Structural evolution of basement gneisses and Hadrynian cover, Bulldog Creek area, Rocky Mountains, British Columbia

MICHAEL R. MCDONOUGH AND PHILIP S. SIMONY

Department of Geology and Geophysics, The University of Calgary, Calgary, Alta., Canada T2N 1N4

Received June 18, 1987

Revision accepted February 2, 1988

Two gneiss bodies are contained in thrust sheets on the west edge of the Rocky Mountain Main Ranges near Valemount, British Columbia. The Bulldog Gneiss comprises Aphebian or older paragneiss and amphibolitic gneiss intruded by Aphebian orthogneiss sheets. The Yellowjacket Gneiss is granodioritic orthogneiss of unknown age. Both gneiss bodies are basement highs with thin Hadrynian metasediment cover sequences. The cover sequences are assigned to the lower Miette Group and are correlated with Horsethief Creek Group.

Internal shortening of gneiss thrust sheets is expressed by recumbent folding and stacking of thin thrust sheets of gneiss and cover. The Bulldog Gneiss and its cover were carried on the postmetamorphic Purcell Thrust. The Yellowjacket Gneiss and its cover were carried on the pre- to synmetamorphic Bear Foot Thrust. Northeast and northwest displacement is documented on the moderately southwest-dipping Bear Foot Thrust, and a dextral oblique-slip – thrust model is proposed to explain the duality of thrust and dextral strike-slip kinematic indicators in mylonite from the fault. An estimate of shortening in the foreland suggests that basement thrust sheets were translated more than 200 km to the northeast.

Correlation of gneisses and cover with the westerly adjacent Malton Gneiss and its cover precludes major dextral strike-slip motion on the Southern Rocky Mountain Trench (SRMT) during and after thrusting. The SRMT was the locus of post-thrusting and postmetamorphic, Eocene(?), brittle, west-side-down, normal faulting.

Deux massifs de gneiss sont incorporés dans les nappes de charriage situées sur le rebord occidental des chaînes principales des Rocheuses près de Valemount, Colombie-Britannique. Le Gneiss de Bulldog est formé d'un paragneiss de l'Aphébien, ou plus ancien, et d'un gneiss amphibolitique recoupé par des nappes d'orthogneiss aphébien. Le Gneiss de Yellowjacket est un orthogneiss granodioritique d'âge inconnu. Les deux massifs de gneiss représentent d'anciens socles élevés recouverts de minces séquences métasédimentaires d'âge hadrynien. Ces séquences de couverture sont assignées au Groupe inférieur de Miette, et elles sont corrélées avec le Groupe d'Horsethief Creek.

Le raccourcissement interne des nappes de charriage renfermant les gneiss est exprimé par des plis couchés et par l'empilement des minces nappes de gneiss et des métasédiments de la couverture. Le Gneiss de Bulldog et sa couverture furent charriés sur la nappe de Purcell postmétamorphique. Le Gneiss de Yellowjacket et sa couverture furent aussi charriés sur la nappe de Bear Foot pré- à synmétamorphique. Les études démontrent qu'il y a eu déplacement nord-est et nord-ouest sur la nappe de Bear Foot dont le pendage modéré est sud-ouest, et il est proposé un modèle de faille de décrochement oblique dextre pour expliquer la dualité des failles de chevauchement et les indices dans la mylonite de la faille d'un mouvement de décrochement dextre. Une évaluation du raccourcissement dans la zone de failles suggère que les nappes de charriage de socle ont glissé de plus de 200 km vers le nord-est.

La corrélation des gneiss et de leurs métasédiments de couverture avec le Gneiss de Malton et sa couverture juxtaposé du côté ouest s'oppose à un mouvement majeur de décrochement dextre contre le Sillon des Rocheuses du Sud durant et après le charriage. Le Sillon des Rocheuses du Sud était le lieu d'apparition des failles normales, cassantes, avec basculement du côté ouest vers le bas, postérieures au charriage et au métamorphisme de l'Éocène(?).

[Tradiut par la revue]

Can. J. Earth Sci. 25, 1687–1702 (1988)

Introduction

Bodies of basement gneiss with Precambrian isotopic ages (Chamberlain *et al.* 1980; Parrish and Armstrong 1983) are exposed on both sides of the Southern Rocky Mountain Trench (SRMT) between 52° and 52°45′N. Two such bodies in the Bulldog Creek area of the Selwyn Range of the Rocky Mountains, approximately 25 km southeast of Valemount, British Columbia (Fig. 1), were carried on southwest-dipping thrust faults and are bounded on the southwest by normal faults in the SRMT (Campbell 1968; Price and Mountjoy 1970). The two bodies, separated by a major postmetamorphic thrust fault, are Bulldog Gneiss and, to the east, the newly discovered and named Yellowjacket Gneiss, which is bisected by Yellowjacket Creek (Fig. 1).

The gneisses are composite bodies of multiple, thin thrust slices within two large thrust sheets. The Bulldog Gneiss contains at least three thin thrust slices composed primarily of banded paragneiss and amphibolitic gneiss, with lesser orthogneiss, younger amphibolite, and metasediment. The Yellowjacket Gneiss is a fault-dissected body composed of four or more thin slices of granodioritic, augen-bearing orthogneiss and lensoidal thrust slivers of metasediment.

This report concerns the stratigraphy and structural history of basement gneiss and their cover rocks on the west edge of the Rocky Mountain Main Ranges. The gneisses represent the east edge of the hinterland and offer a unique opportunity to study the structural and kinematic links between the hinterland and the foreland to the east and their implications for the tectonics of the southeastern Canadian Cordillera. Constraints on dextural motion on the SRMT, new data on oblique motion of thrust faults, and a new shortening estimate across the foreland are discussed.

Regional geology

Campbell (1968) and Price and Mountjoy (1970) noted similarities between the Bulldog Gneiss and the westerly adjacent Malton Gneiss and mapped both bodies in the hanging wall of the Purcell Thrust (Fig. 1). We maintain that the remarkable

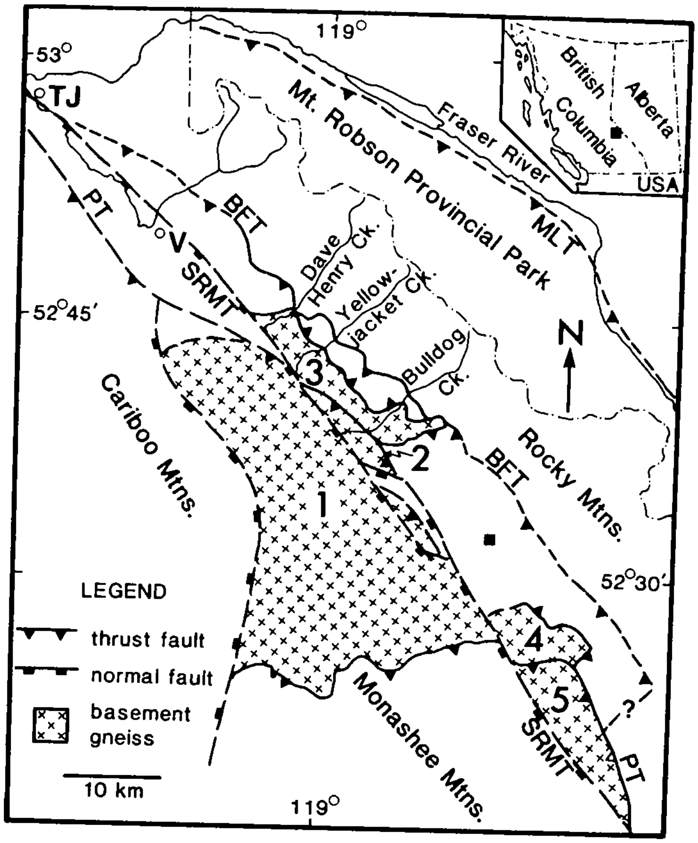

FIG. 1. Location map and generalized geology map for the gneisses near Valemount (V), British Columbia, modified after Campbell (1968), Oke (1982), and McDonough (1984). BFT, Bear Foot Thrust; MLT, Moose Lake Thrust; PT, Purcell Thrust; SRMT, Southern Rocky Mountain Trench; TJ, Tête Jaune Cache. 1, Malton Gneiss; 2, Bulldog Gneiss; 3, Yellowjacket Gneiss; 4, Blackman Gneiss; 5, Hugh Allan Gneiss. Hadrynian sediments are shown in white. Sample location for K/Ar date reported by Wanless *et al.* (1968) and Price and Mountjoy (1970) given by solid square.

similarity of gneiss and cover lithologies on either side of the SRMT suggests that the Malton and Bulldog gneisses are thrust slices that once formed parts of the same gneiss complex (McDonough and Simony 1984), despite apparent geochemical and geophysical dissimilarities cited by Chamberlain and Lambert (1985) and Chamberlain *et al.* (1985).

The Purcell Thrust is defined to the southeast as a major regional thrust fault (Wheeler 1963) that truncated earlier formed Rocky Mountain structures in its footwall (Simony and Wind 1970; Craw 1978; Simony *et al.* 1980). A postmetamorphic thrust that carried the Bulldog Gneiss onto the Yellowjacket Gneiss and truncated earlier structures was therefore mapped as the Purcell Thrust (Fig. 2). The Yellowjacket Gneiss and its cover were allochthonous on the Bear Foot Thrust (McDonough 1984, 1985), a synmetamorphic regional thrust fault that carried the easternmost exposed gneiss in the southern Canadian Rocky Mountains.

The Bulldog and Yellowjacket gneisses are both considered as basement to a facies of Hadrynian metasediment because they are complexly deformed bodies with thin mylonite zones marking their respective gneiss–cover contacts (Fig. 2). The cover rocks associated with the gneisses have been assigned to the Hadrynian Miette Group of the Windermere Supergroup (Campbell 1968; Price and Mountjoy 1970). The gneisses and their cover form the deepest part of a regional plunge culmination in the Rocky Mountains that exposes Hadrynian strata over a large area around Yellowhead Pass (Price and Mountjoy 1970).

The gneisses are enveloped by staurolite- and kyanite-bearing metasediments (Campbell 1968), which form the northeast margin of the metamorphic hinterland, the Shuswap Metamorphic Complex (Okulitch 1984). Physical conditions at the peak of metamorphism have been estimated at approximately 5 kbar (1 kbar = 100 MPa) and 540°C (McDonough 1984), corresponding to a minimum 15–18 km tectonic burial depth. Recrystallization occurred during two main phases of metamorphism: (*i*) prograde, Barrovian metamorphism up to staurolite–kyanite grade of the middle amphibolite facies during Mesozoic deformation; and (*ii*) retrograde lower greenschist-facies metamorphism during Eocene(?) extension and cataclasis in the SRMT (McDonough 1984).

Gneiss lithologies

Bulldog Gneiss

The Bulldog Gneiss is subdivided into four lithologic units: (B1) melanocratic, amphibolitic gneisses with interlayered quartz-rich paragneisses; (B2) leucocratic, granitic augen gneisses and associated aplite; (B3) weakly foliated, leucocratic L-tectonite having a hornblende plus biotite lineation; and (B4) dykes and tectonic pods of amphibolite, and schistose mafic dykes.

B4 amphibolites are the youngest. They clearly differ from lineated B1 amphibolitic gneisses by their coarse grain size, their unoriented hornblende aggregates, the schistose fabric of some dykes, and local discordant contacts with other units, which are in marked contrast to the concordant nature of B1 amphibolitic gneisses.

Yellowjacket Gneiss

The Yellowjacket Gneiss is a granodioritic orthogneiss body having four gneiss lithologic units, tectonically intercalated with slices of parautochthonous pelite: (Y1) foliated, granodioritic augen gneiss; (Y2) crenulated, granodioritic augen gneiss; (Y3) weakly foliated, leucocratic, granitic orthogneiss; and (Y4) foliated amphibolite dykes.

Y4 amphibolites are the youngest. Y4 foliated dykes display discordant contacts relative to compositional layering in the gneiss, which suggests they intruded units Y1, Y2, and Y3. Inclusions of Y2 in Y4 amphibolite are highly strained, and it is not known if they are xenoliths. Y4 amphibolites may be the same age as B4 amphibolites, and both may represent feeder dykes for amphibolite dykes and sills of the semipelite–amphibolite unit (Simony *et al.* 1980) of the Horsethief Creek Group.

Mapping of the entire Yellowjacket Gneiss body reveals that only its westernmost exposures along Kinbasket Lake are cataclasites (Fig. 2), and the body is certainly not composed of cataclastic metasediments as Chamberlain *et al.* (1985) concluded from their sampling. Extreme cataclasis of outcrops in the SRMT locally has produced highly altered greenschist-facies gneiss lithologies in both gneiss bodies.

