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**STRATIGRAPHY AND STRUCTURE OF THE
MONASHEE TERRANE IN THE
MOUNT ENGLISH AREA, WEST OF
REVELSTOKE, B.C.**

by

Robin Michael Harrap, B.Sc. (Eng.)

**A thesis submitted to
the Faculty of Graduate Studies and Research
in partial fulfilment of
the requirements for the degree of
Master of Science**

Department of Earth Sciences

Ottawa-Carleton Geoscience Centre

Ottawa, Ontario

May 18, 1990

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ISBN 0-315-60492-1

The undersigned hereby recommend to
The Faculty of Graduate Studies and Research
acceptance of the thesis, Stratigraphy
and Structure of the Monashee Terrane
in the Mount English Area, west of
Revelstoke, B.C., submitted by
R.M. Harrap, B.Sc. (Eng.)
in partial fulfilment of the requirements
for the degree of Master of Science

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May 18, 1990

ABSTRACT

The Monashee decollement, a westerly dipping and northeasterly verging shear zone, is exposed on Mt. English, southwest of Revelstoke, B.C. It crosses the Trans-Canada Highway immediately west of Victor Lake. The decollement separates migmatites of the Selkirk Allochthon, above, from gneisses of the Monashee Terrane, below, and is associated with an intense mylonitic foliation and lineation.

Monashee Terrane rocks are divisible into five map units, the lowermost separated from the others by an unconformity. The units overlying the unconformity comprise paragneiss in alternating quartzite and pelite-calcsilicate domains. The Selkirk Allochthon gneisses, on the other hand, may be divisible into three subunits, depending on the presently-unresolved degree of structural complexity in the Allochthon.

Monashee Terrane gneisses record three phases of isoclinal folding, with the later two seen in the study area. Second phase, synmetamorphic folds dominate the map pattern, while third phase postmetamorphic folds warp the second phase folds and decollement. Second phase folds are progressively attenuated as they near the decollement, demonstrating that profound shear is not limited to the decollement zone proper. Three previously unnamed second phase folds have been outlined, defining a fold stack that now comprises Mulvehill Syncline, Begbie Anticline, Tilley Anticline, Wap Creek Syncline, Mt. English Anticline, and finally Ledge Syncline in the immediate footwall of the Monashee decollement. The folds are northeasterly verging, and appear to have fold axes parallel to a strongly developed regionally-present stretching lineation.

Structural geometries require mylonite exposed in the Columbia River fault to be correlative with the decollement, and limit brittle motion on the fault to less than a few kilometers.

ACKNOWLEDGEMENTS

The production of this thesis has been an uphill battle in the face of my many other commitments and interests. Any attempt to finish in a short time was abandoned long ago, and in this regard I thank Dr. R.L. Brown, my thesis supervisor, for his patience as well as his attention and direction. I thank Drs. G. Ranalli , J.M. Moore and P.F. Hoffman for geological discussions while at Carleton, and Dr. S.L. Jackson for discussions while at the Ontario Geological Survey. I also thank the staff at Carleton for assistance with thin section preparation and other technical and logistical support.

A great deal of the atmosphere in any graduate department derives directly from the graduate students, and Carleton is no exception in this regard. Any attempt to name individuals would inevitably degenerate into a very long, or else very biased list.

I feel that my strongest motivational force at Carleton has been the interest and attention of undergraduate students that I worked with as a teaching assistant. They constantly reminded me why I love geology, and what aspects are the most important and relevant to me. In this regard I especially appreciate interaction with Marc O'Dea. Lastly, I thank Joyce Hostyn for emotional support during the long road to defending this thesis.

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CHAPTER I - GENERAL INTRODUCTION

1.0 - Preamble

The structural history of mountain belts generally includes early compressional structures and later, superimposed extensional structures. The processes may also overlap in time, with both compression and extension proceeding simultaneously in nearby areas. In the case of the Canadian Cordillera, extensional structures are prominent in parts of the metamorphic and plutonic hinterland of the orogen, where they tend to mask earlier, compressive structures that thickened the crust and balanced shortening in the foreland.

Fortunately for those unravelling the tectonic history of the hinterland of the southern Canadian Cordillera, a record of the compressional history is preserved in rocks exposed in an extensional complex, the Shuswap Metamorphic Complex. The area of particular interest, the Monashee Terrane of the Shuswap Complex, and its bounding shear zone, the Monashee decollement, present a unique opportunity. They provide a glimpse of a major compressional shear zone and associated footwall structures that developed during the relatively early evolution of the Cordillera.

The format of this introduction is as follows. First, the regional tectonic elements and current models of their development are reviewed to familiarize the reader with elements of concern to this thesis. Second, a brief description of metamorphic core complexes in general and the Shuswap Complex in particular is presented, with the redefining of terms used in the complex to clarify relations. Finally, a brief review of current problems in tectonic interpretation and a statement of objectives will be presented.

1.1 - Tectonic Elements

Tectonic elements of regional interest to this study are shown in Figures 1 and 2. These include suspect terranes, their bounding faults and/or shear zones, and numerous granitoid intrusions. This study is principally concerned with the development of the Monashee decollement (MD in Figs. 1, 2) and of related structures in its footwall, the Monashee Terrane (FCD and TOD and enveloping paragneiss in Fig. 1). However, the decollement is a product of the interaction between the sedimentary wedge of the ancient margin, suspect terranes and plate motions on the large scale, and so the gross structure and evolution of the Cordillera is relevant to detailed studies of the Terrane.

The Canadian Cordillera can, in general terms, be divided into five belts that roughly parallel the present continental margin. These are, from east to west, the Rocky Mountain Belt, the Omineca Crystalline Belt, the Intermontane Belt, the Coast Plutonic Complex, and the Insular Belt. The belts represent composite tectonostratigraphic assemblages with superimposed tectonothermal sutures (the Omineca and Coast Plutonic belts) related to the successive accretion of allochthonous terranes to the ancient North American margin (Monger et al., 1982).

The Omineca Crystalline belt, in the southern Canadian Cordillera, marks the suture between distal North American shelf sediments and an assemblage of terranes accreted in Mid-Jurassic time to the ancient margin and the pericratonic Kootenay Terrane; the accreted terranes now form the Intermontane belt. The Omineca belt was further shortened and thickened during the accretion to the developing paleomargin of North America of a second assemblage of terranes in Late Cretaceous time, with significant shortening once again transferred into the Rocky Mountain belt to the east. The Coast Plutonic Complex is the tectonothermal suture that resulted from this second accretion event, and the Insular belt comprises the second terrane assemblage. It is generally accepted that the Insular and Coast Plutonic Belts and northern Intermontane and Omineca Belts have experienced significant northward displacement on dextral transcurrent faults since accreting to the margin (Eisbacher, 1983; Gabrielse, 1985; Irving et al., 1985; Price and Carmichael, 1986).

1.2 - Compressional Development

The Mesozoic compressional development of the southern Omineca Belt thus began in the Early-Middle Jurassic when a suspect terrane assemblage (superterrane 1 of Monger et al., 1982) collided with the ancient North American margin. The collision shortened and thickened marginal basin rocks. The terrane assemblage was partially obducted onto the collapsed ancient margin, with the main structural contact being the Quesnel Lake Fault (Brown et al., 1986; QLF in Fig. 1). This easterly verging, westerly rooted crustal shear zone carried rocks of the Quesnel Terrane at least 60 km, and possibly as much as 150 km, onto the ancient margin (Brown et al., 1986; Rees, 1987). Synkinematic, east-verging folds developed in response to obduction.

Further shortening of the margin is interpreted to have resulted in an eastward-propagating blind thrust, with displacement balanced in the hanging wall

by westerly-verging, easterly rooted recumbant isoclines, or backfolds. These backfolds continued to grow as long as the thrust remained blind (Brown and Lane, 1988) thus thickening the crust and resulting in regional metamorphism. When the thrust daylighted, these metamorphosed rocks of the Selkirk Allochthon were thrust eastward over rocks of the underlying Monashee Terrane (Brown et al., 1986). The thrust, an easterly-verging, westerly rooted shear zone, has been named the Monashee decollement (Read and Brown, 1981) and mapped for over 200 km in the Monashee mountains (Brown and Read, 1983; Brown et al., 1986; Journeay, 1986; Scammell, 1986; Journeay and Brown, 1986; Bosdachin and Harrap, 1988; Coleman, 1989) (MD in Fig. 1). The Monashee decollement apparently had an episodic history of motion, with major displacement occurring synchronous with Mid-Jurassic and Late Cretaceous - Paleocene superterrane collisions.

1.21 - MD₁ - Early Motion on the Monashee Decollement

Tectonic models describing motion of the Monashee decollement must fit a number of constraints and describe the evolution of a number of observed features in the footwall terrane of the decollement, the Monashee Terrane. Notably these features include two prograde metamorphic events, with an early, high pressure and temperature peak (M₁) overprinted by a high temperature, low pressure peak (M₂) that manifests itself as an inverted metamorphic gradient on Frenchman Cap dome (Journeay, 1986). The decollement consists of, at least on the north and south flanks of the Monashee Terrane, a lower pre to syn-M₁ shear zone (MD₁) and a higher and overprinting syn-M₂ zone (MD₂) (Figs. 1, 2). M₁ isograds clearly cross MD₁, and the inverted M₂ metamorphic gradient decreased downwards from MD₂.

First motion (MD₁) occurred before the peak of early metamorphism; motion on the decollement carried thickened crust of the Selkirk Allochthon over

the Terrane and resulted in metamorphism of the Monashee Terrane to amphibolite grade. Pressure sensitive metamorphic assemblages constrain the decollement to a depth of 25-30 km during early motion (Journeay, 1986). The decollement truncates at least three major premetamorphic (F_1) folds on the north and west flanks of Frenchman Cap dome (Fig. 2). The structures reappear on the south flank of the dome, suggesting that development of the dome postdates F_1 but predates the end of MD_1 motion.

MD_1 is thought to postdate the development of synmetamorphic backfolds in the Selkirk Allochthon. M_1 in the Selkirk Allochthon quenched between 166 and 156 Ma (Armstrong, 1982; Archibald et al., 1983). Monashee Terrane metamorphism (M_1) must be this age or younger, as motion on the decollement uplifted its assemblages quenching the Allochthon yet burying the Monashee Terrane.

The Monashee Terrane M_1 assemblage must have been quenched by the time MD_2 resulted in an inverted metamorphic gradient (M_2) on Frenchman Cap dome. This is constrained to be in Late Cretaceous to Paleocene time (see below). Quenching of M_1 requires either profound erosion or tectonic uplift or both. Given the much lower pressure of M_2 metamorphism (Journeay, 1986), it is reasonable to assume that the Monashee Terrane was uplifted along the thrust ramp resulting from the Monashee decollement breaking forward to a basement shear zone beneath the Terrane (Brown et al., 1986). This basement zone would continue to feed deformation in the foreland.

1.22 - MD_2 - Late Motion on the Monashee Decollement

A second period of motion (MD_2) occurred on the Monashee decollement in the Late Cretaceous - Paleocene, following the collision of a second composite terrane with the margin (superterrane 2 of Monger et al., 1982). MD_2 followed at least 10-12 km of uplift, presumably on a footwall ramp, as M_2 metamorphism

was low pressure in nature (Journeay, 1986). The reactivated decollement (MD₂) parallels the early decollement (MD₁) along the west flank of the Monashee Terrane but diverges at the north and south (Fig. 1). The divergence between the zones is likely a consequence of arching of MD₁ and the Monashee Terrane that occurred during basement duplexing.

The second decollement zone (MD₂) on Frenchman Cap consists of an interlocking network of ductile shears that contain lozenges of older mylonitic gneiss (Journeay and Brown, 1986). It has been called the Shuswap Thrust at that location (Journeay and Parrish, 1988). Stratigraphy between MD₁ and MD₂ is uncertain in affinity. At the south end of Thor-Odin dome MD₂ is the roof thrust of a footwall duplex and has been called the Cariboo Thrust. Footwall horses on Thor-Odin dome become progressively attenuated from south to northwest as MD₁ and MD₂ converge (Coleman, 1989). In both locations MD₂ is the site of an abrupt change in metamorphic grade, with migmatites of the Selkirk Allochthon lying on amphibolite grade rocks of the Monashee Terrane (Journeay and Brown, 1986; Coleman, 1989).

During reactivation, MD₂ moved deeper and hotter rocks of the Selkirk Allochthon up the ramp onto the (quenched) Monashee Terrane. MD₂ truncates footwall M₁ isograds obliquely, and the hot upper plate generated an inverted metamorphic gradient, M₂, that extended from amphibolite grade at the decollement to greenschist grade in the core of Frenchman Cap dome (Journeay, 1986). Pressure sensitive minerals recorded a depth of 10-15 km during M₂ (Journeay, 1986). This inverted M₂ metamorphism is not observed on the south flank of Thor-Odin dome (Coleman, 1989).

Hornblende cooling ages in the footwall of the decollement at Revelstoke require that all high temperature metamorphic assemblages of the Monashee

Terrane were quenched by the latest Cretaceous - Paleocene (Lane et al., 1989). U-Pb zircon geochronology reveals that, at Cariboo Alp on the south flank of Thor-Odin dome, MD₂ was active at 59 +/- .5 Ma but inactive by 58 Ma. (S.D. Carr, pers. comm., 1989). On Frenchman Cap dome MD₂ is thought to have been active at 57 +/- 1 Ma but inactive at 54 +/- 1 Ma (Journeay and Parrish, 1988). However, the Eocene age of 57 +/- 1 Ma may be kinematically related to extension, rather than compression (R.L. Brown, pers. comm., 1989). The decollement thus had a second-stage history in Late Cretaceous - Paleocene time, consistent with a dynamic link to the accretion of superterrane 2.

