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Tectonic denudation of the Shuswap metamorphic terrane of southeastern British Columbia

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ABSTRACT

Large-scale overthrusting and regional extension are both known to have been operative within the Shuswap metamorphic terrane of the southern Omineca belt. The Monashee core complex of the northern Shuswap terrane is interpreted to be a crustal-scale duplex that was developed during late Mesozoic shortening and thickening of the crust. Uplift of the Monashee complex, caused by basement duplexing, is estimated to have been in excess of 25 km. Late Cretaceous overthrusting of high-grade metamorphic and related plutonic rocks, during later stages of uplift and basement duplexing, led to weakening of the crust and to gravitationally driven extension of a regional crustal welt (Shuswap culmination). Denudation and spreading of this uplifted metamorphic terrane are attributed to displacements across listric-normal shear zones and faults localized along the outward-dipping flanks of the Shuswap culmination. Total extension across the Shuswap culmination at the northern end of the Monashee complex is estimated to be no greater than 30%. This model of denudation and gravity-induced spreading is extrapolated southward into the Valhalla and Okanagan regions, where extension may be far more significant.

INTRODUCTION

The possibility that there is a dynamic link between crustal shortening and extensional faulting within the metamorphic core complex terranes of the North American Cordillera has been suggested by Armstrong (1982) and has most recently been supported by Coney and Harms (1984). Similar models have been proposed to explain crustal shortening and coeval near-surface extensional faulting within the Himalayas of southern Tibet (Burchfiel and Royden, 1985).

With these thoughts in mind we pose the question: Are the extensional faults that flank high-grade gneiss complexes of the Shuswap metamorphic terrane in southern British Columbia and northern Washington (Fig. 1) a direct response to crustal shortening, tectonic thickening, and related uplift of the metamorphic-plutonic complex? Within the Monashee core complex of the Shuswap terrane (Figs. 1 and 2), constraints on the uplift and thermal history appear to support this view.

