27th FORUM ON THE GEOLOGY OF INDUSTRIAL MINERALS

SOME SIGNIFICANT INDUSTRIAL MINERAL PRODUCERS OF THE SOUTHERN ROCKY MOUNTAINS

GUIDEBOOK FOR FIELDTRIPS 2 AND 3

May 9 and 10, 1991

BANFF - GOLDEN - RADIUM AREA

Guidebook prepared by
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Sponsored by the
British Columbia Geological Survey
and the
Alberta Geological Survey

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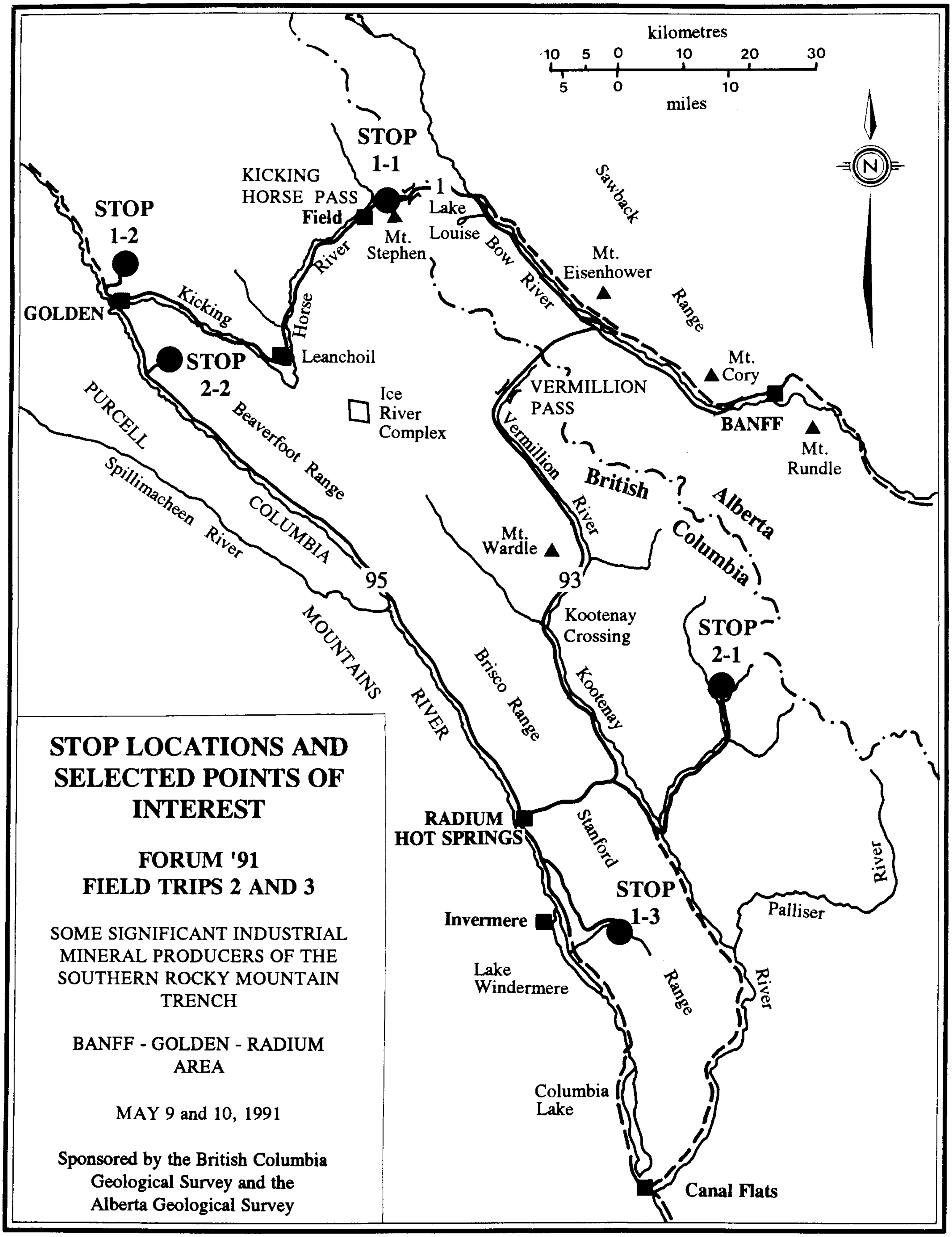


Figure 1: Stop locations and selected points of interest for Field Trips #'s 2 and 3 at the 27th Forum on the Geology of Industrial Minerals.

GEOLOGY OF THE SOUTHERN ROCKY MOUNTAINS

INTRODUCTION

The Rocky Mountains are part of a major tectono-stratigraphic package of western North America. The Foreland Belt extends from the Yukon and Northwest Territories of Canada through the Sierras of California. The Rocky Mountains in the area of Banff, Golden and Radium show an excellent section through this major geologic province. (*see* Figures 1 and 2) The stratigraphic section extends almost continuously from the Hadrynian (Precambrian) to the present and records a maximum accumulation of 18 000 metres (60,000'; Price, 1981). There are three major subdivisions in the stratigraphic section. (*see* Figure 3) The first is a Precambrian to Early Cambrian clastic wedge which rests upon the crystalline basement of North America. The next subdivision is predominantly a carbonate reef/platform sequence with some clastic material that extends through the Paleaozoic to the Mesozoic. Finally there is a Mesozoic to Tertiary elastic package which represents the erosional product of the preceeding rocks. The region is typified structurally by thrust faulting and open through isoclinal folds. The thrusts are deep crustal features and the maximum tectonic shortening across the belt is estimated at 200 kilometres (Price, 1981). The region hosts several industrial mineral deposits in production and many prospects. These include magnesite in Cambrian carbonates, silica in Ordovician quartzite, gypsum in Devonian evaporites, barite vein/replacement ore bodies, and phosphate in Jurassic shale and siltstone. Coal is also richly abundant in Jura-Cretaceous shale and siltstone.

STRATIGRAPHY

The stratigraphy of the Rocky Mountains records a long continuous history of sedimentation on a platformal edge of the North American craton. The miogeoclinal sequence is thick and fairly continuous. It was terminated by a major orogenic event that caused uplift and extensive erosion. The resulting clastic wedge extends back over the the original platform sediments. Figure 3 is a composite, diagrammatic section of the miogeocline and the clastic wedge, through the southern Rocky Mountains. Figure 4 has graphical representative sections at various locations in the southern Rocky Mountains. Recent glaciation has shaped the mountains to their present form.

The miogeoclinal sequence extends from the Late Precambrian (Hadrynian) through to the Early Jurassic. This package accounts for a maximum aggregate thickness of 12 190 metres (40,000') in the Western Main Ranges structural sub-province (Price, 1981). Provenance for all these sediments is east to north which includes the North American craton and the Peace River Arch (Ketner, 1966). The geoclinal sequence can be broken into two major sections, pre- and post- Early Devonian. An Early Devonian unconformity marks a significant erosional break that

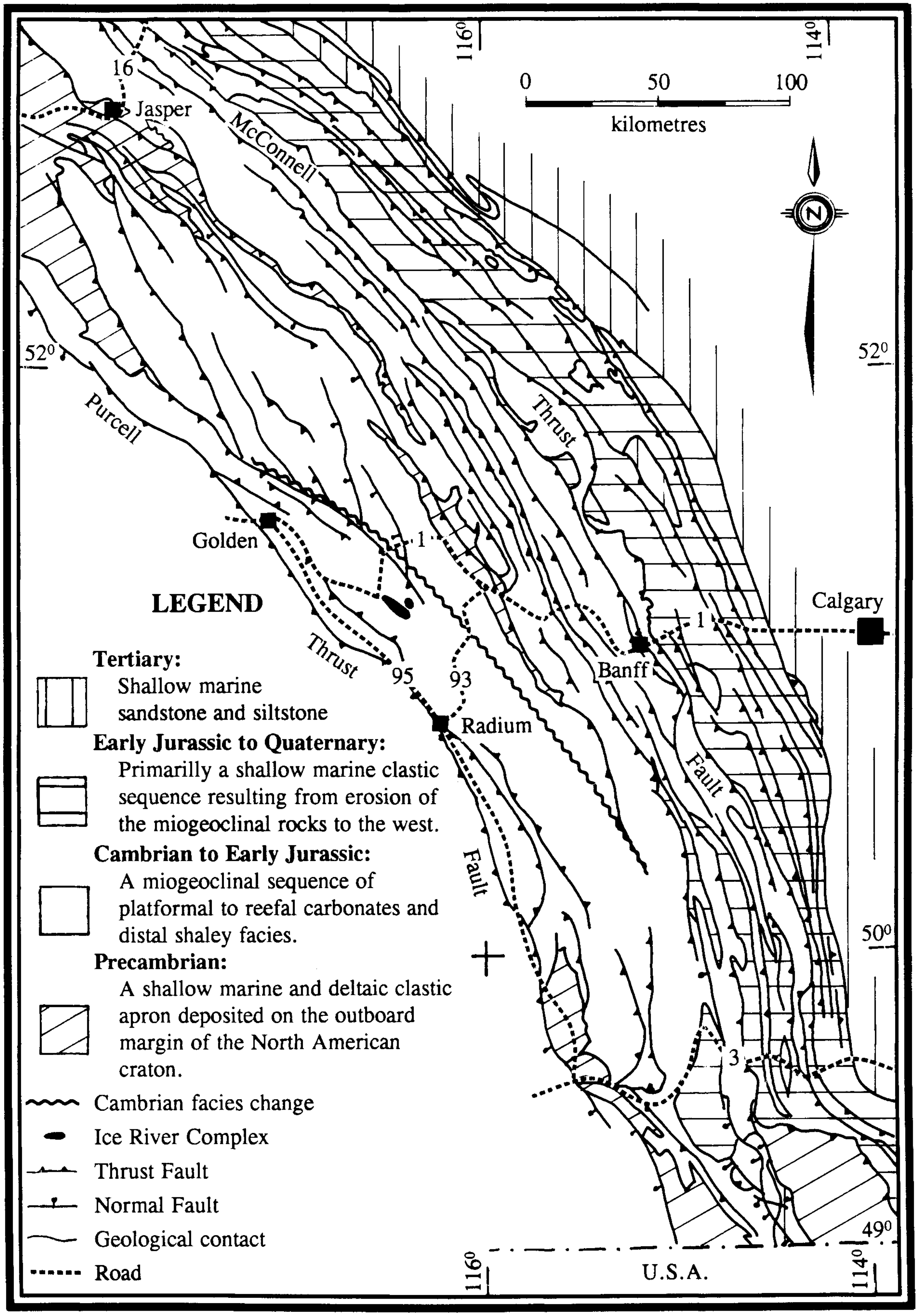


Figure 2: Simplified regional geology of the southern Rocky Mountains (modified from Tipper *et al.*, 1981)

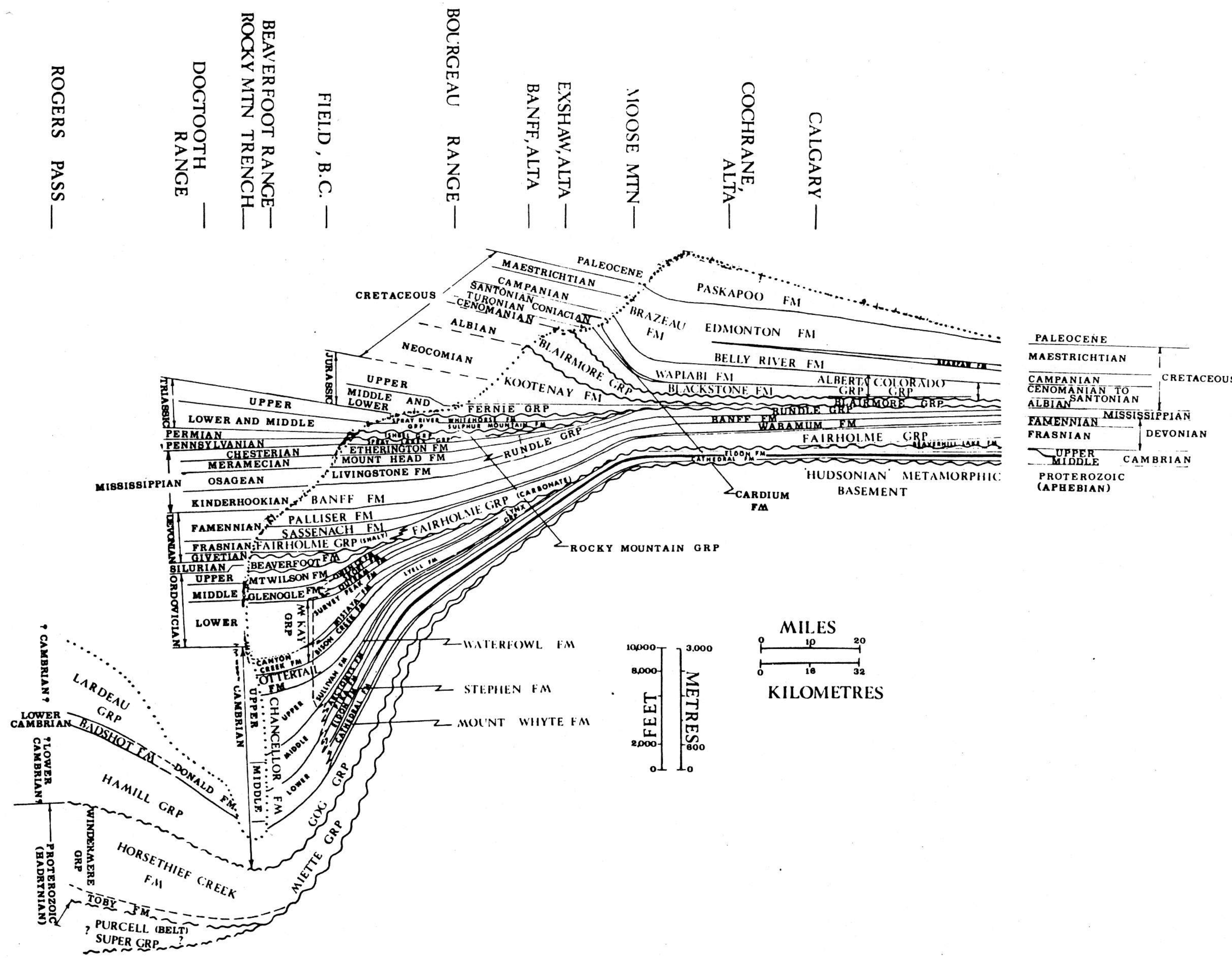


Figure 3: Composite, restored schematic section across the southern Rocky Mountains (from Halliday and Mathewson, 1971).

allows Devonian rocks to rest on Silurian to Cambrian rocks. The pre-Devonian sequence consists of two parts, a lower clastic division and an upper carbonate division.

The first section extends from the Precambrian to the Early Cambrian. This represents a series of prograding clastic and carbonate sediments with provenance from the east and northeast. The Helikian Purcell Group sediments are described as clastics deposited into a basin by a prograding delta similar to the Mississippi River delta (Price, 1964). The group is truncated by an unconformity upon which rests the Hadrynian Windermere Group. These are immature conglomerates and clastics again truncated by an unconformity. The Windermere Group rocks are overlain by a sequence of quartzites and some conglomerates. These are the Late Hadrynian Miette Group and Early Cambrian Gog Group. The basal Purcell and Windermere Groups are not exposed in the Rocky Mountain section, however the Miette and Gog Groups are.

The Palaeozoic to Mesozoie sedimentary package is typified by major carbonate sequences. This includes platformal carbonates, reef facies and fore-reef to distal facies. Individual formations are regionally extensive, often traceable to south central Alberta from the western limit of the Rockies. The carbonate facies commonly shale out at their eastern limits. Also, there are some thin transgressional shale units which separate the thicker carbonate formations. Work by Aitken(1966, 1978) and others defined a cyclic series of shale to carbonate progressions which he defined as "Grand Cycles" extending from the Middle Cambrian through the Ordovician. This includes a package of sediments about five kilometres (16,400') thick and comprise the body of the Main Ranges of the Rocky Mountains. Significant units include the Cathedral and Stephen Formations (Middle Cambrian). The Cathedral Formation hosts the Monarch and Kicking Horse Mississippi Valley type lead-zinc mines that are now mined out. The Cathedral Formation is also host to the currently producing Mount Brussilof magnesite mine of Baymag Mines Ltd. The Stephen Formation is the strata which hosts the Burgess Shale. This is a rare location, on the slopes of Mt. Wapta in the Kicking Horse Pass, in which Middle Cambrian fauna are extremely well preserved. It is also significant beacuse not only is there a wide variety of known phyla but there is an almost equivalent number of fauna of unknown phyla. The top of the pre-Devonian section is more clastic, composed of the Ordovician Mount Wilson Formation (quartzite) and the Ordovician-Silurian Beaverfoot Formation (limestone and argillite). The Mount Wilson Quartzite is host to the Mt. Moberly and Nicholson silica operations.

There is another major feature which is part of the pre-Devonian strata. At Kicking Horse Pass and extending well north and south is a major facies change of carbonates to shales from east to west. The facies change essentially corresponds with the change of carbonate sedimentation above a platform and reef complex to the more distal forereef and basinal equivalents. This boundary is quite profound in the Rockies, locally a well developed escarpment, as at Kicking Horse Pass. The zone of the faeies change is known as the Kicking Horse Rim as defined by Aitken (1971).

