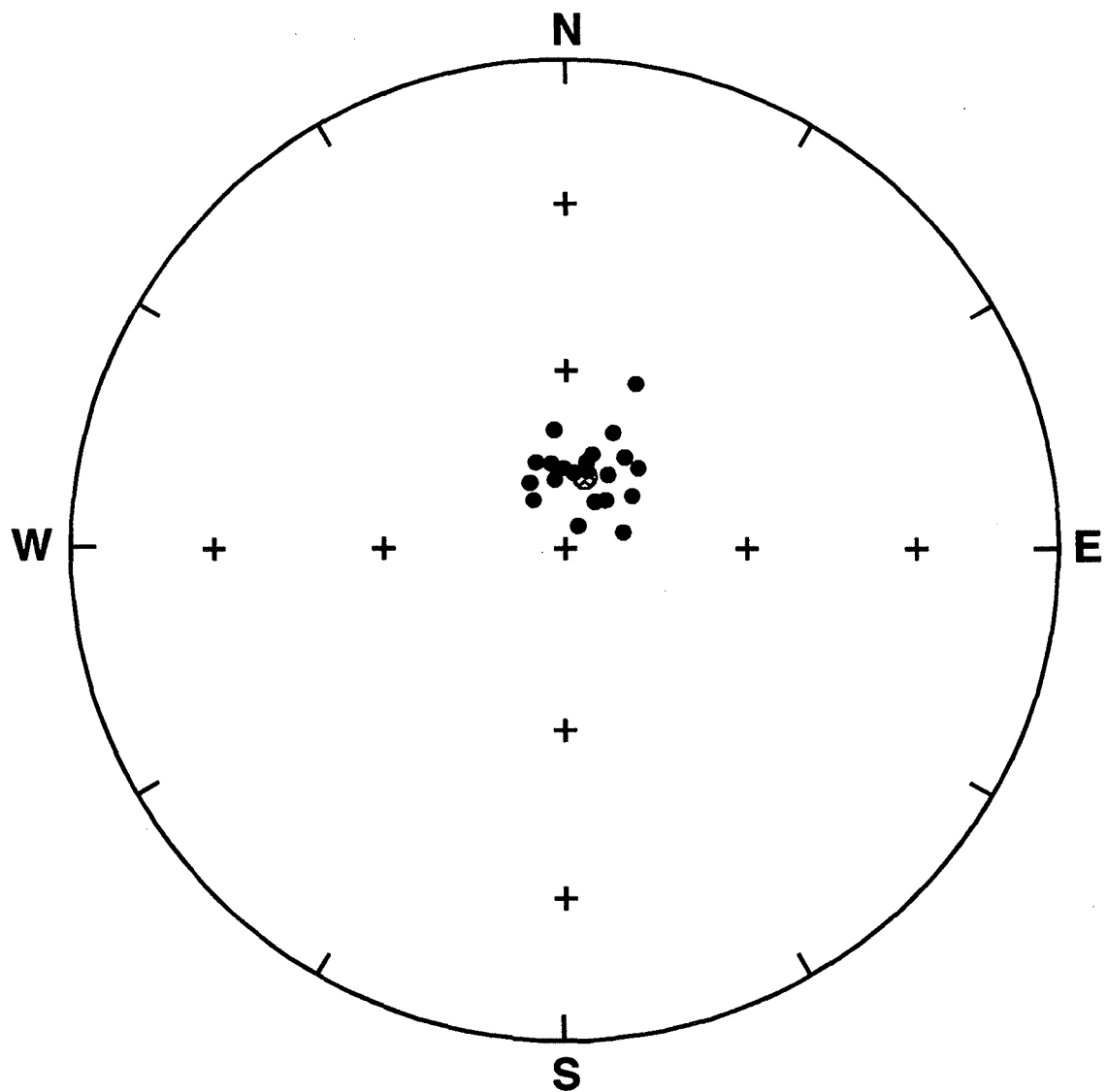


Figure 5 - Stereonet plot of the 21 sites of the Whitehorse pluton, and the mean (cross) and cone of 95% confidence after Fisher [1953].

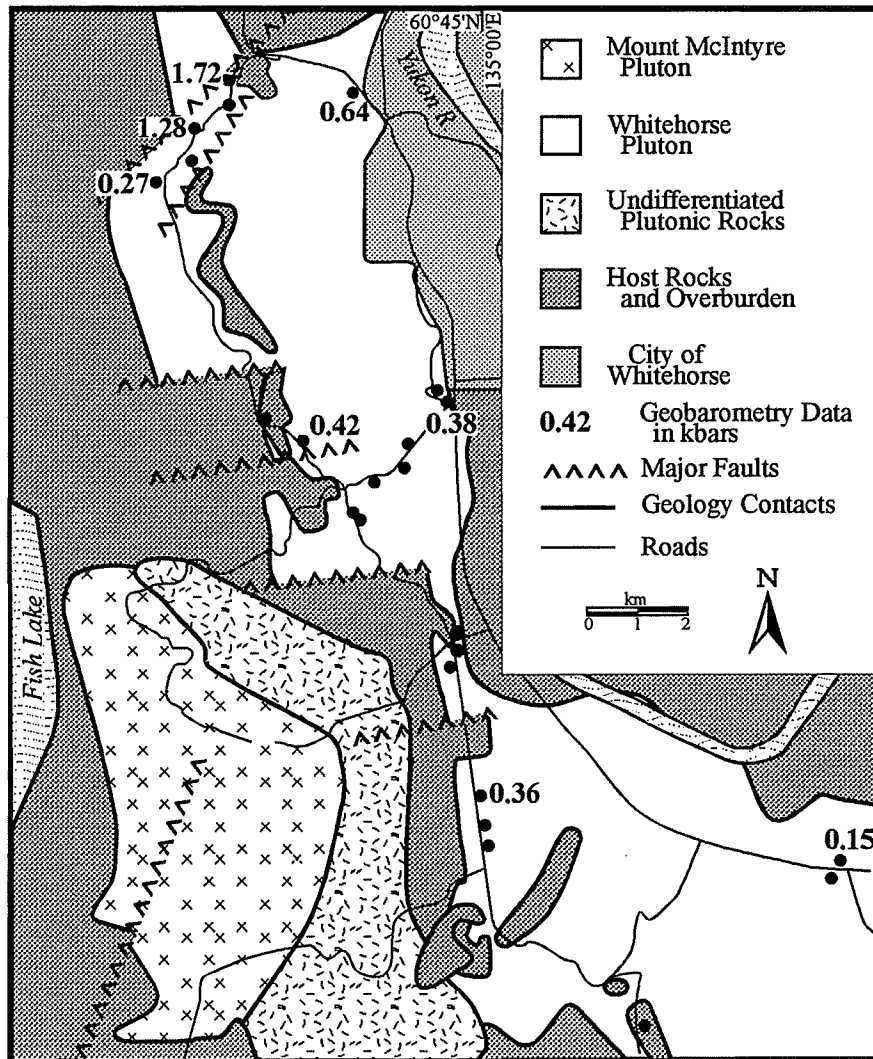


Figure 6 - Preliminary site averages of geobarometry data using the geobarometer of Hollister *et al.* [1987].

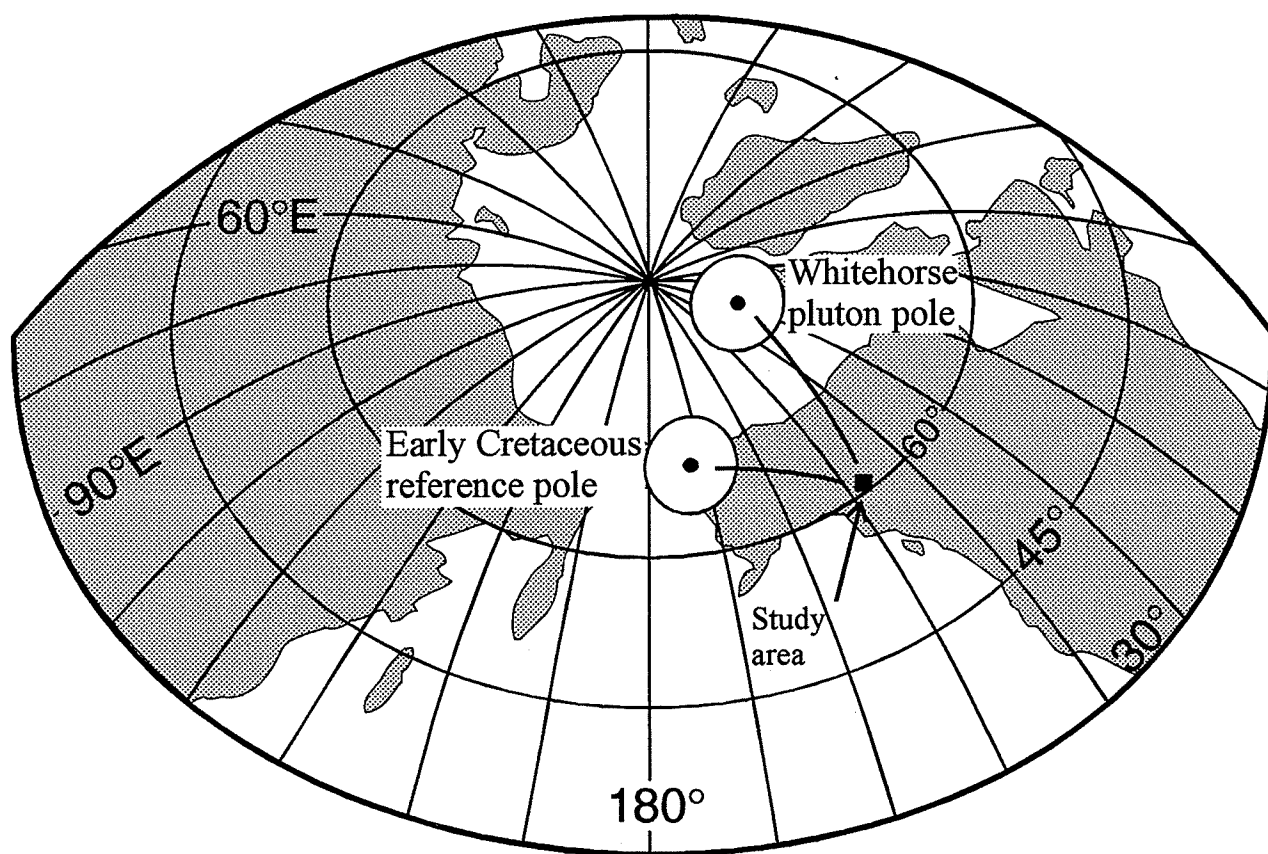


Figure 7 - Locations of the Whitehorse pluton preliminary unit mean pole and the Early Cretaceous reference pole from Van der Voo [1993].

THE KLUANE METAMORPHIC ASSEMBLAGE, SW YUKON - AN ACCRETIONARY WEDGE OF BACKARC BASIN AFFINITY

Mezger, Jochen E., Department of Earth and Atmospheric Sciences, University of Alberta, Edmonton, Alberta, T6G 2E3

The Kluane Metamorphic Assemblage (KMA) forms a 150 km NW-SE striking belt of greenschist to amphibolite grade graphitic mica-quartz schist with interlayered ultramafic lenses in the northern Cordillera. The protolith and metamorphic-tectonic history of this assemblage, which underlies an area of 3000 km² in the southwestern Yukon, are largely unknown. Detailed fieldwork and thermobarometric, petrologic, structural and neodymium isotope studies now provide the framework for a preliminary tectonic model.

The major structural element of the KMA is a NE dipping schistosity with a shallow plunging 100°, trending mineral stretching lineation. A sinistral sense of shear determined from well developed c/s fabric in lower grade parts of the mica-quartz schist is in contrast with a dextral sense along the adjacent Denali Fault, and may represent earlier NE-SW directed transpression. The Ruby Range Batholith intruded the KMA in early Eocene time and resulted in local amphibolite grade metamorphic overprinting. The lack of synkinematic growth of staurolite and garnet, increasing temperatures and metamorphic isograds around the intrusion indicate a wide contact aureole. Geothermobarometry records peak metamorphism at more than 630°C and 6 kbar.

Studies of the Nd isotopic systems of six samples of the KMA and the Dezadeash Formation (DF) (a weakly metamorphosed Jurassic-Cretaceous flysch sediments exposed to the SW, previously interpreted as possible source rocks of the KMA) enable the distinction of different protolith provenances. Geochemical analyses show that the DF has an andesitic composition, while the KMA is closer to an upper continental crust composition. ϵ_{Nd} -values for the DF of +2.1 and +2.7 indicate a juvenile source with depleted mantle model ages (T_{DM}) of 815 Ma and 950 Ma, while KMA samples with ϵ_{Nd} of -5 to -3 (T_{DM} : 1166 Ma to 1336 Ma) reflect influence of continental sources. These results contrast with strongly negative ϵ_{Nd} -values and early Proterozoic model ages for the pericratonic Yukon-Tanana-Terrane and suggest that the KMA did not derive its bulk detritus from an Archean continent.

A possible model of the evolution of the KMA involves Jurassic-Cretaceous (?) deposition in the distal part of a backarc basin, the formation of an accretionary wedge which includes pelitic sediments and offscraped ocean floor during eastward subduction underneath Nisling Terrane, and metamorphic overprinting during Eocene emplacement of the Ruby Range Batholith.

What might Bolivia tell us about the Northern Cordillera, 80-45 Ma?

E. Irving, Geological Survey of Canada, Pacific Geoscience Centre, Sidney, B.C.,
V8L 4B2.

Apparently, the Bolivian Plateau is held up by stress concentration at the Arica coastline deflexion. A fold-and-thrust belt develops to the east. Incipient coastal trench slivers occur in Chile, activated by oblique convergence of the Nasca Plate, but northward motions (on the Atacama Fault) is small, being blocked by the coastline deflexion. Paleomagnetic data from the Cordillera show that Coast Domain (= approximately but not exactly the Insular and Coast Belts in earlier more equidimensional form) moved northwards (beginning about 80 Ma) from latitudes of Baja California to amalgamate (70 to 65 Ma) with the Interior Domain (= approximately the Intermontane Belt also in earlier more equidimensional form) in latitude of Oregon, being driven by the Kula Plate. Movement further north was temporarily blocked by the 50°N coastal deflexion, the analogue of the Arica deflexion. Stress became concentrated here, producing the Omineca coastal welt, deformation in the Eastern Cost Belt, and the Rocky Mountain Fold and Thrust Belt. Blockage was only temporary as continued rapid oblique subduction of the Kula Plate detached the combined Domains along the Pinchi, Northern Rocky Mountain Trench and Tintina Faults. The domains then were dismembered and stretched in an orogen parallel sense as demonstrated paleomagnetically. Most stretching appears to have been complete by about 45 Ma, but continues through the Neogene to Present in the west, as a result of predominantly transform interactions with the Pacific Plate.

T. J. Lewis, W. H. Bentkowski
GSC: Pacific (Pacific Geoscience Centre),
and
M. Burgess
Terrain Sciences,
Geological Survey of Canada

Temperature controls all the properties of materials: rigidity, phase stability, density, electrical resistivity, seismic velocity, etc. Consequently, it produces many of the geophysical anomalies observed from the surface, and it controls what processes and phases can be present at depth. Geothermal data (surficial heat flow and crustal heat generation) are required to calculate lithospheric temperatures.

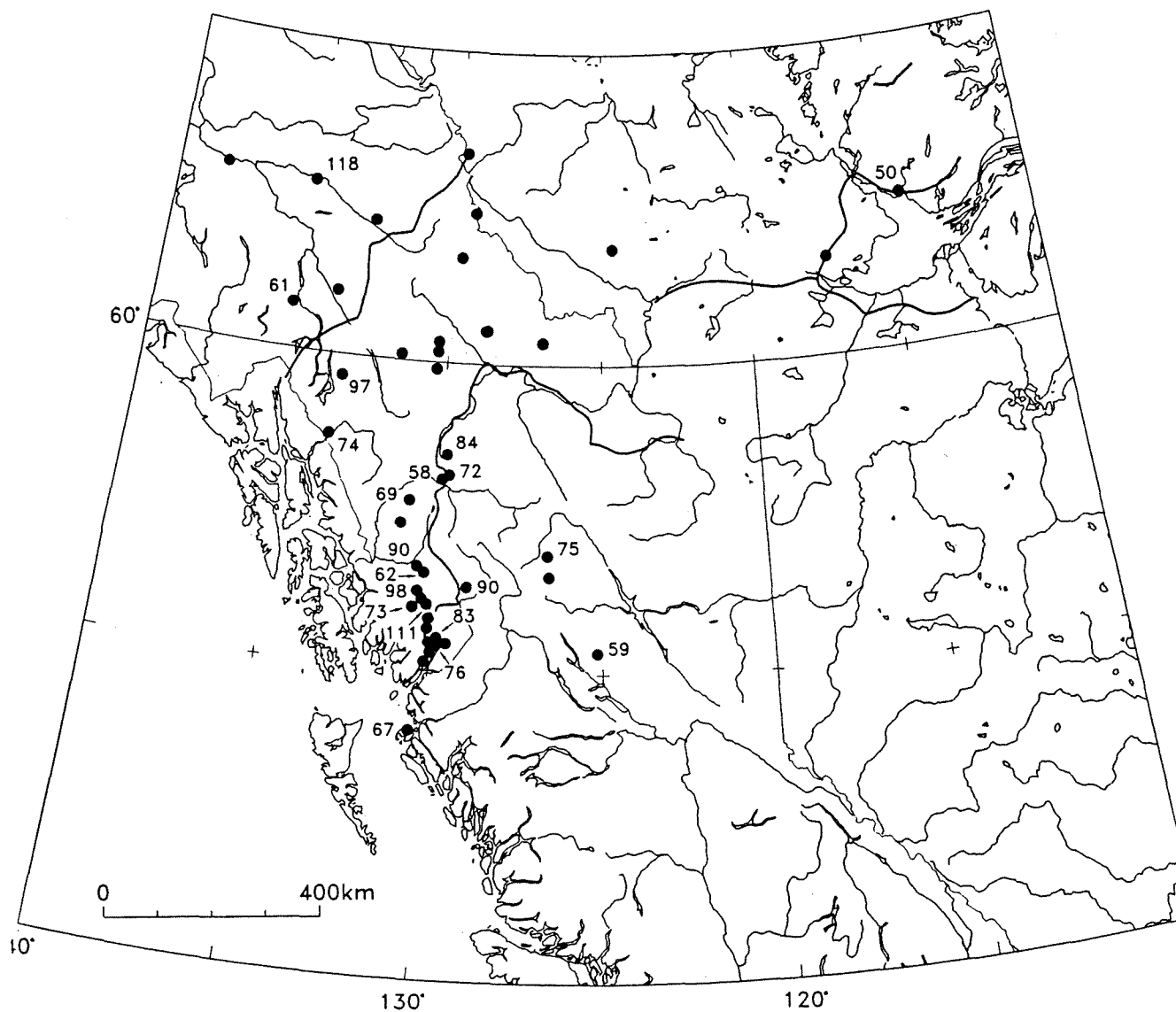
Heat flow measurements are generally made in vertical or steeply dipping boreholes drilled for mineral exploration. We log the temperature with light, portable equipment sometime after drilling. The thermal conductivity must also be measured on samples of core or drill cuttings representing the country rock. Dots on the map (figure 1) indicate where we have obtained heat flow data in relation to the proposed SNORCLE transects shown as thick lines. The 21 published values are given in mW/m². Dots also indicate where marine type measurements adopted to fjords were made along and near the Portland Canal where the ACCRETE transect is located.

We determine the amount of heat being generated in the crust by measuring in our lab the trace amounts of naturally occurring, radioactive isotopes (uranium series, thorium series, potassium) on samples representing the average crust- usually the most recent plutonic rocks exposed at the surface. (Geologists studying and mapping such bodies can best supply typical samples to us for such measurements, and we share such results with the contributors.) Initial results from some plutonic bodies on either side of the northern Rocky Mountain Trench-Tintina Fault in the southern Yukon indicate a higher heat generation on the northeast side. Based on this result, we might expect higher heat flows on this side and therefore relatively higher temperatures at depth, 100 - 200 °C warmer at 10 km depth.

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Figure 1. Symbols indicate sites at which thermal data have been obtained near the SNORCLE transects, shown as thicker lines. Published values are given in mW/m².



Seismicity along the SNORCLE Corridors

John F. Cassidy, Robert B. Horner, Garry C. Rogers, and R.D. Hyndman
Geological Survey of Canada, P.O. Box 6000, Sidney, B.C. V8L 4B2

The SNORCLE transect corridors are located near some of the most seismically active regions in Canada. This paper summarizes the seismicity and seismotectonics of northwestern Canada - a corner of North America that is a region of significant variation in both seismicity and tectonics. On the plate margin, motion changes from strike-slip off the west coast of British Columbia and the Alaska Panhandle, to simple subduction along the Aleutian Trench. Moving inland, the tectonic setting changes from an active plate boundary regime to a stable cratonic environment.

The most seismically active region is the coastal and offshore area (Fig. 1), where convergence between the Pacific and North American plates (and the intervening Yukatat Block) is resulting in a major orogeny of crustal shortening and uplift. Eight earthquakes of magnitude greater than 7 have occurred in this coastal and offshore region since 1899. The western end of SNORCLE corridor 3 lies in the St. Elias Mountains - near this active region, where uplift rates of 20-30 mm/a are observed.

The most significant inland seismicity in this region occurs along segments of the Denali fault zone system ('D.F.' in Fig. 1), where the seismicity rate is an order of magnitude lower than along the coast. The largest earthquake known to have occurred along this fault system is a $M=6.5$ in 1944. Earthquake focal mechanisms in this area show nodal planes that are not consistent with motion along the fault, but rather suggest reactivation of optimally aligned fault strands by the NE-SW regional stress field. There is no evidence for Holocene displacements along the Denali fault system in the Yukon, and the rate of seismicity suggests slip rates of about 1 mm/a along this fault zone.

Both SNORCLE corridors 2 and 3 sample the relatively aseismic region between the Denali and Tintina fault systems. There appears to be an alignment of epicentres along the Tintina fault ('T.F.' in Fig. 1); however, most of the activity is farther north, close to the Alaska border.

Further inland, along the boundary between the Cordillera and stable Shield, there is a concentration of seismicity in the MacKenzie Mountains fold and thrust belt, and in the Richardson Mountains (just north of the SNORCLE corridors). The northern end of SNORCLE corridor 3 and the western end of corridor 1 are near the epicentres of the two 1985 Nahanni $M=6.6$ and $M=6.9$ earthquakes. These are the two largest earthquakes ever recorded in the fold and thrust belt of the Canadian Cordillera. These earthquakes show pure thrust motions and are interpreted to have occurred along a blind Laramide thrust fault under the Mackenzie plain. Two other $M=6.5$ earthquakes in the northern Mackenzie mountains also show pure thrust mechanisms and pressure axes consistent with the regional stress regime. In the Richardson Mountains, where steeply dipping, North-striking faults dominate, earthquake focal mechanisms for two $M=6-6.5$ earthquakes show that strike-slip motion

dominates, with NE-SW orientated pressure axes again consistent with the regional stress field.

The variation in the focal mechanisms throughout the Mackenzie and Richardson Mountains, but the consistency of the earthquake pressure axes, suggests that the regional stress regime is reactivating optimally aligned faults (both thrust and strike slip) in the northern Canadian Cordillera. One interpretation is that the seismic activity in these regions is the result of crustal stresses associated with the plate interactions at the northwestern corner of North America.

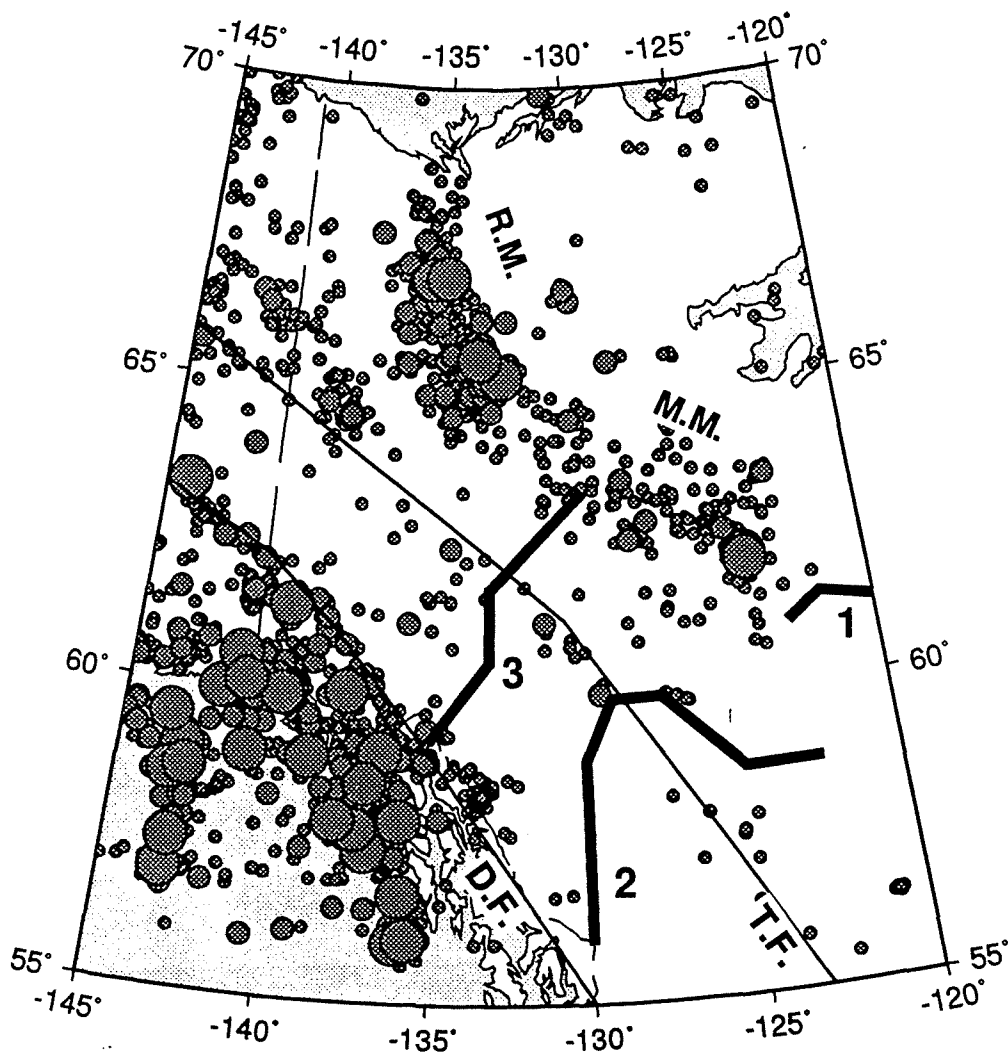


Figure 1. Seismicity of northwestern Canada and adjacent parts of Alaska to the end of 1991. The smallest dots represent earthquakes of magnitude 3-4.5; the mid-sized dots represents M=4.5-6; and the largest dots represent M>6.0. The thick lines denote the SNORCLE corridors. Thin lines labelled 'T.F.' and 'D.F.' represent the Tintina and Denali fault systems, respectively. 'M.M.' and 'R.M.' denote the Mackenzie Mountains and Richardson Mountains, respectively.

Implications of Probable Late Proterozoic Dextral Strike-Slip Movement on the Snake River Fault

Grant Abbott
Canada/Yukon Geoscience Office
Box 2703
Whitehorse, Yukon Y1A 2C6
Ph. (403) 667-8508
FAX. (403) 667-7074
E-mail gabbott@yknet.yk.ca

The interpretation of the Snake River Fault and associated Richardson Fault Array as a Late Proterozoic dextral strike-slip fault system is not new. The concept was implied by Eisbacher (1981), proposed by Bell (1982), and more clearly articulated by Aitken and McMechan (1991). Their evidence was largely based upon the dramatic discordance of pre-Windermere stratigraphic assemblages across the Snake River Fault which is exposed in the Wernecke Mountains, for a strike length of about 100 km in a window beneath Paleozoic cover. In particular, Mackenzie Mountains Supergroup (MMSG) on the east is different in significant detail from the Pinguicula Group on the west (Eisbacher, 1981; Aitken and McMechan, 1991). The two sequences are similar enough that Young and others (1979) correlated them. However, the lack of precise age controls left open the possibility that the two sequences were of different ages. Aitken and McMechan (1991) however, noted the significant differences and concluded that if the MMSG and the Pinguicula group were the same age, then they must be juxtaposed along a strike-slip fault. They presented stratigraphic arguments that the Pinguicula Group and older Wernecke Supergroup were transported possibly as far as 450 km northwest and rotated counterclockwise.

More recent evidence and other lines of reasoning support this proposal. These include the following.

1. Isotopic dating of detrital zircons from quartz arenite of the Katherine Group in the MMSG and from unnamed quartz arenite from a roughly similar stratigraphic position in the upper part of the Pinguicula Group from the eastern Ogilvie Mountains gives a maximum age of 1.0 Ga for both sequences (Rainbird et al, in prep). These ages greatly increase the probability that the two sequences are equivalent in age and add support to the strike-slip hypothesis.

2. The onset of Late Proterozoic rifting in the northern Cordillera is thought to have been initiated in the Mackenzie Mountains with deposition of the Coates Lake Group (Eisbacher, 1981; Jefferson and Parrish, 1989). A diabase intrusion dated isotopically at $777.7 \pm 2.5/-1.8$ Ma (Jefferson and Parrish, 1989) is thought to mark the onset of this event or predate it slightly. The Coates Lakes Group predates overlap of the Snake River Fault by orthoconglomerate and glacial diamictite of the Sayunei and Shezal Formations. The orientation of normal faults associated with deposition of the Coates Lake Group trend north to northeast, and are compatible with a north northwest-trending strike-slip fault as suggested by Eisbacher (1981). Younger rifting associated with the Sayunei Formation postdates overlap of the Snake River Fault, but it appears to follow the pattern of older structures.

3. West of the Snake River Fault in the western Ogilvie Mountains, the Mount Harper volcanic complex located immediately north of the Dawson Fault (dated at $751 \pm 26/-18$ Ma by Roots and Parrish, 1988) may be coeval with the Coates Lake Group. Paleomagnetic studies of the Mount Harper volcanic complex indicate clockwise rotation of at least 60° relative to reference poles in the Mackenzie Mountains and Canadian Shield (Park et al, 1992). Some or all of this rotation could have occurred prior to overlap of the Shezal and Sayunei formations across the Snake River Fault.