Overall, the Monashee Decollement is a 300-1000 m thick mylonite zone of consistent top to the northeast sense of shear. It is characterized by transposed lozenges of stratigraphy, sheath folds, mylonitic fabrics, and complex metamorphic relations. It records a minimum of 80 km of displacement (Brown et al., 1986) in which hanging wall rocks of the Selkirk Allochthon were transported over footwall rocks of the Monashee Terrane. In addition, to juxtapose pre-existing structures of similar character in the hanging wall and footwall of MD, a minimum displacement of 100 km is required (Brown et al., 1986).

1.3 - Unroofing of the Monashee Terrane

M₂ metamorphic assemblages of the Monashee Terrane were quenched by Paleocene time, as indicated by hornblende cooling ages in the footwall of MD at Revelstoke (Lane et al., 1989). This quenching was a result of uplift and tectonic denudation of the Terrane by motion on low angle normal faults (Brown and Journeay, 1987; Parrish et al., 1988), which added to pre-MD₂ uplift on ramps. The relative importance and relationship of these two modes of uplift has been confused in the past, leading to the definition of the Monashee "Complex" as a metamorphic core complex of compressional origin (Brown and Read, 1983).

Questions concerning the evolution of the Monashee Terrane are intimately related to its definition, which is reconsidered below.

1.31 - Extension, Core Complexes and the Shuswap Metamorphic Complex

Metamorphic core complexes (MCC) are metamorphic terranes uplifted by normal-sense motion on bounding shear zones, or decollements. They consist of three zones: a relatively high (metamorphic) grade core zone, a decollement, and lower grade cover rocks (Coney, 1980). Core complexes typically display ductile deformation within the core zone, a ductile to brittle transformation within the decollement, and brittle deformation in hanging wall or cover rocks. Complexes are usually arch shaped with one flank more steeply dipping and with cover rocks exposed marginal to the complex (Coney, 1979).

A great number of core complexes are disposed in a discontinuous belt extending from northern Mexico to Alaska. Core complexes are not restricted to the North American Cordillera, although they have only recently been recognized elsewhere. For example, recent mapping in southern Tibet has led to the recognition of a series of gneiss domes overlain by extensional faults and inferred to be metamorphic core complexes (Hodges et al., 1989).

Ductile deformation in the core of MCC's consists of intense mylonitic foliation and lineation. The fabric is most intense at the decollement, and intensity drops off rapidly downwards. The pervasive foliation conforms to the general shape of the complex but is locally truncated by the decollement. The stretching lineation is commonly regionally consistent and roughly perpendicular to the long axis of the complex. The constancy of direction of extension lineations may imply a regional control on extension (Wust, 1986). S-type granitoid intrusions are common in core zones. They are overprinted by mylonitic fabrics near the decollement but are massive at deeper levels (Armstrong, 1982).

The decollement is an intensely brecciated zone generally subparallel to fabric in underlying rocks. Younger brittle deformation is seen to have shattered mylonitic rocks recording early motion. This ductile to brittle transition results from the emplacement of progressively shallower and cooler tectonic levels of the cover onto core rocks. The decollement is typically best developed on the shallower limb of asymmetric complexes (Coney, 1979) and is the site of a steep metamorphic gradient. It truncates structural trends in both hanging wall and footwall.

Cover rocks generally show brittle deformation and may show severe attenuation as a result of down-dip displacement on the decollement. Displacement on structures within the cover are generally down-dip but do not necessarily strictly parallel linear fabric in the core. The average initial cover thickness above the decollement is over 10 km (Coney and Harms, 1984).

All MCC's lie inboard of the craton edge as defined by a $0.706 \text{ }^{87}\text{Sr}/^{86}\text{Sr}$ ratio in intrusives (Armstrong et al., 1977). Complexes north of and within Nevada lie at the (Paleozoic) site of a thick miogeoclinal prism of late Precambrian to Paleozoic terrace sediments. The rocks in most of these northern complexes were affected by Paleozoic - Mesozoic metamorphism and deformation and are found in the hinterland of fold and thrust belts (Armstrong, 1982). Complexes to the south, in Arizona and Sonora, lie within what was in Paleozoic time a thin cratonic shelf sedimentary environment and correspond to an area of profound basement cored uplifts in the Mesozoic (Coney, 1979).

The MCC corresponds to a crustal welt generated by crustal thickening in the Mesozoic (Coney and Harms, 1984). There is, however, no present-day crustal thickness anomaly associated with the belt. Extension in northern complexes began within perhaps 10 Ma or less of the completion of crustal thickening; this

gap increases to as much as 70 Ma in southern complexes. Taken together these relations suggest that extension relates directly to the thinning of overthickened crust, with timing controlled by crustal temperature. Models have been proposed relating timing of extension to crustal delamination (Houseman et al., 1981; Ranalli et al., 1989), with detachment of a portion of continental lithosphere thermally triggering crustal collapse by extension. Recently, Dewey (1988) has reviewed Cordilleran, Alpine, and Himalayan regional tectonic relations and concluded that these three orogens reflect different stages in an evolutionary path dominated by catastrophic lithospheric delamination.

1.32 - The Monashee Terrane as a Core Complex

Until recently the Monashee Terrane was recognized as an example of a metamorphic core complex of a second kind, namely, one that evolved via compression rather than extension (Price, 1985). The necessity of a two-fold division for core complexes rests on the interpretation that the Monashee Terrane is sufficiently similar to extensional core complexes in observational respects to warrant such a subdivision.

The Shuswap Metamorphic Complex (SMC) is an amphibolite grade metamorphic terrane located in the southern Omineca Belt, in southern British Columbia. It contains abundant metasedimentary rocks, granitoid intrusions and orthogneiss, and mafic metavolcanics. It is bounded on the east by the Eocene Columbia River Fault (Read and Brown, 1981; Lane, 1984) and on the west by the Eagle River Detachment (in the north) (Johnson, 1989; Journeay and Brown, 1986) and the Okanagan Shear Zone (in the south) (Bardoux, 1985; Parkinson, 1985; Tempelman-Kluit and Parkinson, 1986; Parrish et al., 1988).

The SMC contains, on its east flank, an expanse of upper amphibolite grade metasediments and basement orthogneiss, previously known as the Monashee "Complex" (Brown and Read, 1983; Journeay and Brown, 1986). The

Monashee Complex (MC) is bounded by a westerly rooted, easterly verging crustal scale shear zone, the Monashee decollement.

Dating of the South Fosthall Pluton (SFP in Fig. 1), which contains mylonite along the trace of the Columbia River fault, gives ages of 55.1 ± 0.1 and 55 ± 1.5 Ma (Parrish et al., 1988), requiring that at least some mylonite that developed in the trace of the Columbia River fault is Eocene. The South Fosthall Pluton has previously, on the basis of age and lithology, been correlated with the Eocene Ladybird Granite (Carr, 1989; Carr et al., 1987), a suite intimately associated with extensional structures in the Valhalla Complex. Mylonite exposed within the Columbia River Fault at its southern end is a record of early motion on the fault and clearly records a ductile to brittle tectonic transition (Parrish et al., 1988).

The Eagle River Detachment and the Okanagan Shear Zone likewise record apparent ductile to brittle transitions. Furthermore, on the basis of relations between extensional structures exposed to the south, the relative timing of the Columbia River Fault and the Eagle River and Okanagan structures may be inferred. East-dipping detachment structures in the south are cut by intrusions of the ca. 52 Ma Coryell Syenite suite, implying that they are older than this. However, west-dipping detachment structures, including the Okanagan Shear Zone, locally imprint a mylonitic foliation on rocks younger than this, including Coryell suite rocks and a sill dated at ca. 50 Ma, implying that the west dipping structures are marginally younger. On this basis, it may be argued the denudation of the Shuswap Terrane was accomplished by early motion on the Columbia River Fault and related structures and later motion on the Eagle River and Okanagan structures (Parrish et al., 1988).

The MC is by no means a core complex. While it is uplifted, only a portion

of this uplift is a result of extensional structures. The Monashee decollement is a compressive structure, not an extensional structure, thickening the crust in the Omineca Belt by ramping progressively deeper rocks from the west onto the "Complex" (Journeay, 1986). Furthermore, MD carries rocks of higher grade in its hanging wall than in its footwall and displays no ductile to brittle transition, rather an inverted metamorphic gradient has been generated in the footwall (Journeay, 1986). While the Monashee "Complex" is bounded on the east by the (extensional) Columbia River Fault, the north, south, and west flanks have no coincident extensional faults of significant magnitude. The Monashee Complex cannot, as a result, be considered a true core complex.

The SMC, conversely, is a core complex. As detailed earlier, it is bounded by extensional structures and is of higher metamorphic grade than surrounding terranes. The Columbia River Fault, the Eagle River Detachment, and the Okanagan Shear Zone all display ductile to brittle transitions (Parrish et al, 1988). The Shuswap Metamorphic Complex has therefore been renamed the Shuswap Metamorphic Core Complex (Brown, 1989). It is by far the largest core complex in the North American Cordillera and was unroofed in the Late Paleocene and Eocene, coincidentally unroofing the Monashee Terrane.

The Monashee Complex is, thus, a compressional complex exposed within a core complex. To avoid confusion, while preserving an allochthonous sense, it has been renamed the Monashee Terrane (Brown, 1989). This reinterpretation alleviates the need for a two-fold subdivision of core complexes.

1.4 - Current Debate

Current controversies in regional tectonic interpretation concern the relative role of compression and extension in the structural doming of the

Monashee Terrane, the geodynamic evolution of the Terrane, the significance of regional transcurrent motions throughout its evolution, and the tectonic relationship between the Terrane and the adjacent Clachnacudainn Terrane.

Parrish et al. (1988) have pointed out that cooling dates within the adjacent Clachnacudainn Terrane closely resemble those within the Monashee Terrane. This implies that during the extensional evolution of the Shuswap Metamorphic Core Complex the Clachnacudainn Terrane was an integral part of the core complex, and was detached during late evolution by motion on the segment of the Columbia River fault immediately north and south of Revelstoke (Fig. 1). This suggests that a splay structure of the Columbia River fault coincident with, or adjacent to, the Standfast Creek fault (SCS in Fig. 1) was active as an extensional structure in the Eocene.

Models of the geodynamic evolution of the Shuswap MCC and the Monashee Terrane and of strike-slip deformation in the Cordillera rely on an understanding of oceanic plate motions and interactions in Cretaceous - Tertiary time. The kinematic models of Engbreton et al. (1985, 1984) have recently been replaced by a more rigidly constrained model (Lonsdale, 1988), necessitating a rethinking of the relationship between oceanic plate motions and the evolution of the Shuswap MCC and the Cordillera in general.

The geodynamic evolution of the Shuswap has recently been modelled by Ranalli et al. (1989) following the method of Houseman et al. (1981). Ranalli et al. (1989) incorporated the oceanic plate kinematic model of Lonsdale (1988) and found that detachment of a lithospheric root was not inconsistent with the initiation of extensional collapse of the southern Omineca Belt.

Margin-parallel strike-slip faulting has been recognized in the Cordillera, including the Northern Rocky Mountain Trench - Tintina and Fraser River -

Straight Creek systems. The possibility that the Shuswap MCC extension resulted via a transfer zone between these systems has been suggested (Price, 1979; Price et al., 1981, 1985; Price and Carmichael, 1986).

1.5 - Objectives

The trace of the Monashee decollement across the Trans-Canada Highway has alternatively been placed at Sicamous (Brown and Read, 1983) and east of Three Valley Gap, at Victor Lake (Journeay and Brown, 1986; this study, 1989) (see Fig. 1). The regional case for the placement of the decollement rests on hanging wall stratigraphy: stratigraphy near Three Valley Gap is similar in character to stratigraphy in the hanging wall of the decollement on the west and northwest flanks of Frenchman Cap dome. The test of the hypothesis is simple: if the decollement does pass across the highway at Victor Lake, a discontinuous change in stratigraphy and structural style should be observed, coincident with a mylonite zone. Unfortunately the section at Victor Lake is offset by a late normal fault, and so the section must be examined on slopes and peaks to the south and north.

The goals of this study are threefold: first, to verify or refute that the Monashee Decollement crosses the Trans Canada Highway at Victor Lake, and if verified, to trace it to the south towards Thor-Odin dome; second, to document the character of footwall and hanging wall stratigraphy and attempt to correlate these sequences with regionally recognized units; and finally, to document the structural style in the footwall of the decollement in order to better understand the evolution of both the Monashee Terrane and the decollement. The place of the Monashee decollement and Terrane in the development of the Cordillera will be considered in terms of the results of these three objectives.

The detailed study area consists of a section of the structural depression between Thor Odin and Frenchman Cap domes. Units exposed in the area are principally metasediments of the Monashee Terrane and overlying Selkirk Allochthon metasediments. Core zone rocks of the Monashee Terrane are locally exposed. The area consists of a group of peaks with excellent exposure well above the tree line and tree-filled valleys with poor exposure. The Trans-Canada Highway, in Eagle Pass valley, forms the northern border of the area. The study area adjoins that of Bosdachin (1989) on the north flank of the highway.

Two seasons of mapping were carried out to trace the decollement and establish stratigraphic and structural relations. The first, in the weather-bound summer of 1986, consisted of a joint mapping project with R. Bosdachin in both field areas. The second, in the relatively snow-free summer of 1987, consisted of detailed (1:25000) mapping in the Mt. Tilley and Mt. English area.

Reconnaissance mapping along the Trans-Canada Highway and the adjacent railway line, and local mapping along lumber roads on tree-covered slopes, extended the database. The joint studies resulted in a joint publication (Bosdachin and Harrap, 1988) and greatly reduced the danger of miscorrelation of units and structures between the two field areas.

