Province of British Columbia
Ministry of Energy, Mines and
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MINERAL RESOURCES DIVISION
Geological Survey Branch

GEOLOGY OF THE COTTONBELT LEAD-ZINC-MAGNETITE LAYER, CARBONATITES AND ALKALIC ROCKS IN THE MOUNT GRACE AREA, FRENCHMAN CAP DOME, SOUTHEASTERN BRITISH COLUMBIA

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December 1987

Field camp north of Blais Creek, Monashee Mountains, southeastern British Columbia

SUMMARY

The Mount Grace area includes approximately 200 square kilometres of subalpine to alpine terrain in the Monashee Mountains northwest of Revelstoke. It is on the northwestern flank of Frenchman Cap dome on the eastern margin of the Shuswap Complex between the Columbia River fault on the east and the Monashee décollement on the west.

The area is underlain by paragneiss and orthogneiss of probable Aphebian age in the core of the dome, unconformably overlain by a heterogeneous platformal succession of quartzite, pelitic schist and gneiss, calc-silicate gneiss and marble, referred to as the autochthonous cover succession. Within and part of the succession are the Cottonbelt lead-zinc-magnetite layer and the Mount Grace carbonatite tuff.

The area has undergone intense polyphase deformation at high grades of regional metamorphism. Early Phase 1 isoclinal folds, including the Mount Grace syncline, dip west to northwest and plunge variably to the west. Phase 2 folds, with axes parallel to the prominent west-plunging mineral lineation, formed during the highest grades of metamorphism. They are most conspicuous in the Perry River area to the south where they are the earliest folds recognized. Phase 3 folds are upright, north-trending structures developed after the metamorphic culmination; they form a prominent embayment in the dome in the Perry River area.

Pelitic and calc-silicate mineral asemblages and fabrics record the culmination of regional metamorphism at temperatures of 650 to 700°C and pressures of approximately 7 kilobars during and after Phase 2 deformation. Overprinting of retrograde metamorphic minerals, formed at temperatures of 500 to 600°C but pressures less than 3.5 kilobars, indicates continued thermal metamorphism after tectonic uplift and removal of up to 15 kilometres of overlying rocks.

The Mount Grace carbonatite is a thin, laterally continuous marble layer traced and projected from the Perry River area to Kirbyville Lake, 60 kilometres to the north. It contains high values of niobium, barium, strontium, manganese and the rare earth elements. Lack of contact fenitization, widespread occurrence of included exotic clasts, and its tremendous lateral extent indicate a pyroclastic origin. At least three vent areas are identified, characterized by increasing number and size of clasts and by greater thickness and number of tuff beds. Intrusive carbonatites and nepheline syenites are recognized (McMillan and Moore, 1974) in the Perry River area.

Base and precious metal deposits in the area include a massive, stratiform lead-zinc-magnetite layer, disseminated copper in quartzite, disseminated copper with minor lead and zinc in calcareous rocks, disseminated lead in marble, and molybdenite in syenite. Most exploration has been directed toward the lead- zinc-magnetite layer, referred to as Cottonbelt and Bass on the west limb of the Mount Grace syncline or Complex-McLeod on the east limb. It is an unusual lead-zinc-iron formation, several metres thick and several kilometres in length, that contains an average of 5 to 6 per cent lead, 2 per cent zinc and 50 grams silver per tonne. Although it has many similarities with other stratabound lead-zinc deposits in the Shuswap Complex, including Jordan River, Ruddock Creek, Big Ledge, Colby and CK, noticeable differences in their tenor, mineralogy, host, and stratigraphic and structural settings are apparent.

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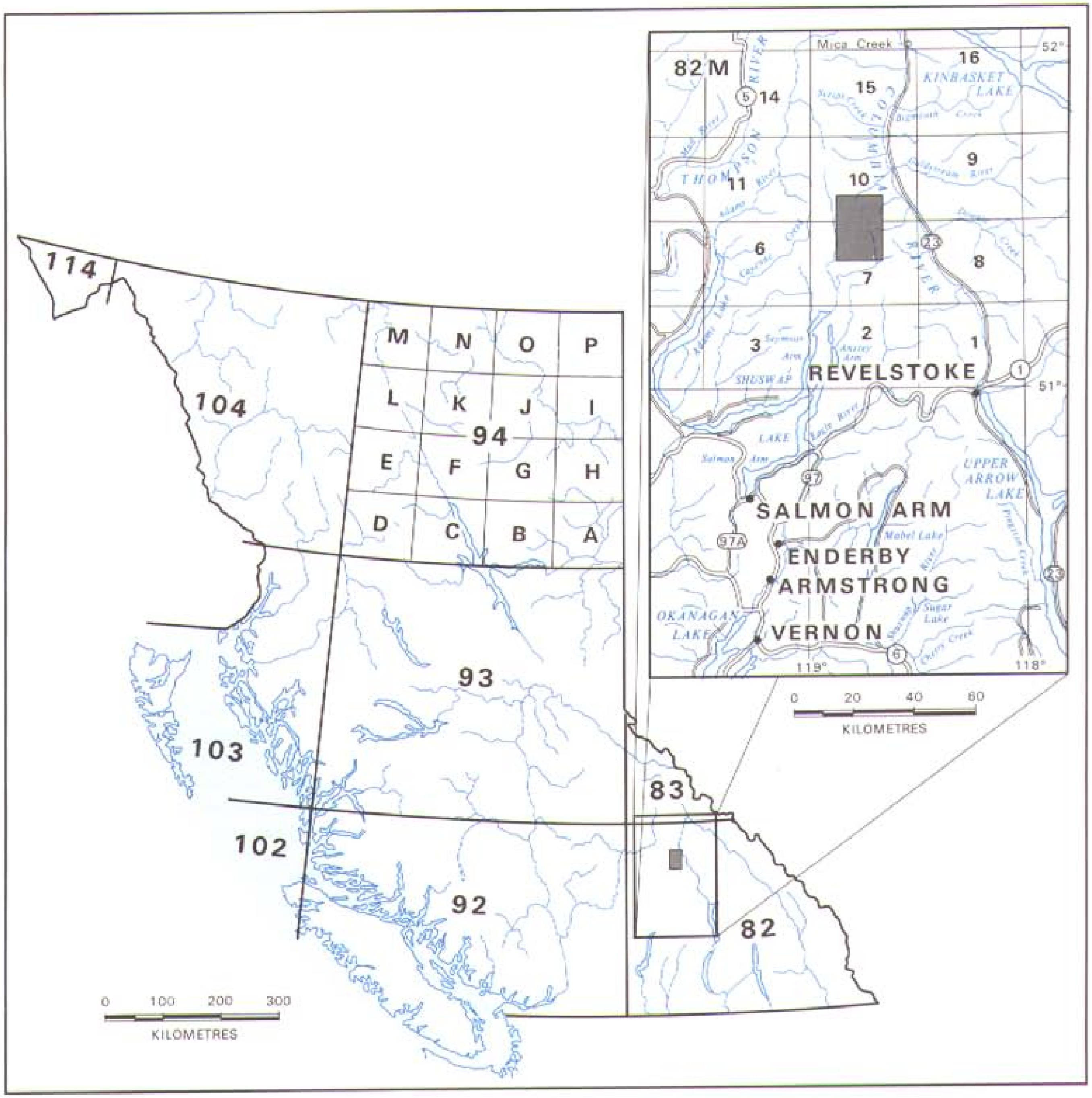


Figure 1. Location map.

CHAPTER 1

INTRODUCTION

LOCATION, TOPOGRAPHY AND ACCESS

The Mount Grace area is within the Monashee Mountains in southeastern British Columbia, between the Columbia River on the east and the Seymour River on the west (Figure 1), approximately 60 kilometres northwest of Revelstoke. It lies between latitudes 51°24' and 51°33' north and longitudes 118°44' and 118°51' west in map areas 82M/7 and 82M/10.

Although a considerable part of the area is above timberline (approximately 2000 metres above sea level) and elevation varies from approximately 730 metres in Blais Creek valley to 2320 metres near the centre of the map area, it is generally not rugged and access on foot to most parts of the area is relatively easy. The western and southern flanks of Mount Grace, the area of most economic interest, are gentle, subalpine slopes covered by a thin veneer of till. Rock exposures are abundant on the alpine plateaus and mountains to the north and northeast, but the steeply incised valleys of the forks of Blais Creek are heavily wooded.

The area is accessible by helicopter from Revelstoke, or by a climb of 1200 metres from the Perry River–Myoff Creek logging road at the southwest corner of the area.

HISTORY OF EXPLORATION

Exploration and development of mineral properties in the Mount Grace area date back to the early 1900s with the discovery by Cotton Belt Mines, Ltd. of a stratiform lead-zinc-magnetite layer. Surface and underground work, detailed in Ministry of Mines Annual Reports, continued intermittently on this property and on immediately adjacent prospects such as the McLeod, Copper King and Complex through to 1929.

Recent work began in the early 1970s and included rehabilitation of underground workings, surface and underground mapping, trenching and diamond drilling by a number of companies. The most recent diamond drilling, two holes completed by Metallgesellschaft Canada Ltd. in 1978 several kilometres north of the more continuous exposures of sulphides on Mount Grace, failed to intersect significant mineralization.

With the recent interest in niobium and rare earth elements, activity in the Mount Grace area, and in the Perry River area to the south, has been concentrated on the intrusive carbonatites and the extrusive Mount Grace carbonatite. This work has included detailed geological mapping and sampling of the intrusive Ren carbonatite just south of Ratchford Creek by Duval International Corp., and regional exploration and sampling of the Mount Grace carbonatite by Active Mineral Explorations Ltd.

GEOLOGICAL WORK

The Mount Grace area lies within the Big Bend map area of Wheeler (1965). His work essentially outlined the regional structures and stratigraphy of Frenchman Cap dome and has formed the basis for all recent, more detailed studies. Fyles (1970a) in the Jordan River area at the southern end of the dome, and McMillan (1970, 1973) along the western margin of the dome, established composite stratigraphic successions and structural patterns and presented both depositional and tectonic evolutionary models.

Work by the author, begun in 1978, (Höy, 1979a; Höy and McMillan, 1979) and by R.L. Brown and his students at Carleton University (Psutka, 1978; Journeay, 1982; Scammell, 1985) have further clarified the stratigraphy, structure and metamorphism of Frenchman Cap dome. The tectonic evolution of the dome, of the Thor-Odin nappe to the south (*see*, for example, Read and Brown, 1981; Journeay and Brown, 1986), and of the Shuswap Complex (Brown and Read, 1983; Okulitch, 1984) is currently the subject of intense study and debate. The purpose of this bulletin is to present details of the structure, stratigraphy, metamorphism and mineralization of the northwestern margin of the dome.

The Mount Grace area was mapped in four weeks in the summers of 1978 and 1979. Brief subsequent visits in 1985 and 1986 concentrated on detailed mapping and sampling of the Mount Grace carbonatite and carbonatites in the Perry River area.

ACKNOWLEDGMENTS

I wish to acknowledge discussions with numerous persons regarding various aspects of this study. In particular, comments by Y.T.J. Kwong and W.J. McMillan of the British Columbia Geological Survey Branch, Jennifer Pell of The University of British Columbia, P.B. Read of Geotex Consultants Ltd., and R.L. Brown and M. Journeay of Carleton University are much appreciated. D.D. Johnson of Calgary, Alberta, assisted in the field and J. Armitage and R. Martin of the British Columbia Ministry of Energy, Mines and Petroleum Resources drafted the figures. The manuscript was improved by the editorial comments of J. Newell, W.J. McMillan and R. Moir of the Geological Survey Branch.

I would also like to express my gratitude to geologists of the various mineral exploration companies that have been and continue to be active in the area. Their cooperation, including logistical support, free discussion of ideas, and providing access to much unpublished data, provides the framework for much of the study. The companies, amongst others, include Duval International Corp., Metallgesellschaft Canada Ltd. and Cominco Ltd.

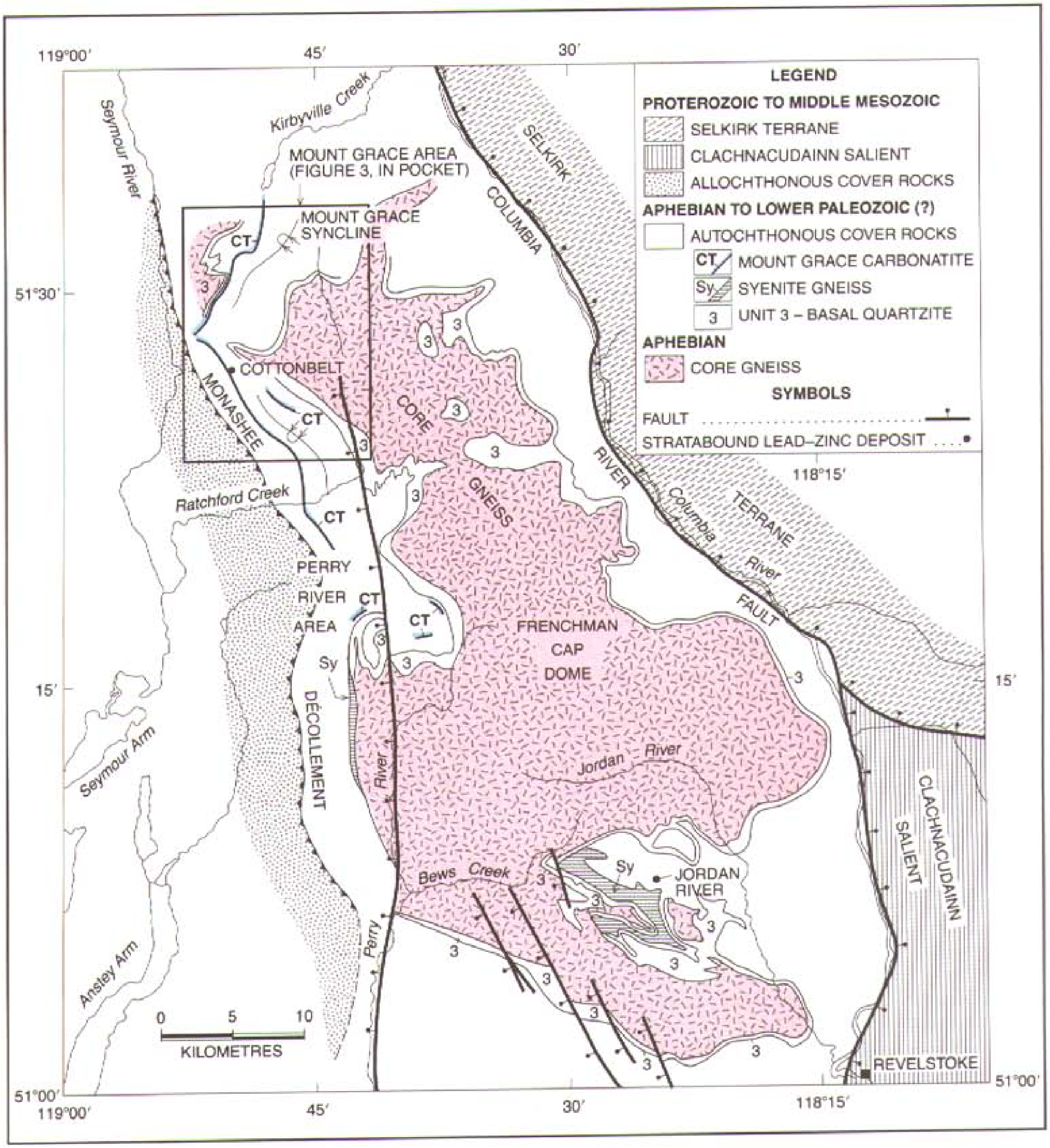


Figure 2. Geological map of Frenchman Cap dome showing distribution of structural and tectonic elements and lithologic units.

CHAPTER 2

LITHOLOGIC UNITS

INTRODUCTION

The stratigraphic succession in the Monashee Complex along the northwestern margin of Frenchman Cap dome comprises a heterogeneous package of generally thin-bedded quartzite, marble, calcareous gneiss and pelitic schist. This succession, referred to as the "autochthonous cover rocks" (Brown, 1980), overlies "core gneiss" of the dome which consists dominantly of feldspar augen orthogneiss, pelitic gneiss, hornblende gneiss and amphibolite (Figure 2). The authochthonous cover rocks are separated from an overlying package of metasedimentary rocks by the Monashee décollement, a west-dipping reverse fault (Read and Brown, 1981). The allochthonous cover rocks include quartz feldspar paragneiss, micaceous quartzite, amphibolite and calc-silicate gneiss that have been extensively invaded by granitic gneiss and pegmatite (Wheeler, 1965). They are described only briefly in this report.

The following sections describe the character and distribution of metasedimentary, metavolcanic and intrusive rocks along the northwestern margin of Frenchman Cap dome. Tracing and correlation of units throughout the area are considerably hampered by facies changes, particularly in calc-silicate gneiss and pelitic and semipelitic units, and by layer-parallel faults. Stratigraphic thicknesses of units are difficult to estimate because they have been considerably modified by deformation; estimated and measured thicknesses are generally from the attenuated limbs of folds and hence are minimum values.

CORE GNEISS

Core gneisses in the northern Frenchman Cap area have been subdivided into three structural units by Journeay (1982). The lowest unit consists of intercalated biotite paragneiss, pelitic schist and quartzofeldspathic gneiss that is locally intruded by potassium feldspar augen gneiss. It is not exposed in the map area (Figure 3, in pocket and Figure 4). A central, dominantly orthogneiss complex (Unit 1), the lowest unit exposed within the area, includes feldspar augen gneiss overlain by well-layered amphibolite and amphibole gneiss, alaskitic and charnockitic gneiss, syenite gneiss and, at the structural top, homogeneous biotite quartzofeldspathic gneiss. The uppermost unit (Unit 2) is a heterogeneous paragneiss succession that includes interlayered quartz feldspar schist, biotite schist, hornblende gneiss and amphibolite, and feldspathic gneiss.

UNIT 1: ORTHOGNEISS

Unit 1 is exposed northeast of Mount Grace, west and south of the headwaters of Ratchford Creek (Figure 4). It consists of massive to layered biotite-potassium feldspar augen gneiss and foliated granitic and monzonitic gneiss (Plate 1). Hornblende gneiss and amphibolite layers, uncommon at deeper structural levels, become more abundant at the top. Crosscutting pegmatite lenses are common. Unit 1 grades upward through a zone of intermixed hornblende paragneiss and orthogneiss into Unit 2.

UNIT 2: PARAGNEISS

Unit 2 is a well-layered paragneiss succession dominated by biotite and muscovite schist, quartzofeldspathic gneiss, feldspathic schist, thin layers of hornblende gneiss and amphibolite and, near the top, minor micaceous or calcareous quartzite. It is intruded locally by late crosscutting pegmatite dykes. Northwest of Blais Creek, Unit 2 is dominated by well-layered amphibolites and hornblende gneiss (Plate 2). A thin feldspathic orthogneiss unit containing minor molybdenite intrudes the succession here. Although the contact with the overlying Unit 3 is conformable, it is sharp and can be shown elsewhere to be an unconformity.

AUTOCHTHONOUS COVER ROCKS

The autochthonous cover rocks unconformably overlie the core gneisses. Within the study area the basal quartzite (Unit 3) of the cover succession rests on core paragneiss whereas south of the Mount Grace area, along the southwestern margin of the dome (Figure 1; Wheeler, 1965; McMillan, 1973), the quartzite overlies core orthogneiss. Facies changes and thickness variations, in large part due to structural disturbance, are conspicuous in all units of the cover succession. A prominent grey-weathering marble layer (Unit 5) is the most reliable marker, but locally the Cottonbelt sulphide-magnetite layer and a regionally extensive carbonatite tuff layer, the Mount Grace carbonatite, are also useful markers. A number of stratigraphic top determinations in quartzite units confirms the established stratigraphic succession.

UNIT 3: BASAL QUARTZITE

The basal quartzite, Unit 3 (Figure 5), overlies core gneiss throughout the entire margin of Frenchman Cap dome. Within the Mount Grace area, Unit 3 thickens from a few metres at its most northern exposures along the southeast limb of the Mount Grace syncline, to several hundred metres southeast of Mount Grace. It consists generally of a basal coarse-grained feldspathic and micaceous quartzite, overlain by an orthoquartzite that commonly grades upward to a micaceous quartzite, and is capped by a quartz-rich, micaceous schist unit. On the ridge due south of the headwaters of Blais Creek, the basal part of Unit 3 is a very thin to thin-bedded, medium to coarse-grained feldspathic quartzite (arkosic to subarkosic). Muscovite partings and thin micaceous layers are common. A silica cement is generally present but locally a calcareous cement was noted. Crossbeds and beds that grade upward from coarse-grained feldspathic quartzite to fine-grained micaceous quartzite provide reliable top determinations.

The basal part of Unit 3 is overlain by a thick-bedded, generally massive orthoquartzite unit 15 to 20 metres thick. Northeast of Mount Grace, the orthoquartzite grades upward

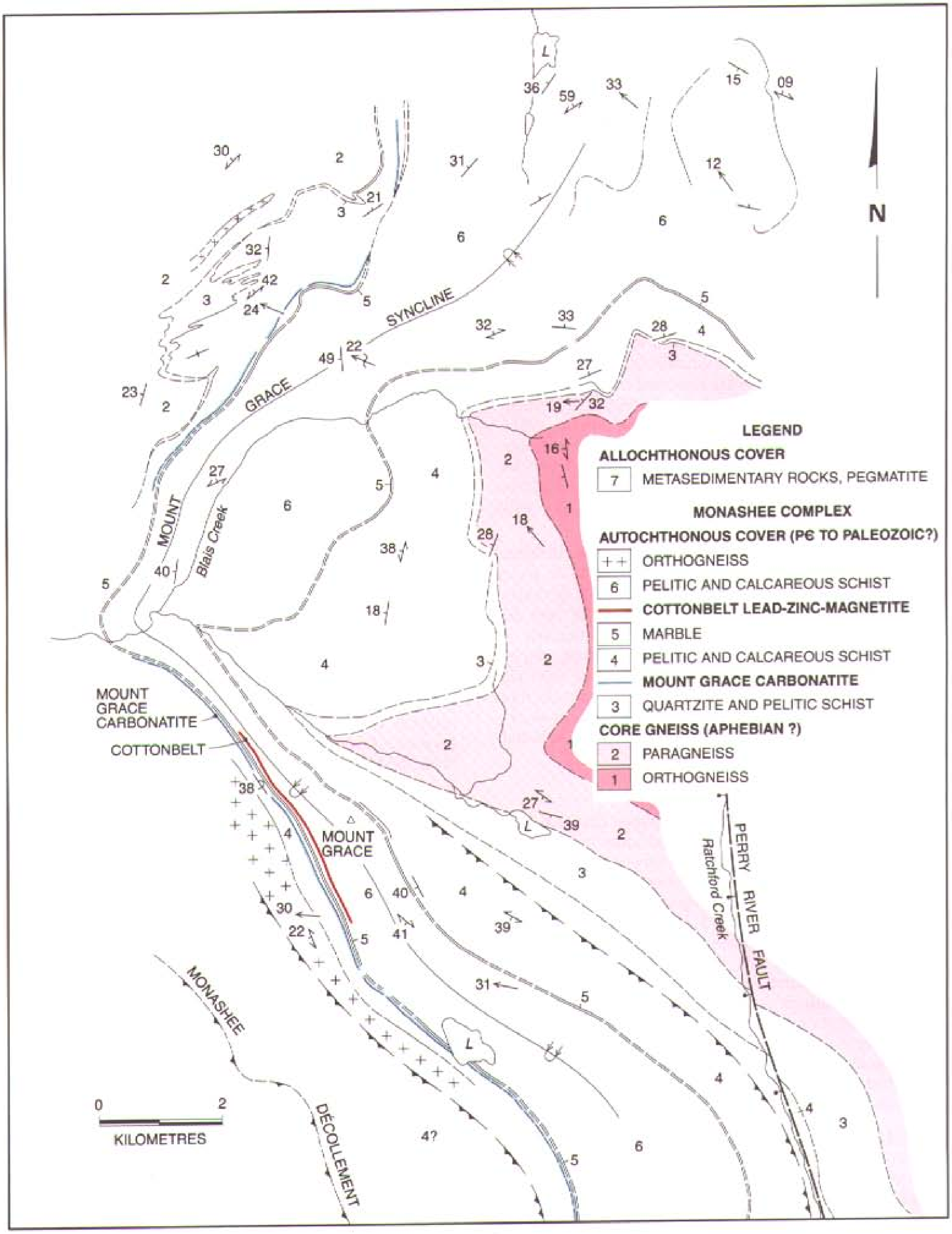


Figure 4. Simplified geological map of the Mount Grace–Blais Creek area, northwest margin of Frenchman Cap dome.

Plate 1. Foliated potassium feldspar augen gneiss (1A) and more massive granitic gneiss (1B), Unit 1.

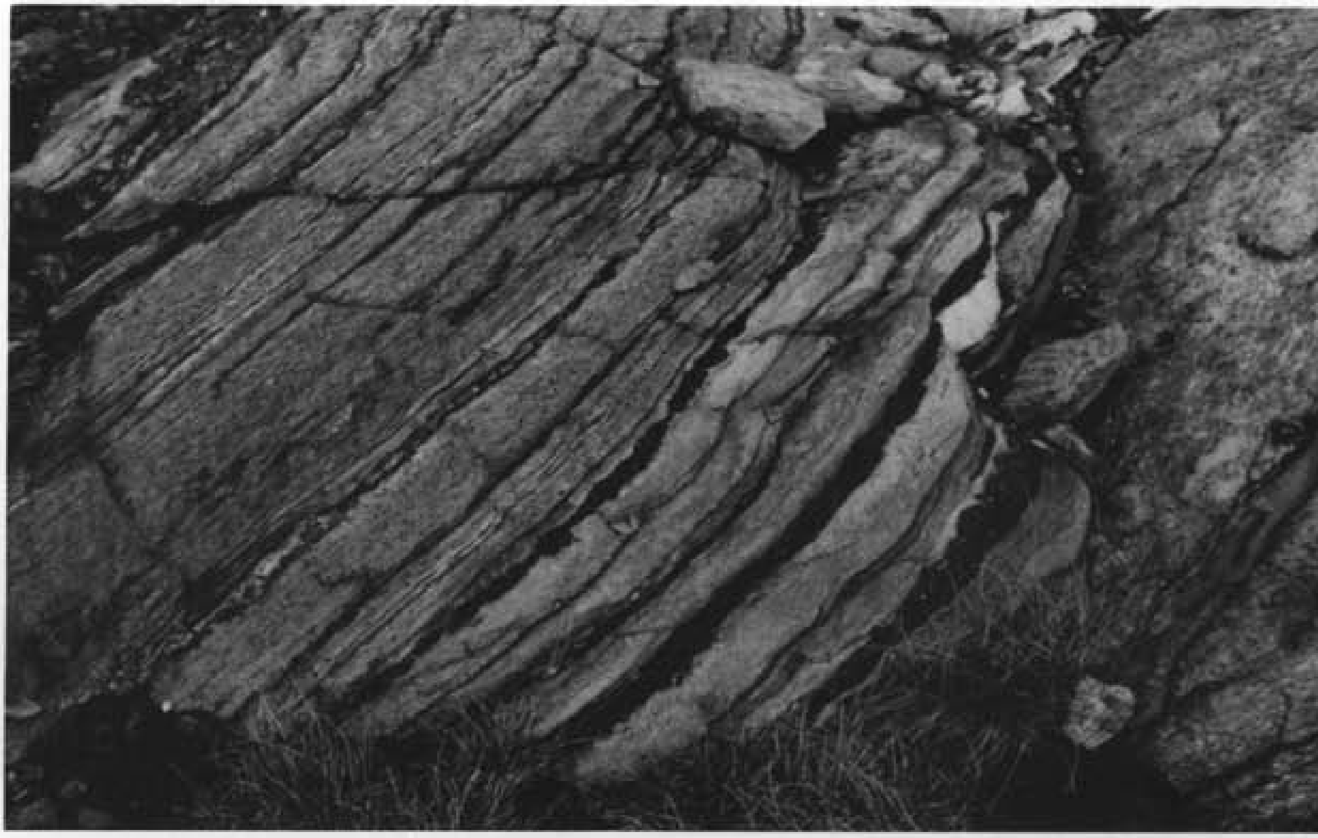


Plate 2. Layered amphibolite and hornblende gneiss of Unit 2 (core gneisses) northwest of Blais Creek.

over a few metres into a thin-bedded, fine-grained micaceous quartzite and is capped by a few metres of micaceous schist. It is directly overlain by calc-silicate gneiss of Unit 4.

On the northwest limb of Mount Grace syncline, Unit 3 is a thin (a few tens of metres thick) micaceous quartzite and the division into three units is not as apparent. Locally, it has been considerably thickened by southwest-plunging Phase 2 folds. Crossbedding in a slightly rusty weathering orthoquartzite (Plate 3) northeast of the folds indicates that the beds are overturned.

UNIT 4: PELITIC AND CALCAREOUS SCHIST

Unit 4 is a sequence of dominantly calcareous and pelitic schists between the underlying quartzite of Unit 3 and an overlying, regionally extensive crystalline marble of Unit 5 (Figure 5). Calcareous and pelitic rocks interfinger extensively and grade laterally into each other. Hence correlations based on either of these rock types are very unreliable.

The top part of Unit 4 is thinner bedded and more heterogeneous, and includes impure marble layers, quartzite, amphibolite, and the Mount Grace carbonatite, a conspicuous brown-weathering pyroclastic carbonatite tuff. The carbonatite is described in detail in Chapter 4.

UNIT 4A

A sequence of interlayered calc-silicate gneiss and micaceous quartz feldspar schist and gneiss (Unit 4a) form the basal part of Unit 4. Its thickness varies from less than a hundred metres north of Blais Creek, to an apparent thickness of several hundred metres northeast of Mount Grace. This apparent thickening is due largely to the influence of late southwest-trending Phase 3 folds. Unit 4a is dominantly a well-layered, light grey-brown, diopside-bearing calc-silicate gneiss with interlayers of micaceous schist, kyanite and/or sillimanite-bearing pelitic schist, and quartz feldspar gneiss. Impure (diopside and phlogopite) marble, hornblende gneiss and amphibolite form thin and sparsely distributed layers within the gneiss unit. A few thin (less than 2 metres thick) quartzite and orthoquartzite layers occur near the base. Due to the incompetent nature of the unit it is generally very contorted: coarse quartz-feldspar-mica sweats are common within the micaceous and pelitic layers and late tourmaline-bearing pegmatites locally crosscut foliation and folds.

In thin section, the calc-silicate gneiss layers are seen to consist of granular quartz, plagioclase, microcline and diopside. Aligned phlogopite and actinolite define the foliation, and calcite, where present, is interstitial. Garnet is common and scapolite may constitute at least 10 per cent of some layers. Zircon and sphene are common accessory minerals.

The contact between Unit 4a and overlying micaceous schist of Unit 4b is gradational and somewhat arbitrary. It is a diachronous lithologic contact, not a stratigraphic contact, that marks the upper limit of dominantly calcareous rocks of Unit 4a.

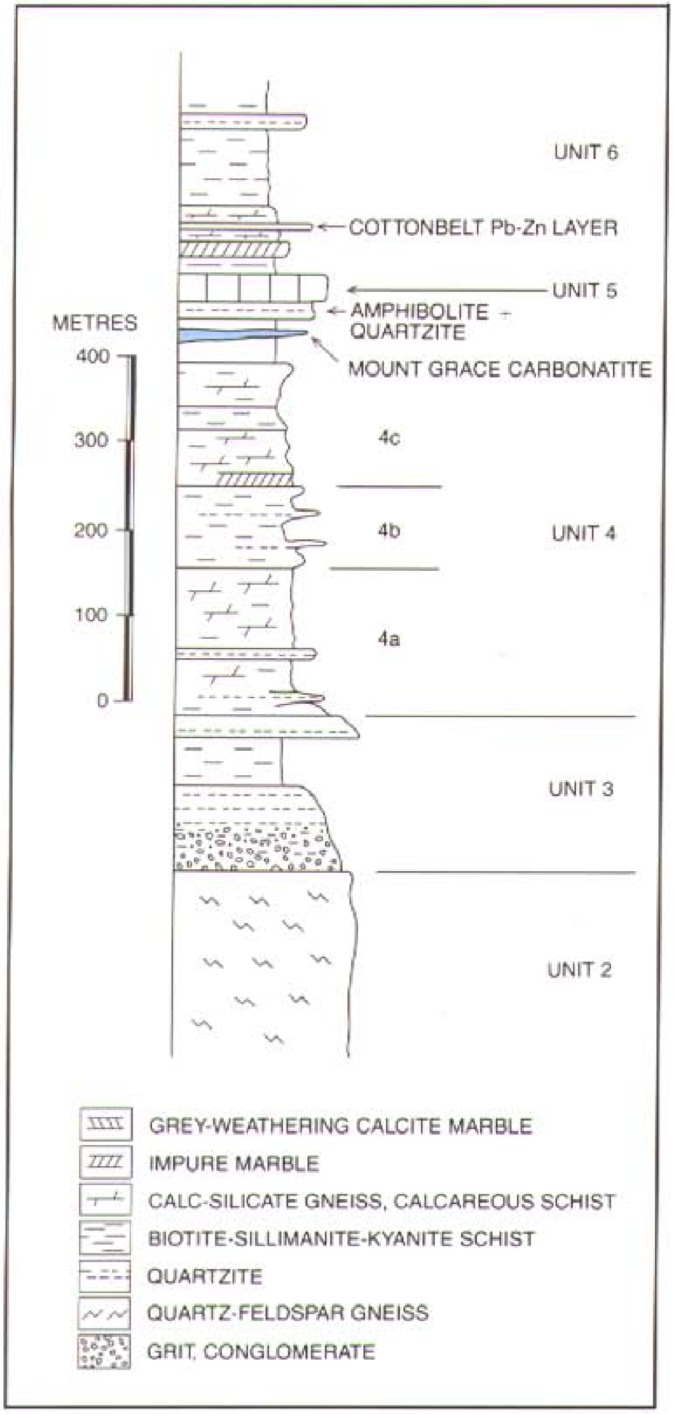


Figure 5. Stratigraphic succession in the Mount Grace–Blais Creek area.

UNIT 4B

Unit 4b comprises interlayered micaceous and kyanite/sillimanite-garnet schist, quartz feldspar gneiss and hornblende-bearing gneiss. Thin, blocky feldspathic quartzite, micaceous quartzite and orthoquartzite layers are common. Locally, pelitic schist grades laterally into calcareous schist and calc-silicate gneiss which is lithologically similar to much of the underlying Unit 4a. The incompetent schist layers are contorted and swirled, and commonly cut by pegmatite.

UNIT 4C

Unit 4c is dominantly a calcareous section beneath the white crystalline marble of Unit 5. It is well exposed on the ridge north of Blais Creek, east of the tight folds in Unit 3, and on both limbs of the Mount Grace syncline in the Mount Grace area (Figure 3). The Mount Grace carbonatite occurs near the top of the unit.

The basal part of Unit 4c includes up to 100 metres of interlayered calcareous schist, calc-silicate gneiss, rusty weathering micaceous and kyanite/sillimanite schist, and thin beds of grey-weathering to rusty weathering impure, siliceous dolomite or calcite marble. On the ridge north of Blais Creek, the basal part of the unit is 90 metres thick and includes a 20-metre thickness of sillimanite garnet schist in its central part.

The top 20 to 30 metres of the unit is a thin-bedded, heterogeneous assemblage of calc-silicate gneiss, marble, amphibolite and quartzite (Plate 4). Detailed sections of parts of Unit 4c in the vicinity of the Cottonbelt lead-zinc layer and Mount Grace carbonatite are illustrated in Figures 24 and 35. Thin beds of micaceous schist, kyanite/sillimanite schist and quartz feldspar gneiss are common. A thin-bedded and well-layered sequence of diopside-rich calc-silicate gneiss, epidote-hornblende-biotite gneiss, impure dolomitic marble and minor micaceous schist form a distinctive package near the top of Unit 4c on the ridge east of the folded basal quartzite (Figure 3). Further east, north of the headwaters of Blais Creek, the unit is more calcareous and includes a 10-metre-thick grey to tan-weathering impure marble near the base, that was not recognized in exposures 4 kilometres to the southwest. Micaceous and pelitic schist and quartzite are less abundant and thin beds of impure dolomitic and calcite marble, more abundant. Near the Cottonbelt and McLeod mineral showings on the slopes of Mount Grace, Unit 4c is similar to the ridge section to the north, with a thin-bedded, well-layered hornblende gneiss and calc-silicate gneiss section at the top.

In thin section, calc-silicate gneisses and pelitic schists of Unit 4c are similar to those occurring throughout Unit 4. Diopside is the most common calcareous mineral in calc-silicate gneisses, and thin scapolite-rich layers are common.

The Mount Grace carbonatite is a distinctive brown to tan-weathering calcite-dolomite marble that contains numerous subangular to subrounded albite and lithic clasts; it is a prominent marker horizon within Unit 4c along the western and northern margin of Frenchman Cap dome; it is described in detail in Chapter 4.

UNIT 4D

Massive to thin-bedded amphibolites interlayered with quartzite and minor quartz feldspar schist occur near the top of Unit 4c in the Blais Creek area and are designated Unit 4d. The amphibolites and schists are metavolcanic rocks derived from interlayered flows and tuffs. Analyses of a few samples (Table 1) suggest that these volcanics are predominantly alkaline (Figure 6), ranging in composition from basalt to trachyte (Figure 7). Immobile element data are required to

Plate 3. Crossbedded orthoquartzite of Unit 3.

confirm this suggestion. In the two drill sections west of the McLeod showing, a thin, fine-grained chlorite hornblende schist occurs at the very top of Unit 4 structurally above the white crystalline marble (Figure 36). It is probably a basic tuff that correlates with the more massive amphibolites at Blais Creek. Numerous crosscutting and conformable amphibolites occur approximately 10 kilometres further north (Scammell, 1985).

UNIT 5: MARBLE

A grey, crystalline marble layer (Unit 5) has been traced throughout the Mount Grace area on both limbs of the Mount Grace syncline. It is one of the most distinctive marker units within the autochthonous cover succession. It is commonly underlain by a clean, white orthoquartzite or by the orthoquartzite and a few metres of intervening calc-silicate gneiss.

Unit 5 is a nearly pure, white calcite-dolomite marble, 10 to 15 metres thick, that weathers to a light grey colour. Laminations a few millimetres to a few centimetres in thickness are due to variations in the relative abundance of calcite and dolomite (Plate 5A) or, less commonly, due to impure calcareous layers (Plate 5B). They are conspicuous on weathered surfaces and outline the contorted nature of much of the unit. Common accessory minerals in the marble include tremolite, diopside, quartz, phlogopite, muscovite and pyrite.

On section H85P25 just north of Blais Creek (*see* Figure 24), the basal 3 metres of Unit 5 is less pure and weathers to a light buff colour. Ferrous dolomite, actinolite and micas are more abundant than in the more pure marble.

UNIT 6: PELITIC AND CALCAREOUS SCHIST

Unit 6, the youngest of the autochthonous cover rocks in the map area, is exposed in the core of the Mount Grace syncline. It is dominantly a succession of calc-silicate gneiss and pelitic schist that stratigraphically overlies the crystalline marble of Unit 5 (Figure 5). The basal part (Unit 6a) is calcareous and includes the Cottonbelt sulphide-magnetite layer; the upper part (Unit 6b) is primarily micaceous schist and gneiss.

Interlayered calc-silicate gneiss and micaceous or pelitic schist (with abundant kyanite/sillimanite) forms the base of Unit 6a. In the Mount Grace area it is overlain by a crumbly, grey to rusty weathering, impure dolomitic marble containing abundant biotite, actinolite and diopside and referred to as the "camp marble". It is overlain by interlayered calcareous schist, calc-silicate gneiss and micaceous schist.

The Cottonbelt sulphide-magnetite layer (described in Chapter 5) occurs near the top of Unit 6a. It varies in thickness from a few tens of centimetres to approximately 2 metres and has been traced intermittently over a strike length of approximately 5 kilometres in the western limb of the Mount Grace syncline and 2 kilometres in the eastern limb. It is enclosed in either calc-silicate gneiss or sillimanite schist. Thin, impure quartzite layers are common within a few metres of the sulphide layer.

The contact of Unit 6a with overlying schist and gneiss of Unit 6b is placed above the last conspicuous calc-silicate gneiss or marble unit. In the Mount Grace area it occurs generally less than 20 metres above the Cottonbelt layer. It is

Plate 4. Interlayered quartzite (massive), amphibolite (Unit 4d), calc-silicate gneiss, marble and minor micaceous schist of Unit 4c, north of Blais Creek.

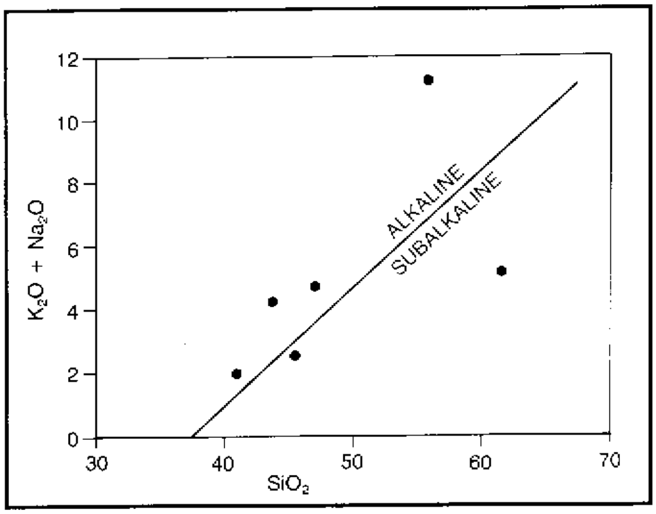


Figure 6. Alkali-silica plot of metavolcanic rocks of Unit 4d; the alkaline-subalkaline dividing line is from Irvine and Barager (1971).

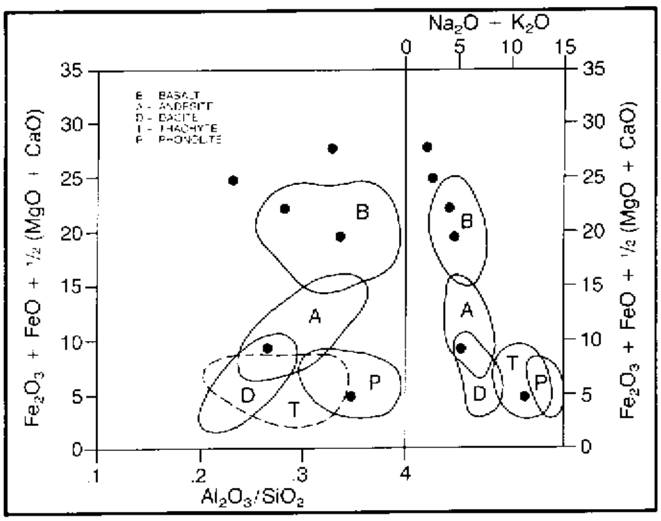


Figure 7. Triaxial oxide plot (after Church, 1975) of metavolcanic rocks of Unit 4d.

commonly a gradational contact that undoubtedly varies in stratigraphic position throughout the map area.

Unit 6b consists dominantly of micaceous schist, sillimanite and kyanite gneiss, biotite-quartz-feldspar paragneiss and minor hornblende gneiss, amphibolite and quartzite. Crosscutting pegmatite is common, as are sections of light grey, homogeneous quartz feldspar orthogneiss. The orthogneiss has been deformed by all recognized phases of deformation. In the Mount Grace area, the basal part of Unit 6b is more siliceous. Thin orthoquartzite, micaceous and feldspathic quartzite and, less commonly, quartz-pebble conglomerate bands are interlayered with schist and gneiss. The conglomerate layers consist of large flattened and elongated clasts of orthoquartzite in a granular quartz-feldspar-mica matrix. They are commonly graded with coarse-grained feldspathic quartzite (grit) at the top. North of Blais Creek, thin to thick-bedded micaceous quartzite and orthoquartzite occur in the core of the Mount Grace syncline. These are the youngest autochthonous cover rocks within the map area.

ALLOCHTHONOUS COVER ROCKS

Hangingwall rocks of the Monashee décollement, referred to as allochthonous cover rocks (Brown, 1980), are exposed only in the southwest corner of the map area. They are included in Unit 3 of Wheeler (1965) where they are referred to as the "paragneiss and pegmatite" map unit. Allochthonous cover rocks include micaceous schist, quartz-feldspar-mica gneiss, hornblende gneiss, amphibolite and minor quartzite, impure marble, calc-silicate gneiss and feldspathic grit. These rocks have been extensively invaded by numerous lenses of pegmatite and granite.

The pegmatites have been described in detail by Wheeler (1965) and Fyles (1970a) and the following description is taken from these workers. The pegmatites are "generally simple mineralogically, comprising quartz, feldspar in which potash feldspar greatly predominates over plagioclase, minor muscovite and biotite, and rare hornblende, garnet and tourmaline" (Wheeler, *op. cit.*, page 6).

They frequently form large parallel lenses within the enclosing metasedimentary rocks, but also commonly occur as crosscutting dykes or split into branching bodies that crosscut the gneisses. A vague foliation and lineation may be present, but are usually absent in the coarser grained varieties. Contacts with the enclosing gneisses may be sharp or gradational.

TABLE 1. CHEMICAL ANALYSES OF METAVOLCANIC ROCKS OF UNIT 4d, BLAIS CREEK AREA (in %)

Sample No.	Lab. No.	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	LOI
CB21-14	32438	45.47	1.35	10.51	11.68	0.36	12.91	13.23	1.47	1.05	0.17	1.15
CB22-1	32439	43.70	1.61	12.33	10.68	0.21	10.47	12.31	3.76	0.45	0.20	4.00
CB22-2	32440	47.10	2.40	15.82	12.11	0.18	5.07	9.68	3.44	1.28	0.34	1.60
CB22-3	32441	61.53	1.20	16.27	5.13	0.11	0.79	7.18	0.71	4.44	0.32	1.60
CB22-21	32442	55.91	0.37	19.37	2.70	0.10	0.66	3.55	5.90	5.36	0.35	4.08
P28	31766	40.95	2.67	13.42	16.34	0.23	8.21	14.50	0.56	1.44	0.36	1.01

Analyses by the British Columbia Geological Survey Branch Analytical Laboratory.