4. Aitken and McMechan (1991) terminated the Snake River Fault against the Leith Ridge Fault, the southeasternmost of a series of northeast trending faults exposed near Great Bear Lake that are pre-Late Proterozoic in age, involve basement and are reflected in Phanerozoic cover farther west by facies changes and the orientation of younger faults. The Snake River Fault cannot end against the Leith Ridge Fault because the several hundred kilometers of postulated displacement would require generation of oceanic crust for which there is no evidence. Alternatively, the fault could project beneath Phanerozoic cover farther

west than Aitken and McMechan proposed, possibly near the Coal River in southern Yukon. In this area, the fault could cross the Leith Ridge structures and continue south at least to the Gataga River area in northeastern British Columbia.

5. The Dawson fault, which is located west of the Snake River Fault, may be an offset equivalent to the Leith Ridge structures. It marks the northern boundary of Selwyn Basin, and the southern limit of exposure of the Pingucula Group and Wernecke Supergroup. It trends west, dips steeply, has Mesozoic offset, but clearly shows a prolonged Paleozoic and Proterozoic history which involved basement. A pre-Windermere age for the Dawson Fault is indicated by the 1380 Ma Hart River sills which intrude Early Proterozoic rocks in a linear belt parallel to it (Abbott, 1993). Removal of about 80° of clockwise rotation and 500 km of dextral offset on the Snake River fault would align the Dawson fault with the Leith Ridge Fault.

6. This model proposes that the "Windermere rift event" in the northern Canadian Cordillera may have been largely a strike-slip event with up to 500 km of dextral offset on the Snake River Fault. One of the more important implications of this model is that rift strata and structures exposed in the Mackenzie Mountains may be related to a relatively small dilatant zone along the Snake River Fault. The style of Late Proterozoic deformation and sedimentation on the buried west side of the fault could be totally different. Clockwise rotation on the western side may reflect a restraining bend in the Snake River Fault. If that bend were in the present location of the Richardson fault array in the Richardson and Wernecke Mountains, it would also explain the dilatant zone on the east side of the fault.

7. The "real rift event" in the Northern Cordillera was Early Cambrian in age and is reflected in the siliciclastic rocks of the Hyland Group. The Hyland Group, and equivalent strata in Alaska, with 450 km of offset on Tintina Fault removed, define a gently curving east-west trending belt about 1200 km long and 200 km wide. This configuration suggests an east-west trend for the Cambrian rift axis. The Dawson Fault sharply defines the northern limit of the Hyland Group, indicating that Windermere and basement structures controlled the orientation and development of this rift.

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Tectonic Evolution of the Eagle Plain Region and Basement-involved Deformation of the Southern Richardson Mountains, Yukon Territory

(Expanded Abstract)

Larry S. Lane,
Geological Survey of Canada
3303-33 St., NW, Calgary, Alberta, T2L 2A7
(lane@gsc.emr.ca)

Introduction

Eagle Plain is an intermontane basin with proven petroleum reserves, located in the northern Cordillera. Its regional stratigraphy, tectonic evolution and regional crustal structure are key links relating the tectonic evolution of the northern Cordillera to that of Arctic Alaska and the Beaufort-Mackenzie region. Through the Frontier Geoscience Program (1985-1990) the Geological Survey has completed gravity and aeromagnetic coverage, and acquired crustal seismic refraction data covering Eagle Plain and adjacent areas. In addition, since 1988, the Survey has acquired and reprocessed some 1280 km of industry seismic reflection data, comprising two north-south, and three east-west transects tied to the regional refraction transect. Although interpretation and modelling of these data are ongoing, several conclusions of regional significance can be made.

Crustal Structure

The northern Cordillera, including Eagle Plain differs from the adjacent northern Interior Platform (Fig. 1) in its crustal structure (O'Leary et al. 1995). Although the depth to Moho varies little across the region, at depths of 36-39 km, Cordilleran basement is thinner (6-12 km), more variable in thickness, and has a higher seismic velocity (7.1-7.2 km/s) consistent with a mafic composition. In contrast, the basement beneath the Interior Platform has a thicker (ca. 20 km), more uniform character with a seismic velocity of 6.8-6.9 km/s. Also, the middle crust beneath northern Yukon is thicker, and has a uniform seismic velocity of 5.9-6.2 km/s, consistent with an interpretation of a thick Proterozoic continental margin prism; whereas under the interior platform the middle crust is thinner and has higher velocities of 6.6-6.8 km/s.

A Middle Proterozoic or older continental margin underlies the region, approximately following the eastern edge of the Richardson

Mountains. The change in character of the basement from "granitic" in the east to mafic in the west, and the westward thickening of the middle crust reflect this continental margin (e.g. Cook et al. 1991; O'Leary et al. 1995). That early mechanical boundary likely localized later rifting which produced the early Paleozoic Richardson Trough, similar to the manner in which the same feature localized Jura-Cretaceous extension at the southeastern Beaufort Sea continental margin (Cook et al. 1987; Stephenson et al. 1994).



Figure 1. Regional tectonic features of northern Yukon, showing the distribution of early Tertiary structures, basins (light shading), platforms (darker shading), and location of Figure 3 (modified from Lane 1996).

Although the refraction data indicate that northern Yukon is not underlain by normal "granitic" basement, an intense positive aeromagnetic anomaly extends westward from the Interior Platform, beneath the southern Richardson Mountains and across Eagle Plain, and continuing as far as Tintina Trench. Preliminary gradient modelling (Lane, unpub. data) indicates a source depth in the 8-12 km range. This anomaly is interpreted to reflect a magnetic unit within the upper part of the preserved proterozoic succession, probably mafic volcanic(?) rocks. It therefore indicates the continuity of the Proterozoic succession from the Interior Platform across Eagle Plain. The anomaly beneath Eagle Plain coincides with structure in the sub-Paleozoic succession, indicating a pre-Paleozoic deformation event. Evidence for this deformation event is most pronounced in eastern Eagle Plain. Elsewhere, the Paleozoic rocks lie paraconformably on the Proterozoic succession.

Tertiary Orogenesis

The latest major tectonic event to affect the Eagle Plain region was a regional compressional orogenesis which climaxed in the Early Tertiary time (Lane and Dietrich 1995; Lane 1996). The tectonic setting of that event reflects North America - Eurasia convergence at the same time as the north Atlantic spreading system propagated across the Arctic. Arctic Alaska was displaced eastward on the Kaltag and other faults to produce east-west shortening of eastern Alaska and northern Yukon against the North American craton (Fig. 2). The north-south strike of structures in the northern and southern Richardson Mountains, northern Ogilvie Mountains, and Eagle Plain reflect this regional tectonic setting of east-west convergence (Fig. 1). The Dave Lord Mountains strike northeastward and link the shortening accommodated by the northern Ogilvie mountains with shortening accommodated farther north and east in the northern Richardson Mountains. The trend of the Dave Lord range is interpreted to reflect pre-existing structural trends in the basement (Lane 1996).

The Dave Lord and Ogilvie mountains, and western Eagle Plain contain exposures of lower Paleozoic carbonate rocks which have been incorporated into thrust-core folds, which are clearly imaged in the industry seismic data. The deformation intensity decreases progressively

from west to east, so that the eastern half of Eagle Plain is essentially undeformed. Accordingly, the early Tertiary deformation is interpreted to have propagated from the west across Eagle Plain. Across central Eagle Plain, individual thrust faults verge east or west, have less than 2 km of displacement and are commonly blind. This contrasts with northeastern Eagle Plain, where both Dave Lord and Richardson ranges (Fig. 1) are bordered by well defined triangle zones (Lane 1996).

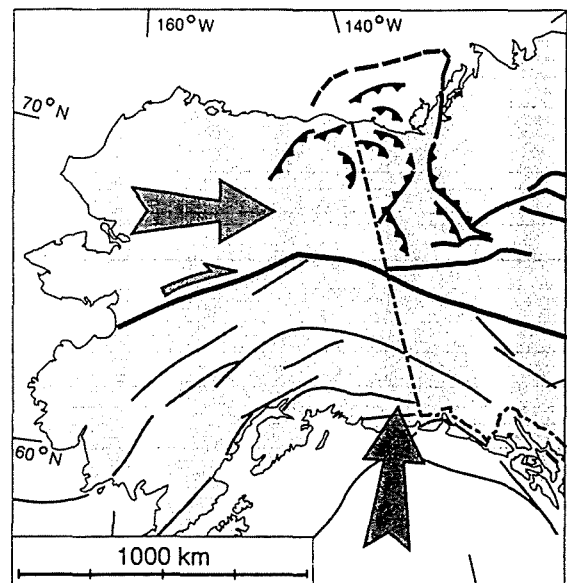


Figure 2. Tectonic setting of Early Tertiary deformation in northern Yukon. Arctic Alaska was displaced eastward on the Kaltag and other faults, driven by North America - Eurasia convergence (Lane 1995). Rocks of northern Yukon and eastern Alaska were shortened against the North American craton, producing the predominant north-south structural trend. Location of Figure 2 is shown.

The unusual distribution of deformation intensity along the strike of the orogen is interpreted as being due to boundary conditions imposed by variations in the competence of basement and supracrustal rocks in the region. The highly deformed zones are shale troughs or basins, which have been tectonically inverted. The Richardson and British-Barn mountains troughs are early Paleozoic in age; the Blow Trough and Kandik Basin (Fig. 1) are Early Cretaceous in age. In each case, the extensional events are believed to produce structures or fabrics in the underlying basement, making it

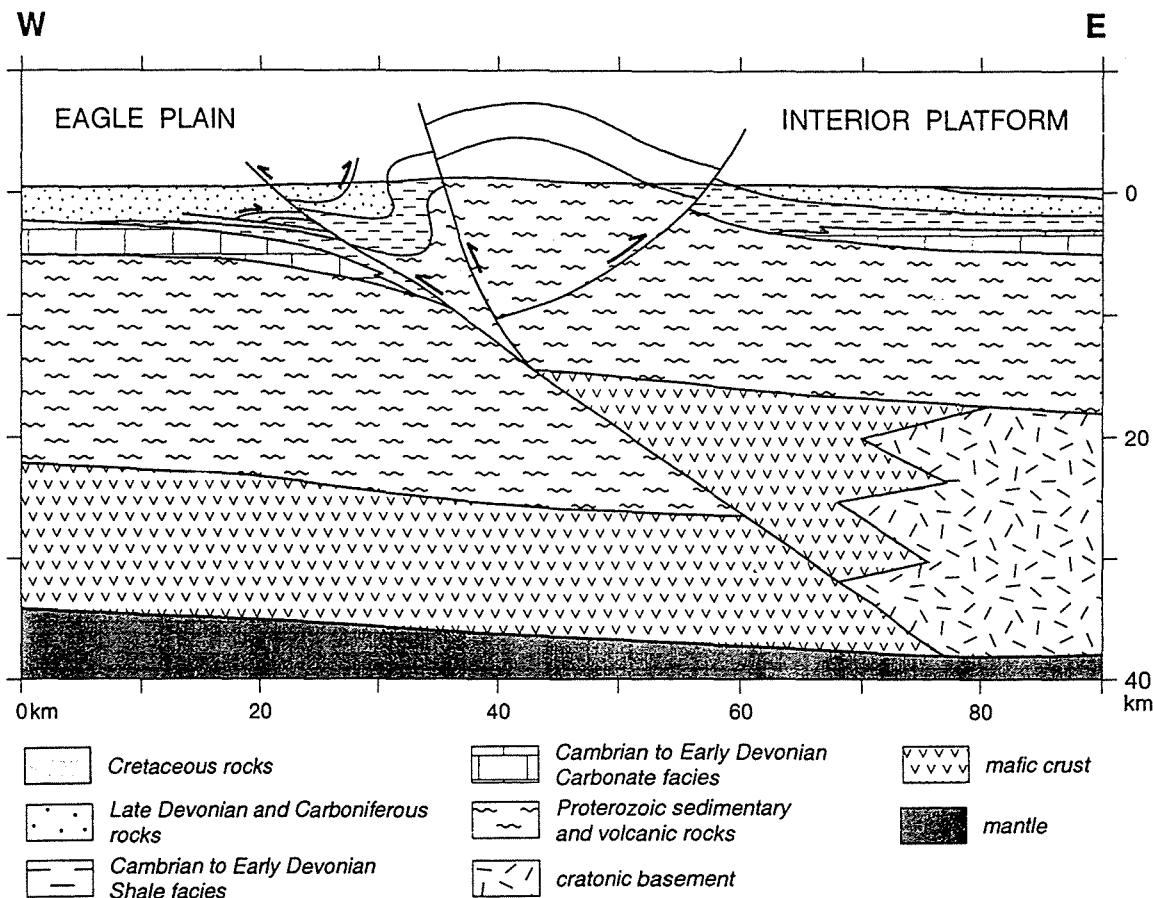


Figure 3. Balanced crustal-scale cross-section, southern Richardson Mountains (Fig. 1), reconciling anticlinorium geometry with the identification of shallow faults at its margin. The cross-section was drawn using published sources as well as unpublished seismic and well control (Lane 1996). Thrust faulting and folding in the upper crust is balanced locally at depth by duplication and uplift of the basement. Interpreted horizontal shortening is 17 km.

more susceptible to later reactivation than adjacent basement (Lane 1996). In contrast, the less deformed Eagle Plain is underlain by Porcupine Platform, a thick succession of lower Paleozoic competent carbonate rocks, Proterozoic metasediments and mafic basement. As the Tertiary deformation progressed eastward onto the Porcupine Platform, the more competent rocks there were relatively resistant and deformed less intensely. The more intense deformation in the Richardson Mountains farther east indicates that the entire crustal block beneath the Porcupine Platform was translated eastward so that the Richardson Anticlinorium is a local thick-skinned deformation zone, or crustal-scale wedge.

Southern Richardson Mountains

The southern Richardson Mountains have been characterized as an anticlinorium associated

with steeply-dipping, basement-involved, regionally important faults of the Richardson Fault Array (e.g. Gabrielse and Yorath 1991). Regional faults were important in defining the anticlinorium through their control on the development of the early Paleozoic Richardson Trough, and previous interpretations suggested their reactivation during Early Tertiary convergence (e.g. Norris 1985).

The southern Richardson Mountains have a core of older rocks surrounded by progressively younger strata dipping away from it. However, the recent interpretation of triangle zones at the margins of the Dave Lord and Richardson ranges has shown that the southern Richardson Mountains are underlain by shallowly dipping thrust faults (Lane 1994, 1996). Shallow thrust faults at the margins are compatible with an anticlinorium geometry if much of the shortening is accommodated by duplication of the Paleozoic succession together with the underlying rocks

(Lane 1996). Figure 3 is a balanced crustal-scale east-west cross-section through the southern Richardson Mountains at the latitude of the Arctic Circle, showing a structural geometry based on known surface geology and on regional crustal structure. The anticlinorium is the expression of a deep crustal-scale wedge, where Porcupine Platform basement was driven beneath cratonic North America. The platform's upper crustal layers were delaminated by a wedge of Proterozoic and Paleozoic supracrustal rocks. This cross-section incorporates 17 km of horizontal shortening (folding + thrusting) over a deformed width of 40 km, for a tectonic shortening across the anticlinorium of 30% at this locality.

The pronounced positive gravity anomaly underlying the southern Richardson Mountains is a well-known regional feature. The gravity high is restricted to the southern Richardson Mountains. In contrast, a pronounced gravity low exists over the northern Richardson Mountains, and the deep crust does not appear to be involved in the shortening (O'Leary et al. 1995). Accordingly, basement involvement is interpreted as being restricted to the southern Richardson Mountains, the only segment adjacent to a competent crustal block interpreted as having been displaced eastward. The mass excess producing the positive gravity anomaly is interpreted as being due to duplication and uplift of a mafic basement and mid-crustal Proterozoic supracrustal rocks, combined with the erosional loss of less dense upper crustal Mesozoic and Paleozoic rocks over the crest of the range.

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Structure of the Eagle Plains and Richardson Mountains, Yukon Territory, Canada.

K.W. Hall and F.A. Cook
(hall@litho.ucalgary.ca, cook@litho.ucalgary.ca)
The University of Calgary
Department of Geology and Geophysics
2500 University Dr. N.W.
Calgary, Alberta
T2N 1N4

A 250 km long east—west geological and geophysical transect has been constructed at about 66°40' N, from near the Yukon—Alaska border to the Interior Platform. It crosses the Eagle Plain foldbelt and the Richardson Mountain anticlinorium at a position where extension associated with the opening of the Canada Basin was minimal. The transect includes reprocessed industry seismic reflection profiles, regional gravity data and drill hole information.

In our interpretation, the north trending Richardson Mountain anticlinorium is a contractional (pop—up) structure, bounded on the east and west by outward verging thrust faults and cored by Proterozoic rocks, possibly the Wernecke supergroup. Gravity modelling implies the location of the pop—up may be associated with a west—facing crustal scale ramp at the top of the crystalline basement. Major thrust faults on the east and west flanks of the mountains (Deception and Trevor faults) were active after deposition of the Carboniferous Tuttle formation, but before deposition of Cretaceous (and Jurassic ?) rocks.

Horizontal displacement required to accommodate the pop—up is about 10–30 km, and probably occurred above one or more regional detachments that project westward beneath the Eagle Plains. Major contractional deformation in the Eagle Plain foldbelt probably occurred at about the same time (post—Carboniferous, pre—Mesozoic), although minor deformation has affected the Cretaceous rocks of the Eagle Plains.

Progress Report on Seismological Investigation of the Lithosphere Below SNORCLE

M. G. Bostock and A. W. Frederiksen
Department of Geophysics & Astronomy
University of British Columbia
Vancouver, British Columbia, V6T 1Z4

J. F. Cassidy
Pacific Geoscience Center
Geological Survey of Canada
Sidney, British Columbia, V8L 4B2

We report on progress to date in a broadband teleseismic experiment designed to elucidate the nature of the upper mantle beneath the *SNORCLE* transect. A quasi-linear array comprising 10 seismographs has been deployed with the objective of characterizing the transition in upper mantle properties beneath the northern Cordilleran orogen and the Canadian shield. The array is a composite of 5 permanent stations from the Canadian National Seismograph Network (CNSN) and 5 portable stations operated out of the University of British Columbia. Traveltime perturbations observed across the array point to both large scale variations in mantle velocity (from cordillera to shield) and smaller scale signatures indicative of more complex structures. We are currently preparing to perform a formal inversion of the traveltime perturbations for smoothly varying upper mantle structure. In addition, efforts have focussed on retrieving sharp mantle impedance structure from converted phases beneath the southern Slave Craton using data recorded at Yellowknife. Images of stacked amplitude plotted with respect to time and epicentral distance reveal a variety of phases which may be used to assess the physical state of the underlying mantle.

THRUST FOLDS IN THE CANADIAN ROCKY MOUNTAIN FOLD AND THRUST BELT

C. Willem Langenberg, Alberta Geological Survey
6th Floor, 9945-108 Street
Edmonton, Alberta T5K 2G6
E-mail: Langenberg@enr.gov.ab.ca

Fold geometries observed at the surface can be correlated with the architecture of its sedimentary succession. Two possible architectures are: 1). successions with alternating competent and incompetent units, where the competent units do not exceed 100 m in thickness (Architecture A - e.g. Mesozoic of Central Alberta Foothills) and 2). successions with competent units, that exceed 100 m in thickness and have relatively thin incompetent units in-between (Architecture B - e.g. Paleozoic of Southern Alberta Front Ranges).

Architecture A often shows much folding above detachment zones (detachment buckle folds). Steep limbs of these folds are not imaged by seismic methods and consequently folding is under-represented on cross sections, which include data from seismic sections. Thrust faults form in a later stage of the buckle-folding process, whereby faults cut through the fore-limbs of tight folds (fault-propagation folds), which were originally initiated at buckling instabilities. Low-angle thrust faults are generally well-imaged in seismic sections. Buckle folds can be modified by fault-bending at a later stage, after thrust faults formed. The resulting structures show the combined effects of sequential detachment folding, fault-propagation folding and fault-bend folding and can be described as thrust folds. These structures are well displayed in the Grande Cache and Cadomin coal fields and in Mississippian sections of the Front Ranges in Willmore Wilderness Park.

Thrust-ramps in Architecture B seem to be localized by a buckling instability in the layered succession in an early stage of buckle-folding. These successions show relatively little folding. It is well displayed in the Calgary-Banff cross section.

Low-taper intercutaneous wedges: a model for opposing displacement senses on coeval, subparallel shears

Jacqueline Windh, Department of Earth and Planetary Sciences, McGill University
3450 University Street, Montréal, Québec, H3A 2A7

The triangle zone at the front of the Canadian Rocky Mountains, Alberta, is a well documented example of an intercutaneous wedge. Many published geological cross-sections of this triangle zone, based upon geological and seismic data, show the geometry of the intercutaneous wedge to be low-taper, such that the dip of the backthrust, or upper décollement, shallows at depth, merging into parallelism with the forethrust, or basal décollement (e.g. Jones, 1982; McMechan, 1985; Price, 1986; Skuce et al., 1992; Lawton et al., 1994). This interpreted geometry implies that the upper and basal décollements formed as subparallel and coeval structures with opposite senses of displacement. The apparent mechanical problems of such a system have led some workers to dispute these geological interpretations, offering alternative interpretations for the décollement kinematics and thus for wedge geometry.

If low-taper wedges do indeed exist, any mechanical model which accounts for their formation must consider the following four points:

1. The geometry and kinematics of the wedge provide constraints on the relative timing of its three component structures: the upper décollement, the basal décollement, and the linking ramp. The basal décollement soles into other thrust faults in the hinterland; displacement along it is tectonically driven by the advancing orogen. The upper décollement soles towards the foreland, and is linked to the basal décollement. If it formed before the basal décollement, it could not be mechanically coupled to the advancing hinterland, and had no driving force for movement. The upper décollement therefore must have formed after the basal décollement, which linked it to the advancing deformation belt via the ramp and the basal décollement. The order in which the incipient structures form must therefore be: first, the basal décollement as an incipient blind thrust, followed by formation of the upper décollement. Significant slip along these incipient décollements (i.e. wedge insertion) may occur only after formation of a linking ramp.
2. The stress régime at the foreland of a compressive orogenic belt predicted by Hafner (1951) implies that there is an "unstable" region near the orogenic belt where faulting is expected to occur, and a "stable" region in the foreland where initiation of new faults is not

predicted. The boundary between these two regions dips towards the foreland. In the "unstable" region, forethrusts are predicted to be listric and to have shallower dips than backthrusts.

3. Formation of the décollements occurs within mudstones in an actively subsiding foreland basin, at depths of ~2500-3500 m, an environment where pore fluid pressures are predicted to have been high ("abnormal"), and possibly near or at the lithostatic pressure (e.g. Rubey and Hubbert, 1959; and many others). Any shortening of the mudstones due to tectonism would further, and instantaneously, increase pore fluid pressures.

4. The geometry and kinematics of the upper décollement cannot be related to the regional stress field alone. In some respects, it is analogous to transfer faults, which form parallel to the regional shortening direction, accommodating movement on other, linked structures, and which therefore must be analysed in terms of the displacements along the other structures with which they are linked.

A model is developed whereby a blind forethrust (the basal décollement) propagates from the deformation belt into the foreland. Propagation of the basal décollement occurs within an environment where pore fluid pressures are predicted to have been high, and possibly approaching or reaching the lithostatic pressure. Incipient foreland-vergent slip on the basal décollement causes homogeneous shortening in its hangingwall (or horizontal compaction), further raising pore fluid pressures above the tipline region of the décollement. Horizontal failure occurs within this highly pressured region, above the basal décollement. Where pore fluid pressures approach lithostatic, compaction is halted or reversed, and a *dilatant zone capable of flow* forms. Where pore fluid pressures exceed lithostatic, a *discrete extensional fracture* may form. The subhorizontal attitude of this zone or fracture is a result of the subhorizontal maximum compressive stress, the mechanical anisotropy of the mudstone unit, and confinement of the driving force (the high pore fluid pressures) to within that mudstone unit. Once it has formed, this extensional fracture or zone behaves as a free surface, across which shear stresses cannot be maintained. As foreland-directed movement on the basal décollement continues, glide begins on this free surface, accommodating the tectonically driven movement along the basal décollement, and the free surface becomes the upper décollement.

Little net slip can be accomplished until the basal and upper décollements have been linked. Once the linking ramp is formed, insertion of the wedge commences and strata in the foreland are progressively delaminated. The upper décollement propagates back towards the hinterland, eventually cutting up-section to break to surface as a backthrust.

An important implication of this model is that the upper décollement forms as an extensional fracture or zone. A similar mechanism has been invoked by Morgan and Karig (1995), who interpret the forethrust of the Nankai accretionary margin, Japan, to propagate as an extensional fracture forming due to high pore fluid pressures developed in advance of the deformation front.

The upper décollement was subsequently (re)activated as a shear ("backthrust") that accommodated foreland-vergent movement on the underlying basal décollement. Strata on its hangingwall are uplifted, but are not laterally displaced, and are therefore autochthonous (e.g. Jones, 1982; Skuce et al., 1992; Lawton et al., 1994). Accommodation structures cannot be analysed using conventional Anderson-Coulomb failure criteria, but rather, must be analysed with respect to the structures to which they are mechanically linked. The vergence of the upper décollement, if defined by the transport direction of the *allochthonous* material, rather than by the *relative* displacement of the *hangingwall* material, is foreland-vergent, compatible with the vergence of structures within the rest of the orogen. It is thus more appropriately considered to be an "underthrust" than a "backthrust" (e.g. Jones, 1982).

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APATITE FISSION-TRACK DATA FROM BELOW THE LEWIS THRUST FAULT AND ITS IMPLICATIONS FOR THE THERMAL HISTORY OF THE CORDILLERAN FORELAND BELT AND THE AGE OF THE FLATHEAD NORMAL FAULT

Kirk G. Osadetz¹, Barry P. Kohn², Shimon Feinstein³, and Raymond A. Price⁴

¹Institute of Sedimentary and Petroleum Geology, 3303 33rd St. N.W., Calgary, Alberta T2L 2A7, CANADA;

²Victorian Institute of Earth and Planetary Science, School of Earth Science, La Trobe University, Bundoora, Victoria 3083, AUSTRALIA;

³Department of Geology and Mineralogy, Ben Gurion University of the Negev, P.O. Box 653, 84 120 Beer Sheva, ISRAEL;

⁴Department of Geological Sciences, Queen's University, Kingston, Ontario K7L 3N6, CANADA.

Apatite fission-track age and mean horizontal confined track length (HCTL) data from strata lying below the Lewis Thrust Fault show systematic variations with current elevation and present structural position. These variations are consistent with data obtained earlier in the Lewis Thrust Sheet. Ages decrease from about 70 Ma at elevations of 2500 m to about 30 Ma at -1000 m. Mean HCTL data that are approximately 13.8 microns, or longer at elevations of 2500 m decrease to less than 12 microns at elevations of about 1300 m. At lower elevations, about +750 m mean HCTL's are again observed to be >13 microns. These decrease to less than 12 microns at -750 metres. The "dog-leg" in the mean HCTL profile is fortuitously coincident with the lowest sampled locations in Lewis Thrust sheet. The variations in age and HCTL data from below the Lewis Thrust are superimposed on the orogenic structure. Likewise, the RockEval/TOC thermal maturity profile is also superimposed upon the Laramide structure. Current geothermal gradients are 17 mK/m and structural reconstructions suggest up to 8 km of erosion in the footwall of Flathead Normal Fault. These data show that rocks in Lewis thrust sheet underwent

profound cooling and erosion at approximately 75 Ma in response to the overthrusting. Samples below the Lewis Thrust reached their maximum temperatures in response to tectonic burial by the cooling and eroding Lewis thrust sheet, in a geothermal gradient field that was lower than that of the present day. The data suggest that Flathead Fault begins to move in Eocene time, whence the rocks below Flathead Fault were progressively cooled and uplifted. During the same interval local geothermal gradients have increased. Thus, peak organic maturity in rocks below Lewis Thrust Fault was achieved post-deformationally in response to tectonic burial, and the remarkable similarity of coal ranks in Kootenay strata above and below Lewis Thrust is accidental.

Paleomagnetic constraints on the tectonic history of the Foreland Belt, southern Canadian Cordillera.

R.J. Enkin, K.G. Osadetz, P.M. Wheadon and J. Baker

Geological Survey of Canada

The paleomagnetic analysis of folded Paleozoic carbonate strata in the Main and Front Ranges and the Inner Foothills of the Cordilleran Fold and Thrust Belt show no record of their deposition at low latitudes. Instead each folded structure exhibits a similar but asynchronous sequence of events that results in an eastwardly progressing, predeformational chemical remagnetization during Columbian and Laramide orogenies. The remagnetization of representative "Main Range" structures occurs in a period of normal polarity before the Cretaceous Long Normal Superchron (CLNS) suggesting that the subsequent deformation of the "Main Range" is early Cretaceous or later. The remagnetization of representative "Front Range" structures occurs either during CLNS or chron 33N in the interval Aptian to earliest Maastrichtian. From other evidence the deformation of the "Front Range" is essentially Maastrichtian in age. The predeformational remagnetization of a representative "Inner Foothills" structure occurs during a reversed magnetic period that is no older than chron 33R. A syndeformational remagnetization of a Lower Cretaceous sill in Lewis Thrust Sheet occurred when the sill had acquired 70% of its current dip, during either chron 32R or some other reversed chron prior to the end of motion on Lewis Thrust Fault. The consistent relationships between remagnetization and local deformation, coupled with both the inference that this sequence of events migrates eastward with time in the van of the deforming Cordilleran tectonic wedge and the similarities in character and style of the remagnetizations suggests that a single chemical process of great, but hitherto unappreciated importance is active advance of the deformation front.

The southeast termination of the Main Ranges geological province of the Southern Canadian Rockies near Crowsnest Pass, southeast B.C.