Compilation of previous work adjacent to the study area (Map 3) was carried out to extend coverage of footwall structures, which have limb-lengths larger than the study area. Laboratory analysis of thin sections was carried out during winter months to document metamorphic textures and grade.

CHAPTER II - STRATIGRAPHY AND REGIONAL STRATIGRAPHIC RELATIONS

2.0 - Introduction

The Mt. English area and the Trans-Canada Highway immediately to the north are relatively accessible areas in which to study the juxtaposition of Selkirk Allochthon and Monashee Terrane stratigraphy. This juxtaposition has previously been described in remote areas on the north and west flanks of Frenchman Cap dome to the north (Journey, 1986; Scammell, 1986; Brown, 1980), and immediately to the north in an adjoining M.Sc. research area (Boslachin, 1989). The Mt. English area also serves to illustrate the distinct differences between footwall and hanging wall stratigraphies across the Monashee decollement. As such it presents an excellent opportunity to view the stratigraphic relations that dominate the western flank of the Monashee Terrane (see Fig. 2).

Two distinct stratigraphic sequences are found in the study area, the upper and western sequence (Selkirk Allochthon) occurring only on Mt. English while the lower, eastern sequence (Monashee Terrane) is widespread. The contact between them is an apparently westerly dipping ductile shear zone, the

Monashee decollement. This structural break wraps around the summit of Mt. English, projecting down to the Trans-Canada Highway immediately west of Victor Lake (Maps 1-3), where it outcrops in roadcuts as a mylonite zone in migmatitic semipelitic gneiss. Monashee Terrane stratigraphy is well exposed along the highway to the east, while Selkirk Allochthon stratigraphy outcrops to the west, notably along the south shore of Three Valley Gap Lake (Maps 1-3).

2.1 - Monashee Terrane Stratigraphy

Rocks of the Monashee Terrane in the study area have been subdivided into two sequences, with a total of five distinct and continuous units, on the basis of inferred affinity and age. They are described below in order of structural superposition. This structural section is inferred from regional correlations to be in normal stratigraphic order (see Scammell, 1986; Journeay, 1986). No unambiguous internal stratigraphic facing direction was determined within the study area; however, the section is obviously right way up where basal units of mantling gneiss rest unconformably on the basement gneisses that form the core of Thor-Odin and Frenchman Cap domes (Fig. 1).

2.1.1 - Unit 1

This lowermost, composite unit of para- and orthogneiss is locally uniform though regionally variable. Where observed, on Mt. English, it is dominantly migmatitic semipelitic augen paragneiss (Plate 1a), [Qtz-Kfs-Sil-Grt-Bt] with concordant granitic leucosome [Qtz-Kfs-Bt] bands up to 10 cm thick occurring throughout and making up as much as 10% of the unit. Lower portions of the unit display a scalloped appearance, with foliation warping around paragneiss lenses several centimetres in thickness and up to a dm in length. Only the uppermost 75 m of the unit is exposed within the detailed area of study.

Regionally the unit contains both migmatitic semipelitic paragneiss and compositionally zoned, granitoid orthogneiss (Journeay, 1986). Whole rock Rb-Sr isochrons from orthogneiss in the core of Frenchman Cap give an Aphebian age (2.17 Ga, Armstrong, 1979). Similar studies in Thor-Odin dome have given ages of up to 3 Ga (Duncan, 1978), while U-Pb zircon dating of orthogneiss has given an age of 1.9 Ga (Wanless and Reesor, 1975). As a result of the gross similarity between these ages and ages on North American cratonic rocks to the east, it has been suggested that this core unit represents remobilized attenuated North American basement (Brown, 1981). Parrish and Ross (1989) have inferred basement structures of cratonic North America as far west as Revelstoke on the basis of reef trends that correspond to basement structural grain. They suggest that the basement likely extends as far west as the Okanagan Shear Zone (Fig. 1) on the basis of crustal contamination of volcanic rocks.

2.12 - Unit 2

Overlying this gneiss package is a muscovite-bearing quartzite of regional extent. The contact at the base of the quartzite has been interpreted as a major unconformity between the mixed Aphebian gneisses below and metasedimentary cover above (Fyles, 1970; Brown, 1980; Read, 1980; Journeay, 1986). A quartz-pebble conglomerate at the base of the unit has been described immediately to the north (Bosdachin, 1989), while Journeay (1986) described both basal conglomerate and heavy-mineral lag deposits on the western flank of Frenchman Cap dome farther to the north.

The basal quartzite floors a sequence of metasediments (locally referred to as the "mantling gneisses"), deposited on eroded Aphebian basement. The basal unit is a regionally persistent, clean quartzite of variable thickness (<30 m to >150 m) that contains characteristic but minor proportions of muscovite (<5%) and tourmaline (<1%). The quartzite is thinly but evenly bedded, with muscovite partings up to 2 centimetres thick defining beds on the 5 cm to 1 dm scale. Some

beds within the quartzite contain significant feldspar and so are likely arkosic rather than orthoquartzitic in protolith. Biotite occurs locally.

Tourmaline within the unit occurs both as lineated, pulled apart megacrysts up to 15 cm in length (Plate 4d) and as unoriented, smaller, unfragmented crystals. Both varieties are generally contained in quartz-pegmatite lenses between beds. Tourmaline is also conspicuous in discordant pegmatites [Qtz-Kfs-Grt-Tur] that have intruded the quartzite.

At least two horizons of mafic to ultramafic boudins occur within the quartzite where it is exposed on Mt. English. The pods are typically dark green hornblende [Hbl-Pl] or black amphibolite [Pl-Hbl-Grt]. They may be up to 1 m thick, and display no conspicuous fabric. The pods are likely the boudinaged and metamorphosed relicts of once-continuous flows or sills.

2.13 - Unit 3

The basal quartzite is overlain by a heterogeneous carbonate-clastic-pelite assemblage that varies between 50 and 450 m in thickness. Within the mapped area the assemblage has been subdivided into various discontinuous members consisting of pelitic schist, calc-silicate gneiss, biotite and hornblende quartzofeldspathic gneiss, marble, and interbedded psammitic and calc-silicate gneisses. With the exception of a prominent white marble marker horizon within the assemblage and a pelitic schist horizon that is generally present at the base of the unit, facies changes along bedding are frequent and prevent any fine-scale subdivision of the assemblage. The extreme variability in unit thickness, although ascribed by Read (1980) to stratigraphic facies changes, appears to be structural in origin, requiring that some structural dissection and transposition did occur.

Metapelitic horizons (Plate 1b) within the unit are well foliated and

lineated and are aluminosilicate-rich, with occasional kyanite and, more commonly, both fibrous and lathlike sillimanite lying in the foliation plane and defining the lineation. Variations in the percentage of quartz within the pelite led to the description of such horizons both as pelitic schist and semipelitic schist or gneiss in the field. Although the differences are likely primary, boundaries between the two are generally gradational and thus arbitrary. The pelitic and semipelitic horizons are invariably migmatitic (Plate 1c), are laminated on the centimetre scale, and contain abundant augens representing dissected migmatitic leucosome.

Calc-silicate gneisses [Di-Cal-Qtz-Bt-Grt] vary between diopsidic and solely calcitic members, both varieties being thickly bedded (1 m on average) and containing interbeds of pelitic to psammitic gneiss. Discontinuous horizons of diopsidic quartzite occur within the calc-silicate. The calc-silicate itself is speckled green and tan, poorly foliated, and unlineated.

Numerous marble horizons occur within the calc-silicate assemblage, although only one, being the white marker unit mentioned earlier, is laterally continuous. It typically occurs about two - thirds of the way up through the unit, is between 1 and 10 m thick, and can be traced for tens of kilometres to the north on the flanks of Frenchman Cap dome (Brown, 1980; Journeay, 1986; Scammell, 1986). A carbonatite horizon is both regionally and locally associated with the marble, generally occurring immediately beneath it in the stratigraphic succession (Journeay, 1986). Three occurrences of carbonatite on the north flank of Mt. English are cited by Read and Klepacki (1981), all poorly exposed, of which two were verified in the field as indicated on Map 1. Scammell (1986) described this unit in the north as a stratiform block-lapilli carbonatite tuff. Journeay (1986) described the carbonatite layer as lying several metres below the marker marble on the west flank of Frenchman Cap dome.

Biotite and hornblende quartzofeldspathic gneiss occurs within the assemblage on Mt. MacPherson, making up approximately one third of its total thickness. The gneiss contains up to 10% migmatitic leucosome. It occurs only as interbeds elsewhere. Lastly, interbedded psammitic gneiss and calc-silicate gneiss beds dominate the unit on the eastern end of Mt. MacPherson, while metapelitic material dominates unit 3 on Mt. English.

2.14 - Unit 4

Above the heterogeneous assemblage lies a thin (<25 m), thinly bedded, biotite-bearing quartzite (unit 4) which contains abundant amphibolite boudins [Hb-Pl-Bt] (Plate 1e). The quartzite is foliated and strongly lineated, with the lineation defined locally by sillimanite in metapelitic partings (Plate 1f), and defined elsewhere by elongate quartz crystals and biotite grains streaked out in the plane of foliation. It locally contains sillimanite-biotite knots and contains abundant quartz-biotite gneissic interlayers. The proportion of amphibolite boudins increases to 50% near the top of the unit, both within the study area and to the north (Bosdachin, 1989). The quartzite is an excellent marker horizon in the Monashee Terrane. It outcrops twice on the Trans-Canada highway immediately north of Victor Lake, immediately east of the outcropping of the decollement, defining the limbs of a third phase antiform (Maps 2 and 3).

2.15 - Unit 5

The highest observed footwall unit comprises augen-bearing migmatitic pelitic schist [Qtz-Bt-Sil-Kfs-Pl-Grt] that locally grades upward into massive diopsidic calc-silicate gneiss [Di-Tur-Pl-Qtz-Cal] containing discontinuous marble horizons. Coarse Quartz -Biotite -Sillimanite -Plagioclase knots occur within the metapelite. A maximum of 75 m thickness of the unit is exposed, within the cores of isoclinal synforms.

2.2 - Monashee Decollement

A distinct and separate stratigraphic assemblage outcrops on the upper and western flanks of Mt. English. This higher assemblage is unrepresented in the cores of Monashee Terrane synforms and so is suspect in relation to the Terrane's stratigraphy. This higher stratigraphy was originally inferred to be a right-way-up continuation of Monashee Terrane stratigraphy (Read and Klepacki, 1981). It was later inferred to be in the hanging wall of a major crustal shear, the Monashee decollement, on the basis of similarities to relations on the west flank of Frenchman Cap Dome (Journeay and Brown, 1986). Fieldwork in the detailed study area supports this second view; the observed shear zone will be described in detail below. Hanging wall stratigraphy, inferred to be of the Selkirk Allochthon, will be described in turn.

The structural and stratigraphic sequence of the Monashee Terrane within the map area is cut by a chaotic zone of highly variable stratigraphic character and intense structural fabric. The zone is regionally sub-parallel to structurally - controlled stratigraphic contacts within the Terrane, but locally truncates both stratigraphy and the axial planes of folds (see Map 2). The zone, which is roughly west-dipping and north-striking, cuts through the top of Mt. English, separating Monashee Terrane stratigraphy below from distinct stratigraphy above. It projects down the north flank of Mt. English, subparallel to stratigraphy, and crosses the Trans-Canada Highway immediately west of Victor Lake. The chaotic zone averages 50 m in thickness but is up to 150 metres in thickness locally. Mylonitic fabrics extend into both the hanging wall and footwall.

The chaotic zone is best exposed on the south flank of Mt. English (Plates 2a, 3) where it truncates units 4 and 5 of the Monashee Terrane (Map 2). The exposed zone is a highly pegmatized shear zone with abundant transposed

stratigraphic slivers of both Monashee Terrane and hanging wall (Selkirk Allochthon) rocks. The slivers include quartzite, psammitic gneiss, calc-silicate gneiss, and amphibolite; they range in size from greater than 10 m to less than 1 m in long dimension (Plate 2b) and are lenticular in shape. The slivers are embedded in a mylonitic matrix of semipelitic composition, which contains up to 50% pegmatite locally. The pegmatite [Qtz-Kfs-Bt-Tur] ranges from unstrained intrusive bodies to dissected, mylonitic lozenges (Plate 2g).

Foliation and lineation in the mylonite zone are visably warped around the margins of tectonic slivers entrained in the semipelitic matrix. Tectonic slivers show foliations parallel to the surrounding mylonitic fabric near margins, but frequently preserve older fabrics internally, at a high angle to the mylonitic foliation.

A cryptic pseudo-stratigraphy was observed within the chaotic zone. Tectonic slivers of footwall, Monashee Terrane affinity dominate near the base of the zone, while slivers of hanging wall affinity dominate near the top. Although the base of the chaotic zone is distinct, frequently placing semipelitic mylonite against less-strained quartzite (unit 4), the top of the chaotic zone is arbitrary. The hanging wall shows considerable discontinuous strain and includes at least one discrete shear zone (Plate 3, Maps 1-3).

2.3 - Selkirk Allochthon

The hanging wall comprises three distinct assemblages that are laterally continuous in character, although no continuous markers were observed. The assemblages have gradational contacts and are defined only locally due to incomplete mapping of the hanging wall. Their definition and disposition on the south flank of Mt. English (Maps 1, 3) makes the implicit assumption that the hanging wall contains no mesoscopic recumbant isoclinal folds disposed with

axial planes subparallel to the shear zone. This assumption is necessary as mapping of the hanging wall was restricted to the south flank of Mt. English, and so represents a two dimensional view of the hanging wall. The Selkirk Allochthon, with which the hanging wall stratigraphy is correlated, does contain large, west-verging isoclinal folds (Raeside and Simony, 1983; Brown and Lane, 1988), but these are much larger than the scale of observation in the mapped area.