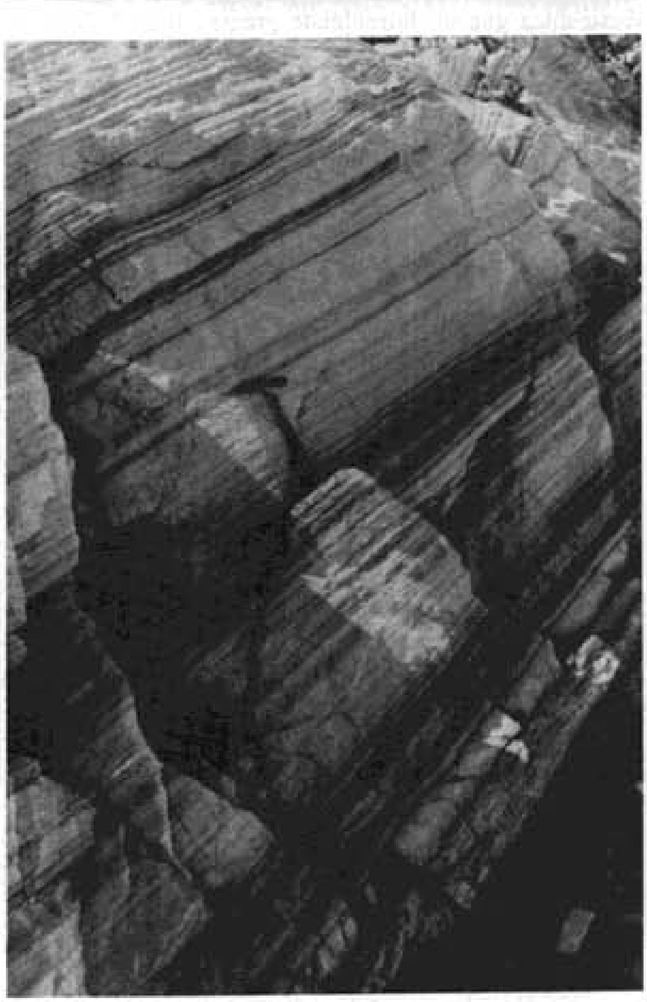


Plate 5. Well-layered marble (5A) and impure diopside-actinolite-bearing calcite marble (5B) of Unit 5.

The Ruddock Creek sulphide deposit, approximately 35 kilometres north of the Cottonbelt deposit (Fyles, 1970a), is hosted by rocks included in the allochthonous cover succession (Wheeler, 1965). The deposit consists of a series of layers and lenses of sphalerite, pyrrhotite, galena, pyrite and minor chalcopyrite associated with quartz, calcite, fluorite and barite in a calc-silicate gneiss, marble, quartzite and sillimanite schist succession. Pegmatite and associated granitic rocks comprise more than 50 per cent of outcrops on the Ruddock Creek property.

REGIONAL CORRELATIONS

Correlation of cover rocks in Frenchman Cap dome is facilitated by a number of distinctive marker units. These include the basal quartzite (Unit 3) and the prominent white marble (Unit 5). Of more local extent is the Mount Grace carbonatite in Unit 4, recognized along the western and northern margin.

These correlations are illustrated in Figure 8. The basal quartzite varies considerably along the margins of the dome. Along the northeastern margin it comprises three distinct quartzite beds only a few metres to several tens of metres thick, separated by a considerably thicker succession of interlayered pelitic schist, psammite, and minor calc-silicate gneiss and impure marble (Psutka, 1978). Within the Mount Grace–Blais Creek area, it varies from a thin orthoquartzite to a thick succession of quartzite and quartz-rich schist. To the south in the Perry River area, it includes a thick succession of dominantly feldspathic quartzites (McMillan, 1970).

Further south, the basal quartzite thins to a few metres (McMillan, 1973), but thickens rapidly again in the Bews Creek area along the southwest margin (Höy, 1980a). In the Jordan River area, along the south margin of the dome, it comprises a thick orthoquartzite overlain by interlayered micaceous schist and quartzite (Fyles, 1970a).

Unit 4, a variable succession of interlayered calcareous and pelitic rocks, is correlative around the margins of the dome (Figure 8). It is generally thinner in the more northern sections, increasing to an estimated thickness of approximately 600 metres in the Bews Creek area and 900 metres in the Jordan River area. Quartzite in the central part of Unit 4 along the southern, southwestern and western margins of the dome thins and pinches out northwestwards in the Mount Grace and Downie Creek areas.

The white marble of Unit 5 is the most distinctive marker in the autochthonous cover rocks of Frenchman Cap dome. It can also be correlated with a similar marble along the margins of the Thor-Odin nappe to the south. It is commonly underlain by a conspicuous thin orthoquartzite or less pure micaceous quartzite.

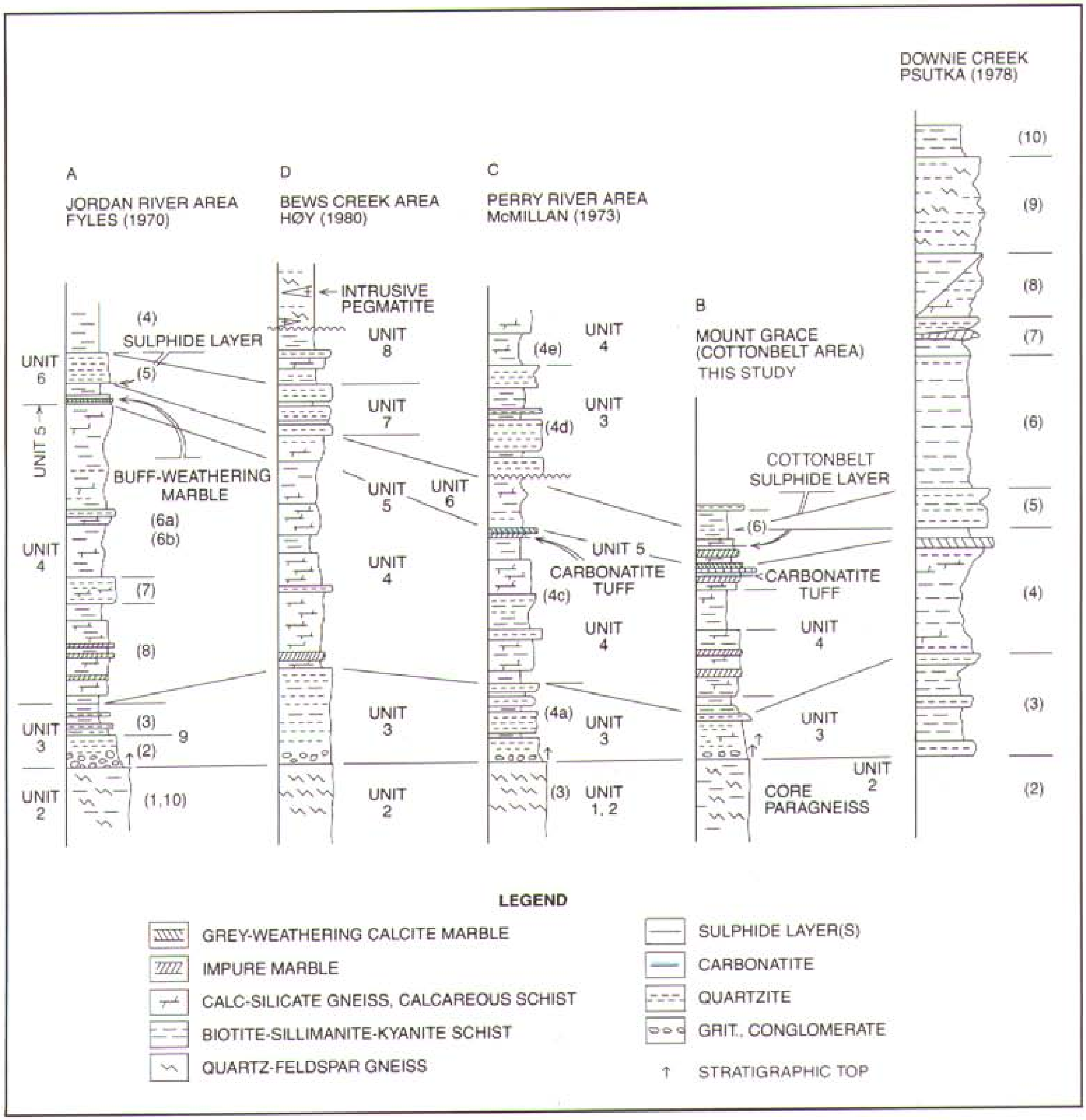


Figure 8. Regional correlation of autochthonous cover rocks around the margins of Frenchman Cap dome.

Correlation of units above Unit 5 is more difficult. A prominent quartzite-grit package above schists and gneisses of Unit 6 may be a correlative suite. It was not distinguished in the Mount Grace area possibly because rocks this young are not exposed in the core of the Mount Grace syncline. However, thin grit layers near Mount Grace and a thick (30-metre) orthoquartzite north of Blais Creek within Unit 6 may be the basal part of the quartzite-grit package. Overlying rocks, collectively included in Unit 8, are only well exposed in the Downie Creek area (Psutka, 1978) and southward along the eastern margin of the dome (Höy and Brown, 1981). They are missing, due to structural complications, along the northern, western and southwestern margins.

AGE CORRELATIONS

The ages of core gneisses and overlying autochthonous cover succession are not well known. Whole rock rubidium-strontium dating of core gneisses (R.L. Armstrong, personal communication, 1980) yield 2.2 billion year dates. This Aphebian age is similar to minimum isotopic ages determined for core gneisses of the Thor-Odin nappe to the south (Wanless and Reesor, 1975; Duncan, 1978).

The overlying autochthonous paragneiss succession has been correlated with Eocambrian or lower Paleozoic platformal rocks (Wheeler, 1965; Fyles, 1970a; Höy and McMillan, 1979) and with late Proterozoic Belt-Purcell rocks (Brown and Psutka, 1979). A uranium-lead date of 773 million years (Ma) (Okulitch *et al.*, 1981) was obtained from zircon extracted from a syenite gneiss interpreted to be intrusive into autochthonous cover rocks, supporting a Helikian or Late Aphebian age for the basal part of the cover succession.

Lead isotope dates of the stratiform Cottonbelt deposit indicate an early Cambrian age for the deposit and immediate host succession (Höy and Godwin, in preparation) supporting suggestions of an early Paleozoic age, based on regional correlations and tectonic environment. The lead-lead ratios are virtually indistinguishable from ratios of stratiform lead-zinc deposits in the Anvil camp in the Yukon Territory (Godwin *et al.*, 1982) demonstrated to be Early Cambrian in age.

DEPOSITIONAL ENVIRONMENT OF THE AUTOCHTHONOUS COVER ROCKS

A shallow marine shelf or platform environment for deposition of the autochthonous cover rocks of Frenchman Cap dome has been interpreted by McMillan (1973), Höy and McMillan (1979), Brown (1980) and Höy and Kwong (1986). These authors recognized the tremendous lateral extent of a clean carbonate unit, the thin-bedded and heterogeneous nature of much of the succession, and the association of carbonates and quartzites, features common though not restricted to platformal environments. Due to intense deformation and regional metamorphism to upper amphibolite facies, which have combined to obliterate most sedimentary textures, it is difficult to define the depositional environment of the succession more closely. However, a few features do place further constraints on a model.

The basal quartzite unit (Unit 3) appears to have been deposited on an unconformity of regional extent. It overlies core gneiss throughout the entire margin of Frenchman Cap dome and Thor-Odin nappe (Read, 1979), an area of greater than 15 000 square kilometres. The unconformity appears to cut across core gneisses at a low angle. The basal quartzite rests on core paragneiss (Unit 2) in the Mount Grace–Blais Creek area and along the western margin of Frenchman Cap dome, but on core orthogneiss in the Perry River area. However, on a local scale, layering in underlying paragneiss appears essentially parallel with layering in the cover rocks, though this may in part be due to transposition of layering into parallelism during regional deformation.

The lowest member of Unit 3 is a basal conglomerate with large (to several centimetres across) rounded quartzite pebbles in a finer grained quartzite matrix that grades upward to finer grained orthoquartzite locally displaying crossbedding (Fyles, 1970a; McMillan, 1973; Psutka, 1978; Höy, 1980a). Elsewhere, as in this map area, it is less mature and feldspathic grit predominates at the base. An overlying orthoquartzite grades upward into finer grained feldspathic and micaceous quartzite and is capped by micaceous schist. The coarse conglomerate fractions, fining-upward sequences, crossbeds and well-washed sands suggest fluvial deposition. In a region devoid of vegetation, braided river systems would have developed as indicated by a scarcity of silt and mud fractions (now schistose rocks) in quartzite sequences several hundred metres thick. Micaceous schists at the top of a graded sequence are lithified and metamorphosed muds and silts dropped from suspension in abandoned river channels, on levees, or on tidal flats seaward of the river mouths. Local coarsening-upward sequences are probably deltaic deposits. The ubiquitous presence of the basal quartzite unit above the core gneiss complex, if only a few metres thick in places, and its tremendous lateral extent suggest that much of the quartzite may be marine beach sands, spread as a blanket on the basement as the sea advanced over the ancient land surface. Local carbonate cement suggests a marine origin and immediately overlying calc-silicate gneiss indicates a marine transgression.

Thin-bedded interlayered micaceous schist, quartz-feldspar paragneiss, hornblende gneiss and calc-silicate gneiss (Unit 4) that overlie the basal quartzite were originally deposited as muds and silts with varying amounts of carbonate. These rock types are not restricted to or diagnostic of any specific sedimentary environment, but rather are common in all marine environments, from the deep-sea abyssal plain, through the continental rise and shelf, to tidal flats and lagoons. However, thin beds of impure scapolite-bearing marble within the more calcareous sections suggest deposition under very saline conditions, with salt (halite) a possible constituent of the original sedimentary rock. Hietenan (1967) has argued convincingly that thin scapolite-bearing layers in Helikian Belt rocks in Idaho, lithologically similar to these layers, represent original salt-bearing calcareous sediments rather than limy sediments in which chlorine was introduced during metamorphism. Hypersaline conditions are common in areas where clastic input is low and evaporation high, typically in restricted lagoons or tidal flats. Limited clastic input is also indicated by the amount of calcareous sediment, now calc-silicate gneiss and marble in Unit 4. These were originally calcareous muds and perhaps oolitic sediments or algal mat deposits. Thin quartzite and quartz-pebble conglomerate layers are probably clastic deposits formed in drainage channels that crossed the tidal flats.

The Mount Grace carbonatite tuff was deposited near the top of Unit 4 in a dominantly tidal flat environment. The tuff would have been deposited in part in a shallow to relatively deep-water intertidal to subtidal regime with concomitant deposition of normal marine carbonate, in a shallow water and subaereal intertidal environment, and in a supratidal environment with little or no marine carbonate input. The variability in thickness and composition of the carbonatite layer may therefore be due to the amount of contamination by limestone and dolomite as well as proximity to a source or vent area. Carbonatite grading to normal grey-weathering marble suggests a decrease in supply of pyroclastic carbonate into an environment where marine carbonate continues to form or is being introduced. Similarly, reworking of pyroclastic carbonatite with marine carbonate would tend to dilute the pyroclastic content and make its recognition as a carbonatite difficult.

A relatively pure marble layer (Unit 5) overlies Unit 4 throughout the map area and has been traced or correlated with a similar marble around the margins of Frenchman Cap dome and Thor-Odin nappe to the south. Its tremendous lateral extent and its relative purity indicate formation on a flat, stable continental shelf that was receiving little clastic input.

A mixed calcareous-pelitic succession, similar to Unit 4, overlies the platformal carbonate. It contains thin layers of scapolite-bearing marble, calcareous gneiss and quartzite. It is interpreted to have formed in a shallow water platform to intertidal environment similar to Unit 4. The Cottonbelt lead-zinc-magnetite layer occurs near the top of the basal calcareous interval of Unit 6. It is an unusual deposit, an iron formation that contains abundant base metals. The deposit is interpreted (Chapter 5) to have formed in a shallow restricted basin within the platform.

The transition from a thin-bedded heterogeneous calc-silicate gneiss, marble, pelitic schist and quartzite platform assemblage (Unit 6a) to thicker bedded, more massive micaceous and pelitic schist (Unit 6b) may indicate a change to a deeper water invironment. Quartzite and quartz-pebble conglomerate in the basal part of Unit 6b may be channel deposits or perhaps turbidite layers that formed during subsidence and local basin development.

In summary, the autochthonous cover rocks probably reflect a general marine transgression over a low relief basement, now the core gneiss complex. Coarse fluvial sandstones and conglomerate and perhaps a veneer of marine beach sands overlie a low-angle unconformity. These pass upward into fine-grained, low-energy calcareous muds and siltstone, deposited on extensive tidal flats. Clastic input was minimal and carbonate rocks predominate. A relatively pure platform carbonate layer (Unit 5) is recognized throughout most of the autochthonous cover succession. It is overlain by thin-bedded platformal or tidal flat carbonates and clastics. The Cottonbelt sulphide-magnetite layer occurs near the top of the succession that is interpreted to be of shallow marine origin. It is overlain by predominantly fine-grained clastic rocks that appear to have deposited in a deepening shale basin.

CHAPTER 3

STRUCTURE AND METAMORPHISM

STRUCTURE

INTRODUCTION

The Mount Grace–Blais Creek area is at the northwestern margin of Frenchman Cap gneiss dome within the Monashee Complex along the eastern margin of the Shuswap metamorphic complex.

The Monashee Complex (Figure 2) consists of gneissic basement rocks of probable Aphebian age, the "core gneisses" of Frenchman Cap dome and Thor-Odin nappe, unconformably overlain by dominantly metasedimentary rocks referred to as the autochthonous cover succession (Brown, 1980). The complex is exposed between the Columbia River fault to the east (Read and Brown, 1981; Lane, 1984) and a low-angle, west-dipping reverse fault zone, the Monashee décollement, on the west (Journeay and Brown, 1986). Rocks within Frenchman Cap dome have undergone intense polyphase deformation that culminated in the late Jurassic, but continued into the Cretaceous and Tertiary (Fyles, 1970a; McMillan, 1973; Journeay and Brown, 1986).

The earliest recognized deformation in the Mount Grace area affected both core gneisses and autochthonous cover rocks and produced large isoclinal folds, such as the Mount Grace syncline. Phase 1 structures are overprinted by tight to isoclinal second generation folds. These second generation structures are not prominent in the Mount Grace area, but dominate the structure of the Perry River area to the south (McMillan, 1970, 1973). Late, post-metamorphic folds, north- trending fractures and normal faults deform and offset the earlier structures. They also are not prominent in the Mount Grace area, but account for the distintive Z-shaped distribution of core and autochthonous cover rocks in the Perry River area (McMillan, *op. cit.*).

Within the Mount Grace and Blais Creek areas, three phases of deformation are readily discernible. They are recognized and distinguished on the basis of interference and crosscutting relationships, the form of individual structures, and their relationship to metamorphic fabrics. Phase 1 folds are generally recumbent west-plunging isoclines with well-developed axial planar foliation. Phase 2 structures are generally tight, west to northwest-plunging folds with prominent mineral lineations parallel to their axes. Phase 3 structures include late, post-metamorphic open folds, crenulation cleavage and associated north-trending fractures.

The Mount Grace–Blais Creek area has been subdivided into four structural domains. Domain 1 includes both limbs of the Phase 1 Mount Grace syncline in the southern part of the area. Domain 2 includes core gneiss and autochthonous cover rocks adjacent to the north and Domain 3 is centred on the Mount Grace syncline as it swings around the northwestern margin of the dome. Domain 4 at the northern end of the dome is dominated by an easterly trending structural fabric.

PHASE 1

The Mount Grace syncline is the earliest recognized macroscopic fold within the map area. Phase 1 structures include minor folds, a prominent mineral foliation, and poorly developed mineral lineations. These Phase 1 structures are plotted in Figure 10 and described following.

MINOR STRUCTURES

A prominent mineral foliation (S1) essentially parallel to layering (S0) occurs throughout the area in both core gneisses and autochthonous cover rocks (*compare* Figures 9 and 10). It parallels the axial plane of the Mount Grace syncline and the axial planes of the earliest minor folds, cutting across layering only in their hinge zones (Plate 6). It is defined by an alignment of platy metamorphic minerals such as mica, amphibole and kyanite, by segregation of quartz and feldspar

Plate 6. Isoclinal Phase 1 minor folds in sillimanite gneiss in Unit 6 just north of the headwaters of Blais Creek; note prominent foliation cutting fold hinge.

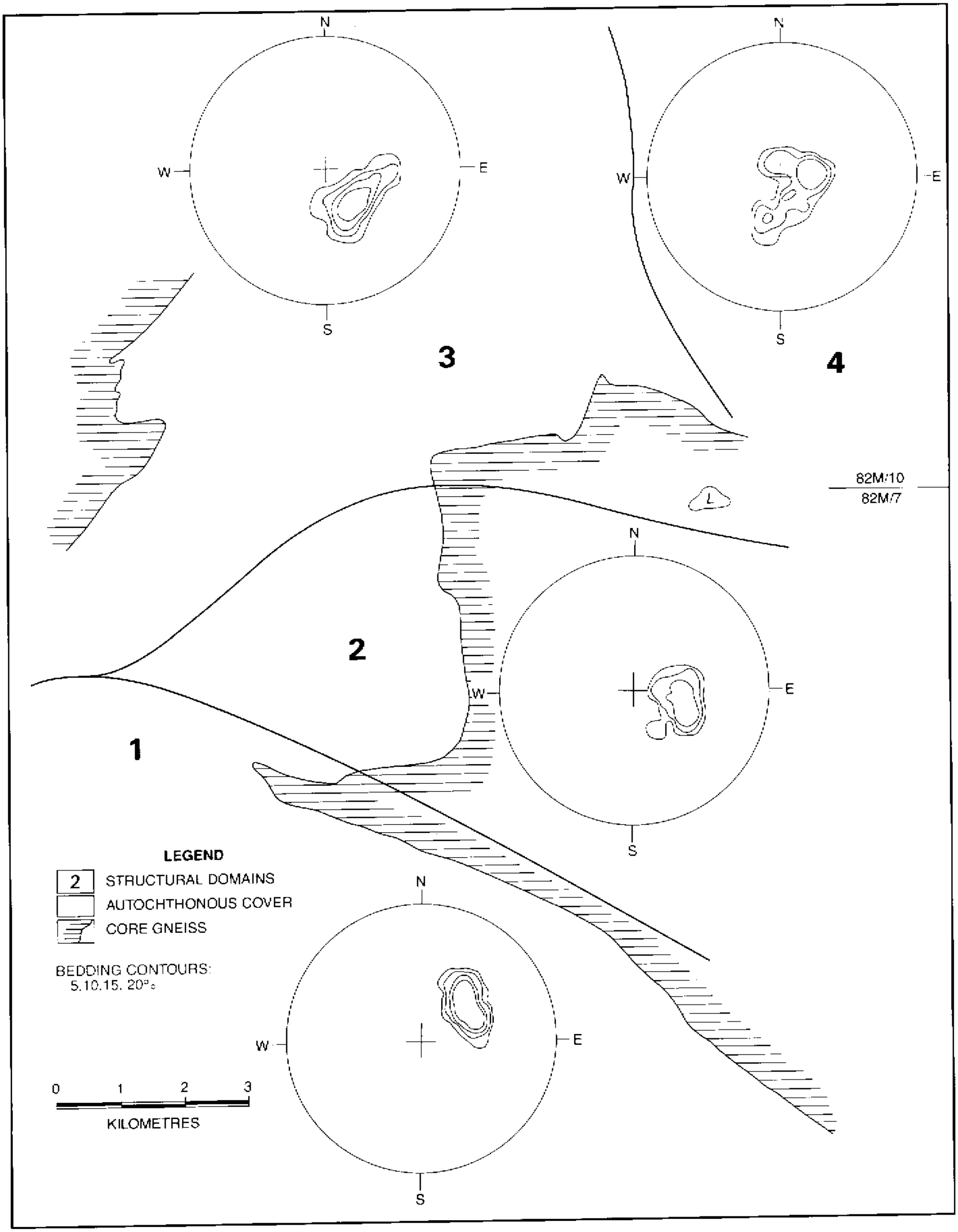


Figure 9. Bedding (SO) attitudes; equal-area projections from the lower hemisphere.

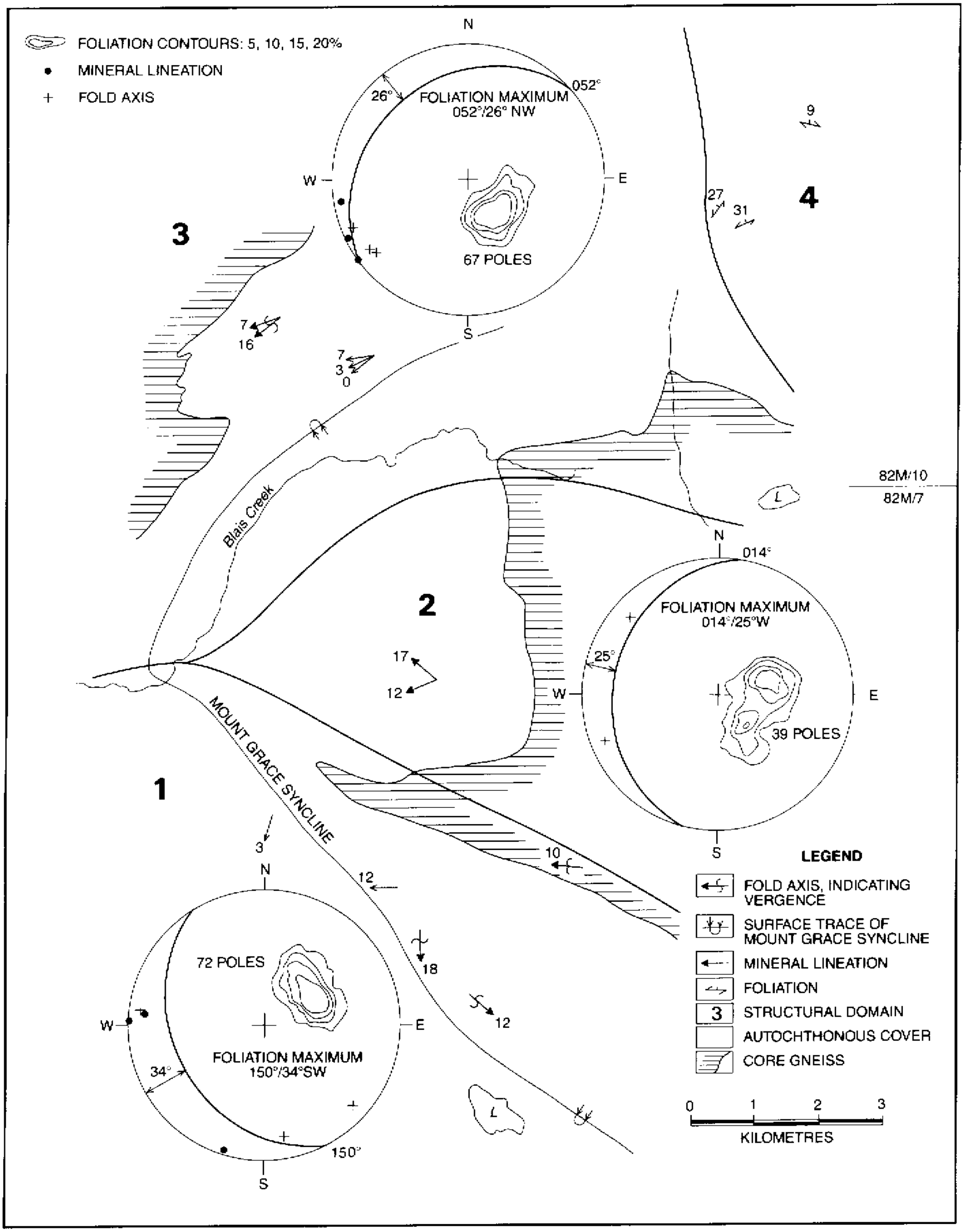


Figure 10. Phase 1 structural elements; equal-area projections from the lower hemisphere.

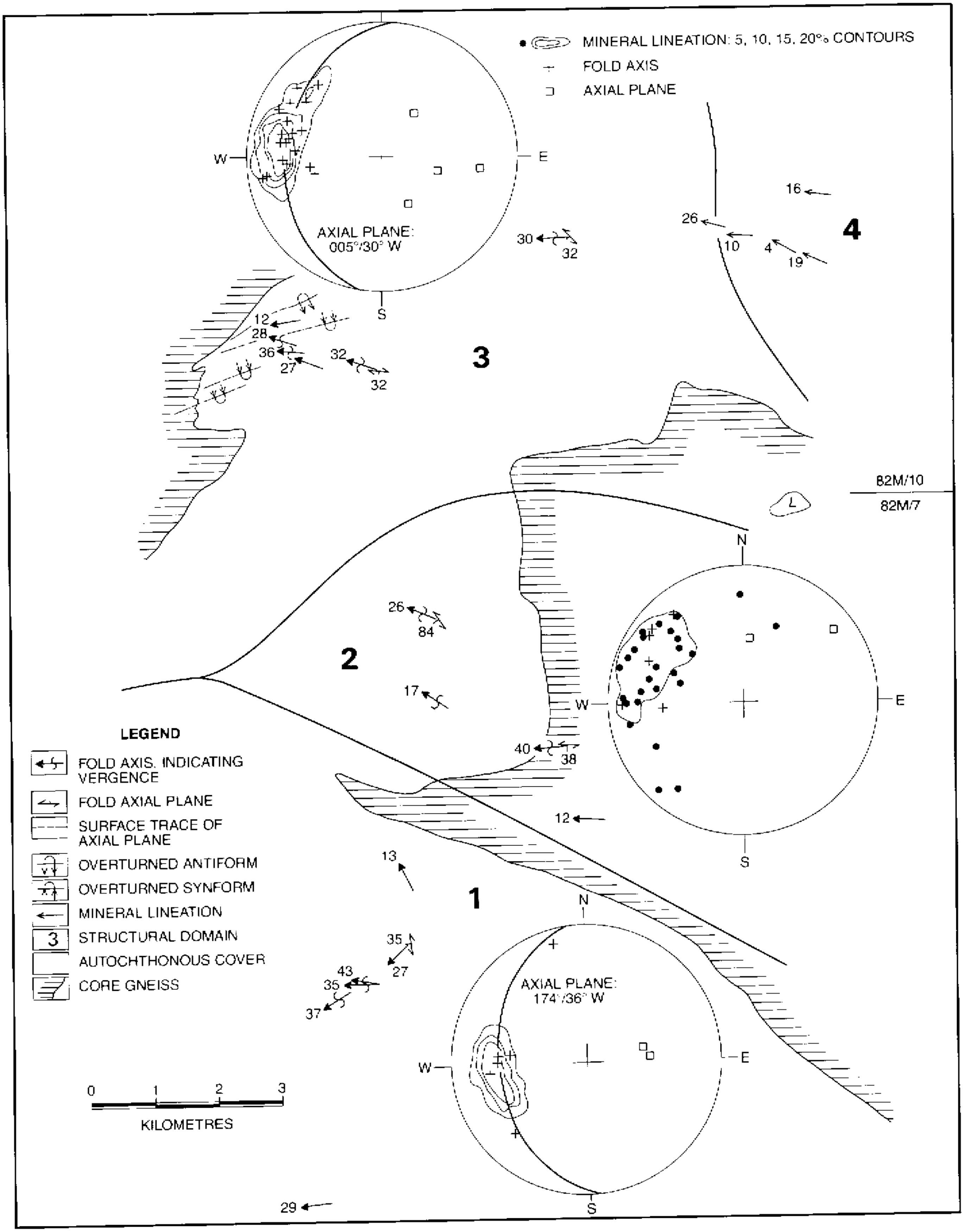


Figure 11. Phase 2 structural elements; equal-area projections from the lower hemisphere.

into augen structures, and by flattening of quartz and feldspar grains.

The foliation swings from northwest trending along the western margin (Domain 1, Figure 10) to north trending (Domain 2) and northeast trending north of Blais Creek (Domain 3). Along the northern margin of the dome, on the south limb of the Mount Grace syncline (Domain 4), it generally trends east-west parallel to layering and the margins of the dome.

Phase 1 minor folds include small rootless isoclines with tight appressed hinge zones and attenuated limbs. Their plunge is variable, but generally toward the west (Figure 10). Although they are characterized by a penetrative axial planar foliation (S1), lineations parallel to their axes are not conspicuous. An early lineation, consisting of aligned kyanite or faint alignment of granular minerals, is developed only occassionally and is overprinted by the conspicuous Phase 2 linear structures.

The vergence of Phase 1 minor folds is generally consistent with rotation on the limbs of the Mount Grace syncline. However, exceptions to this symmetry (Figure 10) indicate that unrecognized Phase 1 folds occur on its limbs. They are interpreted to be second-order intrafolial folds that are confined to specific units such that they do not appear to repeat stratigraphy.

The Mount Grace Syncline

The Mount Grace syncline dominates the structure of the northwestern and northern margins of Frenchman Cap dome. It has been traced approximately 20 kilometres from north of Ratchford Creek where it is referred to as the Kirbyville syncline (Brown, 1980) to the southern limit of the map area. Journeay (1982) projected it southward to the Perry River area and correlated it with an early fold described by McMillan (1973). This fold, referred to as the West fold (McMillan, *op. cit.*), is a tight to isoclinal syncline that plunges and closes to the southwest. However, foliation in the West fold wraps around its hinge and the prominent mineral lineation parallels its axis (McMillan, 1973), features diagnostic of Phase 2 folds in the Mount Grace area. It is therefore probable that the West fold, and other early folds described by McMillan (*op. cit.*), correlate with Phase 2 structures in the Mount Grace area, rather than with Phase 1 folds such as the Mount Grace syncline.

The Mount Grace syncline is an isoclinal fold; bedding attitudes in both its limbs are essentially parallel (*see* Domains 1 and 2, Figure 9). It is recumbent, with both limbs and its axial surface dipping moderately to the southwest, west or northwest. Its eastern limb is right-way-up, but its western limb is overturned and hence the Cottonbelt layer and a large extent of the Mount Grace carbonatite are part of an inverted stratigraphic succession.

Minor folds and a few recognized Phase 1 lineations indicate that the Mount Grace syncline plunges variably toward the west, approximately parallel to the dip of its axial surface. Hence, it closes sideways and it is therefore difficult to classify it as either synformal or antiformal.

PHASE 2

The only Phase 2 structures large enough to affect the distribution of rocks as depicted in Figure 3 are a number of tight folds in quartzites of Unit 3 northwest of Blais Creek. However, south of the Mount Grace area, large Phase 2 folds are conspicuous (McMillan, 1973). These are the earliest folds recognized by McMillan (*op. cit.*) and hence were described by him as Phase 1. Minor Phase 2 folds are common throughout the Mount Grace area (Figure 11), and the most prominent mineral lineation is a Phase 2 structure that parallels the axes of Phase 2 folds.

Minor Structures

The most prominent lineation throughout the area, a penetrative mineral lineation (L2) defined by the preferred orientation of elongate metamorphic mineral grains and elongate clusters of minerals, parallels the axes of Phase 2 folds. It is a stretching lineation as clasts in quartzite in Unit 6 just south of Mount Grace are elongated parallel to L2. Locally, L2 is defined by prominent "grooving". Phase 2 lineations plunge 30 to 40 degrees to the west or west-northwest throughout all domains (Figure 11).

Phase 2 minor folds are conspicuous throughout the area. They are generally tight folds with L2 parallel to their axes but with only a poorly developed axial plane cleavage (Plate 7). The prominent foliation, S1, is folded around the hinges of Phase 2 folds. Phase 2 folds generally plunge 30 to 40 degrees to the west and their axial planes, although variable, generally strike north-south with dips of 30 to 40 degrees to the west (Figure 11).

The vergence of minor Phase 2 folds is not consistent throughout the area (Figure 11) indicating the presence of large-scale intrafolial folds. Some of the most conspicuous are tight to isoclinal recumbent folds in Unit 4b on the southeast-facing cliffs northwest of Blais Creek. They have amplitudes of several tens to hundreds of metres, but are confined to specific lithologies within Unit 4d and are not plotted on the map (Figure 3).

Phase 2 Folds

Tight Phase 2 folds are outlined by quartzites of Unit 3 northwest of Blais Creek (Figure 3). A plot of Phase 2 lineations and minor fold axes within the immediate vicinity of these folds indicates that they plunge approximately 30 degrees westerly. These folds have complex hinge zones with thickened quartzite due to structural repetition, and very attenuated limbs (section A-A', Figure 3). They verge to the southeast and hence have the opposite sense of rotation to Phase 1 structures on the north limb of the Mount Grace syncline.

On outcrop scale, minor folds in the hinges of these structures range from moderately tight to isoclinal. Foliation wraps around their hinges and the Phase 2 lineation parallels their axes. These minor folds are commonly warped by late open Phase 3 folds and the scatter of lineation plots here and regionally may be due to superposition of Phase 3 folding.

PHASE 3

The youngest folds recognized in the area are small scale, generally open minor folds (Plates 8A and 8B). They are

Plate 7. (7A) Open Phase 2 minor folds in pelitic gneiss of Unit 6, north of Blais Creek; (7B) tight Phase 2 minor folds in interlayered paragneiss and orthogneiss of Unit 2 (core gneiss) at the headwaters of Blais Creek.

most prominent in Domains 2 and 3. The extensive exposure of Unit 4a west of core gneisses in Domain 2 is due in part to a dip-slope exposure but also to an apparent thickening of this unit by Phase 3 folds. Phase 3 folds plunge variably to the north and northwest (Figure 12). Their axial planes are generally steep, dipping 50 to 60 degrees toward the west. Phase 3 minor folds are most commonly asymmetrical and generally verge to the northeast (Figure 12).

Minor structures associated with Phase 3 folds include widely spaced axial planar fracture cleavage in competent amphibolites, quartzites and gneisses, crenulation cleavage in less competent schists and occasionally poorly developed linear grooving parallel to their axes.

Phase 3 folds are not large enough to affect the distribution of map units in Figure 3. However, plots of poles to planar structures in Domains 2 and 3, including bedding and foliation (Figures 9 and 10), are scattered along a great circle that is approximately perpendicular to Phase 3 fold axes, indicating the regional (but minor) influence of Phase 3 folding in the area.

FAULTS

INTRODUCTION

Two distinct fault types are prominent within the area. The earliest are west-dipping reverse or thrust faults that, on a local scale, are essentially parallel to foliation. They are early structures, probably related to the development of easterly verging Phase 2 folds. Although they are generally not conspicuous in the field and may be difficult to recognize in individual traverses, they become apparent on regional map synthesis and play an important role in the structural and tectonic evolution of Frenchman Cap dome and the eastern margin of the Shuswap Complex (Read and Brown, 1981; Journeay and Brown, 1986). They include the Monashee décollement and two reverse faults on the limbs of the Mount Grace syncline that have been projected northward from the Perry River area by Journeay and Brown (*op. cit.*). Late, generally north-trending faults with normal displacement are more conspicuous in the field, but played a lesser role in the structural evolution of the area.

MONASHEE DÉCOLLEMENT

The Monashee décollement, a west-dipping reverse fault along the western edge of Frenchman Cap dome, separates the autochthonous cover succession from overlying allochthonous cover rocks (Brown, 1980; Read and Brown, 1981). It is a zone of intense shearing and mylonitization, several metres to several hundreds of metres thick, that records a complex history of displacement and uplift presumably related to thrusting of the Selkirk allochthon eastward over the Monashee Complex in Late Jurassic time (Read and Brown, 1981; Journeay and Brown, 1986). The Monashee décollement cuts across footwall stratigraphy, Phase 1 folds including the Mount Grace syncline north of Frenchman Cap dome (Scammell, 1985), and axial surfaces of megascopic Phase 2 folds (Journeay, 1982).

OTHER WEST-DIPPING FAULTS

Two other west-dipping faults with inferred reverse displacement have been projected northward from the Perry River area by Journeay and Brown (1986). They were not recognized during the course of this mapping, nor by McMillan (1973) in the Perry River area, but their projected traces are shown as assumed faults in Figures 2 and 3.

The most westerly of these faults projects to the slopes west and south of Mount Grace and separates Unit 4c from an overlying succession of hornblende gneiss, kyanite schist and gneiss, minor quartzite and marble, and a prominent granitic orthogneiss unit (Figure 3). The relative age of this succession is not known; it is not similar lithologically to either Units 3, 4b or 4c on the east limb of the Mount Grace syncline, but is somewhat similar to core gneisses (Unit 2) exposed northwest of Blais Creek. It is possible that it correlates with younger overlying autochthonous cover rocks exposed only on the northeast margin of Frenchman Cap dome or further to the north, beyond the limits of the map area (Figure 2). The more easterly fault is inferred (Journeay and Brown, 1986) to be within Unit 3 east of Mount Grace. It is also a west-dipping reverse fault and may be responsible for the thickness of Unit 3 here.

LATE NORMAL FAULTS

Small, commonly north-trending faults with normal displacement cut other structures. Offset on them is generally not sufficient to appear on maps. They are late faults related to a period of extension that postdated the crustal shortening of Phases 1, 2 and 3. Similar north-trending faults, some associated with fine-grained basic dykes, have been described elsewhere in Frenchman Cap dome by Wheeler (1965), Fyles (1970a), McMillan (1973), Psutka (1978), Journeay (1982) and others. One of the larger of these, the Perry River fault, is a steep, west-dipping normal fault that traces along the Perry River–Myoff Creek valley for several tens of kilometres south of the Mount Grace area (Höy and Brown, 1981). It may continue northward into the Ratchford Creek valley east of Mount Grace with some displacement of core gneisses and the basal quartzite (Figure 3), but does not appear to continue to the northern part of the map area where control is considerably better. Displacement on the Perry River fault increases southward from several hundred metres in the Perry River area (Journeay, 1982) to greater than a kilometre in the Bews Creek area, where other late northwest-trending, west-dipping normal faults are conspicuous (Höy, 1980a).

SUMMARY — STRUCTURAL SYNTHESIS

The oldest structures recognized along the northwestern margin of Frenchman Cap dome are tight to isoclinal folds with a prominent axial planar foliation, but with only poorly developed axes lineations. They are recognized in both core gneisses and overlying autochthonous cover rocks. The Mount Grace syncline, a recumbent, west-plunging Phase 1 isocline, dominates the structure of the Mount Grace area. It has been traced and projected from Ratchford Creek north and northeastward to the Columbia River where it is truncated by the Columbia River fault.

Tight to essentially isoclinal Phase 2 folds are superposed on Phase 1 structures. They fold the penetrative Phase 1 foliation and are characterized by a prominent stretching mineral lineation. Minor Phase 2 folds are common throughout the Mount Grace area, but the only macroscopic folds are east-verging isoclines outlined by the basal

Plate 8. Late, open Phase 3 folds in feldspathic quartzite (8A) and interlayered hornblende gneiss and calc-silicate gneiss (8B) of Unit 4.

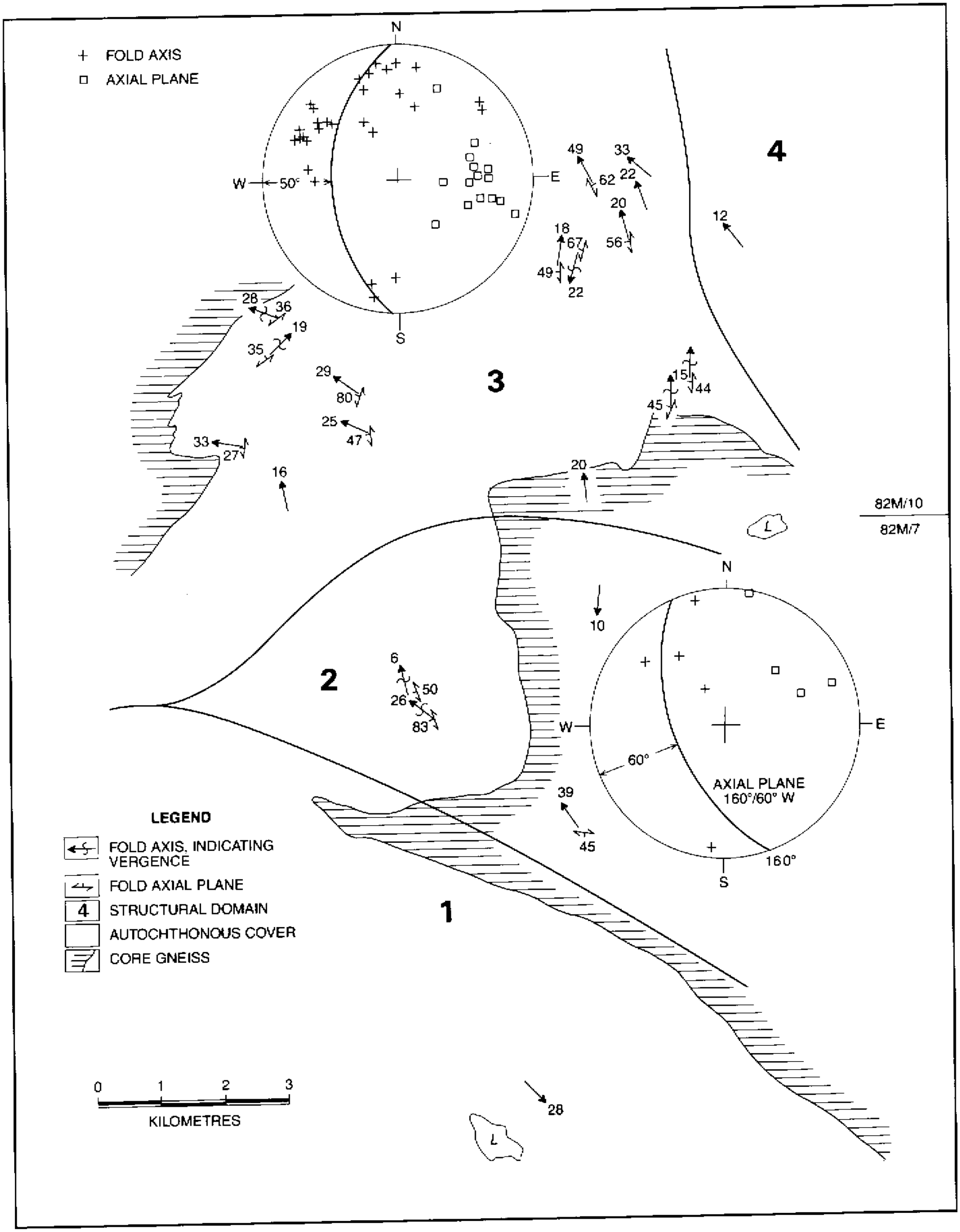


Figure 12. Phase 3 structural elements; equal-area projections from the lower hemisphere.

quartzite (Unit 3) northwest of Blais Creek. However, the earliest large folds recognized in the Perry River area to the south (McMillan, 1970, 1973) are assumed to be Phase 2 as they also fold the penetrative Phase 1 foliation. This interpretation casts doubt on the correlation of Phase 1 folds in the Mount Grace area and, in particular, the Mount Grace syncline, south to the Perry River as suggested by Journeay and Brown (1986).

West-dipping thrust faults, including the Monashee décollement, imbricate the autochthonous cover rocks along the western margin of the dome (Read and Brown, 1981; Journeay and Brown, 1986). Initial movements on these faults may have begun during regional prograde metamorphism and the Phase 2 deformation, but most movement occurred later; the décollement and other thrust faults truncate Phase 1 and Phase 2 structures and at least some of the metamorphic isograds (Journeay and Brown, *op. cit.*).

Late, post-metamorphic, open Phase 3 folds, warps and crenulation cleavage occur throughout the Mount Grace area. Although they are not regionally significant here, they are important in the Perry River area where they account for the prominent embayment in core gneisses of the dome (McMillan, 1970, 1973). The latest regional deformation is a gentle north-south warping running essentially through the axis of Frenchman Cap dome producing the broad domal structure.