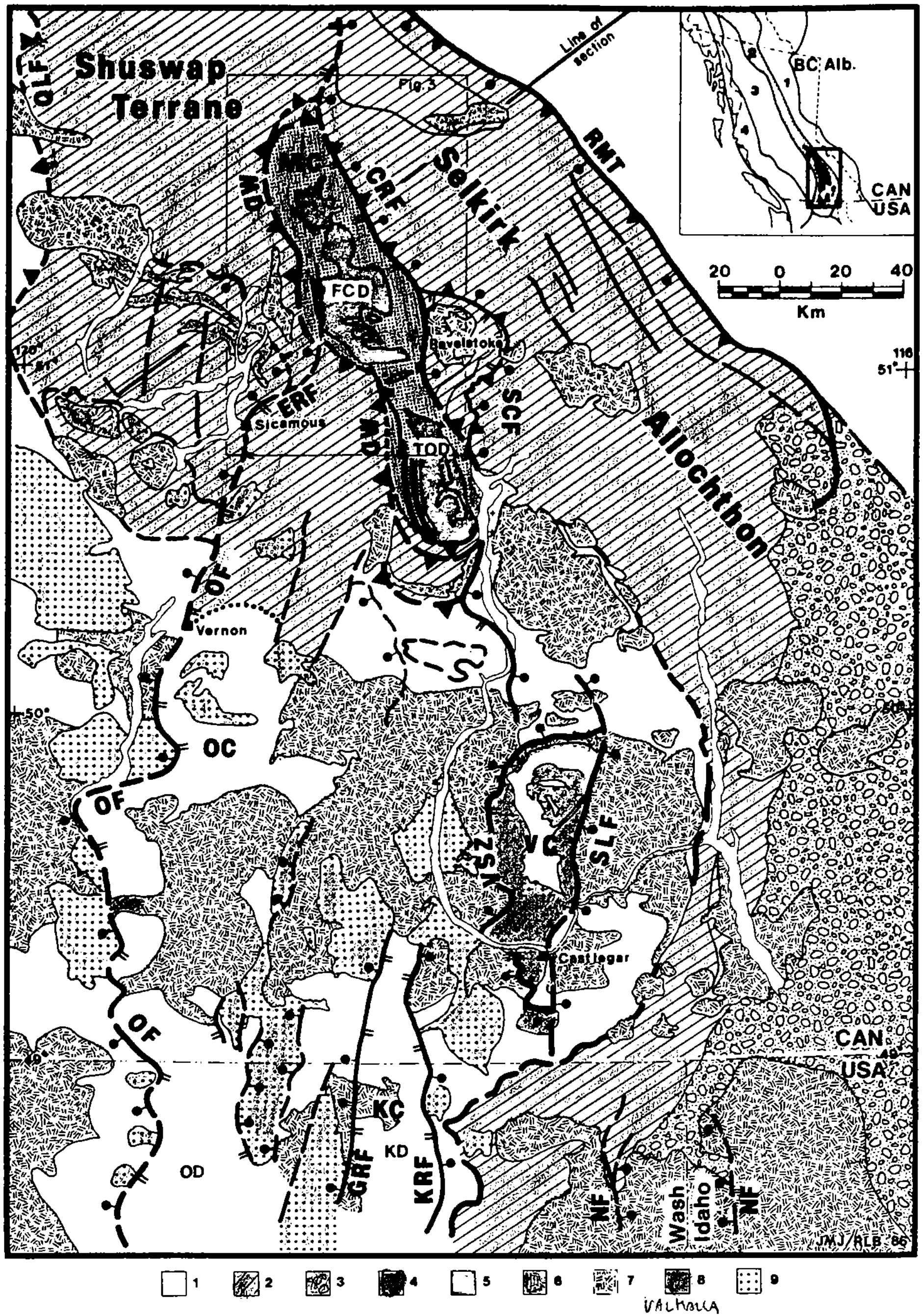
COMPRESSIONAL HISTORY

Brown and Read (1983) have argued that the Monashee complex is a metamorphic core complex that evolved primarily in Mesozoic time, during and after the accretion of a western allochthonous terrane (see Okulitch, 1984, for an overview of the regional geologic setting). They considered final arching and uplift of the complex to be coincident with Eocene low-angle normal faulting and unroofing. A more detailed reconstruction of the tectonic evolution of the region has recently been presented by Brown et al. (1986); it includes a model of obduction, backfolding, and piggyback thrusting in which the detachment and eastward telescoping of the Rocky Mountain foreland is balanced by crustal-scale duplexing of continental crust within the adjacent metamorphic-plutonic hinterland (see also Monger et al., 1985). In this model, Middle Jurassic and Late Cretaceous to early Tertiary episodes of tectonic thickening and uplift within the Shuswap metamorphic terrane are interpreted to be coeval with and kinematically linked to thin-skinned shortening within the Rocky Mountain foreland (Fig. 2A and 2B).

Basement duplexing and uplift are best documented in Frenchman Cap dome (Figs. 1 and 3), where deep-level metamorphic and related plutonic rocks of the Shuswap terrane (Selkirk allochthon) have been thrust onto high-grade metamorphic rocks of the Monashee complex (Fig. 2A). The boundary between these two metamorphic terranes is a mylonitic shear zone known as the Monashee decollement (Read and Brown, 1981). Lower plate Proterozoic metasediments of the Monashee complex are exposed in a tectonic window through the Monashee decollement and rest unconformably on a basement terrane of Aphebian gneiss (2.2 Ga; Armstrong, 1983). Synkinematic, high-pressure (bathozone 6) mineral assemblages within the Monashee complex indicate a burial depth of at least 25–30 km during the early stages of basement-involved thrusting (Journeay, 1983, 1985, 1986).

Detailed studies of the Monashee decollement, along the northwest flank of the Monashee complex (Frenchman Cap dome, Fig. 3), have shown it to be a zone of episodic crustal shear that records both an early high-pressure (MD1) and a late low-pressure (MD2) history of displacement and uplift (Journeay, 1983, 1985; Journeay and Brown, 1986). Early displacement along the high-pressure (MD1) shear zone carried upper-plate rocks of the Selkirk allochthon eastward onto the Monashee complex during peak conditions of regional metamorphism (MD1) in Middle Jurassic time. Pressure-sensitive mineral assemblages that developed within synkinematic pull-aparts (Misch, 1969) of MD1 indicate that uplift of the underlying Monashee complex must have been coeval with late-stage overthrusting of the Selkirk allochthon. These relationships are best explained in terms of a break-forward sequence of piggyback thrusting within the Monashee complex in which displacement was progressively transferred from a roof thrust (MD1) to deeper level shear zones within the crystalline basement (Fig. 2A). Cumulative uplift of the Monashee complex (relative to earth surface) during this episode of piggyback thrusting is estimated to have been between 10 and 15 km (Journeay, 1985, 1986).