2.31 - Unit 6a

The boundary between the chaotic zone and the lowest continuous hanging wall assemblage is arbitrary, as strain and pegmatization continues well up into the hanging wall (Plate 2d, 2e). The chosen boundary corresponds to a significant decrease in the degree of pegmatization and the last appearance of tectonic slivers of footwall lithologies. This lowest assemblage is 150 m thick.

The assemblage consists of psammitic to semipelitic gneiss [Qtz-Kfs-Bt-Hbl-Grt-Sil] with minor diopside-bearing quartzite and calc-silicate gneiss. Amphibolite boudins [Hbl-Pl-Grt-Bt] are abundant throughout (Plate 1g). The unit contains up to 25% sheared pegmatite [Qtz-Kfs-Bt-Ms].

Semi-pelitic schist horizons in the assemblage are migmatitic, with the leucosome fraction dissected and transposed by shearing and often appearing as augen, providing sense-of-shear information. Sillimanite is the sole aluminosilicate observed in semi-pelitic schist, occurring as fibrous sprays in the foliation plane.

Amphibolite boudins within the unit range between 1 and 3 m in long dimension, contain an old mineral fabric, and show recrystallization where cut by pegmatite dikes. The old mineral fabric, defined by alternating hornblende- and plagioclase-rich bands, is typically disposed at a high angle to the enveloping

shear foliation. Ghent et al. (1977) suggested that amphibolite boudins of this unit, as exposed at Three Valley Gap, are igneous in origin.

2.32 - Unit 6b

A 250 m thick gritty paragneiss unit, [Qtz-Bt-Sil-Kfs], overlies the psammitic gneiss assemblage. The paragneiss contains a central, discontinuous, impure quartzite [Qtz-Kfs-Pl-Di], which is overlain by an intensely deformed and pegmatized diopsidic marble up to 3 m thick. As much as 50% of the local outcrop is sheared pegmatite [Qtz-Kfs-Ms-Bt].

The assemblage contains amphibolite boudins [Hb-Grt-Qtz-Pl-Bt] that display marked compositional layering. The presence of quartz and marked layering suggests that the boudins are metasediments dissected during shearing.

The shear zone occurring within the marble horizon (Plate 3, Maps 1-3) is less than 2 m in average thickness, mylonitic, and free of obvious transposed tectonic slivers. It is similar in grade and vergence to the chaotic shear zone and is likely a minor, sympathetic and coeval shear.

2.33 - Unit 6c

The highest observed assemblage on Mt. English comprises iron-stained pelitic to semi-pelitic migmatitic schist, [Qtz-Kfs-Bt-Sill-Grt]. It contains minor amphibolite boudins [Hbl-Pl-Grt-Bt] and discontinuous, impure quartzite horizons [Qtz-Kfs-Bt-Pl]. It is significantly less pegmatized and sheared than lower hanging wall units. It outcrops on the peak of Mt. English and along ridges to the west (Plate 1h).

This unit is grossly similar to unit 6a although less pegmatized and sheared. As minor fold closures were observed within unit 6b on Mt. English there is the possibility that a pre-decollement-motion closure passes through unit 6b,

and that units 6a and 6c are limbs of a reclined isocline. Further mapping in the hanging wall to the west would be necessary to demonstrate or refute the presence of such a structure.

2.4 - Interpretation of Stratigraphy

The relation between stratigraphy in the Monashee Terrane, Selkirk Allochthon, and environs presents a possible constraint on the origin of the Terrane and its evolution and thus on the general evolution of the southern Cordillera. For example, age and depositional setting are useful in constructing palinspastic reconstructions such as those of Brown et al. (1986). The following section addresses the depositional setting and age of the units described above in broad terms and suggests possible correlations advocated by previous workers. Such correlations presuppose knowledge of the regional stratigraphy of the Cordillera. A brief and admittedly superficial review of the stratigraphic assemblages of regional significance follows.

The stratigraphy of the ancient North American margin in the south can in broad terms be divided into three assemblages or sedimentary wedges: comprise the Lower Proterozoic Belt-Purcell Supergroup, the Upper Proterozoic Windermere Supergroup, and overlying Paleozoic units. These are detailed below in order of decreasing age.

The Belt-Purcell Supergroup consists of clastics and minor volcanics deposited on attenuated continental crust, in basins oblique to the ancient margin. These basins are inferred to have formed as a result of rifting and developed in the Early Proterozoic (McMechan, 1981). Volcanics in the Supergroup reflect the rifted nature of the basin floor.

A second volcanic and clastic wedge, unconformably overlying the Belt-Purcell wedge, consists of Late Proterozoic Windermere Supergroup. The Windermere basin was roughly parallel to the ancient margin. This Supergroup notably includes the Horsethief Creek Group, represented in the study area and throughout the Selkirk mountains. Details on the character of the Horsethief Creek Group are presented in the discussion of Selkirk Allochthon strata. Correlations within the Windermere are currently in question, as much of the Supergroup outcrops in fault-bounded domains (cf. Ross and Murphy, 1988; Pell and Simony, 1987).

The Rocky Mountain fold and thrust belt deforms rocks of the miogeocline as well as parts of the platform cover and foreland basin deposits (Price, 1986). These Mesozoic and Cenozoic foreland basin deposits preserve a record of collisions as basin subsidence was driven by lithospheric flexure under the load of advancing thrust sheets (Price, 1973; Bond and Kominz, 1984).

2.41 - Interpretation of Monashee Terrane Stratigraphy

To briefly review, Monashee Terrane stratigraphy within the detailed study area consists of five continuous units. A basement terrane of mixed Aphebian gneiss, unit 1, is unconformably overlain by a basal quartzite, unit 2, that locally contains a basal conglomerate and mafic to ultramafic sills or flows. This is in turn overlain by a heterogeneous carbonate - clastic - pelite assemblage, unit 3, displaying rapid lateral and vertical facies changes and containing a stratabound carbonatite horizon. A second clean quartzite, unit 4, also containing mafic to ultramafic flows or sills, overlies the heterogeneous package and is overlain by a pelitic unit, unit 5, which locally grades up into a calcareous member. The total thickness of the cover sequence is 650 metres.

On the more regional scale it has been found that the thickness of cover

preserved increases from less than 40 m to the south, on the flanks of Thor-Odin dome (Coleman, 1989), through 650 m between the domes, to 2200 m on the northwestern flank of Frenchman Cap dome (R.L. Brown, pers. comm., 1989). Since the stratigraphy is in all cases truncated by the Monashee decollement it is inferred that the decollement is ramping up, structurally, to the north.

Correlation of stratigraphy between the study area and the flanks of Frenchman Cap dome to the north is presented in Fig. 3. Correlation between the Mt. English section and the Eagle Ridge section of Bosdachin (1989) is clear and unambiguous as both workers did extensive fieldwork in both areas (Bosdachin and Harrap, 1988). With the exception of a semi-continuous quartzite horizon within the heterogeneous package, unit 3, to the north, the stratigraphies are essentially identical. However, correlation farther northward to the map areas of Journeay (1986) and Scammell (1986) is less certain; it is essentially a refinement of the correlation of Scammell (1986), which is based on the assumption that carbonatite horizons in each section are correlative, as is the basal quartzite unit.

2.42 - Monashee Terrane Depositional Environment and History

Interpretation of tectonic environment and regional correlation have been hampered by two factors. First, the stratigraphy is exposed in a tectonic window, which is the Monashee Terrane, so that direct correlation beyond the boundaries of the complex is impossible. Second, penetrative deformation and regional metamorphism have obliterated many primary sedimentary features, including original bed thickness, that might otherwise allow reliable correlation through the comparison of detailed facies models and unit thicknesses. However, internal models of depositional history have been generated and have led to preliminary correlations with regional sequences. Two models have been postulated on the basis of detailed fieldwork on the flanks of Frenchman Cap dome.

Journeay (1986) divided the mantling gneisses into three upward-fining

cycles, quartzite - semi-pelite-/carbonate/calc-silicate - pelite, with thickness variations within members corresponding initially to basement topography and later solely to changing depth of a westward dipping basin floor. Fining upwards cycles were interpreted as periods of marine transgression punctuated by periods of rapid uplift and regression. Bosdachin (1989) interpreted the stratigraphy of Eagle Ridge similarly.

Scammell (1986; Scammell and Brown, 1990) proposed that a stable platformal shelf environment underwent tectonic disturbance, with rifting resulting in a stratigraphic succession characterized by immature sediments, mafic volcanic flows and sills, alkaline magmatism, and carbonatite phreatomagmatism. The bulk of the section that is interpreted in these terms is not exposed in the study area, although lower units correlate clearly (Fig. 3). Scammell (1986) argued that the question of the detailed deposition history within the complex is presently unconstrained; unambiguous cycles cannot be demonstrated.

Constraints on the time of deposition of the mantling stratigraphy are few. While the gneisses must be younger than the Aphebian basement on which they lie and thus be Early-Middle Proterozoic in age at the oldest, younger constraints are ambiguous. The 740 ± 36 Ma (Parrish and Scammell, 1988) Mt. Copeland syenite crosscuts lower horizons in the gneisses, requiring that the lower horizons be at least this old. Journeay (1986) argued that the Mt. Copeland stock limits the lower mantling gneisses in the north to being Belt-Purcell equivalents, while the uppermost gneisses might well be early Windermere equivalents.

Scammell (1986) argued that the phreatomagmatic carbonatite horizon and the Mt. Copeland stock are likely coeval, such that the upper sequence reflects earliest Windermere rifting, the 'Monashee Extensional Disturbance'. Since no stratigraphic discontinuities are present in the lowest mantling gneisses, the lower

gneisses are likely earliest Windermere in affinity as well, not Belt-Purcell. This presupposes that Belt-Purcell stratigraphy is absent; Windermere stratigraphy is deposited directly on Aphebian basement. Such a situation has been described in the northern Cordillera (Evenchick et al., 1984) and immediately to the northeast by Murphy (1990).

The recent report of a Late Proterozoic to Early Cambrian age for galena in the Cottonbelt deposit (Hoy and Godwin, 1988), which is higher in the stratigraphy of the Monashee Terrane than the carbonatite horizon, implies that the mantling gneisses represent a significant time span. If the carbonatite horizon reflects earliest Windermere rifting, at about 740 Ma, then over 150 Ma of time is represented or omitted in the stratigraphic section between the carbonatite and the Cottonbelt deposit (Scammell and Brown, 1990). The observed stratigraphic separation is only 100 m (Hoy and Godwin, 1988), and no evidence of regional unconformity is seen in this interval. This time period was regionally one of post-rift subsidence and accumulation of thick sedimentary piles (Bond et al., 1985), and so the absence of a thick clastic section in this interval is problematic. It is possible that disconformities exist in the section but have been obscured by deformation and metamorphism (Scammell and Brown, 1990).

Finally, recent mapping by Murphy (1990) reveals Windermere stratigraphy directly on basement paragneiss and orthogneiss in the Canoe River map area immediately northeast of the study area. The paragneisses mapped may be correlative to mantling gneisses of the Monashee Terrane, requiring that the mantling gneisses are Belt-Purcell equivalents. Further work is clearly needed to constrain the age of mantling stratigraphy.

The mantling gneisses in the study area are thus a record of the initiation of tectonic disturbance evidenced by the carbonatite marker in the sequence. This reflects disturbance of the paleomargin of North America during Late Proterozoic

time. The margin apparently was not a locus of thick sediment accumulation for at least 150 Ma. The youngest age constraint on mantling stratigraphy places upper Monashee Terrane stratigraphy at the Precambrian-Cambrian boundary.

2.43 - Interpretation of Selkirk Allochthon Stratigraphy

Selkirk Allochthon strata exposed in the study area comprise, to review, a sequence of amphibolite-laden psammitic gneiss, semipelitic schist, and minor diopsidic marble and quartzite. Facing direction is uncertain, and the regional presence of large, recumbent isoclines in the hanging wall argues against assuming the sequence is upright.

Horsethief Creek group strata of the Windermere Supergroup are a likely candidate for regional correlation of the hanging wall strata, as suggested by Brown (1980). Horsethief Creek Group stratigraphy has been correlated from the northern Purcell mountains, through the Selkirks and northern Monashees, and into the Cariboo mountains (Brown et al, 1978, Pell and Simony, 1987). It occurs in both the Goldstream and Illeciliwaet tectonic slices of the Allochthon that abut the Eocene Columbia River Fault (Fig. 1) (Brown and Lane, 1988), and wraps the north end of the Monashee Terrane (Scammell, 1986). Moreover, discounting the Clachnacudainn salient as a tectonic horse (Brown and Lane, 1988) the stratigraphy on Mt. English is separated from similar strata to the east, along the projected displacement vector of the Monashee decollement, by only approximately 15 km. Thus, for a package that is traceable over hundreds of kilometres to the north and south to occur on the west flank of the complex is not unreasonable. The rocks in the Selkirks are admittedly at lower grade than those on the west flank of the Monashee Terrane, as they have been downdropped on the Columbia River fault.

The Horsethief Creek Group is divisible into three diagnostic sequences

(Pell and Simony, 1987; Brown et al., 1978). The first is an amphibolite-ridden sequence of semipelitic schists interbedded with thin pelite and psammitic layers. The pelite is notably poor in aluminum, hence aluminosilicates are rare. Second is a marble of variable thickness commonly associated with calc-silicate gneiss. Finally, an upper clastic sequence of aluminous pelites, semipelites, and calcareous metasediments is found (Pell and Simony, 1987; Brown et al., 1978). Facies changes in the upper division are noted in the upper clastic division in the northern Selkirks, with pelites in the east giving way to more calcareous sediments in the west (Brown et al., 1978). The upper clastic division is in turn overlain by the Middle Marble unit, locally comprising two thick marbles separated by a clastic horizon (Pell and Simony, 1987).