In summary, Phase 1 and Phase 2 folds developed in a ductile regime during prograde regional metamorphism in response to easterly directed compressive stress, presumably (Read and Brown, 1981) as the Selkirk allochthon (which includes the allochthonous cover rocks) began to override the Monashee Complex in Middle to Late Jurassic time. Episodic reverse movements on the Monashee décollement and other west-dipping faults may have begun during development of these folds, but was ongoing, stacking the Phase 1 and Phase 2 folds on top of each other. Prograde thermal metamorphism locally outlasted the intense deformation, but late compressive warping and buckling, particularly in the Perry River area near the centre of the dome, continued well after the metamorphic culmination.

The latest structures in the dome (Wheeler, 1965; Fyles, 1970a; McMillan, 1970; and others) are north-trending normal faults and fractures. Late normal movement on the Monashee décollement (Journeay and Brown, 1986) may also have occurred during formation of these faults. These structures record a period of extension as has been demonstrated by Parrish (1984) in the Slocan Lake area to the south, probably of crustal dimension as suggested by Price *et al.* (1981).

METAMORPHISM

INTRODUCTION

The regional metamorphic grade along the northwestern margin of Frenchman Cap dome is upper amphibolite facies, similar to that recorded in the Perry River to the south (McMillan, 1973) and in the Jordan River at the south end of the dome (Fyles, 1970a). Although isograds in marbles or calc-silicate gneisses were not delineated, mineral assemblages are characteristic of high-grade regional metamorphism. In pelitic rocks, two prograde metamorphic isograds are identified by plotting all occurrences of reactant and product assemblages of specific metamorphic reactions. These isograds developed during the intense Phase 1 and Phase 2 deformation at pressures of approximately 7 kilobars, corresponding to depths of up to 25 kilometres in the crust. Lower temperature and lower pressure retrograde metamorphic suites overprint higher grade assemblages, recording a period of cooling and unroofing during late-stage, generally more brittle deformation.

CALC-SILICATE ASSEMBLAGES

Metamorphic mineral assemblages in siliceous marbles and calc-silicate gneisses are illustrated in Figure 13. They reflect varying compositions of original sedimentary carbonate rocks, ranging from pure limestone through siliceous dolomite to dolomitic quartzite. With increasing silica content, they include:

(1) calcite-tremolite-dolomite,
(2) calcite-tremolite-diopside,
(3) calcite-diopside-quartz,
(4) calcite-diopside-quartz-tremolite,
(5) quartz-diopside.

These assemblages, with diopside a common and stable phase, are characteristic of medium to high grades of regional metamorphism. The only common four-phase assemblage, calcite-diopside-quartz-tremolite (in the three component system, CaO-MgO-SiO_2), records a retrograde reaction:

$$\text{diopside} + CO_2 + H_2O = \text{tremolite} + \text{quartz} + \text{calcite}$$

as tremolite (or actinolite) occurs rimming or replacing diopside.

Within aluminous or iron-rich calcareous gneisses, metamorphic equivalents of marls, garnet, plagioclase, microcline, biotite and muscovite are common metamorphic minerals. Scapolite, concentrated in layer-parallel laminations in some calc-silicate gneisses, probably reflects marls that originally contained high salt content. Accessory minerals within the calcareous rocks include apatite, sphene, zircon and

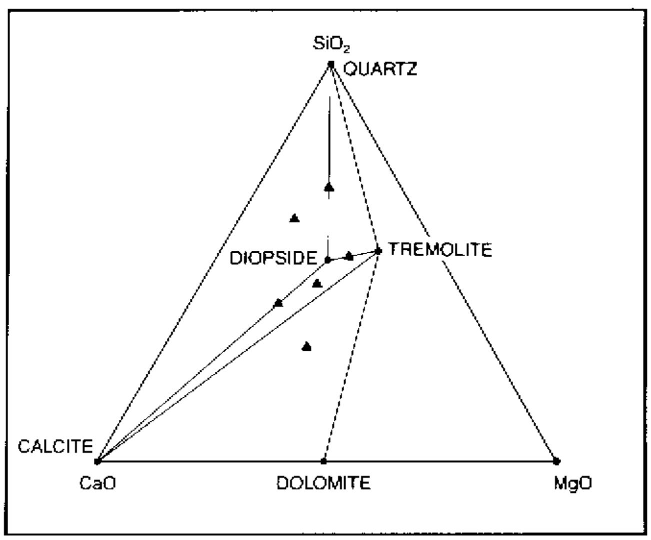


Figure 13. Metamorphic mineral assemblages in marbles and calc-silicate gneisses in the three component system CaO-MgO-SiO_2.

opaques. Clinozoisite, sericite and chlorite, after muscovite or biotite, are common alteration minerals.

PELITIC ASSEMBLAGES AND ISOGRADS

Prograde regional metamorphic assemblages in pelitic rocks are listed in Appendix 1. Two isograds are reasonably well constrained, the kyanite-sillimanite transition and the isograd corresponding to the breakdown of muscovite plus quartz to potassic feldspar and an aluminosilicate. This latter reaction is commonly regarded (Winkler, 1976) as defining the boundary between "medium" grade and "high" grade metamorphism. Overprinted on the prograde assemblages are lower grade minerals, but due to erratic distribution, retrograde isograds are not defined. The fabric of silicate mineral assemblages, both prograde and retrograde, allows a discussion on the relationship between metamorphism and deformation.

KYANITE-SILLIMANITE

The sillimanite isograd, defined by the first appearance of sillimanite, occurs within the autochthonous cover rocks in the western and southwestern part of the area (Figure 14). It is constrained by two occurrences of kyanite without sillimanite (recognized in thin section) just southwest of Mount Grace and by numerous occurrences of kyanite plus sillimanite to the northeast. It is constrained north of Blais Creek by field identifications only; it is possible that the two kyanite occurrences north of the isograd contain traces of sillimanite as well, but southeast of the isograd both kyanite and sillimanite are readily identifiable and occur together throughout a large area. Kyanite decreases in abundance toward the core gneisses, where it is replaced by sillimanite; this "kyanite-out isograd" locates the last occurrences of kyanite readily recognizable in the field.

Textures and fabrics indicate that kyanite is syntectonic whereas sillimanite is syn to post-tectonic. Kyanite is aligned with the Phase 1 foliation (Plate 9), axial planes of Phase 1 minor folds, and Phase 2 lineations; in one locality, it defines a Phase 1 lineation. Early formed kyanite may be broken or rotated during continued deformation (Plate 10) and is commonly replaced or mantled by retrograde minerals such as andalusite or cordierite. Sillimanite may define Phase 1 foliation (Plate 11) or Phase 2 lineations, but also commonly forms radiating fibrous clusters that cut across the tectonic fabric (Plate 12). It replaces kyanite (Plate 13) but may also be mantled by cordierite. Close to the sillimanite isograd at Mount Grace, early formed sillimanite is warped by late (Phase 3?) folds (Plate 14).

POTASSIUM FELDSPAR-ALUMINOSILICATE ISOGRAD

The assemblage potassium feldspar (generally microcline) with sillimanite or kyanite defines the product assemblage of a reaction that breaks down muscovite in the presence of quartz:

muscovite + quartz = aluminosilicate + K-feldspar

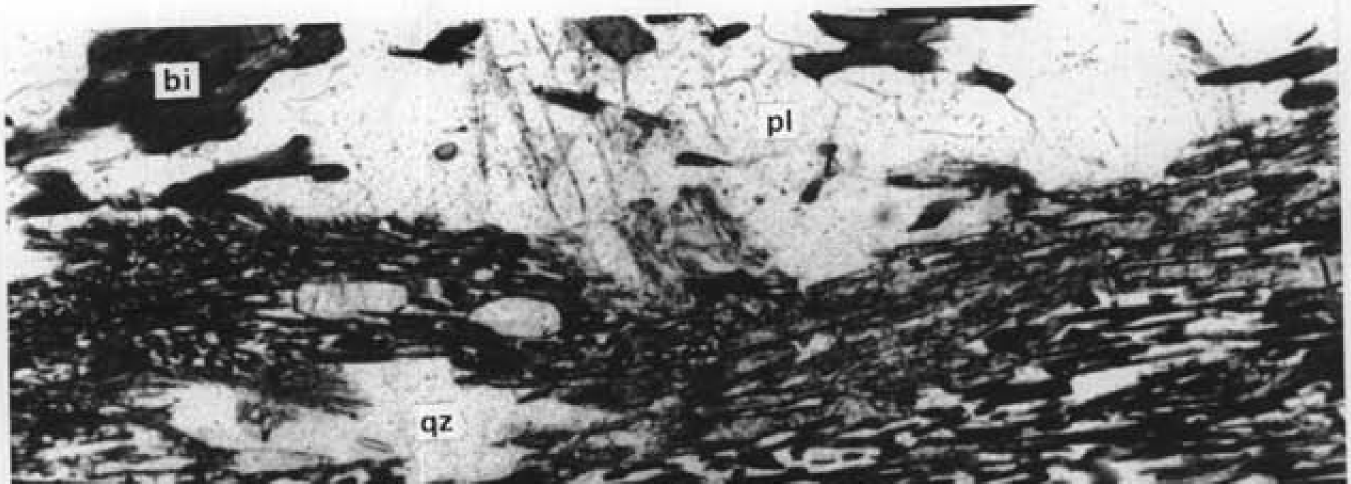


Plate 9. Kyanite, aligned with Phase 1 foliation, in a matrix of quartz, plagioclase, biotite and muscovite. (Sample CB7-3, field of view = 1.8 millimetres, plane light.)

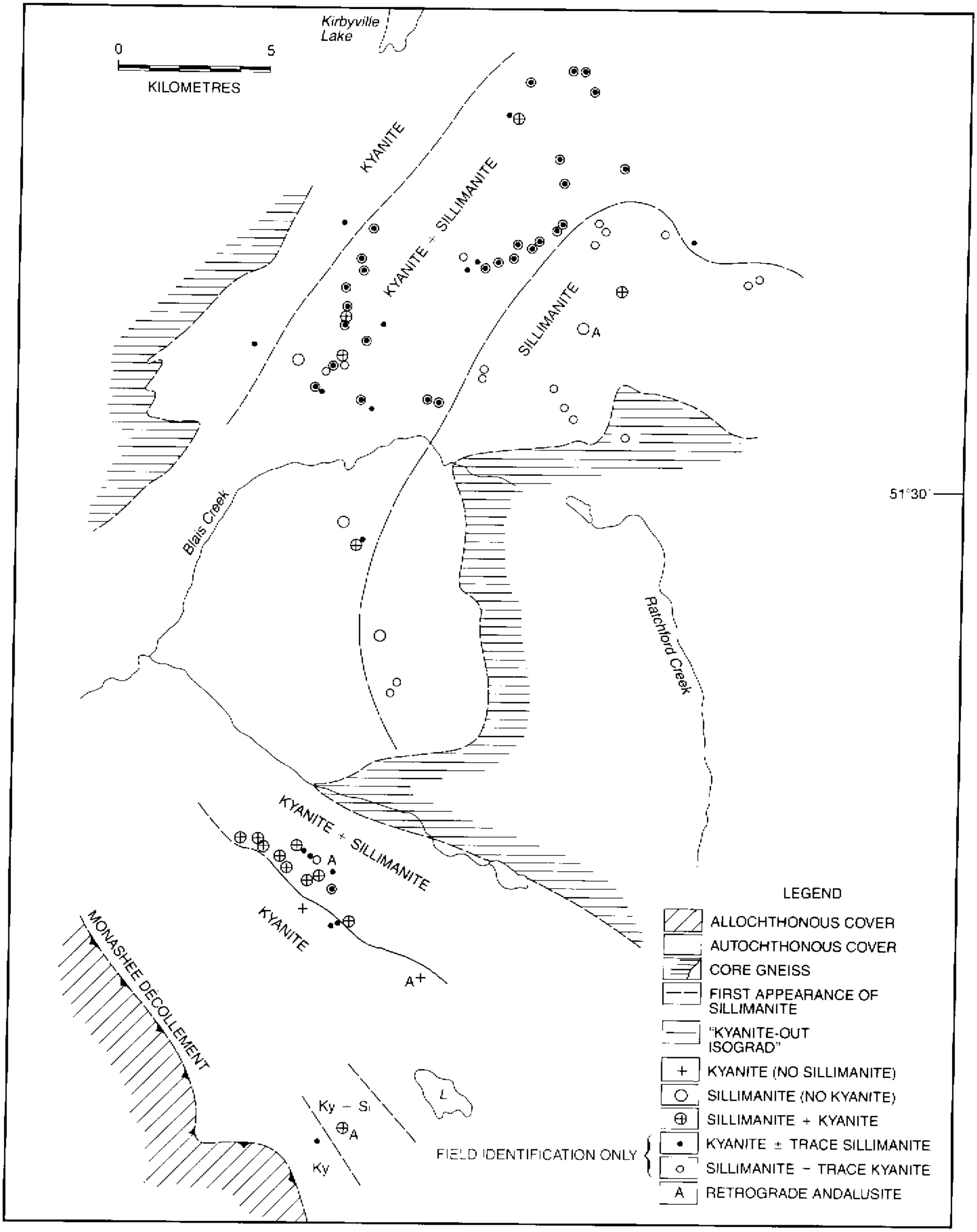


Figure 14. The sillimanite isograd, corresponding to the reaction kyanite = sillimanite, and localities of retrograde andalusite.

Potassium feldspar was identified either on stained rock slabs or in thin sections.

The isograd, marking the first appearance of kyanite or sillimanite with orthoclase or microcline, is only constrained south of Mount Grace. Only two occurrences of the reactant assemblage, muscovite plus quartz without accompanying potassic feldspar, were recognized (Figure 15). The product assemblage is common throughout the area, generally occurring with the reactant minerals and hence forming a wide zone in which all four minerals of the isograd appear to be stable. However, muscovite is a secondary retrograde mineral in many of these occurrences, forming rims around kyanite or sillimanite, or radiating clusters that cross the foliation.

RETROGRADE ASSEMBLAGES

Retrograde minerals are common and indicate that cooling must have been sufficiently slow to allow the generally more sluggish reverse reactions to occur. Retrograde minerals are generally post-tectonic; they either crosscut the Phase 1 and Phase 2 structural fabrics or embay or mantle prograde metamorphic minerals.

Common retrograde minerals include cordierite, andalusite, muscovite, biotite, chlorite and sericite. Cordierite and andalusite (described following) and some of the muscovite and biotite are considered metamorphic minerals that formed during regional metamorphism, but after the maximum prograde assemblages and under reduced temperature and pressure conditions. Retrograde muscovite, and less commonly biotite, include clusters of grains that embay, cut across or completely mantle kyanite or sillimanite. They formed after Phase 1 and Phase 2 deformation, growing across the prominent structural fabric.

Chlorite and sericite, however, are interpreted to be late, post-metamorphic hydrothermal minerals. Chlorite, with anomalous blue interference colours in thin section, occurs in thin veins cutting across garnet and as pseudomorphs after biotite and muscovite. Sericite has a similar habit in garnets and also occurs as small dispersed grains through many silicate minerals, most commonly the feldspars, micas, kyanite and sillimanite.

CORDIERITE

Cordierite, where observed, appears to have formed by a reaction involving the breakdown of either sillimanite or kyanite. It occurs as small clear grains usually embayed or surrounded by biotite, forming mantling textures (Plate 15) like those described by Reesor and Moore (1971) in the Thor-Odin dome to the south. It is erratically distributed throughout the Mount Grace area and occurs in rocks with lower grade metamorphic minerals such as andalusite and retrograde muscovite. The replacement or mantling textures, erratic distribution, and association with lower grade assemblages indicate that cordierite is a retrograde mineral.

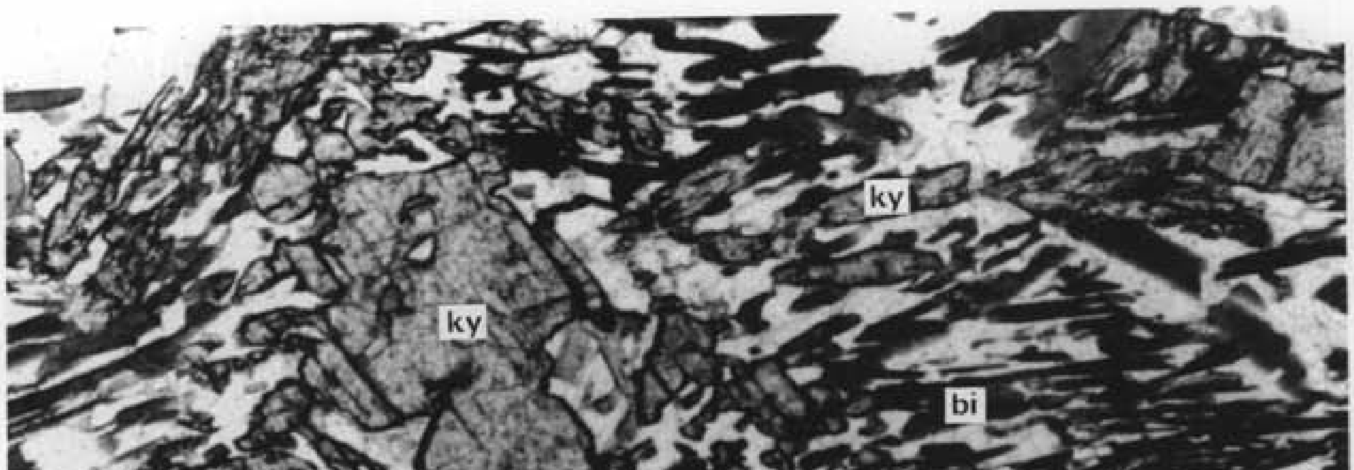


Plate 10. Large porphyroblast of early formed kyanite, rotated and partially replaced during continued deformation; note growth of aligned finer grained kyanite and biotite during this deformation. (Sample CB7-3, field of view = 1.8 millimetres, plane light.)

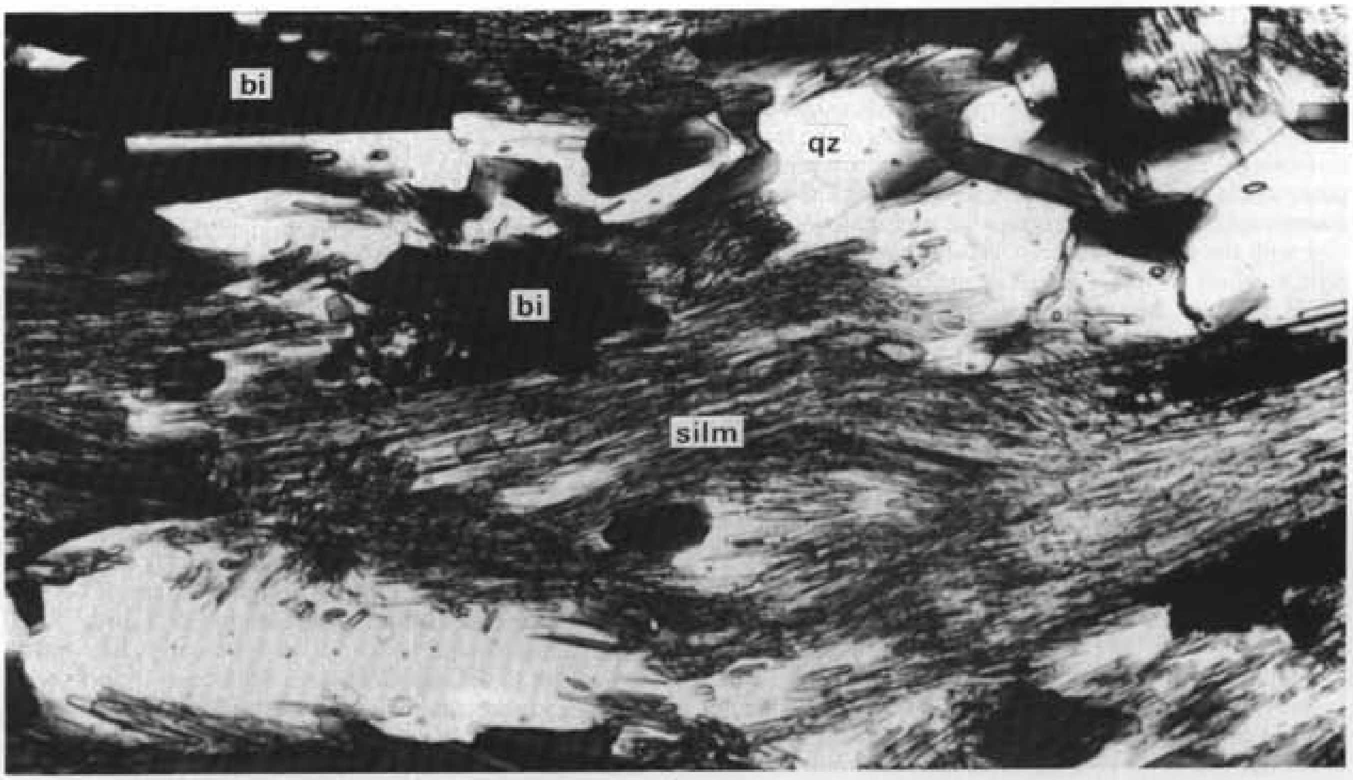


Plate 11. Sillimanite defining Phase 1 foliation in a matrix of quartz, plagioclase and dark biotite.
(Sample CB4-2A, field of view = 1.8 millimetres, plane light.)

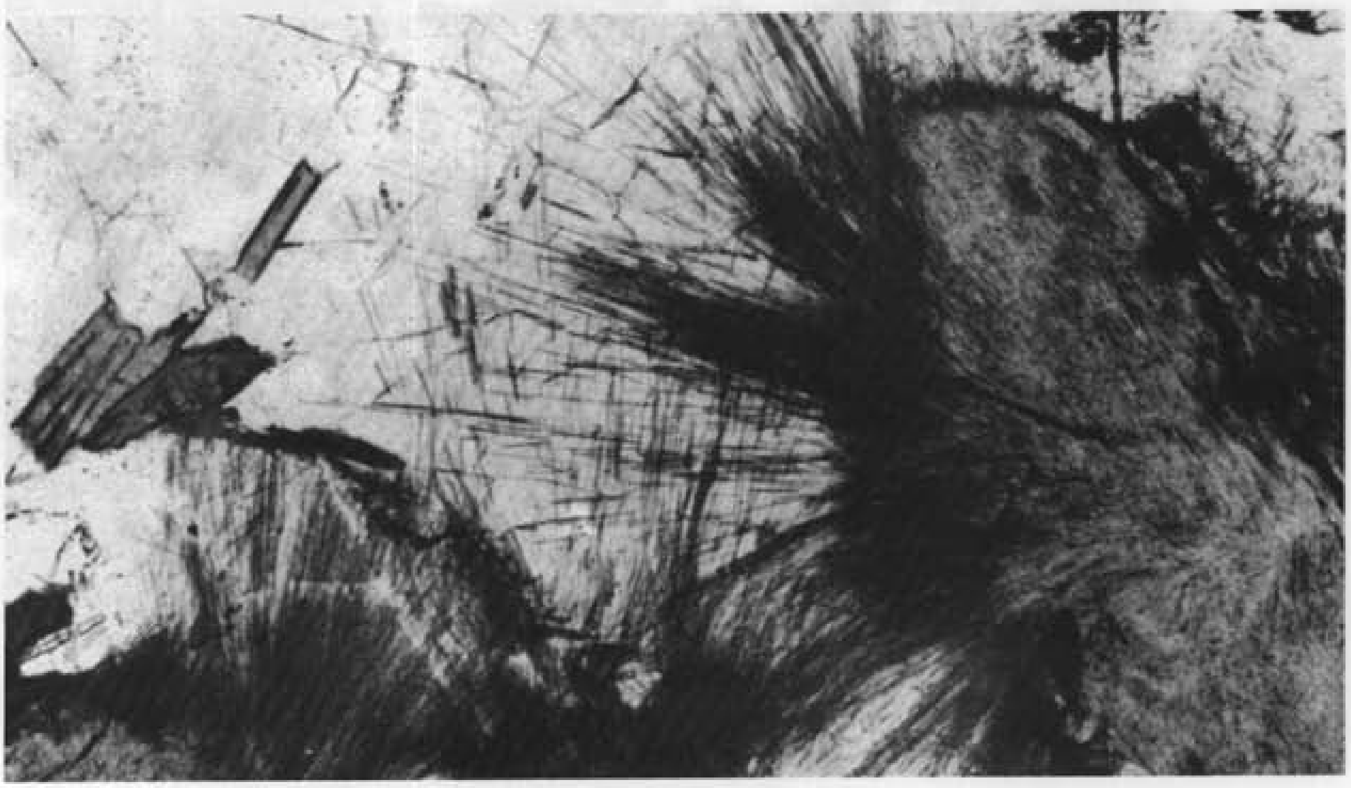


Plate 12. Fine needles of sillimanite (fibrolite) growing in quartz across the prominent Phase 1 foliation.
(Sample CB10-24, field of view = 1.8 millimetres, plane light.)

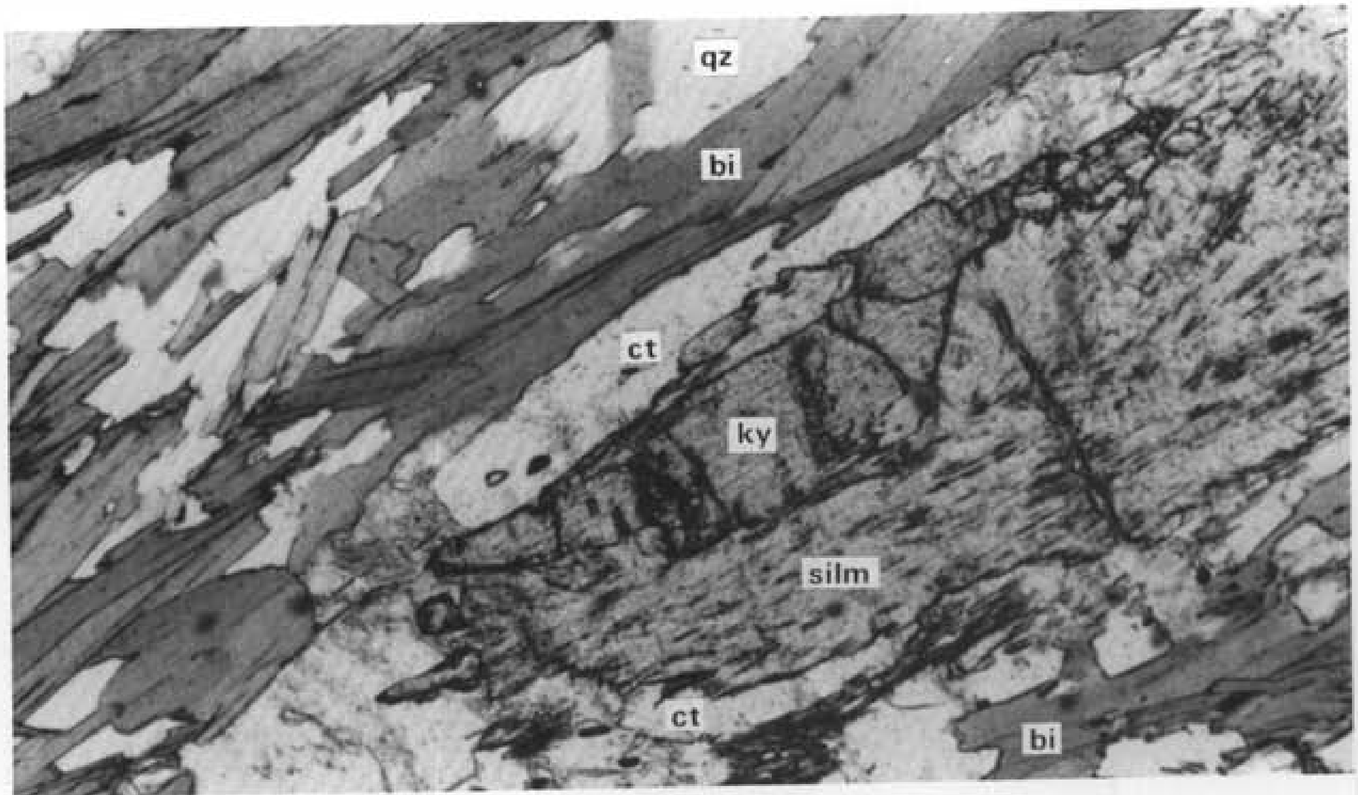


Plate 13. Fibrous sillimanite replacing kyanite; note also cordierite mantling both kyanite and sillimanite. The matrix is biotite, quartz and plagioclase. (Sample CB1-14, field of view = 1.8 millimetres, plane light.)

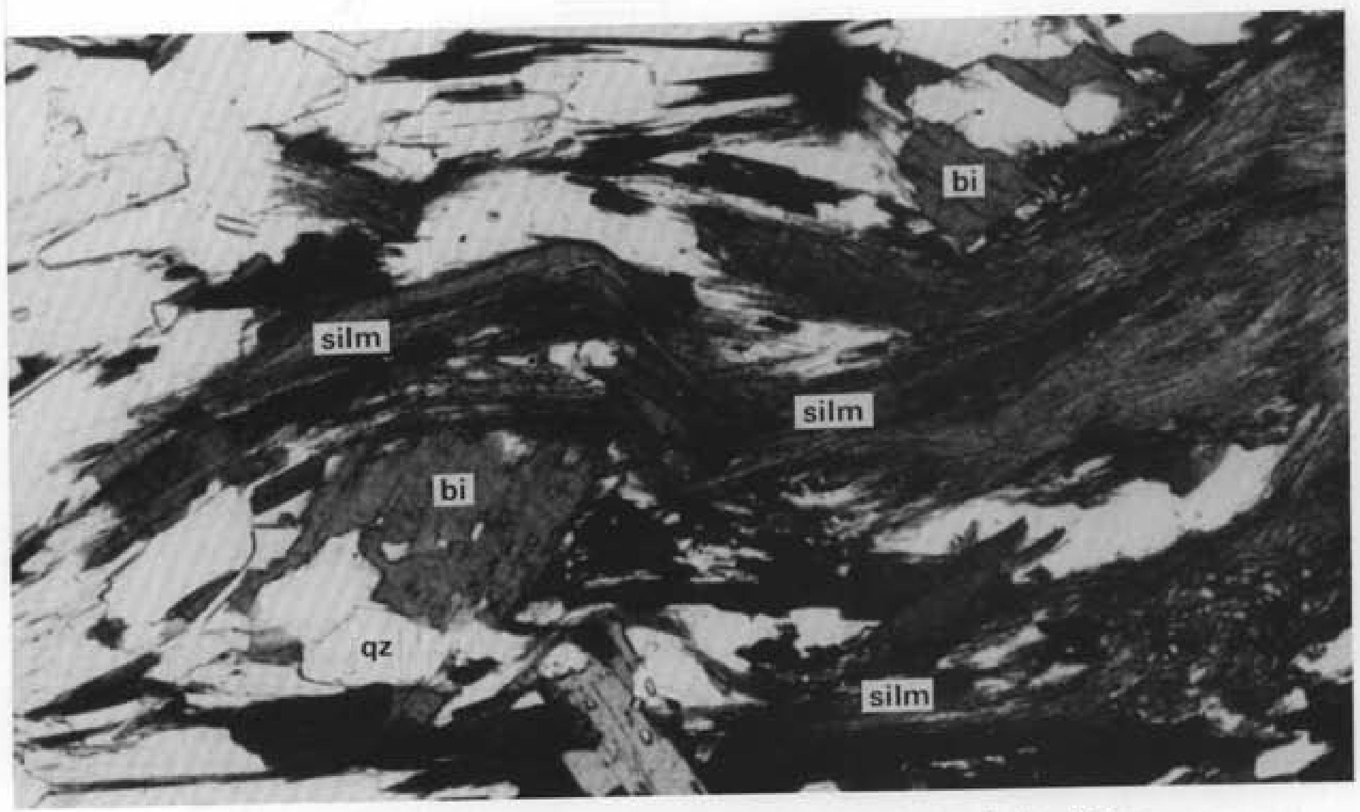


Plate 14. Fibrous sillimanite, formed during Phase 2 deformation(?), is warped by later folding. (Sample CB4-2A, field of view = 1.8 millimetres, plane light.)

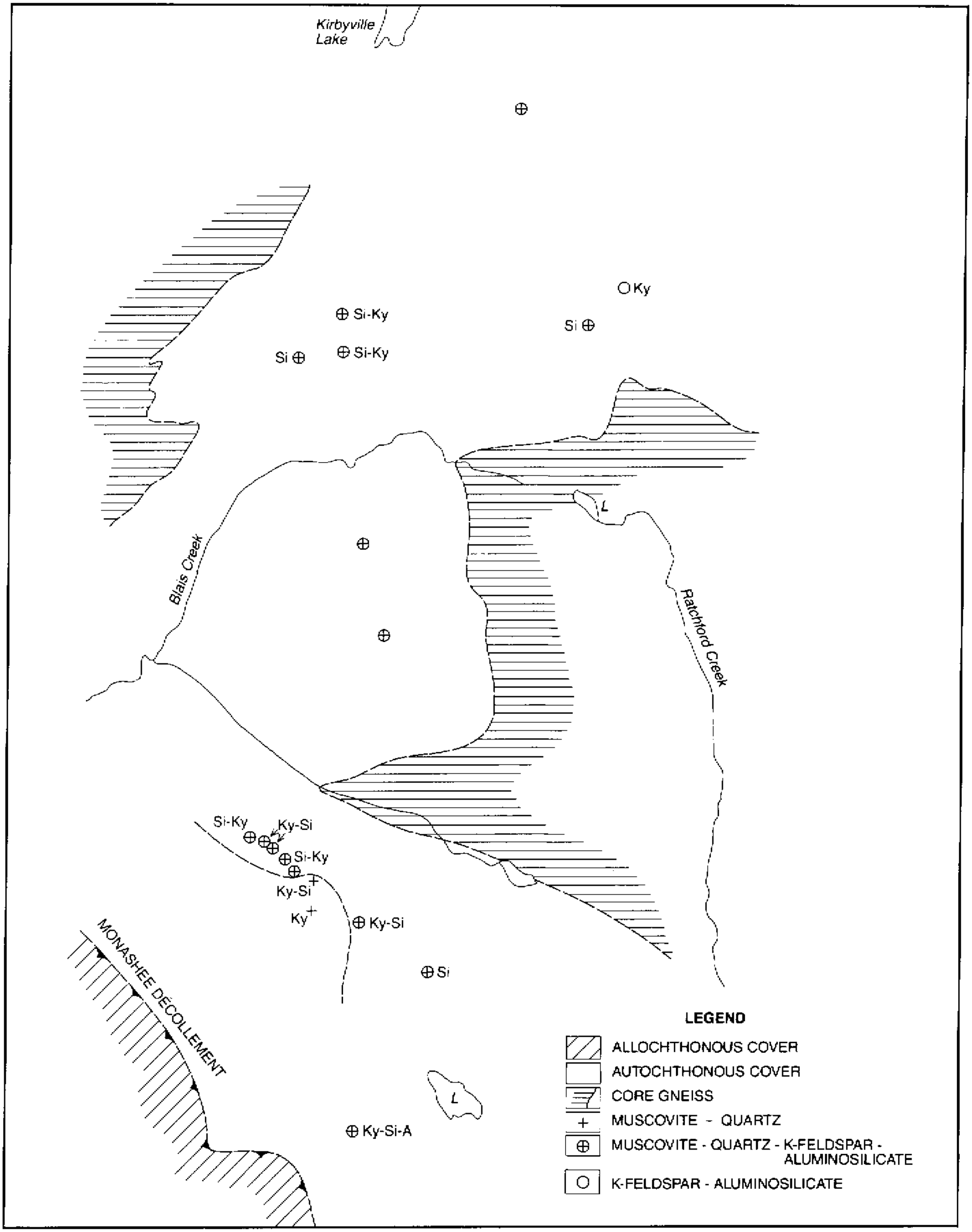


Figure 15. The potassium feldspar-aluminosilicate isograd, corresponding to the reaction muscovite + quartz = aluminosilicate (kyanite, sillimanite) + K-feldspar (microcline, orthoclase).

The stability field of cordierite is pressure sensitive (Wynne-Edwards and Hay, 1963; Turner, 1968, page 127) and increases with decreasing pressure. Hence, cordierite is common in contact metamorphic aureoles of high-level intrusions but less common, except in the granulite facies, in regionally metamorphosed terranes. Its occurrence here as a late post-tectonic mineral is evidence of continued but waning thermal metamorphism at decreased pressures after the intense regional deformation. It indicates that the thermal gradient remained high, perhaps due to relatively slow cooling, during tectonic uplift and removal of overlying crustal rocks.

ANDALUSITE

Andalusite occurrences are also widely scattered throughout the area (Figure 14; Appendix 1). Andalusite is pseudomorphic after kyanite, forms elongate fine-grained granular trains in sillimanite, or occurs as large, late porphyroblasts. Replacement textures, with sillimanite or kyanite overgrown by andalusite then mantled by cordierite (Plate 16), indicate that during cooling and pressure decrease, the stability field of andalusite was reached before that of cordierite.

STRUCTURAL AND TECTONIC SIGNIFICANCE

The two pelitic isograds mapped show that the grade of regional metamorphism increases toward the core of Frenchman Cap dome as has also been shown by McMillan (1973). The isograds approximately parallel the margins of the dome, producing a north-trending and plunging metamorphic culmination that coincides with the late structural arching of the dome.

Prograde regional metamorphism occurred during Phase 1 and Phase 2 deformation. Kyanite produced both Phase 1 and Phase 2 tectonic fabrics whereas sillimanite growth occurred both during and after development of these fabrics. However isograds, although roughly aligned with major structures, cut across them.

The pressure and temperature conditions during prograde metamorphism and the culminating deformation can be estimated on the phase equilibria diagram shown in Figure 16. The overlap of the sillimanite and the potassium feldspar-aluminosilicate isograds (*compare* Figures 14 and 15) indicates temperatures of approximately 650 to 700°C and pressures of approximately 7 kilobars, corresponding to depths of approximately 25 kilometres in the crust.

Retrograde metamorphism occurred after Phase 1 and Phase 2 deformation. The sequential development of post-kinematic sillimanite, muscovite and perhaps biotite, andulusite and cordierite is schematically illustrated as a path of decreasing pressure and temperature in Figure 16. The marked decrease in pressure, to less than 3.5 kilobars, while maintaining reasonably high temperatures, approximately 500 to 600°C, suggests removal of cover rocks continued

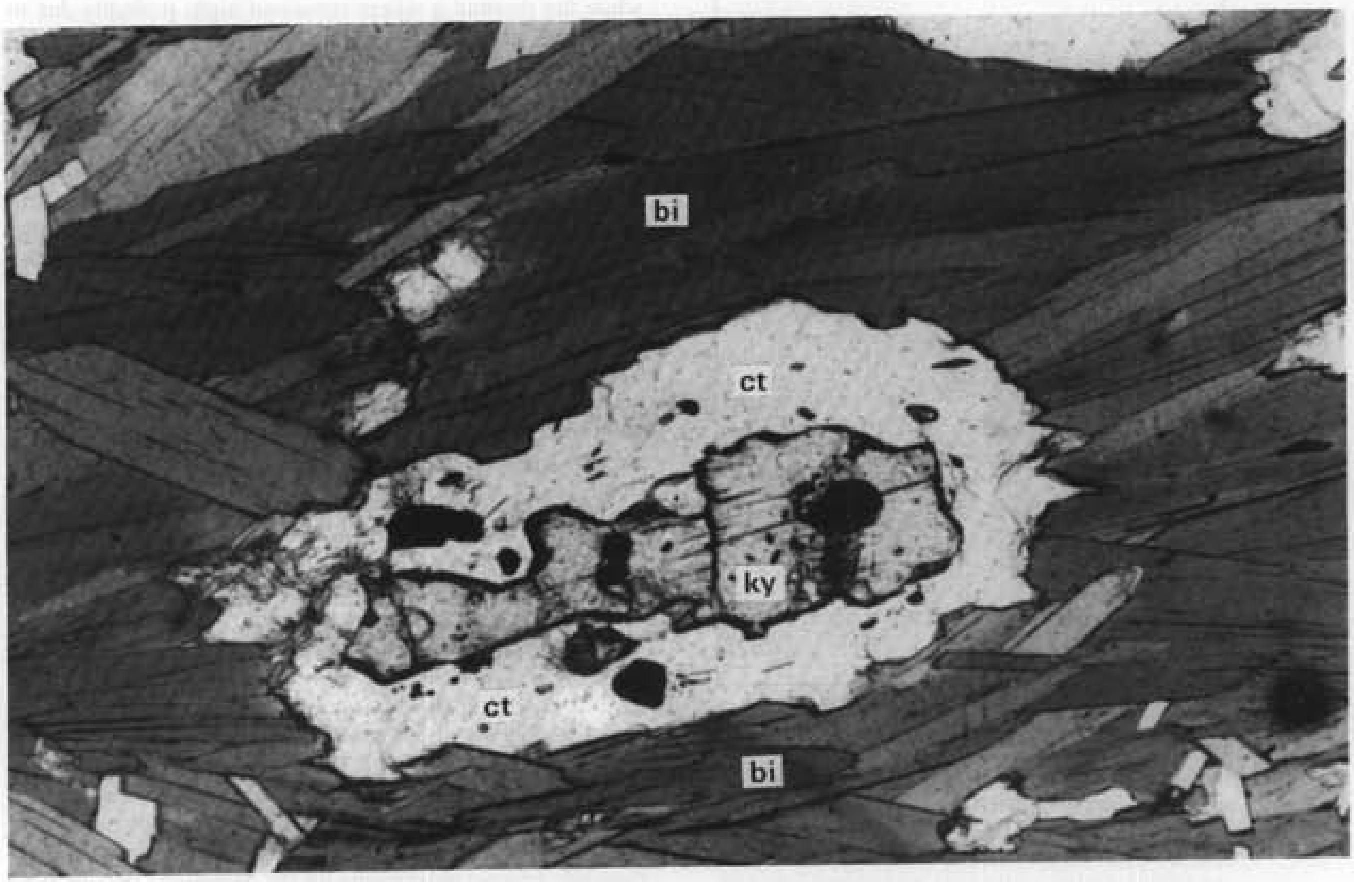


Plate 15. Mantling texture with cordierite surrounding kyanite in a matrix of biotite. (Sample CB1-14, field of view = 1.8 millimetres, plane light.)

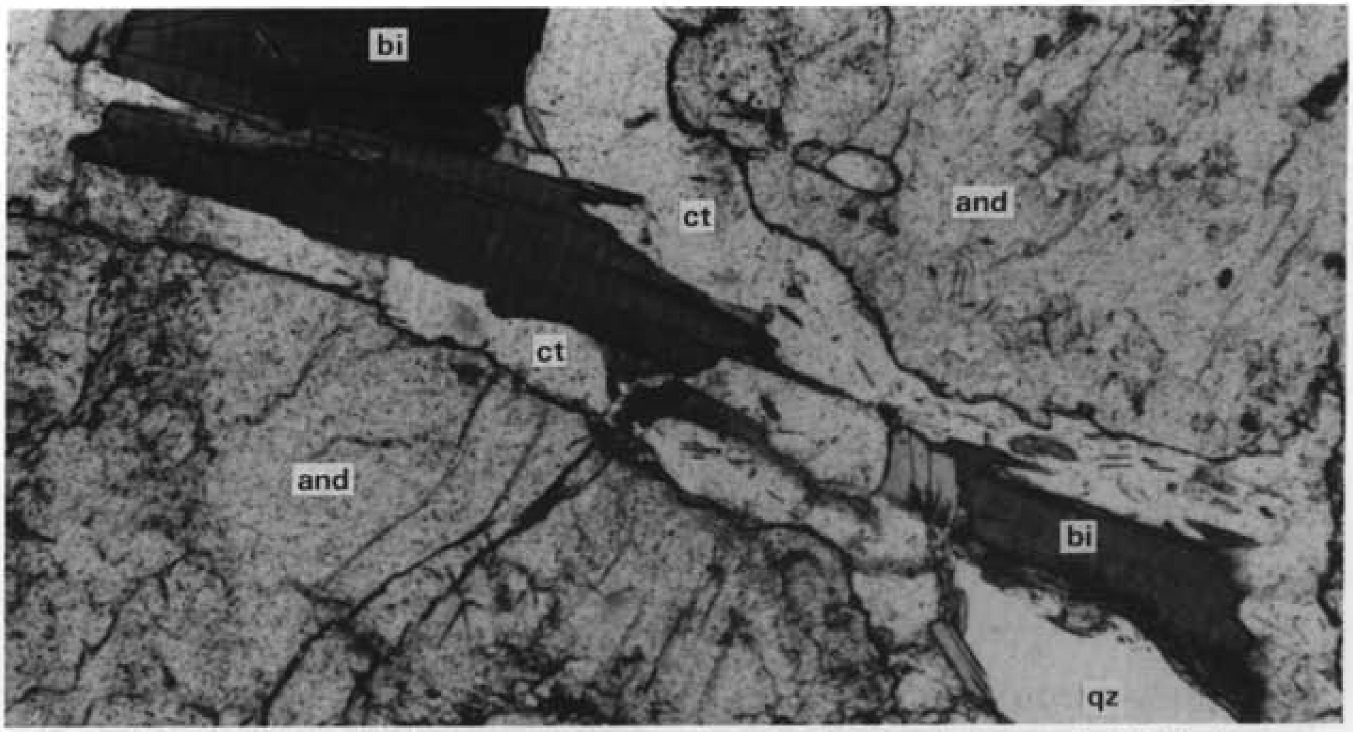


Plate 16. Large porphyroblasts of andalusite (top right and lower left), rimmed by cordierite in matrix of dark biotite. (Sample CB1-14, field of view = 1.8 millimetres, plane light.)

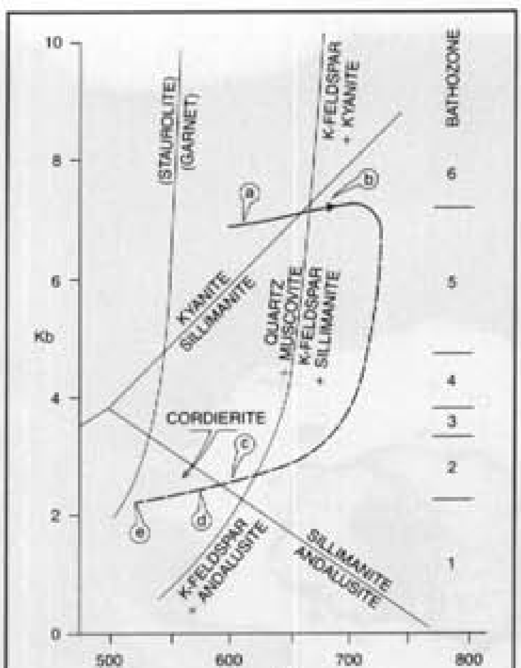


Figure 16. A pelitic grid illustrating reactions upon which the isograds mapped in the Mount Grace area are based. The solid arrow indicates conditions during prograde regional metamorphism, with growth of (a) syntectonic kyanite and (b) syn to post-tectonic sillimanite and breakdown of muscovite; the dashed arrow depicts conditions during retrograde metamorphism with growth of retrograde (c) muscovite, (d) andalusite and (e) cordierite. The grid is after Carmichael (1978).

while the thermal gradient remained high, probably due to tectonic uplift and a slow cooling rate.