G.W. Stretch and R.A. Price, Dept. of Geological Sciences, Queen's University, Kingston, Ont., K7L 3N6

The distinctive stratigraphy and structural style and orientation within the Main Ranges of the Rocky Mountain Foreland Fold and Thrust Belt change abruptly at the Moyie-Dibble Creek (MDC) fault. The MDC fault is a northwest-dipping, right-hand reverse fault that corresponds with part of a 200 km right-hand offset in the boundary between the early Paleozoic Cordilleran Miogeocline and the cratonic platform. South of the MDC fault, a thin, condensed succession of Middle Cambrian platform facies strata is unconformably overlapped northwestward by the Upper Devonian Fairholme Group, which lies directly on Middle Proterozoic rocks of the Belt-Purcell Supergroup adjacent to the MDC fault. Northwest of the fault, the Upper Devonian shaly equivalents of the Fairholme Group and Palliser Formation unconformably overlie approximately 7 km of shaly lower Paleozoic strata in the core of the Porcupine Creek anticlinorium.

Detailed mapping of the lower Paleozoic rocks within an area of approximately 150 km² on the northwest side of the MDC fault has outlined the southeast margin of the Cambrian shale basin. Thick and extensive carbonate slope and distal slope deposits occur in the Middle Cambrian "Tanglefoot Unit" in a zone adjacent to the MDC fault. Suspension deposits and fine grained gravity flow deposits are interbedded with oligomictic carbonate debris flow breccias, the latter becoming relatively more abundant near the MDC fault. Paleocurrent indicators within the debrites indicate that paleoslopes are generally northwest, but vary from northeast to southwest. The "Tanglefoot Unit" is overlain by thick, shallower-water deposits of the Cambro-Ordovician McKay group, marking a second-order sea level regression.

The south-trending axis of the Porcupine Creek fan structure swings to the southwest adjacent to the MDC fault. The anticlinorium ends in a zone of disharmonic folding in the "Tanglefoot Unit" and underlying Eager Formation, above an east-facing homocline in the Middle Proterozoic and basal Cambrian sequence on the east flank of the Hughes Range. The kinematics of the structure are complex, and reflect the influence of older structures on Mesozoic folding and faulting.

Tectonic heredity of the Crowsnest Pass cross-strike discontinuity: Mesozoic-Cenozoic tectonic inversion of Paleozoic structures with Eocambrian, Neoproterozoic, Mesoproterozoic and Archean antecedents

Raymond A. Price, Department of Geological Sciences, Queen's University, Kingston, Ontario K7L 3N6

The northeast-trending Crowsnest Pass (CP) cross-strike discontinuity is marked by profound changes in the stratigraphy and in the style and orientation of the structures in the Cordilleran foreland thrust and fold belt. These include the southern termination of the Porcupine Creek "fan structure" (anticlinorium), and of the Main Ranges and western Ranges provinces of the southern Canadian Rockies. The CP cross-strike discontinuity coincides with the 200-km right-hand offset in the boundary between the Paleozoic Cordilleran miogeocline and the cratonic platform that defines the northwestern margin of "Montania". The discontinuity is also marked by the Crowsnest Pass deflection, a conspicuous structural re-entrant separating the north-trending structures of the Southern Canadian Rocky Mountains structural salient, which coincides with the Paleozoic Cordilleran miogeocline, and stretches northwestward in an 800 km-long arc to the Peace River re-entrant in northeastern British Columbia, from the northwest-trending structures of the northern Montana Rocky Mountains structural salient, which extends 450 km southeastward into central Montana, and coincides with a salient in the Mesoproterozoic Belt-Purcell basin.

Several important faults occur within the cross-strike discontinuity. The transverse, northeast-trending segments of both the Moyie-Dibble Creek (MDC) fault and the St. Mary fault-Lussier River (SMLR) fault are right-lateral, northwest-dipping reverse faults of Early Cretaceous and/or Late Jurassic age. Both change northeastward, in the western Canadian Rockies, into north-trending thrust faults, and both also change southwestward, in the western Purcell Mountains, into northwest-trending thrust faults. Contrasting stratigraphic successions on either side of both faults indicate that the northeast-trending segments are controlled by older (Early Paleozoic, Eocambrian, Neoproterozoic, and Mesoproterozoic) structures. In the case of the northeast-trending segment of the MDC fault, the antecedent structure had the opposite stratigraphic separation (down thrown to the northwest) with more than 7 km of structural relief beneath the sub-Fairholme unconformity. In the case of the northeast-trending segment of the SMLR fault, the eastern part of the antecedent structure had the same sense of stratigraphic separation (down thrown to the southeast) during Early Paleozoic time as it has now; but the western part had the opposite stratigraphic separation (down thrown about 10 km to the northwest) during Late Proterozoic time. Middle Proterozoic rocks of the Purcell (Belt) Supergroup also show conspicuous facies and thickness changes that appear to be controlled by these transverse faults.

Palinspastic reconstruction of the Cordilleran foreland thrust and fold belt shows that the transverse basin margins were aligned with the "Vulcan low", and indicates that they were inherited through reactivation of structures in the Archean basement that extends under the Cordillera from the Western Canada basin. Relationships along unconformities beneath Windermere, Eocambrian, Middle to Upper Cambrian, Upper Ordovician, and Upper Devonian strata can be used to date times of reactivation of the transverse structures that controlled the basin margins, and cross-cutting granitic plutons can be used to date the structures produced during inversion of the basin-margin structures

The CP cross-strike discontinuity is a product of Late Jurassic-Early Cretaceous and Late Cretaceous-Paleocene tectonic inversion of basin-margin structures that were inherited from the Archean basement of western Canada, and developed by reactivation during the Mesoproterozoic (Belt-Purcell), Neoproterozoic (Windermere), Eocambrian and several intervals in the Paleozoic.

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

Marian J. Warren

Department of Geological Sciences, Queen's University,
Kingston, Ontario, K7L 3N6

The Neoproterozoic Windermere Supergroup and the latest Neoproterozoic to Lower Cambrian Hamill/Gog Groups were both deposited on the western margin of ancestral North America during episodes of crustal extension whose plate tectonic settings remain controversial. New and previous stratigraphic and sedimentological data from the Windermere Supergroup and Hamill/Gog Groups in the Purcell Mountains, Selkirk Mountains and Western Main Ranges of the Rocky Mountains provide the basis for construction of palinspastically restored paleogeographic maps and cross sections of the Windermere and Hamill/Gog basins that reveal that the basin configurations and upper crustal behaviour must have been markedly different during the two episodes of extension. Illustration of these differences is critical toward further discussion and elucidation of the plate tectonic setting of the Windermere and Hamill/Gog Groups.

The Neoproterozoic Windermere Supergroup was deposited primarily in submarine fans during rapid and significant subsidence of a single, continuous basin immediately adjacent to rapidly uplifted and deeply eroded North American basement and Belt-Purcell Supergroup sources. The basin was controlled by two sets of west- and northwest-dipping normal faults that trended N-S and NE-SW, respectively. The extension direction was NW-SE, and the basin may have developed, at least initially, during dextral (?) transtension. The faults accumulated as much as 15 km of stratigraphic offset. In contrast, the Neoproterozoic to Lower Cambrian lower part of the Hamill/Gog Groups were deposited in isolated, shallow marine and fluvial basins during relatively little and uniform subsidence across the margin. The extension direction was E-W. The basins were bounded on their eastern edges by north-trending, west-dipping syn-sedimentary normal faults that accumulated no more than 3.5 km of stratigraphic offset during the deposition of the lower part of the Hamill/Gog Groups. Strata deposited in these basins are regionally unconformably overlain by the Lower Cambrian upper part of the Hamill/Gog Groups (Lickorish and Simony, 1995, and this study), which was deposited in a more regionally continuous shelf setting after most of the normal faulting had ceased.

The faults that controlled the deposition of the Windermere Supergroup cut both the North American basement and the Mesoproterozoic Purcell Supergroup. The basins that contain the lower part of the Hamill/Gog Groups are superposed on much thicker accumulations of the Windermere Supergroup, but they apparently did not continue into the more competent Belt-Purcell Supergroup and crystalline basement to the south and east. However, the eastern and southern edge of the continuous upper part of the Hamill/Gog Groups and of the overlying Lower Paleozoic miogeoclinal succession coincides with the eastern and southern edge of the Windermere Supergroup, suggesting that the more significant episode of upper crustal stretching and thinning that controlled later subsidence on the Paleozoic passive margin of North America occurred during the deposition of the Windermere Supergroup, rather than during deposition of the lower part of the Hamill/Gog Groups.

These data and interpretations are consistent with the following tectonic model: Initial crustal stretching was accompanied by regional uplift and the development of an intracontinental rift basin (Windermere) that was bounded to the east and southeast by a zone of listric west- and northwest-dipping normal faults. The footwall of this fault zone experienced significant isostatic uplift and erosion following tectonic removal of hangingwall rocks to the west, and the Windermere Supergroup was deposited in their place. The continental crust in the footwall was thinned abruptly toward the west. During a second episode of crustal thinning (lower Hamill/Gog), less significant west-dipping normal faults developed antithetic to a low-angle, east-dipping, crustal-scale ductile detachment that was located beneath the eastward-thickening Windermere Supergroup and previously thinned continental crust to the east. Motion on this detachment culminated in the initiation of seafloor spreading and continental drift. This second episode of extension was immediately followed by deposition of a westward-thickening passive margin sequence (upper Hamill/Gog Groups and Lower Paleozoic miogeocline) on the thermally subsiding former hangingwall of the detachment. The regional unconformity within the Hamill/Gog Groups is proposed as the most likely expression of the rift-to-drift transition in the stratigraphic record.

This model is compatible with recent studies that concluded that continental separation and the initiation of seafloor spreading occurred in Earliest Paleozoic time (e.g. Bond and Kominz, 1984; Bond et al., 1985). Other

recent models have included a transition to seafloor spreading and thermal subsidence during deposition of the Windermere Supergroup (e.g. Ross, 1991). However, the lack of a conspicuous westward-thickening Neoproterozoic passive margin succession, the lack of a thick, rapidly subsided sequence of coarse, immature sediment of lower Hamill/Gog age, and the coincidence of the hinge line for Paleozoic margin subsidence with the edge of the Windermere basin support neither a model of continental separation solely in Windermere time, nor of two complete, distinct cycles of crustal extension followed by seafloor spreading and thermal subsidence.

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TOWARDS A PALINSPASTIC MAP OF THE US-CANADIAN ROCKY MOUNTAIN FOLD-THRUST BELT

SEARS, J.W., Geology Department, University of Montana, Missoula, MT
59812

A palinspastic map is a map-plane integration of a series of restored cross-sections of an area. In addition to simultaneously satisfying all pertinent cross-sections, the palinspastic map, itself, must be balanced. Lengths of lines on the palinspastic map, such as thrust traces, must equal those line lengths on the deformed map, and map areas, such as the areas of thrust sheets, must be conserved, except in areas of significant volumetric strain. The palinspastic map must also honour the topological relationships among the interwoven faults on the deformed map.

A preliminary palinspastic map of the US-Canadian Rocky Mountains, based on integration of 16 cross-sections and analysis of the topology of interwoven faults on compilation maps of the region restores thrust and extensional fault displacements relative to the North American craton. The cross-sections generally parallel thrust transport directions, normal to the average strike of the fold-thrust belt in a given transect. The cross-sections incorporate seismic, borehole, stratigraphic, and surface structural and geologic data. Displacement decreases southeastward from >215 km in British Columbia to <20 km in west-central Montana. The southeastward decrease in displacement requires significant clockwise thrust rotation of the thrust sheets north of the Lewis and Clark line.

COMMENTS ON THE MONASHEE DÉCOLLEMENT, THOR ODIN CULMINATION OF THE MONASHEE COMPLEX, SOUTHERN OMINECA BELT, SOUTHEASTERN B. C.

Johnston, Dennis H., Williams, Paul F. and Spark, Robert N.

Department of Geology, University of New Brunswick, Fredericton, N.B., E3B 5A3

The Monashee Complex is a domal culmination of high grade metamorphic rocks within the Shuswap Metamorphic Complex in the hinterland of the Canadian Rocky Mountains. Whereas the Shuswap Metamorphic Complex is defined by large Eocene normal faults, the Monashee Complex is presently delimited on most maps by a major east-directed thrust fault- the Monashee décollement. The Monashee décollement has been correlated, on the basis of seismic data, with the sole thrust of the Rocky Mountain foreland belt.

A danger inherent in correlation of the Monashee décollement with foreland thrusting is the inclination to envisage the Monashee décollement as a discrete fault or high strain zone. Along the western flank of the Thor Odin culmination, where the Monashee décollement is presently mapped, we do not see a discrete east-directed fault, fault zone or even a high strain zone (relative to the surrounding area). This is not to say that we do not see evidence for top-to-the-NE movement: top-to-the-NE shear band foliations and s-c fabrics are common, particularly in pelitic schists; F_3 folds, reflecting variable amounts of NE-directed shear, are overturned and have apparent SW vergence at higher structural levels; deeper in the culmination, lesser amounts of NE-directed shear resulted in F_3 folds with east, northeast and north vergences. But top-to-the-NE fabrics and fold asymmetries are ubiquitous, from the core of the culmination to the highest structural levels. Rocks at all structural levels are thoroughly transposed. We see the Monashee décollement as a very broad zone of high strain, a zone of pervasive penetrative strain which must include all of the Thor Odin dome. NE-directed shear may have been funneled through this broad zone to discrete faults in the foreland.

Lithologically we cannot distinguish allochthonous rocks distinct from core or cover rocks that would lie in the footwall of a Monashee décollement. Core/cover lithologies alternate as far west as Joss Pass. Core has not been observed west of Joss Pass so the possibility remains that the Monashee décollement was dropped to the subsurface along a normal fault through Joss Pass.

Thermally there is good evidence that a hot slab was emplaced onto the Monashee Complex. $^{40}\text{Ar}/^{39}\text{Ar}$ hornblende cooling ages are older (~ 70 Ma) deep in the culmination and younger at higher structural levels (~ 55 -60 Ma). The younger cooling ages along the flanks of the Thor Odin dome are interpreted to be the result of protracted cooling of an overriding hot slab. The underlying old ages record a prior Barrovian metamorphic event. The two populations are separated by a zone in which kyanite is preserved: above is a zone in which kyanite is pseudomorphed by silliminite in turn overlain by a zone of silliminite only. K-feldspar/silliminite assemblages occur below the kyanite-preserved zone.

U-PB GEOCHRONOLOGIC CONSTRAINTS ON THE MONASHEE COMPLEX COVER SEQUENCE, CANADIAN CORDILLERA: EARLY PROTEROZOIC DEPOSITION ON BASEMENT

Crowley, James L., Department of Earth Sciences and Ottawa-Carleton Geoscience Centre, Carleton University, Ottawa, Ontario K1S 5B6

The cover sequence in the Monashee complex was deposited unconformably on basement and contains the oldest dated rocks in the Canadian Cordilleran miogeocline. U-Pb zircon data and field relationships from six rocks in the northern Monashee complex place new constraints on the deposition and source ages of the cover sequence. These data have implications for the depositional history of the Cordilleran miogeocline and for reconstruction of the Cordillera to a pre-shortening configuration.

The lower part of the Monashee cover sequence was deposited in the Early Proterozoic, after incorporation of 1.99 Ga detrital zircons and before intrusion of 1852 ± 4 Ma pegmatite and 1759 ± 1 Ma leucogranitic layers which were tectonized during early Tertiary Cordilleran events. Detrital zircon ages suggest that underlying Monashee basement was not a source. The lower part of the sequence was also intruded by 724 ± 5 Ma syenitic gneiss. The presence of a 1.21 Ga detrital zircon in the upper part of the sequence requires that it was deposited at least 0.64 Gyr after the lower part and implies the existence of an unmapped unconformity between the parts. Late Archean (2.95-2.86 Ga) and Early Proterozoic (1.85-1.81, 1.75 Ga) detrital zircon ages suggest that the source of the upper part is the Alberta basement of the western Canadian Shield.

17.6 Ga
gneiss

Combining these ages with previously published interpretations that infer the middle and upper parts of the Monashee cover sequence to be Paleozoic shows that deposition of the entire sequence occurred over a period of ~ 1.3 -1.6 Gyr. This age scenario constrains the present thickness of Middle and Late Proterozoic metasedimentary rocks in the cover sequence to be < 200 m, considerably less than the thickness of coeval Belt-Purcell and Windermere supergroup rocks above the Monashee complex, in the hanging wall of the Monashee decollement. Such a thickness difference implies that deposition of rocks on either side of the Monashee decollement did not occur in the same part of the Cordilleran miogeocline.

PETROGRAPHIC AND THERMOBAROMETRIC CONSTRAINTS ON THE TECTONIC EVOLUTION OF THE VALHALLA COMPLEX, SOUTHERN OMINECA BELT.

Peter M. Schaubs, Department of Earth Sciences and Ottawa-Carleton Geoscience Centre, Carleton University, Ottawa, Ontario, K1S 5B6

The Valhalla complex is an exhumed metamorphic core complex situated within the southern Omineca belt of the Canadian Cordillera. Sheets of upper amphibolite-facies paragneiss occur at three structural levels of the complex. The upper most sheet of paragneiss (1c) is comprised of the Valhalla assemblage, which is interpreted to be an inverted and thinned sequence of Paleozoic strata which was deformed during the Cretaceous. The Valhalla assemblage lies in the hanging wall of the Gwillim Creek shear zones which are two ~ 50 m thick horizons of significant ductile strain which occur in the deepest exposed structural levels of the complex and juxtapose the two structurally lower paragneiss sheets (1a and 1b) against the 100 Ma Mulvey granodiorite. These shear zones resurface in the southern region of the Valhalla complex near Vallican and occur within a larger area of the complex than has been previously documented. The duplication of geology and the apparent easterly-directed shear sense has led to the interpretation that the shear zones are east verging thrust faults (Parrish *et al.* 1988).

Petrography and thermobarometry was carried out on pelitic schists and amphibolite gneisses to determine the relationship between fabrics and metamorphism and the relative pressure-temperature conditions at different structural levels. Petrographic observations reveal that the peak of metamorphism was synchronous with the dominant S_2 foliation and that different structural sheets share a common metamorphic history. S_2 fabric development at high structural levels is synchronous with fabrics associated with the Gwillim Creek shear zones, at structurally low levels. The peak of metamorphism has been dated at 75 Ma (Heaman and Parrish 1991) and therefore the Gwillim Creek shear zones were in part active at this time. Petrographic observations and thermobarometric results from pelitic schists and amphibolite gneisses indicate that peak thermal conditions were $> 800^\circ\text{C}$ and > 7.5 kbars in the structurally highest domain. Pelitic schists from structurally low levels are characterized by plagioclase moats around garnet, a large variation in thermobarometric data ($\sim 775 - 980^\circ\text{C}$, 7.1 - 12.2 kbars) and consistently lower pressure data (~ 3 kbars) recorded by the GRAIL equilibrium compared with the GASP equilibrium. Plagioclase moats and the different closure temperatures of the GASP and GRAIL geobarometers are interpreted to record a period of Late Cretaceous decompression. This may be a response to exhumation due to movement along the underlying Monashee décollement.

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THICK-SKINNED THRUST TECTONICS IN THE SOUTHERN CANADIAN CORDILLERA

Richard L. Brown, Ottawa-Carleton Geoscience Centre, and Department of Earth Sciences, Carleton University, Ottawa, Ontario K1S 5B6.

ABSTRACT

Thin-skinned thrusting above a discrete basal decollement is recognized as a typical style of deformation in the foreland regions of contractional orogens. Deformation style in the hinterland regions is frequently characterized as "thick-skinned", but there is little agreement concerning deformation processes or the nature of the transition from thin-skinned to thick-skinned deformation. In the southern Canadian Cordillera the decollement beneath the Rocky Mountain Thrust and Fold Belt has been tracked into the hinterland region of the Omineca Belt, where surface mapping together with metamorphic, geochronologic and seismic data constrain the structural style and deformation processes. These data indicate a scenario of diachronous penetrative non-coaxial flow within the middle crust. A ductile zone of complex progressive folding and transposition has accommodated upper level displacement of the orogen northeastward toward the foreland. The zone attains a thickness of over 10 km within the hinterland and thins northeastward toward the foreland where it is replaced by the discrete basal decollement that underlies the Rocky Mountain Thrust and Fold Belt. These observations indicate that seismic transects of the hinterland, which have been interpreted in terms of a Rocky Mountain Belt style of thrust imbrication should be treated with caution.

New Apatite Fission Track Results from Vancouver Island, the Southern Coast Mountains, and the St. Elias Mountains: Implications and Questions for the Tertiary and Younger Tectonic History of the Western Canadian Cordillera.

LISEL D. CURRIE, Geological Survey of Canada, 100 West Pender St., Vancouver, B.C. V6B 1R8; SANDY (A.)M. GRIST, Fission Track Laboratory, Dalhousie University, Halifax, N.S. B3H 1J5; and P.B. O'SULLIVAN, LaTrobe University, Bundoora, Victoria, Australia.

For the past 40 million years, southwestern British Columbia has been part of the Cascade magmatic arc, which formed above the subducting oceanic Juan de Fuca Plate. During this time interval, most of Vancouver Island apparently lay in the forearc region between the arc and the subducting plate. The Vancouver Island-Southern Coast Mountains was undertaken to determine the Cenozoic to Holocene cooling history of the forearc, which reflects the thermal, surface uplift and denudation histories of the region.

New apatite fission track geothermometry results indicate that after ~130 Ma the southwesternmost Canadian Cordillera experienced at least five periods of episodic, and in some cases localized, rapid low temperature cooling; each episode can be tentatively linked to a tectonic cause. Mid-Cretaceous rapid low-temperature cooling is attributed to the surface uplift and erosion of the thrust belt that formed along the margin at that time. It is also correlated with a mid-Cretaceous unconformity that is locally preserved. The direct cause of cooling along the western margin of the southern Coast Mountains at ~67 Ma is not clear. 50 Ma rapid cooling recorded farther east, near the Yalakom Fault, is probably the result of normal faulting in this area. ~30 Ma cooling ages in the region of the Fraser River fault zone reflect reheating associated with the formation of the Cascade Magmatic Arc. The <15 Ma rapid cooling recorded north of 50°N may be due to coeval extension in the Queen Charlotte Basin.

Rapid cooling between 30 and 40 Ma on Vancouver Island is attributed to cooling following Cowichan Fold and Thrust System deformation and provides a tool for documenting the extent of this system beyond the bounds of the preserved Nanaimo Group sedimentary rocks. Fission track thermochronology for the Alberni Inlet area indicates that the Cowichan Fold and Thrust System continued farther northwest than previously documented.

The rugged geomorphology of the St. Elias Mountains, including Mt. Logan, is suggestive of a young mountain belt. New apatite fission track data support this inference, and indicate that the Mt. Logan massif experienced rapid low temperature cooling during three distinct periods. Eocene cooling may be due re-equilibration of isotherms following normal faulting caused by a combination of thermal weakening of the crust and a decreased in regional compressional stress due to the ~43 Ma change in relative motions between the Pacific and North American plates. The reason for Miocene cooling is problematic, and appears to reflect a change in heat flow, not necessarily related to denudation. Pliocene cooling reflects erosion due to surface uplift that produced the spectacular topography of these mountains. This surface uplift is probably related to the coeval significant change in relative motion between the North American and Pacific plates and/or resistance to subduction by the Yakutat terrane.

The Cordillera-North American Craton Transition: Crustal Thickness, Heat Flow and Thermal Isostasy

R.D. Hyndman and T. Lewis

Pacific Geoscience Centre

Geological Survey of Canada

P.O. Box 6000 Sidney B.C. V8L 4B2

Introduction

There is a pronounced change in crustal and upper mantle geophysical characteristics from the eastern Canadian Cordillera to the stable North American craton. The crust thickens eastward from ~35 km in the S.E. Cordillera to ~45 km in the N. Am. craton, and the velocity of the lower crustal decreases from about 6.7 km/s to 6.4 km/s (Kanasewich et al., 1987; Cook et al., 1992; Zelt and White, 1995; Burianyk and Kanasewich, 1995; Clowes, 1995, and references therein) (**Figure 1**). However, this geophysical boundary, located beneath the Purcell Anticlinorium (east of Kootenay Arc and west of the Rocky Mountain Trench) in the S.E. Cordillera, may not represent the eastern edge of the ancient N. Am. craton. That edge may lie several hundred kilometres to the east as defined especially by the strontium isotope ratios (Ghosh, 1991). If this interpretation is correct, the deep geophysical boundary represents the eastern extent of the lithosphere affected by a later process. In this article we show that this boundary, especially the crustal thickness change, is primarily a consequence of the thermal contrast across this boundary and of isostasy. There is a decrease in heat flow eastward from high values of 60-100 mW/m² in the Cordillera to 40-60 mW/m² in the craton (e.g., Lewis et al., 1992; Hyndman and Lewis, 1995), probably as a consequence of extension in the Eocene (e.g., Parrish et al., 1988; Brown and Carr, 1990; Bardoux and Mareschal, 1994).

The Canadian Cordillera is characterized by a thin crust and generally high elevation. This is contrasted to the craton to the east which has generally lower elevation and thicker crust. In terms of isostasy, this

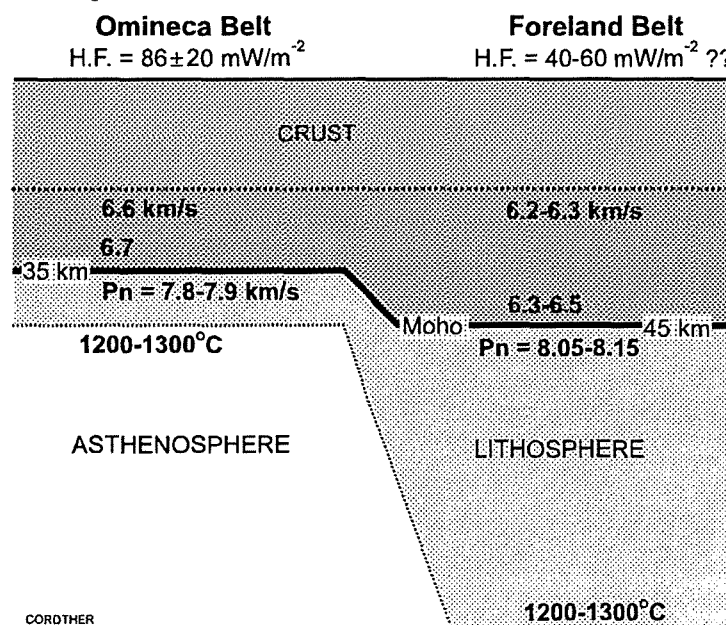


Figure 1 Crustal thickness and velocity transition across the S.E. Canadian Cordillera - North American craton transition (after Zelt and White, 1995). The crust thickens from ~35 km in the S.E. Cordillera to ~45 km in the N. Am. Craton, and the lower crustal velocity decreases from about 6.7 km/s to 6.4 km/s.

juxtaposition is remarkable. If there are no other processes operating, a thick crust should result in high elevation (as shown by the very thick crust and high elevations of Himalayas and Tibet) and a thin crust in low elevation (as is shown by the thin crust and low elevation of the ocean basins). Isostatic balance between the two regions in S.E. British Columbia requires that there be anomalously low densities in the Cordilleran crust or mantle. We can exclude low crustal densities in the Cordillera as the explanation since the deep crust of the Cordillera, especially its eastern part, has unusually high seismic velocity (e.g., Zelt and White, 1995) and thus inferred higher rather than lower crustal density compared to the craton. We conclude that the anomalously low density beneath the Cordillera lies in the mantle, and postulate that its origin is thermal expansion associated with high temperatures (see also Lowe and Ranalli, 1993).

Temperature and Pn Velocities

The main constraint to models of crustal and upper mantle temperature is surface heat flow and radioactive heat generation. There is considerable heat flow and heat generation data in the eastern Cordillera (Lewis et al., 1992). There is also extensive data in the craton much further to the east that defines the lower heat flow.

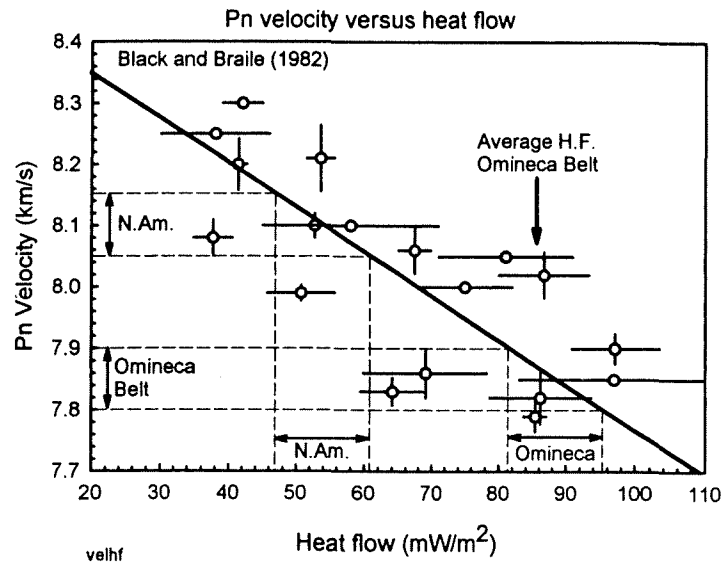


Figure 2 Uppermost mantle Pn velocity as a function of heat flow from the North America and Australia compilation of Black and Braile (1982). The line is their least squares fit. The Pn velocity from the Omineca Belt is 7.8-7.9 km/s and just to the west in the craton it is 8.05-8.15 km/s, from the results of Zelt and White (1995). This implies heat flow of 81-95 mW/m² for the Omineca Belt and 47-61 mW/m² to the east in good agreement with the range observed.

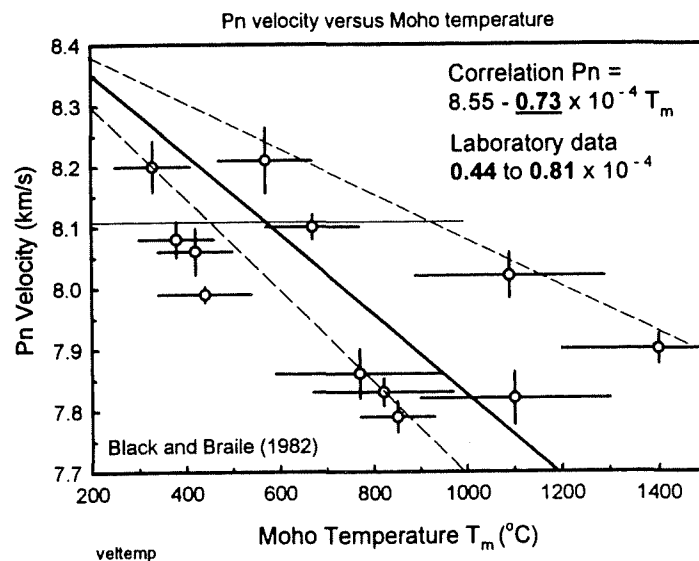


Figure 3 Upper mantle Pn velocity as a function of estimated Moho temperature (taken at 30 km) from the compilation of Black and Braile (1982). The dashed lines give the range of velocity versus temperature from laboratory measurements of upper mantle composition rocks.