The lowermost, semipelite-amphibolite (SPA) division is a likely candidate for the regional equivalent of the hanging wall rocks on Mt. English. Pell and Simony (1987) noted the presence of both (abundant) amphibolite boudins of igneous origin and rarer metasedimentary amphibolites in the SPA in the Cariboo Mountains, as were described on Mt. English. It is also possible that the three divisions on Mt. English directly correspond to the divisions of the Horsethief Creek Group, a correlation strengthened by the presence of quartzite immediately beneath the marble horizon as documented both in the Selkirks (Brown et al., 1978) and on Mt. English. A Middle Marble equivalent should thus overly the stratigraphy observed on Mt. English. Alternatively, the stratigraphy on Mt. English may correspond to the entire SPA - Middle Marble, and overlying Upper Clastic units in attenuated form. In such a scenario higher stratigraphy should be dominated by meta-psammite - metapelite cycles and metamorphosed grits.

During geological reconnaissance a thick clean marble was located in the vicinity of Frog Falls, immediately west of Mt. English. Further, Jones (1959)

describes a thick marble on the shores of Greer Bush Lake, a few kilometres to the south, and Johnson (1988, 1989) has mapped a possible equivalent for the SPA middle marble in the Hunters Range immediately west of the field area. All of these marbles lie in the Selkirk Allochthon, may correlate along strike with one another, and are likely candidates for a Middle Marble equivalent. The Frog Falls outcrop projects above Mt. English, assuming reasonable planarity and no intervening late faults, and so it is suggested that the hanging wall on Mt. English represents the Horsethief Creek group in attenuated form.

2.5 - Summary

Two distinct stratigraphic assemblages are found in the study area, separated by a major, east-verging shear zone. Footwall stratigraphy correlates clearly with Monashee Terrane stratigraphy described on the flanks of Frenchman Cap Dome. Hanging wall stratigraphy is similar in character to Selkirk Allochthon rocks in the hanging wall of the Monashee decollement described in the north, and to units in the Selkirk mountains.

These observations confirm the suggestion of Journeay and Brown (1986) that the boundary between classic Monashee Terrane and higher stratigraphy on Mt. English is a significant structural break, the Monashee decollement. The Monashee decollement crosses the Trans-Canada Highway immediately west of Victor Lake; the bulk of the zone is not exposed, but truncates in the subsurface against the Victor Creek Fault, a late normal fault.

Regional correlation and age of mantling gneisses of the Monashee Terrane is uncertain, although a Late Proterozoic to Earliest Cambrian age seems likely. Selkirk Allochthon stratigraphy on Mt. English, conversely, is correlative to the Windermere Supergroup and represents the Horsethief Creek group.

CHAPTER III - STRUCTURES

3.0 - Preamble

Structural interpretation in the field area is complicated by the overprinting nature of structures, by the large number of apparent deformation events, and by the transposition of domains on shear surfaces. Recognition that the Monashee decollement is a fundamental boundary simplifies the problem by separating the area into two more or less coherent domains, the Monashee Terrane and the overlying Selkirk Allochthon. The decollement that separates these domains constitutes a third structural domain.

The nature of the decollement is fundamental to understanding the evolution of the entire Monashee Terrane - decollement - Selkirk Allochthon system. However, many of the attributes of the decollement are properties of its relation to the Monashee Terrane. The following description thus covers the Monashee Terrane first, the decollement second, and finally the Selkirk Allochthon. Metamorphic field relations and evolution are then considered, and finally structures that postdate the termination of motion on the decollement are discussed.

3.1 - Footwall Structures

Three phases of folds are recognized in the Monashee Terrane (Read, 1980; Read and Klepacki, 1981; Journeay, 1986; Bosdachin and Harrap, 1988). The first phase comprises regionally recognized basement-cored isoclinal folds, while the second and third phases are locally recognized isoclinal folds and tight folds, respectively. The second-phase structures are the dominant control on map pattern in the study area; their interpretation is greatly complicated by the effects of topography.

3.1.1 - First Phase Folds

First phase, basement cored isoclinal folds with eastward vergence have been mapped on the flanks of Frenchman Cap dome (Fyles, 1970; McMillan, 1970; Read and Brown, 1981; Journeay, 1986) and on the west flank of Thor-Odin dome (Reesor and Moore, 1971). In the north these structures formed immediately prior to early, easterly verging shear zones as mapped by Journeay (1986). However, neither first-phase fold closures nor the shear zone (with the exception of the Monashee decollement) apparently extends into the detailed study area, except as the source of an early, bedding-parallel foliation. The foliation is defined by biotite in quartzite and metapelitic units and by quartz-feldspar and hornblende-biotite domains in intermediate gneisses. It is poorly developed to absent in calc-silicate gneisses.

The presence of a foliation without associated minor or major fold closures suggests that the detailed study area lies on the upright limb of a single large structure that closes outside of the mapped area. Any original associated minor structures were likely dissected by later layer-parallel shearing. Given the presence of a major, basement-cored first phase isoclinal fold on the south flank of Frenchman Cap dome immediately to the north (Map 3, Fig. 1) this argument seems reasonable. However, it must be noted that the exact manner in which this

or any other isocline projects into the field area is presently unclear, but could be clarified by mapping of known first-phase structures on Thor-Odin dome (Reesor and Moore, 1971) northwards.

3.12 - Second Phase Folding

Second phase folds dominate the map pattern within the study area. They are east-northeasterly verging, southwesterly rooted, basement cored isoclines which appear to have their fold axes parallel to the regionally developed, shallowly southwest plunging stretching lineation. The orientations of stretching lineations and minor structures are shown in stereonets on Map 2. The folds have limb lengths of 5-8 km and rounded hinges outlined by the thick, prominent basal quartzite unit (unit 2). Axial planes within the detailed study area are generally subparallel to the Monashee decollement surface, although the decollement locally truncates the structures as on the south flank of Mt. English (see section on Map 2). In ascending structural position these structures are MacPherson syncline, Begbie anticline, Mulvehill syncline, Tilley anticline, Wap Creek syncline, Mt. English anticline, and Ledge syncline (Section 1). The Ridge syncline is truncated locally by the decollement.

Axial planes of second-phase structures strike northeasterly and dip northwesterly on the west side of the compiled area (Map 3) but trend southeasterly and dip northeasterly along the west bank of the Columbia River. This change in orientation is a result of third-phase folding (described below) which furthermore complicates the map pattern and repeats second phase axial surfaces in the area north of Mt. Tilley (Section 1 and Map 2).

Second phase folds deform the early micaceous foliation (S_1) and generate a sparsely developed micaceous axial planar foliation that transects bedding and S_1 . The second phase foliation (S_2) is best developed in minor fold closures in

quartzite (Plate 4e, f) and consists of a peak metamorphic mineral assemblage [Qtz-Ksp-Sil-Bt-Grt-Pl+/-Ky].

Minor structures associated with second phase macrofolds are typically large (0.5 m to 10 m short limb length) and best developed in quartzite (Plate 4a). They are cylindrical, typically classes 1c (quartzite) and 3 (pelitic schist) (Ramsay, 1967) folds that display no evidence of discrete slip. Bosdachin (1989) described non-cylindrical centimetre scale folds in the immediate footwall of the decollement to the north; no such structures were observed in the study area.

The minor and macro second phase structures everywhere contain a prominent, second-phase mineral and stretching lineation which is statistically subparallel to the fold axes of second phase minor structures. The lineation is defined by the alignment of sillimanite and kyanite blades, by oriented fibrolite felts, by aligned tourmaline crystals (Plate 4d), and by ellipsoidal quartz grains. Sillimanite, kyanite, and tourmaline are typically pulled apart on microfractures perpendicular to the local mineral lineation.

On the basis of the correspondence between this stretching lineation, fold axes, and the presence of axial planar mineral growth in second phase fold closures it appears that second-phase folds are syn-peak deformation and metamorphism. The truncation of second phase structures on the south flank of Mt. English requires that second phase folding predates a significant portion of motion on the decollement.

3.13 - Third Phase Folding

Third phase, asymmetric open to tight northeasterly verging folds transect the study area from northwest to southeast, oblique to second phase closures. Two southwest dipping, southeast trending syncline-anticline pairs, with short limbs of ca. 1 km and long limbs of ca. 10 km were mapped by Read and Klepacki (1981)

and verified in the study area. The eastern pair, comprising the Wetask anticline and an unnamed syncline below, cross the Trans-Canada Highway east of Clanwilliam Lake (Map 3) and project along the eastern margin of the study area. A previously unnamed anticline, herein named the Victor Lake fold, transects the study area and projects along the closure of the second-phase Begbie anticline (Map 3). The Victor Lake fold is partially exposed in roadcuts on the Trans-Canada Highway immediately north of Victor Lake, where it repeats quartzite of the mantling gneisses (unit 4).

Third phase folds in the study are non-cylindrical, postmetamorphic asymmetric structures that fold both the early (S_1) bedding-parallel foliation and second phase axial planes and axial planar foliation (S_2). The amplitude of the folds increases to the southeast, where the folds are truncated by the Columbia River fault. The closures (Plate 4b) generate transitional type 1 interference folding where they cross second phase structures (Map 3, Section 1; Ramsay, 1967). No axial planar foliation is seen associated with third phase macro or minor structures. Minor structures are best developed in marble horizons and quartzite, include box folds (Plate 4c) and are sympathetic in vergence to the sense of shear of the decollement. A third phase, weakly developed stretching lineation has been described by Bosdachin (1989) but was not observed in the study area.

The intersection and thus timing relations between third phase folds and the decollement are uncertain as the intersection is unexposed. However, third phase folding is postmetamorphic, and yet third phase minor structures with antithetic sense were not observed in the study area. This implies either sufficient syn-third phase folding shearing to prevent nucleation of antithetic minor structures, or that the minor folds are related to shearing on the decollement rather than the larger folds. As well, the decollement appears to be regionally folded. It thus is likely that third phase folding accompanied the final stage of motion on the

decollement and is in part responsible for the change in dip of the decollement across the Monashee Terrane.

3.2 - Monashee Decollement

Footwall stratigraphy and structures are truncated by a mylonitic shear zone, the Monashee decollement, as described in Chapter 2 (Map 2). The decollement is inferred to be the roof thrust of an antiformal duplex structure that shortened and thickened the crust in response to terrane accretion and obduction to the North American margin (Journeay and Brown, 1986). To review, the decollement as exposed in the study area is internally chaotic, varies between 50 and 150 metres in thickness, and places the dissimilar Selkirk Allochthon and Monashee Terrane stratigraphies in fault contact. It contains a crude pseudostratigraphy of transposed tectonic lozenges derived from both hanging wall and footwall terranes in a matrix of intensely sheared pegmatite and semipelitic schist.

A penetrative stretching and mineral lineation, as well as mineral and mylonitic shear foliations are developed in the shear zone and extend into both the hanging wall and footwall terranes. Footwall foliation is transposed into the mylonitic shear foliation locally, and lineation orientation is consistent across the decollement. The lower boundary of the decollement is characterized by undulations in foliation (Plate 2a,c; Bosdachin 1989), which flatten into the mylonitic shear foliation upwards, with an increase in pegmatization and a decrease in grain size and tectonic lozenge size. Mylonitic textures penetrate deep into the footwall but are most intense in the decollement proper.

Tectonic lozenges in the footwall and hanging wall limits of the chaotic zone are locally boudinaged internally; amphibolite lozenges near the upper limit

of the chaotic zone display chocolate-tablet structure (Ramsay, 1967), indicating extension in all directions within the mylonitic shear plane. This requires a component of regional pure shear, although the dominant method of accommodation of regional strain was simple shear, localized in the chaotic zone.

3.21 - Kinematics

A variety of asymmetric microstructures, observed in outcrop, hand-sample and thin-section, provide kinematic sense of shear for rocks within the study area. These include rotated augen, rotated garnet and feldspar porphyroclasts, S-C fabric (Lister and Snoke, 1984; Berthe et al., 1979), and shear band foliations (Simpson, 1986). In general, the kinematic indicators were considered reliable only when at least two different indicator systems gave consistent sense. Individual augen, especially, were often of inconsistent sense with other indicators.

The long axes of augen are typically disposed at a small angle to the shear foliation in shear zones. The rotation or shear couple that would rotate this long axis into parallelism with the shear foliation through the smallest angle is the inferred shear couple for the rock mass containing the augen (Plate 2g). The augen must be considered in a statistical sense, as augen with large aspect ratios do not rotate with shear and may back-rotate given a component of pure shear in the local environment (Ghosh and Ramberg, 1976). Augen observed included feldspathic and granitic lozenges and boudinaged amphibolitic pods. The amphibolite pods show an internal foliation oblique to the enveloping foliation, consistent with rotation following boudinage.

Rotated porphyroclasts in thin section occur in two modes. Polycrystalline tails of biotite, feldspar, sillimanite, and quartz are aligned tangential to garnet and feldspar porphyroclasts (Plate 4h). These tails likely formed by the preferential nucleation of metamorphic minerals in low-strain pressure shadows. The second

mode consists of garnets that experienced synmetamorphic growth, which enveloped neighbouring quartz, feldspar and biotite grains now evident as inclusion trails.

Asymmetric foliations, or S-C fabrics, comprise shear or slip planes (C-planes) at a small angle to a second mineral foliation (S-planes). The S-plane is perpendicular to the maximum shortening direction of the incremental strain ellipsoid and progressively rotates towards the C-plane with continued shear. The acute angle defined by the planes opens in the direction of one member of the shear couple, which is disposed parallel to the C-plane. In thin section, the C-planes are defined by biotite, quartz, and feldspar grains and locally truncate eroded garnets. S-planes are defined by biotite and quartz axes, the grains typically being elongate, and terminate into C-planes. S-planes are best developed in quartzofeldspathic lithons in semipelitic mylonite. Acute angles observed range from 45 to 20 degrees (Plates 2h, 5c).