SUMMARY AND DISCUSSION

Frenchman Cap dome, one of a series of domal structures along the eastern margin of the Shuswap metamorphic complex, consists of a central core comprising orthogneiss and paragneiss of probable Aphebian age, unconformably overlain by dominantly metasedimentary rocks referred to as the autochthonous cover succession. Core gneisses and cover rocks are collectively referred to as the Monashee Complex. The complex is exposed between a west-dipping fault on the west, the Monashee décollement, and the Columbia River fault on the east. Allochthonous cover rocks, part of the Selkirk terrane, occur above the Monashee décollement and are also exposed east of the Columbia River fault.

The Mount Grace area at the northwestern edge of Frenchman Cap dome is within core gneisses and autochthonous cover rocks directly beneath the Monashee décollement. It has undergone intense polyphase deformation and high grades of regional metamorphism. Three phases of deformation, related to compression and crustal shortening, are apparent in both core gneisses and cover rocks. The earliest produced the Mount Grace syncline, a recumbent west-trending and dipping isocline that dominates the structure from Ratchford Creek north and northeast to the Columbia River fault. Tight to isoclinal Phase 2 folds deform the limbs of the Mount Grace syncline. They are essentially co-axial with Phase 1 folds, dip west, and verge to the east. Episodic reverse movements on the Monashee décollement and on other west-dipping faults may have begun during Phase 2 deformation, but certainly continued after its culmination. Both early phases developed during progressive and increasing regional metamorphism that culminated near the end of the Phase 2 deformation with temperatures of 550 to 600°C and pressures of 6 to 7 kilobars.

In summary, Phase 1 and Phase 2 structures record a period of crustal shortening, accompanied by amphibolite facies regional metamorphism in both core gneisses and autochthonous cover rocks of the dome. The age of these structures is not known; they may have developed, in part, during early movement on the Monashee décollement in Middle to Late Jurassic time (Journeay and Brown, 1986) perhaps in response to overthrusting of the Selkirk allochthon (Read and Brown, 1981), but as the structures are truncated by the décollement, it is possible that they record an earlier tectonic event (Okulitch, 1984).

Retrograde metamorphism, after Phase 1 and Phase 2 deformation, continued during a dramatic decrease in pressure, presumably caused by rapid tectonic uplift and removal of up to 15 kilometres of cover rocks. Late, open folds and warps occurred after the regional metamorphism but before extensional tectonism that produced normal faults and controlled emplacement of north-trending mafic dykes.

The model described above is similar to models published by Journeay (1982) and McMillan (1970) for this area and the area to the south. However, it differs in many minor and some major aspects from Journeay's synthesis. The most important differences involve the correlation of major structures between Mount Grace and the Perry River area, and consequently the relative and absolute timing of deformation and thermal events. Journeay (*op. cit.*) correlated the earliest large-scale folds in the Perry River area with the Phase 1 Mount Grace syncline. However, these folds warp the foliation that is axial planar to the Mount Grace syncline and are therefore Phase 2 structures.

CHAPTER 4

CARBONATITES AND ASSOCIATED ALKALIC ROCKS

INTRODUCTION

Carbonatites along the west margin of Frenchman Cap dome were originally recognized by McMillan (1970) in the Perry River area south of Mount Grace and Ratchford Creek. Two varieties were described (McMillan and Moore, 1974): Type I intrusive sills and dykes and a Type II extrusive layer. Detailed mapping in the Mount Grace area led to the discovery of the continuation to the north of the Type II carbonatite, referred to as the Mount Grace carbonatite (Höy and Kwong, 1986), and confirmed the suggestion (McMillan and Moore, *op. cit.*) that it is an extrusive layer. Subsequent detailed sampling and mapping (Höy and Pell, 1986) recognized that the Mount Grace carbonatite comprises a number of thin, laterally persistent tuff layers in addition to the main blocky tephra layer. The Mount Grace carbonatite has also been mapped north of Kirbyville Lake (Scammell, 1985) extending its total strike length to at least 100 kilometres.

Alkalic rocks, syenites and nepheline syenite gneisses, common in the Perry River area (McMillan, 1970; McMillan and Moore, 1974; Currie, 1976b) and Jordan River area (Fyles, 1970a), are restricted to a few occurrences in the Mount Grace area. Two separate units are recognized in the Perry River area: one is probably a metamorphosed and deformed intrusive syenite and the second, comprising thin layers intimately intermixed with fenite and intrusive carbonatite, probably results from ultrafenitization of paragneiss.

SETTING

The Mount Grace carbonatite, intrusive carbonatites and bodies of syenite gneiss occur within autochthonous paragneiss above the core gneisses of Frenchman Cap dome. The core of the dome comprises a mixed paragneiss and orthogneiss succession that is basement to the unconformably overlying paragneiss succession.

The structure of the northwestern margin of Frenchman Cap dome is dominated by the Phase 1 Mount Grace syncline (Höy, 1979; Chapter 3). The Mount Grace carbonatite occurs on both its limbs. Phase 2 folds, most prominent in the Perry River area (McMillan, 1973), also deform the Mount Grace carbonatite, intrusive carbonatites and syenite gneisses. Amphibolite facies regional metamorphism has recrystallized the carbonatites to form medium to locally coarse-grained granoblastic marbles.

CARBONATITES AND ALKALIC ROCKS

Carbonatites and alkalic rocks along the southern, western and northwestern margins of Frenchman Cap dome are restricted to the basal few hundred metres of the autochthonous cover succession. In the Jordan River area, a thick, laterally continuous syenite gneiss unit is intimately folded with surrounding calcareous paragneiss (Fyles, 1970a). It has been subdivided into a core of nepheline-bearing syenite gneiss surrounded by a thin screen of alkaline amphibolite which in turn is surrounded by less alkaline syenite gneiss (Currie, 1976a). Although Currie (*op. cit.*, page 24) argues that these alkaline rocks, including carbonatites in the Perry River area "arose entirely, or principally, as the result of intrusion of alkaline igneous rocks rather than partly by intrusion and partly by extrusion of lavas", it is suggested that the alkaline amphibolites and a large part of the surrounding syenite gneisses may be the products of ultrafenitization. Supporting evidence includes the spatial symmetry of the alkaline rocks with progressively less alkaline rocks at the margin of the complex and the gradational contacts between the major alkalic units and between syenite gneiss and surrounding paragneiss.

Carbonatites and alkalic rocks in the Perry River–Mount Grace area (Figure 17) include:

(1) Unit 4S–syenite and nepheline syenite gneiss,
(2) D & R–an intrusive syenite,
(3) Unit 3C–intrusive carbonatites and associated fenite,
(4) an intrusive carbonatite, the "Ren" carbonatite, and
(5) the extrusive Mount Grace carbonatite.

These units are generally concordant with the surrounding layering in the metasedimentary rocks and are commonly intimately intermixed. Descriptions following are summarized in part from McMillan (1973), McMillan and Moore (1974), Höy and Kwong (1986) and Höy and Pell (1986).

THE INTRUSIVE SUITE

UNIT 4S: SYENITE/NEPHELINE SYENITE

The largest syenite body in the Perry River area (Figure 17) is a concordant unit up to 300 metres thick and 12 kilometres long (McMillan, 1973). It is internally foliated and layered with alternating bands of syenitic and feldspathoidal rock. Paragneisses along its contact are fenitized with development of a rusty zone enriched in feldspar, pyroxene, muscovite and/or pyrrhotite. Analyses are shown in Table 2 and these, as well as some obtained by McMillan (1973), are plotted in Figure 18. They are all alkalic, but with variable compositions ranging from alkali gabbro to syenite. Semiquantitative emission spectrographic analyses of these samples indicate enrichment, relative to granites, of gallium (Ga), beryllium (Be), yttrium (Y), ytterbium (Yb), niobium (Nb), zirconium (Zr) and barium (Ba).

D & R ORTHOGNEISS

A quartz syenite orthogneiss is exposed northwest of Blais Creek within pelitic and hornblende paragneiss correlated with Unit 2. It is up to several hundred metres thick and greater than 1200 metres in length. Although it hosts a small molybdenite occurrence, the D & R (Chapter 5), little work has been done on it.

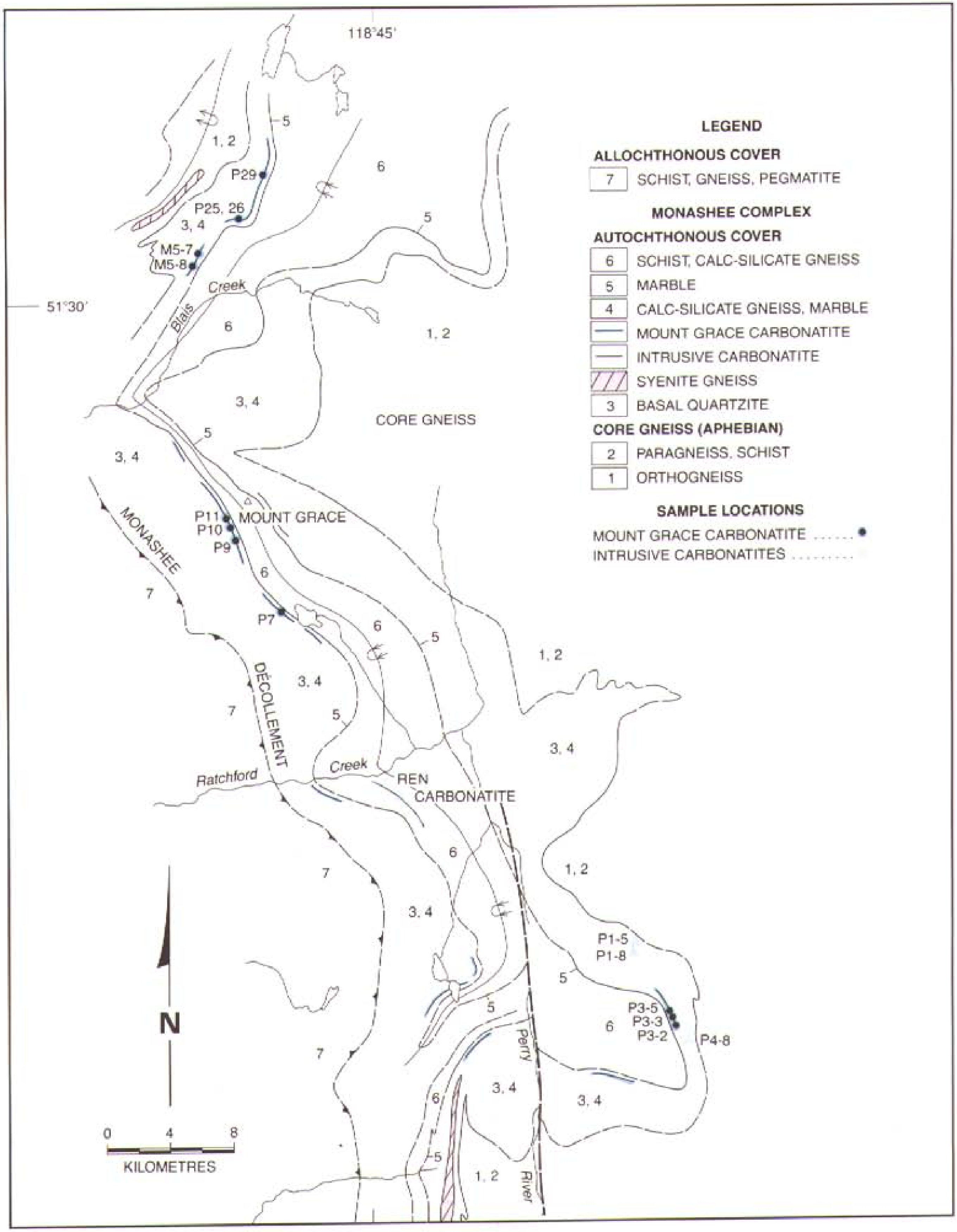


Figure 17. Location and structural setting of Mount Grace carbonatite, intrusive carbonatites and syenites in the Mount Grace–Perry River area. (Geology after McMillan, 1973; Höy, 1979a; Journeay, 1982; this report).

TABLE 2. CHEMICAL ANALYSES OF SAMPLES OF SYENITE GNEISS (UNIT 4S) AT THE HEADWATERS OF ANSTEY RIVER, PERRY RIVER AREA*
(in %)

Sample No.	SiO_2	Al_2O_3	Fe_2O_{3T}	MgO	CaO	Na_2O	K_2O	TiO_2	MnO	H_2O	$-H_2O$	CO_2	P_2O_5	S	FeO	Fe_2O_3
H78MC-1	53.57	19.76	5.54	0.37	2.79	6.037	10.9	0.597	0.154	0.45	0.05	0.62	<0.08	<0.01	1.30	4.10
H78MC-2	51.88	22.07	4.93	0.26	2.26	5.070	10.3	0.881	0.142	1.34	0.08	0.70	<0.08	<0.02	3.29	1.27

* For additional analyses, see McMillan and Moore (1974).
Analyses by the British Columbia Geological Survey Branch Analytical Laboratory.

UNIT 3C: CARBONATITE/FENITE

Unit 3C is a zone of minor carbonatite and intense fenitization near the base of Unit 3, just above the core gneisses (Plate 17). Two sections (H85P1 and H85P4; Figures 19 and 20) were measured; they appear to be part of a continuous unit at least 4 kilometres in length (*see* Figure 3 of McMillan, 1973; McMillan and Moore, 1974). The unit is concordant with layering but on a regional scale may cut up-section to the south. Carbonatites in the unit consist of thick layers or thin discontinuous lenses and are volumetrically less than the intensely fenitized rock.

Unit 3C Fenites

Fenites of Unit 3C are well layered, probably reflecting variation in composition of original sedimentary layers. Remnant, well-bedded metasedimentary calc-silicate gneiss, quartz feldspar paragneiss, and less commonly marble layers a few centimetres to greater than 5 metres in thickness, occur throughout the fenites (Plate 18). In general, contacts between fenite and quartz feldspar paragneiss are sharp, whereas those between fenites and more calcareous rocks are gradational. Furthermore, thick sections of mixed calc-silicate gneiss and paragneiss have gradational contact zones with enclosing fenite; the contact zones comprise interlayered fenite and paragneiss but no calc-silicate gneiss. These contact relationships suggest that fenitization is selective, preferentially affecting more calcareous layers and only with increasing intensity affecting the granular quartz feldspar paragneiss layers.

Three types of fenite are distinguished in Unit 3C:

(1) mafic pyroxene-amphibole fenite,
(2) albite fenite, and
(3) potassic feldspar-albite fenite that has been referred to as syenite, nepheline syenite or monzonite (McMillan and Moore, 1974; Höy and Pell, 1986).

Although the first two types are interlayered, commonly with gradational contacts, the more mafic fenite is far more abundant. The layering in the fenites is similar in scale to layering in adjacent or enclosing metasedimentary rocks and may reflect this regional metasedimentary layering. The potassic feldspar-albite fenite commonly has sharper contacts with the other fenites and may occur as thicker, more massive units.

Pyroxene-amphibole fenites, the most abundant fenites in Unit 3C, are dark green to black, massive, foliated or well-layered pyroxenites and amphibolites. Biotite content ranges from trace amounts to over 50 per cent; sphene, ilmenite and magnetite are conspicuous throughout the fenite and also commonly occur as well-formed crystals several centimetres across in pods with coarse-grained calcite, amphibole and pyroxene. Aegerine-augite is the dominant pyroxene, occurring as small stubby euhedral grains or as large anhedral poikiloblastic crystals that enclose albite or sphene. Aegerine occurs locally and in one sample is the only pyroxene. Amphiboles include riebeckite associated with aegerine, and sodic actinolite (?) or sodic hornblende (?) with aegerine-augite. They occur as large anhedral poikiloblastic grains with pyroxene, calcite and sphene inclusions, as small euhedral grains, or as clusters of small anhedral to subhedral grains. Richterite, intergrown with riebeckite, occurs as a late mineral within and along cleavage traces in aegerine. Variable amounts of albite ($<An_5$), phlogopite, apatite and sphene are present in some samples; interstitial calcite is common. Potassium feldspar (orthoclase) and nepheline are rare, the latter only recognized in the aegerine fenite. Epidote, zircon, hematite, magnetite, chalcopyrite and ilmenite are common accessory minerals.

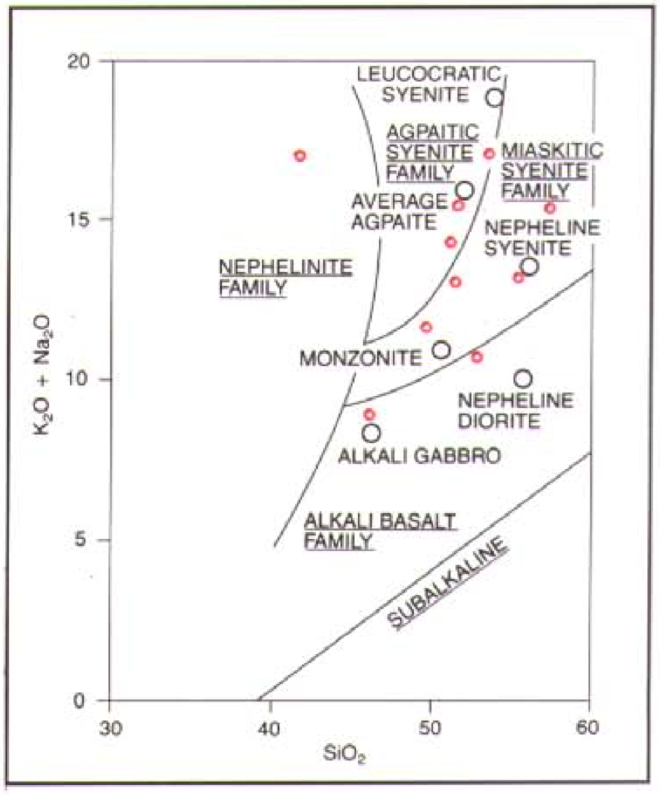


Figure 18. Plot of analyses of syenite gneiss, Unit 4S, Perry River area; the diagram is from Currie (1967a); shown in circles are compositions of various types of alkaline rocks.

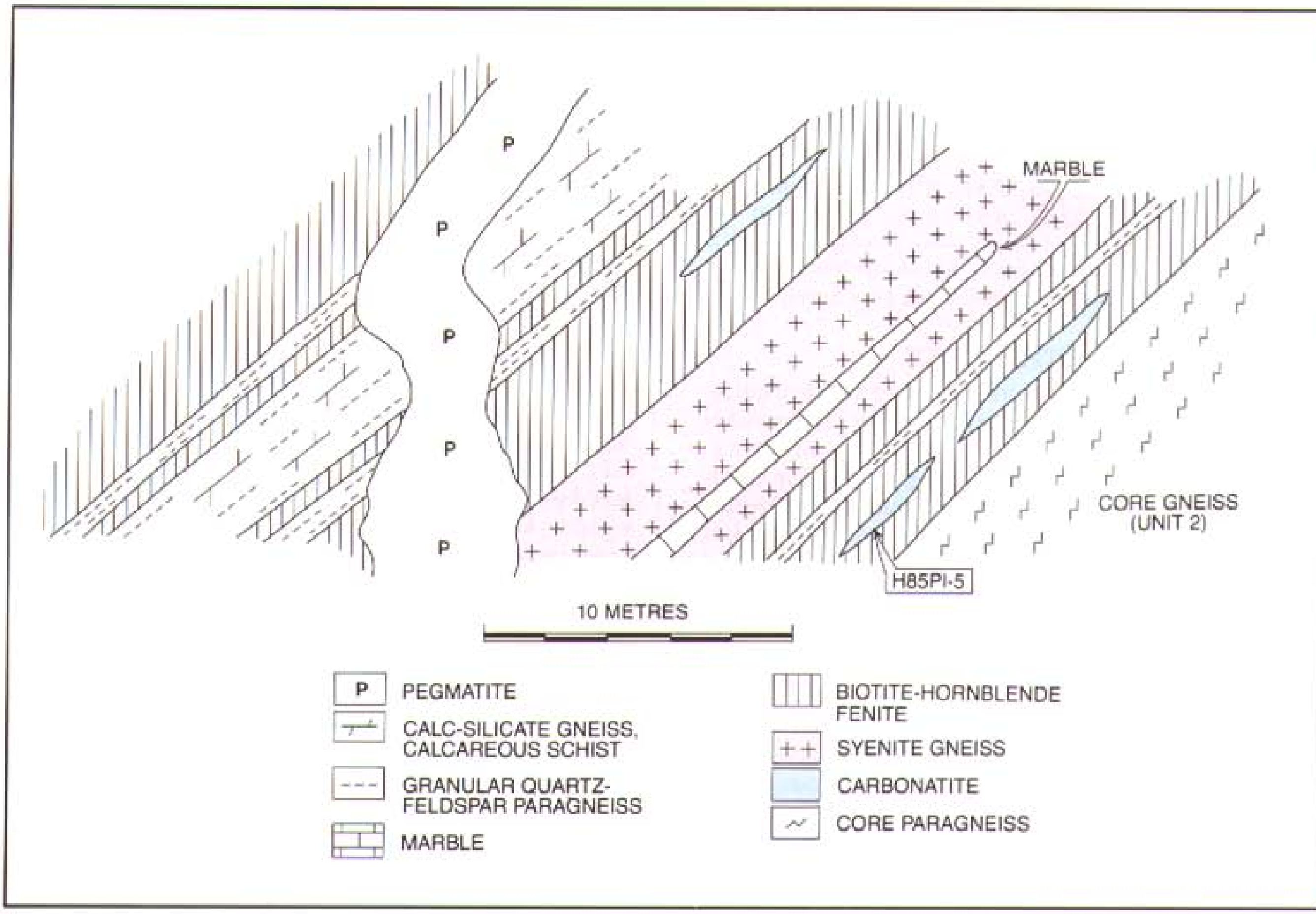


Figure 19. A schematic vertical section through the intrusive carbonatite-fenite, Unit 3C, at site H85P1 (*see* Figure 17).

The pyroxene-amphibole fenites are interlayered with minor, more leucocratic fenites that are characterized by appreciable quantities of albite. A granoblastic albite fenite, consisting of approximately 90 per cent well-twinned, unaltered albite (An_{3-5}) with poikiloblastic aegerine-augite and minor biotite, sphene, apatite, epidote, microcline, magnetite and sulphides, is the least mafic fenite in this series. It is similar to the "albitite" clasts in the Mount Grace carbonatite. A thin albite fenite layer at site H84P1 contains abundant coarse molybdenite.

The potassic feldspar-albite fenites are composed of 70 to 80 per cent plagioclase (andesine), microcline and perthite in varying proportions. Principal mafic minerals are aegerine, aegerine-augite and biotite, and accessory minerals include calcite, muscovite, allanite, sphene, apatite, magnetite, ilmenite, pyrrhotite and chalcopyrite. Variable amounts of nepheline may also be present.

Unit 3C Carbonatites

Carbonatites within albite and pyroxene-amphibole fenites occur as relatively thick, buff-weathering, foliated and laminated layers (Plate 19), as swirled discontinuous lenses (Plate 20A), or as small coarse-grained irregular pods with typically calcite centres and biotite-amphibole margins. Thin continuous carbonatite layers also occur in the potassic feldspar-albite fenites and in metasedimentary layers (Plate 20B). These are generally fine grained, include thin discontinuous pyroxene-amphibole fenite lenses and may have pyroxene-amphibole fenite margins. The carbonatites consist of 80 to 90 per cent calcite, variable amounts of sodic amphibole, apatite and phlogopite, and may contain minor sphene, aegerine, plagioclase, magnetite, pyrrhotite, pyrochlore, chalcopyrite, pyrite and ilmenite.

Discussion

The fenites result from intense alkaline metasomatism of original calc-silicate and quartz feldspar paragneisses. Composition of the original sedimentary layers undoubtedly controlled the extent of fenitization with more calcareous layers apparently more reactive with the alkaline solutions. Two trends are apparent, an iron-magnesium trend and an alkalic trend, and both are accompanied by aluminum, iron, phosphorus and calcium metasomatism. Furthermore, alkali metasomatism may be either dominantly sodic or potassic-sodic producing albite fenites or phlogopite and potassic feldspar-albite fenites. With increasing intensity, pyroxene amphibole fenitization appears to evolve into alkali fenitization. The potassic feldspar-albite fenites are similar to syenites and nepheline syenites but they commonly retain the well-bedded nature of the protolith sedimentary rocks, many include remnant sedimentary layers, and some have gradational contacts with other fenites. With extreme develop-

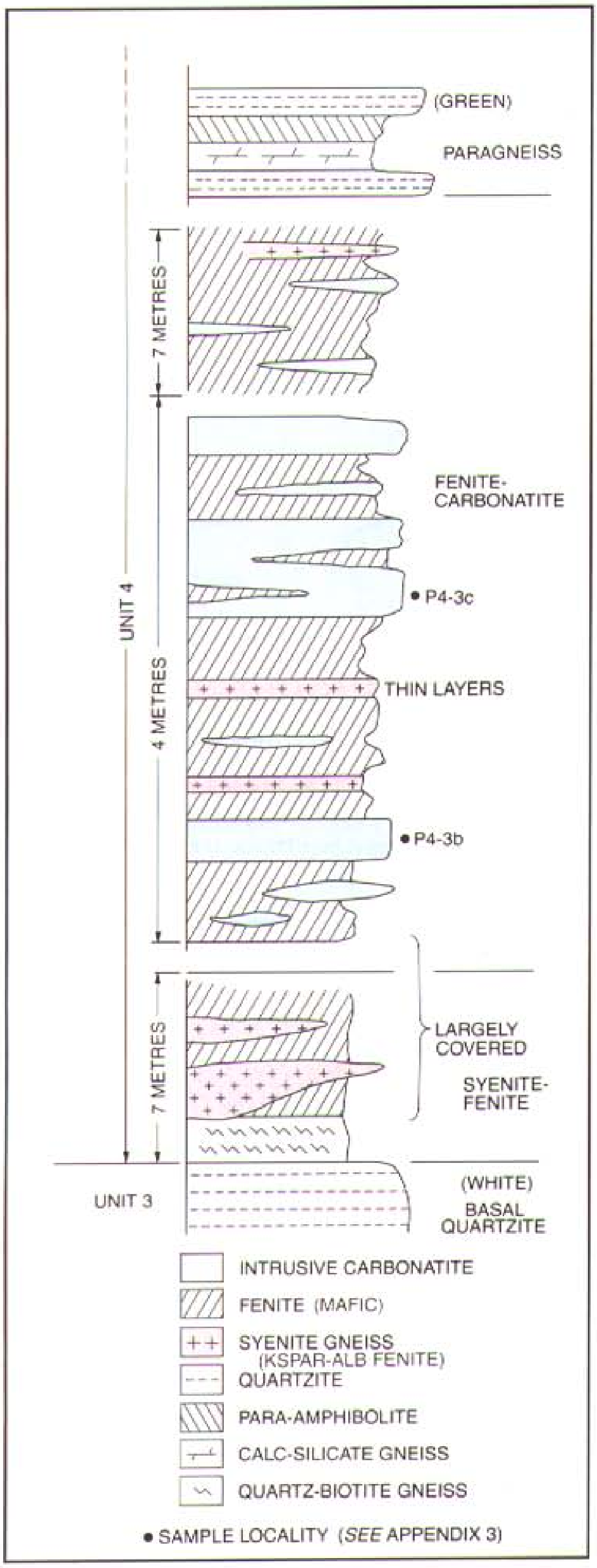


Figure 20. A measured section through the intrusive carbonatite-fenite, Unit 3C, at site H85P4 (*see* Figure 17).

ment, they have remobilized to produce rheomorphic fenites with sharp intrusive contacts and showing crosscutting relationships with adjacent rocks.

Carbonatites include the thick buff-weathering layers enclosed in fenite as well as small discontinuous swirled lenses and coarse-grained phlogopite and amphibole-rich pods or "sweats" The thick layers are interpreted to be intrusive carbonatites whereas the discontinuous lenses and pods may be hydrothermal carbonatites that crystallized from late volatile-rich magmatic fluids. These may be analogous to pegmatites in siliceous intrusive complexes.

REN CARBONATITE

The Ren carbonatite, named after the claims on which it occurs, is a concordant unit at least 3 kilometres long and varying in width from 20 to 300 metres (Figures 21 and 22). It outcrops on the southern slopes of Ratchford Creek in the core of the Mount Grace syncline (Figure 17). It is within Unit 6 and hence occurs stratigraphically above other known intrusive carbonatites, syenites and the extrusive Mount Grace carbonatite. The following description is summarized largely from Pilcher (1983), augmented by personal communications with staff of Duval International Corp., a brief visit by the author, and analyses of samples by the Analytical Laboratory of the British Columbia Geological Survey Branch.

The Ren carbonatite has mafic fenite margins and zones within it (Plates 21 and 22; Figure 22). A zone of intense fenitization extends several hundred metres into the hangingwall and includes within it thin discontinuous carbonatite lenses, remnant paragneiss layers cut by biotite-amphibole-carbonate veins, and minor quartzite layers. Nepheline syenites reported within the carbonatite may be potassic feldspar-albite fenites similar to those described in Unit 3C. The Ren carbonatite is massive to well layered, is orange-brown weathering and consists of 60 to 80 per cent calcite, 10 to 30 per cent apatite, accessory biotite, amphibole, pyroxene and sphene, and minor pyrrhotite, pyrite, magnetite, ilmenite, sphalerite, chalcopyrite, pyrochlore (?) and monazite (?).

Analyses of the Ren carbonatite by Duval International Corp. are summarized in Table 5 and analyses of samples in section Ren 5 (Figure 22) are listed in Table 3 and plotted on Figure 26. These analyses indicate that the rock is a magnesio carbonatite, in contrast to predominantly sövites in the Mount Grace carbonatite and the intrusive Unit 3C carbonatite. Additional analyses are needed, however, to confirm this difference. The Ren carbonatite is enriched in the light rare earth elements with lanthanum (La) ranging up to 0.69 per cent, cerium (Ce) to 1 per cent, and neodymium (Nd) to 0.06 per cent. Niobium (Nb) content averages 618 ppm and tantalum (Ta) is low, ranging from less than 3 ppm to 72 ppm.

MOUNT GRACE CARBONATITE

GENERAL DESCRIPTION

The Mount Grace or Type II carbonatite of McMillan and Moore (1974) is essentially a thin calcite marble layer that averages between 3 and 5 metres in thickness and has been traced or extrapolated for at least 100 kilometres of strike

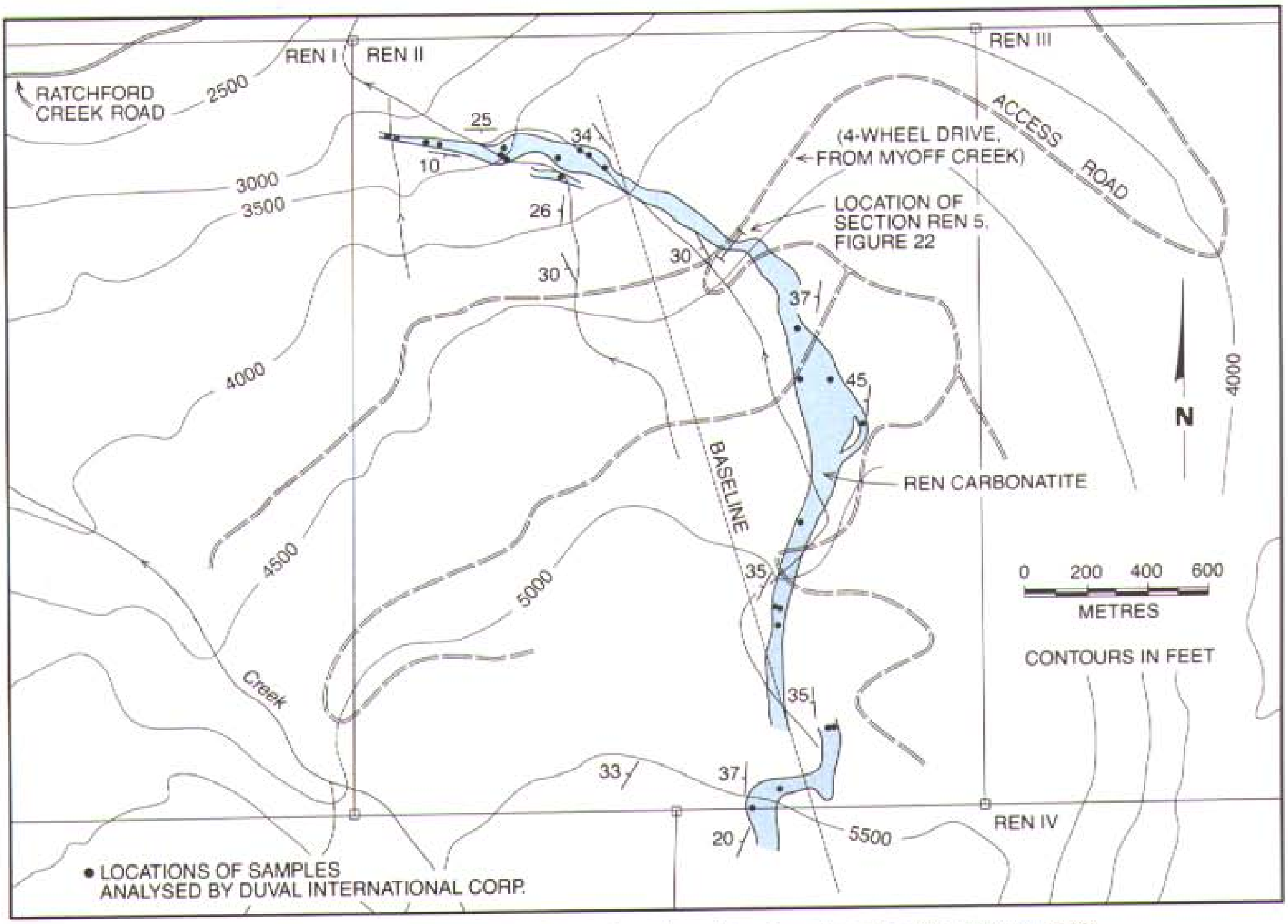


Figure 21. Map showing the form of the Ren carbonatite and location of samples (from Pilcher, 1983).

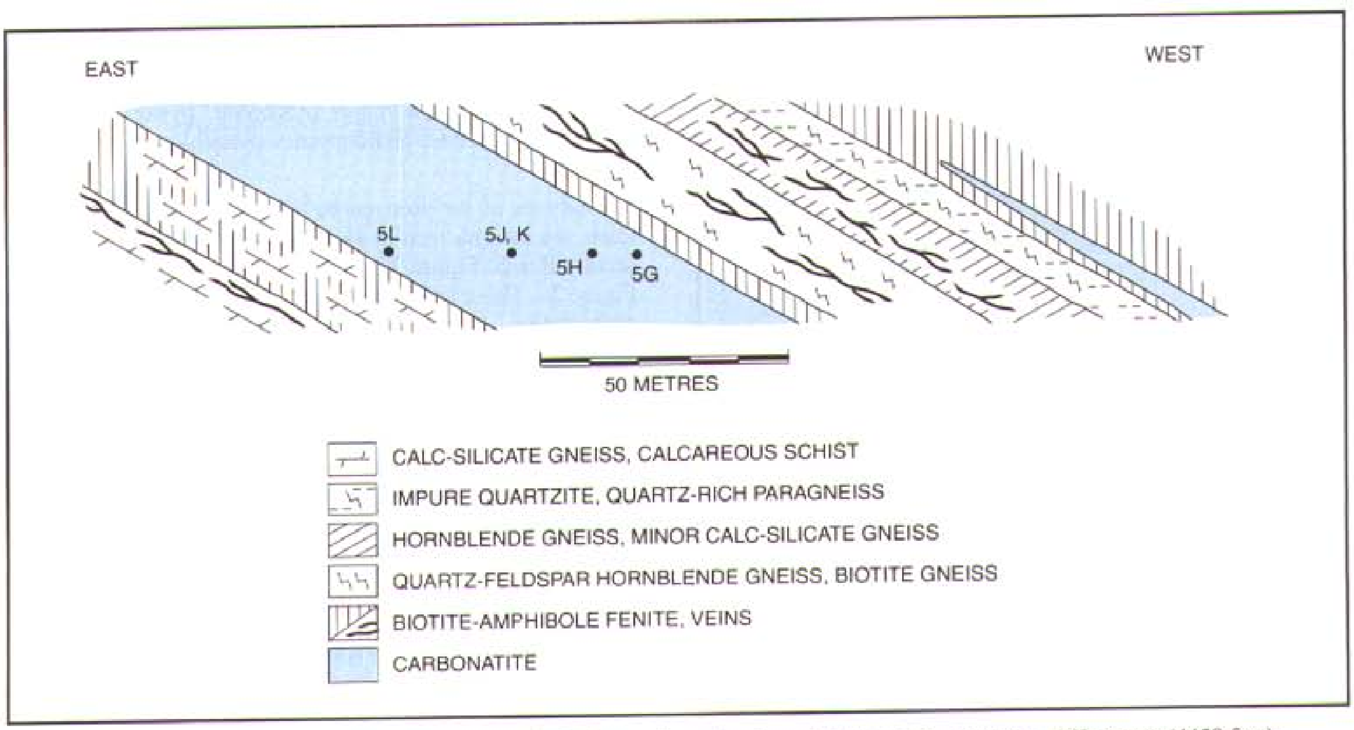


Figure 22. A schematic vertical section through the Ren carbonatite, viewed to the south, elevation 1360 metres (4450 feet); numbers refer to sample localities listed in Table 3. (*See* Figure 21 for location.)

TABLE 3. CHEMICAL ANALYSES OF REN CARBONATITE, SECTION REN 5
(See Figure 21 for location.)

TABLE 3A
(in %)

Field No.	Lab. No.	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	CO_2	S	LOI
5-G	32433	1.51	0.06	0.22	3.45	0.31	6.30	43.82	0.08	0.02	4.20	36.30	0.41	36.61
5-J	32435	4.57	0.04	0.55	2.87	0.43	17.30	31.05	0.24	0.12	3.60	38.47	0.06	38.27
5-K	32436	0.85	0.04	0.07	2.71	0.41	16.69	33.83	0.04	0.01	2.16	41.41	0.14	42.46
5-L	32437	4.15	0.06	0.72	3.29	0.43	15.40	32.86	0.16	0.17	3.60	36.44	0.02	38.36

Analyses by the British Columbia Geological Survey Branch Analytical Laboratory.

TABLE 3B
(in ppm)

Field No.	Sr	Zr	Rb	Nb	Ba	Cr	Y
5-G	5188	297	26	60	213	<10	60
5-J	4628	96	26	27	1133	36	27
5-K	4271	92	25	25	676	<10	25
5-L	4828	108	29	1516	162	38	31

Analyses by the British Columbia Geological Survey Branch Analytical Laboratory.

length. It occurs within a calc-silicate gneiss, pelitic gneiss and marble succession (Unit 4) between underlying core gneisses and the basal quartzite and overlying marble of Unit 5. In the Mount Grace area, the Cottonbelt lead-zinc layer occurs in the overlying Unit 6. The Mount Grace carbonatite is repeated on both limbs of the Mount Grace syncline (Höy and McMillan, 1979; Höy and Kwong, 1986) and, to the north, on the limbs of the Kirbyville anticline (Brown, 1980; Scammell, 1985).

The original thickness of the Mount Grace carbonatite is not known; it has undoubtedly been thinned dramatically on the limbs of major folds and perhaps locally thickened near fold hinges. It is exposed almost continuously on the inverted southwest limb of the Mount Grace syncline and intermittently in covered areas several kilometres further south. It is hidden beneath overburden to the north of Mount Grace, but has been intersected in two drill holes 1 kilometre north of known exposures; 5 kilometres further north it reappears at the same stratigraphic position in exposures north of Blais Creek (Figure 17).

The contacts of the Mount Grace carbonatite with overlying and underlying calcareous gneisses are generally sharp, but may be gradational through approximately 1 metre into grey-weathering, massive to thin-bedded calcite marble. In contrast with intrusive carbonatite in the Perry River area, the Mount Grace carbonatite has no fenitized margins.

In the field, it is recognized and characterized by an unusual pale to medium brown-weathering colour. Grains of dark brown phlogopite, colourless apatite and needles of amphibole weather in relief. Pyrrhotite, pyrochlore and zircon are locally developed accessory minerals.

CLASTS

The Mount Grace carbonatite is commonly internally bedded with a layer or several layers of "blocky" tephra interbedded with finer grained, massive or laminated carbonatite. The blocky tephra layers contain three distinctive types of matrix-supported clasts: small granular albitite clasts up to 3 centimetres in diameter, consisting of pure albite or albite with variable amounts of phlogopite (Plate 23A); "syenite" clasts, 1 to 10 centimetres in diameter, consisting of potassic feldspar with variable amounts of plagioclase, calcite, apatite and rare feldspathoids (Plate 23B); and large rounded to subrounded heterolithic clasts that are commonly up to 20 centimetres in diameter. These clasts are generally randomly distributed throughout the blocky tephra, but in some layers they are concentrated in the central portion or occasionally graded with clast size increasing up-section.

The albitite and "syenite" clasts are interpreted to be pieces of fenite similar to the albite and potassic feldspar-albite fenites associated with the intrusive carbonatites in the Perry River area. Albite fenites have been described adjacent to carbonatites elsewhere (*see* Le Bas, 1981); they generally occur at deeper structural levels than the more potassic fenites. The interpretation that these clasts in the Mount Grace area are fenite clasts suggests that there is a vertical zonation with more sodic fenites developed at deeper levels and more hydrous, potassic and mafic fenites at shallower depths adjacent to the intrusive carbonatites; albite fenites are generally the most abundant fenite clasts in the Mount Grace carbonatite tuff although potassic feldspar-albite clasts are most abundant in the thick section at site P29.

The lithic clasts (Plates 24A and 24B) are generally subrounded, matrix supported and comprised of gneiss, quartzite and schist derived primarily from the underlying core gneisses. They have a pronounced layering or foliation that is randomly oriented with respect to the regional mineral foliation and many are internally folded. These observations suggest that a metamorphic-structural event occurred in the core gneisses prior to deposition of the Mount Grace tuff and enclosing autochthonous cover succession, an event that is only recorded in these lithic clasts in the Mount Grace tuff.

REGIONAL TRENDS

The Mount Grace tuff has been examined and sampled throughout most of its length in order to document variations in chemical and mineralogical composition, thickness and clast size or lithology that may be related to distribution

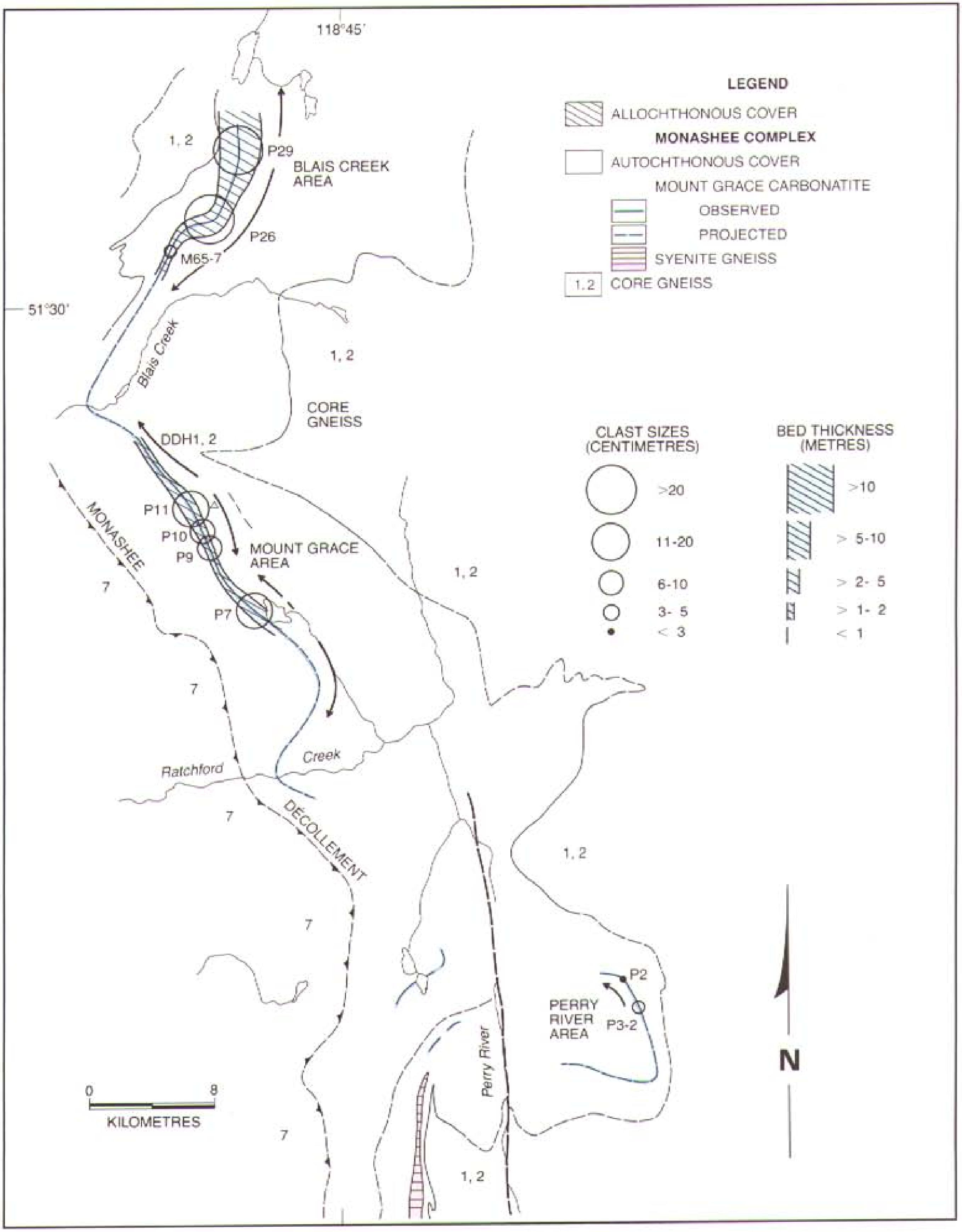


Figure 23. Map illustrating the thickness of the Mount Grace carbonatite and the maximum clast sizes (average diameter of five largest clasts in a 1-metre-square area); note correlation between bed thickness and clast sizes. Arrows show suggested depositional trends of tuff away from vent areas.

TABLE 4. THICKNESS AND DISTRIBUTION OF CLASTS, MOUNT GRACE CARBONATITE

Location	Layer Thickness	Clast Type (Listed in Order of Abundance)	Average Size (Five Largest Clasts	Maximum	Note
H85P3-2	1 m	lithic	2–3 cm	13 cm	
		albite fenite	1–2 cm	2 cm	
		Kspar-albite fenite (rare)		8 cm	
H85P-2	0.5 m	albite fenite	0.5–1 cm	5 cm	
		lithic	<0.5 cm	5 cm	
H85P-7	<1 m	lithic	10–12 cm	18 cm	exposed width is approximately 1 m
		albite fenite	2 cm	<2 cm	
H85P9		lithic	4–5 cm	5 cm	
		albite fenite	<2 cm	<2 cm	
H85P10	2.5 m	lithic	8–10 cm	20 cm	
		albite fenite	1–2 cm	2 cm	
H85-CAMP	2–3 m	lithic	15–16 cm	40 cm	
			2–3 cm	3 cm	
DDH1,2	~2 m				
H85P26	8–9 m	lithic	18–20 cm	40 cm	thickness includes ~2.5 m of mixed marble and tuff
		albite fenite			
		Kspar-albite fenite			
H85P29	>20 m	lithic	50–100 cm	>1 m	data estimated
		Kspar-albite fenite			
		albite fenite			

surrounding eruptive vents. The results of the field observations are summarized in Table 4 and Figure 23; chemical variations are discussed later.

