GEOLOGY AND MINERAL DEPOSITS OF PURCELL SUPERGROUP IN YAHK MAP AREA, SOUTHEASTERN BRITISH COLUMBIA (82F/1)

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INTRODUCTION

The East Kootenay project was initiated to provide new 1:50 000-scale geological maps and stratigraphic studies for base metal exploration and land-use planning processes. The Yahk - Creston area has significant potential for undiscovered base metal deposits. It is underlain by Lower Purcell Supergroup rocks, a sedimentary rock succession that contains a number of significant deposits, including the Sullivan orebody, one of the world's largest massive sulphide deposits; the Troy mine (Spar Lake) and related copper-silver deposits in western Montana; and the Sheep Creek copper-cobalt deposit, also in Montana. In the last five years there have been a number of new discoveries in the Purcell Supergroup, including the Canam, Darlin, David, Dodge, Fors, and Star prospects. These new discoveries of Aldridge-hosted mineralization, coupled with established infrastructure, make this area in southern British Columbia attractive for exploration.

Geological mapping in the Creston area is dated; the most recent available maps were published for the Nelson East Half in 1941 by the Geological Survey of Canada (Rice, 1941). Farther east, the Fernie West Half map area was initially mapped by Daly (1912a), Schofield (1915) and Rice (1937), and later, Leech (1960) completed a 1:126 720-scale map (1" = 2 mile). More recent mapping has been published to the east and north by Höy (1993) and Reesor (1981, 1983, 1993) and south of the international boundary by Harrison *et al.* (1992) and Aadland and Bennett (1979; Figure 1).

Field work in 1993 focused on the Yahk map area (82F/01), where recent exploration activity has included diamond drilling on the Star, Eng and Goatfell properties. A six-week field season has generated a preliminary geological map of most of the Yahk sheet, with only limited coverage of the western third of the map area. Fill-in traverses and measured sections are

planned for the 1994 field season, in addition to extending the area of mapping to the west of Creston.

The Yahk map area is bisected by Highway 3, which follows the broad valleys of the Goat River, Kitchener Creek and the Moyie River. Access on logging roads and four-wheel-drive mineral exploration roads is good throughout the area. Topography is subdued, with the exception of the "Ramparts" east of Creston, where west-facing cliffs rise to peaks in excess of 2100 metres from the Creston valley floor at about 640 metres elevation. Extensive second and third-growth forest cover reflects widespread logging activity in the early 1900s. Outcrops are abundant on ridges above 1800 metres elevation, but are otherwise sparse in most of the map area. Lateral continuity of mappable units and only minor folding allows extrapolation based on widely spaced traverses.
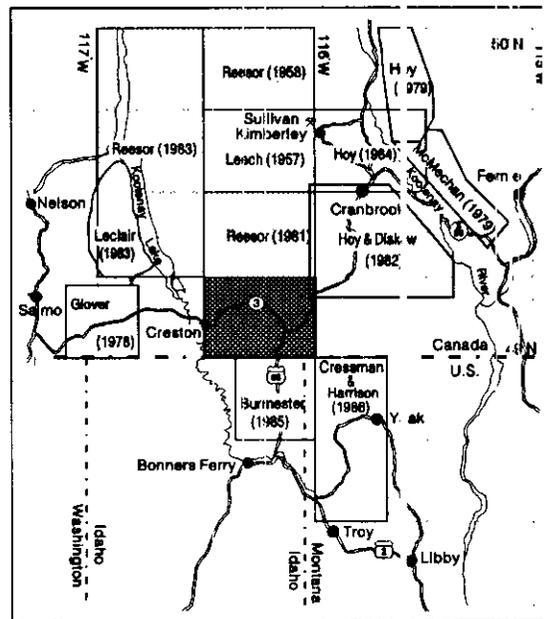

Figure 1. Location of the East Kootenay project map area (dark cross-hatched rectangle) relative to areas of previously published geologic maps. The 1:250 000 scale map coverage is not shown but includes: Fernie West-half (82F/west) -- Leech (1958, 1960), Höy and Carter (1988), Höy (1993); Nelson East-half (82G/east) -- Rice (1941), Reesor (1981, 1983); Sandpoint (82C) -- Aadland and Bennett (1979); Kalispell (82B) -- Harrison *et al.* (1992).

This project is designed to collaborate with and contribute to the Sullivan-Aldridge project -- a multidisciplinary research effort involving the Geological Survey of Canada, United States Geological Survey, Geological Survey Branch, four universities, Cominco Ltd. and other companies.