Shear band foliations consist of discrete, mineral scale shears that trans-pose earlier foliations (both C and S-planes). They form a shallow angle with the (truncated) mylonitic foliation; the angle opens away from the inferred motion of the shear couple member. Within the study area the shear bands are defined by the alignment or realignment of biotite, sillimanite, and quartz grains (Plates 4g, 5b).

With the exception of local mixed augen domains and discrete zones of top to the southwest shear (within the Selkirk Allochthon), kinematic indicators throughout the study area record a top-to-the-northeast sense of shear. This sense is consistent with the inferred role of the decollement as a compressive structure accomplishing significant crustal thickening, based on regional relations. Where opposed indicators were observed they clearly overprint northeasterly verging fabrics.

Rotated augen, S-C fabrics, shear bands and porphyroclasts in thin section are not restricted to the vicinity of the Monashee decollement in the study area. These kinematic indicators are found to the deepest structural level seen (east extent of Mt. MacPherson) and to the highest level (Mt English west ridge). Although the decollement does correspond to a discontinuous increase in simple shear, and although S-C angles within the decollement indicate extreme shear, it is apparent that the entire study area (thickness ~3 km) experienced profound simple shear during motion on the decollement.

3.3 - Hanging Wall Structures

As described in Chapter 2, the interpretation of hanging wall stratigraphy in the study area assumes that no reclined isoclinal folds lie in the immediate hanging wall. However, Bosdachin (1989) described tight synmetamorphic folds with hinges subparallel to the regional stretching lineation immediately to the north. These were correlated with second phase footwall structures in terms of timing, although the two fold sets are likely not genetically related. The hanging wall isoclinal folds are truncated by discrete shear zones parallel to the decollement. Furthermore, Bosdachin (1989) described postmetamorphic west- to northwest-plunging open folds with steep northeast striking axial planes. These late folds deform the mylonitic foliation and so postdate the last significant shearing on Monashee decollement.

With the exception of symmetric minor structures (M-folds) and a metre-scale anticline related to local shearing no folds were observed in the hanging wall. As described in Chapter 2, this may be due to the two-dimensional nature of mapping of the hanging wall.

Selkirk Allochthon rocks contain a penetrative stretching lineation parallel to that observed in the decollement and footwall. Stereonets with lineation data

are inset on Map 2. The lineation is defined by sillimanite laths and fibrolite felts and by the long axes of hornblende, orthoclase, plagioclase, and quartz crystals.

A single, metre-scale discrete mylonite zone (Maps 1-3) was mapped in the hanging wall, with mixed sense of shear and uniformly peak-metamorphic mineralogy. Unlike the area to the north described by Bosdachin (1989) the bulk of hanging wall strain in the study area was not localized in semi-concordant pegmatite sheets, but instead generated protomylonitic textures throughout the hanging wall.

3.4 - Metamorphism

Three distinct metamorphic domains were mapped within the study area. These comprise a high temperature, upper plate assemblage; a high pressure, lower temperature lower plate assemblage; and a prograde, high temperature assemblage that overprints the second assemblage. The zones were delineated based on observations of relations in metapelitic rocks in the field and in thin section and specifically relate to aluminosilicate type and relations. They are illustrated in schematic profile view on Figure 4.

To the north in Frenchman Cap dome (Fig. 1) an inverted metamorphic gradient has been observed and described in the footwall of the Monashee decollement, ranging from upper amphibolite grade at the decollement to greenschist grade deep in the footwall, and overprinting an earlier high pressure assemblage (Journeay, 1986). No inverted metamorphic gradient was detected within the footwall in the study area.

3.41 - Metamorphism in the Monashee Terrane

Two metamorphic assemblages were observed in the footwall of the decollement. The first zone, with the characteristic meta-pelitic assemblage Qtz + Ky + Bt + Grt + Pl +/- Mu, is found in the uppermost 100 m of the Terrane, in the immediate footwall of the decollement. The second zone, which extends deep into the Terrane, has the characteristic assemblage Qtz + Sil + Bt + Grt + Pl +/- Ky +/- Mu (Fig. 4).

Kyanite blades in the upper zone show no signs of prograde overgrowth (Plate 5a). The blades are locally fractured and show undulose extinction, indicating that they grew prior to at least a portion of the strain on the decollement. Quartz occurs as seriate, amoebal grains showing subgrain development and sweeping extinction. It occurs as elongate groups of grains parallel to the shear foliation and more rarely parallel to the finite flattening plane (S-surface). The grains are indicative of dynamic recrystallization; their size in rocks that display mylonitic textures implies annealing and growth following the bulk of shearing on the decollement.

Garnets are out of equilibrium in the quenched assemblage, displaying embayed surfaces and highly irregular preservation. Prominent quartz, feldspar and biotite - ridden cores indicate synkinematic growth, as do traceable tails of inclusions.

The second footwall assemblage clearly overprints the kyanite assemblage. Sillimanite and biotite overgrow kyanite blades within this zone. Sillimanite occurs as dense mats of fibrolite intergrown with biotite and defines a strong lineation within these rocks. Rare sillimanite blades, also aligned, were also observed. Garnets in the second zone include both inclusion ridden, corroded remnants and smaller, inclusion free and well-preserved crystals.

These observations are consistent with a normal geothermal gradient from low temperature above to higher temperature below. The conformity of the isograd surface to the decollement indicates that these metamorphic assemblages were quenched following second phase folding; the assemblages observed are thus unrelated to second phase folds in geometry but are related in terms of timing.

3.42 - Metamorphism of the Decollement and Allochthon

The highest temperature assemblage seen in the study area comprises the Selkirk Allochthon and Monashee decollement zone. The characteristic assemblage in metapelite is Qtz + Sil + Kf + Pl + Grt +/-Ky. Kyanite occurs rarely, as overgrown remnants in the decollement zone. The occurrence of sillimanite and K-feldspar as well as the great volume of pegmatite, requires that these rocks were considerably hotter than the footwall assemblage during peak shearing.

Sillimanite in the upper zone occurs as coarse, frequently fractured laths. Garnet occurs as corroded remnants similar to those seen in the footwall. Quartz is amoeboidal and seriated, with subgrains and sweeping extinction well developed. Prograde metamorphic assemblages were thus quenched prior to the conclusion of shearing.

3.5 Interpretation of Structures and Metamorphism

Given the field and microscopic relations above it is possible to draw a number of conclusions about local and regional structure and evolution, as follows.

3.51 Interpretation of F₂ Monashee Terrane Structures

The limbs of second phase structures show systematic thinning towards the projected trace of the Monashee decollement, as detailed in Table 1 and illustrated in Section 1. The clear correspondence suggests that structures nearer to the decollement were progressively attenuated during shearing on the decollement. Furthermore, the systematic decrease in attenuation away from the shear zone suggests that high strain was not localized to the mylonitic Monashee decollement alone, but extended with decreasing intensity deep into the footwall. The attenuation also demonstrates that basement gneisses of the Monashee Terrane were active participants in the evolution of the current structural geometry by shearing.

The original orientation of second-phase macrostructure fold axes relative to the decollement is uncertain. It is possible that fold axes originated parallel or oblique to the intermediate axis of the mylonitic strain ellipsoid and were progressively rotated into parallelism with the regional stretching lineation. It is also possible that the structures originated during an early, northeastward period of motion on the decollement and have been progressively attenuated by later shearing without significant rotation. Given that degree of rotation is a function of strain, then progressively less rotation at deeper levels of deeper structures should be observed if the first origin is accurate. With the exception of the Mt. English anticline on Mt. English, which may have either an oblique fold axis or a sheath geometry (Cobbold and Quinquis, 1980) (R.L. Brown, pers. comm., 1988), structures in the footwall of the decollement appear to have consistent fold axes, supporting the second origin. However, if the rotation process has gone to completion throughout the fold stack these observations would remain consistent with rotation.

The preservation of second-phase minor structures is directly related to

motion on the decollement. Structures with easterly and northeasterly vergence are common throughout the footwall portion of the study area. Structures verging to the west and southwest are preserved only on the eastern portion of Mt. MacPherson, the portion of the study area farthest from the (projected) decollement. Attenuation of easterly and northeasterly verging structures by upper-plate to the northeast simple shear would accentuate the minor structures, while such shear might transpose and obliterate westerly or southwesterly verging minor structures. This observation suggests that significant strain postdates the latest nucleation of second-phase structures.

3.52 Interpretation of F₃ Monashee Terrane Structures

Journeay (1986) attributed third phase folds on Frenchman Cap Dome to deformation occurring as a result of uplift on basement shear zone(s). The highly asymmetrical and spaced nature of third phase folds in the study area may thus relate to the geometry of basement shear zones, with anticline-syncline pairs corresponding to basement ramps.

In any event, third phase folds are clearly related to the arching of the Monashee Terrane and decollement. The Wetask anticline folds second-phase structures (MacPherson - Begbie - Mulvehill - Tilley - Wap Creek - Ridge - Ledge folds) down to the east to intersect the Earth's surface on the west bank of the Columbia River (Map 3) (Read and Klepacki, 1981). These downwarped F₂ structures are in the immediate footwall of the extensional Columbia River fault (Map 3), which truncates the trace of the third phase structures. The third phase Wetask fold is thus the cause of the change in second phase axial plane attitudes across the Monashee Terrane described in Section 3.12.

The uppermost structures that occur on the bank of the Columbia due to downwarping by the Watask fold are in the immediate footwall of the Monashee

decollement within the western portion of the study area. The Monashee decollement trace, known to be subparallel to the axial planes of second phase structures, should thus 'outcrop' in the Columbia River immediately east of where the second phase closures are repeated (Map 3). Mylonite exposed in brittle-fault bounded lozenges in the Columbia River fault (Brown and Murphy, 1982; Lane, 1984) are thus at least in part related to the decollement. Thus the suggestion that the Columbia River fault to the south is a brittle-ductile extensional fault but that the bulk of the displacement on the fault passes around the east margin of the Clachnacudainn Salient on the Standfast Creek Fault (Parrish et al., 1988) is not contradicted by data from the field area. The Monashee Terrane and Clachnacudainn are separated by the Monashee decollement as well as the Columbia River fault and were thus structurally detached long before the Eocene.

3.53 - Interpretation of Metamorphism

The presence of higher temperature rocks in the hanging wall of the Monashee decollement than in its footwall without an inverted metamorphic gradient is problematic. However, a qualitative solution can be derived by considering regional tectonics.

Quenching of Selkirk Allochthon assemblages likely began during uplift on the Monashee decollement, as follows. The Allochthon is sandwiched between the Monashee Terrane, which is at lower temperature, and the rocks in the hanging wall of the (Eocene) Eagle River Detachment. If it is accepted that late motion on the decollement occurred in latest Paleocene time and that early motion on the Eagle River Detachment occurred at this time, then the following scenario is possible.

The hot Selkirk Allochthon lost heat by conduction both into underlying rocks of the Monashee Terrane and into overlying rocks in the hanging wall of the

Eagle River Detachment. In the vicinity of the study area the Selkirk Allochthon has a structural thickness of approximately 5 km at most. Thus as motion on the Eagle River detachment placed successively cooler rocks on the hot rocks of the Allochthon, it rapidly cooled, preventing sufficient conduction into the footwall (Monashee Terrane) to generate a significant inverted metamorphic assemblage. However, to the north the structural thickness of the Allochthon is greater than 10 km, and so despite cooling upwards a significant portion of the heat in the Allochthon was conducted downwards into the Monashee Terrane, resulting in the inverted metamorphic assemblage seen on Frenchman Cap Dome (Journeay, 1986). Note that in both areas the peak metamorphic assemblage in the Allochthon is similar; however, quenching in the Allochthon at the Trans-Canada Highway merely occurred more rapidly..

If this model is reasonable, then a brittle-ductile transition should occur in the decollement to the east, and sheared pegmatites of similar age but opposed vergence should be found at the base and roof of the Allochthon (R.L. Brown, pers. comm., 1989).

This admittedly qualitative model does not refute the composite shearing model of the decollement (Brown et al., 1986), nor can it refute the argument of Bosdachin (1989) that the decollement was solely active in Late Cretaceous to Paleocene time. As the early (MD₁) and late (MD₂) decollement segments are coincident within the study area, and since the footwall (kyanite-grade) metamorphism is regionally inferred to cross the trace of MD₁ (Journeay and Brown, 1986), the record within the study area cannot, logically, constrain the early history of the decollement.

3.6 - Normal Faulting and Terrane Uplift

A series of northwesterly trending, steeply southwesterly dipping brittle normal faults cut through both footwall and hanging wall rocks in the study area. They are consistently west-side down. With the exception of the Victor Creek fault and splays the faults have displacements of tens of metres or less. The faults are the dominant control on topography within the study area; faults with only metres of displacement are clearly traceable on airphotos. The faults brecciate surrounding gneisses, contain chloritic gouge with prominent slickenside, and are locally filled with quartz veins or undeformed lamprophyre dykes (Plate 2f).

The Victor Creek fault and splays have a minimum of 750 m of steep, right-lateral oblique slip (Read and Klepacki, 1981; this study) as required by the offset of the Monashee decollement across the fault north of the Trans-Canada Highway (Map 3). Journeay (1986) described the northern portion of the fault as a scissor-type structure, with displacement increasing to the south. The fault is actually a sag-style structure, as displacement rapidly decreases towards Thor-Odin to the south. The sag nature of the Victor Creek fault is in part responsible for the broad synclinal warp seen in the Monashee decollement along a northwest-southeast trend (Section 1).