There is a direct correlation between the thickness of the Mount Grace carbonatite and the size of included lithic clasts. In the Perry River area, its thickness is generally less than a metre and the average maximum clast size (the average size of five largest clasts measured in an area approximately 1 metre square) is 2 to 3 centimetres (Plate 25A). Larger clasts (to 13 centimetres maximum) are uncommon, but include folded lithic fragments and rare potassic feldspar-albite fenite ("syenite") clasts (Plate 25B). In the Mount Grace area, the thickness of the carbonatite tuff layer varies from approximately 1 to 2 metres in two drill intersections to the north, to a maximum of 3 metres just north of site P11. It decreases southward but appears to increase again in the most southerly exposures. The size of lithic clasts increases proportionately with thickness, with clasts to 40 centimetres in diameter in the thickest sections, but only 5 centimetres in the thinnest sections.

In the Blais Creek area, the thickness of the Mount Grace carbonatite increases dramatically northward, accompanied by an increase in clast size. Southern exposures are approximately a metre thick with only small clasts. At site H85P25 (Plate 26A) the carbonatite is 8.2 metres thick (Figure 24); clasts are abundant with maximum clast sizes averaging 18 to 20 centimetres in diameter and with individual clasts up to 40 centimetres in diameter. The carbonatite in this structurally inverted section includes a thick section of mixed coarse blocky tephra and fine-grained tuff and marble at the stratigraphic base, overlain by interlayered impure metasedimentary marble and tuff (Plate 26B). Within the basal section are interbedded coarse tephra layers, fine-grained layers and a number of coarsening-upward cycles. The top of the carbonatite is dominated by impure siliceous marble that contains a few thin brown-weathering, fine-grained tuff layers. To the north (section H86CB22, Figure 25), the carbonatite continues to thicken, increasing to greater than 20 metres. Thin-bedded, fine-grained carbonatite tuff layers are interbedded with calc-silicate gneiss and thin marble layers in the basal 10 metres (Plate 27B). Thin tuff layers die out or become indistinguishable from marbles of sedimentary origin in section P25 and P26 to the south. The thickness of carbonatite tephra layers and the size of included clasts increase up-section to a sharp contact with impure marble or calc-silicate gneiss at the stratigraphic top. Large gneissic blocks, several metres across, occur throughout the coarse sections (Plate 27A) and large coarse-grained blocks of syenite are also abundant. Only a few thin, fine-grained tuff layers occur in the overlying metasedimentary rocks.

These sections indicate explosive volcanism began with minor intermittent deposition of fine ash, followed with increasing intensity, by eruption of a thick accumulation of coarse blocky tephra. Explosive activity appears to have ceased abruptly, but was followed by very minor, intermittent and local deposition of fine ash.

The correlation between thickness and size of included clasts and the systematic change in these parameters in restricted areas suggest that these features indicate proximity to a volcanic vent. The abundance of syenite blocks of probable igneous origin in the thick section H86CB22 tends to confirm this suggestion. At least three separate vent areas are indicated: in the vicinity of site P29 (section H86CB22) north of Blais Creek and near sites P7 and P11 in the Mount Grace area (Figure 23). Despite the proximity to intrusive carbonatites in the Perry River area, the narrow width of the Mount Grace carbonatite and the small size of included clasts suggest the carbonatite tuff here is relatively distant from a volcanic vent.

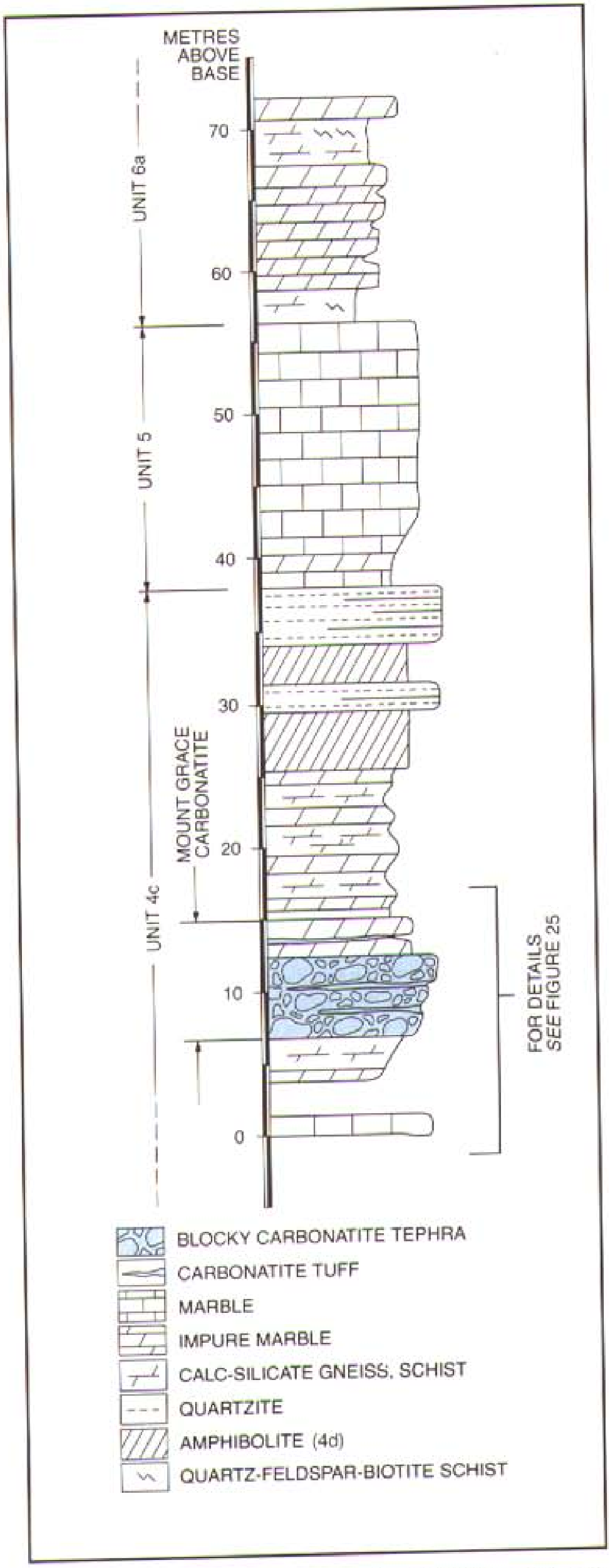


Figure 24. A measured section at stations H85P25 and H85P26, Blais Creek area, that includes the Mount Grace carbonatite and adjacent host rocks.

MINERALOGY

The carbonatite is a recrystallized medium to coarse-grained marble, composed of 80 to 90 per cent calcite in a mosaic of equidimensional grains. Locally, calcite has a cataclastic texture with large grains set in a finer, granulated matrix. Small grains of dolomite are interspersed, as well as exsolved from calcite, and large pale to medium brown subhedral phlogopite and subrounded grains of plagioclase and apatite are common and generally widely dispersed (Plate 28A). Muscovite occurs as small randomly distributed grains, and a grey-green amphibole with anomalous blue interference colours (riebeckite?) forms well-cleaved, subhedral to euhedral crystals (Plate 28B). Pyrochlore occurs as subhedral, subrounded grains up to 2 millimetres in diameter that are commonly zoned with dark cores and lighter rims (Plate 29). Pyrrhotite and sphene are common accessory minerals. Magnetite, pyrite, ilmenite, graphite and rarely chalcopyrite, molybdenite and columbite-tantalite have been identified in a few samples.

Six polished sections were studied with a scanning electron microscope equipped with a semiquantitative energy dispersive X-ray analyser. It was recognized (Höy and Kwong, 1986) that the characteristic elements barium, strontium, niobium and the light rare earth elements are concentrated in discrete, finely disseminated minerals rather than as trace elements in the major and accessory mineral phases. The finely disseminated minerals are pyrochlore, monazite, barite, strontianite, and probably ancylite $[(Sr,Ca)(La,Ce)(CO_3)_2(OH)H_2O]$, synchysite $[(Ca,Ce)(CO_3)F]$, and codazzite(?) $[(Ca,Mg,Fe,Ce)CO_3]$. Because hydrogen, carbon and fluorine were not determined, the latter minerals are not confirmed, but inferred from the relative proportions of the dominant heavy elements. These minerals occur as subhedral to anhedral grains that commonly are only 1 to 20 microns in size. Ancylite and monazite tend to occupy interstitial spaces, whereas the others are more randomly distributed.

Preliminary microbeam and X-ray diffraction studies of the major and accessory minerals in the carbonatite layer (Höy and Kwong, 1986) reveal that the apatite is fluorapatite, almost devoid of light rare earth elements (LREE); plagioclase is albite (An_{3-6}), and phlogopite is iron rich and slightly titaniferous. Calcite ranges in composition from pure $CaCO_3$ to calcite with up to 10 mole per cent of total $MnCO_3$ plus $FeCO_3$ components. Dolomite, commonly exsolved from calcite, is ferroan. Chemical analyses of hand-picked amphibole grains, augmented by X-ray diffraction data, indicate that the amphibole is sodic, most probably an iron-rich riebeckite or eckermannite.

CHEMISTRY OF MOUNT GRACE AND INTRUSIVE CARBONATITES

Major and minor oxide, trace element and rare earth element analyses of samples of the Mount Grace carbonatite, intrusive carbonatites, and one sample of a hydrothermal carbonatite in Unit 3C are listed in Appendices 2 and 3 and summarized in Table 5. The carbonatites have a large compositional range with respect to the major and minor oxides. A plot of whole rock analyses on the triangle CaO–MgO–(Fe_2O_3 + FeO + MnO) (Figure 26) indicates that most of the

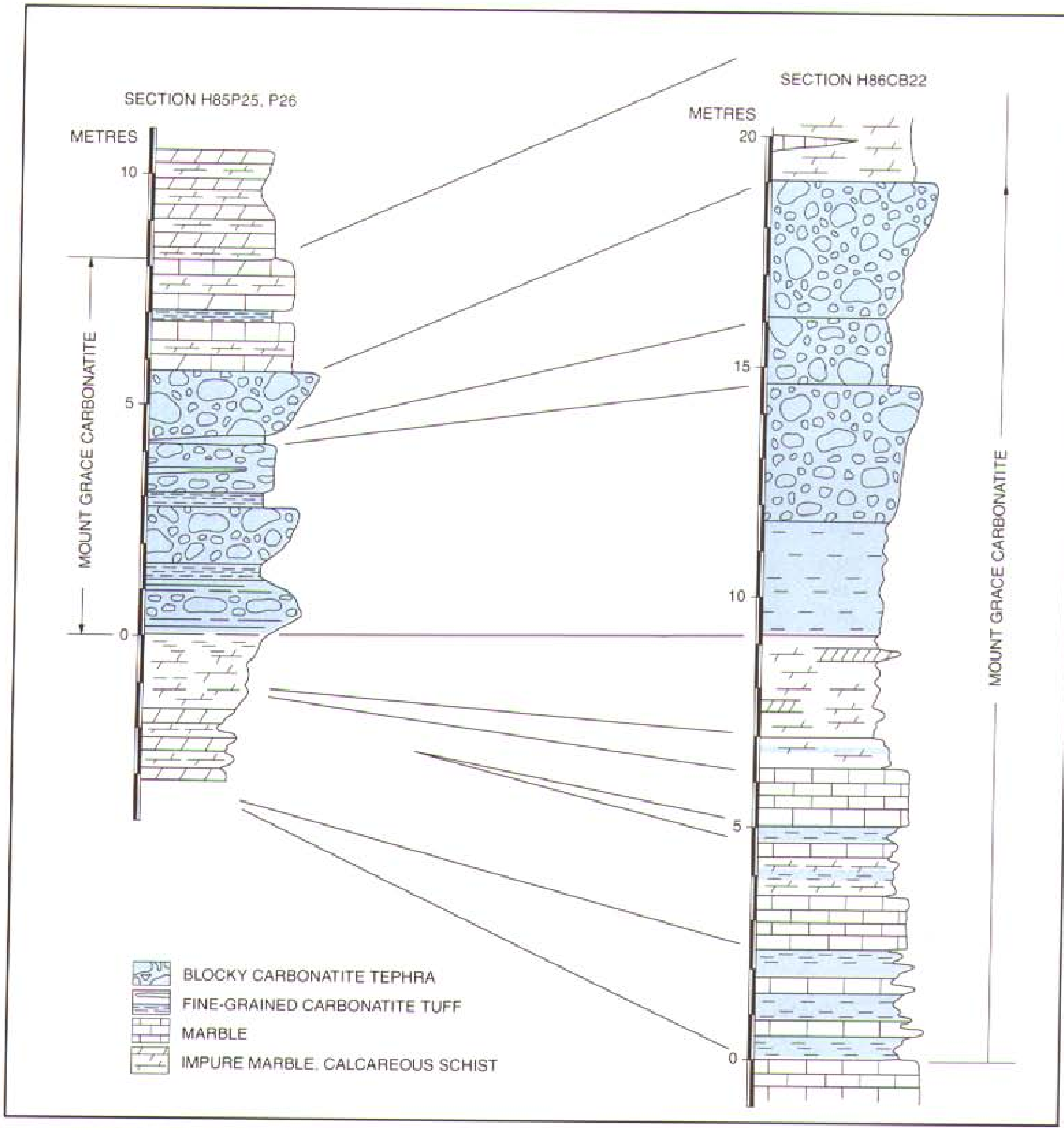


Figure 25. Detailed sections of the Mount Grace carbonatite, Blais Creek area (stations H85P25, H85P26 and H86CB-22).

Mount Grace carbonatite analyses fall within the sövite field as is expected from their high calcite content, however, a considerable number plot within the magnesiocarbonatite and ferrocarbonatite fields. The intrusive carbonatites, including the Ren carbonatite, are sövites and magnesiocarbonatites.

The carbonatites are highly enriched in strontium, barium and manganese, relative to carbonates of sedimentary origin. These element concentrations are compared with analyses of metasedimentary marbles from the enclosing succession and with the compositions of average marine sedimentary carbonate (Figure 27). Five of the metasedimentary marbles are from drill core (*see* Figure 36, Chapter 5) and two are from surface exposures; all occur within 12 metres of the Mount Grace carbonatite layer. Strontium averages 4460 parts per million (ppm) in the Mount Grace carbonatite and approx-

TABLE 5. SUMMARY OF GEOCHEMICAL DATA ON THE MOUNT GRACE CARBONATITE, THE REN CARBONATITE AND OTHER INTRUSIVE CARBONATITES OF UNIT 3C
(in ppm)

	Mount Grace				Ren*				Intrusive		
	Range	X̄	N		Range	X̄	N		Range	X̄	N
Ce	151–4164	886.5	36	Ce	28–9890	876	59	Ce	614–7630	2795	4
Dy	4–20	10	17					Dy	13–55	32	4
Er	<100	<100						Er	<100	<100	
Eu	2–13	7	17	Eu	<1–15	8.2	22	Eu	9.83	30	4
Gd	<240–620	(400)	17					Gd	400–<2800	1088	4
Ho	<1–8	2.7	17					Ho	<3–9	6	4
La	94–3238	542	35	La	14–6965	471	21	La	317–3800	1573	4
Lu	0.2–1.0	0.5	17	Lu	<1	<1	21	Lu	0.2–1.7	0.9	4
Nd	65–924	285	36	Nd	15–560	224	21	Nd	271–3540	1186	4
Pr	<60–170	(70–100)	17					Pr	<71–<550	<300	4
Sc	2.14–8.75	5.2	17					Sc	0.12–8.45	2.3	4
Sm	8.2–56.0	27.5	17	Sm	3–71	42.8	21	Sm	36–313	116	4
Tb	0.8–3.3	1.6	15	Tb	1–4	2.5	21	Tb	1.6–11.0	5.1	4
Th	0.5–30.6	6.7	17	Th	<1–32.5	5.1	21	Th	<0.5–35.9	16.5	?
Tm	<0.5–1.6	1.0	15					Tm	1.2–6.7	3.3	4
Yb	1.6–8.7	4.0	15	Yb	1–3	2	21	Yb	2.9–17.4	9.5	4
Nb	tr–1200	272.9	36	Nb	25–2330	618	24	Nb	8–50	34.5	4
Ta	6–68	19	6	Ta	<3–72	17.4	22	Ta			
Y	10–84	35.9	17	Y	<5–60	31.3	22	Y	34–160	98.5	4
Sr	600–7300	4460	36	Sr	315–5291	3353	24	Sr	2200–31000	16050	4
Ba	518–4000	2363	36	Ba	162–5162	2345	21	Ba	1155–2539	1529	4
Mn	400–7500	3110	35	Mn	1280–4972	3056	21	Mn	580–1300	845	4
Ti	25–1300	591	17					Ti	25–2200	1023	4
Zr	<3–36	10.1	8	Zr	92–297	148	4				
Ti	114–4225	1096	26								

X̄ — Average value.
N — Number of analyses.
* Rare earth element data, Nb and Ta are from Duval International Corp.

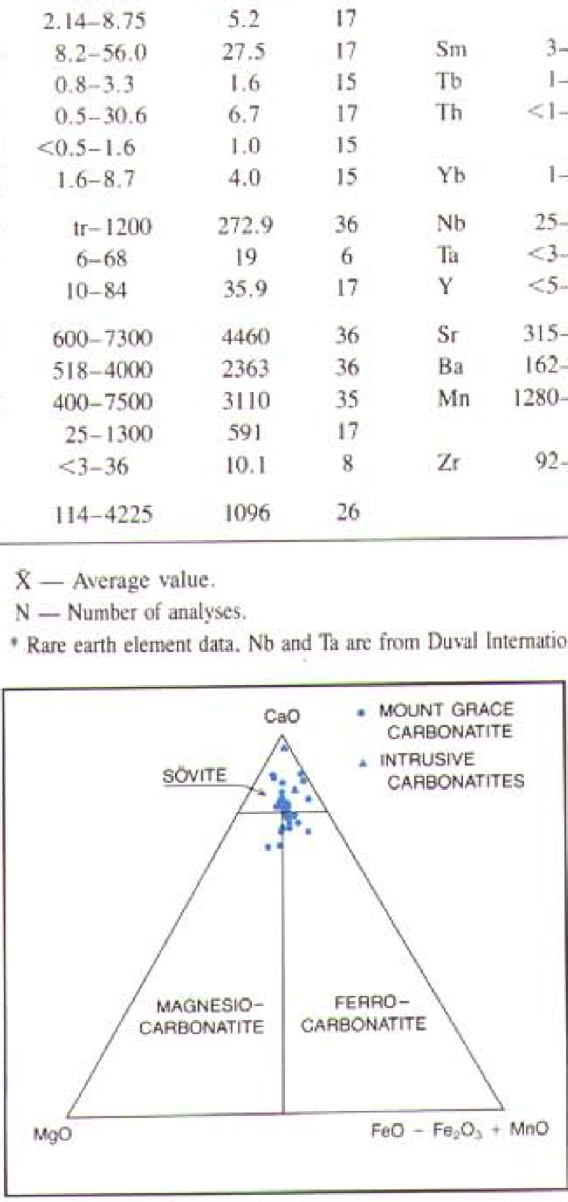


Figure 26. A CaO-MgO-(Fe_2O_3 + FeO + MnO) plot showing analyses of carbonatites, Mount Grace and Perry River areas (plot is from Wooley, 1982).

imately 3300 ppm in the intrusive carbonatites, approximately four times the average value in the metasedimentary marble and seven times the sedimentary carbonate average. The average barium content is similar in both intrusive and extrusive carbonatites (2300 ppm), six times higher than that in the metasedimentary marbles, and manganese (3100 ppm) is also considerably higher in the carbonatites. These high values are characteristic of carbonatites elsewhere (*see*, for example, Le Bas, 1981) and serve as a relatively quick and inexpensive chemical test for distinguishing carbonatites from carbonates of sedimentary origin. Niobium values are considerably higher in the Ren intrusive carbonatite (approximately 600 ppm average) than in the Mount Grace carbonatite (270 ppm average).

The Mount Grace carbonatite has total rare earth element (REE) concentrations that range from approximately 600 ppm to greater than 8000 ppm (0.8 per cent) with average values of 0.1 to 0.2 per cent (Table 5; Appendix 3C). Analyses of six samples through the Mount Grace carbonatite, taken from two holes drilled by Metallgesellschaft in 1979 (Figure 28), suggest that the carbonatite layer is pro-

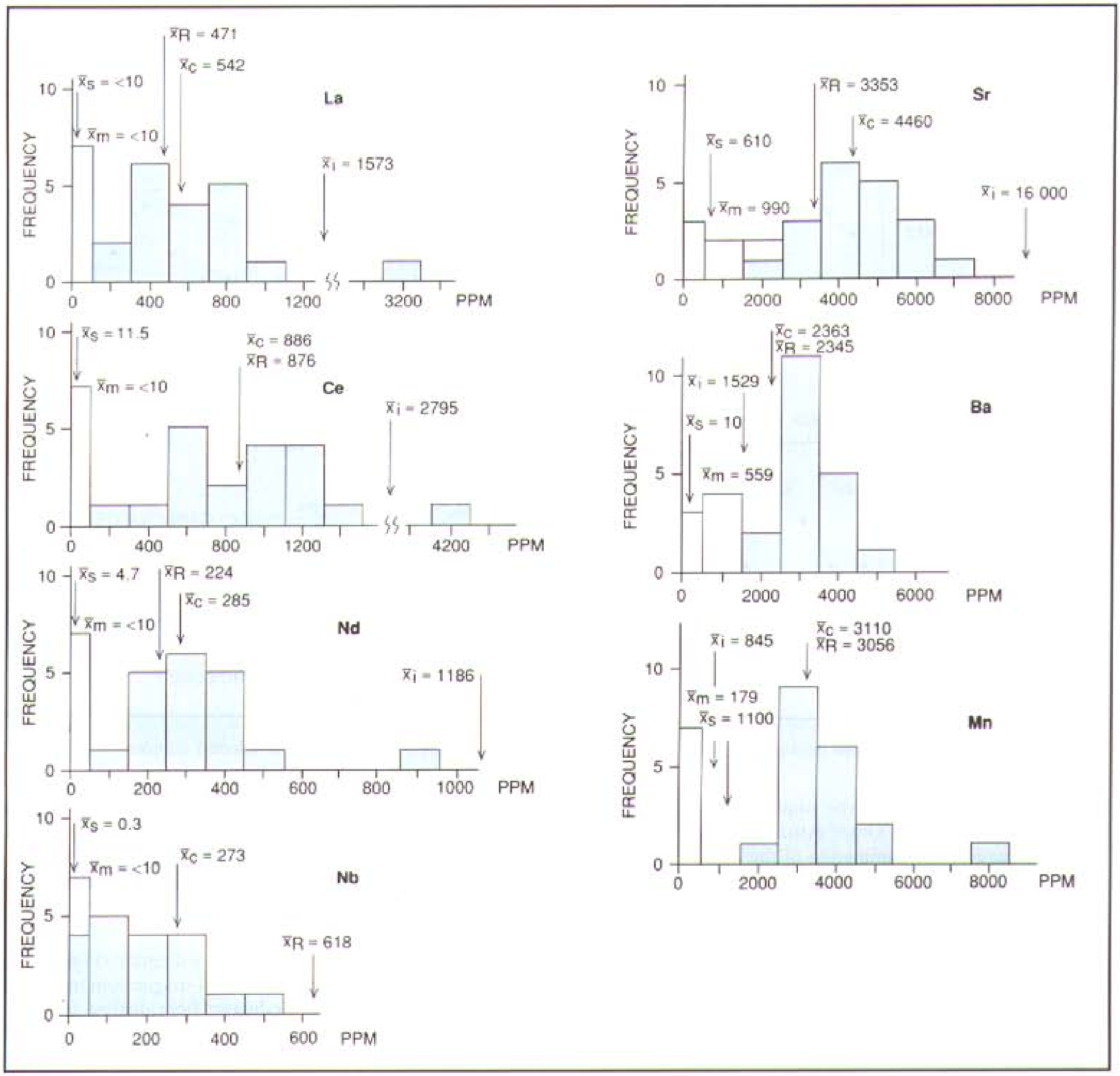


Figure 27. Concentrations of Sr, Ba and Mn in the Mount Grace, Ren intrusive and Unit 4C intrusive carbonatites and comparison with average values in marine limestones ($\bar{x}_s$) and with marbles of sedimentary origin ($\bar{x}_m$) in the Mount Grace area. $\bar{x}_c$, $\bar{x}R$ and $\bar{x}_i$ refer to average values for Mount Grace, Ren and intrusive carbonatites.

gressively enriched in total LREEs toward the stratigraphic top. This enrichment is also apparent in the coarse blocky tephra layers in the Blais Creek section (Figure 28C). The fine-grained layers (P26C, P26Bi) that are interbedded with coarser layers may be largely of sedimentary origin, with only a minor tuff component as they contain considerably lower REE concentrations.

REE concentrations in the intrusive Ren carbonatite are similar to those in the Mount Grace carbonatite (Table 5) although one sample analysed by Duval International Corp. contained greater than 1.7 per cent total REE. Limited REE analyses on carbonatites in Unit 3C are highly variable but generally higher than those from the Mount Grace or Ren carbonatite, ranging from approximately 2400 to 13 000 ppm (0.24 to 1.3 per cent) (Appendix 2C).

Chondrite-normalized REE plots of selected samples of the extrusive and intrusive carbonatites and one hydrothermal carbonatite sample (Figure 29) illustrate the enrichment of the light rare earth elements, lanthanum through europium, that is typical of carbonatites worldwide. A plot comparing the average REE content of these carbonatites (Figure 30) illustrates the higher values in the intrusive.

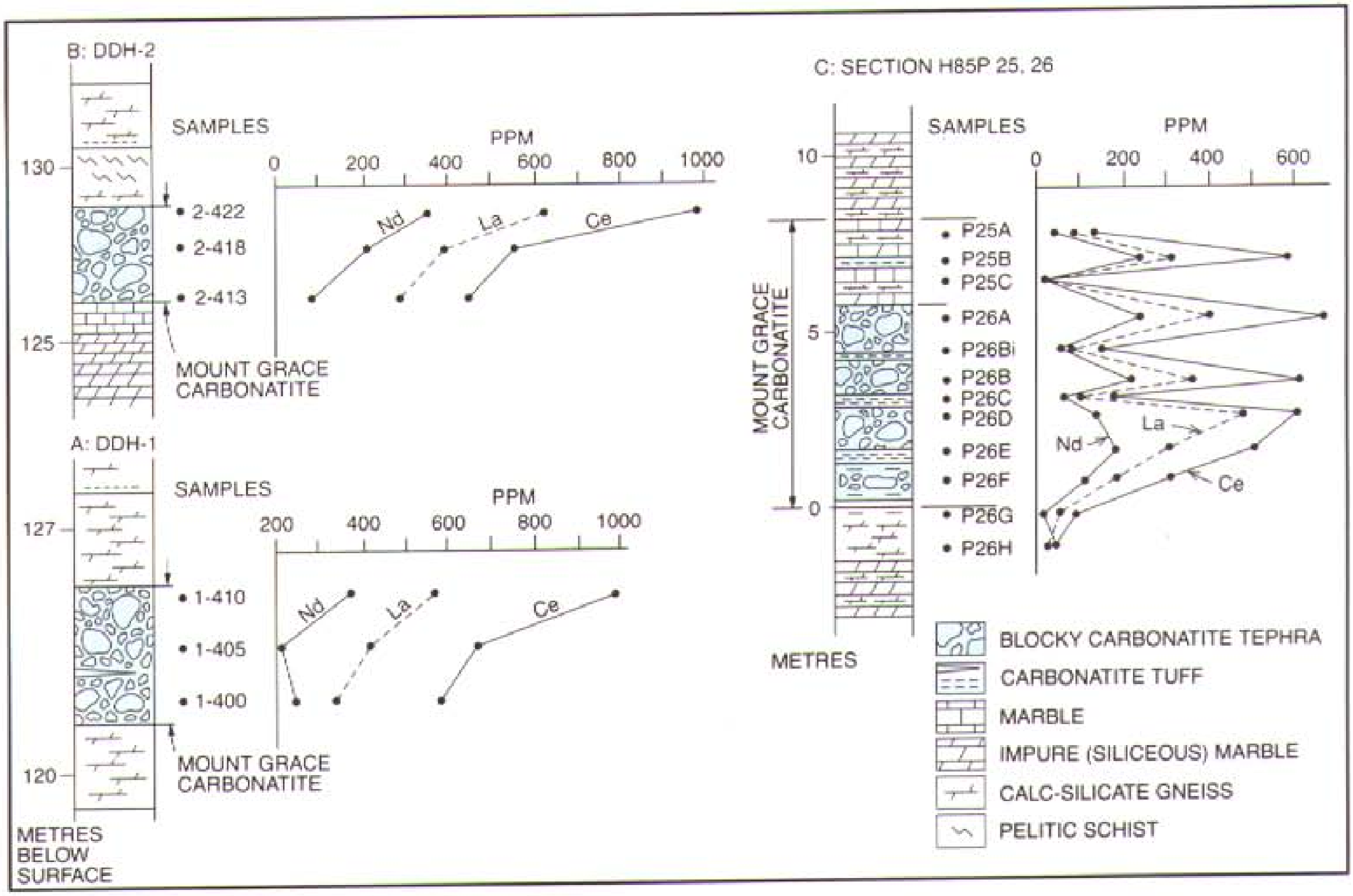


Figure 28. Sections through the Mount Grace carbonatite showing La, Ce and Nd values of selected samples.

carbonatites of Unit 3C and the similarity in values for the Ren intrusive and Mount Grace extrusive carbonatites. This similarity suggests contamination of the Mount Grace carbonatite by simultaneous deposition of marine carbonate, as proposed by Höy and Kwong (1986), was minimal.

DISCUSSION

Intense regional metamorphism has recrystallized the Mount Grace carbonatite into a medium to coarse-grained granoblastic marble. However, the sharp distinction in chemistry between the carbonatite marble and the enclosing metasedimentary marbles suggests that any redistribution of elements must have occurred at only a very local scale. This applies particularly to the rare earth elements where there is no overlap of analyses for the two types of marble. This interpretation of relative immobility of REE during metamorphism is supported by a study on the rare earth element geochemistry of regionally metamorphosed rocks by Muecke *et al.* (1979). These authors have shown that the White Rock metavolcanic suite in Nova Scotia retained its premetamorphic REE chemistry during amphibolite facies regional metamorphism.

FENITES — CHEMISTRY AND ORIGIN

Chemical analyses of fenites associated with the intrusive carbonatites and preserved as clasts within the Mount Grace tuff are shown in Table 6. Pyroxene-amphibole fenites contain appreciably higher MgO and $Fe_2O_{3(T)}$ content whereas the albite and potassic feldspar-albite fenites are higher in alkali content. Trace element contents are also different: the alkalic fenites generally contain higher niobium whereas the more iron and magnesium-rich fenites are enriched in chromium and yttrium (Table 6B).

These analyses, plotted on a ternary diagram (Figure 31), clearly distinguish two trends, an iron-magnesium trend and an alkali trend. As the end products of both alkaline and iron-magnesium loss are the carbonatites, an initial carbonatite magma composition somewhere between these values is inferred (Figure 31). This composition is not similar to the considerably more alkaline composition suggested by Le Bas (1981); it is more mafic and results in intense iron-magnesium metasomatism as well as alkali metasomatism.

Alkali fenitization can be subdivided further into dominantly sodic or potassic-sodic, producing either albite fenites or phlogopite and potassic feldspar-albite fenites (Figure 32). Albite fenites are most prominent as clasts within the Mount Grace carbonatite whereas potassic feldspar-albite and associated pyroxene-amphibole fenites are more prominent adjacent to the intrusive carbonatites. This suggests that fenitization may be depth dependent, with more sodic fenitization developed at deeper structural levels adjacent to a parent magma of the Mount Grace carbonatite, as opposed to more hydrous, potassic and iron-magnesium fenitization occurring at higher levels.

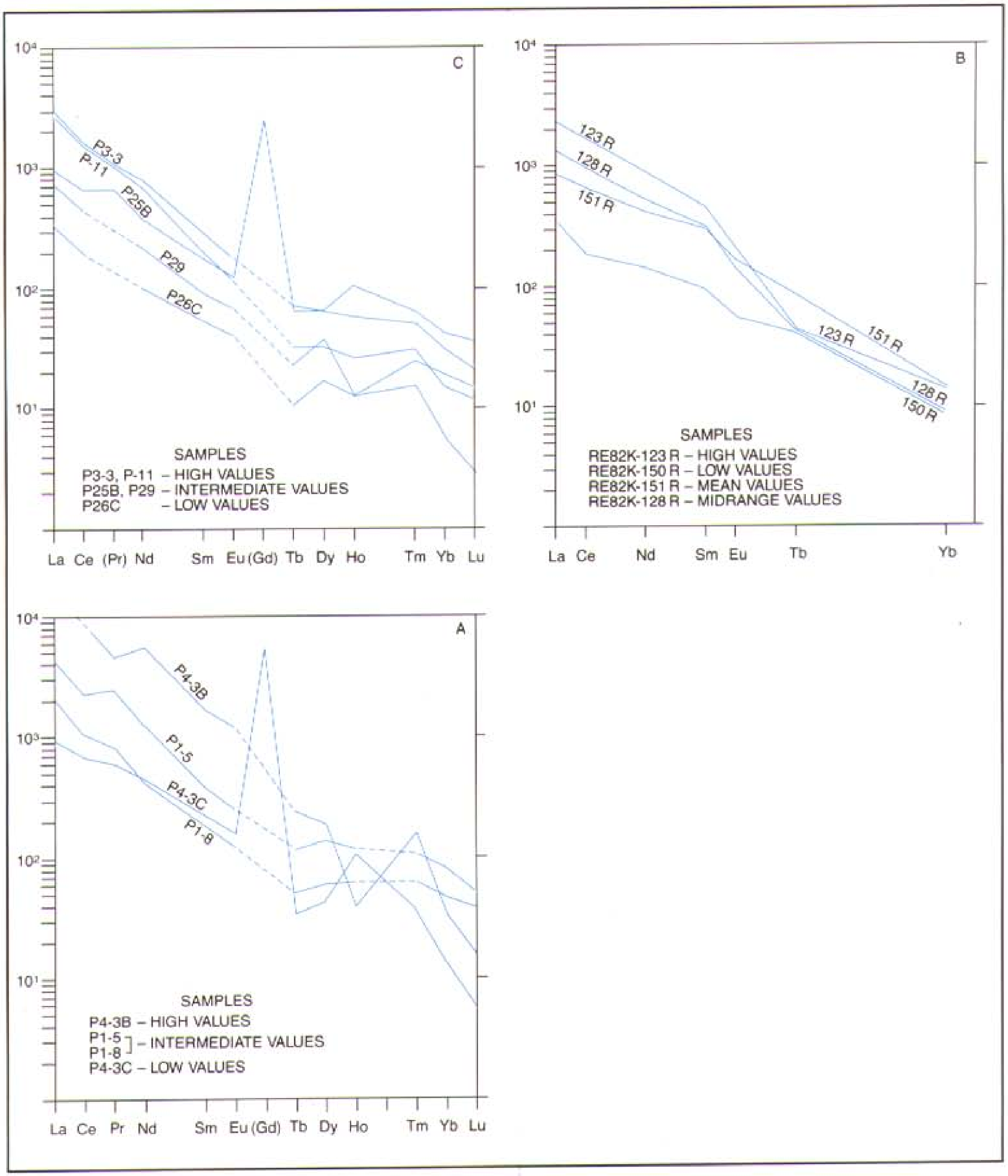


Figure 29. Chondrite-normalized rare earth element plots of: (A) intrusive carbonatite of Unit 3C, (B) the Ren intrusive carbonatite, (C) the Mount Grace carbonatite.

TABLE 6. MAJOR (A) AND TRACE ELEMENT (B) ANALYSES OF FENITES OF UNIT 3C, PERRY RIVER AREA AND ALBITE FENITE CLASTS IN THE MOUNT GRACE CARBONATITE

TABLE 6A (in %)

Field No.	Lab. No.	Type	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	LOI
P1-6	31745	1	55.70	2.22	15.24	7.05	0.22	1.61	3.72	7.38	1.34	0.37	2.94
P1-6A	31746	1	63.96	0.86	18.14	2.90	0.07	0.56	2.81	9.22	0.78	0.07	1.32
P4-2B	31747	1	62.29	0.68	17.72	5.76	0.16	0.19	1.90	7.21	4.27	0.03	0.88
P1-6B	31748	1	63.23	0.54	17.91	3.76	0.13	0.37	1.58	7.48	3.57	0.02	0.21
P4-A	31749	1	59.02	1.17	17.19	5.59	0.15	0.94	2.50	7.97	2.02	0.06	0.41
P4-B	31750	1	62.81	0.78	17.08	5.39	0.15	0.35	1.68	6.48	4.01	0.02	0.84
P4-C	31751	1	62.62	0.46	17.92	4.60	0.12	0.50	1.99	7.83	3.12	0.03	0.79
P1-2	31752	2	35.66	4.35	8.50	15.47	0.31	8.20	13.66	3.12	1.43	2.12	4.07
P1-2B	31753	2	38.44	2.34	1.44	10.73	0.15	12.41	21.70	1.84	0.43	3.32	5.89
P1-2C	31754	2	41.94	2.17	7.27	11.66	0.23	6.82	16.76	4.11	0.80	1.81	5.30
P1-2D	31755	2	38.88	2.64	1.37	11.40	0.15	12.37	21.80	4.10	0.53	3.19	4.64
P4-4	31756	2	37.24	2.86	7.64	13.62	0.27	9.52	12.05	1.41	3.60	0.99	6.61
P4-H	31757	2	35.64	4.01	8.03	10.72	0.25	7.91	14.63	2.63	3.46	1.82	7.44
P1-7	31758	3	49.19	0.04	13.18	0.65	0.12	1.02	15.79	7.06	0.32	2.68	8.96
CB2-3A	31759	4	53.76	0.22	16.09	3.14	2.22	3.16	9.14	9.14	1.16	0.24	3.21
CB2-3B	31760	4	56.58	0.01	16.41	0.89	0.28	0.33	8.12	9.24	0.30	0.75	6.46
CB2-3C	31761	4	57.45	0.31	20.53	3.71	0.14	1.76	2.24	7.82	2.01	0.08	3.39
P26A-2	31762	4	64.31	0.04	19.75	0.43	0.04	0.08	3.16	6.61	5.12	0.36	2.38
P26A	31763	4	57.66	0.03	17.35	0.52	0.10	0.16	6.93	4.81	6.40	0.16	5.76
P26B	31764	4	61.26	0.22	18.58	1.65	0.06	0.41	3.58	7.69	3.36	0.50	2.50
CB22-21	32442	4	55.91	0.37	19.37	2.70	0.10	0.66	3.55	5.90	5.36	0.35	4.08
Ren 5-H	32434	5	62.87	0.06	20.02	0.66	0.02	0.36	3.48	9.04	1.34	0.05	1.61

Type:
1 — Potassic feldspar-albite fenite, Unit 3C.
2 — Pyroxene-amphibole fenite, Unit 3C.
3 — Albite fenite.
4 — Albite and potassic feldspar-albite fenite clasts in Mount Grace tuff.
5 — Albite fenite pod in Ren carbonatite.

Analyses by the British Columbia Geological Survey Branch Analytical Laboratory.

TABLE 6B (in ppm)

Lab. No.	Sr	Zr	Rb	Y	Nb	Ba	Cr
31745	2182	476	43	36	92	851	10
31746	4235	352	15	37	106	560	<10
31747	2707	713	30	32	160	962	<10
31748	1288	1275	29	43	179	1074	<10
31749	3050	1613	42	65	248	613	17
31750	942	569	44	31	139	628	<10
31751	3208	818	20	19	47	996	15
31752	2616	1000	33	79	138	521	124
31753	2654	203	21	47	22	187	14
31754	3120	1142	20	79	24	423	25
31755	2050	220	24	47	33	229	15
31756	5307	1116	89	65	74	2964	242
31757	6785	937	98	85	117	2701	202
31758	6043	117	14	62	<4	183	<10
31759	874	22	92	9	692	1000	10
31760	2267	28	<7	18	339	1060	<10
31761	837	675	141	16	559	830	13
31762	1964	30	105	10	804	5227	<10
31763	2251	286	128	18	1166	5732	<10
31764	1693	79	104	10	200	2928	<10
32442	1674	815	212	28	403	3990	<10
32434	1446	38	13	15	9	995	<10

Analyses by the British Columbia Geological Survey Branch Analytical Laboratory.

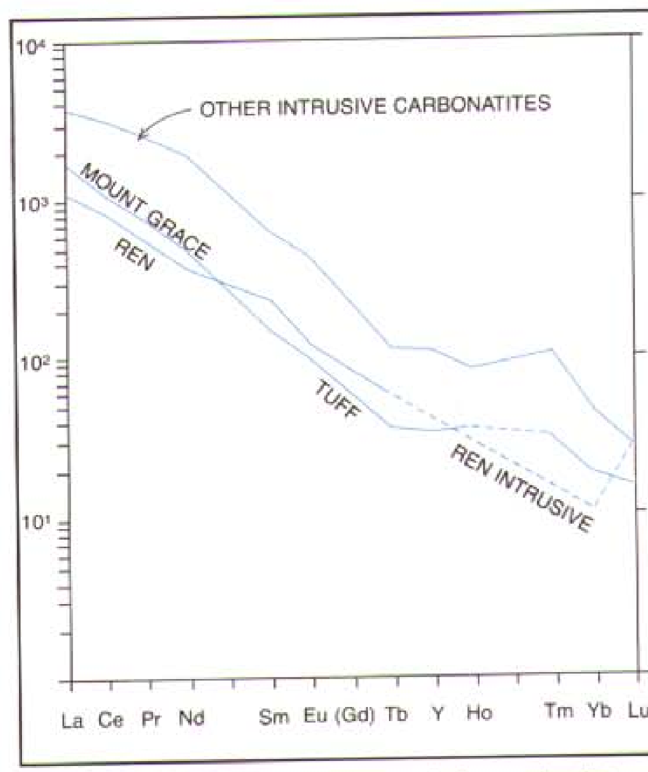


Figure 30. Chondrite-normalized rare earth element plots that compare the average values for the Mount Grace, Ren and other intrusive carbonatites.

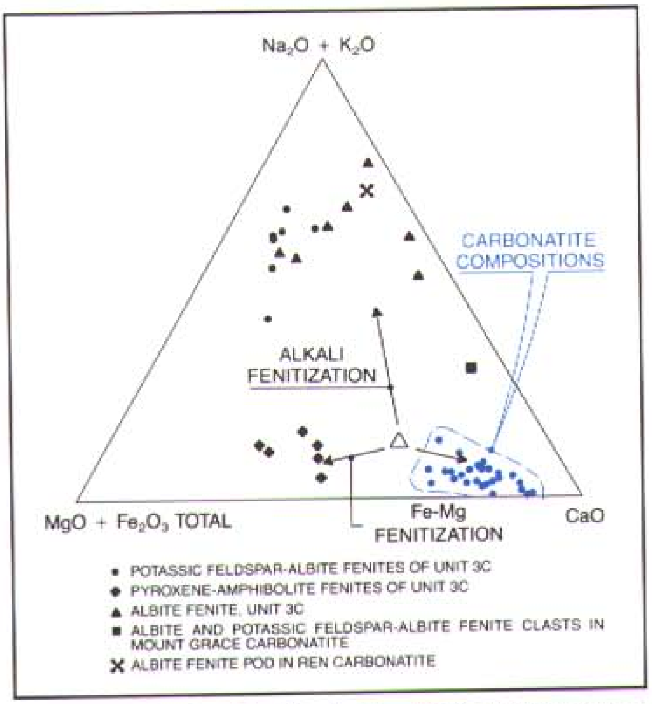


Figure 31. Triangular plot (after Le Bas, 1981) showing compositions of fenites, fenite clasts and carbonatites in the Perry River–Mount Grace area.

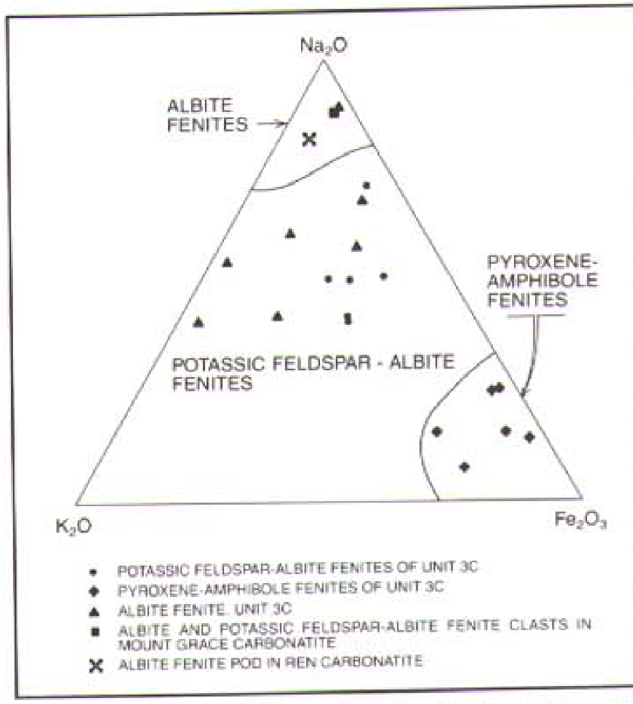


Figure 32. A Na_2O-K_2O-Fe_2O_3 triangular plot showing compositions of fenites, Perry River and Mount Grace areas.

SUMMARY AND CONCLUSIONS

Intrusive carbonatites are restricted to the Perry River area south of Ratchford Creek. Two units are recognized, a zone of intimately mixed fenite and carbonatite (Unit 3C) near the base of the autochthonous cover succession and the Ren carbonatite within Unit 6, higher in the succession. These carbonatites are surrounded by and intimately intermixed with well-banded fenites. Mafic pyroxene-amphibole-biotite fenites are the most important, but minor albite fenites and potassic feldspar-albite fenites, previously referred to as syenite, are also present.

The Mount Grace carbonatite is a unit of predominantly fine to coarse blocky tephra that can be traced from the Perry River area northward through the Mount Grace and Blais Creek areas to north of Kirbyville Creek, a distance of over 100 kilometres. The recognition of this lateral extent supports the suggestion that the carbonatite has a volcanic (McMillan and Moore, 1974) rather than an intrusive (Currie, 1976a) origin. Additional evidence for a volcanic origin includes restriction of the Mount Grace carbonatite to a single unit, its occurrence at a specific stratigraphic horizon, its lack of contact alteration (fenitization), and its stratigraphic position above all known occurrences of syenite gneiss. Furthermore, its large lateral extent, its locally gradational contacts with marbles of sedimentary origin, and locally its laminated nature are compatible with a pyroclastic origin rather than deposition as a volcanic flow.

The Mount Grace carbonatite is therefore interpreted to be a pyroclastic carbonatite (an ash flow and/or an air fall) deposited on shallow marine tidal flats. The local occurrence of carbonatite grading upward to normal grey-weathering marble indicates dilution by contemporaneously deposited marine carbonates as the supply of pyroclastic carbonate decreased. Variations in its thickness, and clast size and distribution, are related to proximity to vent areas.