Reactivation of the Monashee decollement (MD2) and coeval uplift of the underlying Monashee complex record a younger episode of shortening and tectonic thickening within the metamorphic hinterland that is believed to have occurred sometime between the Late(?) Cretaceous and early Tertiary (Journeay, 1985, 1986). During this younger episode of easterly directed thrusting, increasingly hotter and deeper tectonic levels of the Selkirk allochthon were ramped upward and eastward along MD2 onto cooler and tectonically shallower levels of the Monashee complex. Thermal relaxation (cf. Oxburgh and Turcotte, 1974; England and Thompson, 1984) associated with eastward overthrusting resulted in low-pressure reheating of the underlying Monashee complex and in the development of an inverted metamorphic gradient within the immediate footwall of MD2 (Journeay, 1985, 1986).



VALHALLA

Figure 1. Regional tectonic map. (Inset locates tectonic belts of Canadian Cordillera: 1, Foreland fold and thrust belt; 2, Omineca Crystalline Belt; 3, Intermontane belt; 4, Coast Plutonic Complex; and 5, Insular belt.) Bounding faults include Quesnell Lake fault (QLF), Monashee decollement (MD), Okanagan fault (OF), Eagle River fault (ERF), Slocan Lake fault (SLF), Newport fault (NF), Grandby River fault (GRF), Kettle River fault (KRF), Standfast Creek fault (SCF), Columbia River fault (CRF), and Valkyr shear zone (VSZ). Map units: 1, Late Proterozoic and Mesozoic age units of uncertain provenance and accreted terranes; 2, Proterozoic and lower Paleozoic continental margin sequences; 3, Proterozoic Belt-Purcell Group; 4, Proterozoic platform sequence of Monashee complex; 5, Aphebian basement terrane of Monashee complex; 6, undifferentiated Paleozoic plutonic rocks; 7, granitic intrusions, predominantly Middle Jurassic and Lower Cretaceous; 8, deformed Upper Cretaceous to Eocene granitic intrusions; and 9, undifferentiated Cenozoic plutonic and related volcanic rocks. MC = Monashee complex, VC = Valhalla complex, OC = Okanagan complex, KC = Kettle complex, OD = Okanagan dome, KD = Kettle dome, FCD = Frenchman Cap dome, TOD = Thor-Odin dome, RMT = Rocky Mountain trench.

Cumulative Mesozoic to early Tertiary shortening and uplift brought basement rocks of the Monashee complex up from a minimum depth of 25 km to maximum depths of between 10 and 12 km. At this stage in its evolution, the Monashee complex was an uplifted complex of compressional origin.

EXTENSIONAL HISTORY

Extensional faulting, ductile shearing, and prekinematic (Late Cretaceous to Paleocene) and synkinematic (late Paleocene to early Eocene) plutonism have played a significant role in the Tertiary evolution of the Omineca belt of southern British Columbia and northern Washington. Details of this early Tertiary history are well documented by geological mapping and geochronological studies in the Valhalla complex (Parrish, 1984; Parrish et al., 1985a; Carr et al., 1987) and by work in the Newport fault zone (Harms, 1982) and Okanagan fault zone (Bardoux, 1985; Parkinson, 1985; Parrish et al., 1985b; Tempelman-Kluit and Parkinson, 1986). The degree of ductile extensional faulting and plutonism within these southern Shuswap terrane core complexes is in marked contrast to that of the Monashee complex farther north, where extension has caused displacements on brittle shear zones but where significant ductile strain and associated plutonism appear to be absent (Read and Brown, 1981; Brown and Read, 1983).

Monashee Complex

How Similar to MN RG?