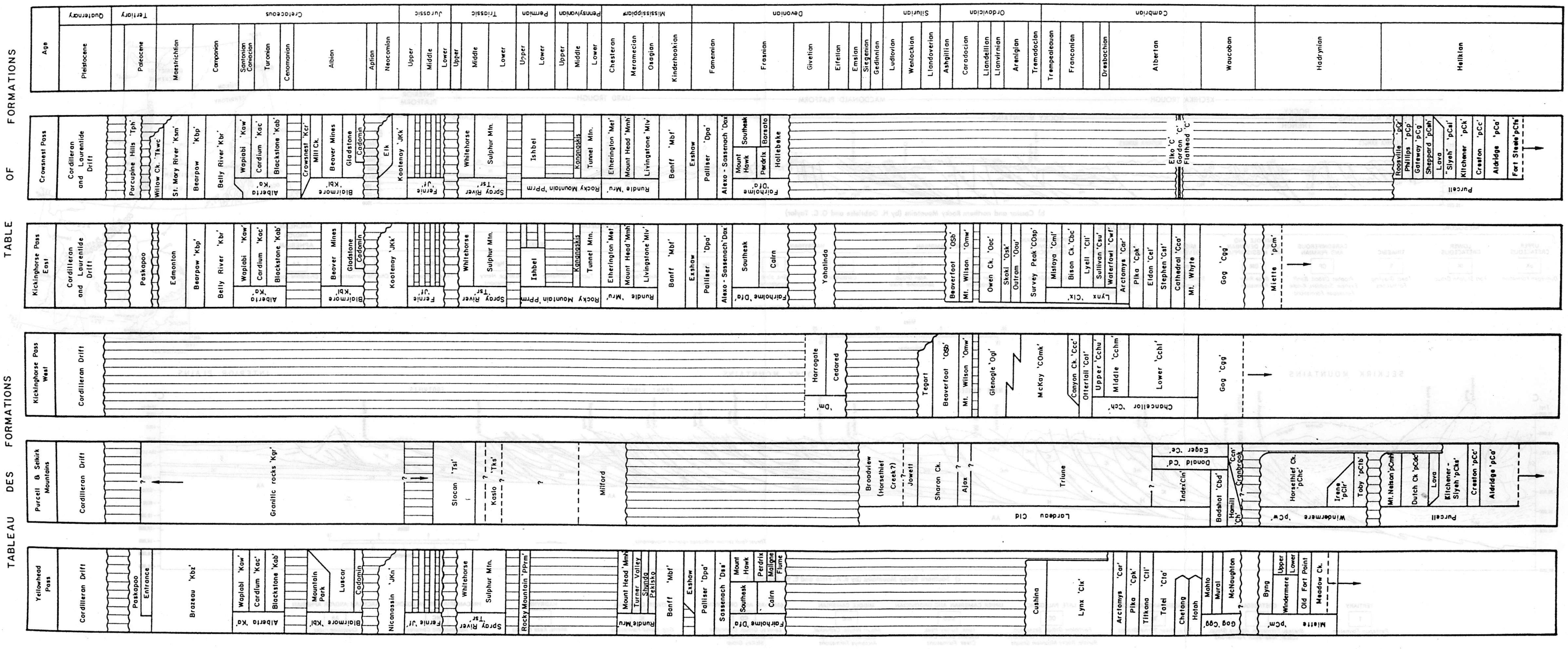


Figure 4: Composite stratigraphic columns at several locations in the southern Rocky Mountains (from Price *et al.*, 1972).

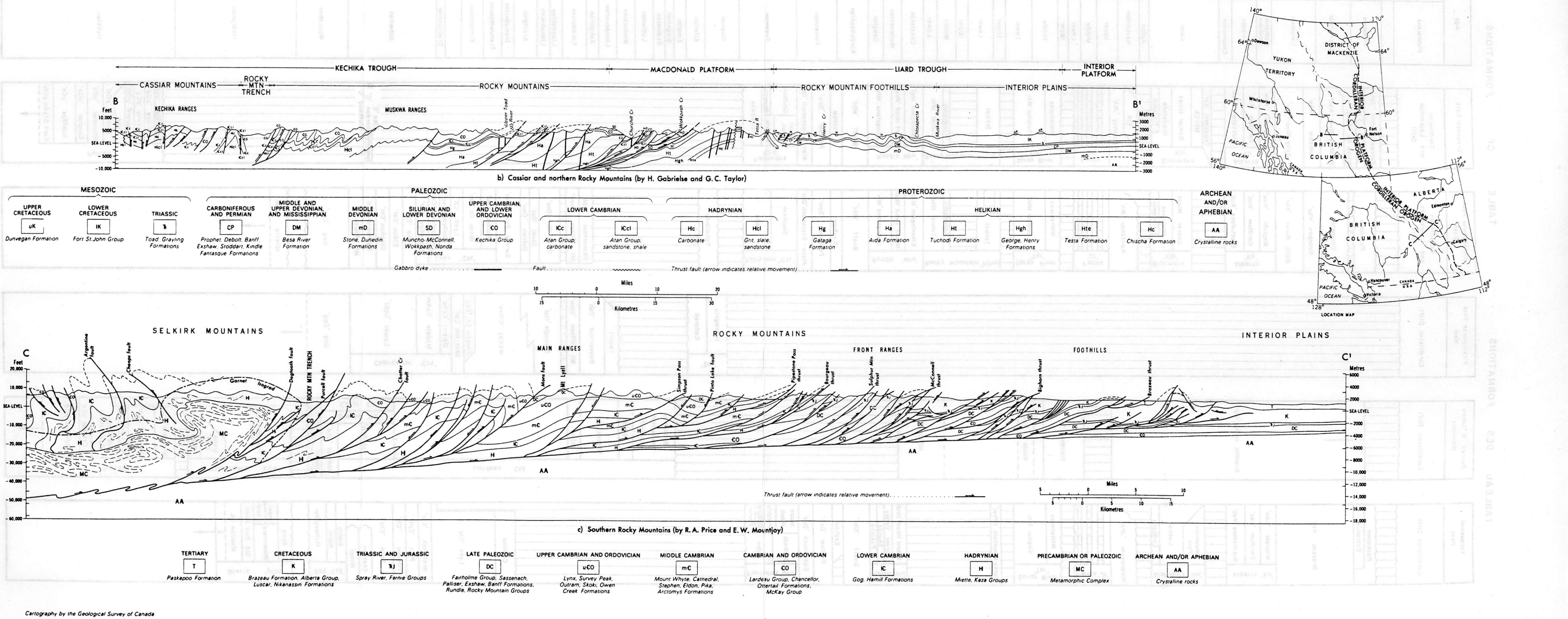
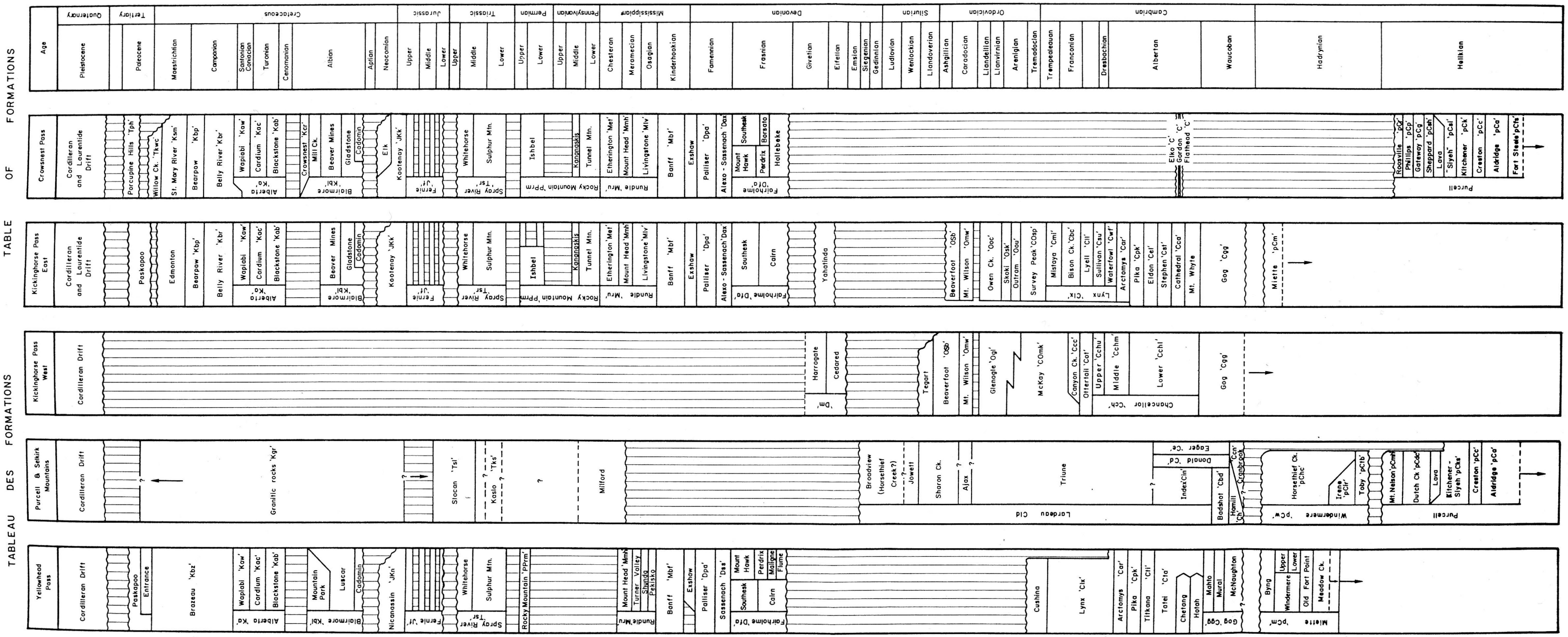


Figure 5: Two balanced structural cross-sections for the Rocky Mountains (from Scott and Taylor, 1972).



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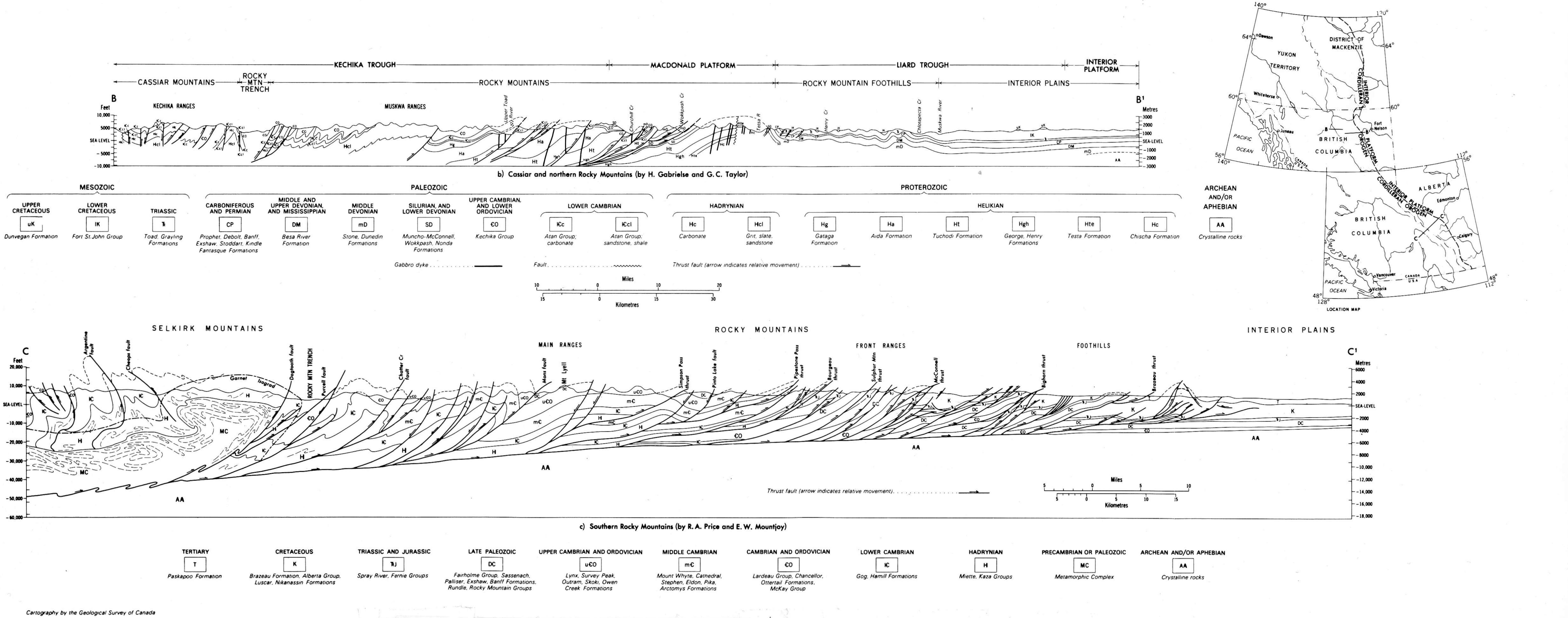


Figure 5: Two balanced structural cross-sections for the Rocky Mountains (from Scott and Taylor, 1972).

The Early Devonian is marked by a distinct unconformity. It was a period of erosion sufficient to expose Late Cambrian strata. As a result, Early to Middle Devonian strata paraconformably overly the older rocks. The immediately overlying strata are the Harrogate and Cedared Formations composed of carbonates (limestone and dolomite) and some argillites. The Burnais Formation, a lateral equivalent of the Cedared Formation, is a thick succession, up to 213 metres (700'), of gypsum and anhydrite. This represents a period of evaporite deposition in a long, narrow restricted basin in what is now the Stanford Range. The Burnais Formation hosts the two major producing deposits of gypsum at Windermere (Westroc) and Lussier River (Domtar). There are many other known gypsum deposits in the area, some of which have some economic potential.

The Cedared and Harrogate formations are the youngest part of the stratigraphy exposed in the Main Ranges. The next units in stratigraphic order are structurally exposed to the east in the Front Ranges. Starting with the Middle Devonian Fairholme Group a thick sequence of platformal limestones and lesser dolomites is continuous through to the Late Triassic Spray River Group. The sequence is continuous and represents uniform deposition in a shallow sea which, over time, slowly became more restricted. The latest sediments of the Spray River Group become more clastic, with siltstones and sandy limestones finishing the section.

The beginning of the Jurassic marks the third and final major stratigraphic subdivision of the Rocky Mountains. The end of the Triassic corresponds with the beginning of the Laramide orogeny. This uplifted the miogeocline onto the apron of the North American craton, exposing the strata. The result was massive erosion of the miogeocline and the direction of sedimentation was reversed to the east. The clastic wedge is thickest in the Front Ranges at 6 100 metres (20,000'; Price, 1981) and tapers well into central and eastern Alberta. The continued uplift of the B.C. cordillera to the west caused continued subsidence of the Alberta basin forming a large, long lived shallow sea.

The youngest strata deposited are marine siltstone and shale of the Jurassic Fernie Formation which is host to phosphatic shale and siltstone. Above this is the Late Jurassic to Middle Cretaceous Kootenay Formation which is shallow marine to deltaic sandstones and shales that now host the major coal-bearing horizons of the southeast Rockies and Foothills. The Kootenay Formation is truncated by an Early Cretaceous (Aptian) unconformity. This is overlain by the regionally extensive Cadomin conglomerate or basal Gladstone conglomerate of the Blairmore Group. The Cadomin conglomerate was used by early coal miners as the marker for the upper limit of the coal measures in the southeastern Rockies.

Strata above the basal conglomerates are dominated by shallow marine sandstones and shales through the whole of the Cretaceous sequence. Deposition was into shallow seas in the Alberta basin. Provenance of the sediments was the rising British Columbian cordillera as evidenced by clasts from intrusions unroofed during uplift and erosion. Sedimentation into the shallow Alberta basin continued into the Early Tertiary (Paleocene). The region was then uplifted and became emergent and erosion has continued since.

The last major event to effect the region was continental glaciation in the Alberta plains and alpine glaciation in the B.C. Cordillera during the Pleistocene epoch. The glaciation has created the landforms now seen in the area. The last glacial stade ended 10 000 ybp and the last vestiges of the great alpine ice sheets are the remaining glaciers, of which the Columbia icefields are the largest contiguous mass. The results of glaciation have included deep till valley fill and marginal moraines in the mountains. In the plains, kettle and kame topography is common. Abundant gravel supplies are found in the remains of eskers and kames.

STRUCTURE

The Rocky Mountains are a spectacular example of a major fold and thrust belt. They were formed by the Laramide orogeny, a long lived, east vergent orogenesis. The Rockies are typified by major thrust systems, transcurrent tear faults and open to isoclinal folds. The classic, comprehensive description of the belt was prepared by North and Henderson (1954). They subdivided the Rockies into five major physiographic-structural sub-provinces. From east to west they are the Foothills, Front Ranges, Main Ranges, Western Ranges and the Rocky Mountain Trench (*see* Figure 6). These are described later in this section.

The Laramide orogeny is probably the most significant tectonic event in the eastern cordillera of British Columbia. It represents a major event of uplift and erustal shortening. The orogeny, the result of northeast directed compression, effects strata from the Purcell Ranges in east-central B.C. to the Foothills of Alberta. This resulted in crustal detachment at or above the Hudsonian ($>$1750 Ma) basement at a depth of approximately 20 kilometres (12 mi.). Shortening began in the Early to Middle Cretaceous. Work by Höy and Van Der Heyden (1988) has determined an age of 122 $\pm$4 Ma for an intrusion that welds an early fault related to the Laramide orogeny. Shortening began in the west and moved progressively eastwards. The last stages of deformation were in the foothills of Alberta and ended in the Eocene. The style of deformation and shortening was by thrust faults which extend through the crust to the basement. It is believed that most thrusts join at depth along a major décollement at the crystalline basement (Price and Mountjoy, 1970). Individual thrust sheets are long but not continuous over the length of the belt. Individual thrusts end in either folds or transverse tear faults. However, the Rockies, specifically the Front Ranges, can be divided into major thrust sheets. Open to isoclinal folding is prevalent throughout the zone of deformation. Across the Rocky Mountains the accepted maximum shortening is 200 kilometres (124 mi.) (Price, 1981). Figure 5 shows two cross sections through the Rocky Mountains.

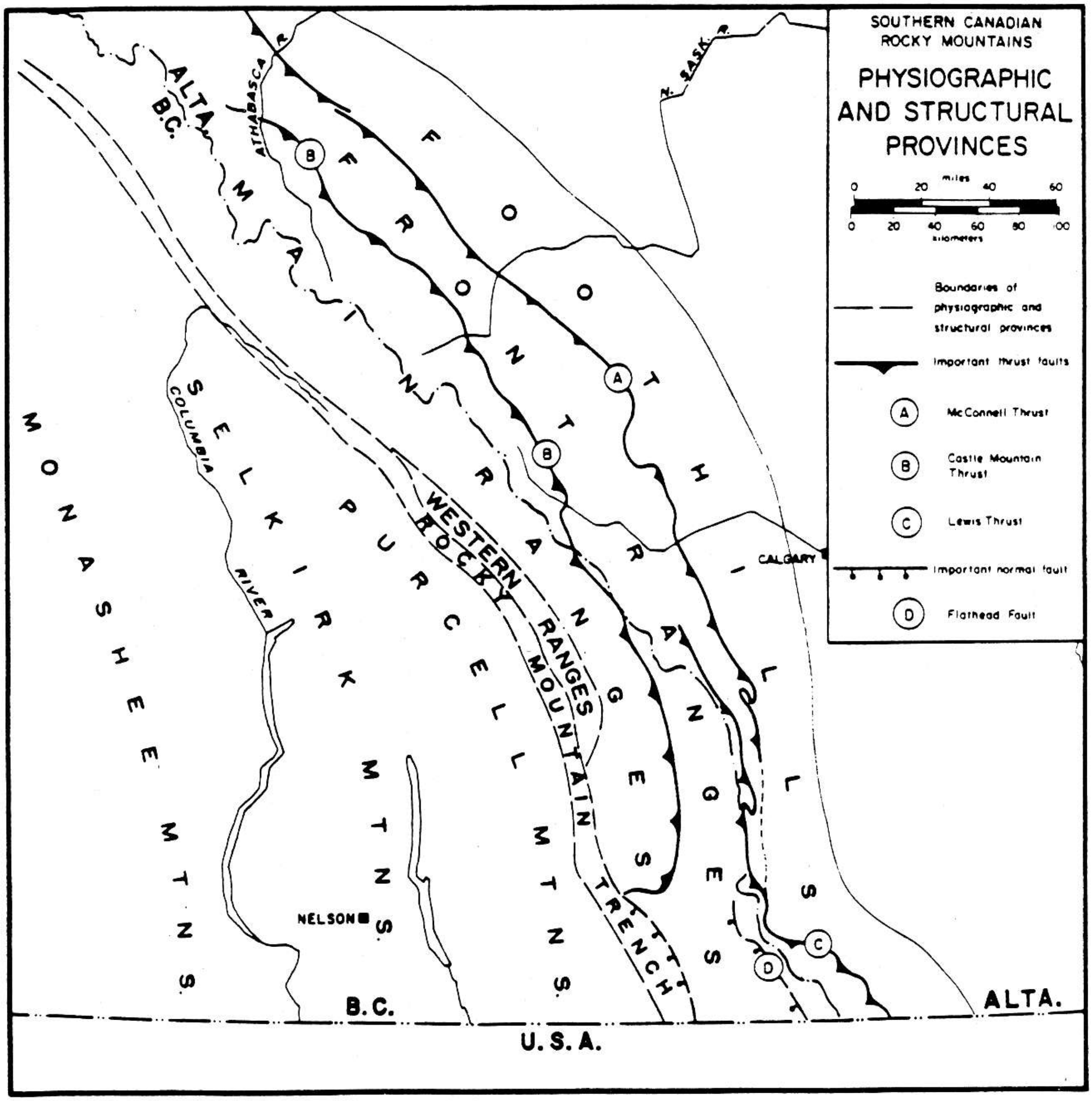


Figure 6: Physiographic/structural sub-provinces of the southern Rocky Mountains (from North and Henderson, 1954; Harrison, 1988).