Age constraints on gneisses

Orthogneiss from unit B2 contains inclusions of B1 paragneiss that are weakly deformed xenoliths, indicating that B2 intruded B1. A U–Pb zircon date of ca. 1900 Ma (R. Parrish, personal communication, 1984) was obtained on B2 ortho-

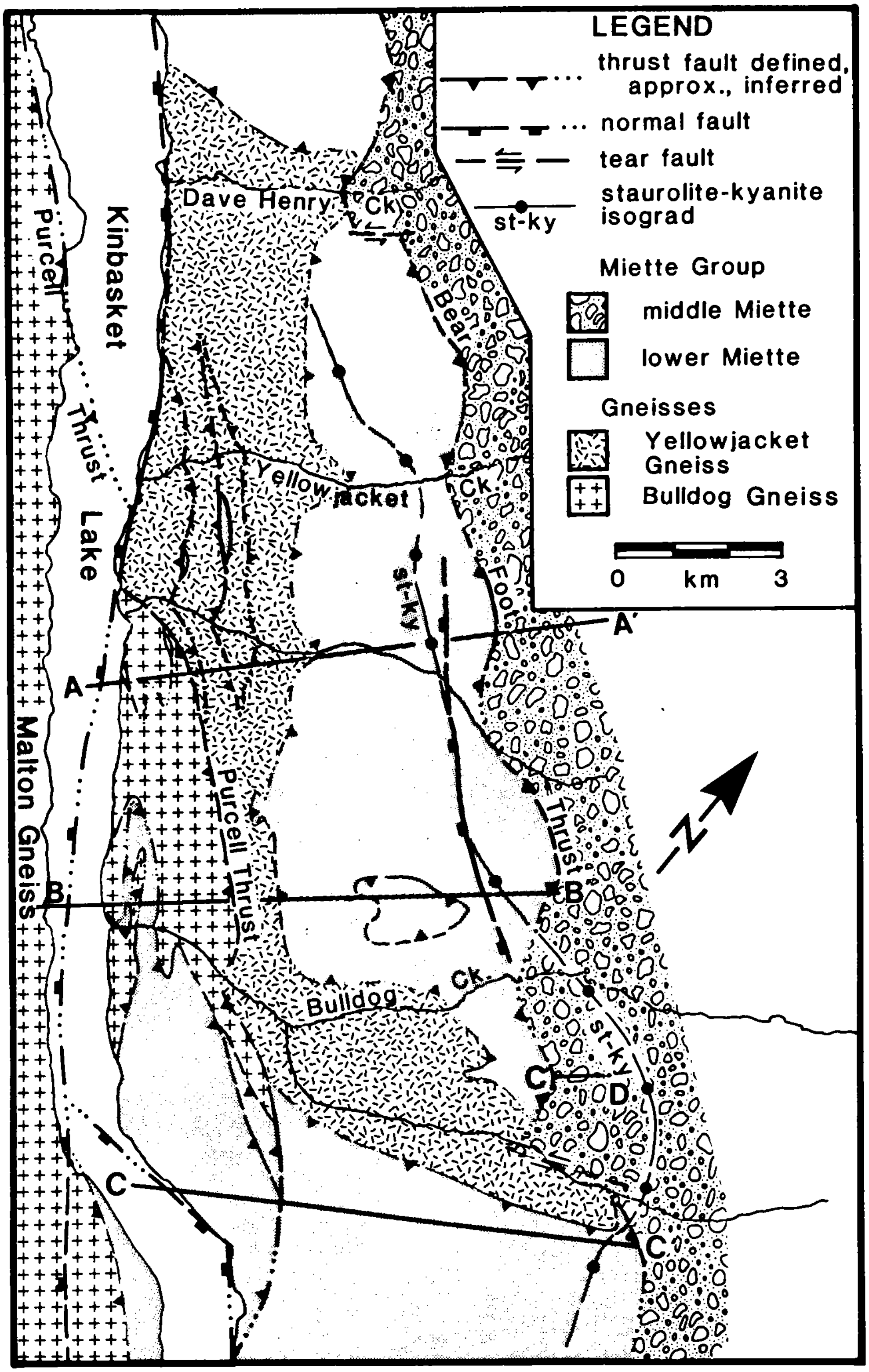

FIG. 2. Geological map of the Bulldog Creek area showing locations of section lines of Fig. 5. A narrow cataclastic zone (≤200 m wide) is exposed on the east shore of Kinbasket Lake between Bulldog and Dave Henry creeks.

gneiss from the inclusion-bearing outcrop. This age is similar to ages of gneiss from the Monashee Complex (Wanless and Reesor 1975; Evenchick *et al.* 1984) and to ages of granitic rocks of the Trans-Hudson Orogen in Saskatchewan (Van Schmus *et al.* 1987). Xenoliths of an older paragneiss and amphibolite sequence in B2 orthogneiss are suggestive of an early Aphebian (or possibly Archean) age for B1 gneisses.

Basement orthogneisses in the Columbian Orogen have a bimodal distribution of U–Pb zircon ages (≤2000 and ca. 750 Ma; Parrish and Armstrong 1983; Evenchick *et al.* 1984). These ages suggest that the attenuated Hudsonian basement of western North America was intruded ca. 750 Ma by anorogenic plutons just prior to extension and Windermere deposition. The ca. 1900 Ma age for the Bulldog Gneiss suggests it constitutes slices of the attenuated western edge of Churchill Province gneiss. Hudsonian U–Pb ages from similar orthogneiss from Malton Gneiss (ca. 2000 Ma; Parrish and Armstrong 1983) and orthogneiss from Sifton Gneiss (1851 Ma; Evenchick *et al.* 1984) indicate that an Aphebian basement terrane(s) existed either on the western edge of North America or as part of an outboard crustal block. Brown *et al.* (1986) suggested that the 2.2 Ga gneisses of the Monashee Complex represent an Aphebian basement terrane on the attenuated western edge of the North American craton. Although Monger *et al.* (1985) showed the Malton and Monashee Complex gneisses as slices of "suspect" basement because it was not known if they were part of the attenuated western edge of the North American craton or if they were translated long distances on dextral strike-slip faults prior to incorporation in the deforming miogeoclinal wedge, the Hadrynian stratigraphy associated with the gneisses can be considered as an overlap assemblage that suggests that the Aphebian basement terrane(s) was tied to North America prior to 750 Ma (see Brown *et al.* 1986).

The Yellowjacket Gneiss has not been dated; however, the field relationships do provide some constraints. The earliest foliation (S_{1+2}) is continuous from the parautochthonous cover through the gneiss, indicating that the Yellowjacket Gneiss intruded the basement prior to the earliest deformation and is probably older than 169 Ma, the age of metamorphic zircons from the Adamant Pluton (Shaw 1980) in the hanging wall of the Purcell Thrust some 150 km to the south. No apophyses of Yellowjacket Gneiss or any other granitic intrusions have been found cutting Miette or younger rocks surrounding the gneisses, suggesting that the Yellowjacket Gneiss is Precambrian and predates Miette Group deposition. The evidence is permissive; however, the balance of possibilities is that the Yellowjacket Gneiss is a young intrusion in the basement that predates the Miette Group and may be related to the Hadrynian anorogenic suite that intruded western North American basement (Evenchick *et al.* 1984).

Miette Group

The Bulldog and Yellowjacket gneisses each have an enveloping metasedimentary cover sequence belonging to the Miette Group of the Windermere Supergroup (Campbell 1968). The Bulldog Gneiss has mainly a parautochthonous cover that is an integral part of the basement complex. The Yellowjacket Gneiss has both a parautochthonous cover within the gneiss body and an overlying detached cover (Fig. 3). Both sequences are characterized by a thin, discontinuous, lower granule sandstone unit, which is overlain by a thick quartzite- and calc-silicate-bearing pelite unit (Fig. 3). The above similarities permit correlation of the two cover sequences across the Purcell Thrust (Fig. 3) despite the following differences.

The Bulldog succession has a 50 m thick unit of thin-bedded (2–25 cm), light gray, very fine grained, foliated, muscovitic quartzite at its base, overlain by a 10 m thick conglomerate unit in which a green, chlorite-rich matrix supports quartzite and feldspar clasts up to 2 cm in diameter. Neither quartzite nor conglomerate is present in the Yellowjacket cover sequence. Interbedded light brown quartzite is rare in the pelite unit of the Bulldog cover but common in the Yellowjacket sequence.

The extreme thinning of the Hadrynian lower Miette and equivalent strata overlying the gneisses is traceable from the southwest and the northeast (Fig. 3) and may be due to depositional phenomena related to a paleogeographic basement high (McDonough 1984). Some of the thinning could in part be tectonic; however, there is clear sedimentological evidence of individual middle Miette units in the Selwyn Range thinning and pinching out to the southwest, which suggests the presence of topographic highs to the southwest that affected deposition of the units carried by the Bear Foot Thrust (McDonough and Simony 1988).

Lithologic and stratigraphic correlations

Morrison (1979, 1982) described the Malton Gneiss as a strongly deformed body consisting predominantly of banded, biotite-rich and biotite-poor paragneisses interlayered with amphibolite gneisses. Paragneisses were intruded by sheets of 2000 Ma leucocratic orthogneiss (Parrish and Armstrong 1983) that are nearly the same age as B2 orthogneiss. These lithologies were observed to be very similar to those of the Bulldog Gneiss. A homogeneous body of augen gneiss in the southwest corner of the Malton Gneiss (Morrison 1982) strongly resembles foliated augen gneiss of the Yellowjacket Gneiss.

The Malton Gneiss has infolds of a parautochthonous cover sequence having foliated muscovitic quartzite at its base, overlain by a thin and discontinuous lower grit unit and a pelite unit (Morrison 1982). This sequence is identical to the parautochthonous Bulldog succession (Fig. 3), which also forms an integral part of the basement complex. Each of these parautochthonous sequences can be correlated with the detached muscovitic quartzite–grit–pelite cover sequences found above the Malton and Blackman gneisses (Oke and Simony 1981) (Figs. 1, 3). The correlation of gneiss and cover units across the SRMT is made with confidence because the two bodies have the same geologic setting of gneiss and cover and their respective covers are of the same lithology, stratigraphic position, and thickness. The detached cover above the Malton Gneiss has been mapped continuously into Horsethief Creek Group strata of the Mica Creek area (Simony *et al.* 1980; Poulton and Simony 1980), making the Bulldog succession Horsethief Creek Group equivalent (Fig. 3).

The pelite and quartzite unit of the Yellowjacket cover sequence can be correlated with a similar succession from the northern Selwyn Range that belongs to the lower Miette Group (Fig. 3) (McDonough and Simony 1986, 1988). There, thick-bedded conglomeratic sandstones typical of the middle Miette Group conformably overlie a pelite and quartzite unit assigned lower Miette status. On the basis of these correlations, we suggest that the Yellowjacket and Bulldog cover sequences both belong to the lower Miette Group, which is a thin equivalent of the Horsethief Creek Group (McDonough and Simony 1984). These correlations are in accord with Pell and Simony's (1987) double-wedge model for the Windermere Supergroup.

The remarkable similarities in cover stratigraphy and gneiss lithology suggest that the gneiss bodies on either side of the SRMT can be used to constrain dextral motion on faults in the SRMT to ≤10 km (Fig. 1). The gneisses are now in separate thrust sheets, each a composite of very thin thrust slices, and were probably all part of one heterogeneous basement in Hadrynian time. The geochemical differences reported by Chamberlain *et al.* (1985) can be more easily explained by incomplete sampling of heterogeneous slices than by large dextral strike-slip displacements between gneiss bodies.