However, in the fold and thrust belt area just to the east of the geophysical transition, there is little reliable data. Large scale regional water flow appears to disturb the upper crustal thermal regime. To obtain a sharper resolution of the thermal boundary we have employed a thermal proxy, uppermost mantle seismic velocity Pn. Black and Braile (1982) have demonstrated that there is a systematic relation between Pn velocity and surface heat flow (**Figure 2**). There is also a relation between Pn velocity and Moho temperature as estimated from the surface heat flow, in approximately agreement with that predicted by laboratory velocity-temperature data for mantle rocks (**Figure 3**). The relations assume that other factors that affect Pn velocity such as anisotropy and detailed composition differences (i.e., refractory shield mantle or mafic intrusion into the uppermost Cordillera mantle) are less important. These relations allow us to map the thermal transition using LITHOPROBE seismic refraction data. The change in crustal thickness coincides with the Pn velocity boundary, and we thus infer it is coincident with the thermal boundary. The inferred heat flow contrast from Pn velocity is from 81-95 mW/m² in the Omineca Belt (in good agreement with measured heat flows of 86 ± 20 mW/m²) to 46-60 mW/m² in the region to the east of the boundary. At 30 km depth the temperatures are about 1000°C beneath the Omineca Belt and 600°C beneath the region to the east. The eastern Intermontane Belt generally has a slightly higher Pn velocity (7.9-8.0 km/s) than the Omineca Belt (7.8-7.9 km/s) (e.g., Burianyk and Kanasewich, 1995) which is in agreement with the difference in average measured heat flows of 73 mW/m² and 86 mW/m² respectively. The inferred temperature at the Moho is 100-200°C higher in the Omineca Belt. However, because of the uncertainties and variability in Pn velocity and because of the factors that affect Pn velocity other than temperature, the inferred difference in deep temperature in the two regions is barely significant.

Crustal Thickness and Thermal Isostasy

In this section we use a semi-quantitative analysis to see whether the temperature and thermal expansion density reduction provide enough buoyancy in the Cordillera lithosphere to balance the thicker crust to the east. The surface elevations are approximately the same so we ignore that part of the isostatic balance in this rough calculation. The model temperature-depth profiles for the lithosphere of the two regions are

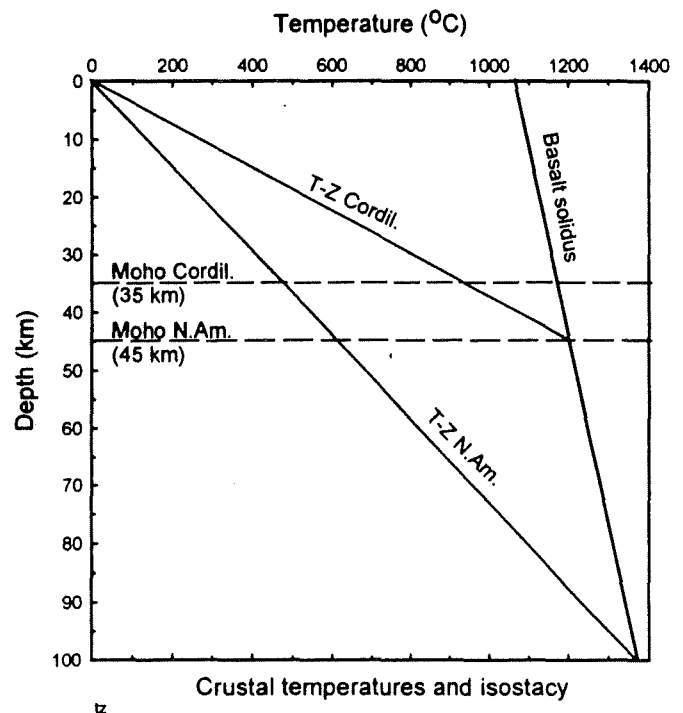


Figure 4 Simplified temperature-depth profiles for the S.W. Cordillera and the N. Am. craton, following the linear approximation analysis procedure of Lachenbruch and Morgan (1992).

shown in Figure 4. The actual temperature-depth profiles have decreasing gradient with depth but they have been approximated by the linear equivalent gradients as a function of surface heat flow, following Lachenbruch and Morgan (1990). An approximate basalt solidus has been taken as the base of the lithosphere. The crustal and mantle compositions have been assumed to be the same across the

boundary. The crustal thickness required for isostatic balance is shown as a function of heat flow in Figure 5.

The Omineca Belt with a 33 km thick crust (Line 9 from Zelt and White, 1995) and a heat flow of 89 mW/m² (Lewis et al., 1992) has been taken as the reference. The 41 km thick crust on the east side of the boundary along the profile of Zelt and White (1995) then requires a heat flow of about 45 mW/m². This is in approximate agreement with the range of 46-60 mW/m² estimated from the Pn velocity and with the few heat flow measurements (Lewis et al., 1992). Our result is similar to that of Crough and Thompson (1976), i.e., a 40 km increase in lithospheric thickness (defined by basalt solidus temperature) results in 1 km decrease in surface elevation. Alternatively, the elevation can be maintained by about a 7 km increase in crustal thickness. We conclude that the crustal thickness contrast is mainly a consequence of the contrast in heat flow and in lithosphere temperature across the boundary.

A reflection profile in northeastern British Columbia in a similar tectonic position (Cook and Van de Velden, 1993) also shows a thickening of the crust by about 10 km eastward. This boundary probably represents a similar transition to that in the south. Heat flow data and Pn velocities, and crustal thickness data in the SNORCLE Lithoprobe area, are needed to map this transition and to confirm that it is associated with the eastern limit of Cordillera high heat flow.

Discussion and Conclusions

1. The transition from thin crust beneath the eastern Canadian Cordillera to thick crust beneath the foreland belt and North American craton (and various other geophysical contrasts) is associated with a thermal boundary.

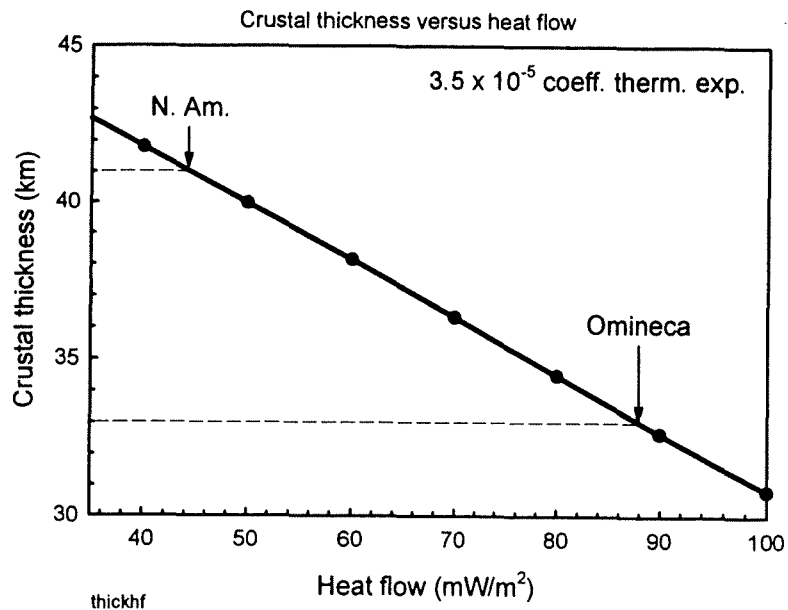


Figure 5 Crustal thickness as a function of heat flow assuming constant surface elevation, constant crustal and upper mantle composition, and thermal isostasy (following Lachenbruch and Morgan, 1992).

2. The uppermost mantle Pn velocity is related to heat flow. The main control of Pn velocity appears to be temperature just below the Moho.

3. Isostatic balance across the crustal thickness boundary is achieved by thermally generated low density in the Cordilleran lithosphere. Major crustal thickness variations are primarily a consequence of thermal isostasy and not the result of previous tectonic process such as thrusting that thickened, or normal faulting that thinned the crust.

4. The crustal thickness boundary mapped by seismic reflection and refraction along the eastern Cordillera should allow definition of the eastern boundary zone of enhanced temperature in the Cordillera. The high temperature may be produced by Tertiary extension or by an asthenosphere upwelling process that markedly reduced the thickness of the thermal lithosphere.

5. The high lithosphere temperatures beneath the Cordillera imply very low lithospheric strength, about a factor of 10 weaker than the craton to the east (e.g., Lowe and Ranalli, 1993). Only the upper crust has significant strength in the Cordillera; in the foreland belt and craton to the east, the upper mantle as well as the crust has significant strength. The high temperatures inferred from the high heat flow and low Pn velocities, imply that in much of the Cordillera the lower crust is now in granulite facies conditions, and that the basalt solidus (and partial melting) is just below the Moho.

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TECTONIC EVOLUTION OF THE CIRCUM-NORTH PACIFIC REGION

J.W.H. Monger¹, W.J. Nokleberg², L.M. Parfenov³

¹Geological Survey of Canada, Vancouver; ²United States Geological Survey, Menlo Park;

³Russian Academy of Sciences, Yakutsk

Rocks of the circum-North Pacific orogenic system can be assigned to four main tectonic settings: (1) the two Precambrian North American and North Asian (or Siberian) cratons (or "backstops") and their overlying cratonal margin deposits; (2) craton fragments and proximal and distal pericratonic rocks formed near cratons but displaced from their paleolocations; (3) arc rocks formed on oceanic and/or transitional and/or continental crust; and (4) accretionary complexes comprising disrupted oceanic lithosphere and overlying sediments. Areal arc and pericratonic terranes are the most extensive in the circum-North Pacific margin. Most terranes appear to be parts of originally more continuous entities, such as linear arc chains and accompanying accretionary complexes, which subsequently became fragmented, displaced, and accreted mainly in the Mesozoic to the craton margins.

The Phanerozoic record of the paleogeography of perhaps half the Earth's surface is preserved only in the collages fringing the Pacific Ocean; the remainder of that record is dispersed within the mantle. Reconstructions of oceanic plates permit paleogeographies to be, at best, ascertained only as far back as the latest Jurassic. How to see farther back in time? Positions of the cratons are reasonably well known, and some terranes carry distinctive paleontological and/or paleomagnetic markers. Other keys to unravelling the cryptic paleogeography of the ancestral Pacific basin are former convergent plate margins, recorded by arcs and accompanying accretionary complexes, facing directions of arcs, and times at which arcs can be linked to cratons.

In Canada and Alaska, most mid-Paleozoic and younger arcs appear to have formed on the North American Plate, that is, facing the Pacific Ocean basin and its ancestors. Possible exceptions are late Paleozoic arcs in Yukon, and mid-Mesozoic arcs in west-central Alaska. In the Russian Northeast, arcs formed on the margin of the continental and oceanic Asian Plate possibly only after early Mesozoic time. A tentative evolution of the North Pacific region follows:

- (1) In the late Proterozoic (ca. 700 Ma), opening of the ancestral Pacific Ocean basin by rifting and separation of the Late Proterozoic supercontinent;
- (2) In the Middle Devonian (ca. 380 Ma), formation of an arc along the North American plate margin, mostly within the pericratonic terranes;
- (3) In the Devonian-Mississippian (ca. 370 Ma), opening of a back-arc basin behind the arc, contemporaneously with rifting of the North Asian craton margin; the basins grew to form a second ocean (represented by Slide Mountain-Seventy Mile-Angayucham terranes)
- (4) In the early Mesozoic (ca. 230-185 Ma), a single North American plate margin arc and its accompanying accretionary complex extended from the southwestern U.S. craton latitudinally across the ocean basin, separating the ancestral Pacific to the south from the (closing) "second ocean" basin to the north; most Cordilleran accreted terranes (Quesnellia, Stikinia, Wrangellia, Cache Creek, "inner Chugach") are fragments of this arc system;
- (5) In the Middle Jurassic-Early Cretaceous (ca. 180-100 Ma), a single arc system featuring sinistral convergence probably extended across the North Pacific; parts of this arc system formed on North Asian and North American craton margins; in Alaska the remaining "second ocean" was closed, and narrowing of the ancestral Pacific Ocean basin was initiated;

- (6) In Early Cretaceous time (ca. 130 Ma), rotation(?) of Arctic Alaska-Chukotka out of its original location in the western Canadian Arctic craton was accompanied by opening of the Canada Basin;
- (7) In mid-Cretaceous time (100-85 Ma), orthogonal convergence between North American and various Pacific plates, was succeeded in Late Cretaceous-early Tertiary time (85-40 Ma) by dextral convergence along the Eurasian-North American plate margin;
- (8) In the Tertiary and Quaternary (40-0 Ma), an arc-transform-arc plate boundary has existed along the North Pacific margin.

ABSTRACTS of POSTER PRESENTATIONS

$^{40}\text{Ar}/^{39}\text{Ar}$ Laser-Probe Dating Studies in the Canadian Cordillera.

Douglas A. Archibald, Department of Geological Sciences, Queen's University, Kingston, Ontario K7L 3N6 (e-mail: archiba@geol.queensu.ca)

Conventional $^{40}\text{Ar}/^{39}\text{Ar}$ step-heating of micas from the Yukon-Tanana terrane and northern Vancouver Island yielded some anomalous age spectra that appear to result from incorporation of minor excess argon-40 and/or reactor-induced recoil redistribution of argon-39. To investigate these problems further, single mica flakes ranging from 0.25 to 1.5 mm in diameter have been studied using the argon-laser probe at Queen's University. The high-sensitivity of the new mass spectrometer permits analysis of small single flakes by total-fusion, analysis of 50u domains ('spots') in larger flakes, or, using a de-focused laser beam, step-heating of single grains or very small samples.

Six sites of high-pressure rocks in the Yukon-Tanana terrane (being studied by Erdmer, Ghent and Stout) are being dated by conventional step-heating and also investigated using the laser probe. White mica from the eclogites and blueschist-facies rocks yields good, but not perfect, $^{40}\text{Ar}/^{39}\text{Ar}$ plateaus. Some conventional spectra have a 'U-shape' suggesting incorporation of excess argon-40 whereas others show an apparent diffusive-loss profile. The laser-probe provides a way to map the distribution of argon in large flakes and test for loss or gain of argon in the margins of grains or in crystal defects. As a test case, the coarsest white mica from an eclogite from Faro (PE80-F3, up to 1.5 mm in diameter) was selected for spot dating. Five of the 8 spots representing a transect of a single flake produced sufficient gas for analysis. Regardless of position in the grain, the dates equal the conventional plateau segment date of 260 Ma. There is no argon isotope gradient preserved in this mica. The isotope correlation plot of the conventional step-heating data does not show the presence of excess argon. The two data sets support the interpretation that the Faro eclogite had cooled to 350°C by 260 Ma. Additional laser probe analyses of micas from other sites in this terrane are in progress.

The plutonic rocks of northern Vancouver Island are being dated as part of a project with the B.C. Geological Survey Branch (Nixon). North of Holberg Inlet all of these rocks show pervasive chloritization of mafic minerals. No 'fresh' biotites were separable and it is estimated that the biotites contain between 1 and 4 %K. In all cases the biotites yielded 'hump-shaped' spectra and in the case of the Rupert stock, dates greater than the U-Pb zircon date for the same rock. Although uptake of excess argon could produce a similar effect, it is more probable that argon-39 was lost from the laminated chlorite/biotite mixtures during irradiation. To test this, single biotite flakes of similar diameter but different thicknesses were fused by laser and analyzed. Thin flakes yielded erratic, anomalously old dates. However, the thickest grains yielded total-gas ages approaching the U-Pb zircon date and $^{40}\text{Ar}/^{39}\text{Ar}$ hornblende date for this pluton. The correlation of date and grain thickness supports the recoil-loss hypothesis and suggests a way in which this common problem may be addressed. Laser dating of chloritized biotite from other plutons in the region is in progress.

SEISMIC INTERPRETATION AND 3-D VISUALIZATION OF ALONG-STRIKE VARIATIONS IN THE ROCKY MOUNTAIN THRUST FRONT, AROUND THE CROWSNEST DEFLECTION IN SOUTHERN ALBERTA

Bégin, N.J., Lawton, D.C., Spratt, D.A. and Kellett, R.L., Foothills Research Project, Dept. of Geology and Geophysics, University of Calgary

Introduction

The Rocky Mountain Thrust Front in the Canadian Cordillera of Alberta is characterized by tectonic wedging of east-verging imbricates that form the integral part of the triangle zone (Dahlstrom, 1970; MacKay et al., 1994; Price, 1986). Rocks were thrust into the foreland succession due to tectonic wedging during the late stages (Paleogene) of eastward propagation of deformation associated with the Laramide Orogeny. In the eastern foothills, allochthonous rocks that make up the intercutaneous wedge are bounded by two faults that carry thrust sheets of opposite structural vergence. Delamination of the foreland succession occurs as the wedge is driven further into the basin (Price, 1986). The base of the triangle zone is a foreland-verging, blind lower detachment that evolves first as a bedding-parallel flat, then cuts upsection in a typical ramp-flat geometry. The top of the wedge is marked by a foreland-dipping upper detachment, usually developed as a bedding-parallel fault in rheologically weak horizons (e.g. shales, coals) of the uppermost Cretaceous rocks. Where the two detachments merge together in the foreland, they define the toe of the wedge. This paper presents results of the interpretation of over 160 line-km of high-quality reflection seismic data in the area of the "Crowsnest Deflection" (CND) (Dahlstrom, 1970), where the trend of the fold and thrust belt in the southern Canadian Cordillera swings sharply from north-south to approximately northwest-southeast. This paper is also intended to provide some new insights on the nature of the Crowsnest Deflection and its relationship to the geometrical and kinematic evolution of geological structures in the southern Canadian Rocky Mountain Foothills.

Geology and seismic data

The rock lithologies of the area are assigned to two major tectonostratigraphic packages. A lower package dominated by Paleozoic continental platform carbonates, overlain by an upper package of Mesozoic and Tertiary age rocks dominated by siliciclastics of the Alberta Foreland basin that were shed from the west during the Laramide orogeny. The seismic data consist of three north-south strike lines and four dip/oblique lines within the area of the CND. These data are valuable in that they provide three-dimensional coverage of the triangle zone in the region of the CND. The strike lines provide an excellent tie northwards to a dip line along the Oldman River (Lawton et al., 1994).

Results of seismic interpretation

The interpretation outlines three major fault-bounded domains in the Rocky Mountain Foothills of southern Alberta. The overall structural geometry consists of an allochthonous wedge of Mesozoic rocks defined by east-verging imbricates, sandwiched between an autochthonous suite of Paleozoic and Mesozoic rocks below, and rocks of the Alberta Syncline above. The main upper detachment, the Big Coulee Fault, and the lower detachment represent the present structural boundaries of these three domains. The Big Coulee Fault marks the boundary between east-verging and west-verging structures as well as the structural base of the Alberta Syncline; the Bearpaw Formation is the décollement horizon for the upper detachment. The lower detachment of the wedge runs bedding-parallel in Fernie Group rocks before ramping up-section into upper Mesozoic rock units towards the foreland. Other detachment horizons at intermediate depths within the allochthonous wedge are observed in shales of the lower and upper parts of the Alberta Group. Strike lines reveal evidence for lateral ramps (8° - 10°) in the Big Coulee Fault, to both the north and south. In addition, the Big Coulee Fault occurs at a greater depth (1.5 s reflection time) on the westernmost strike line than on the easternmost lines (1.0 s reflection time). Given that the thrust sheet is west-verging, this indicates that it has been folded by east-directed wedging of the structurally lower imbricates, similar to that observed by Lawton et al. (1994) further north. Faults above the Big Coulee Fault that repeat the uppermost Cretaceous stratigraphy appear to terminate toward the south, north of the Crowsnest River. In addition, these faults do not show any evidence of folding. This indicates that these faults are younger than the Big Coulee Fault and suggests that west-verging faults above the triangle zone developed successively toward the east.

In the southern part of the CND, a major lateral ramp of 16° occurs in the lower detachment, as it cuts up-section to the north from Fernie Group to Alberta Group rocks. The upper detachment also displays a lateral ramp of 12° cutting up-section to the south. This leads to a difference of about 1000 meters in the overall thickness of the tectonic wedge across the CND. The Blairmore Group remains entirely autochthonous to the north, whereas it is carried within the tectonic wedge farther south. This is evidence for southward thickening of the intercutaneous wedge, in addition to its eastward-tapering geometry documented along the entire fold and thrust belt. When the upper and lower detachment surfaces of the wedge are combined together in three-dimensional perspective views, a lateral ramp can be observed. The ramp is oriented approximately east-west and its location coincides with the change in structural trend from north-south to northwest-southeast, in the vicinity of the Crowsnest River.

Conclusions

Three main features coincide with the location of the Crowsnest Deflection and affect the overall structural architecture: 1) the southward thickening of the allochthonous wedge; 2) the southern termination of the easternmost, youngest west-verging structures; and 3) the lack of folding of the Big Coulee Fault south of the Crowsnest River. As such, the Crowsnest River area represents the approximate limit between two structural domains in the eastern foothills of southern Alberta, along the CND. Our interpretation suggests that the trends of the folds and thrusts in the area were curved when they formed during the Laramide orogeny, possibly mimicking the geometry of the underlying crystalline basement (Cook et al., 1991) that also controlled the geometry of the tectonic wedge as well as the lateral extent of its overlying structures.

Acknowledgments

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THEMATIC STRUCTURAL STUDIES IN THE SLAVE PROVINCE: THE SLEEPY DRAGON COMPLEX

Wouter Bleeker
Geological Survey of Canada
601 Booth Street, Ottawa, ON, K1A 0E8

The geometry of the Sleepy Dragon Complex, a controversial structure in the Yellowknife Domain of the Archean Slave province, is shown to be a mushroom interference pattern between regional F1 and F2 folds (Bleeker and Beaumont-Smith, 1995; Bleeker and Villeneuve, 1995). Critical evidence in favour of a F1 fold hinge on the western side of the complex is provided by a change in vergence of the S1 schistosity and coplanar bulk flattening planes in pillows. The Sleepy Dragon Complex basement uplift was initiated as a high-amplitude F1 anticline, not as a syn-depositional horst (Bleeker, in press).

A well-preserved quartzite/BIF assemblage underlies the Cameron River basalts at Patterson Lake. This assemblage is cross-cut by the deformed and metamorphosed dykes that likely fed the Cameron River basalts.

It is suggested that the contact between the Cameron River basalt pile and an overlying rhyolite unit represents an intravolcanic, angular unconformity that is laterally equivalent with the unconformity at the base of the Raquette Lake Formation. This ca. 2680 Ma unconformity is probably equivalent to the angular unconformity at the base of the Banting Group in the Yellowknife greenstone belt proper.

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The Williston-Liard Project. A major new initiative to study the geology of the foothills and subsurface in central cordillera and southern territories.

M.P. Cecile, Geological Survey of Canada - Calgary, 3303 - 33rd St. N.W., Calgary, Alta. T2L 2A7. FAX - 292 4961; email cecile@gsc.emr.ca

The Williston-Fort Liard Project is planned to be a multidisciplinary, multipartner map and subsurface study of northeastern British Columbia, southern Yukon, and southern Northwest Territories beginning in 1998 (Fig. 1). The project will be managed by GSC and its provincial and territorial partners and will include industrial and academic projects that are compatible or complimentary to the objectives of the main project (see below). The project will be divided into two major activities one focused on detailed 1:50 000 scale mapping in three selected foothills transects with high hydrocarbon potential, and 1:250 000 and 1:500 000 map compilation. The other part will focus on subsurface studies including northeastern B.C., Liard Basin and the southern Northwest Territories.

All maps will be published in both paper and digital form. The new digital maps will be in a GIS format. The three transects, from south to north, are, in order of priority: 1) southern Truch map-area (94G); 2) central La Biche (95C) and Fort Liard (95B) map areas; and 3) central Tuchodi Lake map area (94K).

The new map data will be used to prepare detailed structural cross-sections which hopefully will be augmented with donated reflection seismic data. New Radarsat images will be used to refine and assist in mapping as an experiment in their application. Mapping will also include a detailed structural fabric analysis, and detailed surface stratigraphic and biostratigraphic studies in Upper Paleozoic, Triassic, Jurassic and Cretaceous strata found in the new map-areas. The maps will be integrated with all data collected, and all existing data, including drill holes through a GIS information system.

A number of separate activities or projects will be associated with the core mapping project. These activities and projects will: compile, update and publish existing maps across the entire project area; carry out detailed stratigraphic and sedimentological studies; map areas of high mineral potential; map Quaternary deposits; carry out paleontological/biostratigraphic studies; utilize the data collected for assessment of hydrocarbon potential and land use planning; assessment of coal potential, etc.

The subsurface projects will focus on stratigraphy, biostratigraphy and basin analysis. Projects will be divided on the basis of time and area. Time divisions will be Lower Paleozoic, Devonian, Upper Paleozoic, Triassic, Jurassic-Lowermost Cretaceous, Cretaceous. Focus areas in terms of priority will be Laird Basin, Northeast British Columbia and the southern territories.

There will be related projects using geophysical data, heat flow, basin architecture, resource assessment, etc.

Partnerships and participation

The Williston Liard Project is proposed to be a fundamental project of the Geological Survey of Canada and its provincial and territorial partners. As such its basic funding and manpower will come from these agencies. However the level of funding anticipated from government agencies will be very limited.

Therefore any parties interested in joining the project can generally expect to be supported only through shared effort and logistics. Any partners interested in joining the project should be making a real contribution of manpower, expertise and/or money to the major objectives of the project. Any proposal will be considered but will be prioritized according to how well they fit into the objectives of the main project activities.

Industrial and university participation and expertise is critical to the success of this project. As an example structural cross-sections through the map-areas and regional structural sections, outside these areas, would be relatively primitive without access to seismic data. Purchasing or acquisition of seismic data is beyond the financial ability of the principal partners. In addition industry and universities have a different mandate and perspective on the geology of the area, and on the problems to be addressed. Thus we are open to any contribution that industrial or university, partners are willing to offer. These contributions could be geophysical or geological data, manpower, co-operative projects, financial assistance, advice, etc., and can be directed toward any of the participants - government, university or industrial, or to any aspect of the project.

There is obviously great scope for participants in the SNORCLE Lithoprobe Transect and the Williston Liard project to combine effort and logistics and achieve even greater results, particularly if the SNORCLE Project can be extended to the Alaska Highway. Participants in both projects should consider the possibility of integrated efforts.

Parties interested in the Williston-Liard Project should FAX or Email a detailed proposal to the address above.

Williston - Liard Map Project

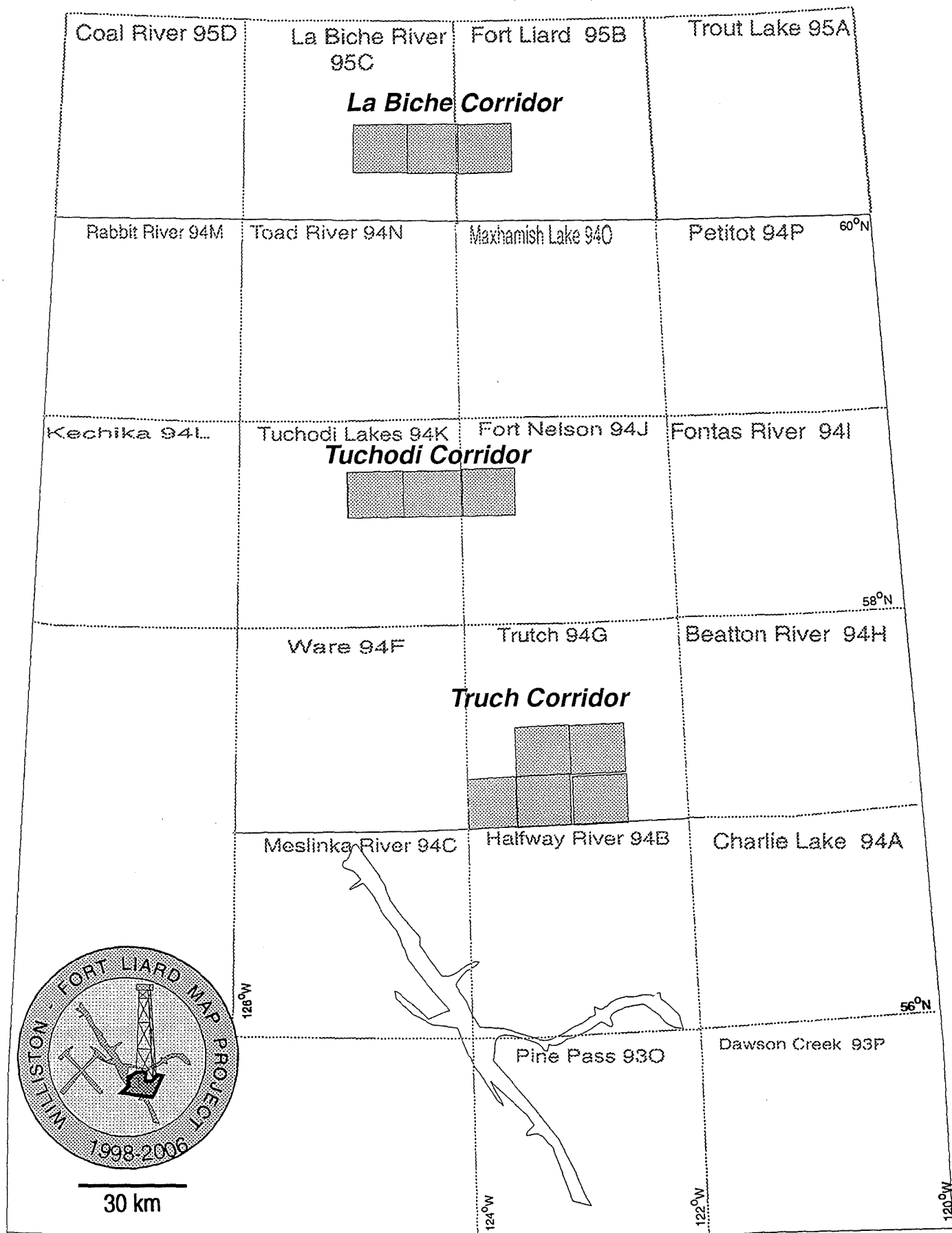


Fig 1. Proposed map compilation project are and future 1:50 000 scale mapping transects. Subsurface studies would include area shown and areas further east and north.