The Foothills are typified by broad, open folds with some thrusts and reverse faults. The Foothills represent the easternmost extent of Laramide orogeny onto the North American craton. The Foothills have low relief that rises above the plains and gradually heightens towards the Front Ranges.

At the McConnell thrust, the Front Ranges rise sharply above the level of the Foothills. The Front Ranges are a stacked series of east vergent, moderately to steeply west dipping thrust plates. Tight to isoclinal, large scale folding of strata against thrust faults is common. At its widest point, the Front Ranges consist of five distinct ranges with as few as two. Ridges and mountains have moderate west-facing dip slopes, steep to vertical east faces and commonly are elongate parallel to the thrusts. Individual ranges extend for tens of kilometres. Ranges end or are truncated where either the bounding thrusts join, end in folds or are truncated by transverse tear faults. The western limit of the Front Ranges is the Castle Mountain thrust, a splay of the Simpson Pass thrust.

The Main Ranges form the main body of the Rocky Mountains. Thrusting again is prominent but is different in style to the Front Ranges. Folds tend to be broad and open with subhorizontal bedding. The eastern edge of the Main Ranges is the Castle Mountain thrust. A regional, open syncline-anticline pair, 200 kilometres (130 mi.) long in the southern Rockies parallels the eastern margin. In the region of Banff, Golden and Radium, the Main Ranges are divided into two sections, Eastern and Western. The Eastern Main Ranges are predominantly flat lying carbonates composed of pre-Devonian strata. These form the prominent, castellated peaks for which the Rockies are well known. This includes mountains such as Mt. Robson, Castle Mountain, Mt. Edith Cavell and Mt. Assiniboine. The Western Main Ranges are west of the pre-Devonian facies change. They are made up of shales, argillites and argillaceous limestones, lateral, basinal equivalents of the platform carbonates. They are tightly folded and have a well developed cleavage. The Western Main Ranges only exist, by definition, over the extent of the pre-Devonian shale facies, west of the Kicking Horse Rim. Elsewhere only the Eastern Main Ranges are present. The western limit of the Main Ranges is the Purcell Thrust Fault. This major feature marks a significant break between the relatively unmetamorphosed Phanerozoic strata and the more deformed and metamorphosed Precambrian Purcell mountains. The Purcell Thrust follows the Rocky Mountain Trench, a narrow physiographic feature that extends across the length of B.C.

The Western Ranges are a small subprovince limited to the western edge of the Rockies. It is bounded to the west by the Purcell Thrust fault and to the east by the axis of the Porcupine Anticlinorium. This roughly includes the Van Horne, Beaverfoot, Brisco and Stanford ranges from Golden to Canal Flats. The Western Ranges are marked by a series of thrusts overturned steeply to the west and transverse tear faults. Strata are variably folded, locally overturned and shuffled with small to moderate displacements.

ROAD LOG 1

BANFF TO GOLDEN AND WINDERMERE

Banff:

In 1885, during the construction of the Canadian Pacific Railway (CPR), workmen discovered hot springs above the town. The springs are located immediately adjacent to the Sulphur Mountain thrust as it traverses the lower slopes of Sulphur Mountain. Meteoric water percolates down the fault system and is heated at depth. The temperature of the water at the springs is approximately 46°C (113°F). Soon after the discovery of the springs, the Government of Canada established a 26 ha. (10 sq. mi.; Warren, 1927) public reverve in the area to preserve the springs. The hot springs quickly became a popular attraction to travellers on the CPR. The hot springs have been developed into a large bath and spa complex which draws tens of thousands of people annually. Continued public pressure encouraged the government to establish the first national park in Canada. In 1887, Rocky Mountain Park was established and encompassed 7300 ha. (260 sq. mi.; *ibid.*) in the immediate vicinity of Banff. Since then the park has been enlarged to its current size of 72 000 ha. (2,600 sq. mi.). Banff National Park is now part of the largest contiguous park system in Canada. These parks encompass approximately 167 000 ha. (6,000 sq. mi.) of the Rocky Mountains along the B.C. - Alberta border and are a major tourist attraction. Climbing, hiking, canoeing/kayaking, skiing, golf and camping are some of the many activities which draw people to the varied environment of the parks.

The first part of the road log describes the Front Ranges. As can be seen on the mountain sides, dips are moderate to steep to the west. Bedding is upright with tops to the west.

The town of Banff is at the base of Mount Rundle, on the Mt. Rundle thrust sheet. It is composed of Devonian through Pennsylvanian limestones, dolomites, siltstones and cherts of the Palliser and Banff Formations and the Rundle and Rocky Mountain Groups.

Immediately past the junction of Highway 1 and the north road out of town, the highway crosses the Sulphur Mountain thrust which separates the Mt. Rundle thrust sheet to the east from the Sulphur Mountain thrust sheet to the west. The Sulphur Mountain sheet is composed of Devonian to Pennsylvanian carbonates with some over lying black siltstones of the Triassic Spray River Group.

At Vermillion Lakes one can see three major thrust plates. Looking south and from east to west are, the Mt. Rundle plate at Mt. Rundle, the Sulphur Mountain plate

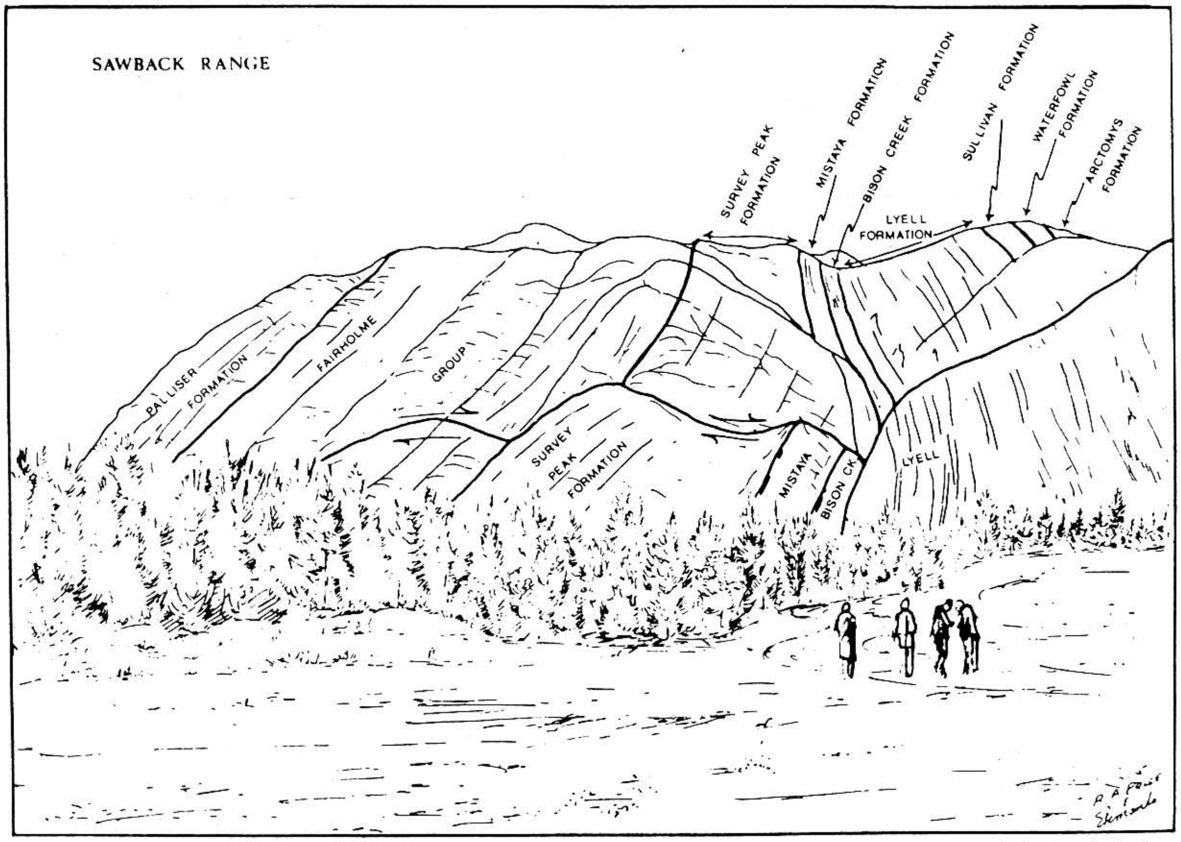
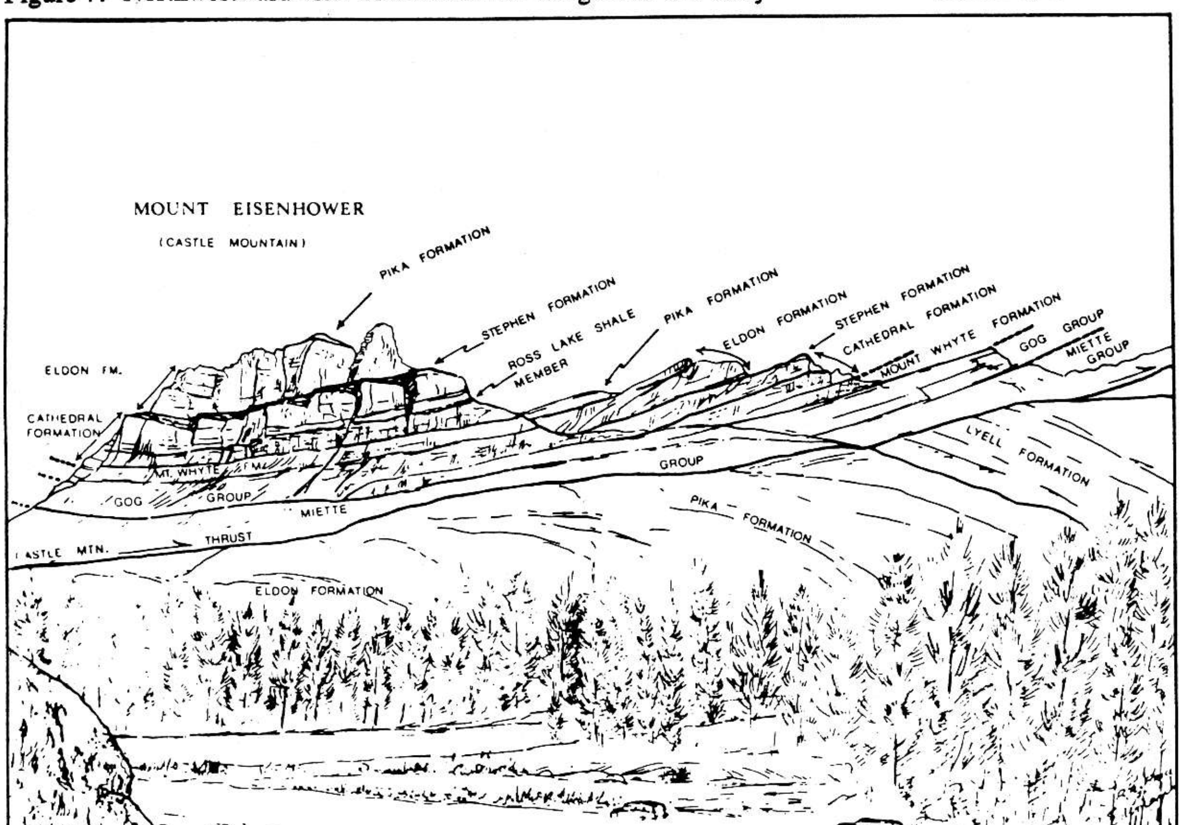


Figure 7: **Northwestward view of the Sawback Range near Mt. Cory** Sketch by R. A. Price.



Sketch by R. A. Price.

Figure 8: **Northeastward view of Mt. Eisenhower (Castle Mountain) showing the Castle Mountain Thrust and the boundary between the Front Ranges and the Main Ranges (from Halliday and Mathewson, 1971).**

at Sulphur Mountain (directly south) and the Bourgeau plate across the Sundance Range.

At the junction with Hwy 1A, the road crosses the Bourgeau thrust into the Sawback thrust plate. This is the last major thrust plate of the Front Ranges. It is a stack of carbonates, siltstones, shales and argillites of the Middle Cambrian Cathedral Formation through to the Triassic Sulphur Mountain Formation. Mt. Bourgeau is directly ahead. It is formed by carbonates of the Mississippian Rundle Group and is capped by a thin klippe of Middle Cambrian shales of the Mt. Whyte Formation. The klippe rests on the Simpson Pass thrust and is a relict of that plate.

The road swings to the northwest and travels obliquely along the strike of the strata. The Sawback Range forms the eastern side of the valley. Two kilometres (1.2 mi.) beyond the junction with Hwy 1A is a good view to the north of Mt. Cory in the Sawback Range. This gives an almost complete section through the Sawback thrust plate (Figure 7). Here the miogeoclinal carbonates and shales are substantially thicker than their platformal counterparts in the McConnell thrust plate of the east Front Ranges outcrops, east of Canmore. For example, the dolomites and siltstones of the Middle Cambrian Waterfowl are 60 metres (200') thick here and only 30 metres (100') thick in the McConnell plate. Also, The Late Cambrian to Early Ordovician Formations which are absent in the McConnell plate are 825 metres (2700') thick here. (Price *et al.*, 1972)

At the junction of Hwy 1 and Hwy 93 (to Radium) the Simpson Pass thrust passes under the highway from the south and then follows north up the valley parallel to the highway. Also, about 2 kilometres south of the junction, the Castle Mountain thrust passes under Hwy 1. This fanlt is the boundary between the Front Ranges and the Main Ranges.

At the Mount Eisenhower (Castle Mountain) viewpoint is an excellent display of the boundary between the Front Ranges and the Main Ranges (Figure 8). The Castle Mountain thrust crosses the lower slopes of the mountain. The Castle Mountain thrust is an imbricate branch of the Simpson Pass thrust which is almost directly underneath the highway here. At Mt. Eisenhower an almost complete section of Precambrian to Middle Cambrian strata forms the upper, castellated peaks of the mountain. The thrust slice puts Miette Group slates, sandstones and shales on top of Middle to Late Cambrian Eldon and Pika Formation dolomites and limestones and structurally juxtaposed Lyell Formation limestones and dolomites. The overthrust Cambrian strata here are relatively flat lying, folded into a broad north-south syncline, typical of the structural style of the Main Ranges. This is in marked contrast to the steeply dipping, thrust imbricate Front Ranges.

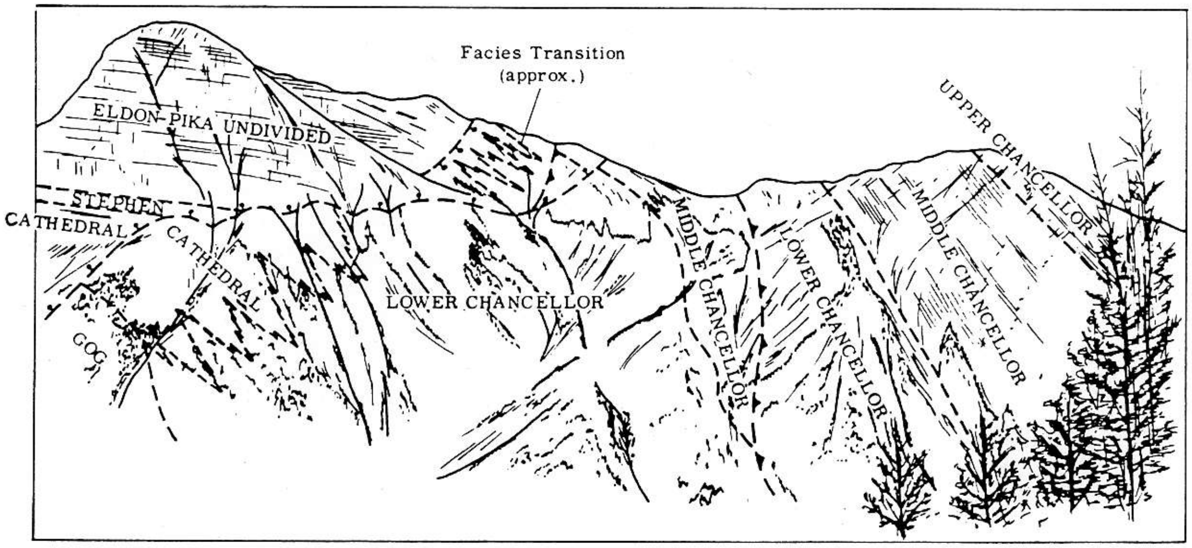


Figure 9: Southward view of Mt. Stephen (left) and Mt. Dennis (right) showing the facies change from eastern carbonate facies to western shaley facies (from Halliday and Mathewson, 1971).

Travelling to the north, parallel to the strike of the strata, to the west are clastic rocks of the Precambrian Miette Group and quartzites of the Early Cambrian Gog Group. These are all strata of the Simpson Pass thrust plate. Middle to Late Cambrian carbonates are just behind the peaks to the west. Castle Mountain is the long set of spires to the east.

At the junction of Hwy 1 and Hwy 93 (to Jasper), Hwy 1 swings west and cuts across the strike of the strata. The highway rises out of the valley through the Miette Group and up into quartzites and conglomerates of the Early Cambrian Gog Group.

At the continental divide the highway crosses from Alberta to British Columbia. The road cuts through quartzites of the Gog Group.

At the Junction with Hwy 1A (back to Lake Louise) the road works up section through shales and siltstones of the Mt. Whyte Formation then limestones and dolomites of the Cathedral Formation. Both of these units are Middle Cambrian.

At the western end of Hector Lake, the Brook Fault, one of many northeast-southwest trending normal faults in the Main Ranges, down drops Middle Cambrian Eldon and Pika Formations against the Cathedral Formation.