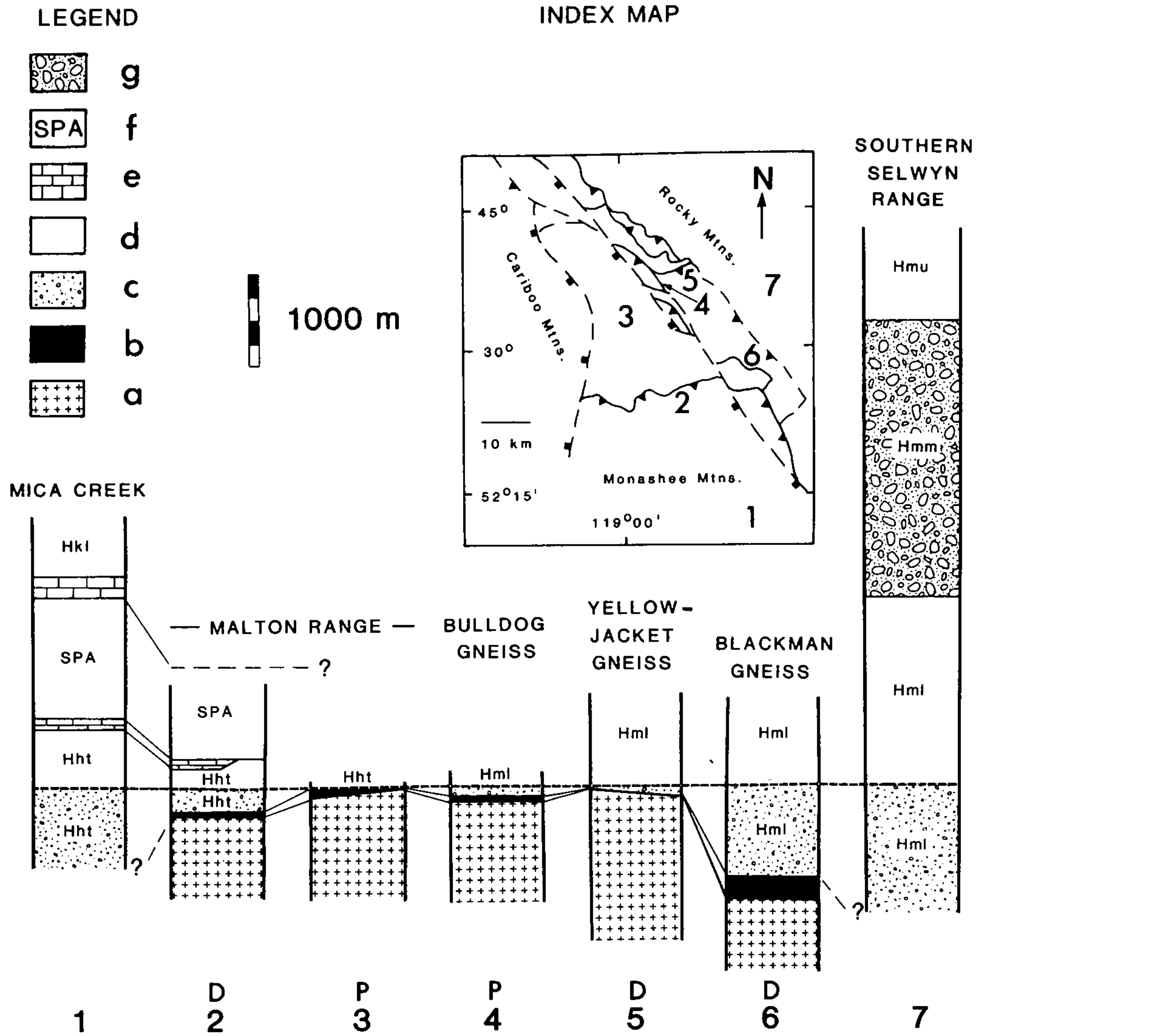

FIG. 3. Stratigraphic correlation diagram for the Selwyn Range and adjacent areas showing the thin nature of the stratigraphy associated with the gneisses. Datum is the base of lower Miette pelite and correlative units. Section locations given in inset map. Data: 1, Poulton and Simony (1980); 2, Simony *et al.* (1980); 3, Morrison (1982); 4 and 5, McDonough (1984); 6, Oke (1982); 7, Mountjoy and Forest (1986). Legend: a, gneiss; b, muscovitic quartzite; c, coarse sandstone; d, pelite; e, marble; f, semipelite–amphibolite unit; g, conglomeratic sandstone. D, detached cover; Hht, Horsethief Creek Group; Hk, Kaza Group; Hm, Miette Group; P, parautochthonous cover within basement; SPA, semipelite–amphibolite unit.

Structural evolution

Five generations of folds, three phases of thrust faulting, and a phase of normal faulting are observed in superposition within two major thrust sheets in the Bulldog Creek area. The first two and last two fold phases are all nearly coaxial and have axial traces parallel to regional strike. They are assigned numeric subscripts (one to four) because they can be related to regional fold events (e.g., Simony *et al.* 1980; Morrison 1982; Murphy 1987). Folds that formed after F_2 and prior to F_3 have axes that trend transverse to regional strike and are called F_t.

Relationships between metamorphic porphyroblasts, leucosomes, and cleavages reveal that first-phase folds are premetamorphic, F_2 are pre- to synmetamorphic, F_t are syn- to late-metamorphic, and F_3 are postmetamorphic (relative to the peak of staurolite–kyanite-grade metamorphism; Fig. 4). Truncations of F_1 axial-plane cleavage (S_1) by quartz–plagioclase leucosome developed at or near metamorphic climax indicate that F_1 predates the peak of metamorphism (Fig. 4). Garnet growth is synchronous with S_2, and kyanite and staurolite cut across S_2, indicating that F_2 are pre- to synmetamorphic (Fig. 4).

F_1, F_2, and F_3 are found in the Bulldog Gneiss, where F_1 and F_3 form type III coaxial interference patterns (Fig. 4). In the Yellowjacket Gneiss, F_1, F_2, and F_3 are present, and its cover contains F_2, F_t, F_3, and F_4. Although the apparent lack of F_1 in the cover is suggestive of an unconformity, we suggest that F_1 is Mesozoic because it is coaxial with F_2, F_3, and F_4 and because F_1 structures involve basement and cover west of the SRMT (Morrison 1982). Furthermore, Raeside and Simony (1983) reported that the F_1 Scrip Nappe formed under garnet-grade conditions and is probably Mesozoic.

Large-scale structure is dominated by northeast-verging F_2 throughout the area (Figs. 2, 5). All folds are northeast verging, except for transverse, symmetric F_t. Transverse F_t are a

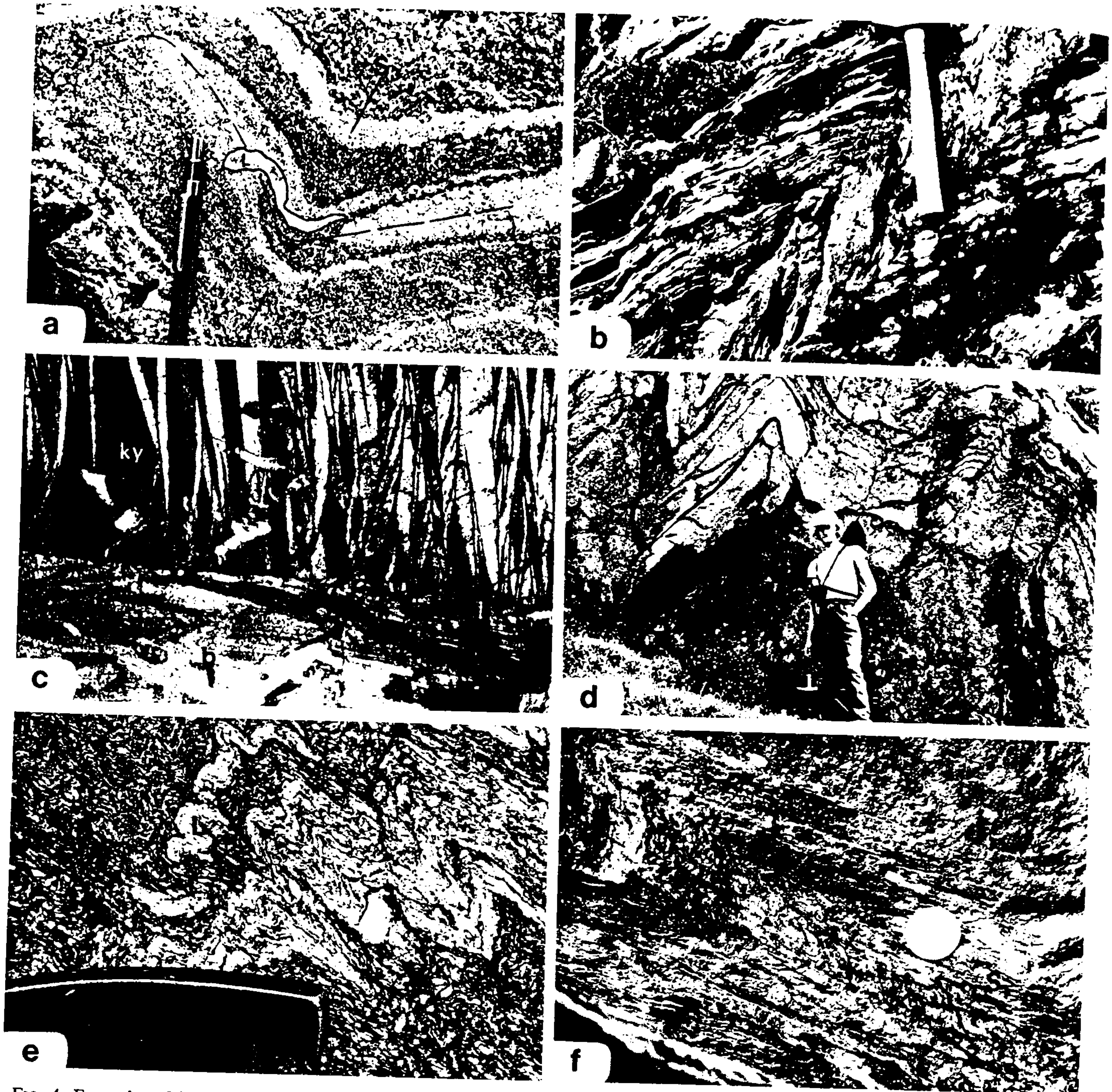

FIG. 4. Examples of folds and foliations and their relationships to metamorphism. (*a*) View to the southeast of F_1-F_3 coaxial interference pattern in B1 gneiss with leucosome (L) that truncates S_1 and is folded by F_3. Pencil is 9 mm in diameter. (*b*) View to the northwest of northeast-verging mesoscopic F_2 folds in the Bear Foot mylonite zone. Hammer handle is 34 cm long. (*c*) Photomicrograph of S_t kink bands internal to a large kyanite (ky) grain in pelite that overgrew biotite (b) in S_2. Cross-polarized light; width of photo is 3 mm. (*d*) View to the northeast of transverse symmetric F_t folds in psammite layers. (*e*) View to the southeast of F_3 crenulations in Y2 gneiss and leucosome (L). Hammer head for scale. (*f*) Transverse crenulation cleavage (S_T) in pelite folded by F_3 crenulations and cut by S_3 cleavage. Dime for scale.

conjugate set of mesoscopic close to tight folds associated with a conjugate set of axial-planar S_t crenulation cleavages that show mutually contradictory cross-cutting relationships, indicating the two cleavages are contemporaneous. Mesoscopic transverse F_t are not regional in extent but for the most part are restricted to the Bear Foot thrust sheet. F_t decrease in amplitude and fold density eastward from the SRMT and form small crenulate folds in the footwall of the Bear Foot Thrust.

Four foliations are found in association with folds in the area. The earliest tectonic foliation (S_1) is not ubiquitous and is seen only in gneisses. On the limbs of F_2 folds in gneiss, S_1 is overprinted by a parallel S_2, forming a composite S_{1+2} foliation. The first foliation in cover rocks is S_2, which is a bedding-parallel foliation that is axial planar to F_2. S_t and S_3 are crenulation cleavages associated with F_t and F_3, respectively. S_3 crenulates S_t, showing that F_t predates F_3. Helicitic quartz–feldspar–epidote inclusion trails internal to garnet porphyroblasts from the Bulldog cover probably represent a

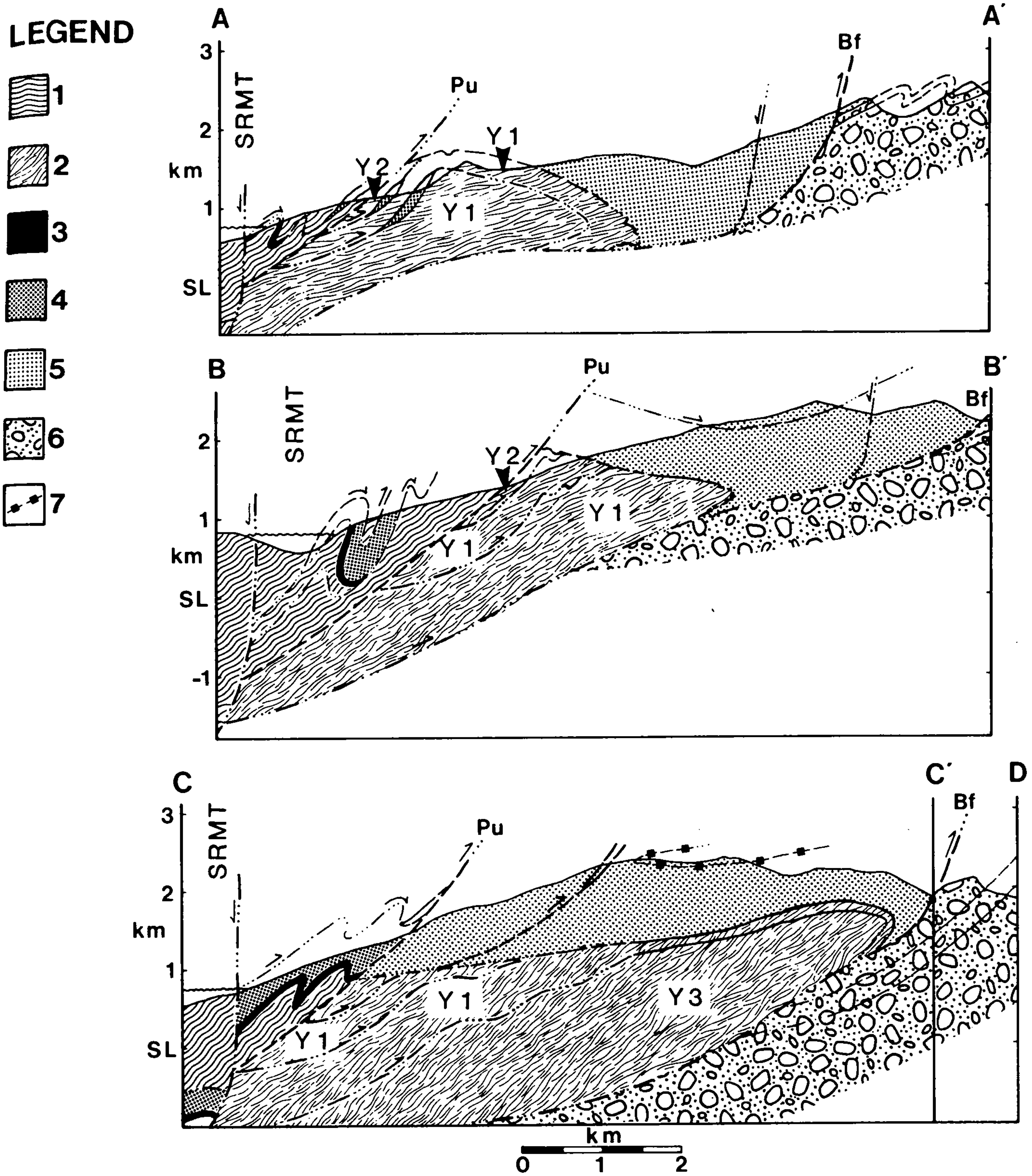

FIG. 5. Cross sections; see Fig. 2 for location of section lines. 1, Bulldog Gneiss; 2, Yellowjacket Gneiss; 3, muscovitic quartzite; 4, parautochthonous lower Miette pelite; 5, lower Miette Group; 6, middle Miette Group; 7, carbonate marker in the lower Miette. Bf, Bear Foot Thrust; Pu, Purcell Thrust; SRMT, Southern Rocky Mountain Trench. Y1, Y2, and Y3 are Yellowjacket Gneiss lithologies in horses of a basement duplex (see text). SL, sea level.

manifestation of S_1 in cover rocks.