$^{40}\text{Ar}/^{39}\text{Ar}$ thermochronometry along the western flank of the Selkirk fan structure, SE British Columbia

Maurice Colpron, Dept. Geological Sciences, Queen's University, Kingston, Ontario K7L 3N6

The Selkirk fan structure is a segment of the regional zone of structural divergence that extends along the Omineca belt from northeast Washington to east-central Alaska (Eisbacher et al., 1974; Price, 1986). It consists of the North American miogeoclinal rocks of the Neoproterozoic to Early Cambrian Horsethief Creek and Hamill groups, and the overlying outer basinal facies of the Lower Paleozoic Lardeau Group (and equivalents). The eastern flank of the Selkirk fan structure is defined by a northeast-verging imbricate thrust system that is part of the Rocky Mountain fold and thrust belt (Simony and Wind, 1970; Kubli and Simony, 1994). The western flank is defined by southwest-verging fold-nappes and thrust faults (Wheeler, 1966). It has been dissected by Tertiary extension of the Shuswap complex.

The western flank of the Selkirk fan structure comprises two structural levels separated by the Standfast Creek fault. At high structural level, rocks of the Lardeau Group are intruded by a suite of Middle Jurassic granitoid plutons in the Illecillewaet synclinorium. $^{40}\text{Ar}/^{39}\text{Ar}$ thermochronometry indicates that rocks in the Illecillewaet synclinorium cooled rapidly after intrusion of the Middle Jurassic plutons. Furthermore, thermobarometric analyses show that rapid cooling of the Illecillewaet synclinorium was accompanied by decompression in the order of ca. 3 kbar. This data is interpreted to reflect rapid denudation of the Illecillewaet synclinorium during Middle Jurassic tectonism.

The lower structural level (the Clachnacudainn "terrane") comprises a sequence of metasedimentary rocks that are correlated with the Lardeau Group (Read and Thompson, 1980; Crowley and Brown, 1994) and multiple intrusives that span in age from Devonian-Mississippian to Late Cretaceous (Clachnacudainn Igneous Complex, Crowley and Brown, 1994). On the basis of Eocene K-Ar mica dates from the Clachnacudainn "terrane" (Birmie, 1976), Parrish et al. (1988) have suggested that significant extension and unroofing of the Clachnacudainn "terrane" has occurred along the Standfast Creek fault in the Eocene. However, the fault is intruded by the mid-Cretaceous Albert Stock (104 $\pm$ 1 Ma, Crowley and Brown, 1994; Sears, 1979). Parrish et al. (1988) have speculated that an extensional branch of the Standfast Creek fault diverges from its compressional segment south of Trans-Canada highway, and carries the Albert Stock in its hangingwall. Crowley and Brown (1994) have challenged this interpretation. They have shown that both segments of the Standfast Creek fault are intruded by mid-Cretaceous plutons, and they have argued that the Standfast Creek fault has minor tectonic significance.

$^{40}\text{Ar}/^{39}\text{Ar}$ thermochronometry from the Clachnacudainn "terrane" indicates that the eastern part of the "terrane" cooled below Ar closure in hornblende (ca. 500°C) shortly after intrusion of the mid-Cretaceous plutons. Hornblende from the western part of the "terrane" have latest Cretaceous cooling dates which reflect intrusion of the Mount Revelstoke leucogranite at ca. 71 Ma (Parrish, 1992). Micas from the southern part of the Clachnacudainn "terrane" typically have disturbed age spectra. Muscovites from the core of the Akolkolex anticline (hangingwall of Standfast Creek fault) yield an integrated age of 91 Ma, and maximum step-ages of ca. 97 Ma, suggesting initial cooling of muscovites after mid-Cretaceous plutonism in the area. Muscovite cooling dates become progressively younger to the northeast, as the Late Cretaceous intrusive body is approached, and there is no sharp variation in cooling ages associated with the Standfast Creek fault. Biotite cooling dates from both hangingwall and footwall of the Standfast Creek fault are generally in the range of 60-70 Ma. This data suggests initial cooling (or resetting ?) of the Clachnacudainn "terrane" in the mid-Cretaceous and subsequent extensive reheating during intrusion of the Mount Revelstoke leucogranite in the Late Cretaceous. The Late Cretaceous reheating event has also affected rocks in the hangingwall of the Standfast Creek fault, suggesting that no significant displacement occurred along the fault after the latest Cretaceous. Thermobarometric data from the Clachnacudainn "terrane" indicate decompression of 2-3 kbar between synkinematic regional metamorphism (presumed to be Middle Jurassic) and mid-Cretaceous contact metamorphism (Sears, 1979; Crowley and Brown, 1994). It is proposed that decompression of the Clachnacudainn "terrane" occurred concurrently with that of the Illecillewaet synclinorium in the Middle Jurassic, and that the post-Jurassic thermal history of the

Clachnacudainn "terrane" reflects slow cooling after emplacement of granitoid plutons in the mid- and Late Cretaceous.

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IMPERIAL ANTICLINE, A FAULT-BEND FOLD WITH FAULT SURFACE BEDDING-PARALLEL IN BOTH RAMP AND FLAT

Donald G. Cook, and Bernard C. MacLean

Geological Survey of Canada, Calgary
3303 33 St. NW, Calgary, Alberta, T2L 2A7

ABSTRACT

Imperial Anticline

Seismic data from Mackenzie Plain west of Norman Wells show the east-west trending Imperial Anticline to be a fault-bend fold in the hanging wall of an overthrust. Tracing of hanging wall and footwall cutoffs demonstrates that displacement on the overthrust increases from 5 km in the west to 12 km in the east. The unconformity under basal Cambrian strata in the footwall of the overthrust truncates, at 10 degrees to 20 degrees, a southward thickening wedge of Proterozoic Mackenzie Mountains Supergroup strata. The thrust ramp is atypical because the detachment climbed structurally, while maintaining stratigraphic position, by following dipping beds in the supergroup wedge (Fig. 1a), to where it intersected the sub-Cambrian unconformity at which point it crossed a few meters of basal Cambrian strata (Mount Clark and/or Mount Cap formations) and diverted into flat-lying salt beds of the Cambrian Saline River Formation. Thus the detachment shifted from dipping Proterozoic beds to horizontal Cambrian salt beds, and Imperial Anticline (the hanging wall anticline) was caused by the forward displacement of the wedge of Proterozoic strata across this deflection zone (Fig. 1b). Basal Cambrian beds in the footwall of the overthrust may include potential reservoir sandstones of the Mount Clark Formation.

Mackenzie Mountains Supergroup

Proterozoic strata penetrated by the PCI Sammons H-55 well on the crest of Imperial Anticline were identified (Wissner, 1986; Rainbird et al., 1996) as Katherine Group and/or Tsezotene Formation, of the Mackenzie Mountains Supergroup. No reflection representing the informal H1 dolomite (Aitken et al., 1982) has been identified above the detachment surface, and accordingly the detachment may occur within, or near the base of, the Tsezotene Formation. If so, a Tsezotene thickness of about 1600 m would be implied, considerably greater than the aggregate estimated thickness of 1220 m in the adjacent Mackenzie Mountains (Aitken et al., 1973). Alternatively if H1 is not reflective the detachment may occur within or below the H1 dolomite. At least 1.5 km of parallel strata are imaged under the detachment surface. Although these older strata do not outcrop in the adjacent Mackenzie Mountains we assign the entire wedge to the Mackenzie Mountains Supergroup. The supergroup unconformably overlies deformed rocks of uncertain correlation which may represent strata deformed during the Early Proterozoic Racklan and/or Forward orogenies.

Regional two-step detachment

Regionally, the detachment surface is interpreted to climb in two steps (one inferred, the other imaged) from a level deep under the Mackenzie Mountains to the shallower level, within the Saline River Formation, under the Northern Franklin Mountains. The southernmost step is interpreted (Fig. 2) on the assumption that the frontal Mackenzie Mountains anticline, some 25 km south of Imperial

Anticline, is a fault-bend fold above a deep large classic thrust ramp. That ramp is inferred to cut across the lower part of the Mackenzie Mountains Supergroup, and older strata, to a bedding-parallel detachment within the supergroup wedge, possibly in the Tsezotene Formation. The bedding-parallel fault progressed up the wedge to the Saline River Formation salt beds to form the second step, the one imaged under Imperial Anticline (Fig. 1, 2). Once into the salt beds the detachment propagated to the north and northeast to form the Northern Franklin Mountains.

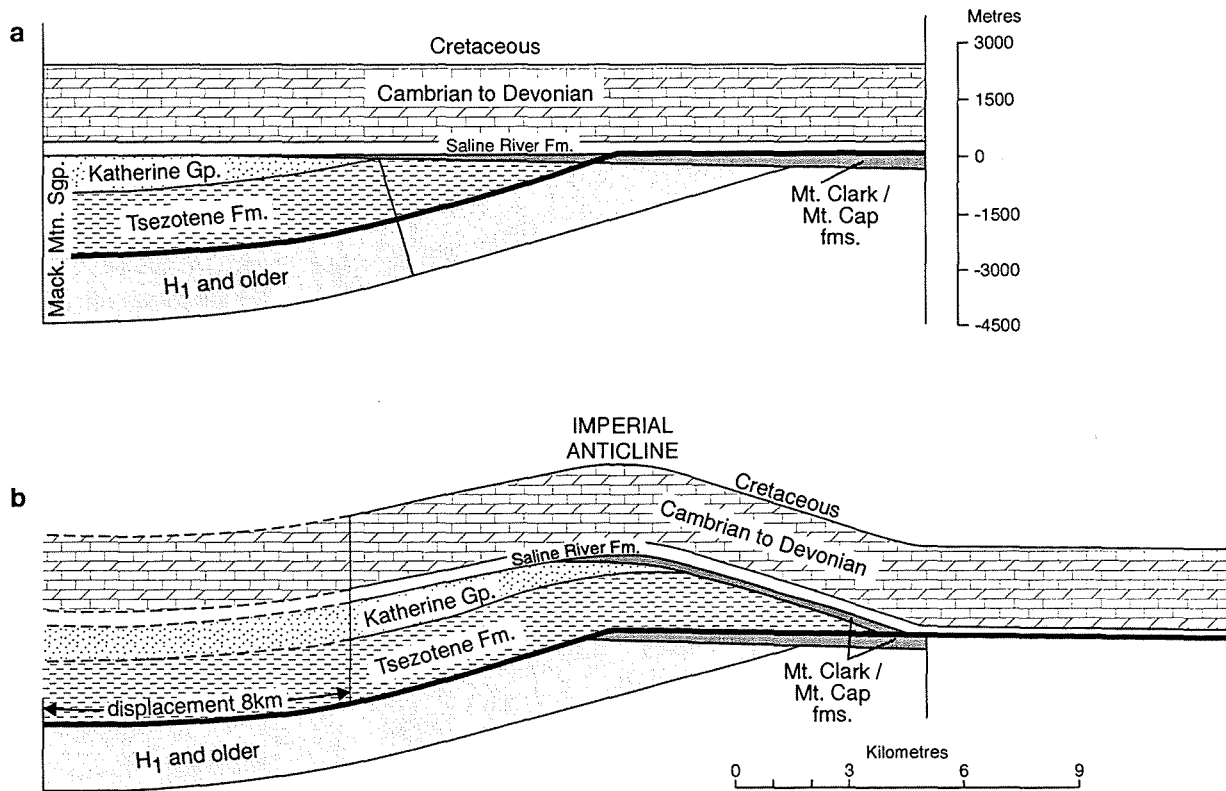


Figure 1. Schematic section illustrating a fault-bend fold wherein the fault surface is bedding-parallel in both ramp and flat. Section is approximately to scale based on Imperial Anticline, NWT.

a: Pre-thrust geometry. Bedding-parallel fault in dipping Mackenzie Mountains Supergroup intersects sub-Cambrian unconformity and diverts into flat-lying Saline River Formation salt beds.

b: Post-thrust geometry resulting from displacement of about 8 km.

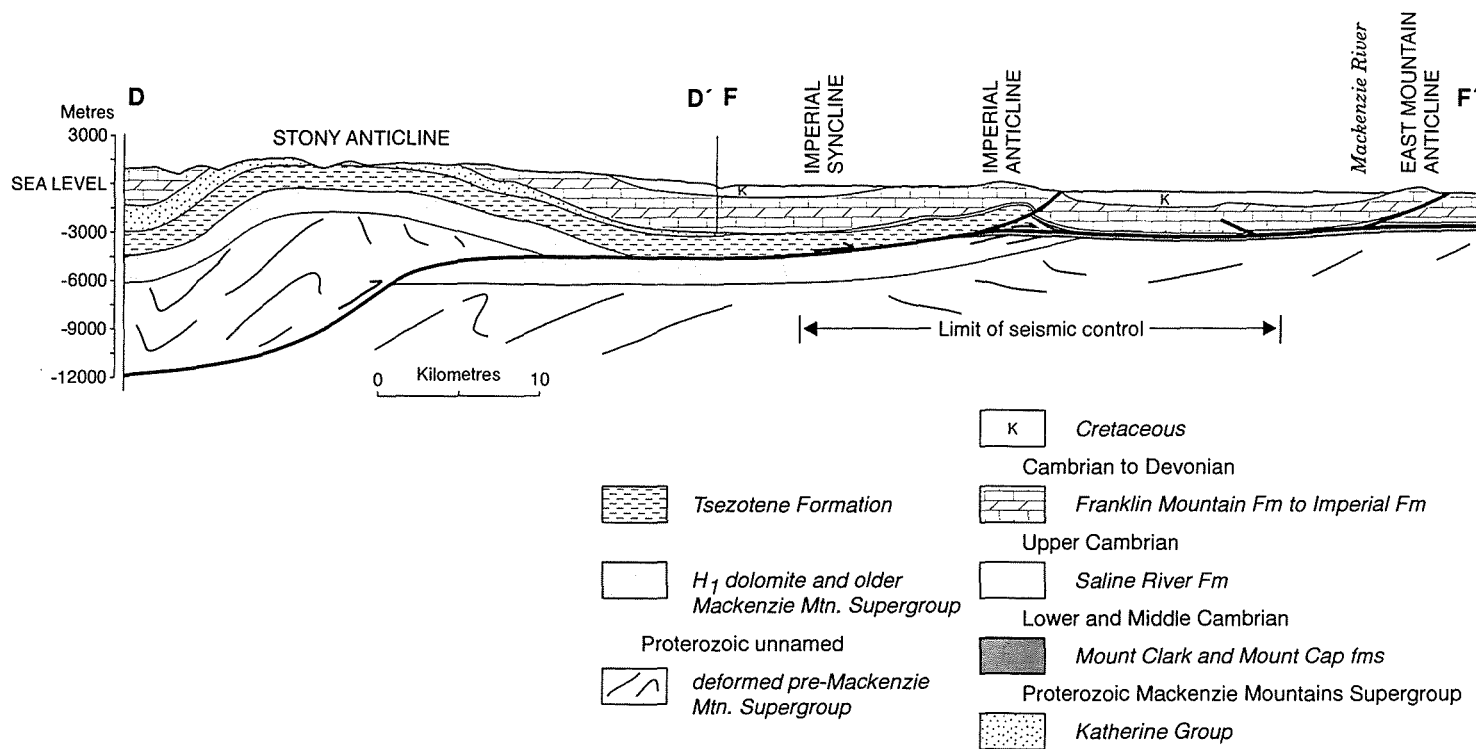


Figure 2. Cross section from Stony Anticline (Mackenzie Mountains) to East Mountain Anticline (Franklin Mountains). Surface geology is a composite section after sections D-D' and F-F' of Aitken et al. (1982). Depth structure under Stony Anticline is schematic; under Imperial Anticline is based on seismic interpretation.

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U-PB GEOCHRONOLOGY AND Nd ISOTOPIC STUDIES OF LOWER CRUSTAL XENOLITHS FROM THE CENTRAL SLAVE PROVINCE

W. J. Davis, Geological Survey of Canada, 601 Booth St. Ottawa, Ont. K1A 0E8

Lower crustal xenoliths recovered from kimberlites in the central Slave Province are mostly mafic granulites and consist of clinopyroxene, plagioclase, garnet, ilmenite, + orthopyroxene, + quartz, + rutile, + zircon, consistent with a mafic lower crust in the Slave Province. U-Pb data for metamorphic zircon overgrowths in a cpx-plag-gt mafic xenolith indicate that granulite metamorphism occurred at ca. 2.55 Ga, approximately 40-25 Ma after regional low P-high T metamorphism and granitic magmatism (2.60-2.58 Ga) in the upper crust. Magmatic activity of this age is present but rare in the upper crust. The pattern of younger metamorphic ages in the lower relative to the upper crust is similar to the thermal evolution of crust of the Superior Province as exposed in the Kapuskasing structure. In addition to the Archean granulite metamorphism, some xenoliths contain concordant zircon at 2.22 Ga or 1.27 Ga, similar in age to the Malley/Mackay and Mackenzie dyke swarms in the area. The dyke swarms are interpreted to have intruded laterally into the crust and inferred mantle source regions were located well outside the area from which the xenoliths were recovered. Nd mineral isochrons also record post-Archean ages, however there is no direct correspondance between zircon ages and Nd mineral isochrons. The sample with ca 2.55 Ga zircon growth has a slightly younger cpx-gt Nd isochron age of 2.48 Ga. The sample with ca 2.22 Ga zircon has a Nd isochron age of 1.87 Ga. A third sample which did not contain zircon yielded a gt-cpx isochron age of 2.06 Ga. The precise nature of the Proterozoic thermal effects in the lower crust remains uncertain.

Analog (centrifuge) modelling of thrust reactivation of normal faults and facies boundaries

John M. Dixon

Experimental Tectonics Laboratory, Dept. of Geological Sciences,
Queen's University

Analog scale modelling using the centrifuge technique is applied to examine how stratigraphic heterogeneities such as facies boundaries and structural heterogeneities such as antecedent normal (growth) faults affect the fold-thrust process. Work to date has involved deformation of generic models, but we aim to construct models with stratigraphic successions that simulate specific prototype examples from the Canadian Rocky Mountains so that the resulting model structures can be compared with natural structures constrained by field and seismic investigations.

Models constructed of materials such as plasticine and silicone putty, serving as appropriately scaled rheological analogues for different rock types, can be subjected, in a unique 20,000-g centrifuge, to high accelerations which simulate the Earth's gravitational field. One advantage of analog modelling is that the model can be studied during its deformation and the kinematic evolution of structures can be documented. By varying the model's design, the influence of these variables on structural evolution can be determined.

Models with reactivation of normal faults: This study examines the effect of a pre-existing zone of weakness representing a pre-existing normal fault on the evolution a fold-thrust belt. The key objective is to assess the conditions which control whether a pre-existing normal fault would be reactivated as a thrust or new thrusts would develop in both the hanging wall and footwall of the early fault without its being significantly reactivated. Exploratory work indicates that pre-existing normal (growth) faults with low cohesion and shallow dip tend to be reactivated as thrusts whereas those with high cohesion and steeper dips tend to remain or become locked and to be overprinted by new fold-thrust structures.

Models with lateral facies boundaries: This study examines the effect of a primary stratigraphic heterogeneity, simulating a lateral facies boundary such as a carbonate bank margin, on the fold-thrust process. Key objectives are to develop an understanding of the geometry of fold-thrust structures that form in this stratigraphic setting and to assess the conditions which control whether the bank margin would be activated as a thrust or whether thrusts would tend to develop preferentially on the basin side or the reef side of the margin. The modelling to date indicates that carbonate bank margins represent very significant mechanical heterogeneities which can have pronounced influence on superimposed fold-thrust structures. The type of structures associated with the facies boundary is influenced by the nature of the reef facies (massive or layered) and the mechanical contrast between the reef and off-reef facies. The orientation of the boundary (both its strike and dip) relative to the shortening direction also influences the superimposed structures.

Acknowledgements: This work is part of the Foothills Research Project, an integrated geological and geophysical study of the 3-dimensional geometry of Foothills structures, which is supported by a consortium of oil-industry partners and by NSERC through the Collaborative Research and Development Program. The Principal Investigators in FRP are Don C. Lawton and Deborah A. Spratt (University of Calgary) and John M. Dixon (Queen's University). The work described here was carried out with laboratory assistance of Jason Chew and Tom Anthony at Queen's University.

STYLE AND SIGNIFICANCE OF NORTHEAST AND NORTHWEST TRENDING STRUCTURES IN NASS RIVER AREA

Evenchick, Carol A., Geological Survey of Canada, 100 West Pender Street, Vancouver, British Columbia, V6B 1R8.

Contractional structures in Nass River area include northwest-trending folds and related faults in the northeast, and northeast-trending folds and faults in the southwest. In both areas cleavage is common in siltstone and rare in sandstone. The grade of metamorphism is sub-greenschist facies except within 2 km of the Hyder pluton and Alice Arm Intrusions, where biotite hornfels is present.

Structures in the northeast are typical of the Skeena Fold Belt. They are northwest-trending, gently plunging, upright, overturned to the northeast and overturned to the southwest, chevron folds tens to several hundreds of metres wavelength. They accommodated a significant amount of northeasterly shortening.

Northeast and north-northeast trending structures dominate in the southwest part of Nass River area. They are gently plunging, upright and overturned to the southeast chevron-style folds tens of metres to several kilometres wavelength. Interference of northwest-trending folds with northeast-trending ones occurs locally where the latter dip gently. Folds of a variety of orientations are present near the Hyder pluton.

The newly recognized structures in southwest Nass River area are part of a suite of northeast-trending contractional structures which occur sporadically on the west side of the Skeena Fold Belt. They are parallel with contractional structures in southwest Yukon which are interpreted to be a result of sinistral displacement on a proto-Denali Fault or parallel structure in Early Cretaceous time (Evenchick, 1995), and are speculatively inferred to be of the same origin. The age of these structures is within the time window of left-oblique convergence along the Cordilleran margin determined by plate motion studies (Engelbreton et al., 1995).

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DIRECTIONAL FILTERING OF 3D GRAVITY MODELS: LOWER CRUSTAL FEATURES REVEALED

H.D. Geiger and F.A. Cook,
Department of Geology and Geophysics, The University of Calgary
Calgary, AB T2N 1N4

INTRODUCTION

Bandpass and directional filtering of gridded Bouguer gravity and magnetic anomaly data allow trends associated with the mid-Proterozoic Great Slave Lake shear zone to be followed more than 50 km southwest of the Tintina fault at 56°N Lat. (Geiger and Cook, 1995). Accordingly, Precambrian basement may project in the lower and middle crust beneath the Tintina fault, which may therefore be confined to the upper crust at this latitude. The interpretation is tested by filtering the gravity response of a simplified 3D model of crustal density contrasts and then by comparing the resulting images with similarly filtered images of the Bouguer gravity anomaly. Directional filtering of the model response clearly shows that specific trends can be enhanced and the interference effects of crossing trends removed.

STUDY AREA

The study area includes a 300,000 km² region in northern British Columbia and Alberta (Figure 1). Archean and Proterozoic basement rocks in the area are covered by late Proterozoic and Phanerozoic sedimentary rocks. The Great Slave Lake shear zone (GSLsz), although obscured by cover rocks, can be followed from the NE as a zone of strong magnetic anomalies as far west as the Alaska Highway (AH) and perhaps to the front of Cordilleran deformation. The front of Cordilleran deformation (CDF) is nearly perpendicular to the trend of GSLsz, and the Tintina-Northern Rocky Mountain Trench fault (TT-NRMT) bisects the area (Figure 1). Crustal seismic data from the Alaska Highway have been interpreted with a crustal scale ramp that dips to the NW near where the trend of the GSLsz projects into the seismic line (Cook and Van der Velden, 1993) with depth to basement increasing from a few kilometres in the SE to as much as 15 km in the NW. The position of the ramp appears to coincide with the transition to the broad regional negative Bouguer anomaly associated with the Cordillera.

SIMPLE MODEL OF CRUSTAL DENSITY CONTRASTS

A simplified 3D model of density contrasts in the crust was created using a system of right rectangular prisms (Figure 2), and the vertical component of the gravitational response was calculated using a program adapted from Montana et al. (1992). In modeling anomalous responses, only lateral variations in density are significant. Thus, density values in the model can be considered relative to some arbitrary vertical function of density that is the same everywhere. Strong NW-SE trending highs and lows associated with the general structural trend of the Cordillera in the vicinity of the TT-NRMT are modeled as slight positive and negative density contrasts ($<0.06 \text{ g cm}^{-3}$) in the upper 10 km of the crust. For modelling purposes, depth to basement remains constant at 10 km over the entire study area. Small NE-SW trending highs and lows associated with the trend of the GSLsz are modeled as slight positive and negative density contrasts ($<0.06 \text{ g cm}^{-3}$) in the middle and lower crust between 10 km and 30 km depth. Although the simple model is not intended to reproduce the complexities of the known geology or the subsurface structure interpreted from both seismic and detailed potential field models, it provides a direct

test of bandpass and directional filters for the separation of anomalous responses and trends arising from spatially distinct sources.

BANDPASS AND DIRECTIONAL FILTER RESULTS

The unfiltered Bouguer gravity anomaly for the study area is illustrated in Figure 3a. The trace of the TT-NRMT is associated with a relative gravity high in the low associated with the Cordillera. The unfiltered model response is illustrated in Figure 3b where the interference pattern of the response from the two trends forms circular highs and lows in the center of the image. Radial bandpass filtering of the Bouguer anomaly (Figure 4a) removes wavelengths longer than 150 km, enhancing shorter wavelength trends visible in Figure 3a. An identical bandpass filter applied to the model data (Figure 4b) produces small amplitude highs and lows over the entire image, an unavoidable effect of wavelength filtering that is minimized by careful choice of ramp functions in the 2-D wavelength or spatial frequency domain.

Direction cut-filters in the 2-D wavelength domain can be designed to remove anomaly trends in any desired orientation. The strong linear anomalies trending approximately N25W (vertical in grid orientation, see Figure 4a) are completely removed with an appropriate elliptical cut filter (Figure 5a) revealing horizontal trends obscured in the bandpass filtered maps. Directional filtering of the model anomalies (Figure 5b) clearly shows that the upper crustal contribution has been removed. The lower crustal contribution appears to be enhanced relative to the original model response (compare with Figure 3b west of AH) only because of differences in the choice of gray-scale amplitudes. Directional cut-filtering of 60 degree trends (Figure 6a) enhances N25W trends by removing the interference effects of the intersecting trends. As expected, directional filtering of the model anomalies (Figure 6b) has removed the lower crustal contribution. Note that the cut-filter has effectively attenuated trends in the model response oriented 30 degrees off the specified direction of the cut filter, illustrating that the aperture of the cut filter is wider for longer wavelengths.

CONCLUSIONS

Directional filtering of the gravity response from a simple 3-D model indicates that anomaly responses from spatially distinct but crossing elongate bodies can be separated. Thus trends in Bouguer anomaly maps arising from density contrasts at different levels in the crust can be effectively separated. The separation of trends does not address the problem of non-uniqueness in potential field models. A number of possible models can be designed to explain the observed trends including density contrasts at the same depth level in the crust.

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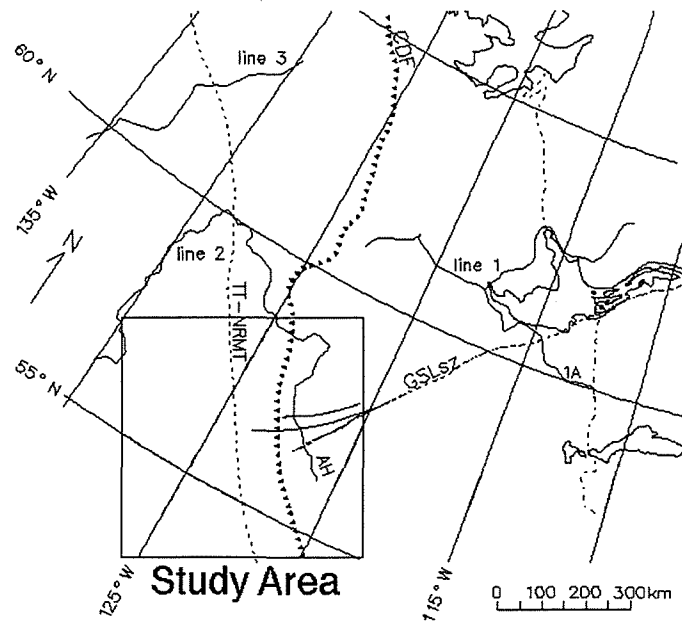


Figure 1: The study area covers a 300,000 km² area in northern British Columbia and Alberta. The Tintina Fault and the trend of the Northern Rocky Mountain Trench (TT-NRMT) are shown as a dashed line bisecting the area. The front of Cordilleran deformation (CDF) is marked by a line of triangles. The Alaska Highway (AH) seismic line, a joint industry-Lithoprobe project, was shot in 1992 and provides some constraints on crustal geometry. Magnetic anomaly trends associated with the Great Slave Lake shear zone (GSLSZ) project to the SW perhaps as far as the CDF.