As the highway moves down the Kicking Horse River valley, it passes down section through the Middle Cambrian Formations and into the Early Cambrian Gog Group quartzites at the Tunnel Mountain lookout.

STOP 1-1: Tunnel Mountain Lookout

Mt. Field is directly across the river, Mt. Wapta behind it and Mt. Stephen the peak above the highway. From the lookout one can see a major lithologic transition. Here, the primarily carbonate facies of the Middle to Late Cambrian strata abruptly change to forereef and basinal shale, argillite and argillaceous limestone equivalents. This facies change is a significant boundary. To the east, the Mt. Whyte, Cathedral, Stephen, Eldon and Pika Formations all shale out into the laterally equivalent Chancellor Formation to the west. Figure 9 is a southward view of the facies change between Mt. Stephen and Mt. Dennis. Also another feature, difficult to see from this vantage point is the Cathedral Escarpment. This the reef facies boundary of the Middle Cambrian Cathedral Formation platform. The escarpment is subvertical and is up to 300 metres (1000') high. A related feature is the associated thickening of the Stephen Formation from 55 metres (180') thick to the east of the escarpment to 320 metres (1050') thick to the west of the escarpment. The reef edge is part of the Kicking Horse Rim as defined by Aitken (1971).

The Cathedral Escarpment is the locus for several other major sites. These include, the Kicking Horse and Monarch lead-zinc mines (just visible on the lower

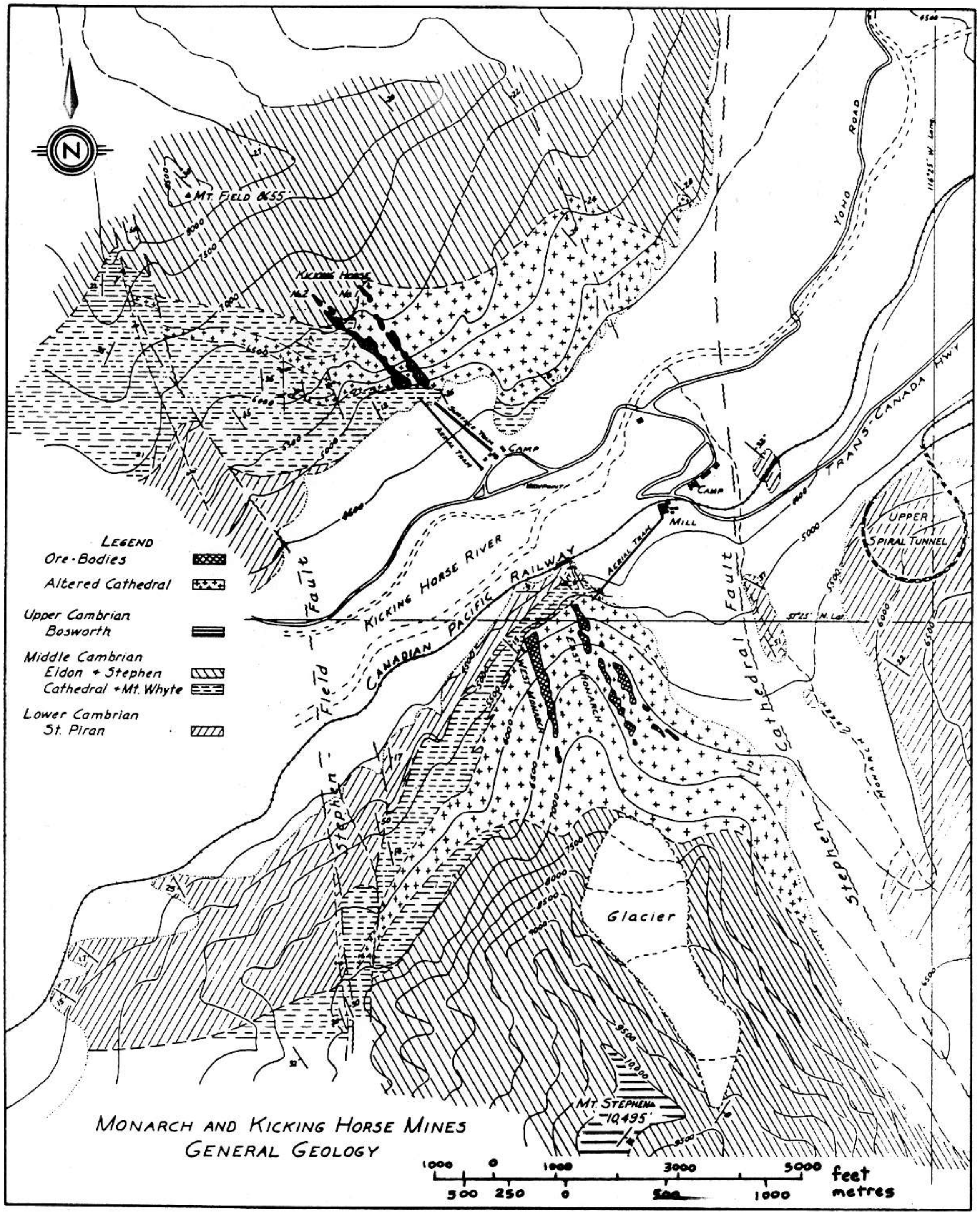


Figure 10: Contemporary map of the Kicking Horse and Monarch mines. Note that Bosworth Fm. = Arctomys Fm. and St. Piran Fm. = Gog Fm. (modified from Ney, 1954)

cliffs of Mt. Field across the river), the Burgess shale on the slopes of Mt. Wapta (just behind Mt. Field from this point) and several magnesite occurrences in the Mitchell/Cross River valleys to the south. Also, this view point overlooks the lower tunnel of the Spiral Tunnels, a major engineering feat during the development of the CP Railway.

Spiral Tunnels:

When the CPR was constructed, it had to go through Kicking Horse Pass (1627 metres; 5340'). To climb out of the valley from Field to the pass, the grade was 8 per cent. This was the steepest grade in North America for a conventional railway and soon became known as the "Big Hill". Unfortunately, the engines of the time had difficulty pulling trains up the grade and holding them going down, even with the specialized 4-8-4 locomotives developed for the trans-Rockies hauls. So, a few years after the original grade was constructed, part of the problem was alleviated by the installation of two switchbacks to take the grade down to 6 per cent. Some of the concrete piers over which the railway travelled are directly behind the lookout. Finally, the CPR constructed the two spiral tunnels to take the grade down to a more conventional 4 per cent. The lower tunnel is visible down and to the right from the view point. The upper tunnel is behind, left and above the viewpoint, out of sight through the trees.

Monarch and Kicking Horse Mines:

The workings of the mines are barely visible from this vantage point. The Kicking Horse mine is located near the bottom of the cliff of Mt. Field that faces the river. The Monarch mine workings are out of sight around the slope on Mt. Stephen. (*see* Figure 10) The Monarch and Kicking Horse mines are carbonate hosted lead-zinc deposits and have been classified as Mississippi Valley type deposits, similar to the Pine Point mine in the Northwest Territories of Canada. The original discovery of the Monarch mine showings, on the slopes of Mt. Stephen, was during the construction of the CPR in 1884 and the Kicking Horse mine showings were discovered a few years later. The mines were operated intermittently from 1884 to 1952. A total of 770 000 tonnes (850,000 short tons) of lead-zinc ore grading 7 per cent lead, 10 per cent zinc and 41 grams per tonne (1.2 oz./st) silver were produced (Ney, 1954). Both mines were underground operations and used innovative cliffside and aerial tramways to take the ore down to the valley for processing. Principal ore minerals were galena and sphalerite with accessory pyrite and chalcopyrite.

Lead-zinc mineralization has been identified in the whole of the Cathedral Formation in this area but ore mineralization was restricted to a zone 60 to 120 metres (200' to 400') above the base of the formation. Stratigraphically, ore mineralization occurred along the contact between a lower, black, thin-bedded dolomitized limestone and a an upper, grey, massive dolomite. Ore occurred in zones of brecciated grey dolomite. A dark grey dolomite forms fine-grained matrix in the breccias. Sulphide mineralization occurs as open space fillings and partially as replacement of dolomite.

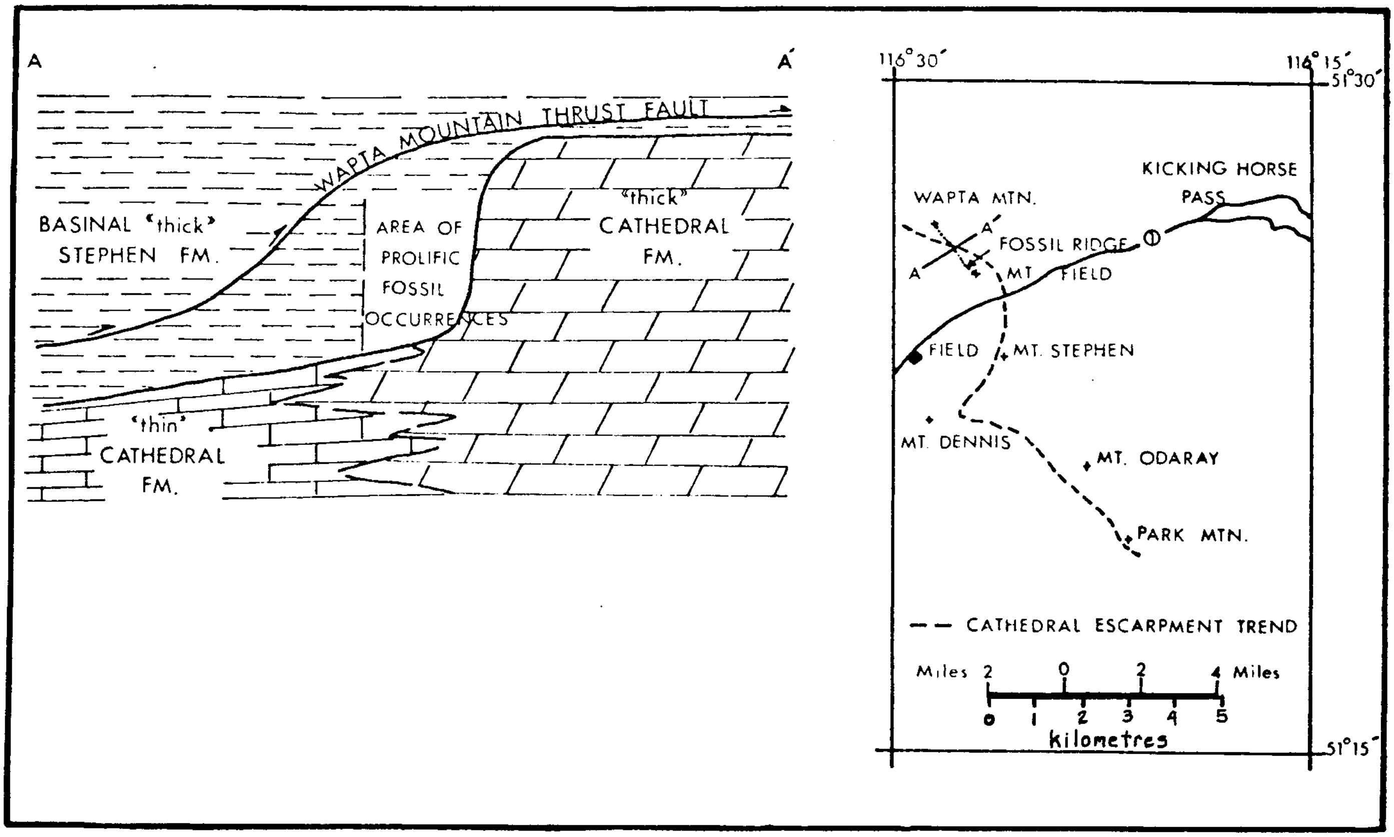


Figure 11: Diagrammatic section through the Cathedral Escarpment showing the location of the Burgess Shale and the Wapta Mtn. thrust (from Harrison and McIlreath, 1977).

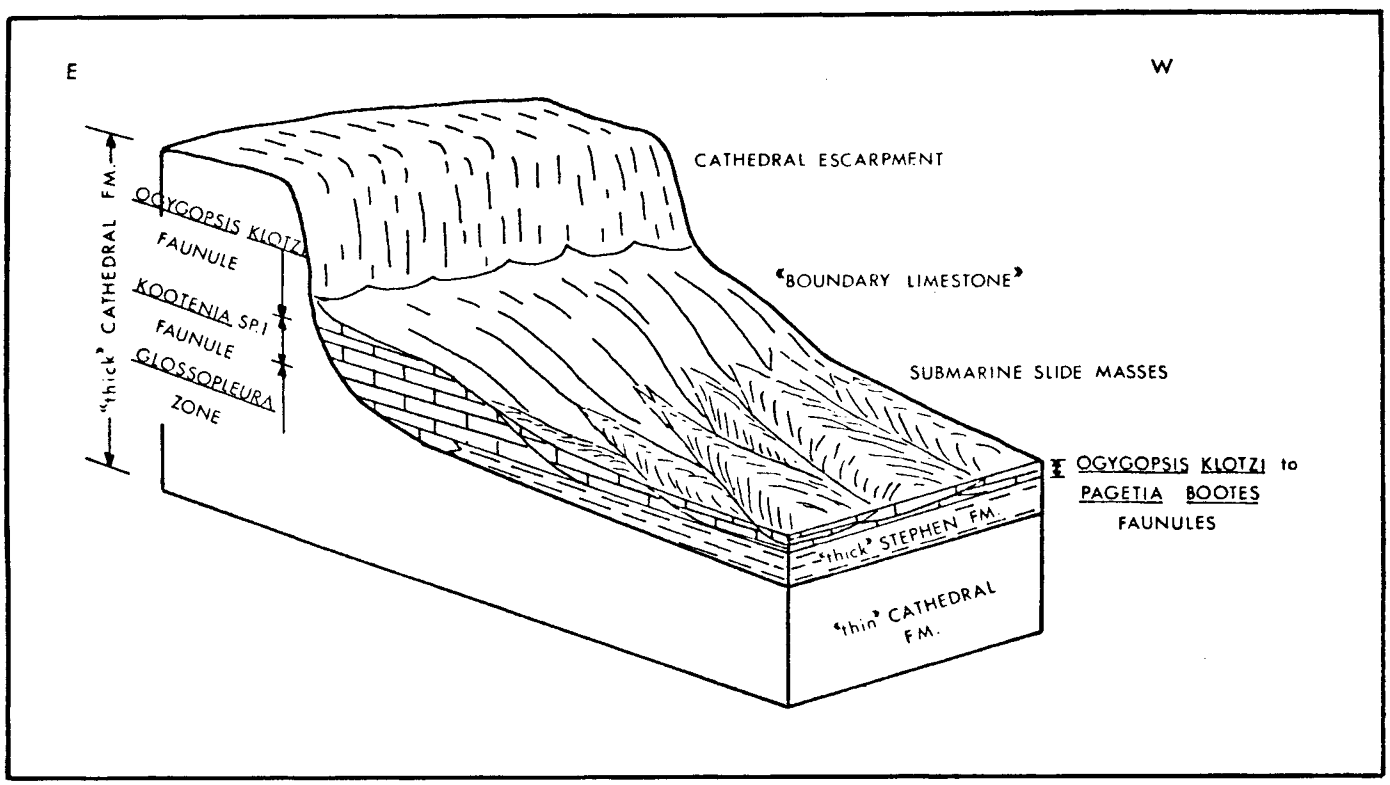


Figure 12: Diagrammatic block view of the depositional environment of the Burgess Shale (from Harrison and McIlreath, 1977).

There is minor sulphide mineralization in cross-cutting fractures. The breccia zones roughly parallel bedding. Ore zones were elongate parallel to the escarpment and generally had a flattened ovoid cross-section. Ore was essentially restricted to the zones of brecciation which provided a good exploration guide for other zones. Occasionally, ore zones graded out along strike and then appeared further along strike. Thus the ore bodies formed elongate pods often in sequence along strike. A late stage white breccia cross cuts most of the ore bodies. This however is a regional feature and has no control on sulphide mineralization.

Ore mineralization consisted of galena, low iron sphalerite with lesser pyrite and chalcopyrite. Galena/sphalerite ratios remained constant in individual ore pods but varied greatly between ore pods. Pyrite was an accessory constituent, commonly found around the margins of the ore pods and into barren dolomite breccia and massive dolomite. Chalcopyrite was a minor constituent, found scattered throughout the ore. Traces of quartz, serpentine and talc have been reported in the proximity of the ore zones. In general, the Monarch ores graded 4 to 5 times greater in lead than ore from the Kicking Horse mine. In fact some of the ore at the Kicking Horse mine was essentially sphalerite. Also, galena rich ore always carried some sphalerite but sphalerite ores conld be devoid of galena. This disparity between ores was a major reason the Kicking Horse mine was developed after the Monarch mine. A complete description of these deposits is available in Ney (1954).

Burgess Shale and Cambrian Fossils:

On the Western slopes of Mt. Wapta, Charles Walcott of the Smithsonian Institute discovered a bed of shales with abundant fossils in 1909. This he called the "phyllopod bed" because of the preponderance of "lace crab" (now *Marella*) fossils. He soon recognised that at this particular location the soft body preservation of fossils was exceptional. In fact later workers have found several species of worms and other soft bodied fauna. Dr. Walcott collected over 80,000 specimens from this quarry between 1909 and 1913 with one season in 1917. This collection is stored at the National Museum of Natural History of the Smithsonian Institute. Further collecting of samples from a small quarry just above Wallcott's site was done by Percy Raymond of Harvard University in 1930. Then in 1966 and 1967 a collection project by the Geological Survey of Canada, lead by Dr. H. Whittington, collected fossils from both Walcott's and Raymond's quarries to provide a Canadian collection from the Burgess shale. Since that time no collection has been allowed as the quarries are within National Parks.