Basal décollements

The gneiss–cover contacts in both gneiss bodies are interpreted as detachments (Figs. 2, 5) because they are marked by banded mylonite. These mylonites retain a weak lineation of oriented biotite grains but lack a distinctive stretching lineation. Mylonite deformation textures in thin section are extensively annealed and exhibit equant, strain-free quartz grains with triple-junction grain boundaries, indicating that gneiss–

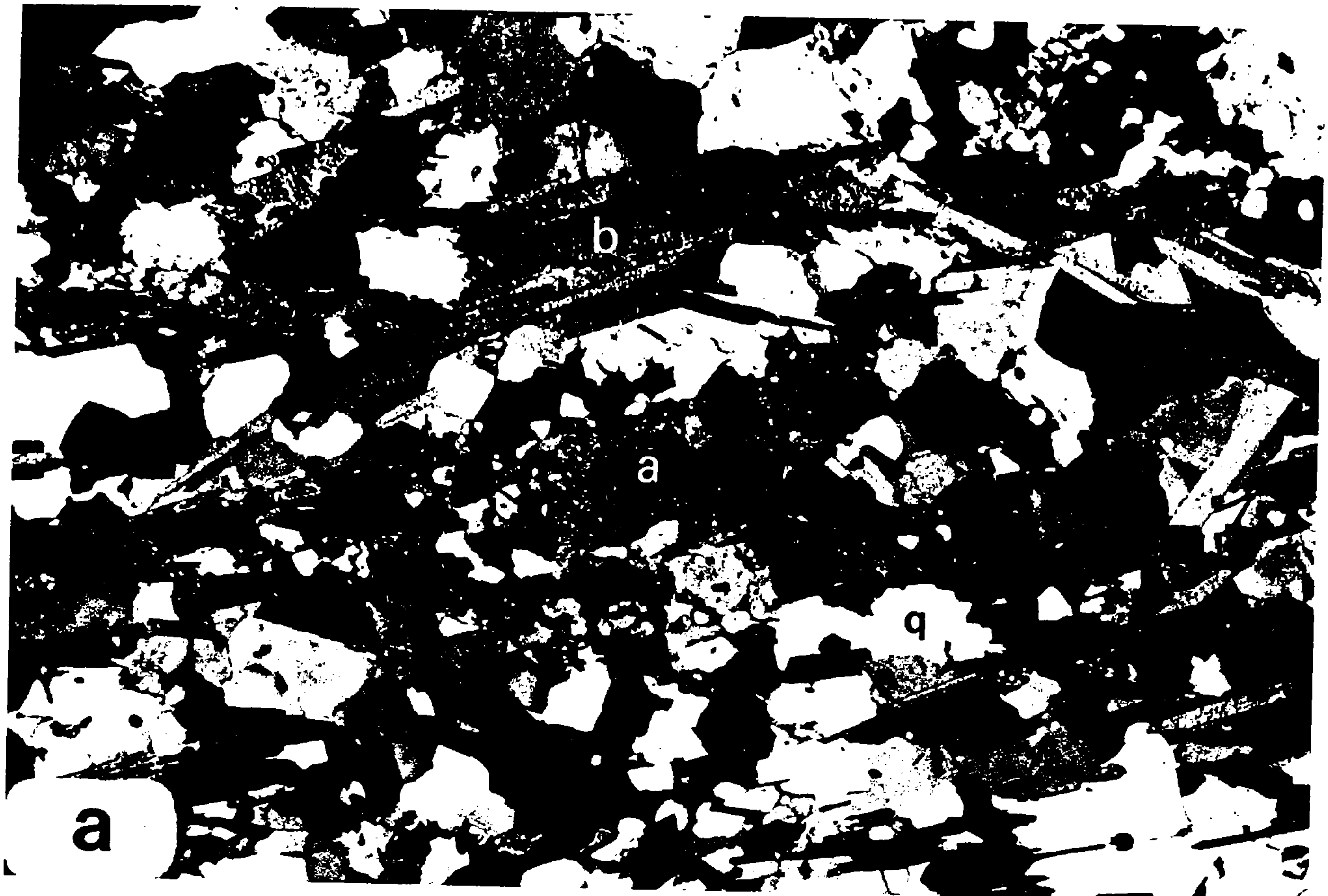

FIG. 6. Photomicrographs (cross-polarized light) of shear zone fabrics. (*a*) Annealed textures in mylonite from the top of the Yellowjacket Gneiss. Note strain-free quartz (q) and biotite (b) grain configurations and relic recrystallized allanite (a) core. Width of photo is 5 mm.

cover detachment was premetamorphic (Fig. 6*a*). Kinematic indicators were destroyed by thermal annealing during metamorphism; thus, the local motion vector for cover detachment is not known.

Cover detachment occurred early during the deformation as a result of different shortening mechanisms of gneiss and cover during F_1. Gneisses and parautochthonous cover deformed by thrusting, isoclinal folding, and foliation development, whereas the detached cover rocks were shortened by the large, west-verging Scrip Nappe (Raeside and Simony 1983) to the west of the Bulldog Creek area. The basement–cover contacts on the Bulldog and Yellowjacket gneisses, as well on the Malton (Morrison 1982), Blackman, and Hugh Allan gneisses (Oke and Simony 1981), show evidence of high strain and shear. The amount of displacement of cover relative to basement is limited to the extent that the "thin" cover facies consisting of thinned or missing stratigraphic units is restricted to the vicinity of the gneisses and to the thrust sheets that carried the gneisses. The "thin" cover facies and the exposure of gneiss in certain thrust sheets are therefore associated, and both are held to be related to the same paleogeographic basement high during the evolution of the North American continental margin.

Bear Foot Thrust

The Bear Foot Thrust is a pre- to synmetamorphic thrust that placed the Yellowjacket Gneiss and its cover on strata that are correlative with the middle Miette Group (Figs. 2, 5). Near Dave Henry Creek (Fig. 2) the fault is well defined by a 2 km wide mylonite zone. Bear Foot Thrust mylonites are strongly foliated, weakly lineated L–S tectonites of Lister and Snoke's (1984) type II, with mylonite foliation (S_m) generally subparallel to S_{1+2} and with a weakly developed quartz-stretching lineation that plunges shallowly to the northwest.

The timing of motion on the Bear Foot Thrust is constrained between F_1 and F_3, because mylonite in the fault zone truncates S_1 in the YG and is crenulated by S_3. Garnets in the fault zone are partially enveloped by and partially truncate S_m, suggesting that motion on the fault is synmetamorphic and synchronous with F_2. The fault does not offset the map pattern of the staurolite–kyanite isograd (Fig. 2), nor does it offset the garnet isograd where it crosses the Bear Foot Thrust east of Valemount (McDonough, unpublished data, 1987), indicating that postmetamorphic motion is minimal. A large, gneiss-cored F_2 antiform in the hanging wall of the thrust is interpreted as having developed as a leading-edge antiform (Fig. 5).

The Yellowjacket Gneiss is dissected by banded mylonite zones that represent thrusts that variably imbricate the gneiss body from centimetric to kilometric scale (Figs. 2, 5). These faults bound lenses of metasediment and gneiss, which are interpreted as horses within the Bear Foot thrust sheet (Fig. 5), creating a duplex (Boyer and Elliott 1982) geometry of stacked

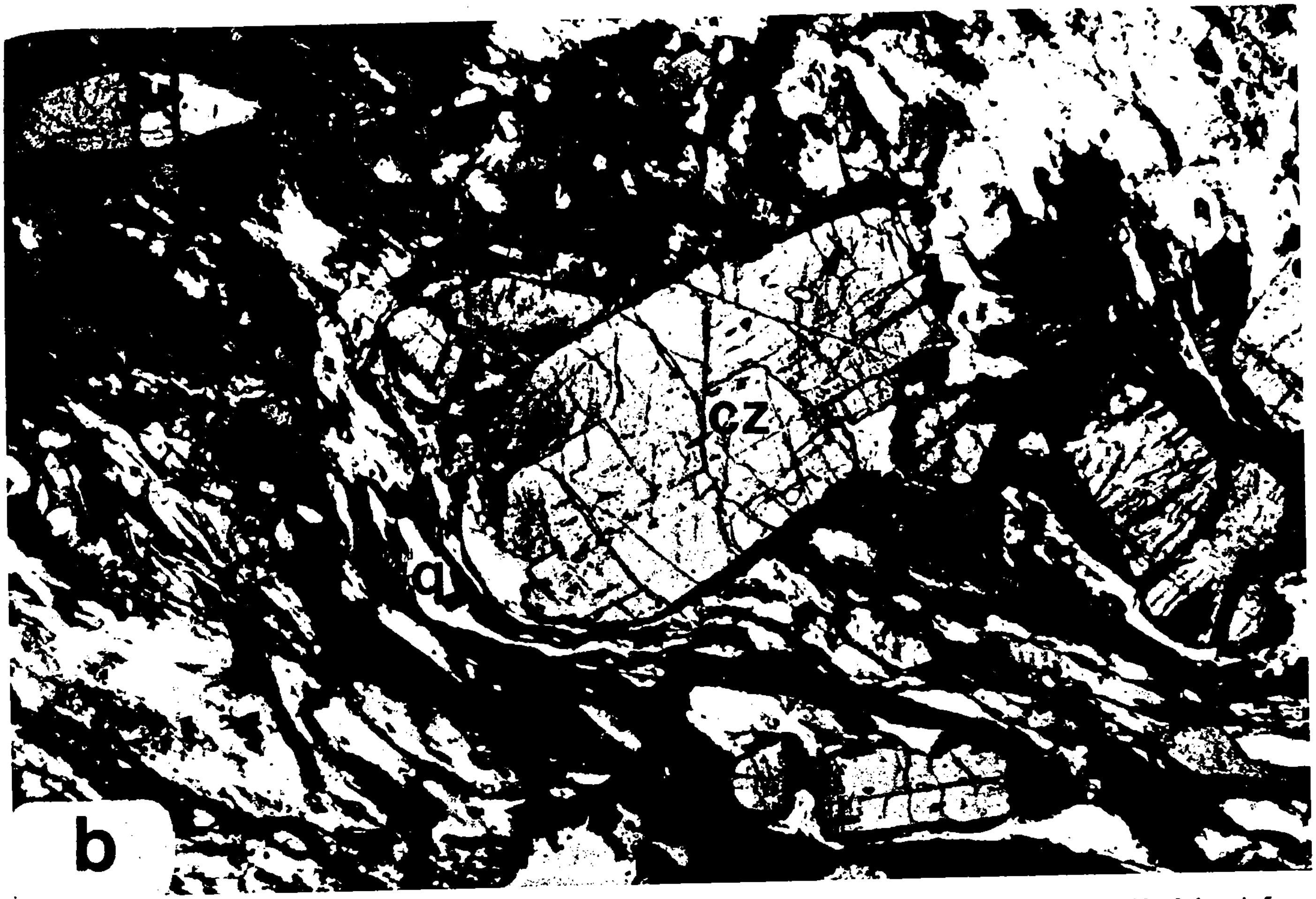

FIG. 6 (*concluded*). (*b*) Clinozoisite (cz) grain from the Purcell thrust zone enveloped by mylonitic quartz (q) fabric. Width of photo is 5 mm.

thrust slices of gneiss and parautochthonous cover. Shortening of the Yellowjacket Gneiss by thrusting alone is a minimum of 20 km (Fig. 5).

Kinematic indicators from the Bear Foot thrust zone were observed at outcrop, centimetric, and millimetric scales (Fig. 7). Outcrop- and centimetre-scale shear-sense indicators are top-to-the-northeast thrust shear couples and transverse shears with sinistral shear couples. Northeast-verging folds have the same orientation throughout the entire area, which suggests they have not been rotated into the lineation direction and are indicative of a thrust regime. Local superposition of fabrics in the fault zone suggest northeast-directed fabrics were overprinted by a weak northwest-plunging stretching lineation during northwest-directed motion, which in turn was cut by northeast-directed fabrics.