Evidence of regional extension *within* the Monashee complex is limited to sets of conjugate high-angle normal faults, related shear fractures, and dike-filled extension joints of probable Eocene age (McMillan, 1973; Reesor and Moore, 1971; Read, 1980; Journeay, 1982; Brown and Read, 1983). Most of these structures cut deeply into the core zones of both Frenchman Cap and Thor-Odin domes and can be traced along the length of the Monashee complex. High-angle normal faults record maximum displacements of several hundred metres within the southern Monashee complex but gradually die out to the north into a set of brittle shear fractures of minimal displacement. These structures are interpreted to be rotational scissor-

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type faults that evolved in response to differential extension throughout the complex. The magnitude of crustal extension produced by these and related structures within the northern Monashee complex is estimated to have been less than 5%, or approximately 4–5 km. In contrast, extension along the eastern and western flanks of the northern Monashee complex is characterized by the development of low-angle detachment faults and associated zones of ductile and brittle shear across which displacements may locally exceed 10–20 km. Along the east-dipping flank of the Monashee complex, down-to-the-east brittle shear zones of the Columbia River fault (CRF; Read and Brown, 1981) have down-dropped both low- and high-grade metamorphic rocks from shallower tectonic levels of the Selkirk allochthon onto high-pressure mylonitic rocks of the Monashee decollement (MD1). In the vicinity of Revelstoke, the CRF cuts through the Monashee decollement and carries rocks of the Monashee complex in its hanging wall (Lane, 1984). The zone of detachment is contained entirely within the Columbia River valley and is clearly not folded around the Monashee complex. It has been mapped nearly 30 km north and at least 60 km south of the Monashee complex; it dies out northward as it is traced to higher structural levels of the Selkirk allochthon. The magnitude of downdip displacement across the CRF is uncertain but is estimated to be no more than 10–15 km (Read and Brown, 1981; Lane, 1984). Displaced and brecciated dikes of Eocene age, along with 55 Ma K/Ar mineral dates of strained micas within the shear zone, date the most recent episode of normal faulting along the CRF (Lane, 1984).

Along the northwestern margin of the Monashee complex, high-grade metamorphic and related rocks of the Monashee complex are structurally overlain by low-grade metasedimentary rocks of the lower Paleozoic Mount Ida Group. This boundary has recently been interpreted as a low-angle, down-to-the-west detachment zone (Journeay and Brown, 1986). The detachment, known as the Eagle River fault (ERF; Fig. 3), dips gently to the southwest in the vicinity of Sicamous, where it places brittlely deformed greenschist-grade metasedimentary rocks of the lower Paleozoic Mount Ida Group onto upper amphibolite grade mylonitic footwall gneiss of the underlying Shuswap terrane. Kinematic indicators within mylonitic rocks of the lower plate record an unambiguous top-to-the-west sense of shear (Journeay and Brown, 1986). To the northeast, the Eagle River fault zone splays into an imbricate fan of high-angle normal faults that extend northward along the west flank of the Monashee complex. These faults are characterized by highly fractured and brecciated hanging-wall and footwall rocks that record evidence of both brittle and ductile behavior. Preliminary mapping suggests that these normal faults may be listric in geometry and most likely root into low-angle mylonitic shear zones of the Eagle River fault. ERF and related faults appear to be continuous with the Okanagan fault, a major down-to-the-west normal fault that extends southward along the west flank of the Shuswap terrane for at least 150 km (OF, Fig. 1; Bardoux, 1985; Parkinson, 1985;