The Burgess shale is of singular importance because of its excellent fossil preservation and abundance. Although complete analysis of all the fossils is not complete, enouglr work has been done to recognise several points. One is that virtually all modern phyla are represented in the collection. Another is that in some cases evolutionary development and speciation from precursors has been recorded. Finally

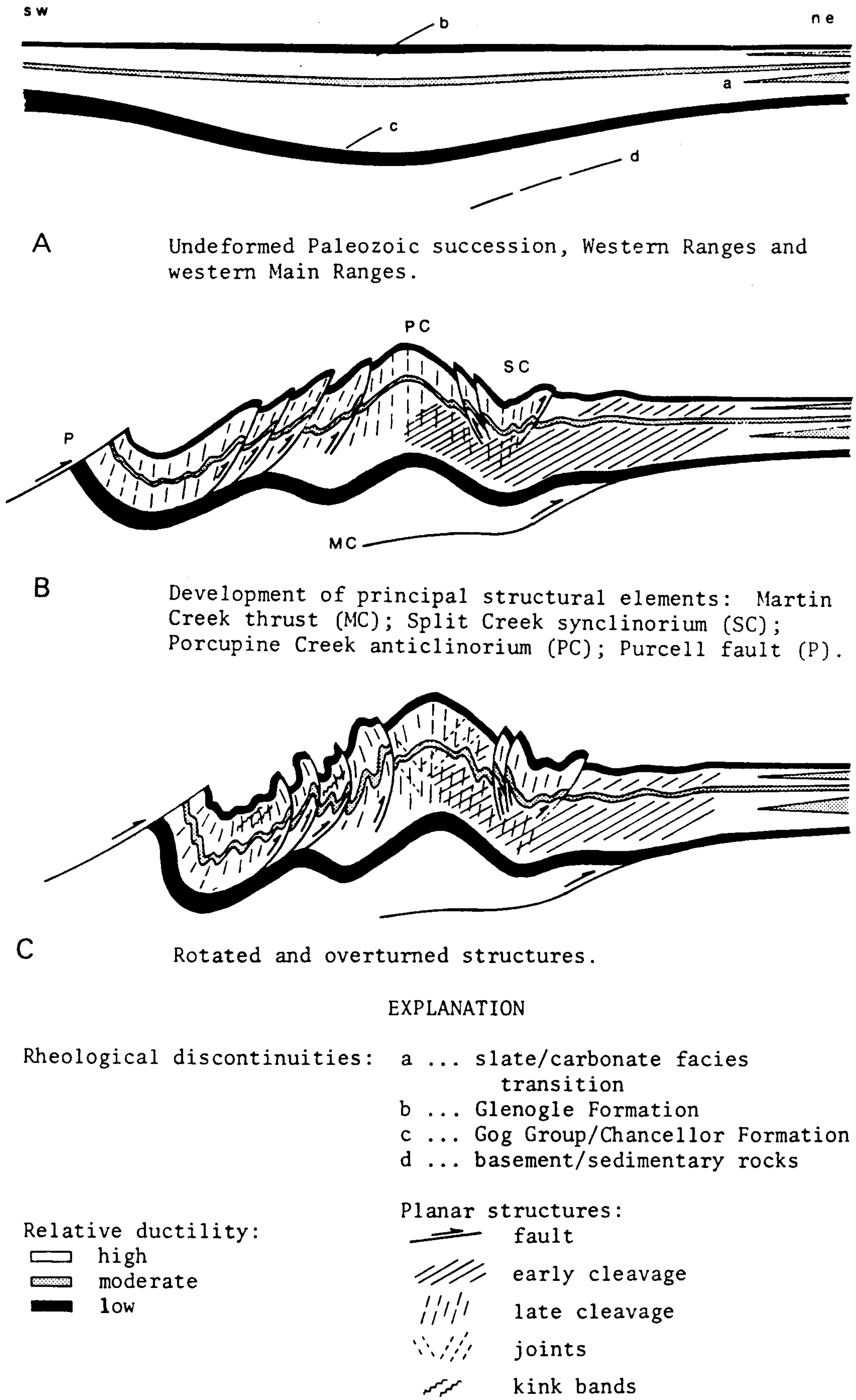


Figure 13: Schematic development of the Porcupine Creek anticlinorium (from Halliday and Mathewson, 1971).

and most interesting is that there are many fauna that do not belong to any known phyla. Some of the creatures identified are very unusual and do not bear any resemblance to known animals. *Hallucigenia* is a fine example, the name even implies its uniqueness. Research of the existing collections is ongoing. The variety and excellent perservation of the fauna represented in the Burgess shale makes it one of a hand full of similar deposits in the world.

A significant factor in the preservation of the Burgess shale is the lack of structural deformation of the strata. Only sedimentary compaction has effected the fossils. The reason for this is that the shale rests within the stress shadow of the Cathedral Escarpment. During compression of the Laramide orogeny, stress was shifted up and over the competent dolomite of the escarpment. This is best demonstrated by the ramping of the Wapta thrust over the escarpment (Figure 11). Thus the fossils are well preserved.

Emplacement of the fossils into the Burgess shale is also significant. It has been determined that the various fauna were swept down over the escarpment (Figure 12) in turbidity currents involving fine muds. The rapid burial of the fauna in single events reduced the effects of dismemberment during multiple stages of transportation before final burial. The rapid burial also allowed the fauna to be buried in a variety of positions relative to bedding. Thus during later analysis different views of individual fauna, which is not always available to paleontologists, allow their complete description.

About 4.5 kilometres (3 mi.) past the Emerald Lakes turnoff the highway crosses the trace of the facies change. It is not exposed at road level because it is still within the underlying Gog Group quartzites. The facies change here marks the boundary between the Eastern Main Ranges and the Western Main Ranges sub-provinces. The change can be seen as the Western Main Ranges rocks are more folded and have well developed cleavage due to their inferior competence.

From the town of Field, B.C. for the next 24 kilometres (15 mi.) outcrops are shales, argillites and argillaceous limestones of the Chancellor Formation. Note that the outcrops are dominated by a prominent cleaveage, the result of tectonic deformation. The road travels across first the Split Creek Synclinorium then the Porcupine Anticlinorium (Figure 13). The feature is not readily visible from the river valley. However, the synclinorium-anticlinorium pair extend from Field to Leanchoil, 19 kilometres (12 mi.) east.

As the road passes the confluence of Porcupine Creek and the Kicking Horse River, to the north, it crosses the axis of the Porcupine Creek Anticlinorium. This is the western end of the Main Ranges in this area. The last subprovince here is the Western Ranges. They are typified by overturned thrusts, tight folds and overturned bedding (Figure 13). The Western Ranges (Beaverfoot, Brisco and Stanford) extend from just north of Golden to Canal Flats in the south.

As the highway turns North at Leanchoil it cuts up through the top of the Chancellor Formation, the Late Cambrian Ottertail Formation and into the Cambro-Ordvician McKay Group. The latter two units are primarilly shale, slate, sandstone and limestone.

Ice River Complex:

Ten kilometres (6 mi.) south of Leanchoil and east of the Beaverfoot River is the Ice River Complex (*see* Figure 1), an alkaline ultramafic intrusion. It is composed of two rock suites, the result of two phases of intrusion. The older phases consist of jacupirangite (nepheline pyroxenite: titanaugite, aegirine-augite, nepheline), ijolite (alkali syenite), urtite (nepheline rich alkali syenite) and a core of carbonatite and cross cutting dikes rich in mafic minerals. The younger, zoned phases consist of syenites and zeolite and feldspar bearing carbonatites. The complex is intruded into clastics of the Chancellor, Ottertail and McKay Formations. There is some hornfels and skarn contact metamorphism, with rare sodic metasomatism, around the body. The complex is host to LREE and strontium mineralization though only in minor concentration. This mineralization is generally restricted to melanocratic syenite and carbonatite. Magnetite is present as pods, lenses and stringers in carbonatite.

Isotopic dating has given a range of dates of emplacement from 392 $\pm$10 Ma (K/Ar; whole rock) to 220 $\pm$8 Ma (K/Ar; mica). However, radiometric work including K/Ar, Rb/Sr and U/Pb analysis suggests a preferred age of 245 Ma, the Permo-Triassic boundary. (Pell, 1987)

The complex is located within Kootenay and Yoho National Parks. As a result, it is only of academic interest. A recent proposal to mine and process magnetite rich talus outside the park for heavy media is currently being evaluated. Also, a sodalite prospect is known at the southern end of the complex, outside the park boundaries.

As the road works its way down the Kicking Horse River it passes upsection through McKay Group slates and shales with some beds and lenses of limestone. Bedding is overturned and dips eastward at steep angle. The well developed cleavage is typical of the Western Ranges subprovince.

Just after the highway crosses over to the south side of the river it crosses an overturned thrust in the uppermost McKay Group. At the end of the road cut past the bridge the McKay Group is in gradational contact with black, graptolitic shales of the Early to Middle Ordovician Glenogle Formation. The highway passes stratigraphically upward but structurally downward due to overturning.

Three kilometres (2 mi.) past the bridge the highway cuts through the Ordovician Mt. Wilson Formation quartzite, host to the Nicholson and Mt. Moberly silica operations.

When the highway crosses back to the north side of the river it crosses stratigraphically upward into dolomites of the Ordovician-Silurian Beaverfoot Formation.

As the road bends west, 2.5 kilometres (1.5 mi.) past the bridge it crosses through a tight syncline and overturned thrust into an upright panel of the western limb. From this point to Golden the road moves down section through the Mt. Wilson Formation quartzite, Glenogle Formation shales and McKay Group slates and shales.

The town of Golden sits astride the Kicking Horse River, 1.6 kilometres (1 mi.) upstream from its confluence with the Columbia River. The Columbia River flows northward along the Rocky Mountain Trench. The trench is the western edge of the Rocky Mountains. The Purcell thrust fault is the actual, structural limit and passes along the bottom of the low hills on the western side of the Trench.

SILICA IN THE SOUTHERN ROCKY MOUNTAINS

GEOLOGY OF THE Mt. WILSON FORMATION

Regional setting of the Mt. Wilson Formation quartzite:

The Mt. Wilson Formation quartzite has two major outcrop areas in the Rocky Mountains. One is between the headwaters of the Clearwater River and the Athabaska River in Banff National Park. The other is between Golden and White Swan Lake near Canal Flats. The two major areas are offset as the result of thrusting. The formation has a maximum thickness of 480 metres (1580') (Evans, 1933) at Horse Creek near Golden and is 167 metres (548') thick in type section at Mt. Wilson, northwest of Banff (Figure 14; Norford, 1969). It is white to buff in colour with well rounded grains, 0.25 to 1 millimetre in diameter. The unit is thickest in the Golden-Radium area and thins to the south. It appears to maintain a fairly constant thickness elsewhere of 18 metres (60').The Golden to White Swan segment will be discussed in detail here, for detailed sections and descriptions see Norford (1969). Mt. Moberly, a few kilometres northeast of Golden, is the northern limit of the Mt. Wilson Formation quartzite in B.C. There it is terminated by a thrust fault which swings east around from the west side of the formation. The Mt. Wilson Formation occupies a faulted syncline in the Beaverfoot Range. It outcrops in parallel, structurally repeated layers. The quartzite is typically massive orthoquartzite with some evidence of crudely laminated and cross laminated beds near the base. Current direction studies indicate sediment transport from the northeast (Ketner, 1966). Conodonts collected from a shale interbed near the top of the formation provide a Late Ordovician age for the unit (Norford, 1969).

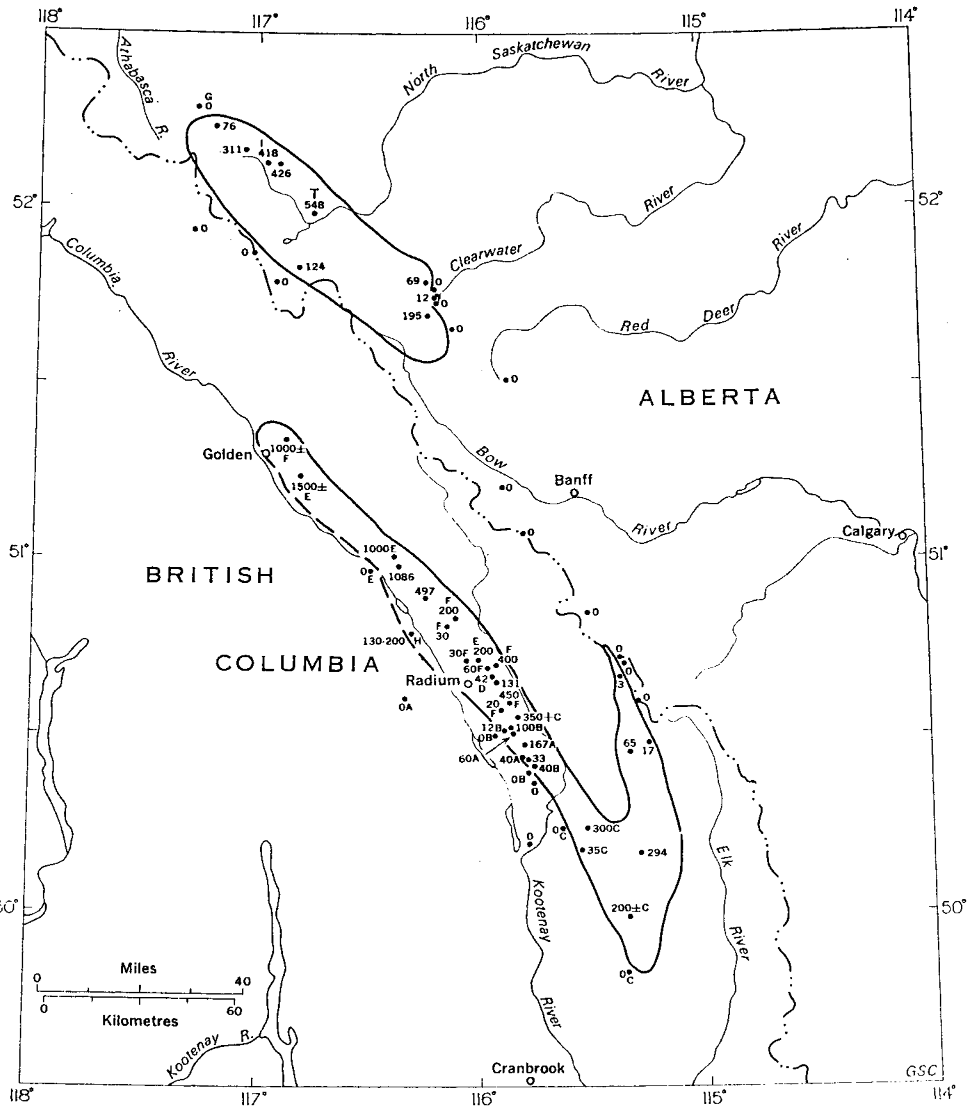


Figure 14: Outline of the regional extent of the Mt. Wilson Formation quartzite with locations of measured thicknesses (from Norford, 1969).

The Mt. Wilson Formation is in conformable contact with the overlying Ordovician-Silurian Beaverfoot Formation. The Beaverfoot Formation is a thick sequence of medium to thick-bedded dolomite and limestone. Above the Mt. Wilson Formation there is a basal subdivision of the Beaverfoot Formation named the Whiskey Trail Member. This member consists of a lower mudstone with some quartz silt and an upper argillite. The member is 28 metres (93') thick at the type section at McMurdo, just south of Golden, but is generally less than half that thickness. The Mt. Wilson Formation conformably overlies the Early to Middle Ordovician Glenogle Formation. The formation consists of shale, siltstone, sandstone, and some limestone. The shales of this formation have abundant graptolites, especially the black shales. Paleontological analysis of the graptolites provides an Early to Middle Ordovician age for the strata (Norford, 1969).

Local setting of the Mt. Wilson Formation; Mt. Moberly to Nicholson:

The Mt. Wilson Formation occupies the core of a south plunging anticline. Associated thrusting has caused some repetition of the strata. The anticline has been disjointed by overturned trusts and related transverse tear faults. Significantly, a major bounding thrust along the the western margin of the anticline swings to the east and truncates it on the north slope of Mt. Moberly. From there the quartzite extends 174 kilometres (100 mi.) south to White Swan Lake. At Mt. Moberly the quartzite is 300 metres (1000') thick and rapidly thins to less than 100 metres (300') at Radium and then tapers out to the south. (Norford, 1969)

Just north of Golden is the Mount Moberly silica quarry. To the south is the Nicholson quarry.

STOP 1-2: Mt. Moberly Silica;

The Mt. Moberly silica quarry, 8 kilometres (5 mi.) northeast of Golden, is owned and operated by Mountain Minerals Company Ltd. of Lethbridge, Alberta. The operation mines friable quartz sandstone of the Mt. Wilson Formation. Mining is by open pit and processing includes crushing, washing and screening. Ore mined from the pit is processed at the company's facility at Donald Station on the CPR, 25 kilometres (14 mi.) northwest of Golden. The main product is glass grade silica with several secondary products for local markets.

The Mt. Moberly quarry is situated in the northwest end of the Mt. Wilson Formation quartzite exposure (Figure 15). Locally the strata have been folded into an open anticline-syncline pair with a thrust fault along the axis of the syncline. The crest of the of the anticline forms the exposure of quartzite that is being mined. The zone is approximately 445 metres (1350') across. The opposite limb of the syncline outcrops 600 metres (1800') east and is 500 metres (1500') across. The quartzite is underlain by

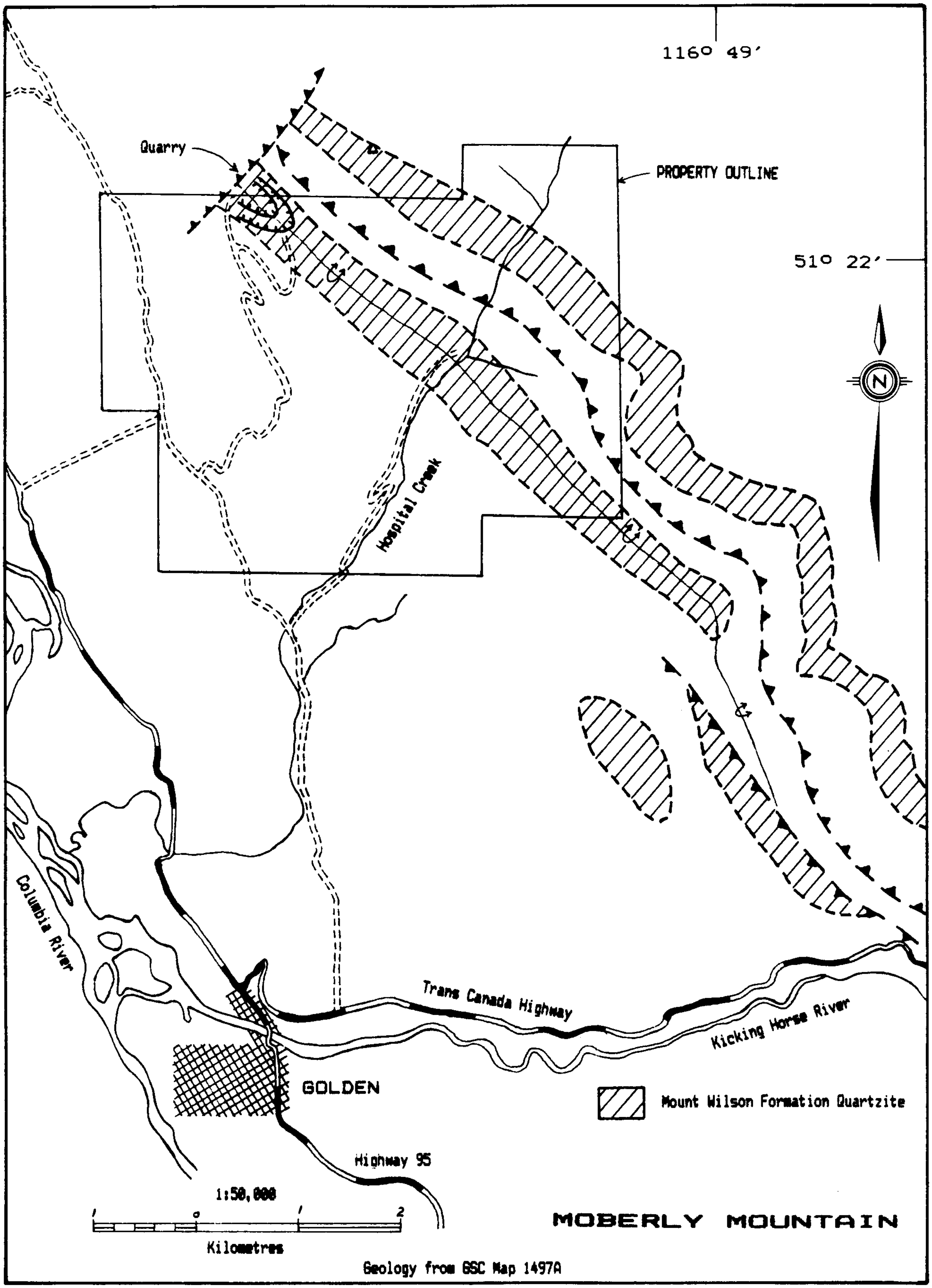


Figure 15: Location of the Mt. Moberly silica quarry and the Mt. Wilson Formation quartzite (from Foye, 1987).

brown argillite and shale of the Glenogle Formation. The overlying dolomites of the Beaverfoot Formation and Whiskey Trail Member shales are exposed in the core of the syncline. To the northwest the strata are truneated by a thrust fault that brings up McKay Group shale and argillaceous limestone.