Millimetric kinematic data from $X-Z$ and $Y-Z$ principal sections are summarized in Fig. 7 and include S–C fabric (both internal and external to quartz grains; Berthé *et al.* 1979), mica fish, and σ_a-type (Passchier and Simpson 1986) feldspar porphyroclasts (Figs. 7, 8). $X-Z$ sections show top to the northwest (dextral in plan view) shear couples in 32 of 35 cases. $Y-Z$ sections show top to the northeast shear couples in 33 samples. S_m is truncated by high-angle microthrusts in $Y-Z$ sections (three samples) that show top-to-the-northeast motion, which is the latest motion expressed in the Bear Foot fault zone (McDonough 1985). Most samples exhibit shear bands in $X-Z$ and $Y-Z$ sections, with top-to-the-northwest and top-to-the-northeast shear couples, respectively.

Recently, oblique-slip–thrust or wrench–thrust models have been proposed for thrust belts with stretching lineations that are nearly orthogonal to the dip direction in the inner parts of orogenic zones (e.g., Coward and Potts 1983; Lagarde and Michard 1986; Ridley 1986). The noncoaxial shear-sense data presented above are more easily explained by an oblique-slip–thrust model than by a divergent-flow model. Well-developed top-to-the-northeast shear-sense indicators in $Y-Z$ sections suggest that the lineation direction does not represent the motion vector for the entire movement history of the Bear Foot Thrust (Fig. 7). A model of dextral oblique slip is presented in Fig. 9 to account for conflicting kinematic indicators from $X-Z$ and $Y-Z$ sections. In the model, the observed shear senses represent the dip-slip and strike-slip component vectors for dextral oblique slip. The kinematic data do not permit the distinction between models of (*i*) large pulses of thrust motion followed by strike-slip and later thrust motion, (*ii*) incremental small pulses of sequential thrust and strike-slip motion, and (*iii*) purely oblique-slip motion. The model is intended to show that the cumulative motion on the Bear Foot Thrust is oblique and that the resultant motion vector is located between the X and Y directions of the strain ellipsoid. The Bear Foot Thrust may be a manifestation of dextral oblique convergence, first suggested by Monger and Price (1979) to account for decreased shortening across the foreland north of 52°N and for the lack of dextral offset of structures and facies belts across the SRMT

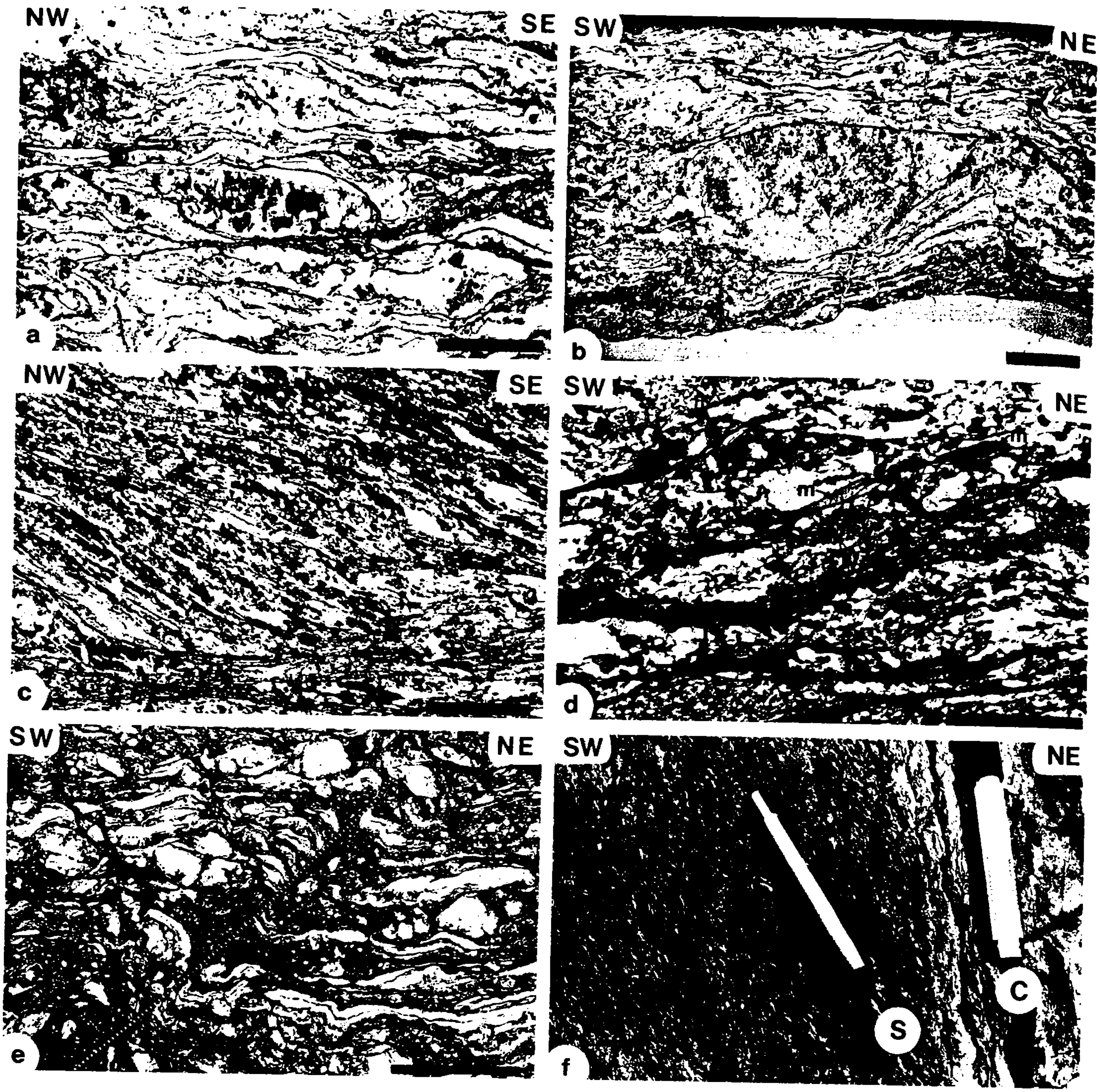

FIG. 7. Examples of kinematic data from oriented mylonite samples from the Bear Foot thrust zone at Dave Henry Creek. Lineation-parallel (||L) sections are viewed up dip to the northeast. Lineation-perpendicular ($\perp$L) sections are viewed to the northwest. Line diagrams are given in Fig. 8. (*a*) ||L section from sample DHM-03 showing σ_a feldspar (f) porphyroclasts that yield top-to-the-northwest (dextral in plan view) shear couples. Plane-polarized light; scale bar is 1 mm. (*b*) $\perp$L section from sample DHM-03 showing a very asymmetric σ_a feldspar porphyroclast that indicates top-to-the-northeast thrust motion. Note northeast-verging microfolds in upper part. Plane-polarized light; scale bar is 2 mm. (*c*) ||L section from sample DHM-20 showing well-developed top-to-the-northwest (dextral in plan view) S–C fabric both internal and external to flattened quartz grains. Cross-polarized light; scale bar is 1 mm. (*d*) $\perp$L section from sample DHM-20 showing S–C fabric and mica fish (m) that yield top-to-the-northeast shear couples. Cross-polarized light; scale bar is 0.5 mm. (*e*) $\perp$L section from sample DHM-02 showing top-to-the-northeast σ_a porphyroclast and a northeast-directed high-angle reverse microfault that cuts S_m. Plane-polarized light; scale bar is 3.5 mm. (*f*) Outcrop photograph of $\perp$L section from strained gneiss outcrop showing a top to the northeast shear couple on the east-dipping limb of an F_3; pencil is parallel to S_{1+2}; marker (13 cm long) is parallel to S_m (C). The steep foliation in the dark Y2 gneiss layer is S_3 crenulation cleavage.

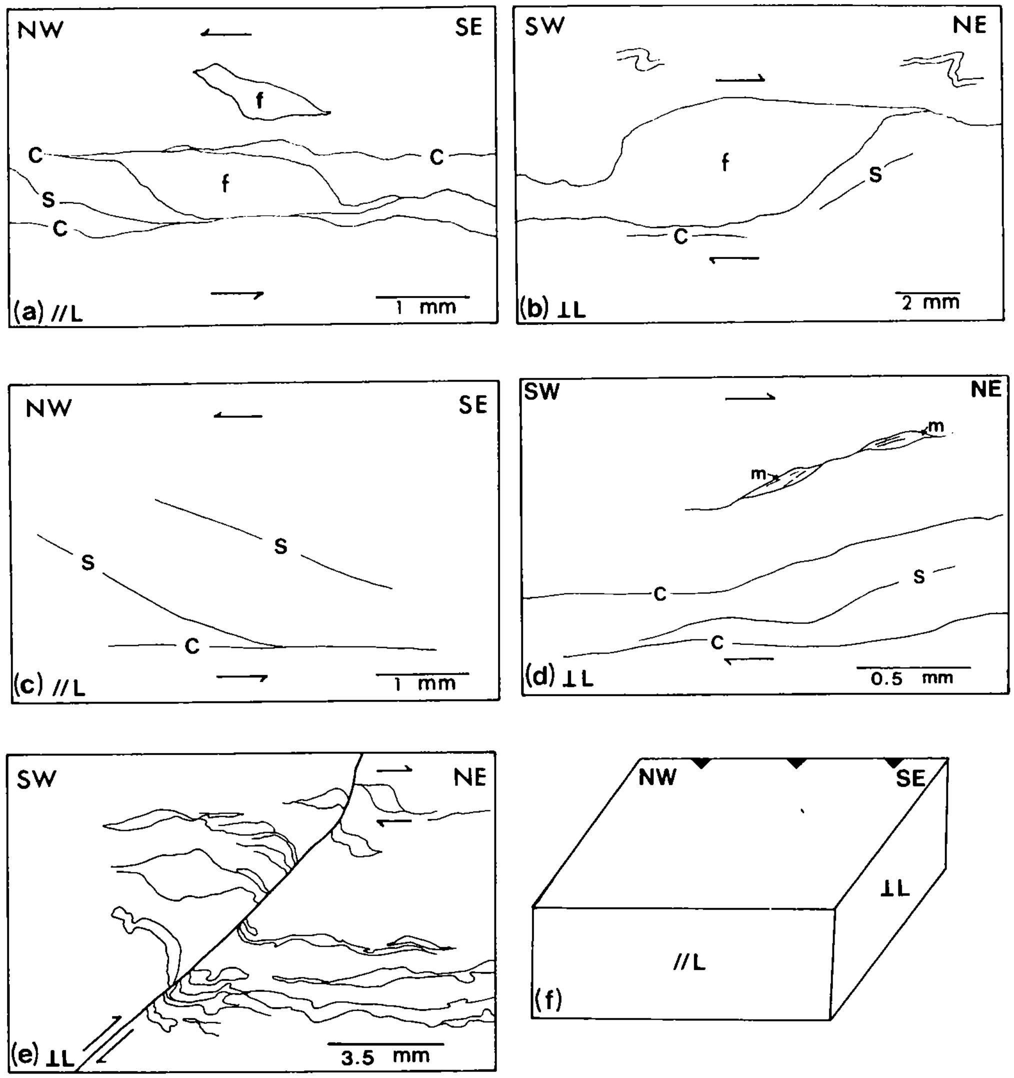

FIG. 8. Line diagrams with interpreted shear couples for photographs of Fig. 7. (*a*)–(*e*) correspond to Figs. 7*a* to 7*e*, respectively. C, cisaillement; f, feldspar; m, mica fish; S, foliation. (*f*) Block diagram showing orientation of photographs: ||L, lineation-parallel section (view to northeast); ⊥L, lineation-perpendicular section (view to northwest).

(Leech 1966; Price 1981; Price and Carmichael 1986).

A similar model was simultaneously developed by Van Den Driessche and Maluski (1986); however, they attributed linear fabrics on the west edge of the Rockies to a transpressional system with a throughgoing dextral strike-slip fault in the SRMT. In our model, motion of the Bear Foot thrust sheet is north-northeast-directed oblique motion that translated gneisses and cover over the future site of the SRMT.

The Bear Foot Thrust is offset by two sinistral tear faults orthogonal to its strike (Figs. 2, 9). Small-scale vertical tear faults in the Bear Foot thrust zone are 2–4 cm wide ductile shears that offset S_m sinistrally. F_t may have formed in response to the geometric constraints imposed by the tear faults. Tear faults geometrically constrain the late motion on the thrust to dip slip and require that the dextral component of motion during the late movement history of the thrust be considerably less than the thrust displacement.

Purcell Thrust

A postmetamorphic fault between the Bulldog and Yellowjacket gneisses is interpreted as the Purcell Thrust because, as does the Purcell Thrust defined to the south, it truncates earlier formed synmetamorphic F_2 structures (Craw 1978; McDonough and Simony 1984). The Bear Foot Thrust cannot be the Purcell Thrust as suggested by Mountjoy *et al.* (1984) because the former is a synmetamorphic F_2 structure. In the Purcell thrust zone, mylonitic foliation is observed in thin section to envelope and, therefore, probably postdate growth of clinozoisite porphyroblasts (Fig. 6b). Porphyroblast–foliation relationships in zoisite-bearing pelite from the footwall indicate that zoisite growth occurred at or near metamorphic climax, suggesting that final emplacement of the Bulldog Gneiss on the Purcell Thrust postdated metamorphism. In the Purcell thrust zone, ductile mylonite fabrics are overprinted by brittle fractures, which themselves are overprinted by later mylonitic fabrics. These relationships suggest 5–8 km of uplift from a purely ductile regime at maximum burial depth (15–18 km) into a brittle–ductile transition zone during motion of the Purcell Thrust.