GEOLOGICAL SETTING

Strata in the pericratonic Proterozoic Purcell (Belt in the United States) Supergroup basin are preserved in an area 750 kilometres long and 550 kilometres wide (130 000 km^2). The rocks extend from southern British Columbia through eastern Washington, Idaho and western Montana (Figure 2). In British Columbia, the Middle Proterozoic strata of the Purcell Supergroup are exposed in the Purcell anticlinorium, a broad, northerly plunging structural culmination flanked by Paleozoic strata in the western part of the Foreland Belt (Figure 3). The stratigraphic nomenclature for the Purcell Supergroup varies across the basin. The East Kootenay project adopted divisions for the Nelson East Half based on Reesor (1983) and Höy (1993); correlative units in adjacent parts of the basin are illustrated in Figure 4.

Paleozoic and Mesozoic rocks of the Rocky Mountain fold and thrust belt lie mainly east of the Rocky Mountain Trench, while Late Proterozoic and younger rocks of the Kootenay Arc overlie the western extent of the exposed Purcell Supergroup rocks in Canada. Jurassic to Tertiary plutonic and gneissic rocks are exposed to the northwest (Bayonne batholith) and southwest (Kaniksu batholith, West Creston gneiss and Corn Creek gneiss) of the Creston area (Archibald et al., 1984; Figure 3).

The Purcell (Belt) basin was the site of extension, crustal attenuation and possible intracratonic rifting in the Middle Proterozoic (circa 1500 Ma). This initiated the accumulation of 10 to 20 kilometres of sedimentary and mafic intrusive rocks in a confined basin. Paleotectonic reconstruction places the basin within a large land mass (Laurentia -- a part of Rodinia) at equatorial latitudes (Hoffman, 1991). Modern anologues could be the Black Sea, Red Sea and Gulf of California or fresh water Lake Baikal (Turner et al., 1993).

The environment during the Proterozoic was significantly different than at present. The earth rotated faster which would have produced a stronger Coriolis force, and it had lower wind speeds , less precipitation and colder polar regions (Hunt, 1979). The atmosphere had less oxygen (about 1% of today's level) and more carbon dioxide (Cressman, 1989). The landscape was devoid of most forms of life including rooted plants that stabilize modern soils. The lack of living organisms to bioturbate sediment means exceptional preservation of primary sedimentary structures.
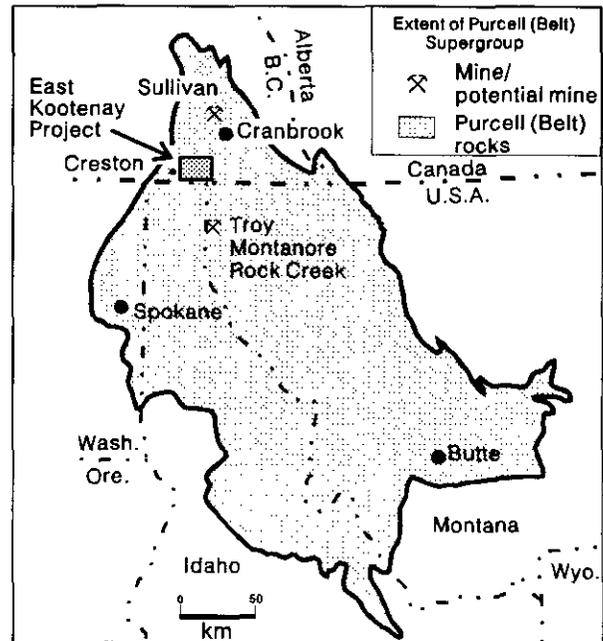