Clasts within the Mount Grace carbonatite include albite and potassic feldspar-albite ("syenite") fenites as well as large clasts of folded and foliated quartzite, schist and gneiss probably derived from the basement core gneiss complex. The abundance of albite fenite clasts, in contrast with the pronounced pyroxene-amphibole-biotite fenites associated with the intrusive carbonatites, suggests a vertical zoning of fenitization. At deeper structural levels, sodium fenitization may be more prominent, resulting in albite fenites adjacent to a parental magma of the Mount Grace tuff whereas at higher levels, now exposed at surface adjacent to the intrusive carbonatites, more hydrous, more potassic and more iron-rich fenitization produced the dominant pyroxene-amphibole-biotite fenites.

A genetic model for carbonatites in the Perry River–Mount Grace area may be developed by comparison with intrusive-extrusive carbonatite complexes in southeast Africa. Initial alkalic magmatism included intrusion of syenites, nepheline syenites and carbonatite lenses in a platformal metasedimentary succession that unconformably overlay a basement complex. Subsequent explosive volcanism, from widely separated vent areas, produced a number of interfingering pyroclastic ash flow or air fall layers now preserved as the Mount Grace carbonatite. The extrusive episodes were separated by quiescent periods and local deposition of marine carbonate. Intrusion of the Ren carbonatite in stratigraphically higher metasedimentary rocks indicates that alkalic magmatism spanned a considerable time interval.

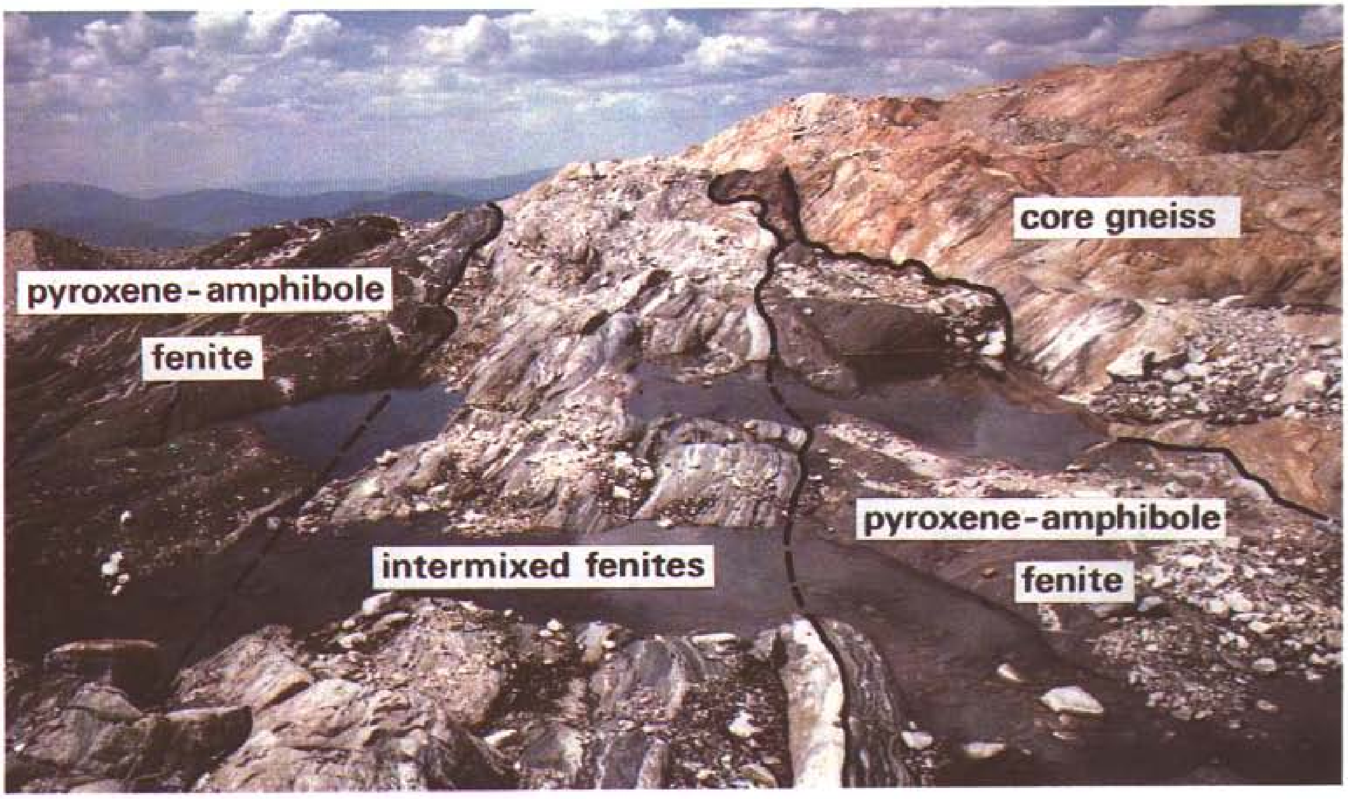
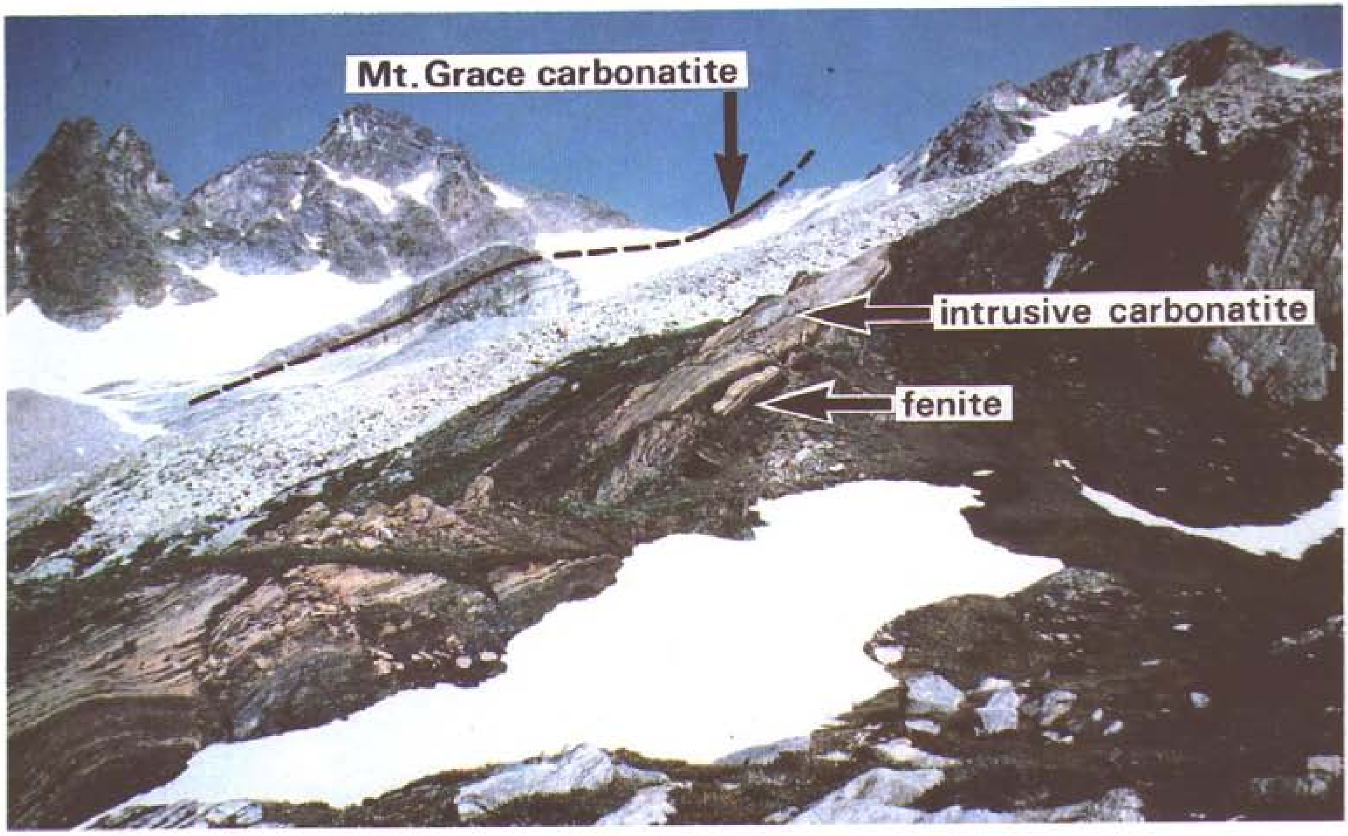


Plate 17. Intimately interlayered pyroxene-amphibole, albite and potassic feldspar-albite fenites, within darker pyroxene-amphibole fenites, Unit 3C, station P1-5, Perry River area; weakly fenitized core gneisses are exposed on right side of photograph.

Plate 18. Dark pyroxene-amphibole fenite with remnant boudinaged layers of quartz feldspar paragneiss, Unit 3C, station P1-5.



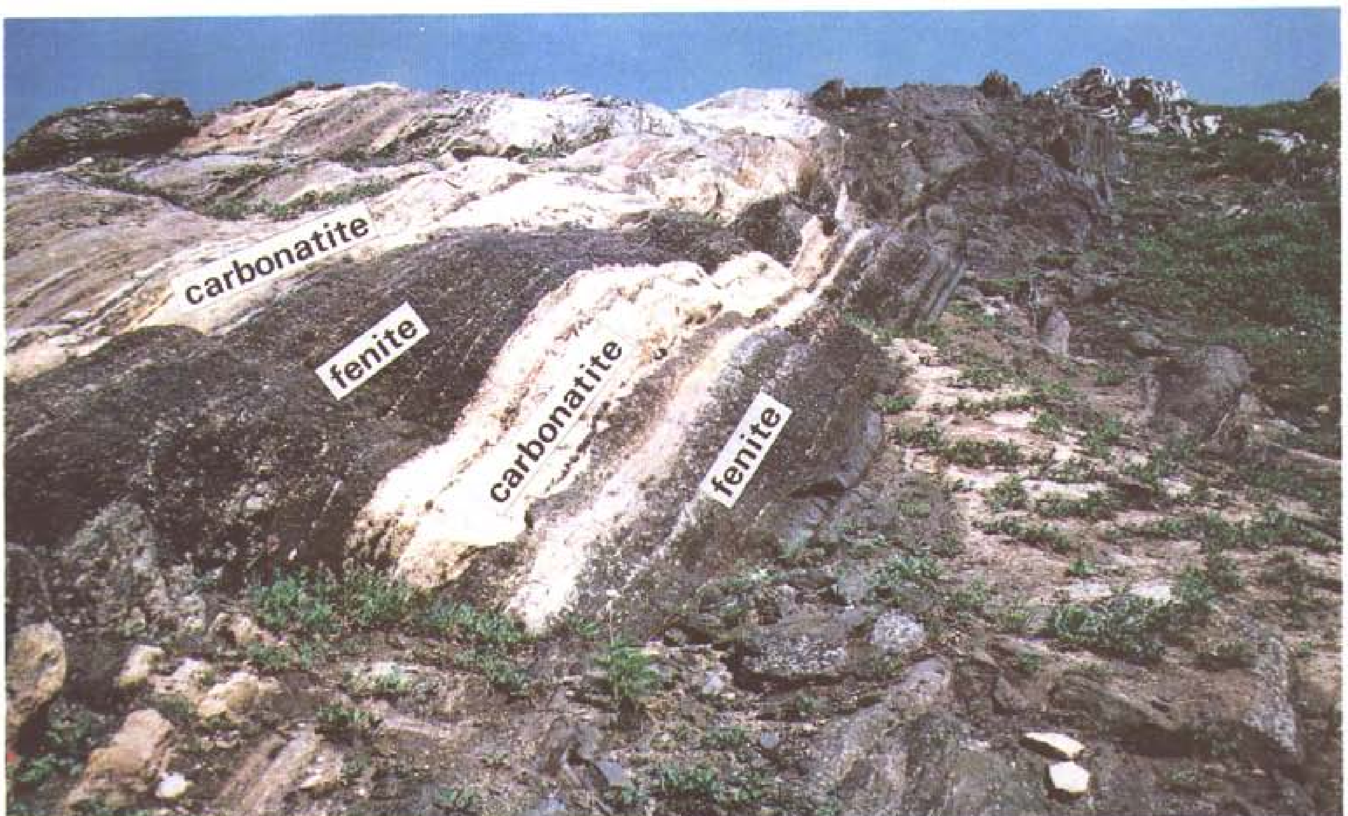


Plate 19. Intrusive carbonatites (light coloured) and pyroxene-amphibole fenites of Unit 3C, just south of station H85P4, Perry River area: (19A) overview showing location of Unit 3C in foreground and overlying Mount Grace extrusive carbonatite in distance; (19B) detail of interlayered intrusive carbonatite and dark fenite.

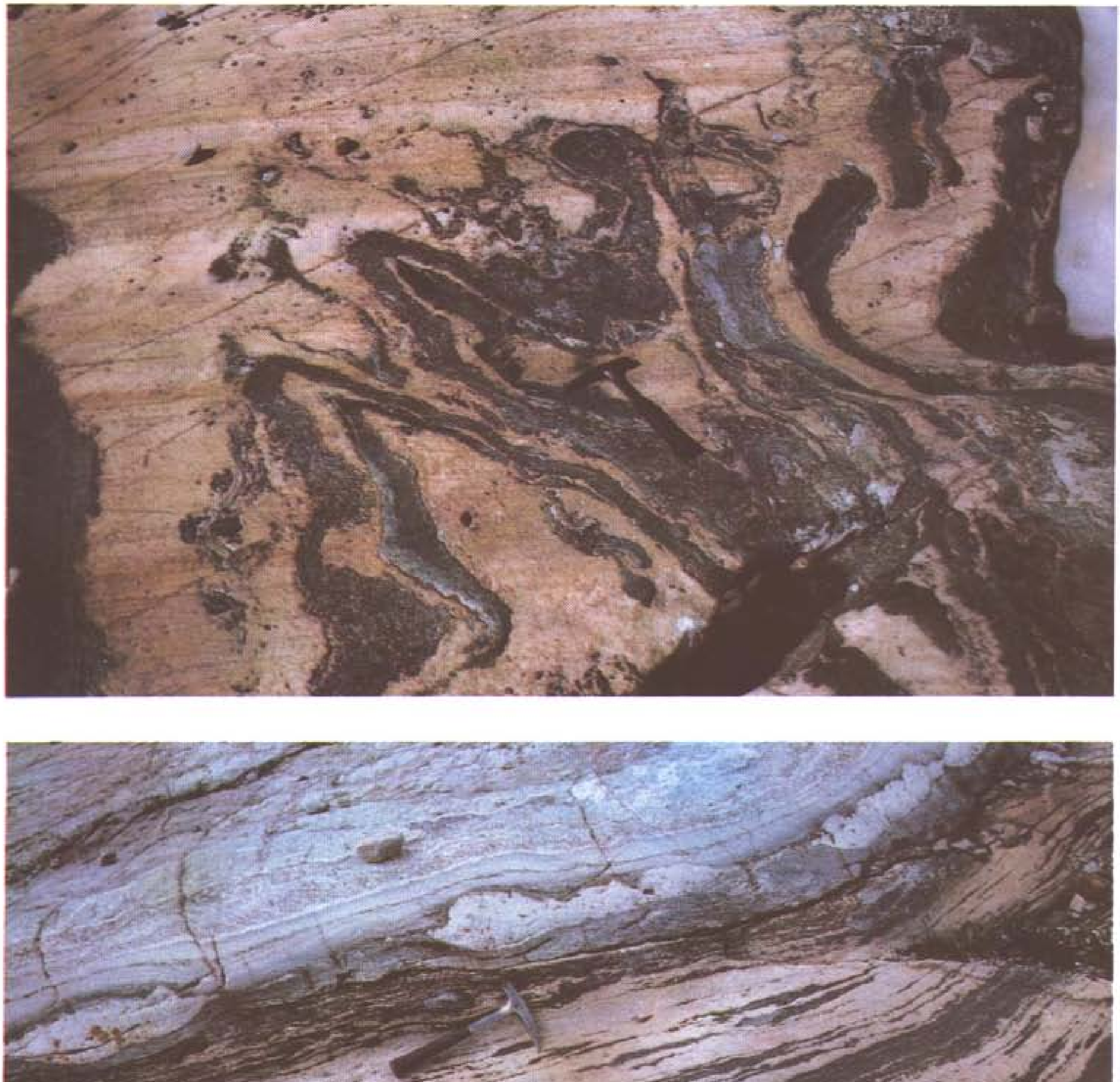


Plate 20. Intrusive carbonatites at station H85P1: (20A) swirled discontinuous carbonatite lenses in pyroxene-amphibole fenite (sample H85P1-5); (20B) intermixed buff-weathering carbonatite and fenite, overlain by grey-weathering carbonatite (sample H85P1-8).

Plate 21. Exposure of the Ren carbonatite at station Ren 5.

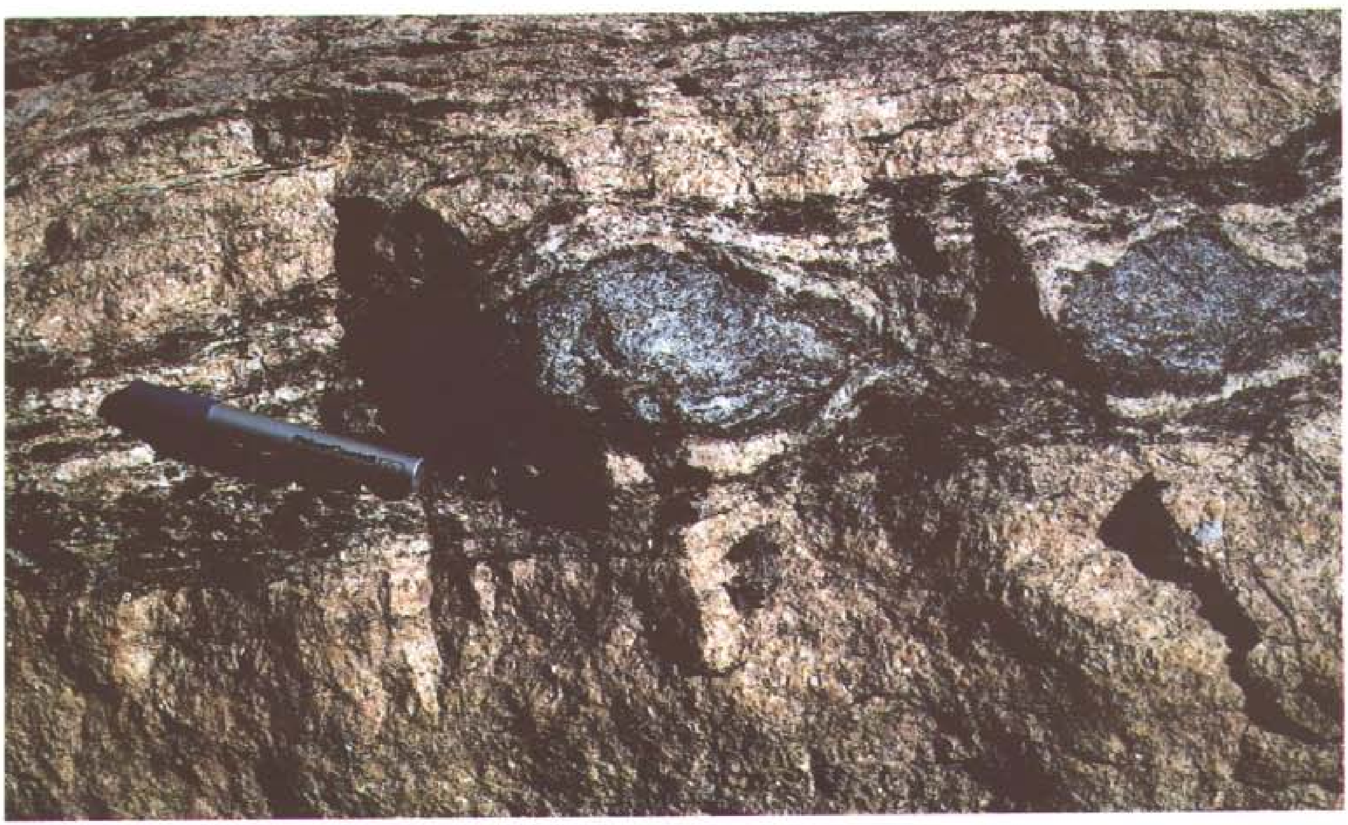


Plate 22. Boudinaged layers of amphibole-rich fenite within the intrusive Ren carbonatite, station Ren 5.

Plate 23. The Mount Grace carbonatite: (23A) well-layered extrusive carbonatite containing small clasts of dominantly albitite (station P3; Perry River area); (23B) subrounded paragneiss and potassic feldspar-albite "syenite" clasts in a crudely layered blocky tephra (station P25; Blais Creek area).

Plate 24. Lithic clasts in the Mount Grace blocky tephra layer: (24A) large gneissic clast and smaller albitite clasts (Mount Grace area); (24B) gneiss-amphibolite(?) contact preserved in clast (Kirbyville Lake area, north of Blais Creek).

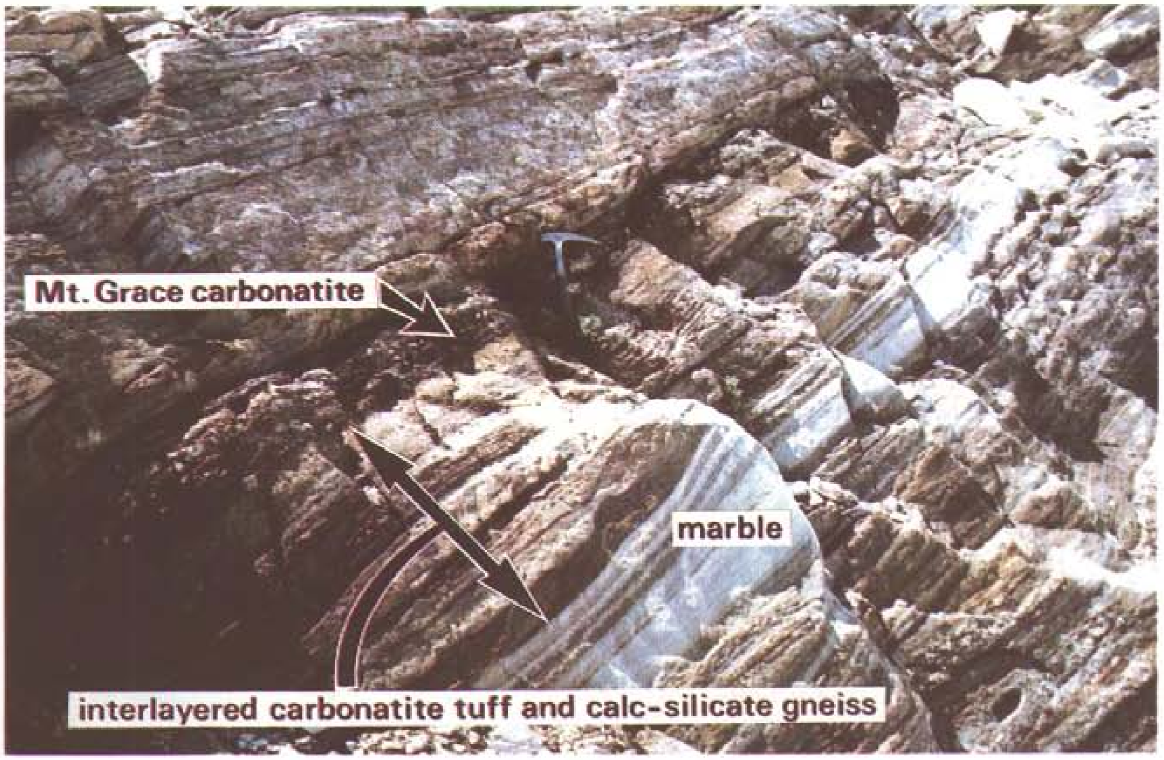


Plate 25. The Mount Grace carbonatite in the Perry River area: (25A) approximately 1-metre-thick carbonatite layer (beneath hammer), coarser with dominantly albitite clasts 1 to 2 centimetres across at top underlain by finer grained carbonatite tuff, in a marble, calc-silicate gneiss, pelitic gneiss and quartzite succession; (25B) large clast with syenite(?)-fenite-gneiss contact.

Plate 26. Exposure of the Mount Grace carbonatite in the Blais Creek area: (26A) note large clasts and crude layering; (26B) detail of overturned section with coarse blocky tephra at the stratigraphic base and layered fine-grained tuff and calc-silicate gneiss above (at bottom of photograph).

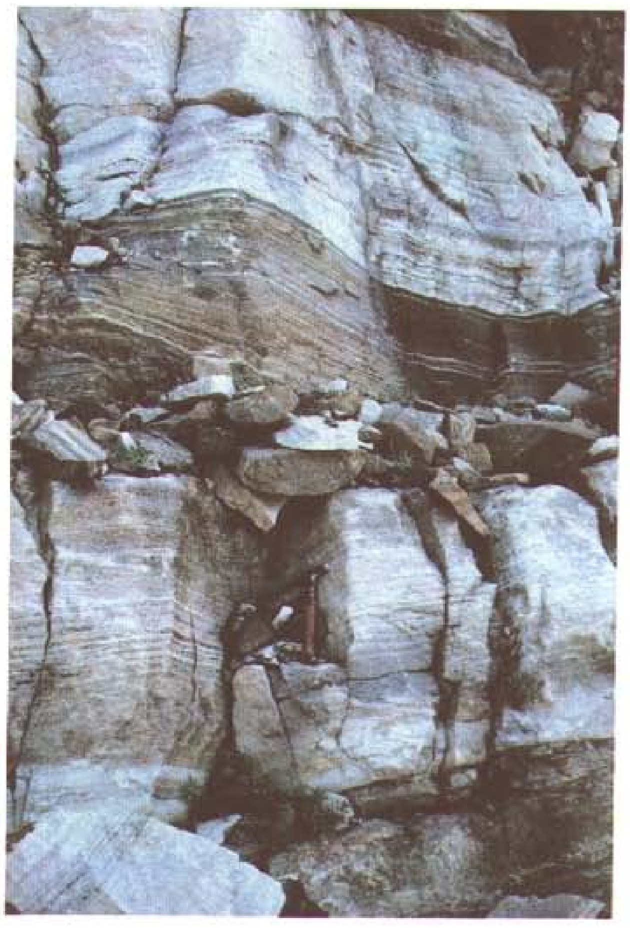
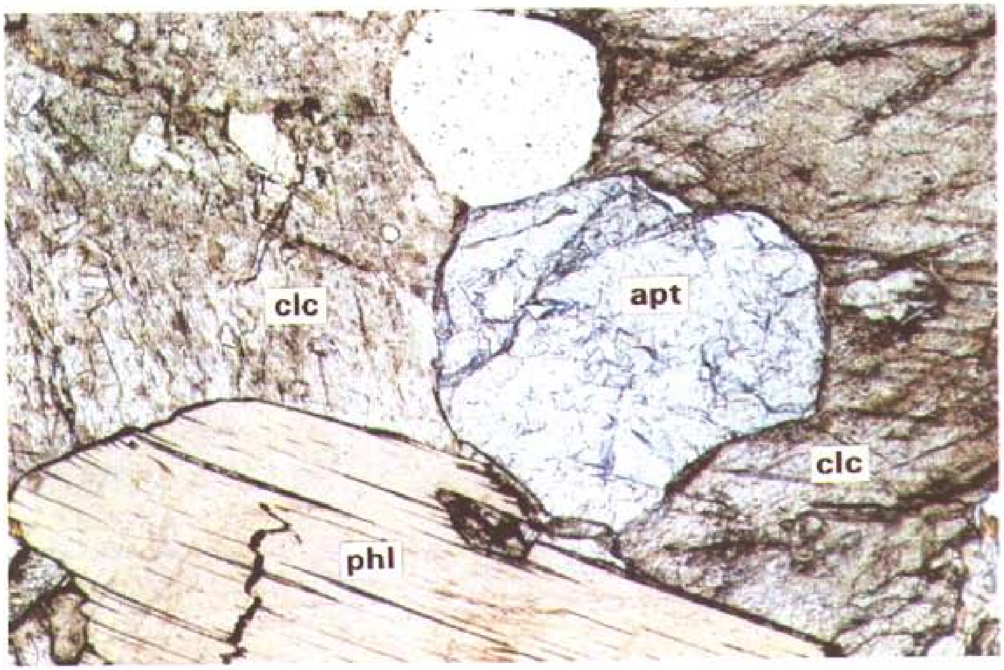


Plate 27. Exposures of the Mount Grace carbonatite at section H86CB22, Blais Creek area; note section is structurally inverted: (27A) coarse carbonatite tephra layer (CB22-11) near stratigraphic top of section (*see* Figure 25); (27B) interlayered marble (white) and fine-grained carbonatite tuff; Units CB22-13 at structural base to CB22-16 at top of photograph.



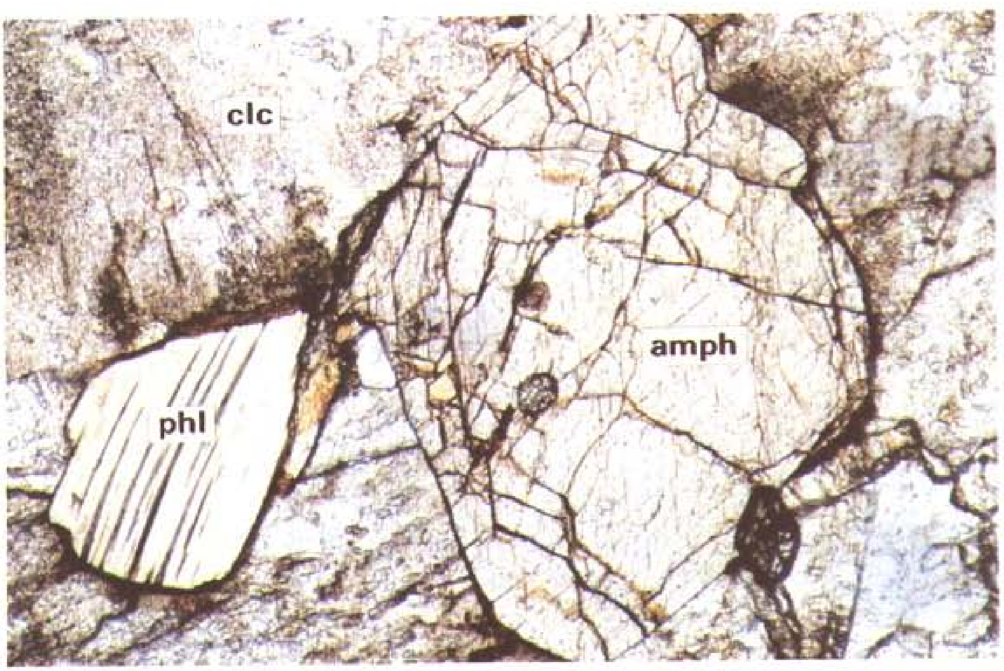


Plate 28. Photomicrographs of Mount Grace carbonatite (field of view = 1.8 millimetres, plane light): (28A) large subhedral porphyroblasts of phlogopite and apatite in a granoblastic calcite matrix; (28B) subhedral amphibole and smaller biotite porphyroblasts in calcite matrix.

Plate 29. Small, zoned pyrochlore grain with calcite and other unknown inclusions in calcite matrix, Mount Grace carbonatite; note apatite grain at top right (field of view = 1.8 millimetres, plane light).

CHAPTER 5

MINERAL OCCURRENCES

INTRODUCTION

The Cottonbelt deposit, one of a number of somewhat similar stratabound lead-zinc deposits on the eastern side of the Shuswap Complex, is the most important mineral deposit in the Mount Grace area. It is an unusual lead-zinc-magnetite layer in calc-silicate gneiss near the base of Unit 6. Similar mineral occurrences in the area (Table 7; Figure 33) include small widely scattered occurrences of galena, chalcopyrite, pyrite and magnetite in calc-silicate gneiss and marble northeast of Cottonbelt. These are also near the base of Unit 6 and indicate the widespread occurrence of this style of mineralization at a common stratigraphic level. They include the Seymour and Blais occurrences (Table 7) and a number of unnamed occurrences further to the northeast. Disseminated copper sulphides in quartzite, the Copper King deposit, and molybdenite in an orthogneiss are the other metallic mineral occurrences in the area. High concentrations of rare earth elements are present in the Mount Grace carbonatite, an extrusive volcanic tuff unit described in Chapter 4. This chapter describes the metallic deposits and occurrences and compares them to other important lead-zinc deposits in the Shuswap Complex, collectively and informally termed the "Shuswap deposits". The larger of these include Jordan River, Big Ledge, Colby, CK and Ruddock Creek.

The earliest record of exploration in the Mount Grace area dates back to 1905 when six claims were located on lead-zinc showings by Cotton Belt Mines, Ltd. Considerable work was done on these claims and on claims subsequently located on the McLeod and the Copper King showings from 1905 to 1911 (*see* Minister of Mines Annual Reports, 1905 to 1928). This work included extensive surface stripping and trenching, bulk sampling, driving of a number of shafts and tunnels along the lengths of the Cottonbelt and McLeod showings, and cutting a trail northward from Seymour Arm (with financial assistance from the British Columbia Ministry of Mines). Work in the area appears to have been suspended in 1912 and did not begin again until 1922. By then, a 12-metre shaft had been sunk on the Bass showing and a 75-metre shaft on Cottonbelt. A 45-metre tunnel on the Copper King showing exposed "quartz ore" that contained chalcopyrite, pyrite, chalcocite, some native copper, and assayed 3.2 per cent copper, 20 grams silver per tonne and trace gold. Underground and surface work continued until 1928. By 1927, 15 buildings had been constructed in the Cottonbelt area (Plate 30) and approximately 500 metres of underground development (drifts, crosscuts and raises) and extensive surface stripping and open-cut work completed. Sixteen short diamond-drill holes put down in the summer of 1926 intersected almost continuous mineralization along a strike length of approximately 2 kilometres, at depths of 82 to 112 metres. Underground work continued through the winter of 1927-1928 and the summer of 1928, concentrating on tunnels that followed the sulphide-magnetite layer at elevations of approximately 1706 metres (No. 1), 1894 metres (No. 2),

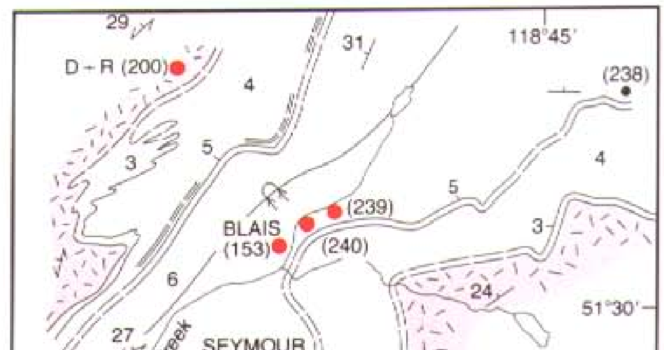


Figure 33. Mineral occurrences in the Mount Grace area; the numbers in brackets are Minfile numbers.

1572 metres (No. 3) and 1493 metres (No. 4, Bass showing). The mineralized widths were variable, averaging less than a metre, grades were low and access to the Cottonbelt property was difficult resulting in suspension of work in 1929. Work was also suspended on the two other mineralized layers in the Cottonbelt camp, the "Complex-McLeod" layer a kilometre to the north and now recognized to be a structural repetition of the Cottonbelt layer, and the Copper King showing, a silver-copper deposit in quartzite stratigraphically above the Cottonbelt layer (Figure 33).

Recent work in the Cottonbelt area began in the early 1970s with surface geological mapping, trenching, an airborne magnetometer survey, and a VLF-electromagnetic survey by Great Northern Petroleum and Mines Ltd. The Copper King adit was reopened and retimbered. United Minerals

TABLE 7. MINERAL OCCURRENCES, MOUNT GRACE AREA

Name Minfile No.	Most Recent Operator	Mineralogy	Deposit Type	Host
COTTONBELT 82M-086	1978 — Cyprus Anvil Mining Corp.; Metallgesellschaft Canada Ltd.	sphalerite, galena, magnetite, pyrrhotite	massive, disseminated; stratabound	calcareous gneiss near base of Unit 6
COMPLEX-McLEOD 82M-125	1978 — Cyprus Anvil Mining Corp.; Metallgesellschaft Canada Ltd.	sphalerite, galena, magnetite, pyrrhotite	massive, disseminated; stratabound	calcareous gneiss near base of Unit 6
COPPER KING 82M-144	1976 — G. Adam (owner)	chalcopyrite	disseminated	quartzite in Unit 6
BLAIS — 1 82M-153	1978 — Cominco Ltd.	galena	disseminated	marble near base of Unit 6
SEYMOUR 82M-155	1978 — Dome Exploration Ltd.	chalcopyrite, galena, sphalerite, magnetite	disseminated	thin quartzite layer in marble in Unit 6
D & R 82M-200	1980 — R.D. Johnson (owner)	molybdenite	disseminated	orthogneiss in Unit 2
BASS	1978 — Cyprus Anvil Mining Corp.; Metallgesellschaft Canada Ltd.	sphalerite, galena, magnetite, pyrrhotite	massive, disseminated; stratabound	calcareous gneiss near base of Unit 6
82M-240	new occurrence	chalcopyrite, magnetite	disseminated, pods	marble-gneiss contact near base of Unit 6
82M-241	new occurrence	chalcopyrite, pyrrhotite, magnetite	small pods	impure marble near base of Unit 6
82M-242	new occurrence	chalcopyrite, magnetite	disseminated, pods	impure marble near base of Unit 6

Services Ltd. then acquired the claims adjoining the original Crown grant and these and others in the area (the Complex and Copper King properties) were remapped and sampled, and covered by magnetometer and induced polarization surveys in the period 1976 to 1978 in a joint venture with Metallgesellschaft Canada Ltd. As well, two holes totalling 517 metres in length were drilled in an attempt to intersect the mineralization in the core of the Mount Grace syncline between the Bass and Cottonbelt showings to the south and the McLeod to the north. It was unsuccessful and only a thin (a few metres) mineralized interval was encountered in the upper, western limb. There has been little subsequent work in the Cottonbelt area.

The small showings in the Blais Creek area (Figure 33) have received little attention. Only a few small pits mark the Seymour and Blais showings, and there is no record of work (other than surface mapping or sampling) in the vicinity of the other occurrences.

COTTONBELT (MI 82M-086)

INTRODUCTION

The Cottonbelt deposit is a thin calcareous layer, containing substantial quantities of galena, sphalerite and magnetite, on the west limb of the Mount Grace syncline. The sulphide-magnetite layer can be traced northward several kilometres where it is referred to as the Bass occurrence, and is repeated on the east limb of the syncline where it is known as the McLeod and Complex showings (Figure 33). These deposits are exposed on the gentle subalpine to tree-covered slopes of Mount Grace, at elevations ranging from approximately 1000 to 1900 metres (3300 to 6300 feet). They are accessible by a well-cut "pack trail" that leads northward from Seymour Arm or by a climb from the Ratchford Creek logging road to the south. The nearest permanent helicopter base is at Revelstoke, 60 kilometres to the south.

Although the general geology of the map area is outlined in Chapters 2 and 3, it is reviewed again as an introduction to the geology of the Cottonbelt deposit.

STRATIGRAPHY

The stratigraphic succession in the vicinity of the Cottonbelt deposit is repeated on both limbs of the Mount Grace syncline. It comprises a thick basal quartzite (Unit 3) that overlies the core paragneiss and orthogneiss, a sequence of calcareous and pelitic schists of Unit 4 (host to the Mount Grace carbonatite), a grey-weathering, white crystalline marble (Unit 5) and dominantly micaceous schist, calc-silicate gneiss and quartzite of Unit 6 (Figure 34). The Cottonbelt layer occurs near the base of Unit 6.

A number of detailed sections through the Cottonbelt deposit is illustrated in Figure 35. Unit 4c, a calcareous section at the top of Unit 4, includes interlayered dark grey, rusty weathering calcareous and micaceous quartzite, quartz-rich micaceous schist, fairly coarse-grained kyanite and sillimanite schist, dark to light green diopside garnet calc-silicate gneiss, and a thin grey-weathering calcite marble layer (*see* section CB4-3, Figure 35). The Mount Grace carbonatite occurs 8 metres below the base of Unit 5. A coarse-grained pegmatite and a fine-grained quartz feldspar orthogneiss occur between the carbonatite and the top of Unit 4. In the drill intersections (Figure 36), hornblende gneiss and a few amphibolite layers occur near the stratigraphic top of Unit 4 and a thin, fine-grained green chlorite amphibole schist layer occurs immediately below the marble of Unit 5. These amphibolite-rich layers are interpreted as basic volcanic flows and tuffs, correlative with massive amphibolites that occur in the Blais Creek section to the north (Unit 4d, Figure 24).

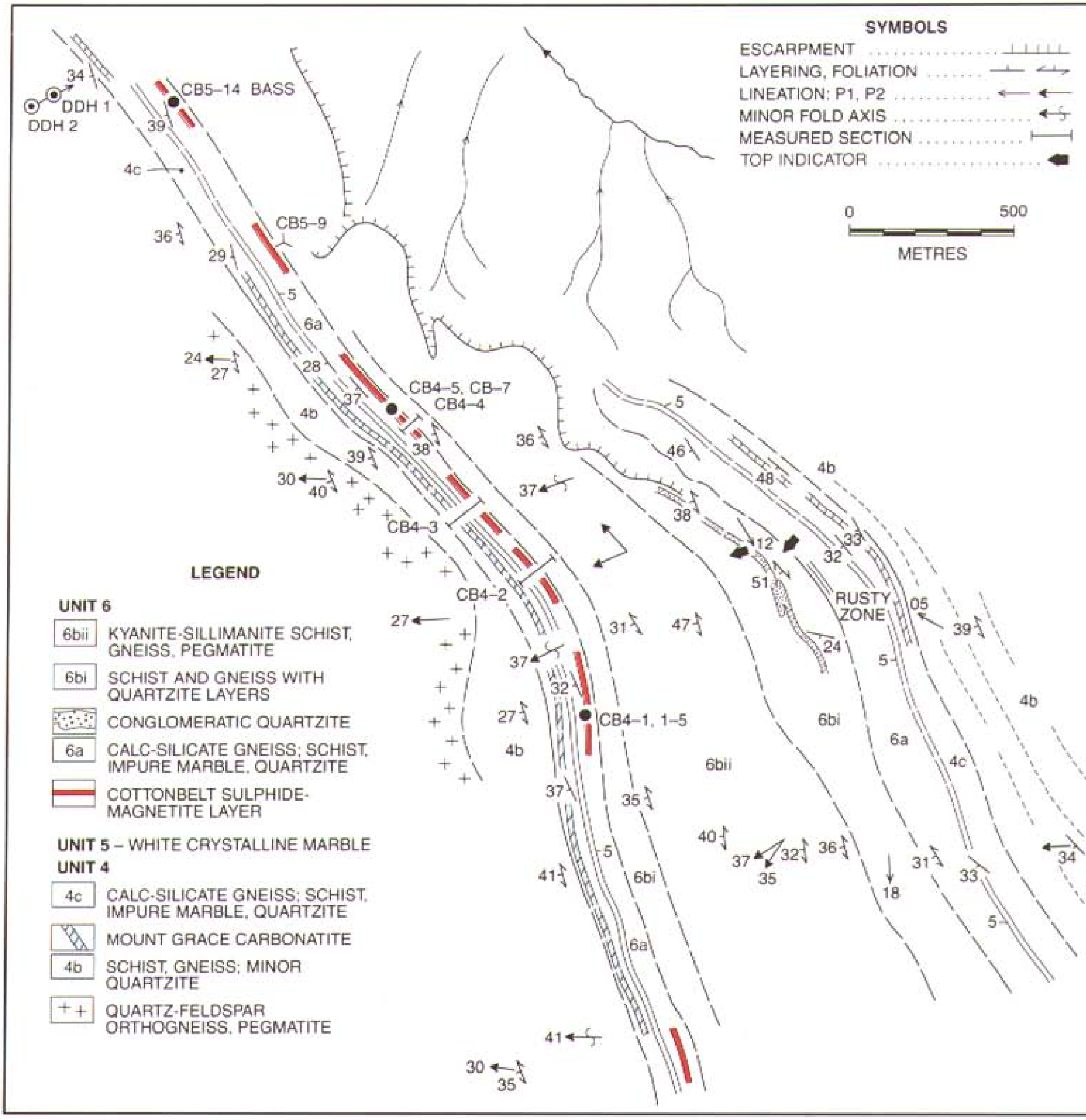


Figure 34. Detailed geology of the Cottonbelt deposit, Mount Grace area, showing sample and measured section localities.

Unit 5, a grey-weathering, white crystalline calcite marble, with thin dolomite and actinolite-rich layers that weather in relief, is 5 metres thick in section CB4-3. It is overlain by a dominantly calcareous succession (Unit 6a) at the base of Unit 6. Unit 6a includes interlayered sillimanite schist and light grey to green scapolite-bearing calc-silicate gneiss, a prominent, crumbly, grey to light brown-weathering impure dolomitic marble, and the Cottonbelt sulphide-magnetite layer. Very thin chert layers occur stratigraphically above the Cottonbelt layer. Calc-silicate gneiss occurs above the sulphide-magnetite layer at the top of Unit 6a in section CB4-3 and CB4-4, but sillimanite schist stratigraphically overlies it in section CB4-2 (Figure 35). Interlayered sillimanite schist, quartz feldspar gneiss, thin chert and impure quartzite layers of Unit 6b overlie Unit 6a.