The Bulldog Gneiss and its cover constitute a stack of gneiss

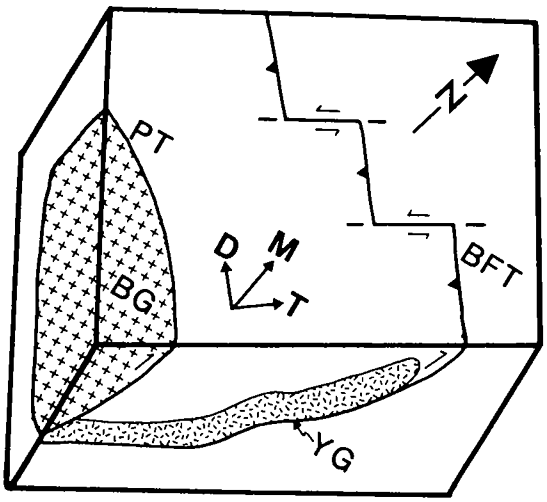

FIG. 9. Block diagram showing dextral oblique-slip–thrust model for the Bear Foot Thrust (BFT). D, dextral motion vector; M, hypothetical resultant motion vector; T, thrust motion vector. BG, Bulldog Gneiss; PT, Purcell Thrust; YG, Yellowjacket Gneiss.

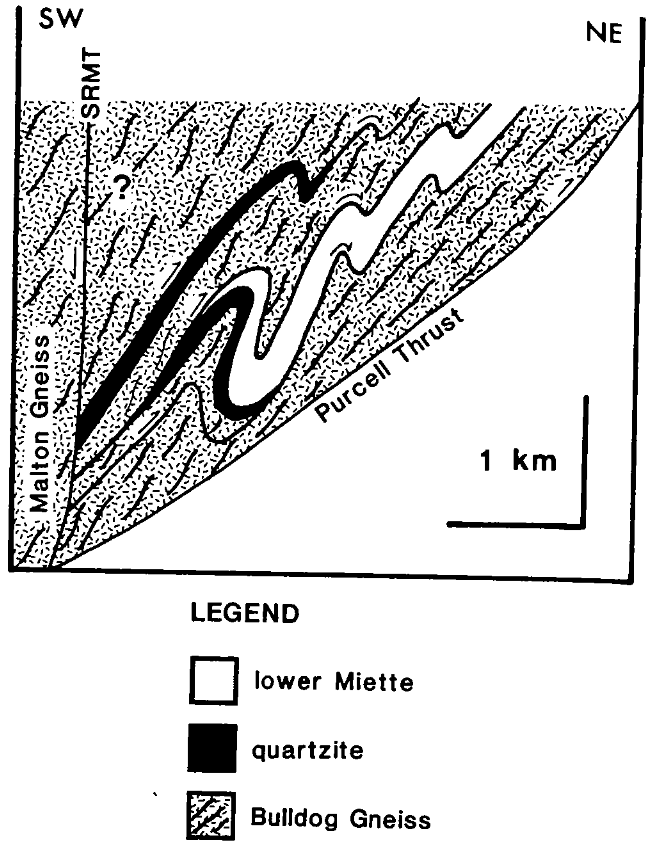

FIG. 10. Schematic cross section through the Bulldog Gneiss complex, showing the thin character of individual stacked gneiss and cover thrust sheets. The folds are F_2.

and metasediment thrust slices in the upper plate of the Purcell Thrust that are folded by a series of large F_2 folds (Fig. 10). These early thrusts are related to easterly directed shortening and stacking of the basement during F_1. This complex package of very thin slices of gneiss and cover form the immediate hanging wall of the Purcell Thrust, as does the Malton Gneiss (Campbell 1968; Morrison 1982), suggesting that the Bulldog Gneiss is structurally equivalent to the basal part of the Malton Gneiss.

Rocky Mountain Trench

The Southern Rocky Mountain Trench (SRMT) is a 600 km long, narrow, geomorphic trench extending from 48° to 55°N, having no documented strike-slip fault offsets (Leech 1966; Price 1981; Price and Carmichael 1986; Cook *et al.* 1987). In contrast, the Northern Rocky Mountain Trench – Tintina Trench (NRMT–TT) system has at least 450 km of post-middle Cretaceous dextral strike-slip motion (Templeman-Kluit 1979; Gabrielse 1985).

The SRMT in the Bulldog Creek area is characterized by greenschist-facies cataclasis of gneiss and metasediment in a narrow crush zone (about 200 m wide) exposed on the east shore of Kinbasket Lake (Fig. 2). Cataclastic deformation textures overprint all foliations and therefore postdate all other structures in the study area. Slickensides in the crush zone are vertical to steep, southwest-dipping surfaces with quartz and calcite fibres indicating west-side-down dip-slip motion. The brittle deformation is therefore probably associated with shallow-level crustal extension and normal faulting that post-dated regional deformation (McDonough and Simony 1984) and may be related to the significant Eocene crustal extension in the southern Omineca belt (see Parrish *et al.* 1988).

West-side-down normal faulting in the SRMT is well documented near 49°N (Leech 1966), and it continued into the Miocene near Cranbrook, British Columbia (Clague 1974). Campbell (1973) suggested the border fault(s) in the trench near Valemount are steeply dipping, west-side-down normal faults of unknown dip slip. In the trench east of Mica Creek, British Columbia, Simony *et al.* (1980) showed that hinged, en échelon faults offset the Purcell Fault in a manner that suggests 0–2 km of west-side-down normal motion. Cooling ages of micas from the Rockies near Valemount are not influenced by rapid Eocene uplift (see below), suggesting that large extensions and tectonic denudation did not occur at this latitude in the foreland.

Models incorporating significant dextral strike-slip motion on the SRMT (Chamberlain and Lambert 1985; Van Den Driessche and Maluski 1986) ignored the timing constraints on motion on the NRMT–TT system, as well as the geology on either side of the SRMT south of 53°N. Transverse foliations adjacent to the trench do not substantiate dextral motion on faults within it. If a Reidel shear model (Tchalenko 1970) is applied, the southerly striking S_t is in the antithetic shear position (R′) for possible dextral motion (Fig. 11). Transverse foliations with the same orientation observed east of Valemount exhibit dextral shear couples however, rather than sinistral (McDonough 1984), suggesting that transverse foliations bear no structural relationship to strike-slip motion in the trench. Also, the west-striking conjugate S_t is unrelated to the orientation of the potential synthetic shear (R) in the Reidel model (Fig. 11). Correlation of gneiss and cover across the SRMT, as well as correlation of middle Miette Group rocks of the Rocky Mountains with middle and upper Kaza Group rocks of the Cariboo Mountains (made by many workers, including Campbell *et al.* 1973; Carey and Simony 1985; Murphy 1987; Pell and Simony 1987), suggests minimal dextral motion on faults in the SRMT (see Fig. 1).

Discussion

Regional shortening

Price (1981) reported a minimum of 200 km shortening

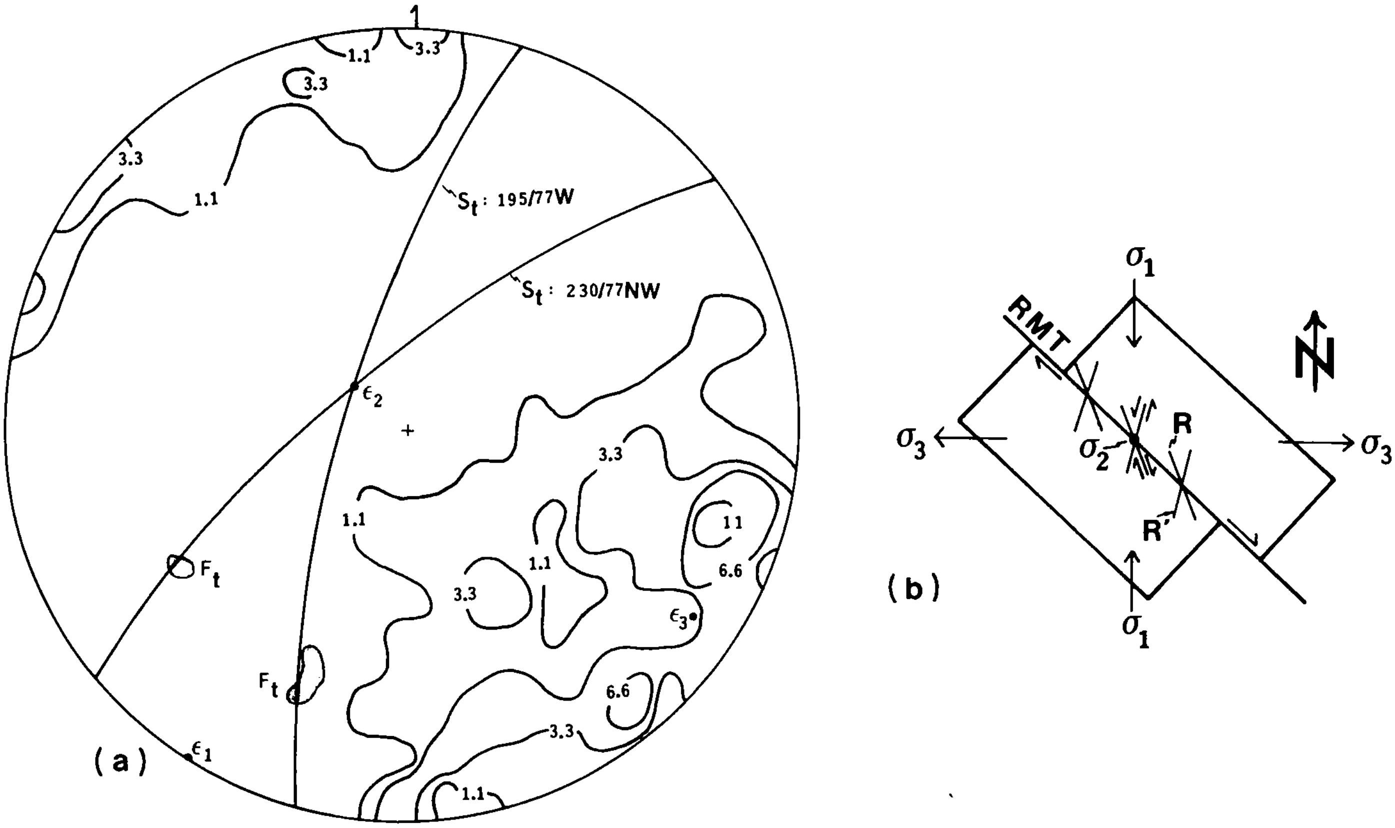

FIG. 11. Transverse foliation data. (*a*) Kalsbeek contoured equal-area plot of 90 poles to conjugate S_t. Contours are 1.1, 3.3, 6.6, and 11% of S_t data per 1% area. The two modal S_t planes are oriented 195°/77°W and 230°/77°NW. Shaded areas are the modes for axes of conjugate F_t folds. E1, E2, and E3 are the principal strains. (*b*) hypothetical Reidel shear model for the SRMT. The southerly striking S_t is in the antithetic shear position (R'); however, shear couples observed on these planes are dextral.

across the foreland at the latitude of Calgary. Monger and Price (1979) suggested that shortening of the foreland decreases north of 52°N and can be accounted for by increasing dextral slip in the NRMT–TT system. Mountjoy *et al.* (1984) reported 230 km of shortening out front of the southern extension of the Bear Foot Thrust (their Purcell Fault), which suggests that foreland shortening does not decrease between 52° and 53°N. However, shortening is distributed differently north of 52°N.

Extension of Zeigler's (1969) section to the west yields a minimum of 240 km shortening in the foreland at the latitude of this study (Fig. 12). Shortening of the Cretaceous Cardium Formation in the Foothills is only 10 km, which is significantly less than the 65 km reported for the Foothills east of Crowsnest Pass by Bally *et al.* (1966). Shortening of the Devonian Palliser Formation in the Front Ranges adds only 65 km. The bulk of the foreland shortening at the latitude of this study is accomplished by shortening of the Hadrynian clastic wedge and by telescoping of basement onto foreland structures on the Bear Foot, Ptarmigan, and Purcell thrust faults (Fig. 12). Motion on the Bear Foot Thrust is a minimum of 50 km, and motion on the Purcell Thrust is a minimum of 15 km (Fig. 12). This shortening must be balanced in part by displacements in allochthonous arc terranes to the southwest (Price 1981). The presence of basement that has been translated in excess of 200 km suggests that shortening in the Rocky Mountains must also be balanced at the level of basement southwest of the present position of gneisses of the Monashee Complex (Monger *et al.* 1985; Brown *et al.* 1986; Brown and Journeay 1987). An implication is that the miogeocline probably developed on attenuated continental crust.

Brown *et al.* (1986) reported 125 km of shortening in the foreland from a section that intersects the SRMT at McBride, British Columbia (120 km northwest of this study). Their section does not have the benefit of detailed structure of Upper Proterozoic rocks in the Rockies, and their shortening estimate may be low, but it shows that shortening in the foreland probably does decrease to the northwest.