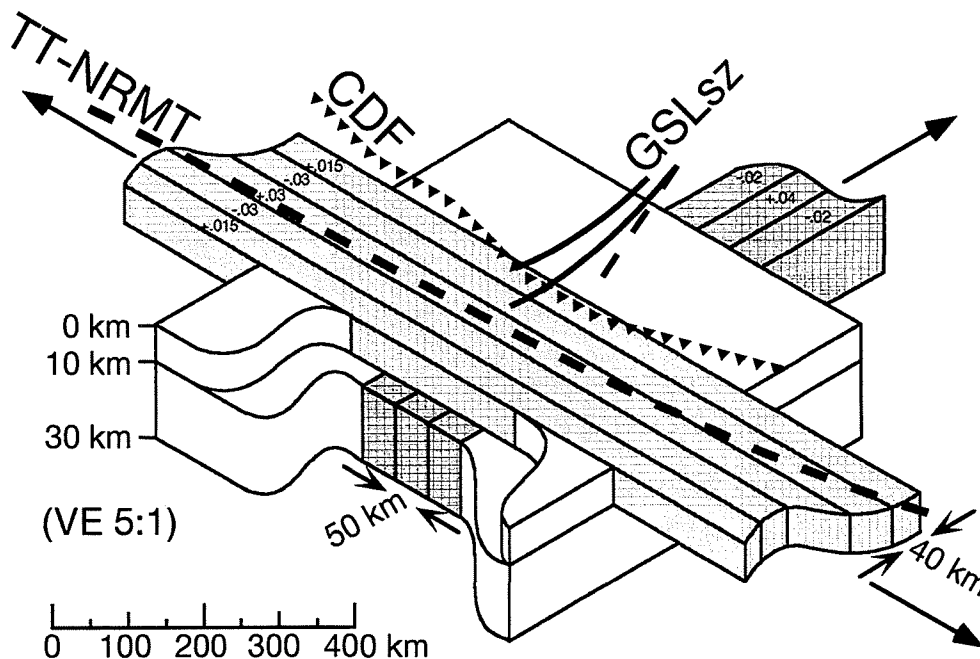


Figure 2: Geometry and density contrasts of simple 3-D model of the crust. Trends following the TT-NRMT and CDF are modeled as elongate bodies in the upper crust. Trends associated with the GSLSZ are modeled as elongate bodies in the lower crust that extend beneath the upper crustal bodies for a distance of 35 km to the SW. Density contrasts are less than 0.06 g cm⁻³. Dimensions of the model and their relationship to major features in Figure 1 are annotated.

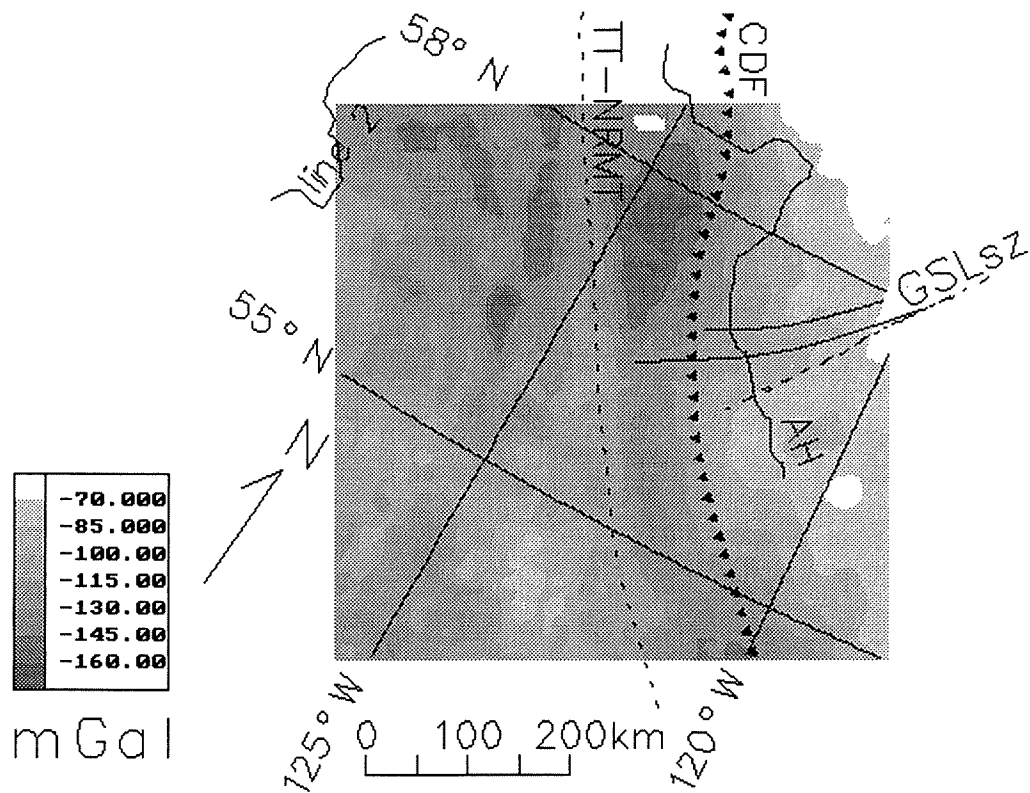


Figure 3a: Bouguer gravity anomaly map. The broad low west of the CDF is associated with the Cordillera. A gravity high generally follows the trend of the TT-NRMT.

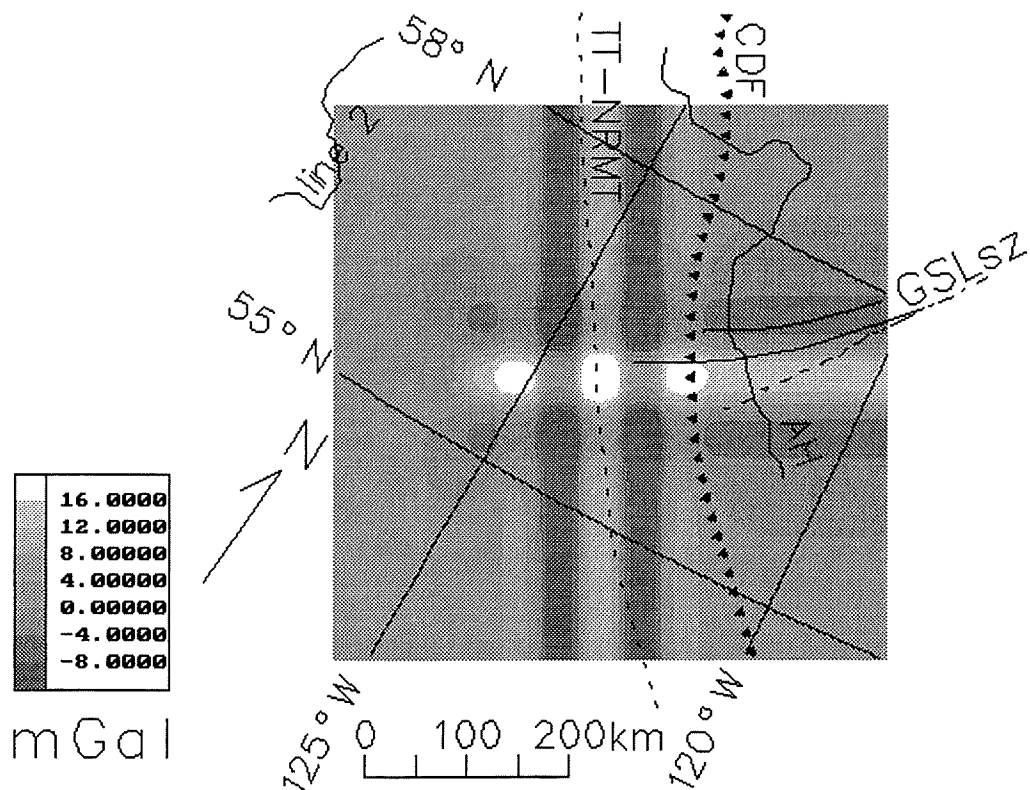


Figure 3b: Vertical component of gravity response of model in Figure 2. An interference pattern of the response from the two intersecting trends forms circular highs and lows in the center of the image.

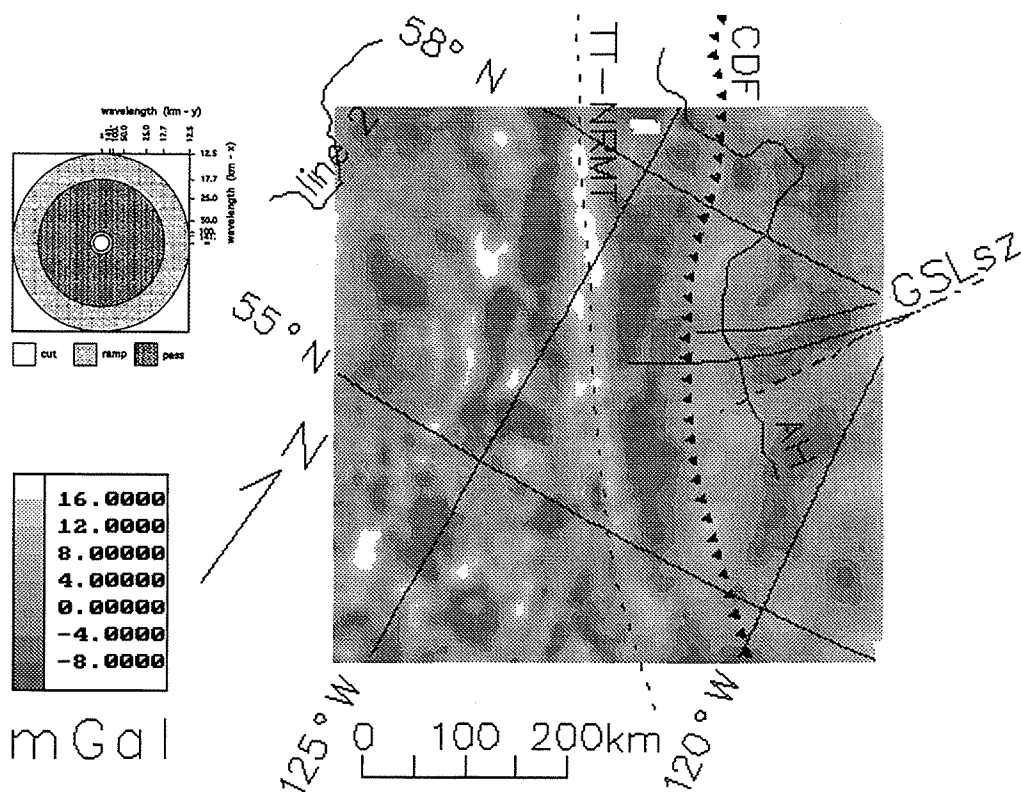


Figure 4a: Radial bandpass (17.7 km - 150 km) filtered gravity anomaly map. Shorter wavelength trends visible in Figure 3a are enhanced.

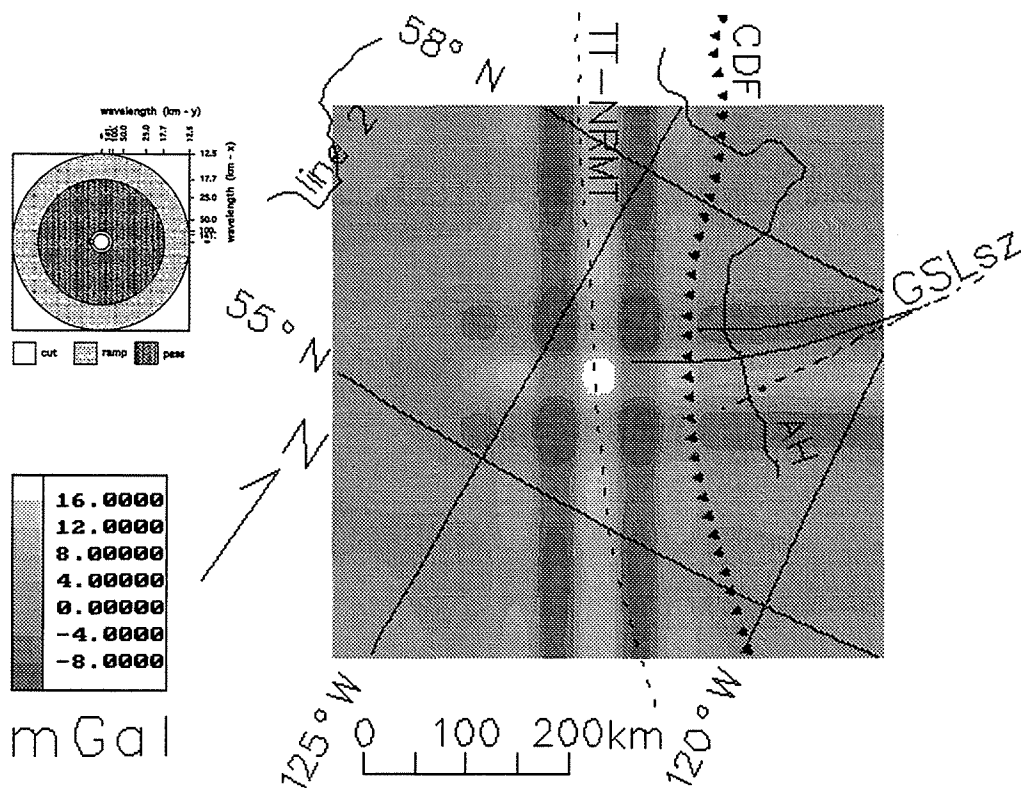


Figure 4b: Radial bandpass (17.7 km - 150 km) filtered model response. Some ringing from the filter is visible in areas away from the density contrasts.

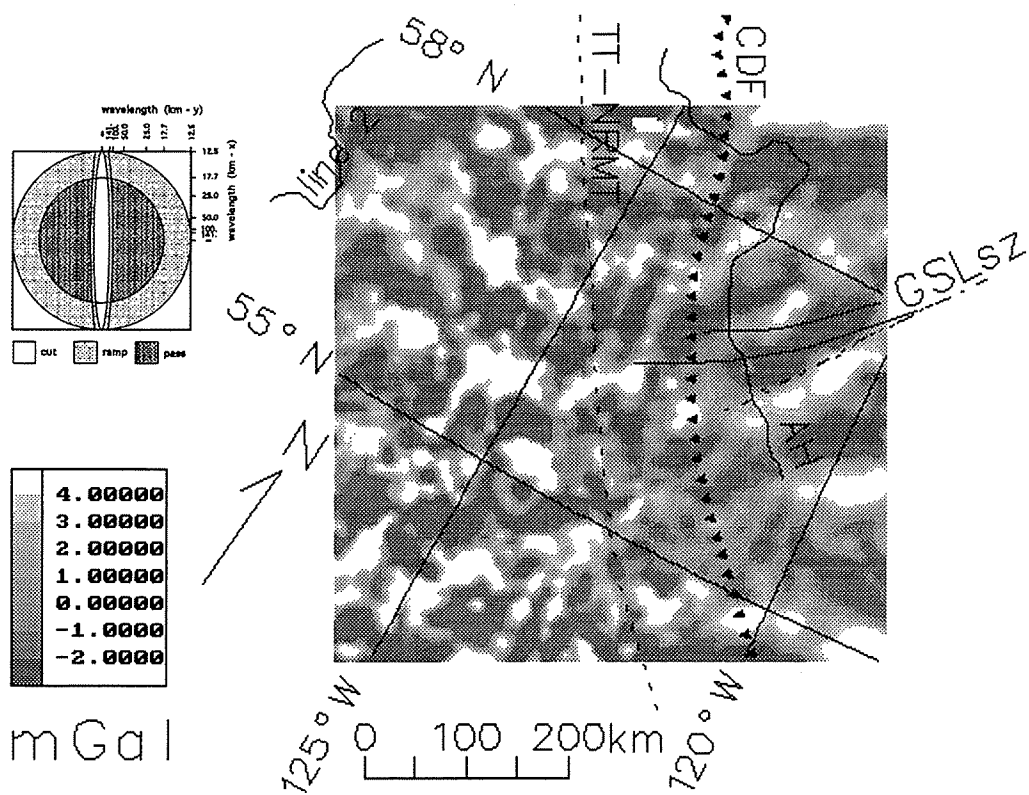


Figure 5a: Vertical (N25W) cut bandpass filtered gravity anomaly map. Trends associated with the TT-NRMT and CDF are effectively removed.

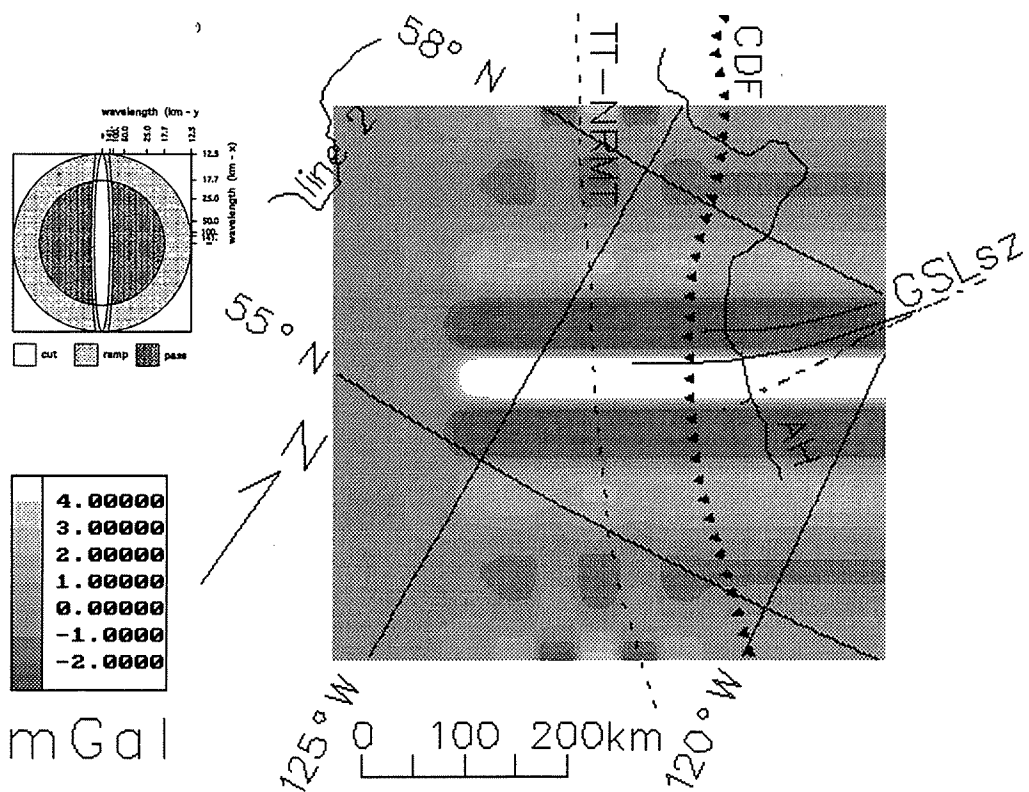


Figure 5b: Vertical (N25W) cut bandpass filter of model response. The upper crustal contribution has been removed revealing the response from lower crustal density contrasts.

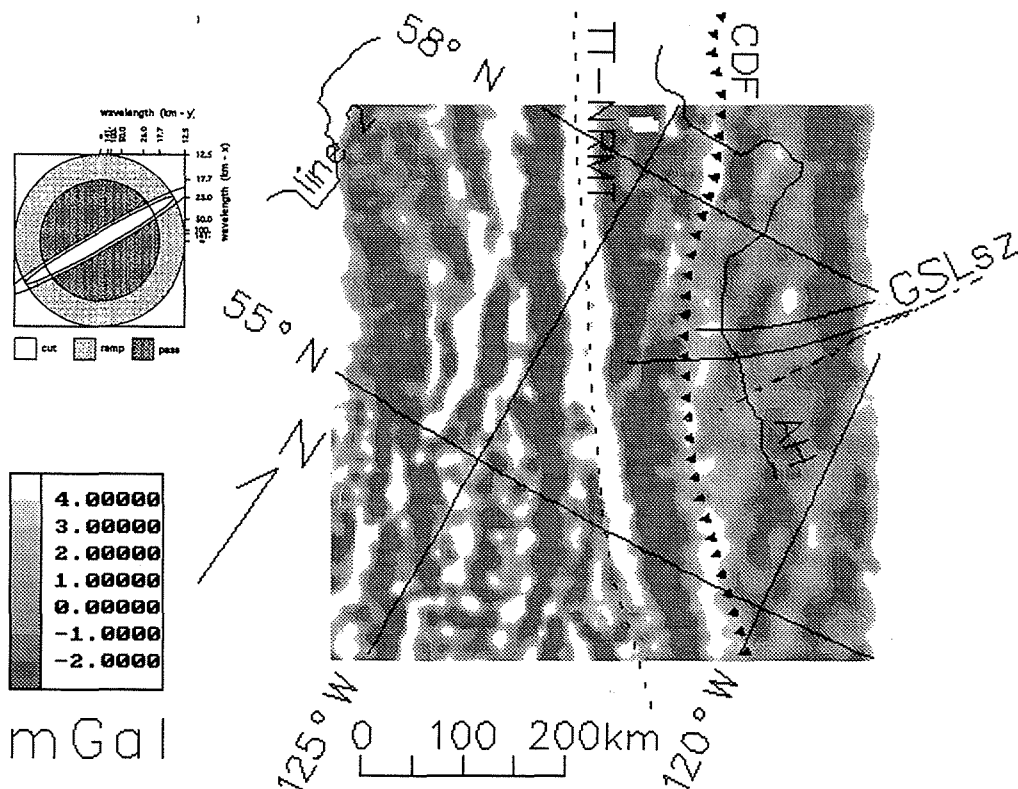


Figure 6a: 60 degree (N35W) cut bandpass filtered gravity anomaly map. Trends associated with the GSLsz have been effectively removed.

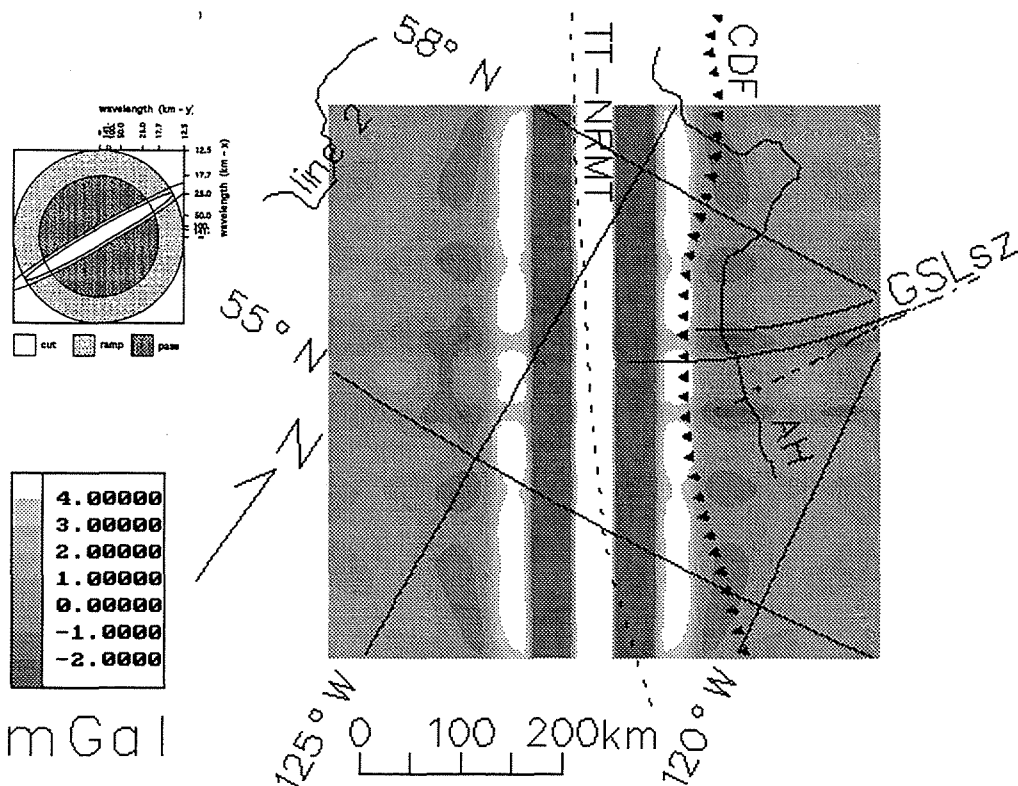


Figure 6b: 60 degree (N35W) cut bandpass filtered model response. The lower crustal contribution has been removed revealing the response from upper crustal density contrasts.

PRELIMINARY ANALYSIS OF STRUCTURE, STRATIGRAPHY, AND METAMORPHISM
OF THE SIBLEY CREEK SYNCLINE: NORTHERN MONASHEE COMPLEX, BRITISH
COLUMBIA

Dan H. Gibson, Ottawa-Carleton Geoscience Centre and Department of Earth Sciences,
Carleton University, Ottawa, Ontario, K1S 5B6.

The Sibley Creek syncline has been mapped as an overturned, south-southeast verging, kilometre scale fold in the Monashee complex. It occurs on the north flank of Frenchman Cap dome within the Kirbyville Creek catchment area where it controls map scale geometry and folds the multiply deformed metasedimentary mantling gneiss. Recent previous mapping documented three phases of folding assigned as D1, D2, and D3. The Sibley Creek syncline is reported as a first phase (D1), pre-early metamorphic structure, with a moderately dipping ($\sim 20\text{-}30^\circ$) periclinal axial surface, and a west-southwest plunging hinge line ($\sim 10\text{-}25^\circ$). The second phase of deformation (D2) is dominant and penetrative throughout the area and is related to an intense regional shearing event producing tight to isoclinal folds that almost completely overprint all D1 structures. D2 folds are interpreted to be syn-metamorphic structures that have moderate west dipping axial planes and shallowly plunging fold hinges approximately coaxial with the west trending regional stretching lineation. Peak metamorphic minerals such as garnet, kyanite, sillimanite, hornblende and feldspar often define the stretching lineation and are also caught up in the D2 structures. Rare third phase (D3) structures are documented to also have west trending hinges, but have nearly vertical axial planes.

During mapping for this study (summer 1995), many observations agreed with those documented above, with only slight but important differences. The most significant distinction lies in the fact that in a localized area atop a 2408m peak in the core of the Sibley Creek syncline, a foliation surface was traced around the hinge, which plunges shallowly ($\sim 10\text{-}15^\circ$) to $\sim 240^\circ$. In addition, to the east in the structurally lower upright limb, rare metre scale, north verging S-folds parasitic to the Sibley Creek syncline were also found to have a foliation going around their hinges. Based on these observations I have tentatively interpreted the Sibley Creek syncline to be at least a second phase structure (D2). Moreover, folds with similar geometries to those assigned to D3 above were found in three localized areas to be refolded by D2 structures, producing type 3 interference patterns. This suggests that either the assignment of D2 and D3 folds is incorrect, or that an intermediate phase of folding took place between D1 and D2, bumping the assignment of D2 and D3 structures to D3 and D4 (possibly D4 and D5 if the Sibley Creek syncline is indeed post-D1).

Mapping also revealed pervasive north/south striking sets of joints and fractures infilled with quartz, epidote, and late carbonate precipitate. There are also larger scale, mappable brittle normal faults parallel to the joints and fractures, displaying apparent down to the east displacement of up to 1-3 metres. These structures are interpreted to be related to the Columbia River fault, a late Eocene normal fault partly responsible for the tectonic unroofing of the Monashee complex.

Presently, samples from strategically selected localities are being prepared for U-Pb analysis. The data should further constrain the deformation and thermal histories across the Sibley Creek syncline. In particular, the data should determine if these events were diachronous, as was documented across major folds further south in Frenchman Cap dome.

ASSEMBLAGE ANALYSIS OF THE DORSEY TERRANE

Tekla A. Harms

Department of Geology, Amherst College, Amherst MA 01002 USA

Robert A. Stevens

Department of Geological Sciences, Queen's University, Kingston, ON, K7L 3N6

ABSTRACT

Most rocks assigned to the Dorsey terrane in 1991 (Gabrielse and Yorath, 1991, and others therein) have subsequently been mapped at 1:250 000, 1:50 000, and 1:25 000 scales (Gordey and Stevens, 1994; Gordey, 1991; 1995; Harms, 1992; Harms and Stevens, 1995; Stevens and Harms, 1995; and this volume) (Figure 1). Several internally consistent assemblages of genetically-linked rock suites can be identified from those results so that a preliminary assemblage analysis of the Dorsey terrane is possible. We recognize the following assemblages:

Thirtymile Assemblage: Dominated by a massive quartzo-feldspathic grit unit and an interbedded chert pebble conglomerate, black argillite, and black banded chert unit. Minor carbonate, pillow basalt, and massive chert also occur. (Units DMps, OMT, Ps and Pc of Gordey and Stevens, 1994 and "Sequences C, D, E, F, and G" of Harms, 1992.) Undated but interpreted to be Proterozoic to Devonian-Mississippian.

Dorsey Assemblage: Strongly sheared and metamorphosed quartzose, pelitic, mafic and intermediate plutonic rocks. ("Lower Unit" of Stevens and Harms, 1995.) Pre-Devonian to Permian.

Ram Creek Assemblage: Sheared mafic to intermediate metavolcanic rocks with quartzite, marble and metaplutonic rocks in discontinuous bodies. ("Imbricate Assemblage" of Stevens and Harms, 1995.) Pre-Permian in protolith age with post-mid Permian - pre-(?)Jurassic deformation.

Swift River Assemblage: Black slate to phyllite and banded or massive chert with minor clastic horizons. May be related to the Klinkit Assemblage. (Upper part of the "Middle Unit" of the "Dorsey Assemblage" of Stevens and Harms, 1995.) Mid Pennsylvanian according to Abbott (1981).

Hazel Assemblage: Schists, including distinctive banded green and yellow porphyroblastic-biotite schist and pink to grey micaceous quartzite. ("Hazel Assemblage" of Stevens and Harms, 1995.) Undated.

Klinkit Assemblage: Massive mafic flows and mafic volcanoclastics associated with thick fossiliferous limestone layers and lenses, massive, clean, varicolored to dark quartz sandstone, and interlayered black argillite, bedded chert, and minor chert pebble conglomerate. (Unit 11 of Gabrielse, 1970; "Sequences A, B, and C" of Harms and Stevens, 1995; "Upper" and "Middle Units" of Stevens and Harms, 1995; Units Mv and Ml of Gordey and Stevens, 1994; and "Sequences A and B" of Harms, 1992.) Late Mississippian or older to Triassic.

Field evidence suggests that these assemblages are structurally juxtaposed. The Dorsey and Ram Creek assemblages are strongly sheared along their contact. Truncation of layers and shear strain occur at several localities along the Thirtymile-Klinkit assemblage contact. The Dorsey-Swift River and Dorsey-Klinkit assemblage contacts are conformable, and the Hazel-Klinkit assemblage contact is covered, but we interpret these contacts as tectonic on the basis of abrupt changes in metamorphic grade and/or dissimilarity in lithologic character and deformation history.

If any once existed, the original genetic relationships between these assemblages, now tectonically juxtaposed, are unclear. On the other hand, close parallels can be drawn between the Thirtymile Assemblage and Proterozoic to Paleozoic strata of the North American

miogeocline in Selwyn Basin (Gordey, 1991; Harms, 1992); between the Hazel Assemblage and Yukon-Tanana (Kootenay) terrane; between Ram Creek Assemblage and Slide Mountain terrane; and between Klinkit Assemblage and Paleozoic basement subterrane of Quesnellia. These correlations suggest that the Dorsey terrane may not be a robust lithotectonic entity and that significant reconfiguration of terrane boundaries along the SNORCLE transect may be justified.