Mining of quartzite is in a zone of friable quartzite 90 to 120 metres (270 to 360') wide. The sandstone is buff to white, uniform, massive, compact, fine-grained, silica cemented and generally nonporous. Sand grains are mature, well rounded and have a bimodal size distribution of 0.50 and 0.15 to 0.25 millimetres. A sample of washed product yielded the following grade:

SiO_2	Al2O3	MgO	K_2O	Fe_2O_3	CaO	Na_2O	TiO_2	LOI
99.67	0.06	0.02	0.02	0.02	0.06	0.01	0.01	0.12

weight per cent

Annual production averages 70 000 tonnes with highs to 100 000 tonnes. Quoted reserves are 10 million tonnes of friable sandstone. There has been no development of the massive quartzite. Mining is by open pit with drill and blast methods. Two bulldozers are used to move broken ore to draw points where a front end loader fills highway dump trucks. These trucks haul the ore to the processing plant at Donald Station. There the ore is crushed, washed, screened, sized and packaged (if required). Shipping is by either rail or truck, bulk or bagged. Three quarters of production is -30 to +100 mesh glass grade sand. Secondary products include -12 to +20/30 mesh "bunker" grade sand (decorative sand, traction sand, custom ceramic sand); -40 to +10 mesh filter media sand; 1 to 1.5 inch (2.5 to 3.5 cm.) unwashed decorative stone and large dimension rip-rap. The glass sand is shipped nationally and the secondary products supply the local market with special shipments as far as Edmonton and Calgary, Alberta and Hawaii, U.S.A..

Golden to Windermere

South from Golden, along the eastern side of the Trench, strata are structurally complicated by thrusts, normal and overturned, transverse tear faults and tight folding in the Western Ranges. Strata exposed include the Cambro-Ordovician McKay Group through to the Ordovician-Silurian Beaverfoot Formation with some slivers of the Devonian Harrogate and Cedared Formations. Across the valley to the west are the Purcell and Dogtooth Ranges. These are primarilly Precambrian and Early Cambrian clastics.

The town of Radium Hot Springs marks the junction of Hwy 95 and the Kootenay Parkway (Hwy 93). This is an alternate route to Banff.

GEOLOGICAL SETTING OF GYPSUM DEPOSITS IN THE SOUTHERN ROCKY MOUNTAINS

In the Stanford Range, Middle Devonian strata are preserved unlike most of the southern Main Ranges. Preserved here are the Cedared and Harrogate Formations, oldest to youngest. These are primarilly carbonate horizons formed in a shallow basin. The Cedared Formation grades southward into the Burnais Formation which is an evaporitic sequence of gypsum and anhydrite. It is this formation that hosts all the known gypsum occurrences in the southern Rockies.

The Harrogate Formation is incomplete in all sections mapped as the topmost layers have been eroded. In type section at Hatch Creek, 46 kilometres (20 mi.) southeast of Golden, the formation is 90 metres (293'; Belyea and Norford, 1967) thick but due to the eroded top thickness is quite variable. The formation has been separated into two subunits, an upper dolomite and a lower limestone. The lower limestone is argillaceous, dark grey to black, fine-grained limestone. Bedding varies between 15 and 60 centimetres (6" to 24"). The base of the unit is a non-calcareous shale that grades up into argillaceous limestone with shaly partings. The basal contact is conformable with the underlying Cedared Formation. Fossils present in the lower unit include ostracods, brachiopods and crinoids. The fossil assemblage gives a Middle Devenian age for the formation. The lower limestone grades upward into dolomite but the boundary is not stratigraphically consistant. The upper dolomite unit is brownish to dark grey, massive, fine-grained with poorly developed bedding 7 to 40 centimetres (3" to 15") thick. The upper dolomite is generally contains very few fossils.

The Cedared Formation was introduced by Belyea and Norford (1967) to define a sequence of nonfossiliferous carbonates which occur between the Beaverfoot Formation and the carbonates of the Harrogate Formation. The Cedared Formation contact is conformable with the overlying Harrogate Formation. The basal contact is paraconformable with underlying pre-Devonian strata. The contact is not well exposed but in some places bedding is parallel with underlying strata and in others there is an erosional surface. In a regional sense the lower contact is the Early Devonian unconformity which can be traced along the whole of the southern Rockies. The Cedared Formation consists of grey, massive, fine-grained dolomite. It contains characteristic quartz sand grains as well as having layers of argillaceous dolomite, limestone and mudstone.

Toward the south, in the Stanford Range, is an evaporite equivalent of the Cedared Formation. This is the Burnais Formation which consists of laminated, fine-grained, grey to black anhydrite and gypsum. At the type section at Pedley Pass, 12 kilometres (7 mi.) south of the Elkhorn quarry, the formation is 160 metres (522') thick (Belyea and Norford, 1967). In the area of the Elkhorn and Windermere quarries (Westroc) the Burnais Formation is 120 metres (700') thick. To the south the formation thins to around 60 metres (180'). Gypsum grades into anhydrite with depth and, in general, is approximately 33 metres (100') thick. White selenite and native sulphur forms small pods and lenses in fractures and fold noses in the gypsum. Locally a layer of soluble salts occurs at the gypsum-anhydrite boundary. Most of the Burnais Formation is covered and so the extent of the formation is inferred by scattered outcrops and topographic features such as sink holes. Mapping by Butrenchuk (1989) has suggested that the Burnais Formation may not be as extensive as previously mapped. The Burnais Formation is strongly deformed, primarily by folding. This is due to some synsedimentary folding and tectonic folding due to the Laramide orogeny.

Deposition of the evaporites was in a long, narrow restricted basin. The evaporites are over/and underlain by carbonates of the Cedared Formation and sometimes interdigitate. Field and petrographic evidence indicates that the present gypsum is a secondary product from the rehydration of anhydrite. It is suggested that meteoric waters entered the Burnais Formation during uplift and hydrated the upper part of the anhydrite to gypsum. Evidence to support this includes enterolithic folding, relict anhydrite in gypsum and fine-grained alabastine textures. Work by Murray (1964) shows that the anhydrite is a diagenetic product of primary gypsum. He demonstrates that gypsum is the original, stable form deposited in a shallow hyper-saline sea. During burial sufficient temperature and pressure are achieved to dehydrate the gypsum. With sufficient fluid flow through porous rock the anhydrite transformation does not cause distortion of layering. Thus when the anhydrite is brought to surface, bedding is still preserved. Such a scenario is proposed for the Burnais Formation.

Turnoff to the Westroc Gypsum quarries:

To the east are the quarry operations and to the west are shipping facilities.

STOP 1-3: Westroc Gypsum: Elkhorn and Windermere Quarries;

In the Rockies the two producers are Westroc Industries Ltd. at Windermere Creek and Domtar Ltd. at Lussier River quarry, south of Canal Flats. Control of the supply and market of gypsum in B.C. is held between the two companies totalling about 400 000 tonnes per annum. Westroc is by far the larger producer in the Rockies. Mining is by open pit with in pit crushing. The crushed ore is trucked 20 kilometres (11 mi.) to Wilmer for further processing and shipment.

Gypsum of the Burnais Formation is exposed on the north and south sides of Windermere Creek (Figure 16). The northern exposure has been almost mined out by the Windermere quarries. Present production is from the Elkhorn #1 quarry on the southern exposure. There the gypsum forms a roughly tabular unit parallel to the slope of the hill. It is 120 to 250 metres (360' to 760') wide and 12 to 70 metres (36' to 210') deep. Initial reserves ere estimated to be 3.3 to 4.0 million tonnes at >80 per cent gypsum (Clow, 1981). Typical impurities are dolomite, limestone, anhydrite, clays and other residual insolubles. The gypsum layer is underlain by anhydrite

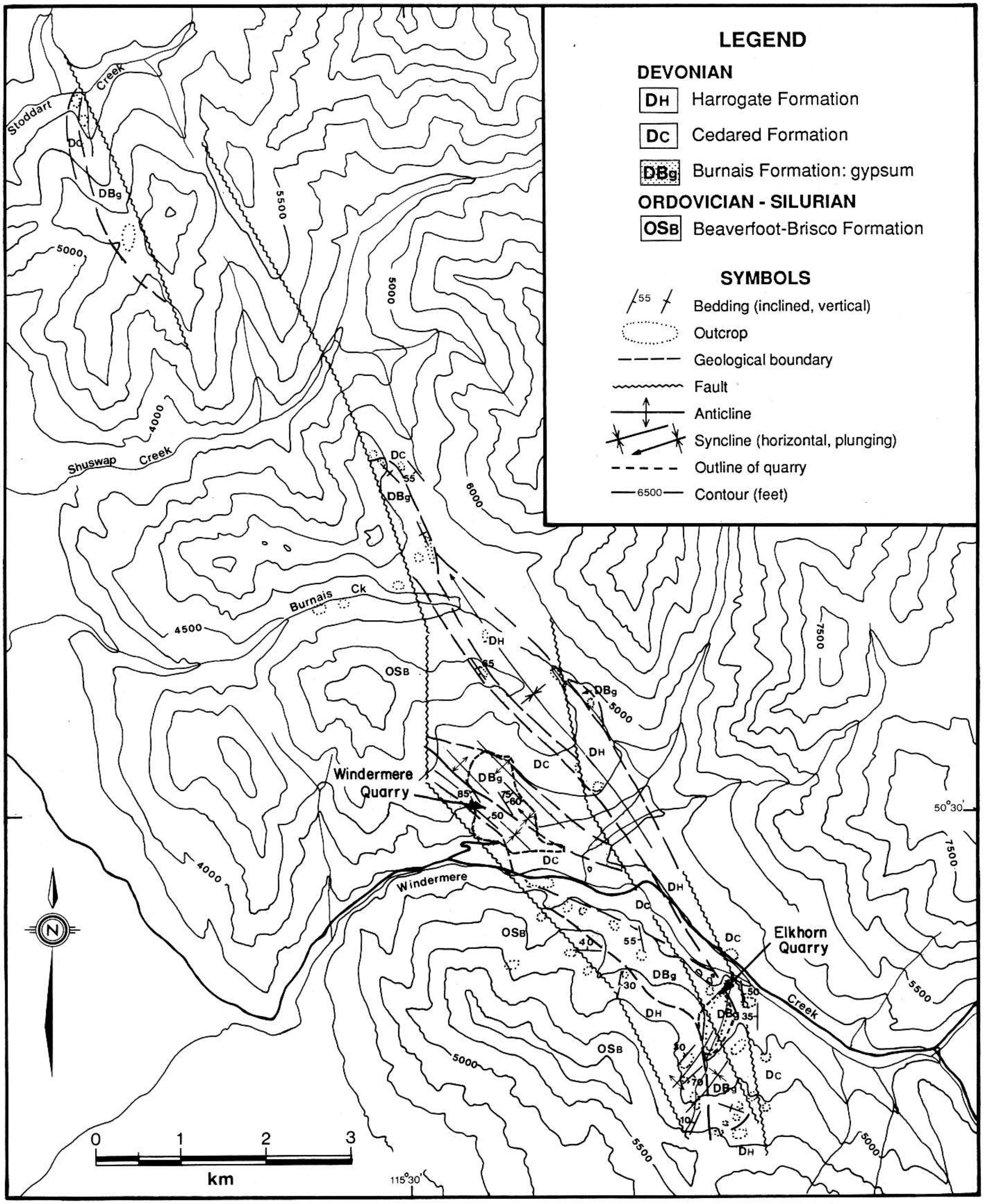


Figure 16: Local geology at Windermere Creek and the gypsum quarries of Westroc Industries Ltd (from Butrenchuk, 1989).

containing interbeds of limestone and some gypsum. The thickness of this unit has not been determined and it is not exposed. The Burnais Formation is conformably overlain by limestones of the Harrogate Formation. The lower contact has been presumed conformable with the Cedared Fromation although is is not exposed in the immediate area. The Burnais Formation is in fault contact with the Cedared Formation along its eastern boundary. The gypsum horizon extends north across the creek through the Windermere quarries.

Structural thickening has made the true thickness of the gypsum layer difficult to measure but estimates range from 50 to 100 metres (150' to 300') (Butrenchuk, in preparation). In the Windermere quarries the gypsum unit was compressed into tight, upright folds. These folds plunge gently to moderately northwest and parallel the regional tectonic trend. North to northwest trending normal faults transect and in many places terminate on strike extensions of the gypsum horizon. Displacements on these faults have not been determined but are only of local significance.

On the crest of the hill above the old Windermere quarries, a second layer of gypsum outcrops (Figure 16). This layer extends northwest, across Burnais Creek over a strike length of 4000 metres (12,000 feet). The layer is 17 to 43 metres (50' to130') thick with grades of 74 to 94 per cent gypsum and an average of 85 per cent. This upper layer is underlain by anhydrite and is bounded by faults.

The Elkhorn and Windermere quarries are owned and operated by Westroc Industries Ltd. Past production from 1950 to 1981 was from the Windermere #1 to #4 quarries. Current production is from the Elkhorn #1 quarry. Production to date has been approximately 7 million tonnes (7.7 tons $x10^6$) with current annual production running between 280 000 and 335 000 tonnes (308,000 to 370,000 tons). Small amounts of gypsum have recently been mined from the Windermere #4 pit for the cement industry. Products include crushed and lump gypsum and run-of-mine gypsum. Westroc supplies its own gypsum plants in Vancouver, B.C. and Calgary, Alberta. These plants produce wallboard, crushed, calcined or uncalcined gypsum for cement as well as other smaller markets.

RETURN TO BANFF: Via Hwy 1 or through Radium and the Kootenay Parkway (Hwy 93). To travel back to Banff via Hwy 93, read Road Log 2 in reverse order from Radium Hot Springs.

ROAD LOG 2

BANFF TO RADIUM HOT SPRINGS AND GOLDEN

Banff:

In 1885, during the construction of the Canadian Pacific Railway (CPR), workmen discovered hot springs above the town. The springs are located immediately adjacent to the Sulphur Mountain thrust as it traverses the lower slopes of Sulphur Mountain. Meteoric water percolates down the fault system and is heated at depth. The temperature of the water at the springs is approximately 46°C (113°F). Soon after the discovery of the springs the Government of Canada established a 26 ha. (10 sq. mi.; Warren, 1927) public reverve in the area to preserve the springs. The hot springs quickly became a popular attraction to travellers on the CPR. The hot springs have been developed into a large bath and spa complex which draws tens of thousands of people annually. Continued public pressure encouraged the government to establish the first national park in Canada. In 1887, Rocky Mountain Park was established and encompassed 7300 ha. (260 sq. mi.; *ibid.*) in the immediate vicinity of Banff. Since then the park has been enlarged to its current size of 72 000 ha. (2,600 sq. mi.). Banff National Park is now part of the largest contiguous park systems in Canada. These parks encompass approximately 167 000 ha. (6,000 sq. mi.) of the Rocky Mountains along the B.C. - Alberta border and are a major tourist attraction. Climbing, hiking, canoeing/kayaking, skiing, golf and camping are some of the many activities which draw people to the varied environment of the parks.

The first part of the road log describes the Front Ranges. As can be seen on the mountain sides, dips are all moderate to steep to the west. Bedding is upright with tops to the west.

The town of Banff is at the base of Mount Rundle, on the Mt. Rundle thrust sheet. It is composed of Devonian through Pennsylvanian limestones, dolomites, siltstones and cherts of the Palliser and Banff Formations and the Rundle and Rocky Mountain Groups.

Immediately past the junction of Highway 1 and the north road out of town, the highway crosses the Sulphur Mountain thrust which separates the Mt. Rundle thrust sheet to the east from the Sulphur Mountain thrust sheet to the west. The Sulphur Mountain sheet is composed of the same Devonian to Pennsylvanian carbonates with some over lying black siltstones of the Triassic Spray River Group.