STRUCTURE

The structure of the Cottonbelt area is dominated by the Mount Grace syncline, an early Phase 1 isoclinal recumbent fold that is draped around the northwestern margin of Frenchman Cap dome (Figures 2 and 3). The youngest rocks in the Cottonbelt area, schist and gneiss of Unit 6a, are

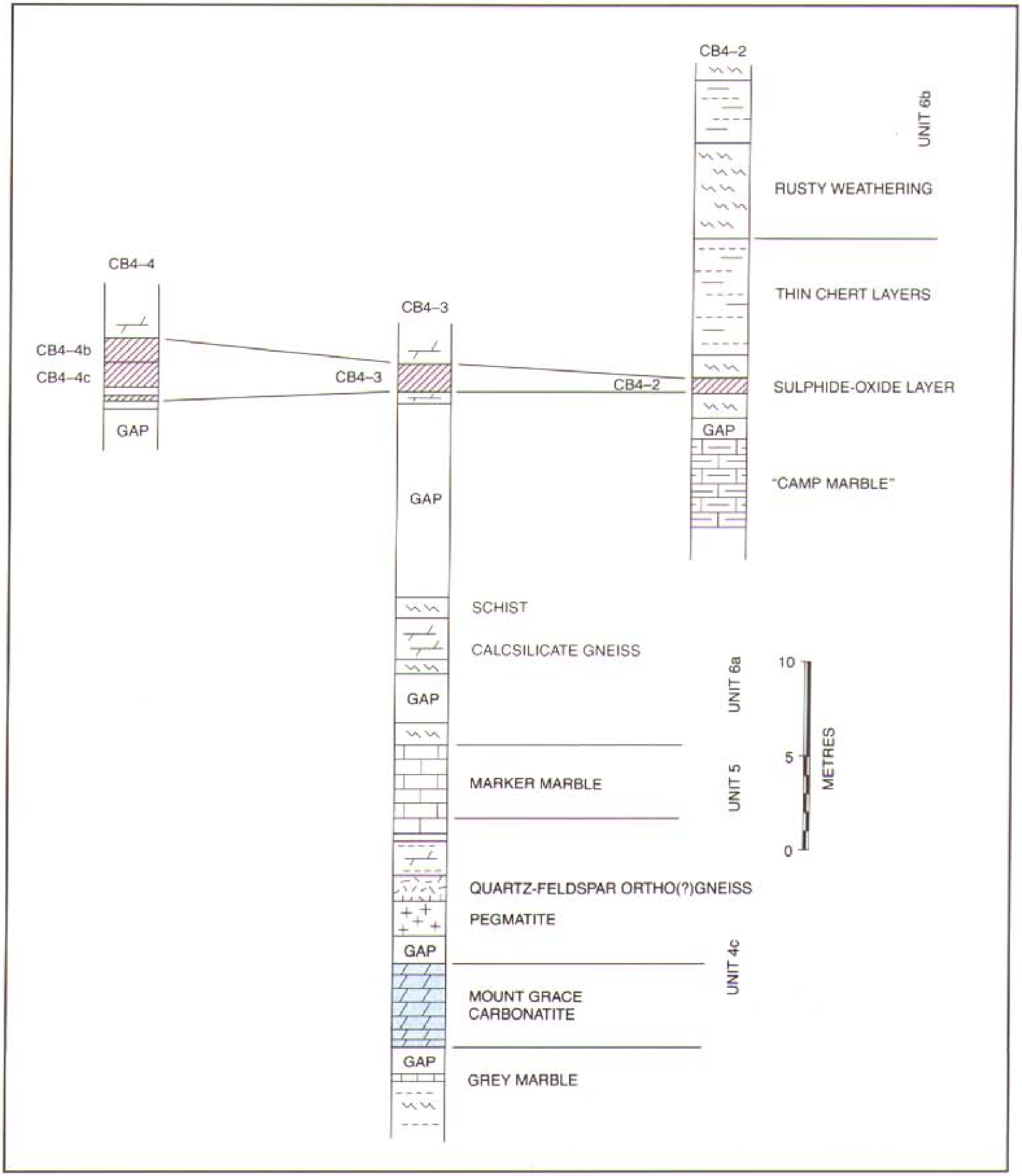


Figure 35. Measured sections through the Cottonbelt deposit; sections are located in Figure 34.

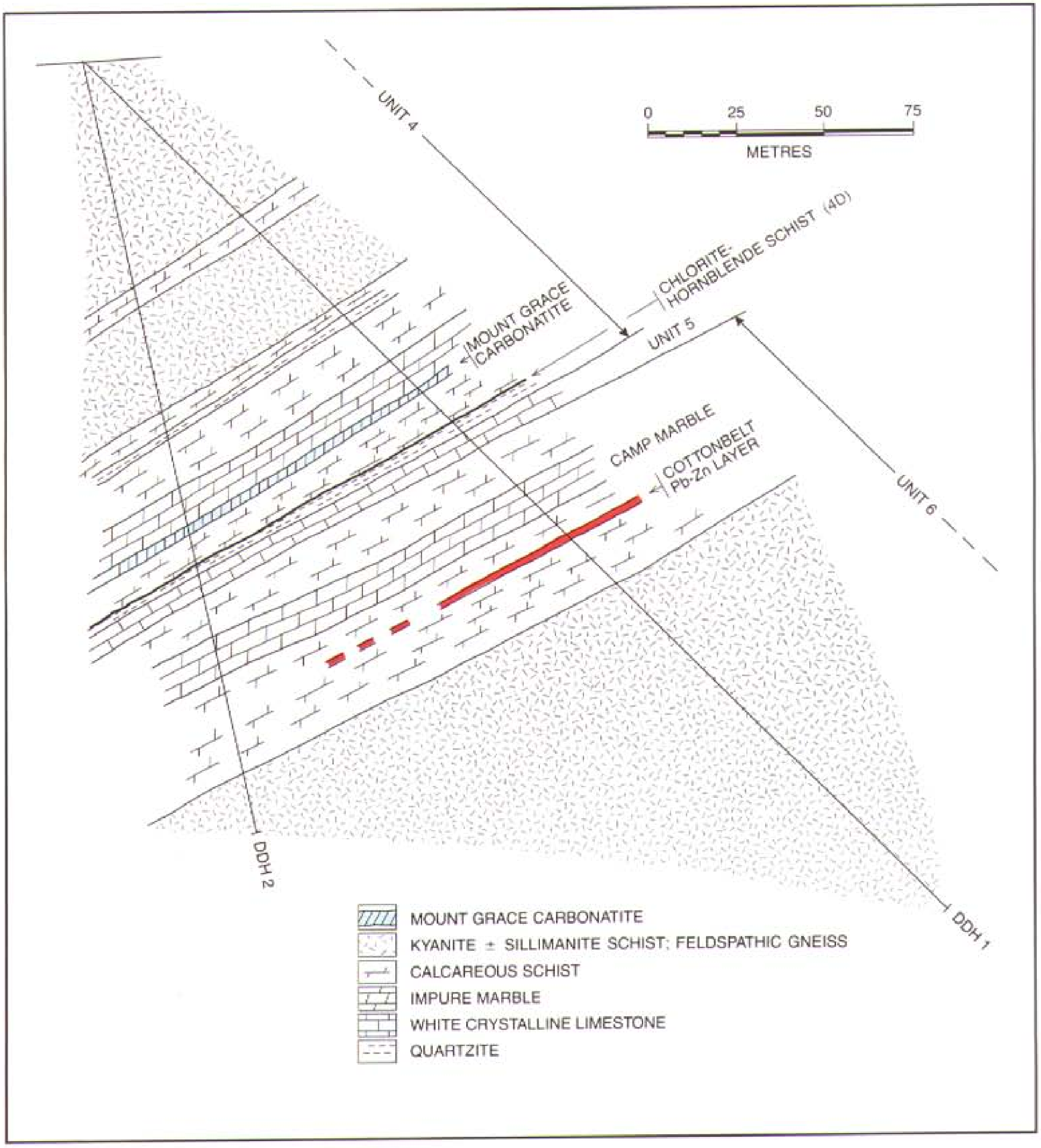


Figure 36. Drill sections through the Cottonbelt deposit, viewed to the north. Note section is structurally inverted on the west limb of the Mount Grace syncline (drill holes are located in Figure 34).

TABLE 8. BASE METAL AND PRECIOUS METAL VALUES OF COTTONBELT SAMPLES

Field No.	Lab. No.	Description	Pb %	Zn %	Au ppm	Ag ppm	Cu %	Cd ppm	Fe %	Mo ppm	Co ppm	Cl ppm
CB4-1	20025	1	4.45	0.27	<1.0	30	0.0125	25	34.4	13	7	
CB4-2	20026	1,5	7.81	0.87	<1.0	78	0.0155	55	18.3	14	8	
CB4-3	20027	1,5	11.25	1.03	<1.0	65	0.0070	60	19.1	16	7	
CB4-4B	20028	1,5	4.18	3.50	<1.0	23	0.0090	170	23.8	10	10	
CB4-4C	20029	1,5	6.75	1.40	<1.0	52	0.0060	87	30.0	6	7	
CB-7	25528	5	0.17	0.52		5	0.014		34.8	3		
CB5-9	25529	5	8.2	3.90		78	0.0025		26.0	<3		
CB5-14	25530*	1,5	3.8	0.20		29	0.0025		35.95	5		
CB1-5	30318	1	5.36	0.11	1	24	0.003	19		<3		27
CB1-5A	30319	1	0.018	0.48	<0.3	<10	0.007	8		<3		<25
CB1-5.1	30320	1	16.4	0.59	4.8	94	0.009	48		<3		<25
CB1-5.3	30321	2	0.68	0.018	<0.3	<10	0.001	29		<3		<25
CB4-2	30322	5	0.72	0.49	0.7	62	0.013	26		<3		27
CB4-2B	30323	3	0.48	0.56	<0.3	<10	0.003	19		<3		100
P13-3	30324	1	0.38	0.70	0.3	<10	0.005	19		<3		48
CB13-5	30325	4	0.05	0.02	0.3	<10	0.002	5		<3		<25
P14	30326	1	0.06	0.69	0.7	<10	0.003	20		<3		39
P14-2	30327	2	0.88	3.76	<0.3	<10	0.002	200		<3		<25
P16-1	30328	1,5	2.40	0.90	<0.3	<10	0.004	20		<3		51
P16-2	30329	1,5	6.82	2.65	0.3	64	0.005	115		<3		72
P17	30330	1,5	0.26	0.75	<0.3	<10	0.003	11		<3		37
P17-2	30331	2	0.77	0.019	<0.3	<10	0.002	6		<3		<25

Description:

1 — Massive magnetite, sulphides with siliceous gangue.

2 — Marble with disseminated sulphides ± magnetite.

3 — Calcareous gneiss with disseminated sulphides ± magnetite.

4 — Black, graphitic schist, minor magnetite, sulphides.

5 — Dark green, massive, siliceous "skarn" with magnetite, sulphides.

* Bass occurrence.

exposed in its core, and the calcareous succession that hosts the Cottonbelt deposit and the Mount Grace carbonatite layer are repeated in its limbs.

Metallgesellschaft Canada Ltd. attempted to drill the Cottonbelt-McLeod sulphide-magnetite layer in the hinge of the Mount Grace syncline (Wellmer, 1978). However, mineral lineations and minor folds indicate that the fold plunges west to southwest (*see* Chapter 3) and its closure is therefore located south of Cottonbelt; hence the two holes drilled (Figure 36) penetrated only the inverted upper limb of the fold.

MINERALIZATION

INTRODUCTION

The Cottonbelt sulphide-magnetite layer has been traced or projected on surface for approximately 2.5 kilometres along the upper western limb of the Mount Grace syncline and a thin mineralized interval has been intersected in drill holes a further 2 kilometres to the north. The thickness of the layer varies from 15 centimetres in the drill intersections to a maximum of approximately 3 metres, with average widths of 1 to 2 metres (Plate 31). Geological reserves are estimated at approximately 725 000 tonnes containing 6 per cent lead, 5 per cent zinc and 50 grams silver per tonne. Northwest of Blais Creek, a zone of rusty weathering calcareous schist occurs at approximately the same stratigraphic interval.

The sulphide-magnetite layer in the northeast limb of the Mount Grace syncline, referred to as the McLeod and Complex showings and interpreted to be a fold repetition of the Cottonbelt deposit, is up to 3 metres thick and has been traced approximately 600 metres along strike. It continues for an additional 2200 metres to the southeast as a zone of disseminated pyrrhotite in calcareous gneiss (Kovacik, 1977). It is described in more detail following.

SULPHIDE-MAGNETITE MINERALIZATION

Three types of mineralization are evident in the Cottonbelt deposit. The most abundant is massive to crudely banded, dark green, hard, massive olivine-pyroxene-amphibole calc-silicate gneiss containing variable amounts of sphalerite, galena and magnetite, minor pyrrhotite, and traces of chalcopyrite, pyrite, tetrahedrite and molybdenite (Plate 32). Additional gangue minerals include biotite, carbonate and apatite. Sulphides and magnetite are generally medium to coarse grained and may be closely intergrown or segregated into essentially monominerallic layers or magnetite-sphalerite and sphalerite-galena layers a few millimetres thick. In general, however, the rock is massive and layering is only poorly developed. With an increase in silicate content, the mineralized layer becomes lighter coloured and layering is more pronounced. Thin sulphide-magnetite layers, mineralogically similar to the massive layers, occur interbedded

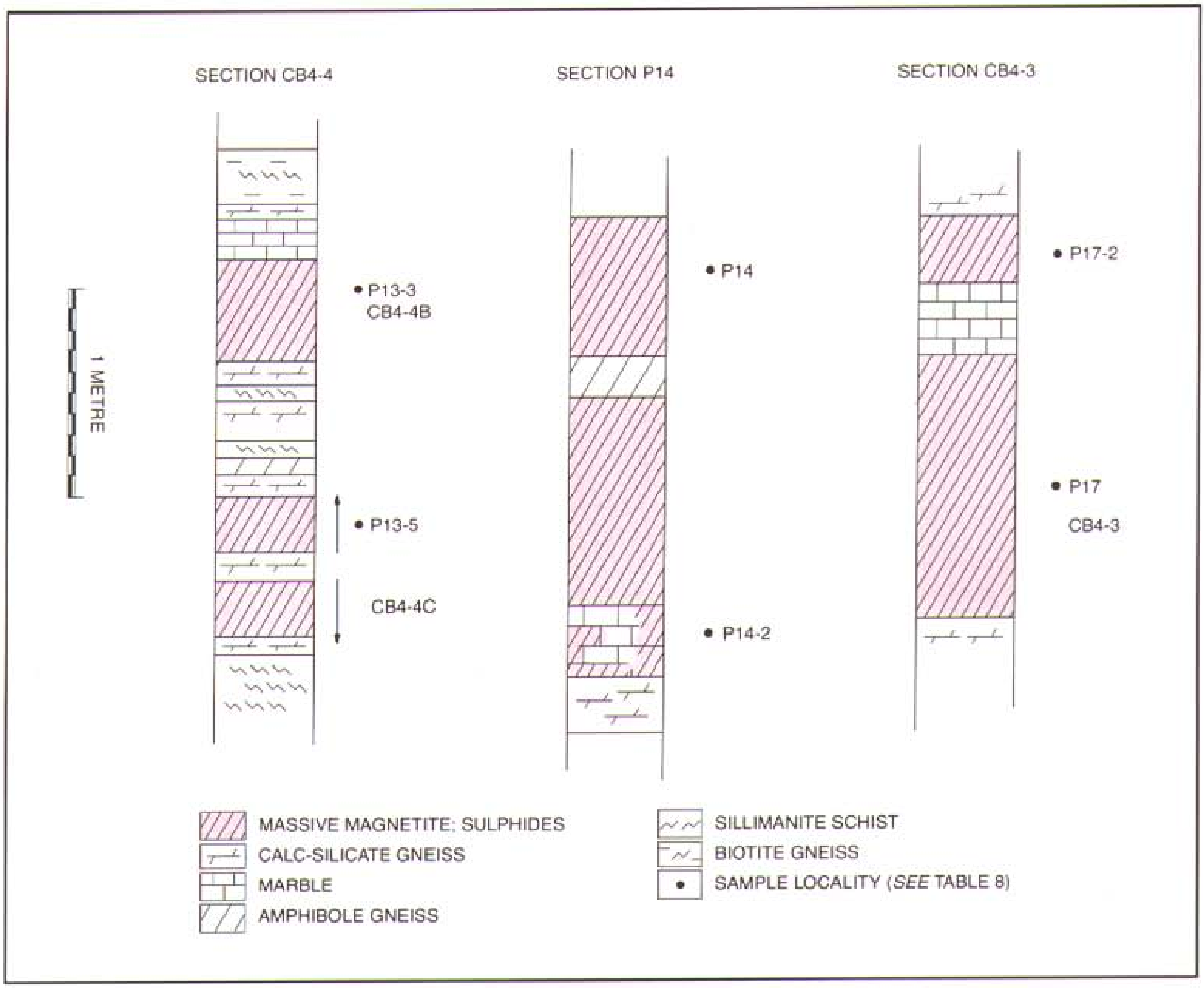


Figure 37. Detailed sections through the Cottonbelt sulphide-magnetite layer and location of analysed samples.

with thin bands of garnet-diopside calc-silicate and sillimanite schist. The third type of mineralization consists of disseminated galena and sphalerite with only minor magnetite and pyrrhotite in a light grey granular marble (Plate 32). Accessory minerals in the marble include garnet, diopside, actinolite and phlogopite.

Detailed sections through the Cottonbelt zone (Figure 37) illustrate the well-layered nature of the deposit, with massive to bedded sulphides and magnetite interlayered with calc-silicate gneiss, sillimanite gneiss, impure marble and amphibolite. Immediate hangingwall and footwall rocks are most commonly calc-silicate gneiss or impure marble. Sillimanite schist or biotite gneiss that commonly overlies the mineralization are invariably separated from the sulphide layer by a thin selvage of amphibolite or calc-silicate gneiss.

Chemical analyses of both chip and selected grab samples of the Cottonbelt layer are shown in Tables 8 and 9. Samples are located in Figure 34 and some are plotted on the sections in Figure 35. Gangue mineralogy and oxide chemistry are discussed in the section following.

Table 8 shows the highly variable tenor of the sulphide-magnetite layer, largely reflecting the variable nature of the samples, including marble and calc-silicate gneiss with disseminated sulphides, magnetite-rich silicates and massive magnetite and sulphides. Lead analyses vary from 0.05 to 16.4 per cent, zinc from approximately 0.02 to 3.9 per cent, and silver from 10 to 94 ppm. Copper is generally low, with only one analysis approaching 1 per cent. Base metal ratios are also highly variable. Pb/Pb + Zn ratios vary from 0.04 to 0.98 with approximately 40 per cent in the range 0.90 to 0.98.

These metal values and ratios, with relatively high lead and low copper, are more typical of carbonate-hosted than clastic-hosted lead-zinc deposits (Sangster, 1968). However, the unusual gangue mineralogy and chemistry distinguish Cottonbelt from these deposits.

TABLE 9. MAJOR ELEMENT ANALYSES (A) AND TRACE ELEMENT VALUES (B) OF COTTONBELT SAMPLES

TABLE 9A
(in %)

Field No.	Lab. No.	Description	SiO_2	Al_2O_3	Fe_2O_3	MgO	CaO	Na_2O	K_2O	TiO_2	MnO	P_2O_5
CB1-5	30318	1	14.31	1.55	55.42	6.92	1.46	0.02	0.009	0.08	2.12	0.02
CB1-5A	30319	1	15.25	1.20	61.43	5.92	1.68	0.03	0.020	0.02	2.53	0.02
CB1-5.1	30320	1	9.87	1.84	46.08	6.53	2.74	0.03	0.060	0.04	9.61	0.17
CB1-5.3	30321	2	11.75	4.21	12.33	11.50	26.59	0.04	1.49	0.22	2.40	0.37
CB4-2	30322	5	31.62	2.81	18.72	4.91	1.22	0.04	0.026	0.08	7.98	0.31
CB4-2B	30323	3	48.22	15.98	9.45	4.62	11.46	0.47	5.00	0.56	1.40	0.19
P13-3	30324	1	27.23	1.86	53.56	4.36	0.60	0.03	0.182	0.03	12.08	0.05
P13-5	30325	4	3.03	1.21	47.57	4.14	11.74	0.06	0.153	0.06	11.83	0.09
P14	30326	1	14.60	1.50	61.67	4.94	1.57	0.03	0.080	0.03	13.28	0.11
P14-2	30327	2	12.03	1.69	18.50	4.93	25.44	0.05	0.89	0.08	5.40	0.10
P16-1	30328	1,5	31.29	0.71	53.33	5.30	1.18	0.04	0.021	0.01	9.79	0.07
P16-2	30329	1,5	27.36	1.21	49.79	4.39	1.11	0.05	0.038	0.01	9.62	0.10
P17	30330	1,5	29.69	0.89	53.41	4.95	1.69	0.02	0.182	0.01	10.72	0.05
P17-2	30331	2	6.26	2.99	19.19	4.65	26.79	0.06	0.94	0.13	6.14	0.20

Description:

1 — Massive magnetite, sulphides with siliceous gangue.

2 — Marble with disseminated sulphides ± magnetite.

3 — Calcareous gneiss with disseminated sulphides ± magnetite.

4 — Black, graphitic schist, minor magnetite, sulphides.

5 — Dark green, massive, siliceous "skarn" with magnetite, sulphides.

* Bass occurrence.

TABLE 9B
(in ppm except as noted)

Field No.	Lab. No.	Ti	Ta	Rb	Sr	Ba	F	V	Zr	Mn (%)
CB4-1	20025	625	<30	<5	55	71	300	46	51	7.99
CB4-2	20026	1540	<30	<5	15	33	375	100	103	6.39
CB4-3	20027	390	<30	<5	33	25	260	45	66	6.36
CB4-4B	20028	625	<30	<5	8	40	350	46	49	7.48
CB4-4C	20029	660	<30	<5	40	65	575	200	63	7.86
CB7	25528									6.78
CB5-9	25529									5.13
CB5-14	25530									8.26
CB1-5	30318				<50	449				
CB1-5A	30319				<50	348				
CB1-5.1	30320				57	172				
CB1-5.3	30321				602	726				
CB4-2	30322				<50	84				
CB4-2B	30323				224	1457				
P13-3	30324				<50	172				
P13-5	30325				232	134				
P14	30326				<50	58				
P14-2	30327				542	222				
P16-1	30328				<50	<50				
P16-2	30329				<50	<50				
P17	30330				<50	146				
P17-2	30331				459	310				

Gangue Mineralogy and Chemistry

Major element analyses of the Cottonbelt sulphide-magnetite layer (Table 9A) are highly variable reflecting host rocks that range from impure marble to calc-silicate gneiss. Alkali content is low, generally less than 1 per cent, although one sample of calc-silicate gneiss containing abundant phlogopite, CB4-2B, returned 5 per cent K_2O. CaO varies from approximately 1 per cent in essentially massive sulphide-magnetite samples that have only minor gangue minerals, to greater than 25 per cent in mineralized marbles. A common and distinctive feature of the mineralized layer is the high MnO content, ranging from 1.4 to 13.28 per cent (Table 9A).

Gangue minerals are unusual as they reflect the high manganese content and overprinting of regional metamorphism to upper amphibolite facies. Recognition and identification of these gangue minerals are by standard petrography and X-ray defraction analyses. Silicate minerals include varying proportions of knebelite (a manganiferous olivine), actinolite, diopside and a manganiferous pyroxene, spessartine, biotite and minor secondary chlorite. Ankerite is the dominant carbonate, but minor calcite and kutnahorite, a calcium-manganese carbonate, have also been identified. Accessory minerals include epidote, plagioclase, graphite, gahnite and hematite.

A dark green massive olivine is the dominant silicate gangue mineral in many massive sulphide samples. X-ray defraction analysis indicates it is a manganese fayalite and its optical properties indicate a composition that approximates $(Fe_{56-83},Mn_{10-24},Mg_{7-20})_2SiO_4$ (Johnson, 1980a) and, as such, it is called knebelite. Knebelite is a distinctive mineral in metamorphosed iron-manganese deposits. It also occurs as gangue in massive sulphide deposits at the Bluebell silver-lead-zinc deposit in the Kootenay Arc (Höy, 1980b). Pyroxenes include diopside, hedenbergite, a manganese-rich mag-

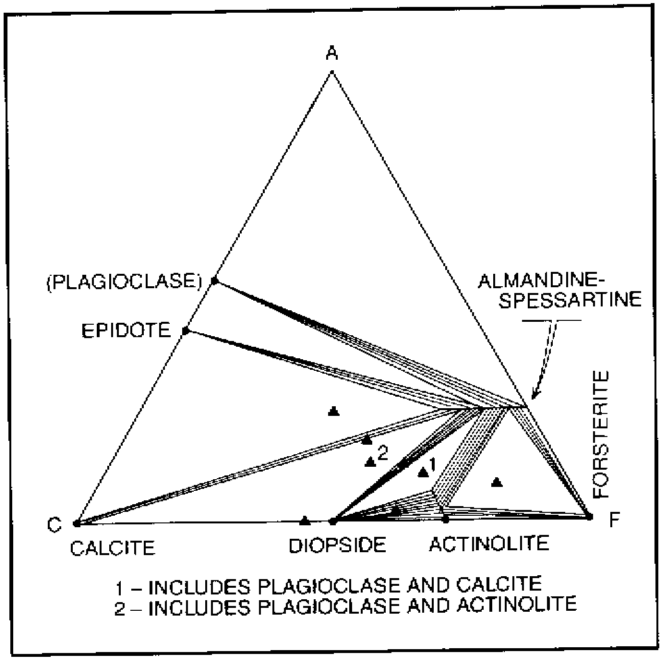


Figure 38. ACF diagram illustrating gangue mineral assemblages, Cottonbelt deposit.

nesium clinopyroxene called kanoite, and less commonly a manganiferous orthopyroxene, eulite (Johnson, 1980a). Kanoite has been recognized in metamorphosed manganese ore in Japan (Kobayashi, 1977) and eulite is reported in some regionally metamorphosed iron-rich sediments (Deer *et al.*, 1978). Actinolite is the dominant amphibole and in some samples is the dominant silicate mineral. Cummingtonite (grunerite?), containing minor manganese, may also be abundant. Porphyroblasts of spessartine-almandine garnet occur in most calc-silicate gneiss host rocks, and biotite occurs as a minor phase in both mineralized impure marble and calc-silicate gneiss. Epidote is uncommon, but was recognized as a minor phase in a mineralized calc-silicate gneiss. Rare plagioclase grains and retrograde chlorite occur in a few samples.

The most common and abundant carbonate mineral associated with the massive sulphides is ankerite. Kutnahorite commonly occurs with ankerite, and calcite is abundant in mineralized marble, but is a minor constituent of the massive sulphide-magnetite mineralization.

Metamorphism

The Cottonbelt mineralized layer has undergone the regional amphibolite grade metamorphism that has affected the country rocks. The prevalent mineral assemblages are graphically displayed on an ACF diagram (Figure 38). These assemblages, and the extensive solid solution among minerals, are diagnostic of amphibolite grades in manganiferous iron formations (Haase, 1982). The compositional ranges depicted on the diagram are schematic but reasonable; they are based on ranges typically occurring in these phases at these metamorphic grades. The diagram, however, only depicts two and three-phase mineral assemblages. The common occurrence of four, and less commonly five-phase assemblages (for example, olivine, amphibole, actinolite, diopside and garnet) is likely the result of extensive solid solution among the minerals and the effect of additional components (such as MnO) in the system.

Depositional Environment

An understanding of the depositional environment is only possible if the original mineralogy of the Cottonbelt layer can be determined. Premetamorphic assemblages are not known as the layer occurs only within rocks of amphibolite grade. This metamorphism has totally recrystallized and annealed the mineral assemblages, masking any original depositional textures. Determination of the pre-metamorphic mineralogy requires comparison with iron formations and sulphide deposits that occur at lower metamorphic grades.

The most common oxide facies of iron formations are hematite and magnetite. Magnetite may be a primary phase (Klein and Buiku, 1977), but is more likely formed during diagenesis (Dimroth and Chauvel, 1973), or during regional metamorphism from a reaction involving siderite or hematite. It is unlikely that magnetite in the Cottonbelt deposit formed from an iron sulphide because other massive sulphide bodies in the Shuswap Complex have retained their sulphide (pyrite-pyrrhotite) assemblages at high metamorphic grades (for example, Jordan River, Fyles, 1970a; Big Ledge, Höy, 1977a). It is assumed, therefore, that magnetite in the Cottonbelt deposit formed early, probably during diagenesis.

The most abundant carbonate in the deposit is ankerite. Ankerite is common in iron formations and is therefore assumed to be formed early and later recrystallized at Cottonbelt. Dolomite is now rare, but was probably more abundant initially, providing a source of magnesium; subsequent metamorphism has converted it and available silica to calcite and calcareous and magnesian silicates. Calcite was undoubtedly present as a primary mineral in the calcite marbles that host disseminated sulphides and magnetite. Kutnahorite, a manganiferous carbonate, may be a metamorphic mineral formed from a reaction involving either a manganese oxide or manganese carbonate such as rhodochrosite with calcite or dolomite.

The two more important sulphide minerals, galena and sphalerite, are common in many unmetamorphosed mineral deposits and are assumed to have been present at Cottonbelt before metamorphism. The metamorphic silicate minerals diopside, actinolite, cummingtonite, knebelite and spessartine formed from reactions between aluminous clays or detrital minerals, calcareous and magnesian carbonates, and manganiferous oxides or carbonates.

In summary, pre-metamorphic minerals are inferred to include dominantly magnetite (or perhaps hematite) and minor pyrite, galena, sphalerite and chalcopyrite. Carbonates included ankerite, probably dolomite, and perhaps a manganese carbonate. Calcite may only have been present in calcareous layers that host disseminated sulphides and magnetite. Clay minerals and perhaps detrital feldspars were the source of aluminum, and silica may have been present as iron silicates such as greenalite or as chert; thin chert layers in adjacent beds suggest some precipitation of silica, but deposition during formation of the sulphide-magnetite layer was

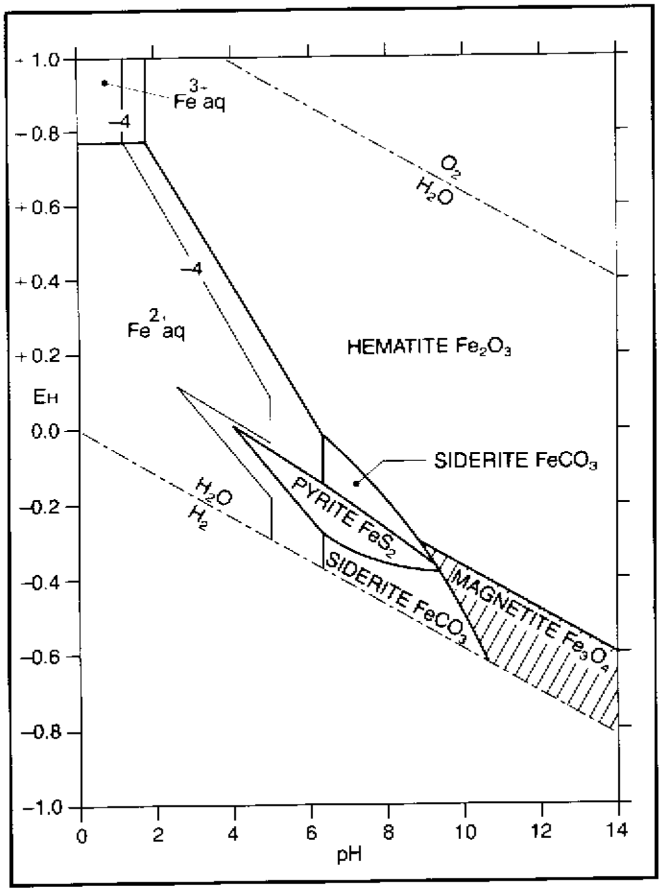


Figure 39. Eh-Ph phase diagram showing stability field of iron phases, Cottonbelt deposit. (after Garrels & Christ, 1977).

minimal as the silica has completely reacted to form metamorphic silicate minerals.

These assemblages may be used to estimate conditions during deposition of the sulphide-magnetite layer. The stability field of magnetite is essentially restricted to a basic, reducing environment (in water at 25°C, 1 atmosphere pressure and in the presence of sulphur; Figure 39). Hematite is stable in a more oxidizing environment. Galena and sphalerite are stable over a larger Eh and Ph range (Garrels and Christ, 1967), a range that overlaps the magnetite field in a basic, reducing environment. Chalcopyrite is the stable copper mineral in this environment and rhodochrosite the stable manganese mineral. The abundance of sphalerite and galena and their association with magnetite therefore suggests deposition in a reducing basin with only a limited supply of sulphur available. As reduction of seawater sulphate is generally considered the primary source of sulphur in stratabound base metal deposits, a restricted basin and hence limited supply of sulphate is inferred.

The succession that hosts the Cottonbelt deposit records a marine transgression over a regional unconformity (*see* Chapter 2). Host rocks were deposited on a shallow marine platform, a sedimentary setting common to many banded iron formations. A shallow, restricted basin within the platform is indicated by the abundance of scapolite, formed by metamorphism of evaporites, and a reducing environment, by graphite. It is therefore concluded that the Cottonbelt sulphide-magnetite layer was deposited directly on the seafloor, in a shallow restricted, perhaps lagoonal basin on a large carbonate-clastic platform.

Volcanism may have been an important factor as the ultimate source of iron and manganese in the deposit and in the generation of a convective hydrothermal system. Basic volcanic rocks occur beneath the projected position of the mineralized horizon north of Blais Creek. The unusually high lead and zinc content, generally characteristic of sedimentary exhalative deposits rather than volcanogenic deposits or iron formations, probably results from scavenging of these metals from the thick underlying accumulation of sedimentary rocks.

CONCLUSIONS

The spatial association of base metals with iron formations is commonly recognized in volcanogenic massive sulphide deposits. Less commonly, iron formations have been described as distal equivalents of lead-zinc deposits. In Ireland, the Tynagh iron formation is believed to have formed as an exhalite in the laterally equivalent Waulsortian mud bank deposits during deposition of the Tynagh lead-zinc-copper-barite deposit (Russell, 1975), and in southwestern Quebec, magnetite-rich iron formations are correlative with stratiform lead-zinc deposits in the Grenville Province (Gauthier and Brown, 1986). Stratabound galena-sphalerite-magnetite deposits similar to Cottonbelt, or iron formations enriched in lead and zinc are uncommon. Gamsberg in South Africa is a stratiform sphalerite-galena-magnetite deposit that has undergone amphibolite facies regional metamorphism (Rozendaal and Stumpfl, 1984). The La Union lead-zinc orebody in southeastern Spain (Oen *et al.*, 1975) consists, in part, of disseminated to banded galena, sphalerite and pyrite in a "greenalite-silica/magnetite rock" or banded iron formation (D.J. Alldrick, personal communication, 1986). Alldrick suggests the deposit may be a "primary chemical precipitate" rather than "subvolcanic-hydrothermal" as suggested by Oen *et al.* (*op. cit.*).

The unusual association of magnetite rather than pyrite with galena and sphalerite in this deposit type is a function of conditions in the depositional environment. Magnetite deposition is favoured in a basic, reducing environment as would occur in a restricted, highly saline, shallow-marine or lagoonal basin. Furthermore, the availability of sulphur from reduction of seawater sulphate would also be limited in a restricted basin, tending to support magnetite rather than pyrite formation; available sulphur reacts initially with lead and zinc and only excess sulphur is available to react with iron to form pyrite. In basins more typical of base metal deposition, lower Ph, higher Eh, and an increased availability of sulphur allows deposition of iron sulphides producing the typical pyrite-galena-sphalerite association.

BASS

The Bass occurrence is the northwestern extension of the Cottonbelt layer (Figure 33), and as such is chemically and mineralogically similar to Cottonbelt. An adit at 1615 metres elevation exposes approximately 1.5 metres of massive, siliceous magnetite-sulphide mineralization. It comprises mag-

TABLE 10. ANALYSES OF SAMPLES OF THE McLEOD LAYER AT THE McLEOD ADIT

(*See* Figure 40 for location.)

Sample No.	Mineralization	Pb %	Zn %	Ag g/t	Cu %	Fe %
CB2-C	massive	4.8	0.10	86	0.88	19.8
CB2-D	disseminated	0.88	0.03	16	0.02	19.4

netite, galena, sphalerite, minor pyrrhotite, pyrite and chalcopyrite. Analyses of a selected grab sample (CB5-14, Table 8) returned 3.8 per cent lead and 0.20 per cent zinc. The high iron (36 per cent) reflects the high magnetite content. The hangingwall and footwall are siliceous marble, 30 centimetres thick, then calc-silicate gneiss. The layer strikes 160 degrees and dips 40 degrees west.

McLEOD AND COMPLEX (MI 82M-125)

The McLeod, and its extension to the northwest referred to as the Complex showing, are a repetition of the Cottonbelt layer on the east limb of the Mount Grace syncline. It has been described by various authors, including Boyle (1970), Kovacik (1977) and Shearer (1985); the following description is summarized from these reports.

Mineralization is similar to Cottonbelt, dominantly magnetite with galena, sphalerite, and minor chalcopyrite, pyrrhotite and pyrite in a layer up to several metres thick. In contrast with Cottonbelt, however, the mineralized zone is part of a right-way-up stratigraphic succession that strikes approximately 155 degrees and dips 40 degrees southwest.

The McLeod-Complex layer overlies a white crystalline marble and a fine-grained, rusty weathering biotite schist (Figure 40). Hangingwall rocks include a thin marble band and calc-silicate gneiss followed by more than 30 metres of interlayered biotite schist and calc-silicate gneiss. Elsewhere, biotite schist directly overlies the mineralized layer (Kovacik, 1977).

The mineralization averages 1.5 metres in thickness and can be traced 100 metres southeast of the McLeod adit before it is replaced by disseminated iron sulphides in calc-silicate gneiss (Boyle, 1970; Kovacik, 1977). The disseminated sulphide facies can be traced a further 2200 metres to the southeast. It is not traceable to the northwest, although the footwall limestone continues to Blais Creek (Boyle, 1970).

The most recent extensive sampling of the McLeod-Complex layer, 21 surface chip samples along the exposed length of the zone, returned an average of 5.37 per cent lead, 6.51 per cent zinc and 97 grams silver per tonne across an average width of 1.4 metres (Allen, 1966). Analyses of two samples from the McLeod adit (*see* Figure 40) are summarized in Table 10. More massive magnetite-sulphide mineralization near the base of the layer contains 4.8 per cent lead, 0.1 per cent zinc and 86 grams silver per tonne; a sample of disseminated mineralization in more calcareous gneiss near the top of the layer returned considerably lower values.

COPPER KING (MI 82M-144)

The Copper King deposit is hosted by quartzite of Unit 6 in the core of the Mount Grace syncline, south of the McLeod adit (Figure 33). The quartzite is interlayered with thin beds of marble and micaceous schist. It is underlain by interbedded light grey quartz feldspar paragneiss and micaceous schist and overlain by schist. Mineralization, comprising disseminated chalcopyrite and minor bornite, sphalerite and pyrite, ranges up to 3 metres in thickness and has been traced along strike for at least 300 metres. An adit 50 metres in length driven along a more extensively mineralized portion of the zone was reopened and resampled in 1970 (*see* Boyle, 1970; Table 11); additional analyses of the Copper King mineralization (Allen, 1966) are also presented in Table 11.

SEYMOUR (MI 82M-155)

Mineralization on the Seymour claims was discovered in 1978 during a follow-up exploration program of silt and soil geochemical anomalies (Woodcock and Booth, 1978). It includes a number of small occurrences of sulphides and magnetite within or adjacent to a marble layer south of Blais Creek (Figures 3 and 33). Its stratigraphic position, near the base of Unit 6, and its mineralogy suggest that these occurrences and their extension north of Blais Creek may be distal equivalents of the Cottonbelt and McLeod-Complex layer. Descriptions of the occurrences are taken from Woodcock and Booth (1978); only occurrence 155c (Figure 3) has been visited by the author.

Showing 155a comprises disseminated chalcopyrite in a quartz-marble breccia bed 10 centimetres thick. Observed mineralization is restricted to a number of boulders at the base of a small cliff. A specimen assayed 1.02 per cent copper.

Showing 155b is a 10-centimetre-thick quartzite layer adjacent to a marble bed that contains minor disseminated chalcopyrite. A galena-rich section 2 metres long assayed 16.1 per cent lead and 0.8 per cent zinc.

Showings 155c and **155d** are along a discontinuous lens of coarse-grained magnetite, garnet and hornblende. Showing 155c has a maximum thickness of 30 centimetres and a possible length of 15 metres; a sample across the lens contained 0.05 per cent zinc, 175 ppm copper and 38 ppm lead. Showing 155d is 25 centimetres thick, possibly 10 metres long and assayed 0.04 per cent zinc, 740 ppm copper and trace lead.

TABLE 11. ANALYSES OF THE COPPER KING DEPOSIT [from Allen, 1966 (1); Boyle, 1970 (2)]

Sample No.	Sample Width	Cu %	Ag g/t	Au g/t	Reference
1	~1.5 m	3.95	~3	~0.15	1
2	~1.5 m	4.35	~10	~0.30	1
3	~1.5 m	3.85	~3	~0.15	1
19576	~2.0 m	1.98	~4.5		2
19577	~2.0 m	1.96	~3.0		2
19578	1.5 m	3.55	~6.5		2
19599	2.0 m	0.08	Trace		2

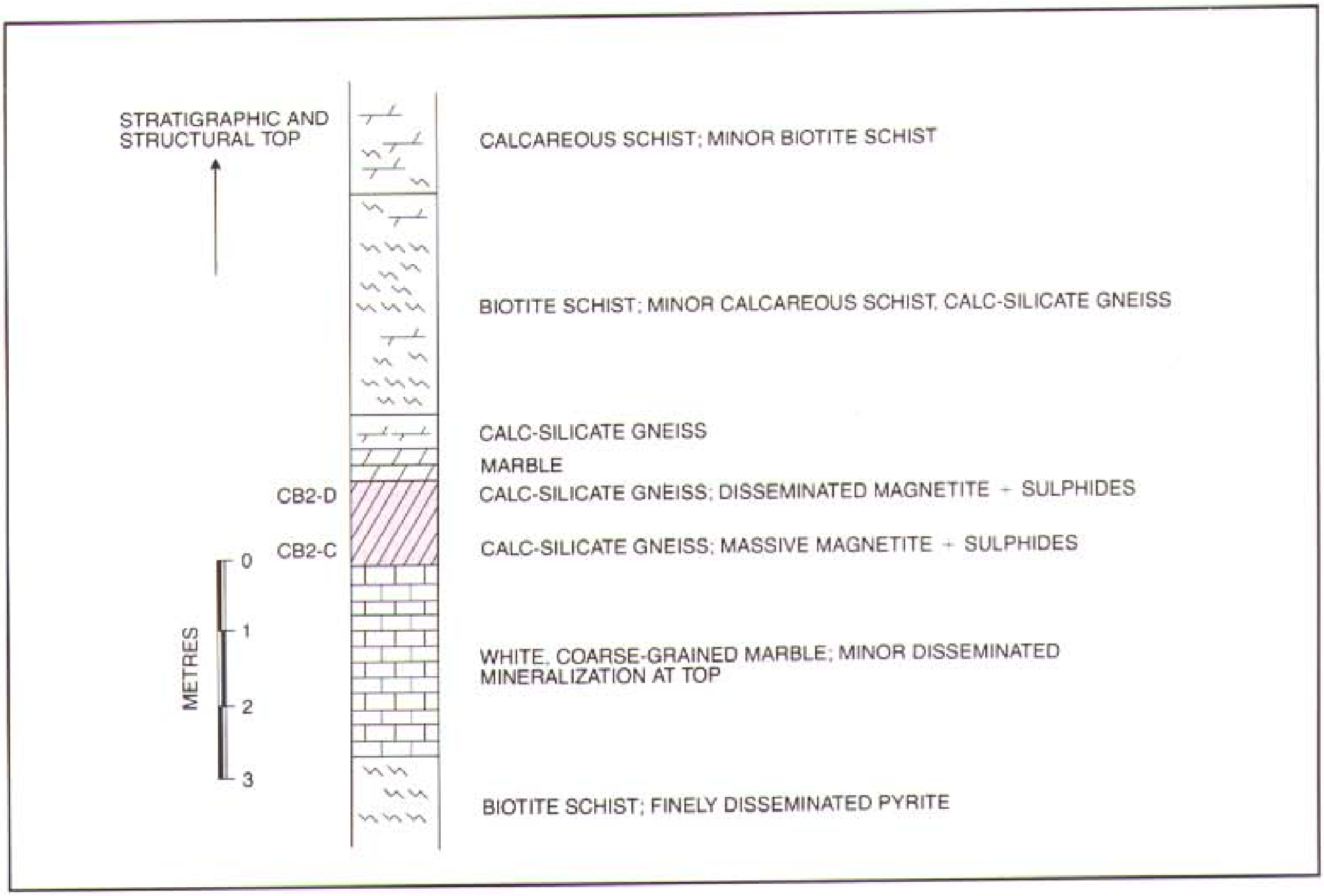


Figure 40. A section through the McLeod layer at the McLeod adit.

Showing 155e is a lens of quartzite 15 centimetres thick and 1 metre long that contains a few coarse grains of chalcopyrite and galena.

BLAIS (MI 82M-153)

The Blais occurrence, and a number of similar occurrences to the northeast (Figure 33), are at approximately the same stratigraphic level as the Seymour showings. Blais consists of a carbonate lens with disseminated galena approximately 15 centimetres thick and up to 20 metres in length (Woodcock and Booth, 1978).

OCCURRENCE CB14-9 (MI 82M-240)

This occurrence consists of magnetite and minor chalcopyrite, marked by conspicuous malachite staining, in a very rusted zone approximately 20 centimetres thick at the contact of a marble and calc-silicate gneiss. A small pit, filled with snow at the time of the author's visit (July 1978), indicates previous exploration of the zone.

OCCURRENCE CB14-12 (MI 82M-242)

This occurrence, approximately 500 metres east of CB14-9 (MI 82M-240, Figure 33), comprises a 15 to 20-centimetre-thick interval of minor chalcopyrite and magnetite mineralization, associated with hornblende, near the top of the coarse-grained white crystalline marble.

OCCURRENCE CB16-2 (MI 82M-241)

Occurrence CB16-2 includes a number of small rusty zones within the coarse crystalline marble. The zones contain chalcopyrite, magnetite and pyrrhotite in a siliceous matrix that includes pyroxene, garnet, amphibole and fayalite, an iron-rich olivine.

D & R (MI 82M-200)

The D & R occurrence consists of minor disseminated molybdenite in a quartz syenite orthogneiss within rocks correlated with core gneisses (Figure 33). It is similar to a small molybdenite showing in syenite orthogneiss in the Perry River area (*see* Chapter 4). The host syenite (Figure 3) has a maximum exposed width of about 200 metres and a strike length of at least 1300 metres. Petrographic descriptions of the syenite (Johnson, 1980b) indicate it consists mainly of feldspar (35 to 55 per cent), perthite (up to 50 per cent), and plagioclase (30 to 50 per cent) with minor biotite and less than 5 per cent quartz. It is conformable with host hornblende and pelitic paragneisses.

Molybdenite mineralization appears to be restricted to an area of approximately 4 square metres near the structural base of the orthogneiss. Three assays of the mineralization returned 0.10 per cent, 0.65 per cent and less than 0.01 per cent MoS_2 (Johnson, 1980a).

SHUSWAP MASSIVE SULPHIDE DEPOSITS

INTRODUCTION

A number of large stratabound lead-zinc deposits occur within dominantly calcareous successions along the margins of Frenchman Cap dome and Thor-Odin nappe to the south (Figure 41). Although a number of these have been extensively explored, there has been no significant production from them. They are thin but very extensive laterally, are commonly structurally complex, and many are in formidable mountainous terrain. These deposits, and others within the complex (Table 12), consist of a single layer of massive to irregularly banded sulphides or a series of lenses generally within thin calcareous or graphitic schist units. They are folded and metamorphosed together with their host rocks.

The Cottonbelt and Jordan River deposits are in paragneiss that overlies core gneiss of Frenchman Cap dome. Ruddock Creek, located approximately 40 kilometres north of Cottonbelt (Figure 41), is also within a highly deformed, dominantly calcareous succession that structurally overlies the Cottonbelt and Jordan River succession. Big Ledge, located 60 kilometres south of Revelstoke, along the southern margin of Thor-Odin nappe, is within a paragneiss succession that correlates approximately with the Cottonbelt succession. Other stratabound lead-zinc deposits within the Shuswap Complex include Colby and CK; the Rift deposit north of Revelstoke is similar to the Shuswap deposits although it occurs just east of the Columbia River fault.