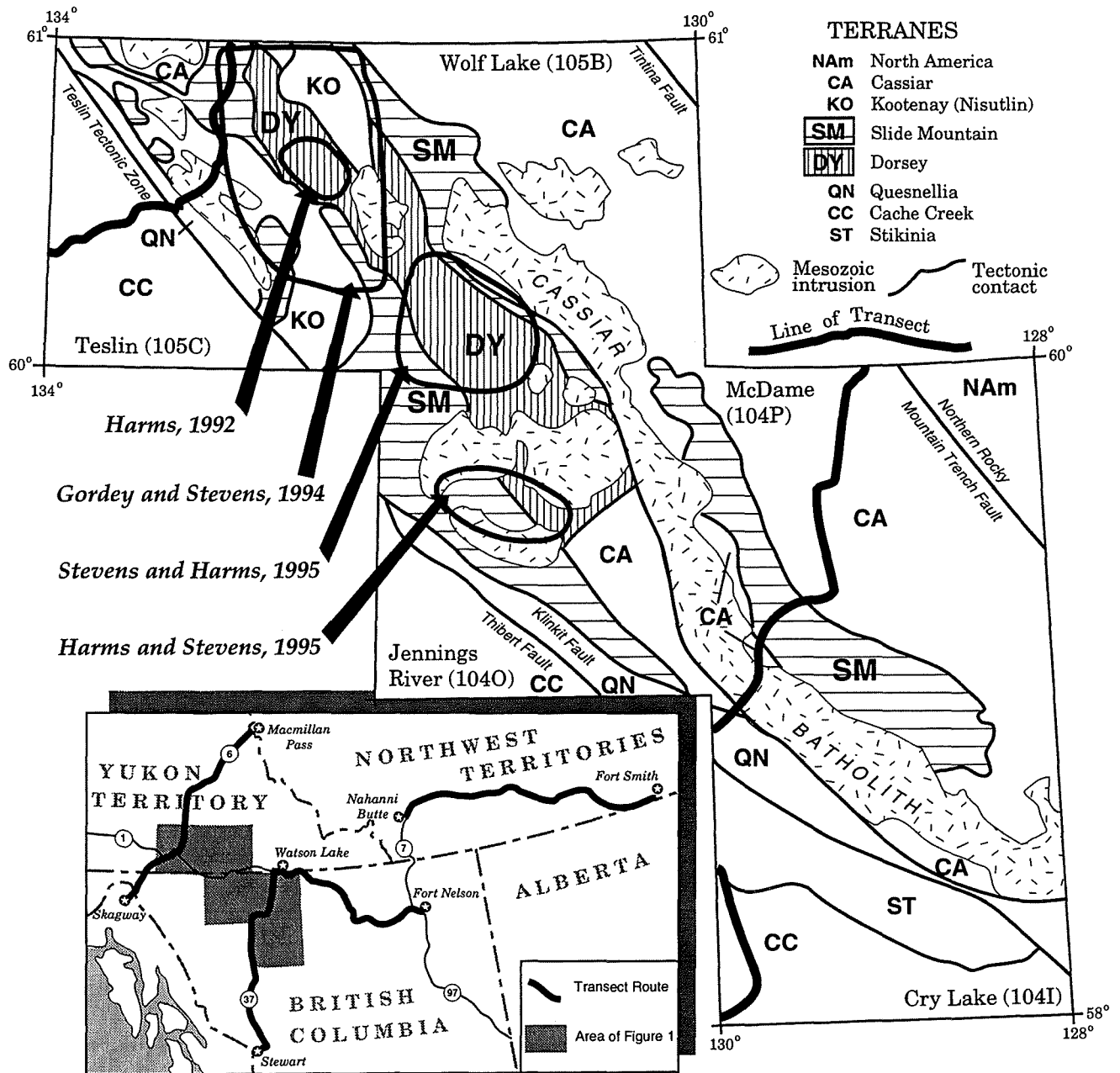


Figure 1: Terrane map of southern Yukon Territory and northern British Columbia in the vicinity of the Dorsey terrane and the SNORCLE transect (adapted from Wheeler and McFeely, 1991). Circled areas indicate post-1991 1:250 000, 1:50 000, and 1:25 000 mapping in the Dorsey terrane (see text for citations). Inset map shows the SNORCLE transect route.

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Preliminary Seismic Results from ACCRETE

Lincoln S. Hollister, Department of Geological and Geophysical Sciences, Princeton University, Princeton, NJ 08544 (linc@geo.princeton.edu), for the ACCRETE science team (John Diebold, Scott Smithson, Igor Morozov, Triparna Das, and others from U.B.C., G.S.C., U. of Arizona, Bryn Mawr College, Columbia U., Princeton U., and U. of Wyoming).

The ACCRETE project is a collaborative endeavor to study terrain accretion in the central segment of the Coast Mountains orogen, on both sides of the border between SE Alaska and British Columbia. The seismic part of the project included 2 experiments: 1) 1700 km of 224 channel marine multichannel [MCS] data were shot by R/V EWING along fjords and inland waterways and 2) a wide-angle refraction/reflection study using the same airgun shots recorded by 60 3-component REFTEK instruments deployed at 3-5 km intervals along the Portland Canal fjord, which transects the Coast Mountains.

P- and S- wave Moho reflections are observed on most record sections. Pn is observed at offsets exceeding 120-140 km. P/S converted phases (including those from the Moho) and intracrustal reflections are abundant in some records.

We developed a tomographic P-wave velocity model for the main ACCRETE line along the SW-NE trending Portland Canal fjord. For the starting velocity model we used the model obtained previously by the ray tracing of 5 selected shots. To comply with the limitations of the inversion program, picked travel times were spatially resampled at 1-2 km spacing. To remove the effects of the sediment cover of the bottom of the fjord, we use the velocity model of the sediment layer based on the results of the MCS study. At the first step of the inversion, we used refracted arrivals to obtain the velocities within the upper 20 km of the crust. Moho reflections were employed to constrain the velocities of the lower crust and Moho depth. The resulting tomographic velocity model shows the thickening of the crust in the landward direction, Moho relief possibly related to the accreted terrai boundaries, and a high velocity bulge under the Paleogene batholith. The velocity model obtained in our present inversion will serve as a basis for a more detailed tomographic

imaging using P- and S- waves, and also for the prestack migration.

The over 800 km long steep to vertical high temperature ductile Coast shear zone, that coincides with a thermal front between the western side of the high temperature rocks of the Paleogene batholith and the previously cooled crust of the mid-Cretaceous orogen, appears to extend to the Moho, with the Moho on the east side being 5km deeper than on the west side.

The high velocity bulge under the batholith consists of velocities of over 7 km/sec at only 10 km depth. The high velocity bulge dips west from the eastern boundary of the batholith, to about 20 km depth at the Coast shear.

Although conventional processing of the MCS data reveals deep crustal structures, including Moho, reflectors in the shallow [0 - 10 km] structure are poorly imaged due to the topographic complexity of the water-sediment and sediment-crust interfaces. Reflector coherence was improved by applying a systematic set of time shifts, called "statics" corrections. For the most part, this two dimensional processing removes a large percentage of the incoherence.

A 3-D INTERPRETATION OF SEISMIC HORIZONS FROM THE CROWSNEST DEFLECTION REGION: SW ALBERTA

Richard L. Kellett and Normand J. Bégin

Foothills Research Project

University of Calgary

2500 University Dr N.W., Calgary, Alta., T2N 1N4

In the foothills of the Rocky Mountain Fold and Thrust Belt (RMFTB) closely spaced 2-D seismic lines are important datasets for interpreting the complex structures. Extending the analysis of the seismic data from 2-D to 3-D requires efficient data handling and visualization tools. In the vicinity of the Crowsnest Deflection, in southwestern Alberta, seven seismic lines have been interpreted in a study of the geometry of the triangle zone, and its variation along strike. In this area the RMFTB changes strike, from north-south to northwest-southeast, complicating the structure of the triangle zone. This study uses the interpretations of five of the seismic lines, in the southern part of the region, to investigate the geometry of the lower detachment, the upper detachment, and a single thrust sheet within the triangle zone. The interpreted lines are stored in a relational database, that enables discrete horizons to be extracted and presented in 3-D. The lower and upper detachments of the triangle zone are traced along strike, and show strong evidence for the existence of a major lateral ramp on the basal thrust. An individual thrust sheet, at the base of the wedge, shows significant thickening in the vicinity of the lateral ramp, that may have implications for the mechanics of wedge development. Detailed datasets, such as the Crowsnest Deflection seismic data, combined with visualization tools are required to answer questions about the growth of antiformal stacks and duplex structures within the allochthonous wedge of the fold belt.

The use of photogrammetric methods to map the geology of the Brocket area, Alberta (82H/12)-Southern Alberta NATMAP project

Daniel Lebel and Ronald Da Roza
Geological Survey of Canada (Calgary)
3303-33rd Street NW, Calgary, Alberta, T2L 2A7

Bedrock mapping of the Brocket area was conducted as part of the third year of research associated with the Southern Alberta Foothills NATMAP project. This five-year project (1993-1998) will produce a new digital geoscience database for the eastern edge of the Cordillera in southern Alberta, comprising new bedrock geological maps and new cross-sections of subsurface structure established in cooperation with the petroleum industry using proprietary seismic information.

The Brocket map area (NTS 82 H/12) includes portions of the easternmost Alberta Foothills and the Alberta Syncline in the vicinity of the Porcupine Hills. The bedrock exposures consist of recessive Upper Cretaceous to Paleocene mudstone and sandstone (Willow Creek Formation) and resistant Paleocene sandstone and mudstone (Porcupine Hills Formation). The sandstones are heavily cross-bedded, hindering precise measurement of bed attitudes (generally shallow dips, 1 to 5 degrees). However, numerous semi-continuous, cliff-forming sandstone exposures can often be followed for several kilometres.

Subsurface seismic data show that these rocks overlie an easterly tapering intercutaneous wedge and constitute the hanging wall of a structural triangle zone. Using air photographs and field surveys, more than 10 different resistant sandstone units within the Porcupine Hills Formation have been mapped during the summer of 1995. The exact position of these sandstone units has been plotted in three-dimensions using digital stereo-photogrammetric methods. This procedure permits correction of plotting errors made by the geologist in the range of 20 to 500 meters, who previously used only a few recognizable ground points to register line work ("rubber-sheeting"), without the help of stereographic methods. This exact positioning has allowed the production of digital orthophotos and the calculation of strikes and dips of sandstone ridges, using three-point solutions. These measurements are easy to calculate, using a computer module running on top of a conventional CAD program. The digital orthophotos have also allowed the geologist to further his interpretation and validate the digital transfer of line work by the photogrammetrist and to correct the position of geographic features (e.g. the position of the Oldman River reservoir). Given the uncertainties of structural measurements in the field, the accumulation of photogrammetrically calculated bedding measurements has allowed delineation of several broad folds which parallel the axis of the triangle zone. The precision of the photogrammetric method will be evaluated using accurate surveying instruments on the ground.

Contrasting cooling histories from apatite fission track and ^{40}Ar - ^{39}Ar analysis of the internal and external zones of the Canadian Rockies near Jasper, Alberta and Valemount, British Columbia

Michael R. McDonough¹, Dale R. Issler¹, Glen S. Stockmal¹, Sandy Grist², Marcos Zentilli²
Douglas A. Archibald³ and Robert J. Scammell^{3,4}

¹ Geological Survey of Canada, 3303 33rd Street NW, Calgary, Alberta, T2L 2A7; ² Dalhousie University, Fission Track Research Laboratory, Department of Earth Sciences, Halifax, NS, B3H 3J5; ³ Queen's University, Department of Geological Sciences, Kingston, ON, K7L 3N6; ⁴ present address: Amoco Canada Ltd, Calgary, Alberta

ABSTRACT

We apply ^{40}Ar - ^{39}Ar analyses of K-feldspar and muscovite, and fission track analysis of apatite to establish cooling histories for the internal and external zones of the Rockies in a transect through the Valemount, B. C. and Jasper, Alberta areas.

^{40}Ar - ^{39}Ar analyses of K-feldspar from the Chetamon and Pyramid thrust sheets indicate a maximum temperature of 150-170°C in the Main and Front Ranges (external zone), which suggests that Cretaceous thermal gradients in the thrust belt may have been as low as 15°C/km. In the Omineca belt, ^{40}Ar - ^{39}Ar analyses on muscovite and K-feldspar for Malton Complex gneisses yield spectra which are interpreted to indicate cooling through 350°C at about 55 Ma for muscovite, and through 150°C at about 50 Ma for K-feldspar. These data agree closely with the cooling path for the structurally overlying Neoproterozoic cover sequence derived from K-Ar dating of muscovite.

AFT ages are oldest in the Front Ranges and Foothills, ranging from 52-73 Ma, coincident with the waning stages of thrusting. Westward, AFT ages for the Main Ranges are 30-46 Ma, about 15-30 m.y. younger than thrusting, and probably reflect relatively slow cooling related to coupled erosional and isostatic processes. AFT ages for Neoproterozoic rocks of the Omineca belt west of the Southern Rocky Mountain Trench are 42-48 Ma (Sevigny *et al.*, 1990), and probably also reflect cooling related to erosion and isostasy. AFT ages along the axis of the Trench are anomalously young, ranging from 14-25 Ma. Thus, AFT ages for Malton gneisses and Miette grits located in or near the Trench were probably reset during Oligocene to Miocene times (14-25 Ma), possibly by hydrothermal activity.

$^{40}\text{Ar}/^{39}\text{Ar}$ (muscovite and K-feldspar) and K/Ar (biotite) cooling ages indicate that the basement in the Omineca belt followed essentially the same cooling path as the overlying cover during Paleocene and Eocene time. Oligocene to Miocene heating and subsequent cooling of Malton Complex gneisses is strongly suggested by the fission track age and length data. Due to the retention of a significant population of short fission tracks in Malton gneisses, we hypothesize that the fission tracks were incompletely reset by Miocene hydrothermal activity in the Trench, and probably were reheated to 80 or 100°C. This hypothesis is supported by the presence of modern hot spring activity in the southern Rocky Mountain Trench to the southeast of Valemount. Hot spring activity is accompanied by significant seismic activity along the locus of the southern Rocky Mountain Trench. The young cooling history in the Trench, and modern hydrothermal and seismic activity, suggest the possibility of Miocene or younger displacement on structures in the Southern Rocky Mountain Trench.

FREE, DOWNLOADABLE, WEB-ACCESSIBLE, DIGITAL GEOLOGY OF BRITISH COLUMBIA: CURRENT AND FUTURE OFFERINGS

Mitch G. Mihalynuk and Ward E. Kilby,

Geological Survey Branch, BC Ministry of Energy, Mines and Petroleum Resources
5th Floor, Jack Davis Building, 1810 Blanshard Street, Victoria, BC, V8V 1X4
(email: mmihalynuk@galaxy.gov.bc.ca or via: [HTTP://WWW.empr.gov.bc.ca](http://www.empr.gov.bc.ca))

ABSTRACT

New digital geology maps are available, free of charge, for download from the British Columbia Ministry of Energy, Mines and Petroleum Resources (EMPR) World Wide Web server at [HTTP://WWW.empr.gov.bc.ca](http://www.empr.gov.bc.ca). These maps were compiled at 1:100 000 scale and incorporate data from all available sources, including hundreds of unpublished company assessment reports. The data are presented in GIS-compatible polygon (geological units) and line (faults, drainage, topography, cultural features, reference index) files in .e00 format. Views of the data are also included. These views are in .av format which can be used with ArcView1, a powerful geographic information display and querying tool available free from ESRI Inc. (see our web site).

INTRODUCTION

In 1992 a province-wide mineral potential assessment was initiated by the BC Geological Survey in response to increasing pressure on the British Columbia government to accelerate land use decisions on several fronts including: resource management, resolution of outstanding aboriginal land claims and protection of representative examples of the province's natural, recreational and cultural heritage. Assessments have now been made for seven of nine regions within the province. In March of 1996 this process will be complete for all regions except the Queen Charlotte Islands.

DATA PROFILE AND CONTENT

A key requirement of the assessment process is up-to-date geological maps which can be easily adopted by various government agencies which use a variety of GIS and cartographic mapping systems. An appropriate scale for regional land use decisions is 1:100 000 to 1:250 000. The larger, 1:100 000 scale was adopted for the compilation.

The volume of information represented by the compilation is enormous. Published Federal and Provincial geology maps are just one of the data sources considered. Also incorporated are:

- unpublished company Assessment Reports in EMPR files numbering more than 24 000, and a great many of which contain pertinent geological information. A spatial index to assessment reports can be downloaded from the address above and overlain on the geology compilations.
- MINFILE, the provincial mineral resource database, contains geological descriptions of more than 11 500 mineral occurrences. A spatial index to MINFILE occurrences and a subset of MINFILE data can be downloaded from the address above for overlay on the digital geology compilations.
- Regional stream sediment geochemistry has been used to provide guidance where geological information is lacking. For example, in northwestern British Columbia elevated lutetium is closely correlated with Eocene intrusions and elevated chromium in Middle Jurassic sediments may signal contributions from the emergent Cache Creek terrane.
- Geophysical data, for example, aeromagnetism, have been helpful in determining the position of covered faults or intrusive contacts.
- Published data sources include over 14000 references to papers on BC geology contained in Georef and 4750 entries in the EMPR Index to Bedrock Geology.
- Other key sources of data are the University of BC Geochron File and LandSat.

Digital data have several advantages over paper-based maps. They can be easily stored, corrected, and disseminated. Projections, scales and level of detail can be modified as required. Output can be created on a variety of media at any available resolution. Themes can be created and subsets of the data can be accentuated. Presentation of the data is not determined by individual geologists, but by the needs of the end user. Customizations and simple querying of the data can be performed rapidly with Arcview 1. Advanced data querying can be done with the help of a database management system.

Perhaps the best feature of the digital compilation is that it forms the underpinnings of a continually evolving, geographically referenced, geologic information database. We request the assistance of end users in keeping the maps up-to-date and error free by using the report form at our web site. A log of revisions will accompany each mapsheet.

THE NEOTECTONIC MAP OF THE CANADIAN CORDILLERA: A PROGRESS REPORT

J.W.H. Monger¹, Brian Sawyer² and Robert Kung²

¹Geological Survey of Canada, Vancouver; ²Geological Survey of Canada, Sidney

The neotectonic map of the Canadian Cordillera is a compilation involving a variety of data bases and contributions by workers in several fields. Compilation of the map is justified economically in terms of ready identification of geologically hazardous regions of the Cordillera, and scientifically as a bridge between contemporary tectonics and older tectonics recorded in the geology.

As a working definition (proposed by Sebastian Bell), neotectonic features are "crustal responses representative of contemporary tectonic activity or that may have relevance to the contemporary tectonic regime." Such a definition permits depiction on a map of not only (e.g.) earthquake epicentres and active faults, but also features that have formed over that last several million years and continue to evolve, such as (largely) tectonically generated topography.

The neotectonic map will incorporate data that mostly are available in digital form. These include: (1) elevations (mostly from the GSC Geophysical Data Centre; a coloured shaded relief map is largely completed, will be made available as a separate entity, and also form the underlay for the other map components); (2) young (Q, QT) volcanic units (from the digitized version of the Tectonic Assemblage map of Wheeler and McFeely, 1991); (3) earthquakes (selected from the GSC Sidney data bank); and (4) crustal stress orientations (J. Adams, 1994; Canadian crustal stress data base). Other (non-digital) data to be incorporated include (5) active and recently active faults (mainly recognized offshore and in the Saint Elias Mountains, but there are hints of young fault activity elsewhere); and (6) hot spring data. Together with the map, it is intended to publish a GSC Bulletin of neotectonic and paleoneotectonic(!) papers dealing with specific topics and discussing different regions of the Canadian Cordillera.

NATURAL GAS RESOURCES OF THE FORELAND BELT OF THE CORDILLERAN OROGEN IN CANADA

K. G. Osadetz, P. J. Lee, P. K. Hannigan and K. E. D. Olsen-Heise*

Geological Survey of Canada - Calgary, 3303 - 33rd St. N.W., Calgary,
Alberta T2L 2A7

*Currently at Amoco Canada Petroleum Company Ltd., P. O. Box 200, Calgary,
Alberta T2P 2H8

The Foreland Belt of the Cordilleran orogen in Canada is an accretionary wedge of westward thickening Proterozoic to Middle Jurassic strata overlain by westerly derived and thickening foreland basin deposits of the Upper Jurassic-Lower Cretaceous Columbian and Upper Cretaceous-Paleogene Laramide orogenies. The deformation provides a multitude of structures for the anticlinal accumulation of hydrocarbons. Approximately $908,747 \times 10^6 \text{m}^3$ of raw initial gas in place (RIGIP), occurs in 681 pools within the Foreland Belt. Changes in the stratigraphic succession from south to north control the structural style and the stratal position of the highest major reservoir. These changes provide a rationale for a subdivision into six different regions. The six regions are further subdivided along stratigraphic boundaries that control reservoir style, hydrocarbon charge and natural gas composition. This allowed the grouping of discovered natural gas accumulations into seventeen mature and thirteen immature plays for further analysis. A "discovery process analysis" of mature plays, with reserves of $675,138 \times 10^6 \text{m}^3$ RIGIP in 602 pools, suggests that an additional $799,356 \times 10^6 \text{m}^3$ RIGIP will be found in almost 5,000 undiscovered pools. Confidence in this technique is high, since it can be evaluated using the evolution of the known exploration history. Many plays are affected by technical and conceptual restrictions that have prevented free exploration of the play area. The family of mature plays was subjected to a "discovery process analysis" from which the size of immature and conceptual plays was predicted. Immature plays can be distinguished from conceptual plays using the observed stratigraphic ordering of potential and the empirical relationships between exploration stage and proportion discovered, as constrained by the size of

immature plays. The thirteen immature plays are inferred to have an undiscovered expected resource of $1,112,163 \times 10^6 \text{ m}^3$ RIGIP occurring in almost 4,000 undiscovered pools. Conceptual plays are expected to contain an additional $400,190 \times 10^6 \text{ m}^3$ RIGIP. This analysis supports the inference that hydrocarbon resource potential is directly related to the total amount of Laramide shortening. The significance for this relationship for the hydrocarbon potential of other accretionary wedge settings remains to be determined.

**WOULD DEEP SEISMIC SURVEY ALONG FAULT ZONES
BE ADEQUATE AND SUFFICIENTLY BENEFICIAL FOR LITHOPROBE**

MAKS M. POSAVEC, DEMOFAC GSI, CALGARY

A wealth of new structural data from **satellite imagery** reveals the existence of rhomboidal to off-orthogonal pattern of **regional fault zones** (FZs) in Western Canada. Similar patterns have been better **documented** in the NW-U.S.A.

The majority of FZs manifest **dominant strike-slip** component with associated extensional and compressional structures and intensive **mega-fracturing**. These FZs range in width from several kilometers to couple of dozens kilometers. Such are the northeasterly trending Great Slave Lake and Snowbird FZs. One of the most obvious **transverse** FZs along the west coast trends below the Pearse Canal - NE of Prince Rupert. Its position at the SW end of Lithoprobe-SNORCLE transect warrants special consideration and judgement. Moreover, central segments of SNORCLE transect stretch along the NW and NE trending river valleys within the East-NE trending FZs or along their parts being offset by the North-NW FZs, these all being within the same regional pattern of FZs.

Since the majority of FZs have been **episodically reactivated basement** FZs, their 3D geometry would obviously **influence** parameters that are **essential** for valid final results of any deep seismic survey. Consequently, it is highly advisable to have **in advance** a reliable structural interpretation of the entire extent of SNORCLE transect. This could **best** be **accomplished** from the enlarged TM-satellite imagery, since it clearly shows these FZs. Moreover, this is one of **the most economical** and **least time** consuming approaches.

The imagery is already **available free of charge** from the Federal Government offices.

A New Plate Boundary Model for the Pacific-North America-Juan de Fuca Triple Junction

K.M.M. Rohr Geological Survey of Canada, Pacific Geoscience Centre PO Box 6000
Sidney BC V8L 4B2

R. Govers Geodynamics Research Institute, University of Utrecht, PO Box 90.021, 3508
TA Utrecht Netherlands

K.P. Furlong Dept. Geosciences, Pennsylvania State University, University Park, PA
USA 16802

The plate boundaries of the Pacific, North America and Juan de Fuca plates converge in a triple junction off the west coast of Canada. Previous studies have assumed that a microplate, the Explorer, exists in this triple junction region and is being subducted under North America. Interpretation of newly acquired high resolution bathymetry (Rohr and Furlong, *Geology*, 1995), single-channel seismic reflection data and a re-examination of existing regional data do not support the idea that the Explorer is a separate entity, independent of surrounding plates. Rather, the Explorer plate appears to be a broad deformation zone. Initially when the Explorer ridge segment broke away from the Juan de Fuca ridge, relative motion between the two different spreading directions was accommodated throughout the newly formed lithosphere. A distinct or local plate boundary did not exist. Seismicity and structural evidence indicate that currently the Explorer is being cut by a transform plate boundary which takes up Pacific - North America relative motion (Fig. 1). The Nootka fault zone also formed recently and accommodates North America - Juan de Fuca relative motion. This most recent adjustment of the plate boundaries provides a triple junction vector relationship which both closes and is stable.

We investigated the implications of this plate boundary geometry for the dynamic evolution of the Explorer region with two and three-dimensional finite element modelling. Our working hypothesis is that the response of the triple junction region is a consequence of the interaction of the Juan de Fuca spreading centre and the Cascadia subduction zone. The resistance to subduction of newly created oceanic lithosphere produced forces which led to the creation of the Explorer ridge segment approximately 4 mybp. The young Explorer plate is then a small weak fragment surrounded by the Pacific, North America and Juan de Fuca plates. The interplay of changing forces on the Explorer plate as the ridge migrated westward as well as its rheological structure lead to predicted strain occurring in a region that is Canada's most seismically active. Single-channel seismic reflection data also indicate that widespread deformation has and is still occurring in this region. Predicted patterns of subsidence at the northern end of the Juan de Fuca ridge and compression just north of the Nootka fault are also substantiated by structural and focal mechanism data. The lithospheric mantle of the Explorer plate is deforming predominantly in a strike-slip shear zone with the overlying crust behaving in a more passive manner affected by pre-existing structures.

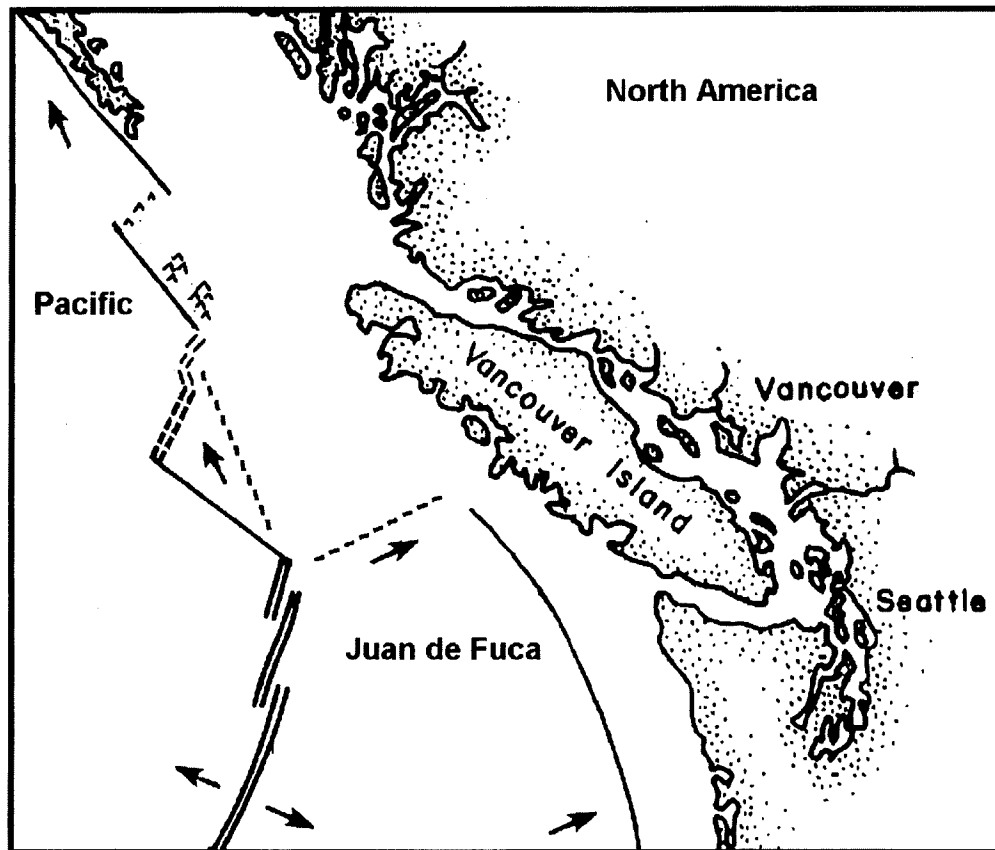


Figure 1. New plate boundary model for the Pacific - North America - Juan de Fuca triple junction. The Tuzo Wilson Seamounts and Dellwood Knolls have been interpreted to be the result of leaky transform activity. The Explorer ridge has being cut off by a transform plate boundary which accommodates Pacific - North America relative motion. The Nootka has also formed recently and accommodates Juan de Fuca - North America relative motion.

Neoproterozoic Carbonate Platforms of the Jasper Area: Are These Part of the Precambrian Rift History?

Urlwin, Ben, Department of Geology and Geophysics, University of Calgary, Calgary, Alberta, T2N 1N4. Ross, Gerald, M., Geological Survey of Canada, 3033-33rd St. N. W., Calgary, Alberta, T2L 2A7.