A penetrative set of conjugate fractures is associated with the fault network. The more prominent set parallels the faults, while a lesser set strikes north-easterly and dips vertically. No faults of significant displacement parallel this second fracture set in the study area, although Bosdachin (1989) mapped one such fault on Eagle Ridge (Map 3). The Eagle Pass Valley (containing the Trans-Canada Highway) parallels the second fracture set.

The faults and fractures are the locus of greenschist grade retrogression. Orthoclase displays sericitic alteration, biotite is chloritized, and clinozoisite is

common (Bosdachin, 1989) within centimetres of fractures.

Cooling ages of micas from the Monashee Terrane demonstrate that rocks within the study area cooled in the Eocene during uplift on bounding faults and shear zones. The grade of the joints and faults suggests they were active during latest uplift of the Terrane, and their sense (west-side down) is sympathetic with the Eagle River Detachment, the extensional structure which accommodated latest low-angle uplift of the Terrane (Fig. 1).

A previously unmapped, significant steep extensional fault was mapped cutting hanging wall rocks on Mt. English (Maps 1-3). The fault, herein named the Mt. English fault, offsets the Monashee decollement by at least 50 m, and was mapped to the north by Bosdachin (1989). The Mt. English fault consists of a brecciated zone 2 m wide laced with quartz veins. It is closely paralleled by lamprophyre-bearing fractures.

Finally, the interpretation that the Monashee decollement should outcrop in the Columbia River immediately southwest of Revelstoke places a constraint on the amount of motion on the Columbia River fault. Given that the decollement is in the immediate footwall of the Columbia River fault south of Revelstoke and is locally in the hanging wall of the fault north of Revelstoke, it is possible to project along strike of the fault and place a constraint on the magnitude of motion on the fault. This is done in schematic form in Figure 5, which supports the view of Lane and Brown (1987) that there is at most 5 km of motion on the segment of the Columbia River fault separating the Clachnacudainn and Monashee Terranes.

3.7 - Summary

The three phases of folding recognized in the footwall of the decollement

relate clearly to the decollement. First-phase structures are evident only as the source of an early, bedding-parallel foliation. Second phase, synmetamorphic structures dominate the map pattern but are refolded by postmetamorphic third phase structures, which greatly complicate relations. Third phase structures repeat highest footwall second phase structures in the immediate footwall of the Columbia River fault, implying that at least some mylonite in the fault is related to the Monashee decollement. The third phase structures may be related to motion of the Monashee Terrane to the east on a basement shear zone. Furthermore, the repetition of structures requires that at most a few kilometres of displacement occurs on the brittle Columbia River fault at Revelstoke.

Structures in the study area appear to be spatially and genetically related to the Monashee decollement. Macrostructures display attitudes reflecting formation or reorientation consistent with the sense of shear on the decollement. Minor structures reflect an environment dominated by profound simple shear with constant and persistent vergence. In effect, the entire volume represented by the study area is a shear zone, with the decollement representing a mylonitic discontinuity within the zone.

Rocks in the study area contain three distinct metamorphic assemblages. The first, kyanite-grade assemblage conforms to the lower boundary of the decollement and penetrates only into shallow levels of the Monashee Terrane. A higher temperature domain, below, overprints kyanite with fibrolite and is inferred to represent a normal metamorphic gradient. The overlying decollement and Selkirk Allochthon, conversely, are at sillimanite - K-feldspar grade. The lack of an observed inverted gradient in the footwall of the decollement is attributed to cooling of the Allochthon by heat transport into underlying and overlying rock masses during shearing.

CHAPTER IV - CONCLUSIONS

As a result of the field and laboratory investigation described in the earlier sections of this thesis, the following conclusions may be drawn concerning the structure and stratigraphy of the Monashee Terrane southwest of Revelstoke.

(1) The Shuswap Metamorphic Complex is a Cordilleran metamorphic core complex. The Monashee Terrane is a footwall duplex exposed through a tectonic window in the Shuswap Complex and is not itself a core complex.

(2) Two separate stratigraphic sequences are found in the study area. The lowermost consists of mantling and core gneisses of the Monashee Terrane. The uppermost consists of gneisses of the Selkirk Allochthon. The contact between the two sequences is a compressional shear zone, the Monashee decollement, and occurs on the flanks of Mt. English. The contact crosses the Trans-Canada Highway immediately west of Victor Lake.

(3) Selkirk Allochthon stratigraphy on Mt. English most likely represents the Horsethief Creek Group of the Windermere Supergroup in attenuated form.

(4) Three phases of folding occur in the Monashee Terrane. Second phase structures are synmetamorphic, are progressively attenuated towards the Monashee decollement, and dominate the map pattern. Third phase structures are late to post-metamorphic and regionally fold the Monashee decollement although they are locally truncated by it.

(5) A third phase structure, herein named the Victor Lake fold, transects the study area and projects along the closure of the second-phase Begbie anticline. In so doing it generates a great deal of structural complexity as seen immediately north of Mt. Tilley in the field area.

(6) Third phase structures repeat highest footwall second phase structures in the immediate footwall of the Columbia River fault, implying that at least some of the mylonite in the fault is related to the Monashee decollement.

(7) The brittle Columbia River fault records at most a few kilometres of motion.

(8) Attenuation of second phase folds towards the decollement, which contain core gneisses in antiform cores, demonstrates that Aphebian basement was actively involved in deformation associated with the Monashee decollement.

(9) No inverted metamorphic gradient is seen in the study area, although the upper plate Selkirk Allochthon is at higher grade than the lower plate Monashee Terrane. The lack of an inverted gradient is attributed to cooling of the Allochthon into overlying and underlying rock masses during shearing.

APPENDIX A - FIGURES AND TABLES

Figure 1

Regional tectonic elements and bounding faults within the southern Omineca Belt. Modified after Parrish et al. (1988) from Journeay and Brown (1986). Map units: Upper Proterozoic and Mesozoic units of uncertain provenance and accreted terranes (diagonal ruled), Proterozoic and lower Paleozoic continental margin sequences of the Selkirk Allochthon (blank), and Proterozoic Belt-Purcell Supergroup (dark shading), Proterozoic platform sequence of the Monashee Terrane (light shading), Aphebian basement terrane of the Monashee Terrane (light dotting), undifferentiated Paleozoic plutonic rocks (light ticking), undifferentiated Mesozoic rocks (large crosses) and deformed equivalents (asymmetric crosses), undifferentiated Cenozoic plutonic and related volcanic rocks (dark dotting), and Eocene Ladybird granite suite (heavy ticking).

MD Monashee Decollement
 CRF Columbia River Fault
 ERD Eagle River Detachment
 OSZ Okanagan Shear Zone
 QLF Quenai Lake Fault
 RMT Rocky Mountain Trench
 DCF Downie Creek Fault
 SCS Standfast Creek Fault

FCD Frenchman Cap Dome
 TOD Thor-Odin Dome
 AB Adamant Batholith
 FS Fang Stock
 BRB Bettie Range Batholith
 AS Albert Stock
 GBS Galena Bay Stock
 KB Kuskanax Batholith
 WB Whetstone Batholith
 SFP South Fork Pluton

Figure 2

Tectonic elements and bounding faults of the central and northern Monashee Terrane and environs. Modified after Brown and Lane (1988) from Journeay and Brown (1986). Compilation box refers to Map 3 and encloses study area and parts of the adjoining study areas of Bosdachin (1989) and Johnson (1988, 1989, in prep.).

Figure 3:

Compilation of stratigraphic columns from the central and northern Monashee Terrane. Ratchford Creek and Kirbyville - Sibley Creek sections are from the compilation of Scammell (1986), Eagle Ridge section is from Bosdachin (1989).

LEGEND

Stratigraphy of the Central and

LOCATION MAP

d Northern Monashee Complex

RMT

ROCKY MOUNTAIN TRENCH

FCD

FRENCHMAN CAP DOME

TOD

THOR ODM DOME

MONASHEE DECOLLEMENT

COLUMBIA RIVER FAULT

ARCHEAN BASEMENT

LOCATION OF SECTION

GEOLOGY AFTER

JOURNEAU AND BROWN (1986)

Figure 4

West-southwest to east-northeast profile view through Mount English following the section line shown on Map 2. Stars refer to positions where macroscopic kyanite was observed; bullets refer to positions where kyanite was observed in corresponding thin sections. Solid line is inferred and observed trace of the Monashee Decollement; light dashed line is approximate kyanite out isograd. Scale 1:25000, no vertical exaggeration.

Figure 5

Schematic serial sections across Columbia River Fault superimposed on reference plan view of left bank of Columbia River. Revelstoke occurs at the position of the words "Trace of CRF." **md** refers to Monashee Decollement, **TA** to Tilley Anticline, and **MEA** to Mt. English Anticline. **Dam** is the Revelstoke Dam site. Sections are referenced to the average height of the Columbia River above sea level at the mouth of Begbie Creek.

This view demonstrates that there is at most a few kilometres of motion on the brittle Columbia River Fault. However, if there is a significant component of rotation (increasing to the north) then it is possible that at the Revelstoke Dam site there is more motion than inferred here.

TABLE 1
Second Phase Fold Limb Thicknesses

Isocline	Unit 1	Unit 2	Units 3-6	Distance from M.D.
MacPherson S.	n.a.	750 m	650 m	3500 m
Begbie A.	300 m	600 m	n.a.	2500 m
Mulvehill S.	n.a.	400 m	650 m	1750 m
Tilley A.	200 m	250 m	n.a.	1250 m
Wap Creek S.	n.a.	200 m	450 m	750 m
Mt. English A.	<200 m	<200 m	n.a.	400 m
Ridge S.	n.a.	n.a.	n.a.	<100 m

NOTES:

Unit thicknesses for Unit 1 and Units 3-6 refer to doubled thickness of unit across axial plane of indicated structure. Unit thicknesses for Unit 2 refer to thickness of member on upper limb of indicated structure.

'A' refers to anticline, and 'S' refers to syncline.

APPENDIX B - PLATES

Plate 1: Lithologic Units and Macroscopic Features

A: Migmatitic, intensely sheared semi-pelitic core gneiss (unit 1) as exposed at Station 114b, southeast flank of Mt. English. Lens cap for scale, approx. 5 cm diameter.

B: Pelitic schist member of composite unit 3. Station 21a, southeast flank of Mt. MacPherson. Field notebook for scale.

C: Migmatic semi-pelitic schist member of composite unit 3 as exposed on Mt. MacPherson. Note pegmatite lens in background. Pack for scale.

D: Siliceous marble (member of composite unit 3) showing symmetric minor folds, exposed in nose of F₃ closure at Station 106d, northwest of Mt. Tilley. Top of field notebook for scale.

E: Biotite-bearing quartzite (unit 4) with approx. 5 cm amphibolite stringer at Station 97b, north of Mt. Tilley. Note even bedding and second stringer near top of view. Field notebook and pencil for scale.

F: Metapelitic parting in biotite-quartzite (unit 4). Parting is approx. 5 mm thick and is continuous for metres across outcrop. Note faint biotite traces defining beds on 2 cm scale. Station 97b as photo E. Pencil tip for scale.

G: Amphibolite boudin exposed in roadcut at Three Valley Gap on Trans-Canada Highway. Note cross-cutting pegmatite, warp of matrix foliation around boudin termination, and offset on late minor fault.

H: Pelitic to semi-pelitic schist and amphibolite of unit 6c as exposed on the west side of the Mt. English fault. Cliff is approx. 200 m in height.

Plate 2: Monashee Decollement

A: Lower boundary of Monashee decollement showing undulating fabric grading upwards into more uniform fabric within the central decollement. Unit exposed at base of photo is unit 4, near Station 120e. Trees in photo are ca. 15 m high.

B: Lozenge of quartzite (unit 4) in the central decollement, in semi-pelitic schist matrix. Field notebook for scale.

C: Lower limit of Monashee decollement showing undulating surfaces. Trees are ca. 15 m high.

D: Chaotic foliation and lithologies in upper zone of Monashee decollement near Station 128b. Note large volumes of semi-concordant pegmatite.

E: As D, showing lozenges defined by angular discordances in foliation and the west ridge of Mt. English in the background.

F: Psammitic gneiss of Selkirk Allochthon (unit 6a) exposed at Three Valley Gap. Note lamprophyre dikes, likely Eocene in age, filling fractures parallel to late brittle faults in area.

G: Augen in mylonite, Station 124f, southern flank of Mt. English. In unit 6a, immediate hanging wall of decollement. Augen suggest top-to-east sense of shear; hammer for scale.

H: Well developed S-C fabric in quartzofeldspathic gneiss of composite unit 3. Fabric indicates upper member to the right sense of shear (top to east). Lens cap for scale, approx. 5 cm diameter.

Plate 3: South Flank of Mt. English

South flank of Mt. English, looking north, showing trace of Monashee décollement and unnamed sympathetic hanging wall shear zone. Plate 2a is a detail of the lower left portion of the photo, straddling the décollement. The trace of the décollement reflects the undulatory lower boundary of the décollement; the upper boundary is arbitrary. The bend in the décollement is a result of a change in topographic orientation (see Map 1). Mt. English fault has minor west side down motion. Mt. English is the central peak in photo.

Plate 4: Folds and Microstructure

A: Second phase macroscopic minor structure in quartzite, on the south flank of Mt. MacPherson. Fold closes to the west (view looks north). Fold height approx 2 m.

B: Third phase closure exposed in ridge between Mt. Tilley and an unnamed knob to the northwest. Ridge is approx. 75 m high at centre of photo. View to the west.

C: Third phase box fold in distinctly layered biotite quartzofeldspathic gneiss. Lens cap. approx. 6 cm. Northwest of Mt. Tilley.

D: Aligned tourmaline crystals defining lineation, L_2 , in unit 3 on the east end of Mt. MacPherson. Brunton for scale.

E: Second phase macroscopic minor structure. Unit 3, northwest of Mt. Tilley. Hammer for scale at centre of photo.