At Vermillion Lakes one can see three major thrust plates. Looking south and from east to west are, the Mt. Rundle plate at Mt. Rundle, the Sulphur Mountain plate

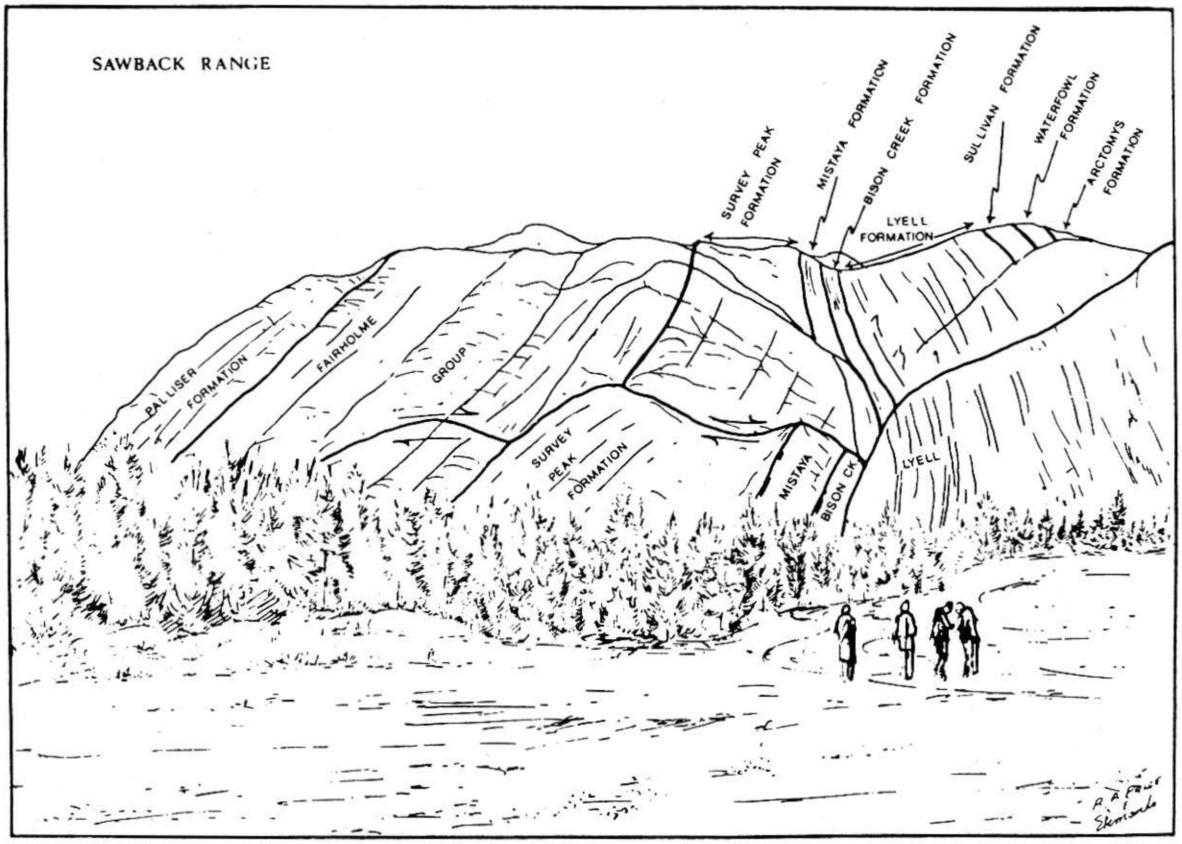
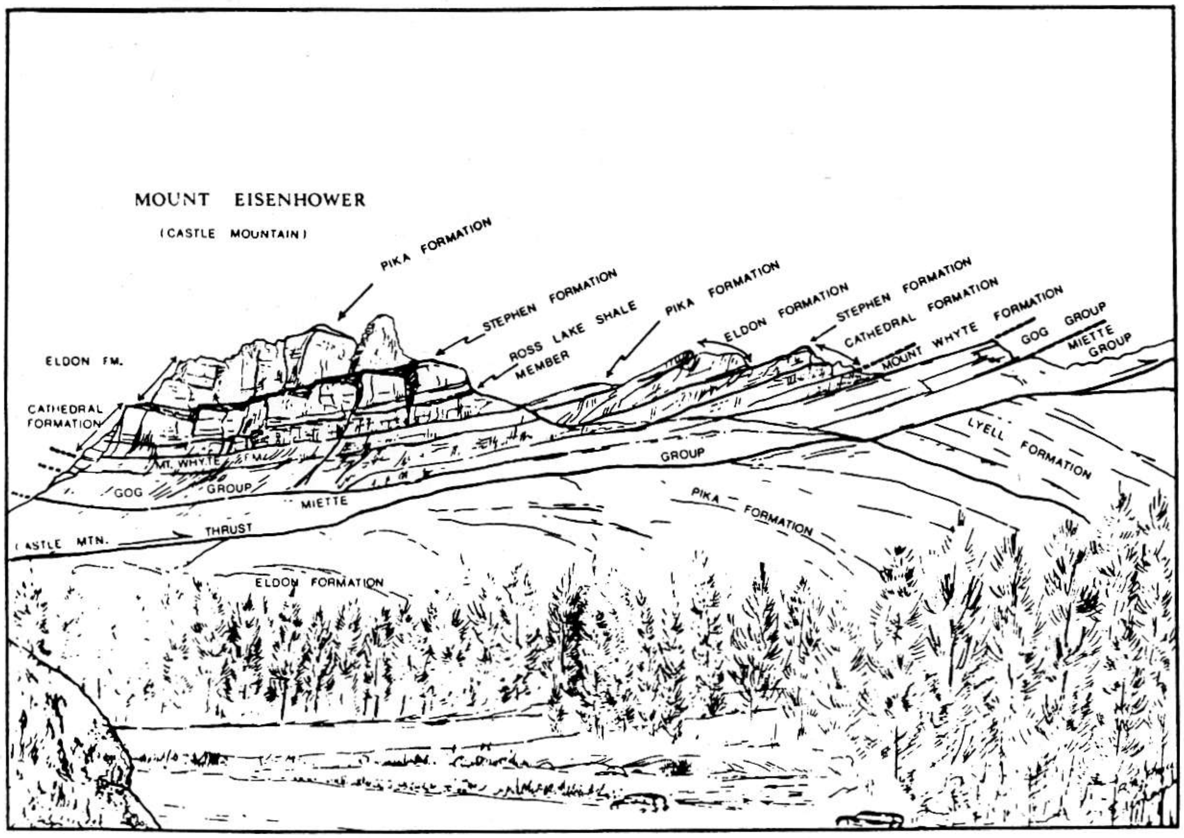


Figure 17: Northwestward view of the Sawback Range near Mt. Cory Sketch by R. A. Price.



Sketch by R. A. Price.

Figure 18: Northeastward view of Mt. Eisenhower (Castle Mountain) showing the Castle Mountain Thrust and the boundary between the Front Ranges and the Main Ranges (from Halliday and Mathewson, 1971).

at Sulphur Mountain (directly south) and the Bourgeau plate across the Sundance Range.

At the junction with Hwy 1A, the road crosses the Bourgeau thrust into the Sawback thrust plate. This is the last major thrust plate of the Front Ranges. It is a stack of carbonates, siltstones, shales and argillites of the Middle Cambrian Cathedral Formation through to the Triassic Sulphur Mountain Formation. Mt. Bourgeau is directly ahead. It is formed by carbonates of the Mississippian Rundle Group and is capped by a thin klippe of Middle Cambrian shales of the Mt. Whyte Formation. The klippe rests on the Simpson Pass thrust and is a relict of that plate.

The road swings to the northwest and travels obliquely to the strike of the strata. The Sawback range forms the eastern side of the valley. Two kilometres (1.2 mi.) beyond the junction with Hwy 1A is a good view to the north of Mt. Cory in the Sawback Range. This gives an almost complete section through the Sawback thrust plate (Figure 17). Here the miogeoclinal carbonates and shales are substantially thicker than their platformal counterparts in the McConnell thrust plate of the east Front Ranges outcrops east of Canmore. For example, the dolomites and siltstones of the Middle Cambrian Waterfowl Formation are 60 metres (200') thick here and only 30 metres (100') thick in the McConnell plate. Also, The Late Cambrian to Early Ordovician Formations which are absent in the McConnell plate are 825 metres (2700') thick here. (Price *et al.*, 1972)

At the junction of Hwy 1 and Hwy 93 (to Radium) the Simpson Pass thrust passes under the highway from the south and then follows it north up the valley. Also, about 2 kilometres south of the junction, the Castle Mountain thrust passes under the highway. This fault is the boundary between the Front Ranges and the Eastern Main Ranges.

Highway 93 turns west and away from Mt. Eisenhower (Castle Mtn.; Figure 18) and the end of the Front Ranges sub-province. The highway junction crosses the surface trace of the Castle Mountain thrust, the boundary between the Front Ranges (east) and the Main Ranges (west). As the Highway climbs out of the valley, it passes through Precambrian Miette Group shales and argillites.

At Vermillion Pass (1639 m.; 5377') the road cuts through quartzite of the Early Cambrian Gog Group. To the north and south, the mountains above the road are composed of Middle Cambrian carbonates (Cathedral, Eldon and Pika Fms.) and capped by shales and carbonates of the Arctomys and Waterfowl Formations.

As the road descends across the Continental Divide (2 km; 1.2 mi. west of Vermillion Pass) it enters the headwaters of the Kootenay River drainage system. The road follows the Vermillion River down to its confluence with the Kootenay River. The Continental Divide here is the boundary of British Columbia and Alberta.

At Tokumm Creek the highway crosses the facies change of the Middle Cambrian section. This is the boundary between the Eastern and Western Main Ranges sub-provinces. To the east is the platformal/reefal carbonate facies and to the west is the forereef/distal basin shale facies. This is the same facies change associated with the Kicking Horse Rim (Aitken, 1971) as that at Kicking Horse Pass (as described in Road Log 1). The shales and slates seen to the west are those of the Middle Cambrian Chancellor Formation. As the road swings to the south, parallel to the strike of bedding, the ridges on either side are cleaved Chancellor Formation. Some of the peaks to the west are capped by limestone and argillaceous limestone of the Late Cambrian Ottertail Formation. The cleavage here dips at about 45° and bedding is subhorizontal.

Where the road turns west the Simpson River joins the Vermillion River from the east. Just downstream from the confluence a small island in the river is formed by phyllites of the Chancellor Formation. The road now cuts upsection through the Chancellor Formation.

Two kilometres (1.2 mi.) past the bridge over Wardle Creek the highway cuts upsection into argillaceuos limestone and limestone of the Late Cambrian Ottertail Formation. Above the highway to the north is Mt. Wardle and the contact between the grey Ottertail Formation and the rusty Chancellor Formation is visible. To the southeast is Spar Mountain which is entirely Chancellor Formation.

Just beyond the view of Mt. Wardle the highway cuts into highly distorted argillite, phyllite and shale of the Cambro-Ordovician McKay Group. Note the well developed, steeply dipping cleavage. Bedding is subhorizontal.

The bridge across the Kootenay River roughly marks the boundary between the Western Main Ranges and the Western Ranges subprovinces. The road swings south again and parallels bedding. The broad Kootenay River valley is deeply filled by Pleistocene till and alluvium. The range of mountains to the east is composed of Ordovician Glenogle Formation shales on McKay Group shales over Ottertail Formation argillites and limestones. To the west is the Brisco Range. It is structurally complicated by overturned thrusts, transverse tear faults and tight folding, typical of the Western Ranges. The peaks are carbonates of the Ordovician-Silurian Beaverfoot Formation on Ordovician Mt. Wilson quartzite all overlying shales of the Glenogle Formation and McKay Group.

The Settlers Road junction is the turnoff to Baymag's Mt. Brussilof magnesite mine. The road to Mt. Brussilof works back through the section just described but no outcrops are visible until near the mine. Those outcrops are shales and argilliaceous limestones of the Chancellor Formation. Settlers Road extends down the Kootenay River to Canal Flats, 72 kilometres (45 mi.) south. Early settlers and explorers crossed the Rockies through Vermillion Pass, Simpson Pass at the head of the Simpson River and Whiteman and Redman Passes (now defunct) at the head of the Cross River. These all lead down to the Kootenay River which joins with the Columbia River Valley

(Rocky Mountain Trench) at Canal Flats. Kicking Horse Pass to the north was the major pass but for travel to the south these other passes were used to varying degrees. The north and south Kananaskis Passes crossed the Rockies further south into the Palliser River which also joins the Kootenay River. Only the Kicking Horse and Vermillion Passes are used as transportation corridors. The others are only used for recreation.

STOP 2-1: Mt. BRUSSILOF MAGNESITE MINE;

Location

The Mount Brussilof deposit is located approximately 35 kilometres northeast of Radium Hot Springs. It is accessible from Highway 93 by an all-weather unpaved road (Figure 1).

History and Production

The Mount Brussilof deposit was discovered during regional mapping by the Geological Survey of Canada (Leech, 1965). Baykal Minerals Ltd. and Brussilof Resources Ltd. staked and explored the deposit. In 1971, Brussilof Resources Ltd. and Baykal Minerals Ltd. merged to form Baymag Mines Co. and in 1979, Refratechnik GmbH. acquired Baymag Mines Co. (MacLean, 1988). In 1980, proven and probable geological reserves were reported as 9.5 million tonnes grading over 95 percent magnesia (calcined product) and 13.6 million tonnes of 93 to 95 percent magnesia (calcined product). Possible reserves were estimated at 17.6 million tonnes averaging 92.4 percent magnesia in calcined product (Schultes, 1986). Since 1982, the company has produced high quality caustic magnesia and fused magnesia (Coope, 1989). Magnesite from the Mount Brussilof deposit was also used in the production of magnesium metal in Magcan's "semi-experimental" plant located near High River, Alberta (Couturier, 1989).

Stratigraphy and Lithology

The Mount Brussilof deposit is located in the Foreland Fold and Thrust Belt, east and adjacent to the Cathedral Escarpment (Simandl and Hancock, 1991). The carbonate rocks east of the escarpment host magnesite mineralization. The stratigraphic relationship between rocks east of the Cathedral Escarpment, and their deeper water equivalents to the west in the Chancellor Formation is described by Aitken and McIlreath (1984) and Stewart (1989). The stratigraphy east of the Escarpment, where all known occurrences of magnesite and associated sparry carbonate other than veins of calcite or dolomite a few centimetres thick, are located is schematically illustrated in Figure 19. The stratigraphic formations are described below in order from oldest to youngest.

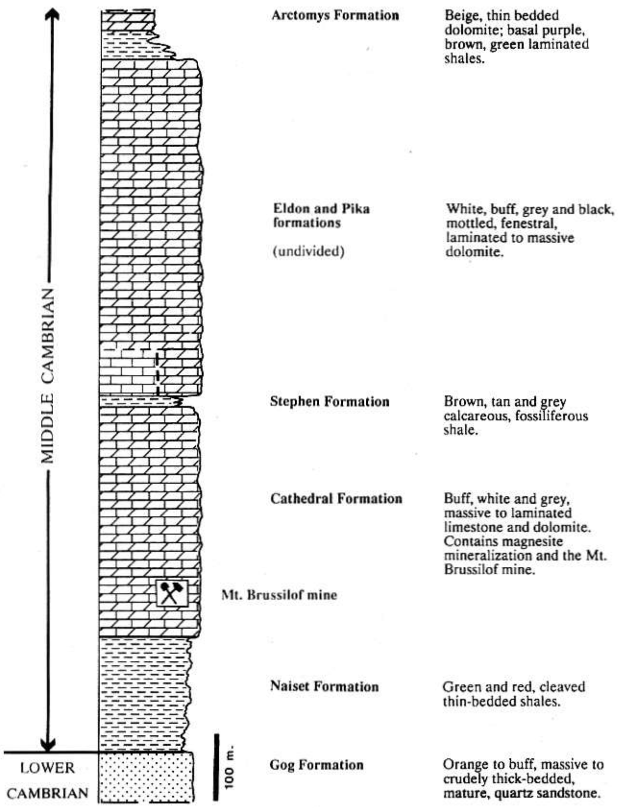


Figure 19: Composite section of the stratigraphy in the Mt. Brussilof area (from Simandl and Hancock, 1991).

OPPOSITE: Figure 20: Geology of the Mt Brussilof area (from Simandl and Hancock, 1991).

LEGEND

Middle Cambrian

7 **Chancellor Formation**: Argillaceous limestone and shales. Basinal equivalent of the Pika, Eldon, Stephen and Cathedral formations

6 **Arctomys Formation**: Purple and red shales with beige dolomite. Overlain by the Waterfowl and Sullivan formations.

5 **Eldon and Pika formations** (undivided): Buff, grey and black massive dolomite, argillaceous dolomite and limestone.

4 **Stephen Formation**: Brown and tan shales. Fossiliferous.

3 **Cathedral Formation**: Buff and grey dolomite and limestone

2 **Naiset Formation**: Thin-bedded, brown and green shale.

Lower Cambrian

1 **Gog Formation**: Massive, tan, quartz sandstone.

SYMBOLS

Open pit

Magnesite

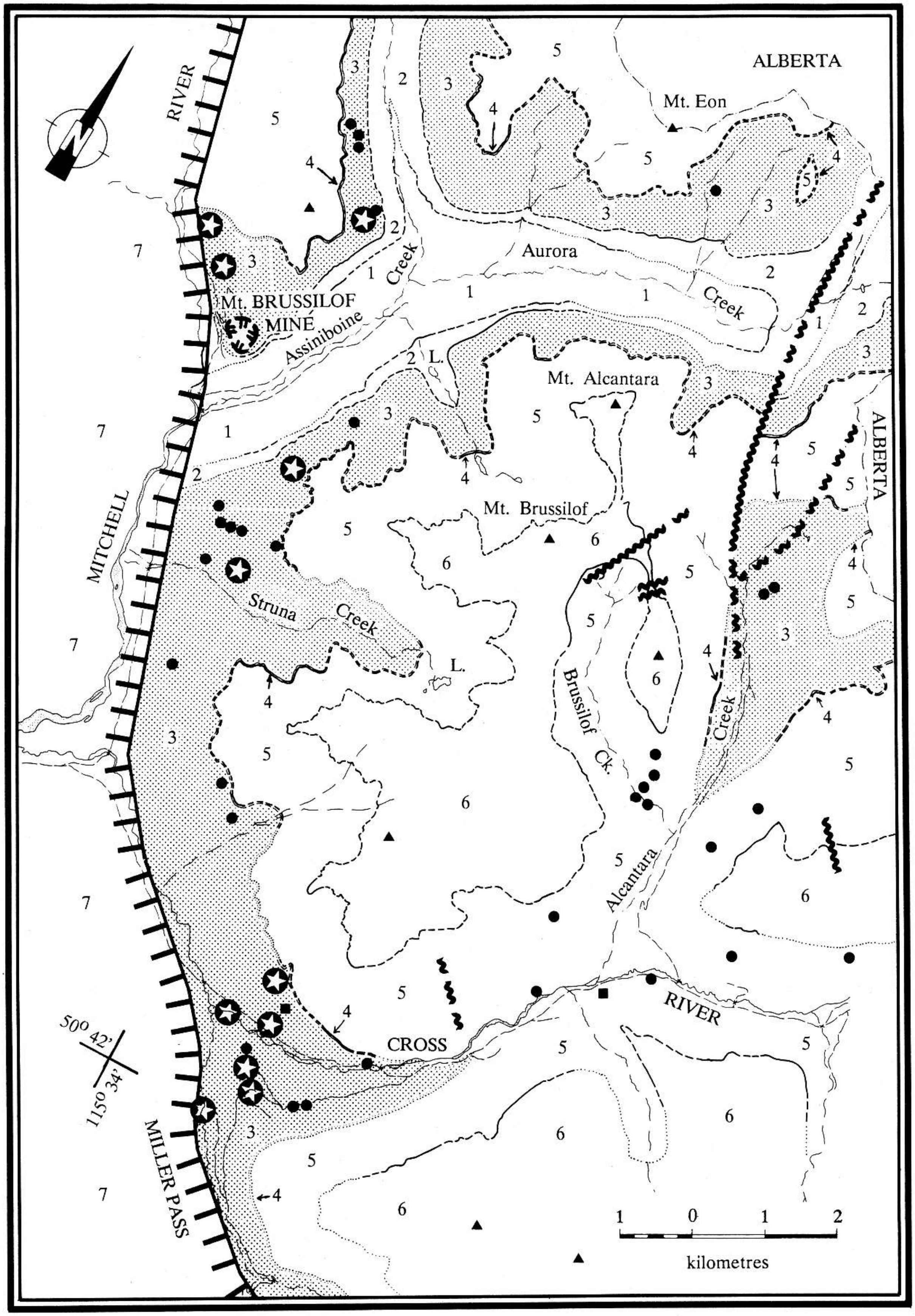
Sparry carbonate

Magnesite (Leech, 1966)

Cathedral Escarpment

Geological contact: defined, approximate, assumed

Fault: defined, approximate


ALBERTA
Mt. Eon
RIVER
Aurora
Creek
Mt. BRUSSILOF
MINE
Assiniboine
L.
Mt. Alcantara
ALBERTA
Mt. Brussilof
MITCHELL
Struna
Creek
L.
Brussilof
Ck.
Creek
Alcantara
RIVER
CROSS
50° 42'
115° 34'
MILLER PASS
kilometres

The Gog Formation is a rusty, grey or buff, medium to coarse-grained, massive to decimetre scale-bedded Early Cambrian sandstone more than 250 metres thick. The Naiset Formation is consists of millimctre to centimetre-scale bedded, brown and green Middle Cambrian shale overlying the Gog Formation. It is 65 to 170 metres thick, characterized by blue-green chlorite spots and a well developed cleavage moderately oblique to bedding. Near the Cathedral Escarpment this shale may be grey and partially converted to talc and serpentine.