The late Neoproterozoic Yellowhead and Astoria Platforms lie beneath the widespread Cambrian quartzites of the McNaughton Formation. Traditionally, these carbonate sequences have been interpreted as part of the uppermost Windermere Supergroup. In this context these platforms are considered to represent shoaling near the close of sedimentation in the Windermere Basin. In order to develop a more complete understanding of the facies, diagenesis and evolution of the Yellowhead and related platformal sequences, a stratigraphic study was initiated. One goal of this study is to develop a sequence stratigraphic context for the interpretation and geometric reconstruction of the platforms. Surprisingly, the new stratigraphic data, derived from detailed mapping and facies analysis of the two best-exposed platforms during the summer of 1995, suggest that the platforms have a stronger affinity with the arkosic synrift clastics of the Jasper Member of the Lower McNaughton Formation rather than the Windermere Supergroup.

The Yellowhead Platform straddles the British Columbia/Alberta border west of Jasper and is exposed over a strike length of approximately 22 kilometers, extending from Yellowhead Mountain in the north-west, across Mount Fitzwilliam and down to Basilica Mountain in the south-east. The Yellowhead Platform has a well-developed platform geometry with a steep seaward (north-west) rim and a wedge of back-barrier facies that thins and interfingers with siliciclastic facies to the south-east. The contact with the underlying Miette Group appears structurally concordant, but represents a major shift in depositional environment from the slope facies clastics of the Miette, to shallow marine clastics of the lower Yellowhead. The platform reaches a maximum thickness of approximately 450 meters on the west face of Mount Fitzwilliam and is composed of a stromatolite-dominated lower portion and a heavily altered middle and upper portion that renders recognition of original textures difficult. Back-reef facies comprise a lower section of mixed siliciclastic and carbonate sediments, a middle portion composed of massive pisolitic carbonate wackstone-packstone and an upper portion of current laminated sandy dolomites. Stromatolitic horizons in the lower parts of the back-reef facies commonly are associated with interbeds of fine siliciclastics and sandy dolomites and form discrete domes and laterally discontinuous units that are interpreted to mark flooding surfaces. These may correlate with the lower third of the platform on the west and north-west faces of Mount Fitzwilliam, which are characterized by significant stromatolite development. Along the updip limit of the outcrop belt, the siliciclastic facies in the lower part of the platform comprise very coarse pebbly arkoses, up to 25 meters thick, that thin dramatically to the north-west into distinctive green shale units that can be traced around most of the platform. Significantly, the feldspars in the arkoses are very fresh potassium feldspars, similar to the unaltered feldspars typical of the Jasper Member. The rapid facies

changes and presence of very fresh feldspar suggest possible fault-related control of sedimentation.

The Astoria Platform outcrops near the Alberta-B.C. border, with best exposures occurring in the Tonquin Valley and Campus Pass areas. During the summer field season of 1995, five sections were measured along the southern flanks of Blackhorn Peak and Chevron Mountain. This area is dominated by back-reef facies, which, similar to the Yellowhead Platform, has a wedge-shaped geometry, thinning both to the north-west and south-east where it interfingers with siliciclastics and shales; the stratigraphic affinity of which is still uncertain. The basal portion of this facies is dominated by thick bedded intraclastic dolomites, which interbed with occasional, dark, micritic, current or crinkly laminated dolomites. Clasts within these beds are dominated by elongate micritic carbonate which are generally under 5 centimeters in length and are often parallel to sub-parallel to bedding. Minor stromatolitic horizons and pisolitic dolomites are seen sporadically through these sequences. Upper portions of the platform are dominated by sandy, current laminated dolomites, which interfinger with and are eventually overlain by, the siliciclastics of the Lower McNaughton Formation. Platform exposures on the southern flank of Old Horn Mountain contain a 200 meter thick stromatolitic unit. This facies interfingers with shales at its base and is gradationally overlain grainstone deposits (Teitz, 1985; section currently not measured for this study).

Both the Yellowhead and Astoria Platforms are overlain by, and locally, interfinger with, siliciclastic sequences that bear a distinct resemblance to the Jasper Member of the Lower McNaughton Formation, as re-defined by Lickorish and Simony (1995). On the Yellowhead Platform, the contact with the overlying McNaughton Formation is sharp and is marked by a quartz pebble conglomerate lag, overlain by very clean quartz arenite. This quartz arenite interval is only about 20 meters thick before the section becomes noticeably arkosic. Perhaps the contact with the Lower McNaughton represents a sequence boundary rather than a regional unconformity. A distinct unconformable contact with this overlying siliciclastic sequence was also observed on the Yellowhead Platform, where noticeable erosion of the platform has occurred.

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, pp. 860-874.

Teitz, M. W. 1985. Late Proterozoic Yellowhead and Astoria Carbonate Platforms, southwest of Jasper, Alberta. M.Sc. Thesis, unpublished. McGill University, Montreal, Canada, p. 107.

Conodont ages refine the timing of Late Devonian exhalites and clastic sedimentation (and therefore rifting?) in the Kechika Trough

by JoAnne Nelson¹, Suzanne Paradis², Steve Irwin² and Fil Ferri¹

The Kechika Trough was a long-lived Paleozoic intracratonic basin on the western margin of North America. Regional mapping shows platform-to-basin transitions on both its east and west sides in Cambrian and in Silurian strata. Ordovician and Cambrian alkalic volcanic suites within it suggest repeated rifting events. On Gataga Mountain, interbedded basalt and felsic pyroclastics lie within Cambrian platformal strata, less than a kilometre west of their thrust contact with the Cambrian basinal section in the centre of the Kechika Trough. Near the Akie River, basalts occur at the contact between calcareous shales and argillaceous limestones of the Kechika Group; and overlying Lower Ordovician black shales of the Road River Group, suggesting that volcanism and basin deepening coincided in the Early Ordovician.

The Upper Devonian Earn Group represents the final episode of basin deepening. It contains, in addition to black shales and chert, coarse westerly derived clastics and exhalative mineralization. Modern exhalites are located along spreading ocean ridges, in rift zones that transect arcs, and in basins in the early (pre-volcanic) stages of rifting. Exhalites in the geologic record may thus be considered evidence for episodes of local crustal extension.

Prior to this study, most fossil evidence suggested that the Kechika Trough exhalites were generally Famennian in age. The exception was an ammonoid from baritic exhalite at the Cirque, identified as Frasnian by Walter Nassichuk. He has reexamined a more extensive collection from that locality and revised the age to Late Famennian. This year we have obtained very detailed conodont age control on two of the zones from the Driftpile deposit. The East Zone is in the early part of the upper *marginifera* zone, and the Main Zone is in the *trachytera* zone. Each exhalite interval is directly overlain by mud turbidites, which represent episodic onset of clastic sedimentation. Two conodont assemblages from within a mud turbidite unit at Driftpile, and one within the coarse clastic Warneford Formation near the Akie River are in the *marginifera* zone. The youngest known exhalite in the Kechika Trough is a barite from the Cirque deposit, which is of *postera-expansa* age. This episodic exhalative activity and clastic sedimentation in middle to late Famennian time may be the record of episodic rifting in the Kechika Trough. With seven conodont zones in the roughly 7 million year long Famennian, each zone represents something like a millenium, and the closely constrained exhalative episodes must each have lasted less than a million years.

The Kechika Trough exhalites span roughly the same age range as felsic tuffs in the Exshaw Formation, which are pre-*marginifera*, middle *expansa* and lower *crenulata* (B. Richards pers. comm. 1996). Tectonic models for the Late Devonian must take into account this coincidence of extension in old intracratonic basins and continental arc(?) magmatism.

1. B.C. Ministry of Energy, Mines and Petroleum Resources, Geological Survey Branch

2. Geological Survey of Canada

THE WINDERMERE CONTINENTAL MARGIN: NEW 1:50,000 SCALE MAPS IN THE SOUTHERN MCBRIDE MAP-AREA (93H)

Gerald M. Ross Geological Survey of Canada, 3303 33rd Street N.W. Calgary AB. T2L 2A7

Charles A. Ferguson, Arizona Geological Survey, 416 West Congress Ave., Suite 100, Tucson, AZ. 85701

The Windermere Supergroup comprises a thick rift and passive margin succession deposited on the trailing western Laurentian plate edge following continental break-up and formation of the protoPacific Ocean during the late Neoproterozoic. The original depositional geometry of the WSG has been modified by a superposed younger rift event during the earliest Cambrian, as well as by plate convergence and contraction during the Mesozoic. Remnants of the Windermere basin are well preserved at low metamorphic grade in a nearly continuous transect from the western Rocky Mountains into the northern Cariboo Mountains, crossing from the western fold-and-thrust belt across the Southern Rocky Mountain Trench and into the orogenic internides (Omineca Belt) at the latitude of ca. 53°N. 4 new 1:50,000 scale geologic maps, the result of 10 years of careful mapping and walking out of stratigraphic units, provide new constraints on the structural history of the region as well as documenting the internal stratigraphic and depositional relationships within the Windermere basin.

The largely covered SRMT forms the boundary between contrasting structural styles that characterize the western Rockies and the northern Cariboo. Evidence of post-folding dextral oblique faulting, likely a southern manifestation of NRMT, is present along the east wall of the Trench whereas the west wall of the Trench is defined by the steeply-west-dipping McBride Fault. The western Rockies are characterized by NE-verging deformation at low metamorphic grades that includes folding and thrust faults formed during imbrication and growth of the Robson synclinorium, a regional structural depression. The northern Cariboo is characterized by a gentle-northwest plunge that exposes different stratigraphic units and hence structural styles along plunge. Ductile deformation characteristic of the lower stratigraphic elements is manifest as upright-folds and high-angle oblique faults at higher structural levels. At least four fabric elements have been recognized each of which can be related tentatively to regional tectonic episodes. D1 deformation is expressed largely as a bedding-parallel cleavage and rare mesoscopic northeast-verging folds formed in the footwall of the obduction boundary between North America and Slide Mountain terrane. The main deformation fabrics (D2) formed during folding of the obduction boundary and are expressed as a crenulation cleavage that is axial planar to mesoscopic folds that form a largely unbroken, remarkably concentric fold train for more 70 km across strike. These folds are predominantly southwest-verging but locally become upright and fan towards a northeast sense of vergence near the SRMT. There are two contrasting interpretations of the timing of D2 deformation. GMR believes that D2 deformation, previously recognized as widespread in the western Omineca Belt, is part of a regional pre-Middle Jurassic fabric that is cut by ca. 174 Ma plutons. CAF believes that the D2 deformation is late Jurassic-early Cretaceous in age and therefore may be linked to NE-verging deformation in the western Rockies. D3 deformation is local in

extent and related to dextral oblique-slip deformation and is manifest as discrete fault zones (Isaac Lake Fault Zone and Matthew Fault) and associated oblique folds and local crenulation cleavage. D4 fabrics are high angle transverse crenulations that although widespread in the southern Cordillera, remain enigmatic. Structural links across the SRMT remain tentative.

In general the Windermere Supergroup comprises a thick assemblage of deep-water siliciclastic and carbonate strata that shoal upwards over a stratigraphic thickness of more than 5 km. Stratigraphic relationships across the SRMT have been refined on the basis of improved resolution of sequence stratigraphic events that have resulted in basinwide lithostratigraphy. In the Cariboo Mountains the deep-water sequences are the Kaza Group, comprising thick-bedded arkosic granule sandstones deposited within a northwest-flowing sand-rich turbidite system, overlain by the Isaac Formation, a mixed succession of granule sandstones, pelites and thin-bedded limestone, interpreted as a southwest-prograding slope facies based on lateral facies changes and common occurrences of intraformational slumps. A thin but continuous pelitic unit in the Kaza Group represents an interval of sediment starvation/condensation during a major sea level rise and is correlated with the second Windermere glacial event. Two deep-water carbonate units punctuate the slope mudrocks of the Isaac Formation and have been traced regionally throughout the Cariboos. Slope facies mudrocks shoal into a ramp carbonate unit, the Cunningham Formation, a predominantly intraclastic-peloidal limestone that changes upwards from a ramp to a shelf rimmed by a windward carbonate sand shoal complex, analogous to the modern Bahamian windward margin. The overlying Yankee Belle Formation represents high-energy marine shelf sedimentation characterized by clastic-carbonate parasequences. The contact with the Cambrian(?) McNaughton quartzites ranges from sharp to gradational. In the western Rockies each of the stratigraphic markers in the Kaza and Isaac Formation have been recognized in the Miette Group although the condensed interval (here known as the Old Fort Point Formation) changes dramatically along strike as the lowstand wedge at the top of the highstand systems tract has cut out up to 150 m of stratigraphy. Pronounced facies changes within the McKale Formation (nee Middle Miette) turbidites (Kaza equivalent) occur across the Mount Rider syncline and suggest that the syncline has initiated along an old intrabasinal, down-to-the-southwest listric normal fault that constricted sedimentation to a northwest-trending trough. No shoal facies are present at the top of the Miette Group although a thin-bedded limestone and overlying distinctive green pelite unit are considered equivalents of the Cunningham and Yankee Belle, respectively. These facies changes may define an unusual "promontory" of shallow water facies in the uppermost strata of the Cariboo Mountains (the McBride Arch of Young (1972)) flanked by deeper water facies to the west and east.

The Canada/Yukon Geoscience Office: A Yukon-based Resource for Lithoprobe Researchers

Staff

Canada/Yukon Geoscience Office

Box 2703

Whitehorse, Yukon Y1A 2C6

Ph. (403) 667-8508

FAX. (403) 667-7074

<http://www.yukonweb.wis.net/government/geoscience/home.html>

The Canada/Yukon Geoscience Office was established in 1992 under the Canada/Yukon Economic Development Agreement with a four year mandate to undertake 1:50 000 scale geological mapping and related studies in areas with high economic potential and general geologic importance. Funded by Indian and Northern Affairs Canada (70%) and Government of Yukon (30%) and administered by Government of Yukon, the office has a staff of seven field geologists. The following projects have been completed:

- Proterozoic structure and stratigraphy, and origin of the Wernecke Breccias, Wernecke Mountains:- D. Thorkelson (now at SFU)
- Structure, stratigraphy and potential for sediment-hosted base metal deposits along the boundary between Ogilvie Platform and Selwyn Basin, eastern Ogilvie Mountains:-G. Abbott (on secondment from INAC)
- 1:250 000 scale geology of Mayo and Lansing map areas, central Selwyn Basin:- C. Roots (on secondment from GSC)
- Structure and stratigraphy western Selwyn Basin and metallogeny of Mesozoic plutons:- D. Murphy
- Reinterpretation of the geology and metallogeny of the Dawson Range with the aid of airborne magnetic and gamma ray spectrographic surveys:- S. Johnston
- Geological transect across central Whitehorse Trough:- C. Hart
- Placer potential of high level terraces along the Stewart, Sixtymile and Yukon Rivers:- E. Fuller (now at B.C. Ministry of Environment, Kamloops)

Funding for the Geoscience Office has now been extended to March 1997 and a decision on whether funding will continue is expected by spring 1996. Tentative plans call for greater integration with Exploration and Geological Services Division (EGSD) of INAC and programs funded entirely by YTG, Department of Energy and Mines Branch. Ultimately, with devolution of responsibility for mining to YTG, the three programs will become the "Yukon Geological Survey". Preliminary plans call for the following new projects:

- Proterozoic Magmatism and Tectonics of Proterozoic Inliers Beneath Mackenzie-Ogilvie Platform:- G. Abbott with D. Thorkelson
- 1:50 000 scale mapping, western Selwyn Basin and metallogeny of Mesozoic plutons:- D. Murphy
- 1:50 000 scale mapping near the Division Mountain coal deposit, western Whitehorse Trough:- To be announced
- 1:50 000 scale mapping Yukon-Tanana Terrane, east of the Tintina Fault:- S. Johnston
- 1:250 000 scale mapping, central Selwyn Basin, western Lansing Map area:- C. Roots
- Metallogeny of gold deposits, Dawson Range:- C. Hart
- Metallogeny of VMS and other base metal deposits, Yukon-Tanana Terrane, east of the Tintina Fault:- J. Hunt (EGSD)
- Surficial deposit and placer potential studies in the Mayo Placer district:- W. Lebarge and others (EGSD)
- Surficial deposit and placer potential studies along the Stewart River:- to be announced

The Geoscience Office contains people with wide-ranging expertise in the regional geology and mineral deposits of most parts of the Yukon. Those considering a proposal to Lithoprobe can reach us for advice and ideas on a variety of problems. Logistical support and collaboration may be possible in areas where we have ongoing projects.

First-order questions on Cordilleran Structure and Tectonics in southern Yukon

An exciting variety of fundamental problems relevant to Lithoprobe are waiting to be addressed. They include:

1. Are pre-Windermere strata west of the Snake River Fault parautochthonous with respect to North America?
 - Sedimentological and stratigraphic studies of the Pinguicula Group
 - Paleomagnetic studies
2. What is the Nature and Evolution of Crust Beneath Selwyn Basin (possibly the best example in North America of a sequence deposited on attenuated continental crust that is still relatively attached to its basement)?
 - What are the effects of Windermere, Cambrian and Devonian extension/ transtension?
 - Geochemical fingerprinting using Paleozoic and Mesozoic intrusive and extrusive rocks

- Crustal thickness and properties
3. Cretaceous Dextral Orogen-Parallel Translation (possibly best place in Cordillera to investigate this problem)
 - Hinterland part of fold-and-thrust belt deformed by Early Cretaceous (140'ish) orogen-parallel structures - part of Cordillera-long story (Valemount Strain Zone)? Accommodating structures? Temporal, spatial and geometric relationships to more typical fold-and-thrust belt structures?
 - Connection to other Cretaceous strike-slip structures? Relationship to Cretaceous extensional? structures in YTT?
 - Setting (intra-arc, back-arc)? Relationship to plate kinematics?
 4. Structure of Fold-and-Thrust Belt
 - Discriminating structures of various ages, kinematics?
 - Basement involvement?
 - Reactivation of basement structures?
 5. Nature of Early to mid-Cretaceous Magmatism intruding Northern Cordilleran Miogeocline
 - Is this a continental arc? Comparison with other magmatic belts in continental crust
 - Setting of inward sweep of magmatic front? Flat slab? Orientation of magmatic belt? Reflection of orientation of paleo-continental margin?
 - Compositional variation function of basement composition?
 6. Late Cretaceous Magmatism
 - Distribution, tectonic setting?
 - Relationship to other Late Cretaceous magmatic rocks in the northern Cordillera?
 7. What is the structure and stratigraphy of the inner (northeastern) margin of Cassiar Platform and its relationship to Cassiar Platform proper?
 8. What is the significance and timing of movement on the Finlayson Lake Fault Zone?
 9. What is the nature of mid-Paleozoic orogenesis(?) and magmatism in the Yukon Tanana Terrane?
 10. How is ~1900 km of post 70 Ma northward displacement of the Carmacks volcanics and associated basement accommodated?
 11. What is the polarity of Triassic magmatism in Stikinia?

Geology in the vicinity of the Dorsey Range, southern Yukon Territory and northern British Columbia; scale 1:50 000.

R.A. Stevens, Department of Geological Sciences, Queen's University, Kingston ON,
K7L 3N6, stevens@geol.queensu.ca
and

T.A. Harms, Department of Geology, Amherst College, Amherst MA, 01002,
taharms@amherst.edu

Rocks underlying the Dorsey Range have been assigned to the Dorsey terrane (Wheeler and McFeely, 1991), which is considered to be a distinct succession of upper Paleozoic sedimentary rocks that overlies rocks assigned to the Slide Mountain terrane (Monger et al., 1991). Mapping in the Dorsey Range during 1994 and 1995 has identified a number of fault bounded assemblages. Each of these assemblages have distinct stratigraphies and structural and metamorphic characteristics, and have probable correlative assemblages in other terranes exposed in the Canadian Cordillera. A simplified version of the legend for the 1:50 000 scale maps of the Dorsey Range is presented below. Figure 1 is a assemblage map of the area around the Dorsey Range.

Ram Creek Assemblage

Paleozoic and/or Mesozoic(?)

Dominated by light to medium green actinolite+chlorite-muscovite±epidote schist and calcareous metavolcanic rocks. Includes quartzite, marble, and sheared felsic to intermediate metaplutonic rocks. Metamorphic grade is low greenschist facies, and rocks are typically strongly foliated and sheared. Individual rock units or groups of units are laterally discontinuous.

Dorsey Assemblage

Proterozoic(?) to Permian

Dominated by grey to red-brown, fine to medium grained muscovite±garnet±biotite±oligoclase or albite±tourmaline schist to quartz-rich schist and grey muscovite±biotite quartzite. The structurally lower (northeast) part of the assemblage comprises dark green to brown, hornblende-oligoclase-quartz±biotite mafic gneiss and schist and intermediate to mafic metaplutonic rocks structurally interleaved with schist and quartzite. Bands of quartzofeldspathic melt from <1 cm to 1 m wide are common in the structurally lower parts of the assemblage. Metamorphic grade is amphibolite facies, and all rocks are strongly sheared and lineated with well developed isoclinal folds (see Stevens, this volume for more information on the metamorphic character of this assemblage).

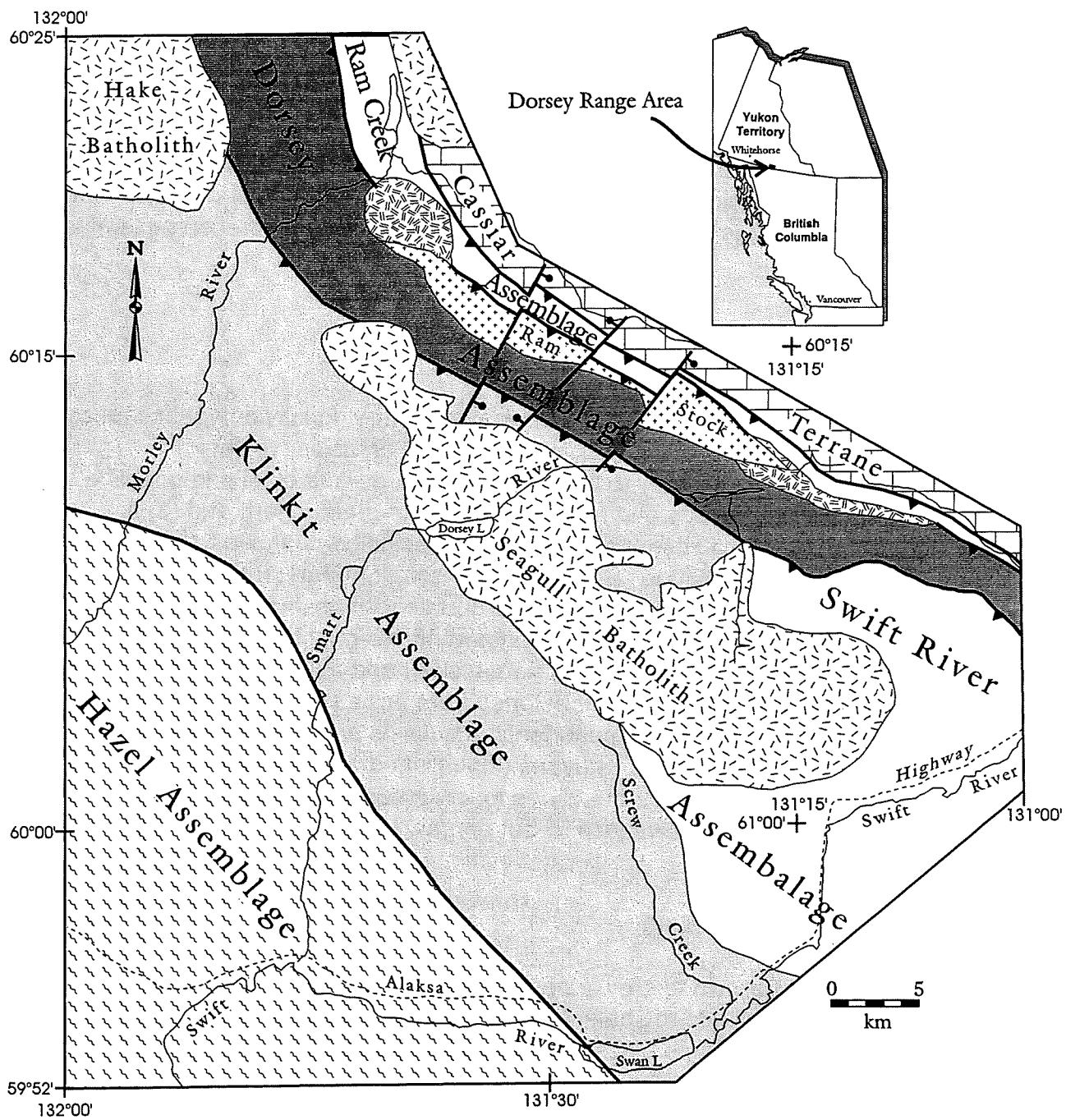


Figure 1. Simplified assemblage map of the Dorsey Range area.

Swift River Assemblage

Carboniferous to Permian(?)

Dominated by black to rusty-red siliceous graphite-muscovite phyllite and slate, and dark grey to black ribbon chert and massive chert. Includes white to black quartzite, quartz-feldspar grit, sandstone and minor chert-pebble matrix supported conglomerate. A single crinoidal limestone band has yielded middle Pennsylvanian conodonts (Abbott, 1981). Metamorphic grade is sub-greenschist facies. A strong tectonic cleavage is present in the structurally lower (northeast) part of the assemblage and locally elsewhere. Bedding is well preserved in most places.

Klinkit Assemblage

Carboniferous to Permian

Dominated by (1) medium to dark green to purple-grey, locally amygdaloidal or vesicular intermediate to mafic volcanic flows, flow breccias, volcanic fragmentals and tuffs; (2) grey to black, bedded, locally crinoidal and coralline, limestone with beds, lenses and nodules of white to green chert; and (3) a heterogeneous epiclastic dominated package that includes brown to grey to purple-grey to green, siltstone, sandstone and conglomerate, tuffaceous siltstone, sandstone and conglomerate, carbonate with associated volcanic and tuffaceous rocks; glassy quartz-grit; green and purple-grey banded tuff and cherty tuff, thin black carbonate beds; ribbon chert and calc-silicate; fine grained quartzite; black shale and slate. Limestones from this assemblage have yielded Carboniferous to early Permian conodonts, fusulinids and coral fragments (Abbott, 1981; Gabrielse, 1968; Stevens unpublished data). Metamorphic grade is dominantly sub-greenschist, but varies to low greenschist locally. A strong foliation or cleavage is present locally, but primary textures and bedding are typically well preserved.

Paleozoic and/or Mesozoic(?)

Dominated by buff-brown to grey impure quartz sandstone and dark brown laminated and cross-bedded shale. Includes siltstone, bedded chert, green banded siliceous tuff(?) and glassy quartz-grit. Affiliation with other units of the Klinkit assemblage is uncertain.

Hazel Assemblage

Paleozoic and/or Mesozoic

Dominated by medium green muscovite-chlorite-actinolite-epidote-albite±biotite schist to quartz-rich schist and distinct green and yellow banded biotite±magnetite porphyroblastic schist and pink to grey micaceous quartzite. Schists are commonly albite porphyroblastic. Metamorphic grade is greenschist and the

rocks are strongly foliated and folded into "giant-clam" type folds.

Mesozoic(?)

Dominated by grey to brown impure gritty sandstone, quartz sandstone, siltstone and shale. Grains of quartz, feldspar and biotite occur in the gritty sandstones. Metamorphic grade is sub-greenschist to low greenschist facies and a foliation or cleavage is well developed locally.

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**Structure of the Oldman River Triangle Zone, Southern Alberta Foothills:
Results of NATMAP Studies in the Maycroft East-Half Map Sheet (82G/16)**

Glen S. Stockmal, Geological Survey of Canada
3303-33rd St. NW, Calgary, Alberta, T2L 2A7 [gstockmal@gsc.emr.ca]

The Maycroft map sheet (82G/16) straddles the structural front of the Cordilleran orogen, encompassing most of the west flank of the Alberta syncline, the triangle zone, and east-directed foothills structures. New 1:50,000 scale structural mapping in Maycroft east-half, as a component of the GSC's Southern Alberta NATMAP Project, coupled with the interpretation of industry seismic reflection data (Stockmal and MacKay, 1994; Lawton et al., 1994; Stockmal et al., in press), indicate substantial differences in interpretation in comparison with those of earlier workers (cf. Douglas, 1950; Price 1981). Notable among these differences are: (1) the identification of the upper detachment of the triangle zone at a deeper stratigraphic level (within the Bearpaw Formation) and therefore in a more westerly geographic position; (2) documentation of substantial deformation in the hanging wall of the triangle zone upper detachment (the Oldman River triangle zone cannot be characterized as a "passive roof duplex"); and (3) the recognition of at least two "nested" triangle zones or tectonic wedges.

Exposed rocks are marine and nonmarine foreland basin siliciclastics with minor freshwater limestone. Stratigraphically, they range from the Cenomanian/Turonian Blackstone Formation to the Paleocene Porcupine Hills Formation. Structural mapping was aided by the field recognition of the Campanian Milk River and Pakowki formations (Stockmal, 1995; cf. Jerzykiewicz and Norris, 1994), defined in the Plains, between the Wapiabi Formation (below) and the Belly River Formation (above). The three members of the Milk River Formation are all mappable in the Maycroft map sheet, further increasing map-scale structural resolution. The three members are, from bottom to top: the Telegraph Creek Member (equivalent to the Lees Lake Formation of J&N, 1994); the Virgelle Member (equivalent to the Burmis Formation of J&N, 1994); and the Deadhorse Coulee Member (not recognized by J&N, 1994).

The west-vergent upper detachment to the triangle zone is confined to the mechanically weak Bearpaw Formation, as indicated by a reversal in structural vergence as well as seismic data. West of the trace of the upper detachment (the Big Coulee Fault), structures are dominated by foreland-directed, steeply dipping thrusts and foreland-vergent folds. East of the Big Coulee Fault, the general west-directed and west-vergent structures are disrupted by two west-directed thrusts which are folded within a south-plunging syncline. This fold forms part of a large (1 km amplitude) west-vergent fold pair developed in the hanging wall of the upper detachment. The folded west-directed thrusts may represent a small west-directed tectonic wedge which developed above the larger east-directed triangle zone.

A balanced and restored cross section indicates approximately 60% shortening across the triangle zone and adjacent foothills structures to the west (Stockmal et al., in press). The style of shortening appears to be dependent upon the stratigraphic level of the lower detachment. Where the detachment immediately underlies thick and competent sandstones, regularly spaced duplex horses develop. Where the detachment lies below thick and incompetent shales, closely spaced imbricate thrust sheets and detachment folds occur. The two "nested" east-directed tectonic wedges at Oldman River appear to have undergone simultaneous deformation for at least part of their history.

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