Age of deformation

The timing of amphibolite-facies metamorphism in the Bulldog Creek area is loosely constrained by isotopic age data. Biotite from the staurolite–kyanite zone south of Bulldog Creek (see Fig. 1) has a K/Ar age of 112 Ma (recalculated from Wanless *et al.* (1968) using the constants of Steiger and Jäger (1977)). Van Den Driessche and Maluski (1986) reported an $^{40}Ar/^{39}Ar$ step-heating age on biotite from the biotite zone at Tête Jaune Cache (Fig. 1) of 100 + 2 Ma, indicating that the rocks cooled to the closure temperature of biotite in the Albian. The muscovite $^{40}Ar/^{39}Ar$ age of 78 + 2 Ma reported by Van Den Driessche and Maluski probably reflects the younger age of post-tectonic muscovite booklets that were observed to cross-cut S_3 at Tête Jaune Cache. Further, metamorphism and deformation in the Bulldog Creek area could be related to the late Middle Jurassic peak of regional metamorphism in the Kootenay Arc (165 Ma; Archibald *et al.* 1983), in which case motion on the Bear Foot Thrust might be related to the oblique convergence of terrane I (Monger and Price 1979; Monger

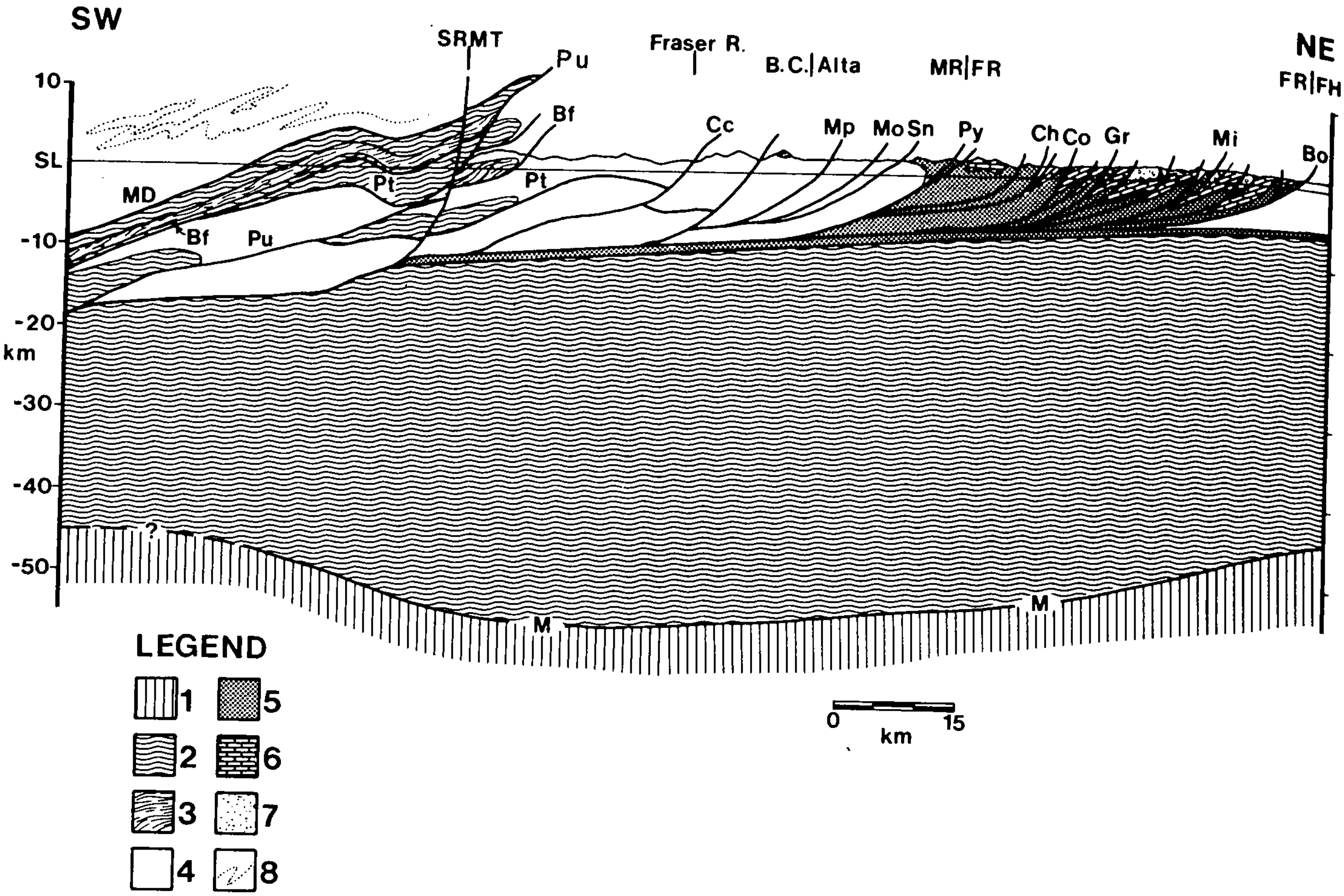

FIG. 12. Regional cross section through the foreland and part of the hinterland at the latitude of Bulldog Creek. The Foothills and Front Ranges part is modified after Ziegler (1969). The western part is modified after Charlesworth *et al.* (1967), Morrison (1982), Oke (1982), Raeside and Simony, (1983), McDonough (1984), Mountjoy and Price (1985), McDonough and Simony (1986), and Mountjoy and Forest (1986). Autochthonous craton surface is constrained by proprietary industry data in the Foothills and by northwestward projection of data given by Bally *et al.* (1966). Thrust faults: Bo, Boule; Mi, Miette; Gr, Greenock; Co, Colin; Ch, Chetamon; Py, Pyramid; Sn, Snaring; Mo, Monarch; Mp, Moose Pass; Cc, Chatter Creek; Pt, Ptarmigan; Bf, Bear Foot; Pu, Purcell; MD, Malton Detachment. FH, Foothills; FR, Front Ranges; MR, Main Ranges; SRMT, Southern Rocky Mountain Trench. 1, upper mantle; 2, Hudsonian basement; 3, younger basement; 4 Upper Proterozoic strata and undifferentiated Phanerozoic strata in the Foothills; 5, lower Paleozoic; 6, upper Paleozoic; 7, Mesozoic; 8, outline of Scrip Nappe. A minimum estimate of 50 km of displacement on the Bear Foot Thrust was obtained by correlation with a fault that carried similar gneisses in the Malton Range.

et al. 1982). Thus, amphibolite-facies metamorphism and oblique-slip thrusting on the Bear Foot Thrust constrained between 165 and 100 Ma. The motion on dextral faults in the NRMT–TT system postdates middle Cretaceous time (Templeman-Kluit 1979; Gabrielse 1985); therefore, the above timing constraints suggest oblique motion on the Bear Foot Thrust predates dextral motion on faults in the northern Canadian Cordillera.

Summary

The Bulldog Gneiss is an early Aphebian or perhaps Archean body of mafic gneiss and felsic paragneiss of probable North American affinity that was intruded by ca. 1900 Ma orthogneisses. The age of the Yellowjacket Gneiss is not known; however, it was deformed at the structural level of basement. Both the Bulldog and Yellowjacket gneiss bodies acted as basement highs to a thin facies of Hadrynian metasediments. Both bodies constitute a stack of thin slices of gneiss and parautochthonous cover. The Yellowjacket Gneiss was carried on the pre- to synmetamorphic, oblique-slip Bear Foot Thrust. The postmetamorphic Purcell Thrust carried the Bulldog Gneiss over the Yellowjacket Gneiss and its cover.

Kinematic data from the Bear Foot thrust zone reveal a deformation history that is manifested as two simple shear components. The dip-slip component of motion is estimated as 50–60 km. The strike-slip component is difficult to quantify but is probably an order of magnitude less than the dip-slip component for the following reasons: (*i*) the tear faults in the study area and south of the Blackman Gneiss (Fig. 1) (E. W. Mountjoy, personal communication, 1987) clearly limit late strike-slip motion on the fault to a few kilometres; (*ii*) the northeast-directed kinematic data, the geometry of the fault, and the northeast vergence of the associated structures are strongly indicative of a thrust system; and (*iii*) the same facies of lower Miette is found in the footwall and hanging wall. Oblique motion on the Bear Foot Thrust thus provides a kinematic link between the Omineca belt to the west and the Rocky Mountain foreland to the east that does not require a transpression model or large strike-slip faults in the SRMT.

Chamberlain and Lambert's (1985) assertion that the Bulldog Gneiss is geochemically different from the Malton Gneiss and is a window of North American basement over which thrust sheets of the supposed superterrane "Cordilleria" rode is not plausible in light of our data. Bulldog Creek area gneisses are contained in the structurally highest thrust sheets in the Main Ranges (Fig. 12) and could not possibly have been overridden by more easterly thrust sheets of Miette Group rocks as suggested by Chamberlain and Lambert (1985). Their model requires not only that there be large dextral motion on the SRMT but also that the thrust sheets of Hadrynian rocks in the Main Ranges west of and including the Snaring Thrust not (Mountjoy 1980) be North American. This would include some thrust sheets that have Hadrynian strata "glued" to Lower Cambrian strata that contain North American trilobite fauna (Fritz and Mountjoy 1975). Thus, the SRMT was probably not the locus of prethrusting dextral motion.

Acknowledgments

This work is an outgrowth of MRM's M.Sc. thesis at The University of Calgary. Financial support in the form of graduate teaching and research assistantships from the University of Calgary to MRM and Energy, Mines and Resources Canada and Natural Sciences and Engineering Research Council of Canada grants to PSS are gratefully acknowledged. We thank J. H. Sevigny, L. D. Currie, and R. R. Parrish for helpful comments on an early version of the manuscript. Thoughtful reviews by two anonymous reviewers significantly improved the manuscript. Shell Canada Ltd. kindly provided a large-scale version of P. Zeigler's cross section.

ARCHIBALD, D. A., GLOVER, J. K., PRICE, R. A., FARRAR, E., and CARMICHAEL, D. M. 1983. Geochronology and tectonic implications of magmatism and metamorphism, southern Kootenay Arc and neighbouring regions, southeastern British Columbia. Part I: Jurassic to mid-Cretaceous. Canadian Journal of Earth Sciences, **20**: 1891–1913.

BALLY, A. W., GORDY, P. L., and STEWART, G. A. 1966. Structure, seismic data, and orogenic evolution of the southern Canadian Rocky Mountains. Bulletin of Canadian Petroleum Geology, **14**: 337–381.

BERTHÉ, D., CHOUKROUNE, P., and JEGOUZO, P. 1979. Orthogneiss, mylonite and non-coaxial deformation of granites: the example of the South Armorican Shear Zone. Journal of Structural Geology, **1**: 31–42.

BOYER, S. E., and ELLIOTT, D. 1982. Thrust systems. American Association of Petroleum Geologists Bulletin, **69**: 1196–1230.

BROWN, R. L., and JOURNEAY, J. M. 1987. Tectonic denudation of the Shuswap metamorphic terrane of southeastern British Columbia. Geology, **15**: 142–146.

BROWN, R. L., JOURNEAY, J. M., LANE, L. S., MURPHY, D. C., and REES, C. J. 1986. Obduction, backfolding and piggyback thrusting in the metamorphic hinterland of the southeastern Canadian Cordillera. Journal of Structural Geology, **8**: 255–268.

CAMPBELL, R. B. 1968. Canoe River (83 D), British Columbia. Geological Survey of Canada, Map 15–1967, scale 1 : 253 440.

——— 1973. Structural cross-section and tectonic model of the southeastern Canadian Cordillera. Canadian Journal of Earth Sciences, **10**: 1607–1620.

CAMPBELL, R. B., MOUNTJOY, E. W., and YOUNG, F. G. 1973. Geology of the McBride map-area, British Columbia. Geological Survey of Canada, Paper 72–35.

CAREY, J. A., and SIMONY, P. S. 1985. Stratigraphy, sedimentology and structure of late Proterozoic Miette Group, Cushing Creek area, British Columbia. Bulletin of Canadian Petroleum Geology, **33**: 184–203.

CHAMBERLAIN, V. E., and LAMBERT, R.ST J. 1985. Cordilleria, a newly defined Canadian microcontinent. Nature (London), **314**: 707–713.

CHAMBERLAIN, V. E., LAMBERT, R.ST J., and HOLLAND, J. G. 1980. The Malton Gneiss: Archean gneisses in British Columbia. Precambrian Research, **11**: 297–306.

——— 1985. Geochemistry and geochronology of the gneisses east of the Southern Rocky Mountain Trench, near Valemount, British Columbia. Canadian Journal of Earth Sciences, **22**: 980–991.

CHARLESWORTH, H. A. K., WEINER, J. L., AKEHURST, A. J., BIELENSTEIN, H. U., EVANS, C. R., GRIFFITHS, R. E., REMINGTON, D. B., STAUFFER, M. R., and STEINER, J. 1967. Precambrian geology of the Jasper region, Alberta. Research Council of Alberta, Bulletin 23.

CLAGUE, J. J. 1974. St. Eugene Formation and the development of the Southern Rocky Mountain Trench. Canadian Journal of Earth Sciences, **11**: 916–938.