F: Second phase foliation transects first phase foliation in core of microscopic minor fold. Scale bar 0.5 mm.

G: Shear band cuts pelitic interlayer in semi-pelitic schist, giving top to the northeast sense of shear (view is to northwest). Scale bar 2 mm.

H: Rotated garnet porphyroclast, with biotite tails and overgrowth. Top to the northeast sense of shear (view to northwest). Scale bar 2 mm.

Plate 5: Kinematics in Thin Section

A: Kyanite blades against garnet and biotite in upper metamorphic zone of the Monashee Terrane. Scale bar 1 mm.

B: Shear band cuts contorted fibrolite-biotite mass, giving top to the northeast sense of shear (view to southeast). Scale bar 0.25 mm.

C: S-C fabric developed in biotite-quartzite, giving upper plate to the northeast sense of shear (view to northwest). Scale bar 0.5 mm.

D: Sillimanite blades and relatively uncorroded garnet in coarse semipelitic gneiss of the Selkirk Allochthon. Scale bar 0.5 mm.

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Murphy, D.C. Stratigraphy and structure, southern Rocky Mountain Trench to the headwaters of the North Thompson River, Cariboo Mountains, B.C.. in Current Research, Part E, Geol. Surv. Can. Pap. 1990-1E, in the press, 1990.

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SECTION 1 Central Monashee Terrane

LEGEND

Abbreviations:

- RS - Ridge Syncline
- MEA - Mount English Anticline
- WCS - Wap Creek Syncline
- TA - Tilley Anticline
- MS - Mulvehill Syncline
- BA - Begbie Anticline
- MS - MacPherson Syncline
- VLF - Victor Lake Anticline
- MD - Monashee Decollement

Scale: 1:50000

Note:

- a: Section line is traced on Map 3.
- b: Ridge and Peak names indicate features that the section line crosses. Note that except by chance the section line does not cross the feature at its highest point. As such, the topography shown does not accurately reflect the height of land near the section line. As a result, some data shown above the topographic datum are projected a relatively short distance out-of-plane-of-section, and so is more accurate than simple distance from surface would indicate.

Scale: 1:50000

- RS - Ridge Syncline
- MLA - Mount English Anticline
- WCS - Wap Creek Syncline
- TA - Tilley Anticline
- MS - Mulvehill Syncline
- BA - Begbie Anticline
- MS - MacPherson Syncline

Symbols

- Unit 1, Core Gneisses
- Unit 2, Quartzite
- F₂ Axial Trace
- F₃ Axial Trace

Stratigraphic Contacts

- established
- inferred
- assumed

Monocline Development

- established
- inferred

- Ridge Syncline
- Mount English Anticline
- Wap Creek Syncline
- Tilley Anticline
- Mulvihill Syncline

- Unit 1, Core Gneisses
- Unit 2, Quartzite

Scale: 1:50000

- RS - Ridge Syncline
- MLA - Mount English Anticline
- WCS - Wap Creek Syncline
- TA - Tilley Anticline
- MS - Mulvehill Syncline
- BA - Begbie Anticline
- MS - MacPherson Syncline
- VLF - Victor Lake Anticline
- MD - Monashee Decollement

Note:

a: Section line is traced on Map 3.

b: Ridge and Peak names indicate features that the section line crosses. Note that except by chance the section line does not cross the feature at its highest point. As such, the topography shown does not accurately reflect the height of land near the section line. As a result, some data shown above the topographic datum are projected a relatively short distance out-of-plane-of-sectionh, and so is more accurate than simple distance from surface would indicate.

T.C.H.

Eagle Ridge

Ridge Syncline
Mount English Anticline
Wap Creek Syncline
Tulley Anticline
Mulvehill Syncline
Bogie Anticline
MacPherson Syncline

Victor Lake Anticline
Monashee Decollement

Unit 1, Core Gneisses

Unit 2, Quartzite

F₂ Axial Trace

F₃ Axial Trace

Stratigraphic Contacts

established

inferred

assumed

Monashee Decollements

established

inferred

traced on Map 3.

Names indicate features that the section line crosses. Note
since the section line does not cross the feature at its highest
topography shown does not accurately reflect the height of
the feature. As a result, some data shown above the topographic
line. A relatively short distance out-of-plane-of-section, and so
the simple distance from surface would indicate.

MAP 3

Geology of the Central Monashee Complex

Scale: 1:50000

LEGEND

Stratigraphic contact	Carbonatite Locality
- established	ec
- inferred	
- assumed	
Fault contact	Minor Shear Zone
Unit Number	
6	
Trans-Canada Highway	Axial Surface Trace
Monashee Decollement	1 - f ₁
- established	2 - f ₂
- inferred or assumed	3 - f ₃
	- synform
	- antiform
	Cross-section endpoint

Lithostratigraphy:

Unit Lithology

ALLOCTHONOUS COVER

- 6c Semipelitic gneiss, locally pelitic schist, with abundant garnet bearing amphibolite boudins. Minor quartzite stringers, likely discontinuous.
- 6b Gritty psammitic gneiss to orthogneiss, with minor diopside bearing marbles, quartzite and abundant pegmatite. The pegmatization is localized around a continuous shear zone that occurs in the middle of this package. Contacts with over and underlying units are diffuse.
- 6a Psammitic gneiss with minor diopside bearing quartzite, calc-silicate gneiss and amphibolite. Contact with Decollement zone is arbitrary.
- MD- Monashee Decollement- shear zone assemblage. Boundaries defined by high degree of disorder and strain, rather than by lithology. Contains abundant slivers of footwall and hangingwall lithologies. Intensely pegmatized.

MONASHEE SEQUENCE

- 5 Semi-pelitic schist. Sillimanite and locally kyanite bearing. Minor calc-silicate gneiss interlayers and
- 4 G₂ quartzite. Prominent marker horizon. Biotite-bearing quartzite with minor amphibolite boudins.
- 3 Calc-silicate gneiss, impure marble, semi-pelitic to pelitic schist and local carbonatites. Schist occurs in middle of package. Marble is locally useful as a stratigraphic marker horizon.

Wap Creek

Columbia

defined by high degree of disorder and strain, rather than by lithology. Contains abundant siliers of footwall and hangingwall lithologies. Intensely pegmatized.

MONASHEE SEQUENCE

- 5 Semi-pelitic schist. Sillimanite and locally kyanite bearing. Minor calc-silicate gneiss interlayers and
- 4 Q_2 quartzite. Prominent marker horizon. Biotite-bearing quartzite with minor amphibolite boudins.
- 3 Calc-silicate gneiss, impure marble, semi-pelitic to pelitic schist and local carbonatites. Schist occurs in middle of package. Marble is locally useful as a stratigraphic marker horizon.
- 2 Q_1 quartzite. Basal quartzite, muscovite and tourmaline bearing, with local biotite. Abundant mafic to ultramafic amphibolite boudins.

Core Sequence

- 1 Mixed paragneiss, including biotite-hornblende gneiss, calc-silicate gneiss, and semi-pelitic schist.

Notes:

- Monashee Decollement shows consistent northeastward vergence where observed, and appears to be westerly rooting.

- Mapping on Mt. English, Mt. Tilley, and Mt. MacPherson is by R.N. Harrap, 1986-7. Other mapping is compiled from Read and Klepecki (1981) and Read (1980), in the south, and from Boedachin (1989, in prep.) north of the Trans Canada Highway.

(1989, in prep.) north of the Trans Canada Highway.

(1969, in prep.) north of the Trans Canada Highway.

MAP 1

Geology of the Mt. MacPherson - Mt. English Area

Geology by R.M. Harrap 1986-7

Scale 1/25000

Drafting by R.M. Harrap 1988

LEGEND

Symbols

Stratigraphic contact

- established
- inferred
- assumed

Fault contact

- established
- inferred
- assumed

Monashee Decollement

- established
- inferred
- assumed

Marble Horizon

- established
- inferred
- assumed

Bedding foliation

Carbonate Locality

Unit Number

Station Number

Minor Shear Zone

- established
- inferred
- assumed

LithoStratigraphy:

Unit Lithology

ALLOCTHONOUS COVER

- 6c Semipelitic gneiss, locally pelitic schist, with abundant garnet bearing amphibolite boudins. Minor quartzite stringers, likely discontinuous.
- 6b Gritty psammitic gneiss to orthogneiss, with minor diopside bearing marbles, quartzite and abundant pegmatite. The

- established
- inferred
- assumed

Marble Horizon

- Minor Shear Zone
- established
- inferred
- assumed

6c Semipelitic gneiss, locally pelitic schist, with abundant garnet bearing amphibolite boudins. Minor quartzite stringers, likely discontinuous.

6b Gritty psammitic gneiss to orthogneiss, with minor diopside bearing marbles, quartzite and abundant pegmatite. The

- established
- inferred
- assumed
- Minor Shear Zone
- established
- inferred
- assumed
- Marble Horizon
- established
- inferred
- assumed

Lithostratigraphy:

Unit Lithology

ALLOCTHONOUS COVER

- 6c Semipelitic gneiss, locally pelitic schist, with abundant garnet bearing amphibolite boudins. Minor quartzite stringers, likely discontinuous.
- 6b Gritty psammitic gneiss to orthogneiss, with minor diopside bearing marbles, quartzite and abundant pegmatite. The pegmatization is localised around a continuous shear zone that occurs in the middle of this package. Contacts with over and underlying units are diffuse.
- 6a Psammitic gneiss with minor diopside bearing quartzite, calc-silicate gneiss and amphibolite. Contact with Decollement zone is arbitrary.
- ND- Chaotic zone - shear zone assemblage. Defined by high degree of disorder and strain, rather than by lithology. Contains abundant slivers of footwall and hangingwall lithologies. Intensely pegmatized.

MONASHEE SEQUENCE

- 5 Semi-pelitic schist. Sillimanite and locally kyanite bearing. Minor calc-silicate gneiss interlayers and diopside marble.
- 4 Q, quartzite. Prominent marker horizon. Biotite-bearing quartzite with minor amphibolite boudins.
- 3 Calc-silicate gneiss, impure marble, semi-pelitic to pelitic schist and local carbonatites. Schist occurs in middle of package. Marble is locally a stratigraphic marker horizon.
- 2 Q, quartzite. Basal quartzite, muscovite and tourmaline bearing, with local biotite. Abundant mafic to ultramafic amphibolite boudins.

Core Sequence

- 1 Mixed paragneiss, including biotite-hornblende gneiss, calc-silicate gneiss, and semi-pelitic schist.

3

of/de

3

MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS
STANDARD REFERENCE MATERIAL 1010a
(ANSI and ISO TEST CHART No. 2)

MAP 2

Structural Geology of the Mt. MacPherson - Mt. English Area

Scale 1:25000

Geology by R.M.Harrap 1986-7

Drafting by R.M.Harrap 1988

LEGEND

Symbols

Stratigraphic contact
 ~ - established
 - - - - - inferred
 assumed

Fault contact
 ~~~~~ - established
 - - - - - inferred
 ..... assumed

Monashee Decollement
 - - - - - established
 - - - - - inferred
 ..... assumed

Kinematic Indicators
 ● - single sense
 ● - mixed sense

Unit Number
 ⑥

Cross-Section Endpoint

Stretching Lineation

Minor Structures
 - F₂ Structure
 - F₃ Structure
 - S Fold
 - Z Fold

Axial Surface Trace

Minor Shear Zone
 - established
 - - - - - inferred
 ..... assumed

Cross-Section

Axial Surface Intersection
 - f₂ surface
 - f₃ surface

Begbie Axial Surface B
 Mulvehill Axial Surface M
 Tilley Axial Surface T

Structural Data: [Plotted on Lambert Equal Area Projections]

Domain 1 - Mount MacPherson [Stations 1-71]

Domain 2 - Mount Tilley [Stations 94-108]

Domain 3 - Mount English, east and north zone footwall
 [Stations 84, 86, 92de, 109-114]

Domain 4 - Mount English, south zone and hanging wall
 [Stations 85, 87, 88, 90, 91, 92abcf, 93,
 120-141]

Domain 4 - Mount English, south zone and hanging wall
 [Stations 85, 87, 88, 90, 91, 92abcf, 93,
 120-141]

an 1

Structural Cross-Section

No Vertical Exaggeration

Domain 4 - Mount English, south zone and hanging wall
(Stations 85, 87, 88, 90, 91, 92abcfg, 93,
120-141)

DOMAIN
2

DOMAIN
2

Domain 4 - Mount English, south zone and hanging wall
(Stations 85, 87, 88, 90, 91, 92abcfg, 93,
120-141)

Symbols

- - Pole to Foliation
- ★ - Stretching Lineation
- ★ - D₂ Minor Structure Fold Axis
- ☆ - D₂ Minor Structure Pole To Axial Plane
- - D₃ Minor Structure Fold Axis
- - D₃ Minor Structure Pole To Axial Plane

Notes:

- Kinematic indicators represent the inferred direction of motion of the upper member of a shear couple.
- Plane of section is vertical. Down-plunge projection is accomplished using an average of local foliations to generate a projection vector.
- Brittle faults on the west end of Mt. MacPherson and the Englishman Creek fault are after Read (1980), verified in the field. Exact displacement on each is uncertain.

○ - D₃ Minor Structure Pole To Axial Plane

Structural Cross-Section

No Vertical Exaggeration

Structural Cross-Section

No Vertical Exaggeration

○ - D₃ Minor Structure Pole To Axial Plane

Notes:

- Kinematic indicators represent the inferred direction of motion of the upper member of a shear couple.
- Plane of section is vertical. Down-plunge projection is accomplished using an average of local foliations to generate a projection vector.
- Brittle faults on the west end of Mt. MacPherson and the Englishman Creek fault are after Read (1980), verified in the field. Exact displacement on each is uncertain.