JORDAN RIVER (MI 82M-001)

A sulphide-rich layer less than a metre to 6 metres in thickness forms part of the lithological sequence in the Jordan River area (Fyles, 1970a) on the southern margin of Frenchman Cap dome (Figure 41). On the Jordan River (King Fissure) property, it is exposed in the limbs and hinge of the tight south to southeast-plunging Copeland synform. Reserves in the south limb have been calculated as 2.6 million tonnes containing 5.1 per cent lead, 5.6 per cent zinc and 35 grams silver per tonne (*see* Fyles, *op. cit.*).

The mineralized bed consists most commonly of a "fine-grained intimate mixture of sphalerite and pyrrhotite with conspicuous eye-shaped lenses of grey, watery quartz and scattered grains of pyrite and galena" (Fyles, *op. cit.*, page 41). Locally, it is well layered and includes minor pods and lenses of calc-silicate gneiss, schist, marble or barite. It is within a calcareous succession of calc-silicate gneiss, micaceous schist, marble and quartzite, and is structurally overlain by a quartzite-rich succession followed by a sillimanite gneiss unit.

Correlation of this succession along the western margin of Frenchman Cap dome (Höy and McMillan, 1979; Höy and Brown, 1981) indicates that the Jordan River sulphide layer lies within Unit 6 at approximately the same stratigraphic level as the Cottonbelt deposit (*see also* Figure 8).

RUDDOCK CREEK (MI 82M-083)

Ruddock Creek (Figure 41) is a sulphide layer up to 15 metres thick that comprises interlayered calcareous quartzite, marble and minor schist with one or more layers or lenses of locally contorted sulphides and quartz, and lenses of fluorite and barite (Fyles, 1970a). It is exposed or projected several kilometres in strike length. Locally it has been thickened in the hinge of a Phase 1 isoclinal syncline and here it is referred to as the E showing. Estimated reserves in the E showing by Falconbridge Nickel Mines Ltd. are approximately 5 million tonnes containing 2.5 per cent lead, 7.5 per cent zinc and trace silver. Mineralization consists of massive sphalerite, pyrrhotite, galena, pyrite and minor chalcopyrite that commonly contains rounded quartz eyes, and as scattered grains of galena and sphalerite in marble, calcareous quartzite and fluorite (Fyles, *op. cit.*).

The sulphide layer is in a succession of calcareous schist, quartzite and impure marble above the Monashee décollement and autochthonous cover succession that hosts Cottonbelt. Although its age is unknown, it has been tentatively correlated with the Hadrynian Windermere Group (R.L. Brown, personal communication, 1985). The succession is highly deformed, metamorphosed to amphibolite grade, and extensively invaded by pegmatite.

BIG LEDGE (MI 82LSE-012)

Big Ledge is a stratabound zinc deposit contained in mantling gneisses of Thor-Odin dome, 60 kilometres south of Revelstoke (Figure 41) (Reesor and Moore, 1971; Read, 1979). It is hosted by a rusty weathering, calcareous graphitic schist interlayered with calcareous quartzite, calc-silicate gneiss and marble (Höy, 1977a). Within the schist, referred to as the "Ledge", are lenses of massive, medium to coarse-grained pyrite or pyrrhotite with variable amounts of dark sphalerite. Sulphides are also disseminated throughout the schist, and occur in discontinuous laminations 1 to 2 millimetres thick and in small fractures crosscutting the layering and foliation (Höy, 1977a).

TABLE 12. STRATABOUND LEAD-ZINC DEPOSITS IN THE SHUSWAP COMPLEX

Name	Estimated Reserves*	Deposit Type	Dominant Host Rocks
Cottonbelt	0.7; 6% Pb, 5% Zn, 50 g/t Ag	stratabound layers	calcareous gneiss
Jordan River	2.6; 5.1% Pb, 5.6% Zn, 35 g/t Ag	stratabound layers, lenses	calcareous gneiss, barite
Ruddock Creek	~5.0; 2.5% Pb, 7.5% Zn, tr Ag	stratabound lenses, layers	marble, quartzite, barite
Big Ledge	6.5; 4% Zn	disseminated, lenses	graphitic schist
Colby	~1.0; 7% Zn, <1% Pb	disseminated, lenses	marble, quartzite, calcareous gneiss
CK	?	stratabound layer	calcareous gneiss
Rift	?; 29% Zn, 5% Pb	stratabound layer, lenses	calcareous gneiss

* In million tonnes.

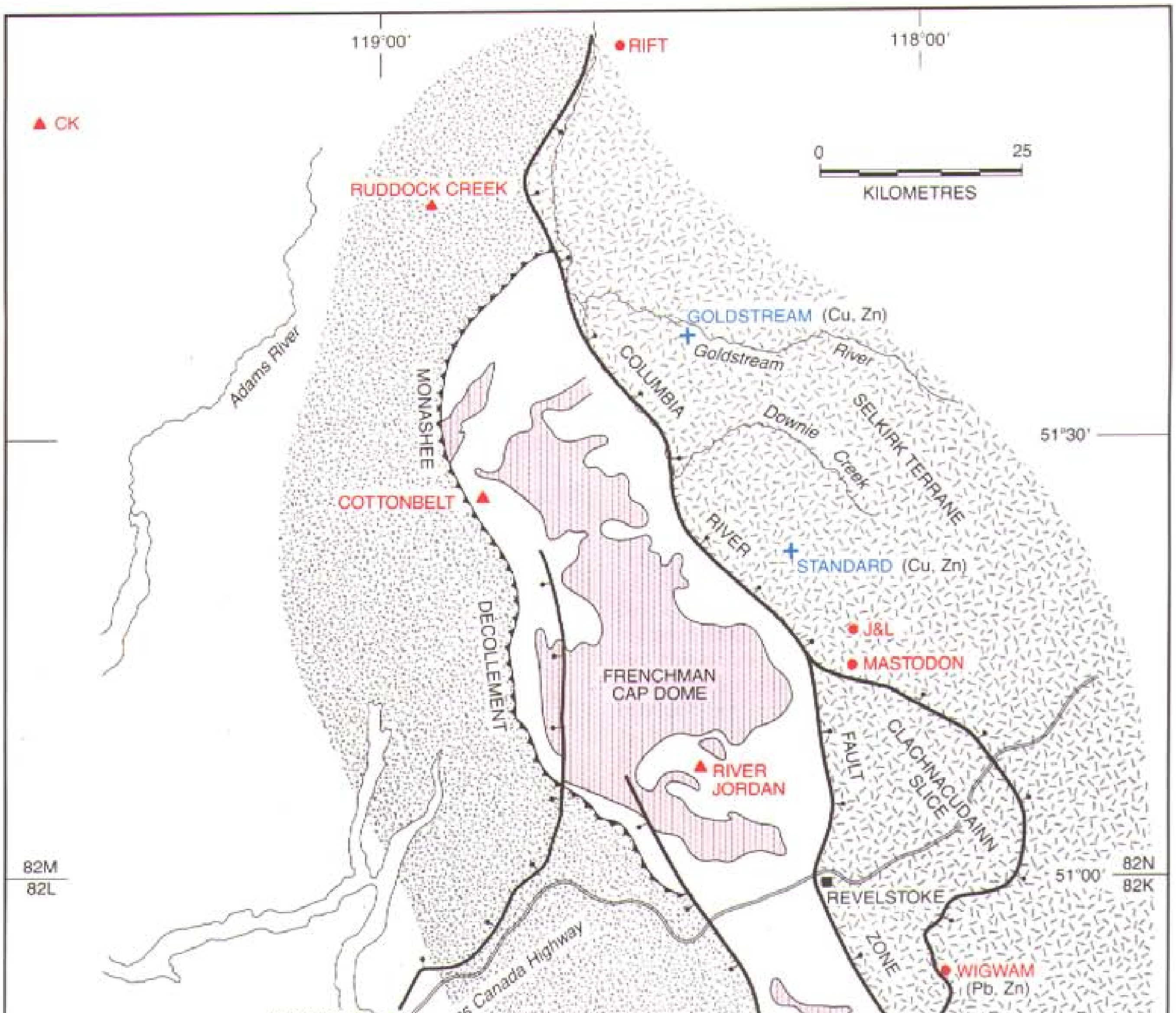


Figure 41. Tectonic setting and location of Shuswap deposits, southeastern British Columbia.

TABLE 13. ANALYSES OF MINERALIZED SAMPLES FROM THE COLBY DEPOSIT

Sample No.	Rock Type	Zn %	Pb %	Cu %	Cd %	Ag ppm	Au ppm	Showing
14311	marble	5.8	0.11	tr	tr	<3	<0.3	Central
14312	quartzite	22.1	6.6	0.015	0.025	<3	<0.3	Central
14313	marble	0.34	0.04	tr	—	<3	<0.3	Central
14314	marble	6.3	0.27	tr	tr	<3	<0.3	Central
14315	marble	7.7	0.70	tr	tr	<3	<0.3	Central
14316	marble	11.3	0.98	tr	tr	<3	<0.3	Mile 12
14317	marble	5.3	0.49	tr	tr	<3	<0.3	Mile 12
14318	quartzite	1.58	0.12	0.015	tr	<3	<0.3	Central
14319	marble	0.88	0.06	0.015	<0.005	<3	<0.3	Central
14320	marble	7.2	0.31	0.015	tr	<3	<0.3	Central
16269	calc-silicate gneiss	1.3	0.2	0.007	0.002	3	<0.3	Central
16270	marble	3.3	0.3	0.005	0.002	4	<0.3	Mile 12
16271	marble	8.9	0.96	0.005	0.006	3	<0.3	Central
16272	quartzite	8.5	8.5	0.01	0.02	5	<0.3	Central
16273	marble	7.1	0.25	0.007	0.001	3	<0.3	Central

The "Ledge" layer can be traced or projected for a distance of over 10 kilometres. It is within a succession of thin-bedded quartzite, marble and calcareous and pelitic schist that structurally overlies core gneisses. Although its age is not known, it is correlated with a similar succession hosting both the Jordan River and Cottonbelt deposits on the margins of Frenchman Cap dome, and with Eocambrian platformal rocks in the Kootenay Arc to the east (Wheeler, 1965; Reesor and Moore, 1971; Höy, 1977a). Read (1979) has suggested, however, that these mantling rocks may correlate with the Late Proterozoic Purcell Supergroup.

COLBY (MI 82ESW-062) (KINGFISHER, BRIGHT STAR)

Colby is located 48 kilometres by road east of Enderby (Figure 41). It is a stratabound lead-zinc deposit in marble, quartzite and calc-silicate gneiss units of the Monashee Group. These units have been traced 6 kilometres on the Colby property, with mineralization restricted to five zones (Höy, 1977b).

Mineralization consists of dark, medium-grained sphalerite with varying amounts of pyrrhotite, pyrite and minor galena disseminated through a medium to coarse-grained white calcite marble. The marble is structurally overlain by calc-silicate gneiss that contains crude layers or irregular zones of sphalerite, pyrrhotite, pyrite and minor galena. Dark sphalerite and pyrrhotite are also concentrated in thin layers in overlying quartzite or disseminated throughout the quartzite. Galena is more abundant in quartzite than in the marble, but is nearly always subsidiary to sphalerite. Sulphide concentration in the quartzite varies from widely scattered individual sphalerite and pyrrhotite grains to almost massive sphalerite-pyrrhotite-(± galena pyrite). Assays of selected samples from the mineralized zones are given in Table 13.

CK (MI 82M-137)

The CK property includes a number of lead-zinc showings located between Ritchie Creek and Raft River, 37 kilometres north of Vavenby (Figure 41). The most important showing, the New showing, is a sulphide layer generally less than 1 metre thick that appears to be continuous, with perhaps minor structural breaks and offsets, for a distance of at least 1300 metres (Höy, 1979b). It consists of massive sphalerite and pyrrhotite, minor galena and trace chalcopyrite. Gangue quartz, diopside, calcite, amphibole and plagioclase are common and fluorite and vesuvianite occur locally.

Assays of selected samples from the New showing, the Main Boulder zone approximately 1 kilometre to the northwest, and the North and Mist showings 4 kilometres to the north, are shown in Table 14. Average grades of the massive sulphide layer and immediate wallrocks, reported by Cominco Ltd., range from 1 to 3 per cent lead and 5 to 15 per cent zinc.

The sulphide layer is hosted by a calcareous succession, structurally underlain by hornblende gneiss and amphibolite and overlain by quartz feldspar gneiss and pelitic schist. The calcareous succession includes calc-silicate gneiss, white marble layers up to several tens of metres thick and micaceous schist and gneiss. It is invaded by pegmatite and granitic gneiss.

RIFT (MI 82M-190)

Rift is a stratiform zinc-lead-(copper-silver) massive sulphide showing located approximately 100 kilometres north of Revelstoke (Figure 41) (Gibson and Höy, 1985). Although it is east of the Columbia River fault, within the Selkirk allochthon, it is included in a description of Shuswap occurrences because of its similarity to these deposits.

TABLE 14. ANALYSES OF MINERALIZED SAMPLES FROM THE CK DEPOSIT

Showing	Sample Type	Pb %	Zn %	Fe %	Cu ppm	Cd ppm
Main Boulder	grab sample	1.45	5.8	—	—	—
Main Boulder	grab sample	4.50	27.1	—	—	—
Main Boulder	grab sample	6.31	23.37	7.76	247	252
Main Boulder	0.6-metre chip	4.88	23.45	14.34	423	260
New	0.6-metre chip	4.19	25.20	12.24	408	255
New	0.6-metre chip	4.41	21.85	20.84	568	203
North	0.6-metre chip	0.81	8.95	19.44	515	87
Mist	0.6-metre chip	2.66	20.70	11.33	512	230

TABLE 15. BASE METAL ANALYSES OF MASSIVE SULPHIDE LENSES AND HOST ROCKS, RIFT SHOWING

Sample No.	Pb %	Zn %	Cu %	Lithology
84R-10	5.75	29.3	0.017	upper massive sulphide lens
84R-9C	13.9	25.1	0.009	main massive sulphide lens
84R-8F	6.83	31.7	0.067	main massive sulphide lens
84R-8E	7.01	31.3	0.067	main massive sulphide lens
84R-9B	0.048	0.012	0.018	siliceous, calcareous schist
84R-9A	9.01	23.9	0.039	lower massive sulphide lens
84R-8C	5.00	26.8	0.032	lower massive sulphide lens
84R-8B	0.015	0.074	0.021	chert, quartzite, siliceous schist

The Rift sulphide layer is within a 400-metre-thick, largely schistose zone between two massive calcite and dolomite marble units. The lower marble is underlain by graphitic and calcareous schist and greater than 900 metres of predominantly grit and laminated chlorite schist. This succession has been traced southward (G. Gibson, personal communication, 1987) and correlated with the succession hosting the Goldstream massive sulphide deposit, and is therefore tentatively assigned to the Lower Paleozoic Hamill or Lardeau Groups.

The Rift showing consists of a number of thin layers of massive sphalerite, pyrite, pyrrhotite and galena exposed for approximately 25 metres of strike length in a steep-sided creek gully; the thickest of the layers is about 2 metres thick. These layers are separated by schistose, quartz-rich and somewhat calcareous rocks with disseminated sulphides. A second massive sulphide zone, the "upper showing", is exposed approximately 90 metres stratigraphically above the main showing. Intervening rocks include calcareous schists and thin marble bands, overlain by more pelitic schists.

The massive sulphide layers are irregularly laminated on a <1 to 10-centimetre scale. Sphalerite is commonly the most abundant sulphide; pyrrhotite is abundant in the southern part of the gully exposure, whereas pyrite predominates to the north (Hicks, 1982). Galena averages from 5 to 8 per cent, and chalcopyrite and arsenopyrite occur in trace amounts. Prominent gangue minerals in the massive sulphide layers include quartz, muscovite, calcite, and minor amounts of clinozoisite. Thin calc-silicate and quartz-rich gangue layers, with variable amounts of disseminated sulphides, occur within the sulphide bands.

Chemical analyses of the massive sulphide layers reflect the high sphalerite content with zinc ranging from 24 to 32 per cent (Table 15). The weighted average of 25 chip samples is 29.75 per cent zinc, 5.28 per cent lead and 0.03 per cent copper (Hicks, 1982). Precious metal values range from 0.06 to 0.25 gram gold per tonne and 0.3 to 10 grams silver per tonne in seven grab samples collected by J.M. Leask (personal communication, 1980). Gold and silver values for the six massive sulphide samples analysed in this study (Table 15) were below the utilized detection limits of 0.3 and 10 grams per tonne respectively.

SUMMARY — SHUSWAP MASSIVE SULPHIDE DEPOSITS

A number of features of Shuswap deposits have been summarized by Fyles (1970a):

(1) The deposits comprise thin, but regionally extensive, sulphide-rich layers in a well-layered platformal succession of dominantly carbonate, schist and quartzite. The host is generally a calcareous schist.

(2) The deposits consist dominantly of pyrrhotite and sphalerite, with minor galena and pyrite. Magnetite is the abundant iron phase at Cottonbelt.

(3) The deposits are part of the enclosing stratigraphic succession and have been metamorphosed and deformed along with it.

Shuswap deposits represent highly deformed and metamorphosed examples of the "exhalative sedimentary group" of base metal deposits of Hutchinson (1980). Host rocks range from calcareous schist and gneiss (Cottonbelt) to dominantly graphitic schist (Big Ledge) within a well-layered and heterogeneous succession that includes relatively pure crossbedded quartzite, grey crystalline marble, hornblende gneiss, and abundant pelitic and calcareous schist and gneiss. Sulphides are presumed to have been deposited with the enclosing calcareous shales in restricted shallow marine basins in a platform environment. They are hosted by clastic rocks but also have features typical of "carbonate-hosted" deposits (in particular, the "Remac" type of Sangster, 1970), such as their association with clean carbonates and their occurrence in a shallow marine platformal environment (Hutchinson, 1980). They are transitional between the "clastic-hosted" and "carbonate-hosted" types, supporting the statement by Hutchinson (1980, page 665) that there are no distinct boundaries between these deposit types.

Shuswap deposits contrast with lead-zinc deposits in the Kootenay Arc to the south (Fyles, 1970b; Höy, 1982). Kootenay Arc deposits include the Bluebell, Duncan and Wigwam deposits and deposits in the Salmo camp (Figure 41). They are hosted by a relatively pure, but locally dolomitized, silicified and brecciated Lower Cambrian carbonate unit. Although deformation may be intense, the regional metamorphism is generally greenschist facies.

Plate 30. Remains of exploration camp, Cottonbelt property, viewed to the northeast across the southern tributary of Blais Creek.

Plate 31. Exposure of very rusted massive sulphides of the Cottonbelt layer within calc-silicate gneiss, pelitic schist, marble and minor quartzite; viewed to the south.

Plate 32. Photograph contrasting two styles of mineralization within the Cottonbelt layer; dark, crudely layered, massive sphalerite, galena and magnetite occur below granular marble that contains disseminated galena and sphalerite. At top of photograph is finely layered calc-silicate gneiss and quartzite.

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APPENDIX 1.
METAMORPHIC MINERAL ASSEMBLAGES IN PELITIC ROCKS, MOUNT GRACE AREA

Field No.	Host Unit	silm	ky	and	qz	mus	bi	gnt	pl	kf	ct	chl
CB2-A	6a	X	X		X	X	X	X	X	X		X
CB-7	6a	X	X		X	X	X	X	X	X		
CB-8	6a	X	X		X	X	X	X	X	X	X	X
CB1-6	6a		X		X	X	X		X	?		
CB1-8	4c									?		
CB1-12	6b	X	X		X	X	X	X	X			
CB1-14	6b	X	X	X	X		X		X		X	
CB3-7	6b	X	X		X		X	X	X			
CB3-27	6b	X	X		X	X	X		X	X		
CB4-2A	6a	X	X		X		X		X	X		
CB4-2B	6a	X	X		X	X	X	X	X	X		
CB4-3	6a	tr	X		X	X	X	X	X	X		X
CB4-4E	6a	X	X		X		X	X	X	X		
CB7-3	6b		X	X	X	X	X		X	?		
CB7-27	4(?)	X	X	X	X	X	X	X		X		
CB10-8	4a	X			X	X	X	X	X	X		
CB10-19	6b	X	X		X	X	X	X	X	X		
CB10-24	6b	X			X	X	X					
CB11-27	6b	X	X		X	X	X		X	X		
CB13-4	6b	X	X		X	X	X	X		X		
CB13-18	6b	X	X		X	X	X	X	X	X		
CB13-35	6b	X		X		X	X	X	X	X		
CB15-25	6a	X		X	X	X	X	X	X	X		
CB18-7	6b	X	X		X	tr	X	X	X	tr		
CB19-14	6a		X		X		X	X	X	X	X	

Note:

Accessory minerals such as zircon, apatite, tourmaline, etc., not listed. Andalusite and cordierite are retrograde minerals, some muscovite and biotite are also retrograde.

tr–trace amount; ?–positive identification not established.

silm–sillimanite, ky–kyanite, and–andalusite, qz–quartz, mus–muscovite, bi–biotite, gnt–garnet, pl–plagioclase, kf–K-feldspar, ct–cordierite, chl–chlorite.

APPENDIX 2. ANALYSES OF INTRUSIVE (AND HYDROTHERMAL) CARBONATITES OF UNIT 3C, PERRY RIVER AREA

APPENDIX 2A
(in %)

Field No.	Lab. No.	SiO_2	Al_2O_3	$Fe_2O_{3(T)}$	FeO	MgO	CaO	Na_2O	K_2O	TiO_2	MnO	P_2O_5	CO_2	H_2O	SO_2	Total
H85P1-5	30256	6.77	0.36	4.64	2.11	2.38	45.34	0.37	0.21	1.32	0.38	0.21	29.92	0.06	1.44	99.7
H85P1-8	30257	0.39	0.16	0.38	0.47	0.46	51.04	0.13	<0.01	<0.01	0.44	<0.01	39.05	<0.05	0.04	100.0
H85P4-3B	30264	6.38	1.57	4.66	3.20	1.85	42.72	0.64	0.85	0.86	0.44	0.85	33.92	0.08	0.37	98.6
H85P4-3C	30265	0.79	0.30	0.68	0.82	0.62	52.44	0.14	0.09	0.03	0.17	0.09	35.06	0.03	2.19	99.8
CAMP-1	31765	4.10	0.91	1.20		0.99	45.29	0.37	0.04	0.05	0.22	0.34	35.95			

By XRF–Analytical Laboratory, British Columbia Geological Survey Branch.

APPENDIX 2B
(in ppm)

Field No.	Lab. No.	Rb[1]	Sr[1]	Y[1]	Zr[2]	Nb[1]	Th[3]	Ga[4]	Ba[2]	Cu[2]	Pb[2]	Zn[2]	Ni[2]	Mo[2]	Cr[2]
H85P1-5	30256	14	1600	160	—	50	359	<5	1155	67	188	67	28	<3	37
H85P1-8	30257	20	3100	80	—	8	<0.5	<5	1217	4	85	41	6	<3	<25
H85P4-3B	30264	34	2100	120	—	50	24.8	17	2539	7	60	40	14	<3	25
H85P4-3C	30265	10	1000	34	—	30	5.0	<5	1205	17	108	82	16	<3	25
CAMP-1	31765	66		107	208	<100									

[1] XRF — X-Ray Laboratories, Don Mills, Ontario.
[2] Atomic absorption — Analytical Laboratory, British Columbia Geological Survey Branch.
[3] Neutron activation — Bondar Clegg.
[4] XRF — Analytical Laboratory, British Columbia Geological Survey Branch.

APPENDIX 2C
(in ppm)

Field No.	Lab. No.	La	Ce	Pr	Nd	Pm	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu
H85P1-5	30256	1470	2010	290	654	-	74	18	<720	5.4	41	9	<100	3.4	17.4	1.7
H85P1-8	30257	704	927	<99	271	-	36	9	<430	2.4	18	5	<100	2.0	10.0	1.3
H85P4-3B	30264	>2000	7630	<550	3540	-	313	83	<2800	11.0	55	<3	<100	6.7	7.4	0.5
H85P4-3C	30265	317	614	<71	279	-	41	11	400	1.6	13	8	<100	1.2	2.9	0.2

By neutron activation — Bondar Clegg.

APPENDIX 3. ANALYSES OF THE MOUNT GRACE EXTRUSIVE CARBONATITE, PERRY RIVER, MOUNT GRACE AND BLAIS CREEK AREAS

APPENDIX 3A
(in %)

Field No.	Lab. No.	SiO_2	Al_2O_3	Fe_2O_3	MgO	CaO	Na_2O	K_2O	TiO_2	MnO	CO_2	P_2O_5
CB4-3H	20805	2.20	0.55	2.64	3.47	48.05	0.36	<0.03	<0.022	0.267	40.70	0.06
CB4-3I	20804	15.15	4.20	4.87	4.54	34.85	2.30	0.38	0.069	0.611	31.10	0.06
CB-51	22258	9.46	2.69	4.47	4.36	41.24	1.16	0.69	0.140	0.469	32.40	0.53
H78-CB	20807	7.96	1.79	3.39	5.42	41.33	0.85	0.68	0.083	0.339	34.80	0.07
CB2-2G	20806	12.72	4.07	5.01	5.72	35.21	1.05	1.73	0.205	0.398	29.20	0.07
H79P	22259	4.84	0.99	4.19	5.10	43.79	0.33	0.75	0.074	0.394	34.70	1.60
H85P3-2E	30261	18.94	7.38	3.00	3.98	34.07	2.24	1.33	0.29	0.073		
H85P3-3	30262	11.78	3.86	5.97	3.85	36.89	1.56	0.38	0.13	0.910		
H85P7	30266	16.87	5.07	5.01	6.55	30.31	2.30	0.91	0.17	0.521	27.69	1.91
H85P9	30267	12.53	3.37	5.46	5.07	35.55	1.55	0.90	0.22	0.628	29.47	1.71
H85P10	30268	9.25	2.66	4.62	4.24	39.48	0.99	0.96	0.19	0.406	28.39	1.41
H85P11	30269	12.92	4.57	4.78	5.90	33.78	1.16	1.74	0.24	0.398	28.28	1.29
MG5-7	30270	15.56	5.79	2.92	3.57	35.40	2.02	1.05	0.23	0.197	28.00	0.08
MG5-8	30271	19.91	7.81	4.52	3.11	30.36	2.46	2.13	0.30	0.246	24.02	0.13
H85P25B	30275	4.17	0.69	4.26	0.55	49.84	0.48	0.24	0.17	0.438	34.58	1.55
H85P26A	30277	7.91	2.26	4.62	0.68	45.25	0.98	0.65	0.19	0.541	31.54	1.93
H85P26B	30278	17.94	6.23	5.30	1.10	35.33	1.76	2.31	0.41	0.502	25.22	1.72
H85P26D	30281	14.92	5.77	3.99	3.28	36.64	1.91	1.46	0.24	0.449	29.94	0.26
H85P26E	30282	2.52	0.72	1.10	4.12	49.59	0.46	0.05	0.03	0.159	38.54	0.06
H85P26F	30283	11.19	3.59	3.09	4.52	39.88	1.51	0.55	0.10	0.365	32.06	0.24
H85P29	30288	25.05	9.62	5.92	2.60	27.34	3.66	2.16	0.39	0.514	20.25	0.23

Notes:

Total iron is expressed as Fe_2O_3.

With the exception of volatiles, all oxides were determined by atomic abosrption spectroscopy; Analytical Laboratory, British Columbia Geological Survey Branch.

APPENDIX 3B
(in ppm)

Sample No.	Lab. No.	Mn[4]	Sr[5]	Ba[5]	Nb[1]	Cu[2]	Pb[2]	Zn[2]	Ni[2]	Mo[2]	Cr[2]	Ga[2]
H85P3-2E	30261	1000	1167	877		18	115	100	34	<3	44	15
H85P3-3	30262	6500	8900	2343	700	9	20	76	25	66	<25	12
H85P7	30266	2800	7200	2330	200	14	6	104	37	34	41	16
H85P9	30267	6000	7900	1834	500	10	5	120	30	19	29	17
H85P10	30268	4000	7600	2356	500	8	9	119	26	7	<25	18
H85P11	30269	2500	8000	2918	100	16	12	126	29	29	56	19
MG5-7	30270	3000	1600	1532	100	9	14	112	23	4	39	17
MG5-8	30271	1300	3300	1318	100	4	11	159	33	3	49	20
H85P25B	30275	1000	7711	700	400	6	19	49	11	<3	<25	15
H85P26A	30277	2500	7328	952	500	7	14	53	16	<3	<25	15
H85P26B	30278	2500	5714	2350	1000	11	16	86	21	3	<25	22
H85P26D	30281	800	3087	1385	200	13	15	105	28	24	36	17
H85P26E	30282	400	1582	700		5	15	50	9	<3	<25	<5
H85P26F	30283	1200	2403	1637	100	5	114	119	19	4	37	12
H85P29	30288	4000	3251	1329	300	10	14	139	34	32	58	20

Sample No.	Lab. No.	Mn[4]	Sr[4]	Ba[4]	Nb[4]	Cu[2]	Pb[2]	Zn[2]	Ni[2]
CB12-6	25534	2500	1500	3000	<10				
DDH 1-400	26470	4000	3200	2000	175				
DDH 1-405	26471	3000	2500	3500	40				
DDH 1-410	26472	4000	5000	2000	300				
DDH 2-413	26476	4000	3500	3000	260				
DDH 2-418	26477	3500	2500	3000	40				
DDH 2-422	26478	3300	4200	3000	330				
CB2-3A	25532	5500	6310	3500	70				
CB	25531	37205	5200	3000	220				
CB-51	22258	36305	4600	3500	300				
CB4-3H	20805	20405	3300	3100	<10		16	69	38
CB4-3I	20804	50255	5700	2800	100		11	132	26
H78-CB	20807	28755	5400	3200	100		16	109	14
CB2-2G	20806	28255	6600	3500	200		10	125	38
M71-80-A	27561	2800	4000	4000	80				
M71-80-B	27562	3000	5000	5000	500				
617A	27564	3300	3500	3000	400				
MJ 128-80	27563	7500	4000	3000	10				
H79P	22259	30505	5800	3600	200				

Notes:

[1] XRF — X-Ray Laboratories, Don Mills, Ontario.

[2] AA — Analytical Laboratory, British Columbia Geological Survey Branch.

[3] Neutron activation — Bondar Clegg.

[4] Emission spectroscopy — Analytical Laboratory, British Columbia Geological Survey Branch.

[5] Atomic absorption - Analytical Laboratory, British Columbia Geological Survey Branch.

APPENDIX 3C
(in ppm)

Sample No.	Lab. No.	Ce[1]	Dy[1]	Er[1]	Eu[1]	Gd[1]	Ho[1]	La[1]	Lu[1]	Nd[1]	Pr[1]	Sc[1]	Sm[1]	Tb[1]	Th[1]	Tm[1]	Yb[1]
H85P3-2E	30261	155	4	<100	2	<240	<1	94	0.3	65	<64	7.42	8.2	0.8	30.6	<0.5	1.6
H85P3-3	30262	1430	20	<130	13	<590	5	957	0.7	469	<130	3.78	56.0	3.3	3.2	1.6	6.6
H85P7	30266	1170	8	<100	8	<540	2	736	0.2	380	<120	7.19	33.2	1.4	3.7	1.0	3.4
H85P9	30267	1190	15	<100	12	<530	3	722	0.5	424	170	6.89	42.7	2.2	15.2	1.6	4.9
H85P10	30268	875	15	<100	12	<440	4	505	0.5	345	100	6.70	43.6	2.3	15.0	1.9	4.9
H85P11	30269	1410	10	<100	9	<580	2	937	0.4	433	<130	8.75	38.2	1.5	5.7	1.0	3.3
MG5-7	30270	198	12	<100	5	<260	2	94	0.4	91	<65	5.37	16.1	1.5	0.7	0.8	3.3
MG5-8	30271	235	11	<100	4	<280	2	131	0.4	88	<68	4.42	14.6	1.4	0.6	0.7	3.3
H85P25B	30275	598	20	<100	9	390	8	320	1.2	236	<80	1.89	33.9	3.0	17.9	2.0	9.0
H85P26A	30277	670	17	<100	8	620	8	400	1.0	247	110	2.35	34.4	2.4	7.1	1.5	8.7
H85P26B	30278	605	14	<100	7	<440	5	362	0.9	224	<96	2.17	28.6	1.8	6.4	1.8	6.1
H85P26D	30281	611	7	<100	4	<440	<1	479	0.3	149	<100	4.67	13.4	0.8	3.1	0.5	2.6
H85P26E	30282	289	7	<100	5	<250	1	151	0.1	123	<60	2.14	15.1	0.8	0.6	0.7	1.6
H85P26F	30283	512	9	<100	6	<370	2	310	0.3	188	<89	5.51	23.2	1.3	1.3	0.6	2.5
H85P29	30288	398	11	<100	5	<400	1	242	0.5	139	<100	5.22	17.8	1.1	0.5	0.8	4.1

Sample No.	Lab. No.	Ce[2]	La[2]	Nd[2]
CB12-6	25534	151	120	93
DDH 1-400	26470	592	345	246
DDH 1-405	26471	656	419	217
DDH 1-410	26472	997	576	379
DDH 2-413	26476	453	296	191
DDH 2-418	26477	560	396	217
DDH 2-422	26478	992	628	353
CB2-3A	25532	1142	826	355
CB	25531	870	542	324
CB-51	22258	658	389	294
CB4-3H	20805	1049	714	350
CB4-3I	20804	561	345	232
H78-CB	20807	814	540	319
CB2-2G	20806	1432	943	405
M71-80-A	27561	1167	860	257
M71-80-B	27562	1251	866	340
M617A	27564	1245	788	452
MJ 128-80	27563	4164	3238	924
H79P	22259	1017	499	432

[1] Neutron activation — Bondar Clegg.
[2] XRF — Analytical Laboratory, British Columbia Geological Survey Branch.

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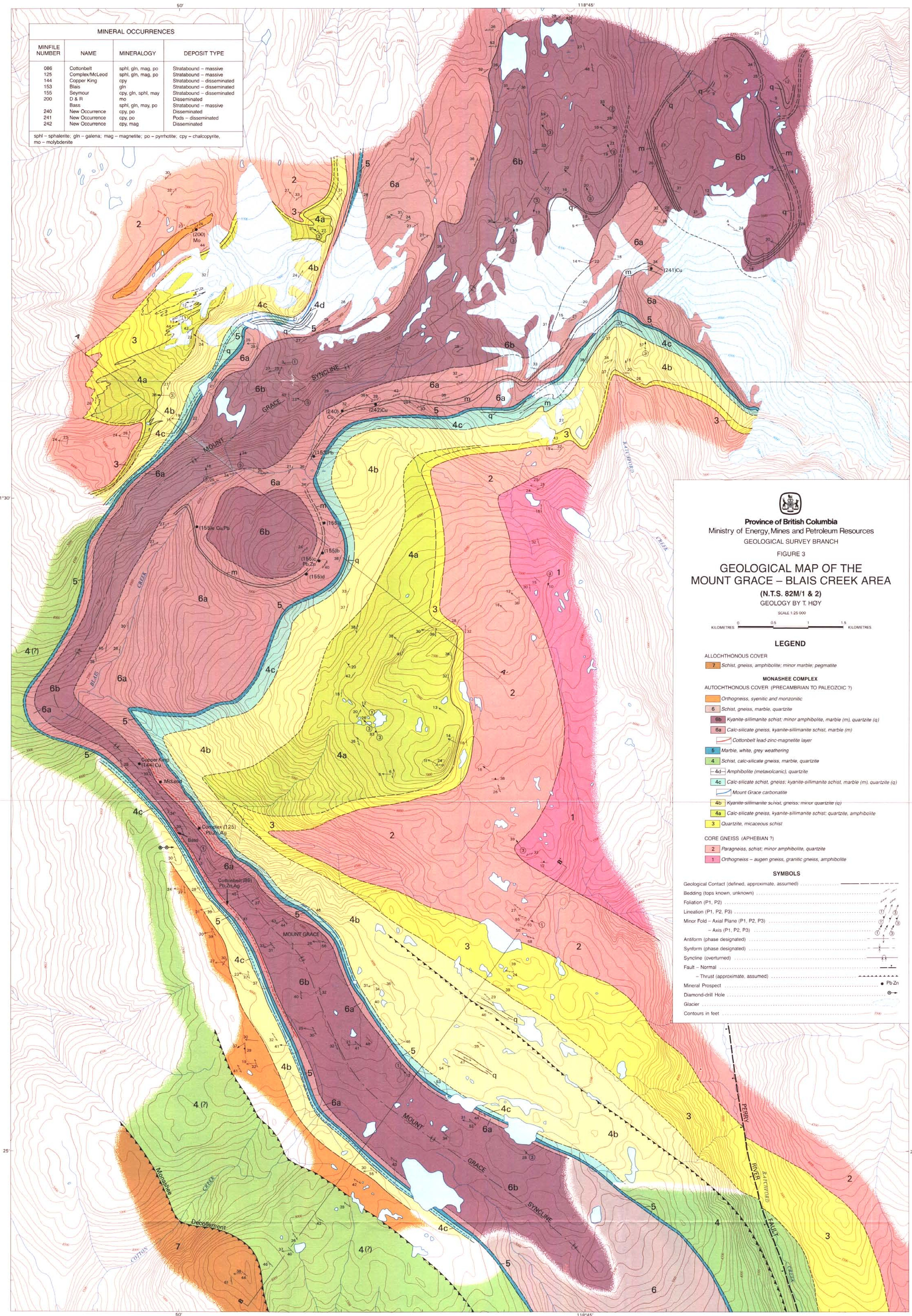
MINERAL OCCURRENCES

MINFILE NUMBER	NAME	MINERALOGY	DEPOSIT TYPE
086	Cottonbelt	sphl, gln, mag, po	Stratabound – massive
125	Complex/McLeod	sphl, gln, mag, po	Stratabound – massive
144	Copper King	cpy	Stratabound – disseminated
153	Blais	gln	Stratabound – disseminated
155	Seymour	cpy, gln, sphl, may	Stratabound – disseminated
200	D & R	mo	Disseminated
	Bass	sphl, gln, may, po	Stratabound – massive
240	New Occurrence	cpy, po	Disseminated
241	New Occurrence	cpy, po	Pods – disseminated
242	New Occurrence	cpy, mag	Disseminated

sphl – sphalerite; gln – galena; mag – magnetite; po – pyrrhotite; cpy – chalcopyrite, mo – molybdenite



Province of British Columbia
Ministry of Energy, Mines and Petroleum Resources
GEOLOGICAL SURVEY BRANCH

FIGURE 3

GEOLOGICAL MAP OF THE MOUNT GRACE – BLAIS CREEK AREA

(N.T.S. 82M/1 & 2)

GEOLOGY BY T. HØY

SCALE 1:25 000

KILOMETRES 0 0.5 1 1.5 KILOMETRES

LEGEND

ALLOCHTHONOUS COVER

7 *Schist, gneiss, amphibolite; minor marble; pegmatite*

MONASHEE COMPLEX

AUTOCHTHONOUS COVER (PRECAMBRIAN TO PALEOZOIC ?)

Orthogneiss, syenitic and monzonitic

6 *Schist, gneiss, marble, quartzite*

6b *Kyanite-sillimanite schist; minor amphibolite, marble (m), quartzite (q)*

6a *Calc-silicate gneiss, kyanite-sillimanite schist, marble (m)*

Cottonbelt lead-zinc-magnetite layer

5 *Marble, white, grey weathering*

4 *Schist, calc-silicate gneiss, marble, quartzite*

4d *Amphibolite (metavolcanic), quartzite*

4c *Calc-silicate schist, gneiss; kyanite-sillimanite schist, marble (m), quartzite (q)*

Mount Grace carbonatite

4b *Kyanite-sillimanite schist, gneiss; minor quartzite (q)*

4a *Calc-silicate gneiss, kyanite-sillimanite schist; quartzite, amphibolite*

3 *Quartzite, micaceous schist*

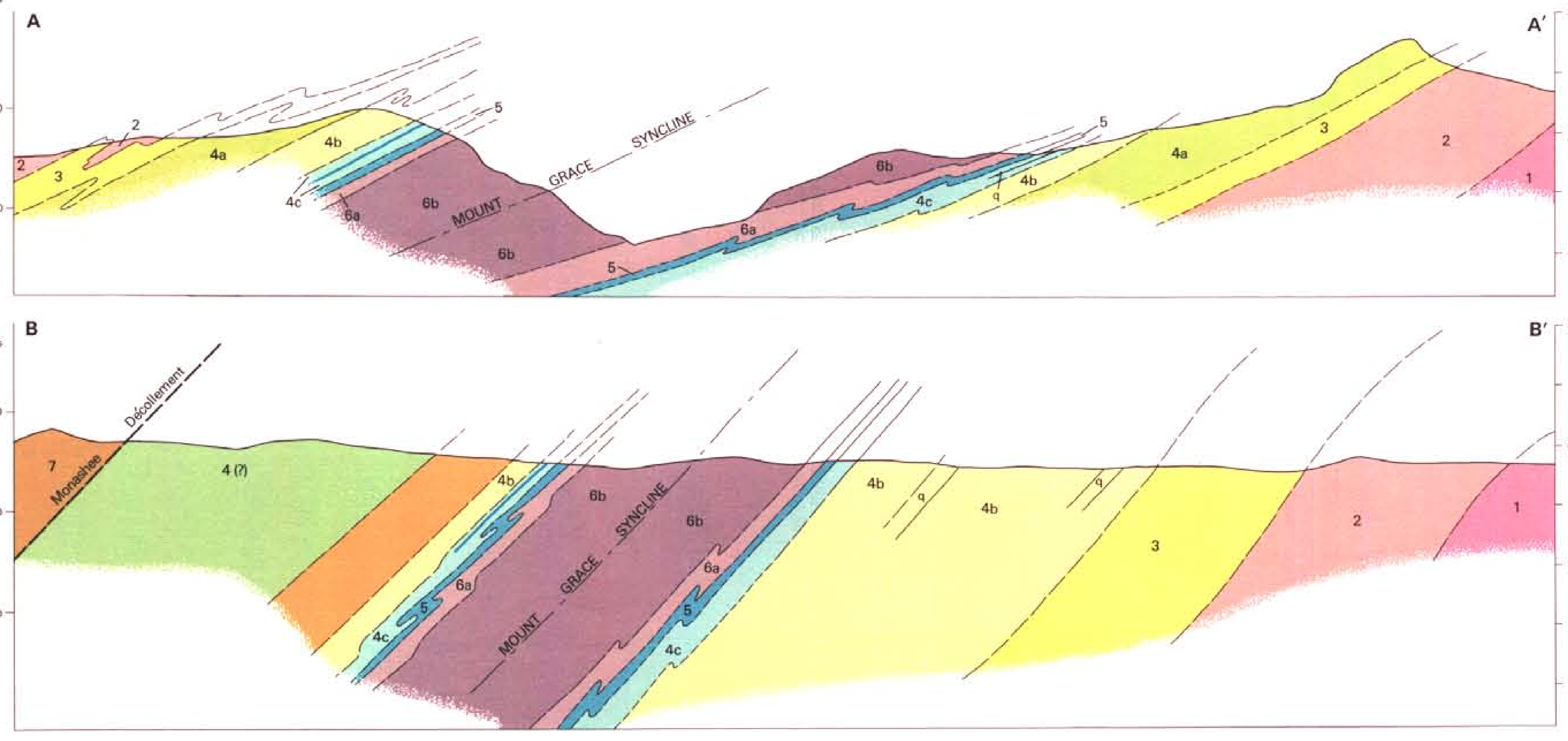
CORE GNEISS (APHEBIAN ?)

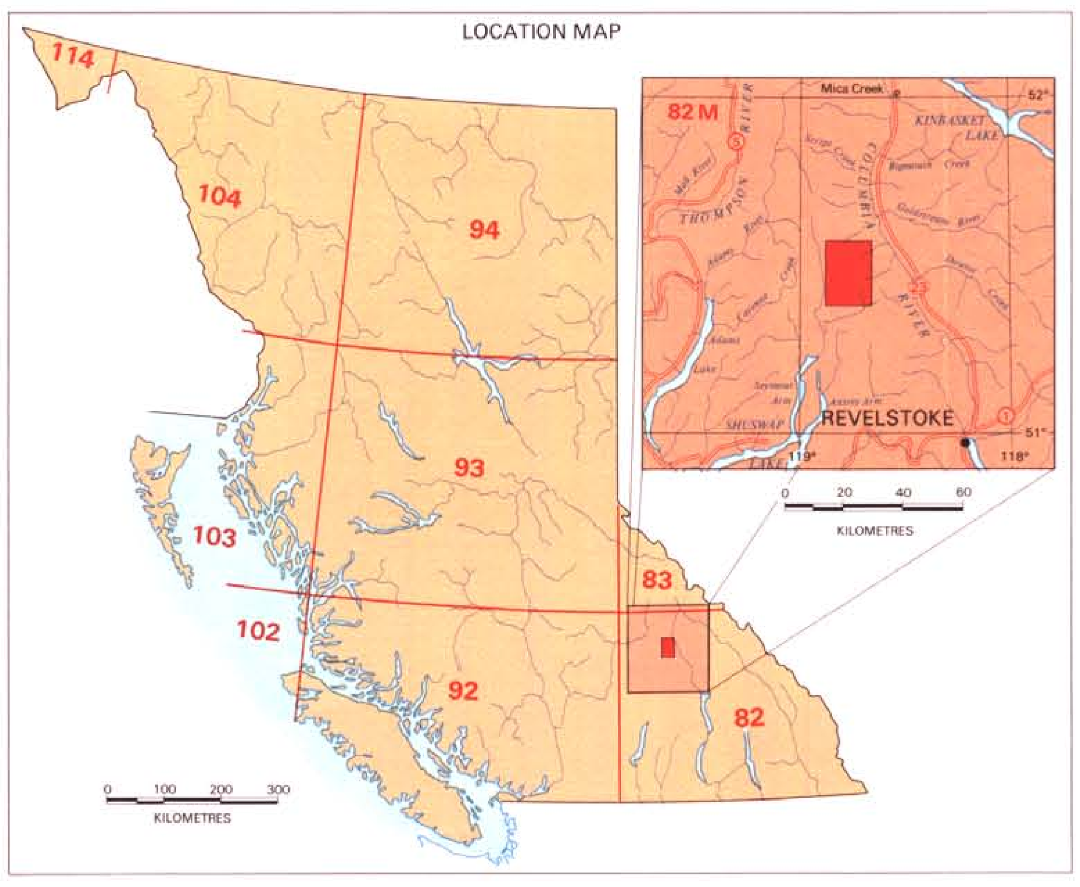
2 *Paragneiss, schist; minor amphibolite, quartzite*

1 *Orthogneiss – augen gneiss, granitic gneiss, amphibolite*

SYMBOLS

Geological Contact (defined, approximate, assumed)
Bedding (tops known, unknown)
Foliation (P1, P2)
Lineation (P1, P2, P3)
Minor Fold – Axial Plane (P1, P2, P3)
– Axis (P1, P2, P3)
Antiform (phase designated)
Synform (phase designated)
Syncline (overturned)
Fault – Normal
– Thrust (approximate, assumed)
Mineral Prospect ● Pb Zn
Diamond-drill Hole
Glacier
Contours in feet





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TO ACCOMPANY BULLETIN 80