COOK, F. A., SIMONY, P. S., COFLIN, K. C., GREEN, A. C., MILKEREIT, B., PRICE, R. A., PARRISH, R., PATENAUDE, C., GORDY, P. L., and BROWN, R. L. 1987. Lithoprobe southern Canadian Cordillera transect: Rocky Mountain thrust belt to Valhalla gneiss complex. Geophysical Journal of the Royal Astronomical Society, **89**: 91–98.

COWARD, M. P., and POTTS, G. J. 1983. Complex strain patterns developed at the frontal and lateral tips to shear zones and thrust zones. Journal of Structural Geology, **5**: 383–399.

CRAW, D. 1978. Metamorphism, structure and stratigraphy in the Southern Park Ranges, British Columbia. Canadian Journal of Earth Sciences, **15**: 86–98.

EVENCHICK, C. A., PARRISH, R. R., and GABRIELSE, H. 1984. Precambrian gneiss and late Proterozoic sedimentation in north-central British Columbia. Geology, **12**: 233–237.

FRITZ, W. H., and MOUNTJOY, E. W. 1975. Lower and early Middle Cambrian formations near Mount Robson, British Columbia and Alberta. Canadian Journal of Earth Sciences, **12**: 119–131.

GABRIELSE, H. 1985. Major dextral transcurrent displacements along the Northern Rocky Mountain Trench and related lineaments in north-central British Columbia. Geological Society of America Bulletin, **96**: 1–14.

LAGARDE, J. L., and MICHARD, A. 1986. Stretching normal to the regional thrust displacement in a thrust–wrench shear zone, Rehamma Massif, Morocco. Journal of Structural Geology, **8**: 483–492.

LEECH, G. B. 1966. The Rocky Mountain Trench. *In* The world rift system. *Edited by* T. N. Irvine. Geological Survey of Canada, Paper 66-14, pp. 307–329.

LISTER, G. S., and SNOKE, A. W. 1984. S–C mylonites. Journal of Structural Geology, **6**: 617–638.

McDONOUGH, M. R. 1984. Structural evolution and metamorphism of basement gneisses and Hadrynian cover, Bulldog Creek area, British Columbia. M.Sc. thesis, The University of Calgary, Calgary, Alta.

——— 1985. Basement involvement, Bulldog Creek area, southern Canadian Rockies. Geological Society of America, Abstracts with Programs, **17**: 658.

McDONOUGH, M. R., and SIMONY, P. S. 1984. Basement gneisses and Hadrynian metasediments near Bulldog Creek, Selwyn Range, British Columbia. *In* Current research, part A. Geological Survey of Canada, Paper 84-1A, pp. 99–102.

——— 1986. Geology of the northern Selwyn Range, western Main Ranges, Rocky Mountains, British Columbia: preliminary report. *In* Current research, part A. Geological Survey of Canada, Paper 86-1A, pp. 619–626.

——— 1988. Stratigraphy and structure of late Proterozoic Miette Group, northern Selwyn Range, Rocky Mountains, British Columbia. *In* Current research, part D. Geological Survey of Canada, Paper 88-1D, pp. 105–113.

MONGER, J. W. H., and PRICE, R. A. 1979. Geodynamic evolution of the Canadian Cordillera—progress and problems. Canadian Journal of Earth Sciences, **16**: 770–791.

MONGER, J. W. H., PRICE, R. A., and TEMPLEMAN-KLUIT, D. J. 1982. Tectonic accretion and the origin of two major metamorphic and plutonic welts in the Canadian Cordillera. Geology, **10**: 70–75.

MONGER, J. W. H., *principal compiler,* WOODSWORTH, G. J., PRICE, R. A., CLOWES, R. N., RIDIHOUGH, R. P., CURRIE, R., HOY, T., PRETO, V. A. G., SIMONY, P. S., SNAVELY, P. D., and YORATH, C. J. 1985. Transect B2. Southern Canadian Cordillera, North American continent–ocean transects. Geological Society of America, Decade of North American Geology Program.

MORRISON, M. L. 1979. Structure and petrology of the southern portion of the Malton Gneiss, British Columbia. *In* Current research, part B. Geological Survey of Canada, Paper 79-1B, pp. 407–410.

——— 1982. Structure and petrology of the Malton Gneiss Complex. Ph.D. thesis, The University of Calgary, Calgary, Alta.

MOUNTJOY, E. W. 1980. Mount Robson, Alberta – British Columbia. Geological Survey of Canada, Map 1499A, scale 1 : 250 000.

MOUNTJOY, E. W., and FOREST, R. 1986. Revised structural interpretation, Selwyn Range between Ptarmigan and Hugh Allan creeks, British Columbia—an antiformal stack of thrusts. *In* Current research part A. Geological Survey of Canada, Paper 86-1A, pp. 177–183.

MOUNTJOY, E. W., and PRICE, R. A. 1985. Jasper, Alberta (83 D/16). Geological Survey of Canada, Map 1611A, scale 1 : 50 000.

MOUNTJOY, E. W., LEONARD, R., and FOREST, R. 1984. Non-basement involvement in the western Main Ranges, Jasper–Valemount, Alberta and British Columbia. Geological Society of America, Abstracts with Programs, **16**: 602.

MURPHY, D. C. 1987. Suprastructure/infrastructure transition, east-central Cariboo Mountains, British Columbia: geometry, kinematics and tectonic implications. Journal of Structural Geology, **9**: 13–29.

OKE, C. 1982. Structure and metamorphism of Precambrian basement and its cover in the Mount Blackman area, British Columbia. M.Sc. thesis, The University of Calgary, Calgary, Alta.

OKE, C., and SIMONY, P. S. 1981. Basement gneisses of the western Rocky Mountains, Hugh Allan Creek area, British Columbia. *In* Current research, part A. Geological Survey of Canada, Paper 81-1A, pp. 181–184.

OKULITCH, A. V. 1984. The role of the Shuswap Metamorphic Complex in Cordilleran tectonism: a review. Canadian Journal of Earth Sciences. **21**: 1171–1193.

PARRISH, R. R., and ARMSTRONG, R. L. 1983. U–Pb zircon age and tectonic significance of gneisses in structural culminations of the Omineca Crystalline Belt, British Columbia. Geological Society of America, Abstracts with Programs, **15**: 324.

PARRISH, R. R., CARR, S. D., and PARKINSON, D. L. 1988. Extensional tectonics of the southern Omineca belt, British Columbia and Washington. Tectonics, **7**: 181–212.

PASSCHIER, C. W., and SIMPSON, C. 1986. Porphyroclast systems as kinematic indicators. Journal of Structural Geology, **8**: 831–843.

PELL, J., and SIMONY, P. S. 1987. New correlations of Hadrynian strata, south-central British Columbia. Canadian Journal of Earth Sciences, **24**: 302–313.

POULTON, T. P., and SIMONY, P. S. 1980. Stratigraphy, sedimentology, and regional correlation of the Horsethief Creek Group (Hadrynian, Late Precambrian) in the northern Purcell and Selkirk mountains, British Columbia. Canadian Journal of Earth Sciences, **17**: 1708–1724.

PRICE, R. A. 1981. The Cordilleran Foreland Thrust and Fold Belt in the southern Canadian Rocky Mountains. *In* Thrust and nappe tectonics. *Edited by* K. R. McClay and N. J. Price. Geological Society of London, Special Publication 9, pp. 427–448.

PRICE, R. A., and CARMICHAEL, D. M. 1986. Geometric test for Late Cretaceous – Paleogene intracontinental transform faulting in the Canadian Cordillera. Geology, **14**: 468–471.

PRICE, R. A., and MOUNTJOY, E. W. 1970. Geological structure of the Canadian Rocky Mountains between Bow and Athabasca rivers—a progress report. *In* Structure of the southern Canadian Cordillera. *Edited by* J. O. Wheeler. Geological Association of Canada, Special Paper 6, pp. 7–25.

RAESIDE, R. P., and SIMONY, P. S. 1983. Stratigraphy and deformational history of the Scrip Nappe, Monashee Mountains, British Columbia. Canadian Journal of Earth Sciences, **20**: 639–650.

RIDLEY, J. 1986. Parallel stretching lineations and fold axes oblique to a shear displacement direction—a model and observations. Journal of Structural Geology, **8**: 647–653.

SHAW, D. 1980. A concordant uranium–lead age for zircons in the Adamant Pluton, British Columbia. *In* Current research, part C. Geological Survey of Canada, Paper 80-1C, pp. 243–246.

SIMONY, P. S., and WIND, G. 1970. Structure of the Dogtooth Range and adjacent portions of the Rocky Mountain Trench. *In* Structure of the southern Canadian Cordillera. *Edited by* J. O. Wheeler. Geological Association of Canada, Special Paper 6, pp. 45–51.

SIMONY, P. S., GHENT, E. D., CRAW, D., MITCHELL, W, and ROBBINS, D. B. 1980. Structural and metamorphic evolution of northeast flank of Shuswap Complex, southern Canoe River area, British Columbia. *In* Cordilleran metamorphic core complexes. *Edited by* M. D. Crittenden, Jr., P. J. Coney, and G. H. Davis. Geological Society of America, Memoir 153, pp. 445–461.

STEIGER, R. H., and JÄGER, E. 1977. Subcommission on Geochronology: Convention on the use of decay constants in geo- and cosmochronology. Earth and Planetary Science Letters, **36**: 359–362.

TCHALENKO, J. S. 1970. Similarities between shear zones of different magnitudes. Geological Society of America Bulletin, **81**: 1625–1640.

TEMPLEMAN—KLUIT, D. J. 1979. Transported cataclasite, ophiolite and granodiorite in central Yukon: evidence of arc–continent collision. Geological Survey of Canada, Paper 79-14.

VAN DEN DRIESSCHE, J., and MALUSKI, H. 1986. Mise en évidence d'un cisaillement ductile dextre d'âge crétacé moyen dans la région de Tête Jaune Cache (nord-est du complexe métamorphique Shuswap, Colombie-Britannique). Canadian Journal of Earth Sciences, **23**: 1331–1342.

VAN SCHMUS, W. R., BICKFORD, M. E., LEWRY, J. F., and MACDONALD, R. 1987. U–Pb geochronology in the Trans-Hudson Orogen, northern Saskatchewan, Canada. Canadian Journal of Earth Sciences, **24**: 407–424.

WANLESS, R. K., and REESOR, J. E. 1975. Precambrian zircon age of orthogneiss in the Shuswap Metamorphic Complex, British Columbia. Canadian Journal of Earth Sciences, **12**: 326–333.

WANLESS, R. K., STEVENS, R. D., LACHANCE, G. R., and EDMONDS, C. M. 1968. Age determinations and geological studies, K–Ar isotopic ages, report 8. Geological Survey of Canada, Paper 67-2A, pp. 1–53.

WHEELER, J. O. 1963. Rogers Pass map-area, British Columbia and Alberta (82 N W1/2). Geological Survey of Canada, Paper 62-32.

ZEIGLER, P. A. 1969. The development of sedimentary basins in western and Arctic Canada. Alberta Society of Petroleum Geologists, guidebook.

#22

BROWN & READ : I

ABSTRACT

SHUSWAP TERRANE

MZ META

MONASHEE CMPX (WITHIN SHUSWAP)

OVERLYING SELKIRK ALLOCHTHON ⟵ MONASHEE DECOLLEMENT

- RECORD STRAIN + META IN MID. - LATE JUR

DURING AND SUBSEQUENT TO ACCRETION OF A TERRANE TO THE WEST

SELKIRK ALL. MOVED EASTWARD ACROSS MONASHEE CMPX

AFTER EMPLACEMENT OF W. ALL. TERRANE BUT

BEFORE late MZ - E. CZ telescoping of ROCKY MTN BELT

- MON. & OVERLYING ALLOCH. SLICES MOVED EASTWARD RELATIVE TO NA craton

ON A SOLE PLT THAT DEVELOPED DURING LISTRIC THRUSTING

OF RMtn FORELAND

- SYNMETA TO LATE META MYLONITES IN MON decoll - from

SHEAR STRAIN DURING MID JUR EMPLACEMENT OF SELKIRK ALLO

NOT RELATED TO UPPER CRUSTAL EXT'N OF TERT.

- UPLIFT, NORMAL FAULTING, BRITTLE REACTIVATION OF MYLONITIC

DECOLLEMENT ZONE, WIDESPREAD RESETTING OF K-Ar & Rb-Sr

MINERAL DATES, AND ARCHING OF TERRANE CULMINATED IN EOCENE

INTRODUCTION

SHUSWAP STRADDLES WASH/BC BORDER

MOST DEF & META OCCURRED IN J

FOLLOWING COLLISION & obduction of allo terranes to west

BEFORE DEF IN RMtn Belt TO EAST

TERT OVERPRINT:

NORMAL FLTING

REACTIVATION OF DECOLL.

ARCHING

BUT B&R CRUSTAL EXT'N NOT OCCURRED IN SHUSWAP

MONASHEE COMPLEX

PreЄ paragneiss & granitic intrusions. min isotope age 2.2 by

UNCONFORMABLY OVERLAIN BY THIN PLATFORM ASSBLG - OLDER THAN LATE PROTEROZOIC (≤ 2 by)

POLYDEF & REG. META CROP OUT IN CULMINATIONS IN SHUSWAP COMPLEX