The Cathedral Formation, which hosts the magnesite deposits, is also Middle Cambrian in age. It is about 340 metres thick and consists of buff, white and grey limestones and dolomites. A wide variety of sedimentary and diagenetic textures are preserved. These include laminations, ripple marks, intraformational breccias, *yoholaminites* a possable cryptalgal mat as defined by (McIlreath and Aitken, 1976), algal mats, pisoliths and ooliths, fenestrae, burrows and grapestone textures, polygonal dessication mud eracks and spindle syneresis cracks. Pyrite is common either as disseminations, pods or veins.

The Stephen Formation consists of tan to grey, thinly bedded to laminated shale about 16 metres thick, with a cleavage subparallel to bedding. It is of Middle Cambrian age and contains abundant fossil fragments and locally well- preserved trilobites and inarticulate brachiopods. Near the sparry magnesite deposits this shale may become "soapy" probably due to the development of talc or serpentine. All formations are well exposed except the recessive Stephen Formation. It was not observed in the southern part of the map area (Figure 20) and it is not clear if this lack of outcrops is due to its recessive nature or non-deposition.

The Eldon and Pika formations can not be lithologically subdivided in the map area. The lowermost beds of the Eldon Formation immediately overlying the Stephen Formation are black limestones, approximately 50 metres thick. This basal unit is very distinctive, containing millimetre to centimetre scale argillaceous layers that weather to a red, rusty colour. These formations can not be readily distinguished from the Cathedral Formation, except by fossil evidence. The Arctomys Formation, also Middle Cambrian in age, is characterized by green and purple shales and siltstones interbedded with beige, fine-grained dolomite. Mud cracks and halite crystal prints are commonly preserved.

Structure

The rocks west of the Cathedral Escarpment (Figure 20), correspond to the Chancellor Group and are strongly deformed and structures strike northeast. Deformation is characterized by numerous small scale and large scale folds, of metre to kilometre wavelength, overturned to the east with subhorizontal fold axes oriented 160°. A well-developed steeply dipping cleavage striking 160° and minor thrust faults dipping slightly to the west are other typical features. Along the Cathedral Escarpment, cleavage is subvertical and closely spaced .

East of the Cathedral Escarpment, cleavage is generally absent in the carbonates (Cathedral, Eldon and Pika formations), well developed in the Stephen Formation shale and strongly developed in the Naiset Formation shale. The rocks outcropping immediately east of the Cathedral Escarpment in the proximity of the mine strike 168°/21°SW. Elswhere bedding is generally subhorizontal and characterized by minor, upright, open folds. Several subvertical faults oriented north-south were observed east of the mine site. These faults have apparent vertical displacements of tens to hundreds of meters. In the northeastern corner of the map area, deformation in the Naiset Formation is similar to that of the Chancellor Formation due to a thrust fault that is exposed farther east (Figure 20).

Magnesite Deposits

Sparry carbonate rocks occur within Rim facies of the Cathedral, Eldon and Pika formations (Figure 19). They consist mainly of coarse dolomite and magnesite crystals in varying proportions. Magnesite-rich sparry carbonates are restricted to the Cathedral Formation where they form lenses, pods and irregular masses. Parts of the Cathedral Formation are entirely altered to sparry magnesite, forming deposits of economic interest. Sparry carbonates are separated from limestone by light grey, massive dolomite, which may contain needle-shaped quartz crystals. The contacts between sparry carbonate masses and fine-grained dolomite are sharp and may be concordant or discordant.

Magnesitic sparry carbonate is usually white or light grey in colour and buff when weathered. It consists of either regularly spaced, alternating white and grey magnesite layers, randomly oriented centimetre-scale white magnesite crystals or a mixture of light grey and white stubby magnesite crystals. Common impurities in magnesite ore are isolated rhombohedral dolomite crystals, calcite veins, pyrite veins, subvertical fractures filled by a mixture of beige ankerite, calcite and chlorite, coarse radiating or single quartz crystals and coarse disseminated pyrite pyritohedrons or octahedrons. Tetrahedrite, malachite, fersmite, phlogopite, talc and palygorskite were found in lab samples from the mine. Boulangerite, huntite and brucite were reported from laboratory analysis by White (1972) and pentlandite, leuchtenbergite and muscovite were reported by Schultes (1986).

Where fine-grained dolomite is not entirely converted to magnesite, replacement features such as coarse, white carbonate crystals growing perpendicular to fracture planes, partings and lenses of fine-grained dolomite enclosed by sparry carbonates bipolar growths of zoned magnesite crystals and magnesite pinolite rosettes. All these features as well as magnesite "zebra rock" are interpreted as replacement textures. Sparry dolomite consists mainly of dolomite rhombs forming lenses, veins or irregular masses in fine-grained dolomite. It occurs at the same stratigraphic horizons and contains the same impurities as sparry magnesite. Dolomite veins cut magnesite, however, magnesite veins were never observed to cut dolomite.

Chemistry of Carbonate Rocks:

The major constituents of the carbonate rocks in the area are MgO and CaO. The magnesium content of the carbonate rocks varies continuously from dolomite to magnesite. Coarse and sparry carbonates have higher magnesia contents than fine-grained carbonates. Typical analyses of magnesite ore from the open pit are given in the following table.

Sample No.	P34a	P10a	P44a	P53	P11c
MgO	48.00	47.00	48.12	47.74	47.89
CaO	0.82	1.41	1.02	0.85	0.87
Fe_2O_3	0.35	0.38	0.37	0.51	0.42
P_2O_5	<0.02	0.03	0.01	0.02	0.01
SiO_2	<0.01	0.10	<0.01	<0.01	<0.01
TiO_2	<0.01	<0.01	<0.01	<0.01	<0.01
Al_2O_3	<0.01	<0.01	<0.01	<0.01	<0.01
MnO	0.01	0.01	0.01	<0.01	0.01
Na_2O	0.01	<0.01	<0.01	<0.01	0.00
K_2O	0.03	0.02	0.01	0.01	0.00
LOI	51.96	51.44	51.86	51.88	52.02
Total	101.23	100.42	101.44	101.06	101.31

weight per cent

Simandl and Hancock: unpublished data.

Elements of the genetic model.

Secondary porosity features, replacement textures, magnesite ore - host rock contacts, spatial distribution of sparry carbonate rocks, paragenesis and absence of fine-grained magnesite suggest that magnesite postdates early diagenesis of the Cathedral Formation and probably deposition of the Stephen, Eldon and Pika formations as well. Widespread dolomitization and subsequent fracturing and brecciation contributed significantly to an increase in porosity. Some of the fracturing may be due to reactivation of a pre-Cathedral Escarpment fault or to a difference in competence of deep and shallow-water sediments during the post-Middle Cambrian tectonic activity. However, most of the breccias were probably produced by partial dissolution and collapse of the carbonate host rock caused by incursion of meteoric water or hydrothermal solutions.

Fluid responsible for crystallization of coarse sparry carbonates reacted with dolomitized, permeable and fractured reef facies situated along the Cathedral Escarpment and moved up-dip along permeable zones. The fluid cooled and evolved chemically along its path due to interaction with the dolomitic host rock. Predictions based on this model suggest that the highest grade magnesite deposits should be located along the edge of the Cathedral Escarpment within the reef facies. Lower-grade sparry magnesite and sparry dolomite deposits sould be located either at a greater distance up-dip, eastward from the Cathedral Escarpment along the same permeable zones or adjacent to the Escarpment but in zones of lesser permeability (Simandl and Hancock, 1991). According to this model, magnesite formation represents the extreme ease of dolomitization.

Summary and conclusions:

The Mount Brussilof deposit is an exceptional, large and high-grade deposit. Besides selective open pit mining no upgrading is required to produce material suitable for production of high quality caustic and fused magnesia or magnesium metal. The Mount Brussilof area has excellent potential to host other high-grade magnesite deposits and lower-grade/large-tonnage "magnesitic dolomite" deposits.

Settlers Road and Hwy 93 Junction:

From the junction the highway climbs out of the Kootenay River valley. Road cuts expose sheared McKay Group argillites and phyllites. Bedding is overturned to the west and dips steeply to the east, subparallel to the cleavage. Quartz veining is common in most outcrops.

As the road crests at Sinclair Pass - Olive Lake (1486 metres; 4875') it crosses the Stanford Fault. It is a normal fault with the east side downdropped placing Ordovician-Silurian Beaverfoot Formation carbonates against phyllites and argillites of the Cambro-Ordovician McKay Group. Going down from the lake, the road cuts downsection through the Beaverfoot Formation carbonates in gradational contact with black shales of the Ordovician Glenogle Formation into shales and argillites of the McKay Group. Travelling down the hill along the Sinclair Creek Valley the road goes through a complex sequence of the Cambrian to Silurian strata. Thrusting, normal and overturned, and tight folding cause repetition of the Beaverfoot, Mt. Wilson and Glenogle formations and the McKay Group. Most of the outcrops seen are either Beaverfoot Formation limestones or McKay Group argillites and argillaceous limestone.

Just past the Iron Gates tunnel and parking lot is a large bluff of crushed and brecciated rock , buff to pink weathering with some Fe-oxide staining, on the right side (north) of the road. This is the Redwall fault zone which juxtaposes Middle to Late Cambrian Ottertail Formation dolomites (west) against Ordovician-Silurian Beaverfoot Formation dolomites (east). This normal fault extends from just north of Radium south along the Stanford Range where it forms a large, discrete block against the Rocky Mountain Trench.

Radium Hot Springs Baths:

The hot springs here have been used for centuries, originally by the aboriginal peoples. In the early 1900's they were discovered by whites. When the Banff-Windermere Highway (Hwy 93) was constructed in the 1920's the springs were developed into a small spa resort. As their popularity increased so did the baths until finally in the early 1950's the present complex was constructed. The temperature of the springs is 38°C (100°F). The hot spring water emanates from shatter zones in a thin sliver of Ottertail Formation carbonates. These are probably due to a fault splay of the Redwall fault. Water from the springs is of meteoric origin, percolates down the fault and is heated at depth.

Sinclair Canyon:

The Canyon is a narrow gap through which Sinclair Creek flows. On entering the east side of the canyon, outcrops are subvertically dipping carbonates and argillites of the McKay Group. The zone of brecciation and red Fe-oxide staining is the locus of two intersecting faults. One dips 30° west and the other 55° east. The red stained rocks on the western side are carbonates of the Beaverfoot Formation. Once through there are well bedded fluvial gravels (Pleistocene?) as the road approaches the park gates.

Radium Hot Springs

The town of Radium Hot Springs is situated on the edge of the Rocky Mountain Trench, the western limit of the Rocky Mountains. The Purcell thrust extends along the valley on the east side at the base of the low hills. The strata across the valley are Precambrian to Early Cambrian clastics of the Purcell Mountains.

Turn north at the junction at Radium Hot Springs toward Golden. Highway 95 travels north along the eastern side of the Rocky Mountain Trench.

SILICA IN THE SOUTHERN ROCKY MOUNTAINS

GEOLOGY OF THE Mt. WILSON FORMATION: **see page 13**

Horse Creek

Horse Creek, the site of the Nicholson silica quarry is approximately 88 kilometres (55 mi.) north of Radium Hot Springs (Figure 1). The shipping facility is to the west at track side and the quarry is 2 kilometres (1.2 mi.) east up the creek.

STOP 2-2: Nicholson Silica;

The Nicholson (Hunt) silica quarry is located 11 kilometres (6 mi.) southeast of Golden on Horse Creek. The quarry is in a fault block of Mt. Wilson Formation quartzite. The operation mines ferrosilicon grade massive quartzite. Mining and processing is done by Bert Miller Trucking and Contracting. All product is shipped to Silicon Metaltech in northern Washington, U.S.A.

The Nicholson quarry is situated in a fault block bounded by normal faults to the north and south and a thrust to the west (Figure 21). Other contacts are conformable with the over and underlying strata. The faults are part of a series of tear faults associated with the dominant thrusts. Thrusting has caused bedding to be overturned, thns tops are downslope in this block. Within the block the quartzite is overlain by shales and argillaceous limestones of the Whisky Trail Member of the Ordovician-Silurian Beaverfoot Formation. Underlying the quartzite are shales and siltstones of the upper Ordovician Glenogle Formation. The quartzite unit is about 400 metres (1200') wide and 2300 metres (7000') long along a northeast trend.

The quartzite is white to buff, mature, massive and silica cemented. Quartz grains are well rounded and range from 0.12 to 0.85 millimetres diameter with the majority between 0.25 to 0.50 millimeters. Analysis of two grab samples of clean crushed ore yielded the following values:

SiO_2	$Al2O_3$	MgO	K_2O	Fe_2O_3	CaO	Na_2O	TiO_2	LOI
99.85	0.10	<.05	<.10	0.04	<0.05	<0.10	<.05	0.32
99.90	0.10	0.05	<.10	0.04	<.05	<.10	<.05	0.31

weight per cent (Foye, 1987).

The Nicholson mine was developed in the late 1970's and production began in 1980. The property is owned by Silicon Metaltech (previously by Hanna Mining Co.) and operated by Bert Miller Trucking and Contracting Ltd. Mining is by open pit and the quartzite is crushed, washed and sized at a trackside facility at the mouth of Horse Creek. The lump silica is shipped in bulk to Silicon Metaltech's ferrosilicon facility at Rock Island near Wenatchee, northeast Washington, U.S.A. The ferrosilicon grade silica is the only product from the mine. Annual production varies from 30 000 to 60 000 tonnes (33,000 to 66,000 tons) as demanded and 40 000 tonnes (44,000 tons) were shipped in 1990.

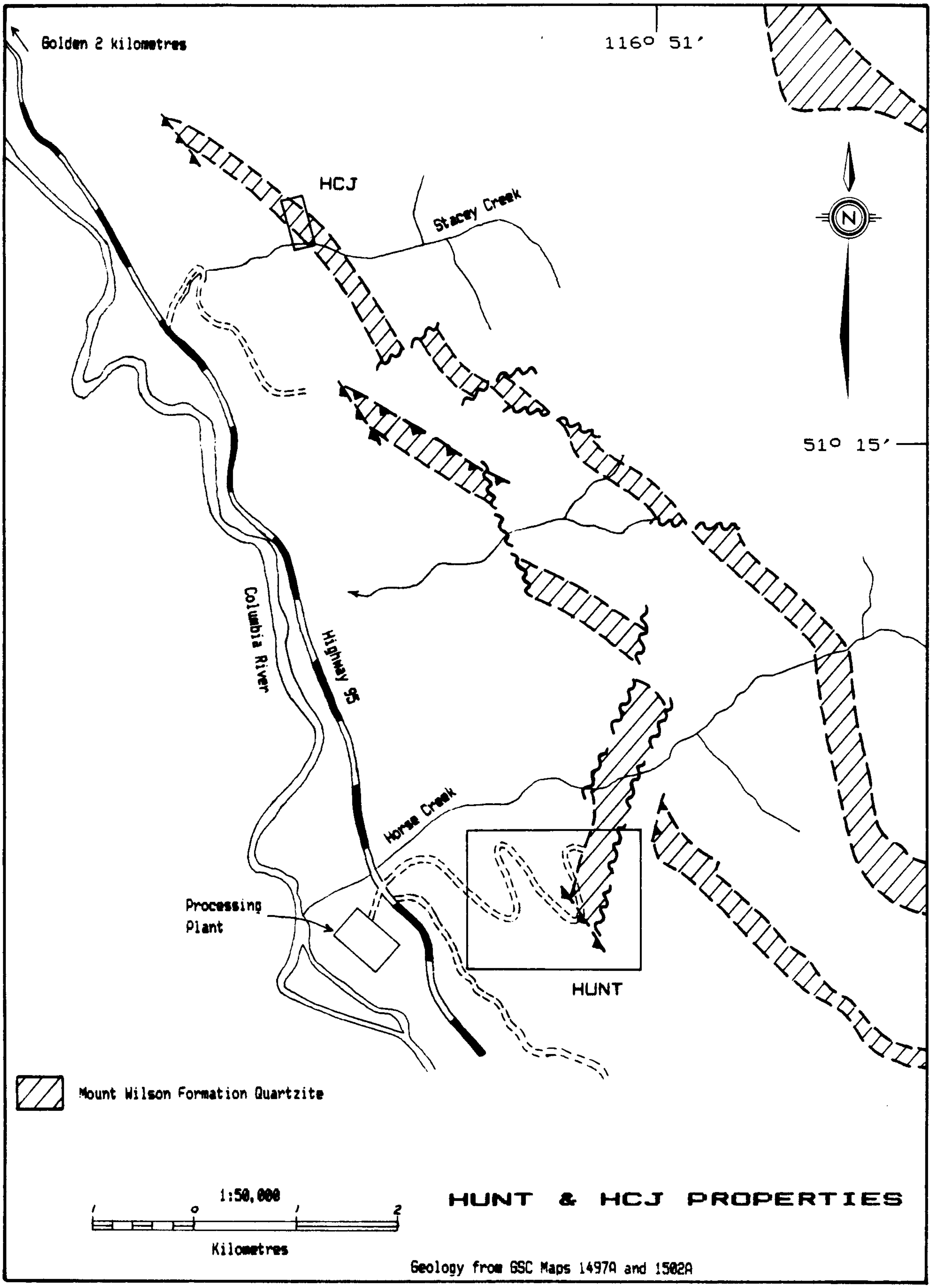


Figure 21: Location of the Nicholson silica quarry and the Mt. Wilson Formation quartzite (from Foye, 1987).

RETURN TO BANFF: Via Hwy 1 and read Road Log 1 in reverse order from Golden to Banff. Otherwise return via Radium and the Kootenay Parkway (Hwy 93).

Acknowledgments:

This paper is a compilation of previous field guides, company property assessment work and Ministry mapping in the area. I thank the authors who prepared field guides and road logs for the Banff - Golden - Radium area. Also, the property descriptions include information from mapping by British Columbia Geological Survey staff and contractors as well as company geologists. The Canada - British Columbia Mineral Development Agreement (1985-1990) contributed support and funding to Geological Survey Branch programs in this area.

Specifically I thank Baymag Mines Ltd., Westroc Industries Ltd., Mountain Minerals Company Ltd. and Bert Miller Trucking and Contracting Ltd. These companies kindly opened their sites for examination on the field trips, provided information included in this guide and contributed financially to support the field trip program.

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