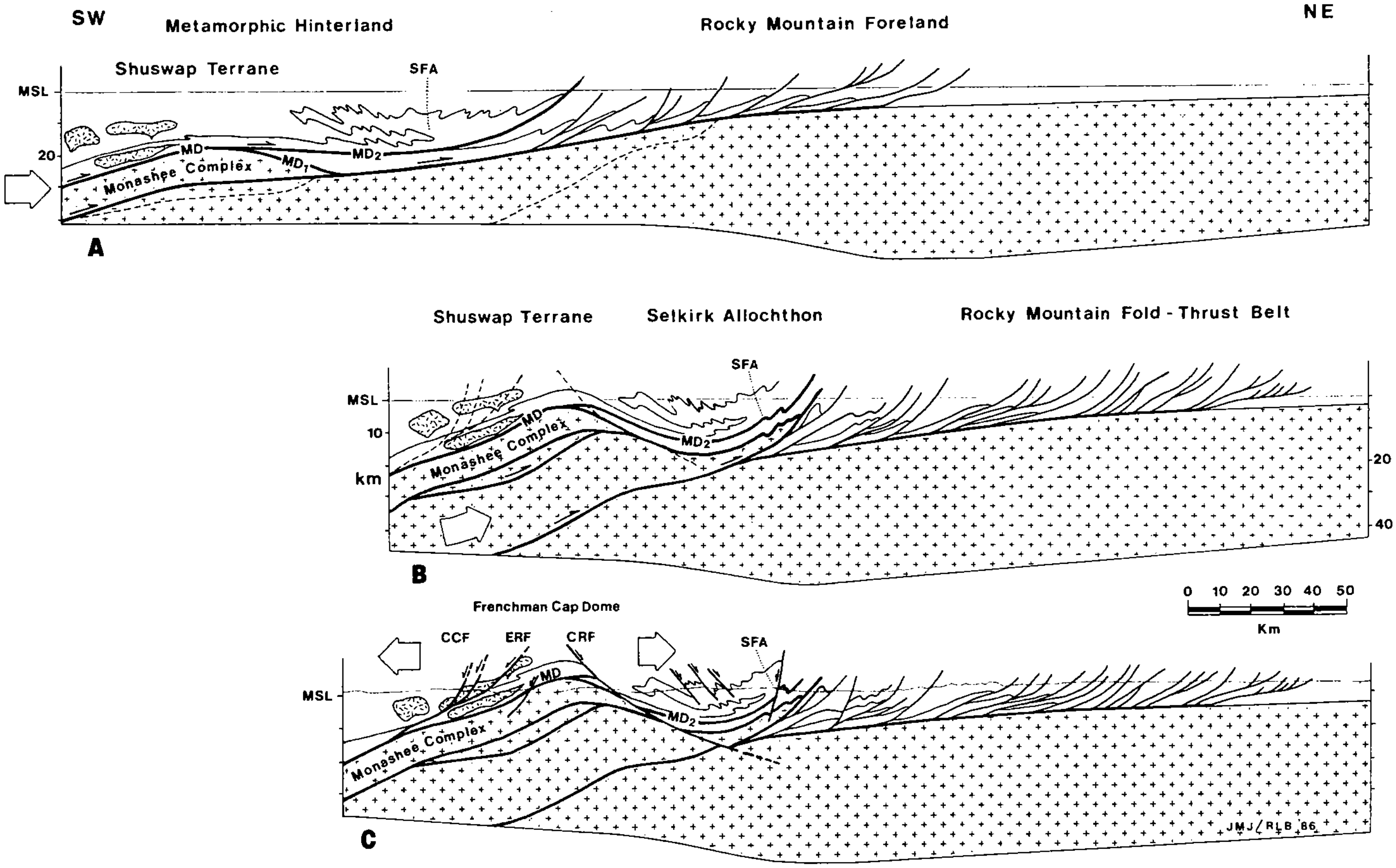

Figure 2. Cross section and sequence diagram for Late Cretaceous to Eocene evolution of southern Omineca belt and Rocky Mountain belt. A: Middle to Late Cretaceous thrusting on Monashee decollement (MD2); B: Late Cretaceous to Paleocene development of crustal duplex and associated uplift of Monashee complex; C: Paleocene to Eocene uplift and extension of structural culmination. Crosses delimit crystalline basement; dashed pattern indicates Late Cretaceous granitic intrusions. SFA = Selkirk fan axis, for reference. CCF = Craigellachie Creek fault; for other symbols see Figure 1 caption.

Parrish et al., 1985b; Tempelman-Kluit and Parkinson, 1986).

The geometry and kinematics of faults that bound the northwestern flank of the Monashee complex mirror those of the Columbia River fault zone on the eastern margin. Breakaway zones for the CRF and ERF flank the culmination of the Monashee complex. The eastern upper plate of the complex has been displaced eastward on the CRF and the western upper plate has been displaced westward. Crustal extension across this northern part of the Shuswap terrane is estimated to be 15 km, or 30% (Fig. 2C).

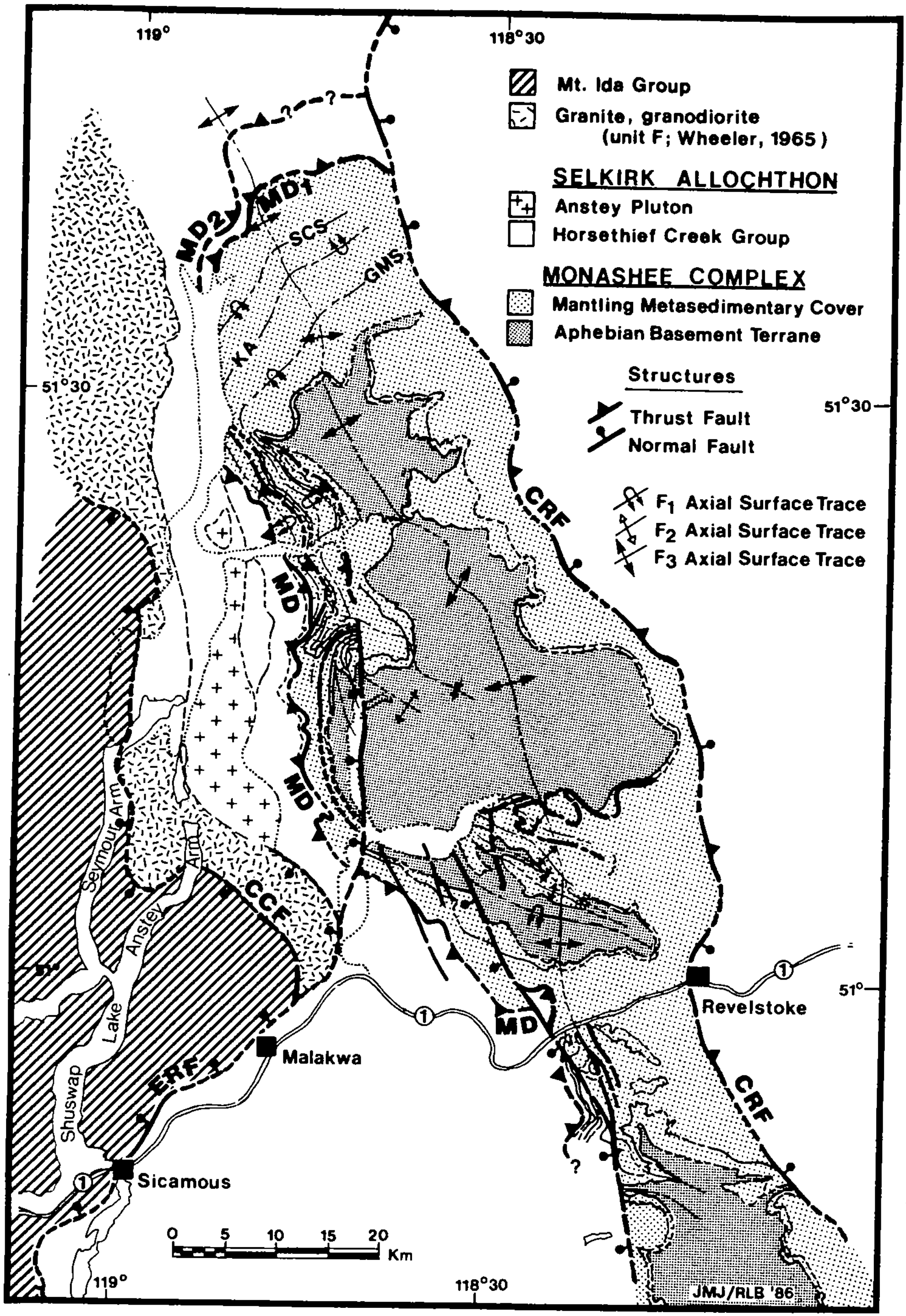

Figure 3. Detail of Frenchman Cap dome and adjacent areas. Major bounding faults of northern Monashee complex and adjacent Selkirk allochthon. Bounding faults include high- and low-pressure shear zones of Monashee decollement (MD1 and MD2, respectively), Eagle River fault (ERF), Craigellachie Creek fault (CCF), and Columbia River fault (CRF). SCS = Sibley Creek syncline; KA = Kirbyville anticline; GMS = Grace Mountain syncline. See Figure 1 for location.

Valhalla Complex

The Slocan Lake fault (SLF) extends southward from the termination of the CRF as an en echelon, down-to-the-east detachment zone along the east-dipping flank of the Valhalla complex (Fig. 1; Parrish, 1981, 1984; Carr, 1985; Parrish et al., 1985a; Carr et al., 1987). The geometry, timing, and displacement history of this detachment are nearly identical to those of the CRF, suggesting that these two structures are related. Detailed radiometric studies (Parrish, 1984; Parrish et al., 1985a; Carr, 1986) indicate that by 54 Ma, the Slocan Lake fault had dropped Middle Jurassic plutonic rocks of the Nelson batholith down onto high-grade metasedimentary rocks of the underlying Valhalla complex. This young fault has a ductilely deformed mylonitic footwall and a brittlely deformed hanging wall along most of its length and appears to die out southward beyond the exposed limits of the complex. Downdip displacement on the fault is estimated to be on the order of 10–15 km (Carr, 1986).

DISCUSSION

Is there a dynamic link between the early compressional history of the Shuswap region and its superimposed extensional history? The geometrical constraints outlined above appear to require a relationship in which the orientation and sense of shear of the flanking extensional faults has been controlled by the geometry of the structural culmination, at least between lat 50° and 52°N.

It is important to recognize that major uplift of the region occurred during the compressional phase (Figs. 2A and 2B); unroofing of the high-grade metamorphic terrane started in the Mesozoic and culminated in the Tertiary (Fig. 2C). Within the northern Monashee complex, it has been established that the culmination developed during uplift and equilibration of inverted low-pressure metamorphic assemblages. Arguments based on thermal models suggest that uplift and arching must have occurred either during or immediately after overthrusting along the Monashee decollement in the Late Cretaceous (MD2, Journeay, 1983, 1986). These observations suggest that the culmination is most likely to have been caused by eastward overthrusting of the Monashee complex onto west-dipping basement ramps near the base of the metamorphic hinterland (see Brown et al., 1986).

This scenario of Late Cretaceous crustal thickening and uplift suggests to us that the extensional faults that developed along the flanks of the culmination and within the upper plate of MD2 reflect gravitational spreading of the overthickened and uplifted crustal welt (cf. Dalmayrac and Molnar, 1981, p. 473; Molnar and Chen, 1983, p. 1184).

Parrish and Carr (1986) have drawn an interpretive cross section for the region south of the Monashee complex that includes Valhalla, Kettle–Grand Forks, and Okanagan core complexes (Fig. 1) in which Eocene extension on the order of 80% is proposed. Such dramatic increase in extension southward from the Monashee complex is envisaged by them to have been accommodated by normal displacements on westward-dipping crustal-scale shear zones within the western side of the Shuswap culmination and by the development of eastward-dipping extensional shears within the eastern side. Extension of this magnitude remains to be proven, but their model of outward-dipping extensional faults, away from a preexisting structural culmination, appears to be compatible with the concept of gravitationally driven extension as presented in this paper.

It remains to be established whether or not the onset of extensional faulting overlapped in time with regional compression. Extensional shearing in the Valhalla complex was initiated at the time of, or shortly after, emplacement of a 59 ±1 Ma granitic intrusion, and compression appears to have affected intrusive rocks as young as 95 ±5 Ma (Parrish et al., 1985a; Carr et al., 1986). In the Monashee complex, overthrusting may have continued as late as 80 Ma (Archibald and Journeay, in prep.). This time gap is narrowed if it can be assumed that compression as young as Paleocene in the Rocky Mountain belt is balanced by contemporaneous shortening in the metamorphic hinterland (see Brown et al., 1986). In any event it does appear that the onset of extension is closely linked to the time of emplacement of granitic intrusions in the southern part of the region, suggesting that thermal weakening was a prerequisite for significant spreading.

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