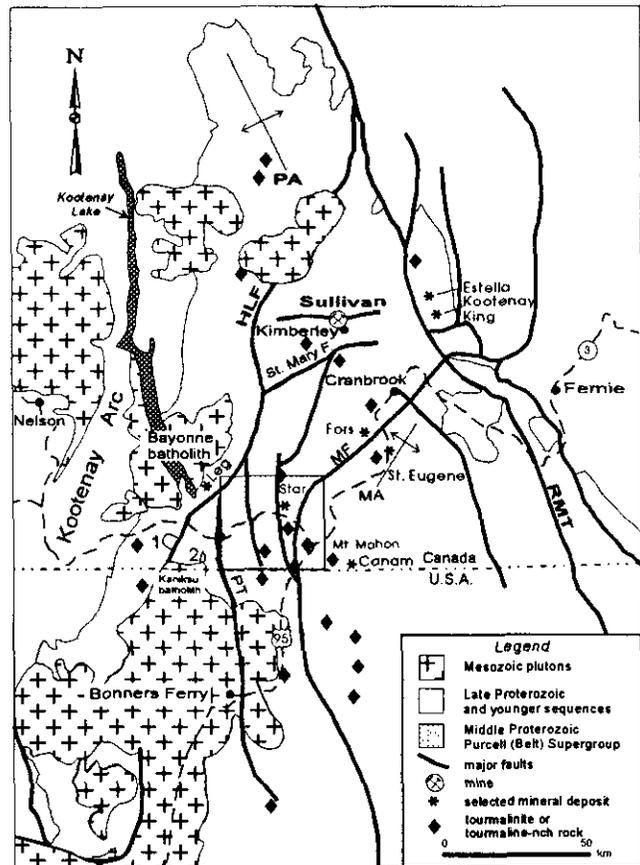Figure 2. Extent of Purcell (Belt) strata relative to East Kootenay project area.

Figure 3. Purcell (Belt) Supergroup distribution and major faults in southern British Columbia and northern Washington, Idaho and Montana. Rectangle marks the project area. HLF = Hall Lake fault, MA = Moyie anticline, MF = Moyie fault, PA = Purcell anticlinorium, PT = Purcell Trench, RMT = Rocky Mountain Trench, 1 = Corn Creek gneiss, 2 = West Creston gneiss. Modified after Wheeler and McFeely, 1991. Tourmaline locations after Slack (1993).
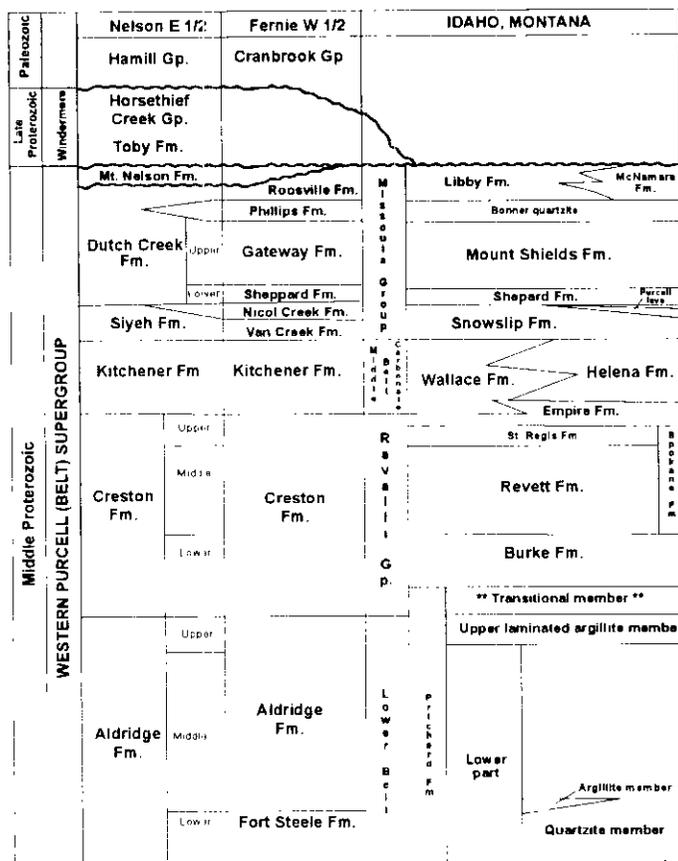
	Nelson E 1/2	Fernie W 1/2	IDAHO, MONTANA	
Paleozoic	Hamill Gp.	Cranbrook Gp		
Late Proterozoic / Windermere	Horsethief Creek Gp. / Toby Fm.			
Middle Proterozoic / WESTERN PURCELL (BELT) SUPERGROUP	Mt. Nelson Fm.	Roosville Fm.	Libby Fm.	McNamara Fm.
		Phillips Fm.	Bonner quartzite	
	Dutch Creek Fm. (Upper)	Gateway Fm.	Mount Shields Fm.	
	(lower)	Sheppard Fm.	Shepard Fm.	Purcell lava
	Siyeh Fm.	Nicol Creek Fm. / Van Creek Fm.	Snowslip Fm.	
	Kitchener Fm	Kitchener Fm.	Wallace Fm. — Helena Fm. / Empire Fm.	
	Creston Fm. (Upper / Midle / Lower)	Creston Fm.	St Regis Fm / Revett Fm. / Burke Fm.	
			** Transitional member **	
			Upper laminated argillite member	
	Aldridge Fm. (Upper / Middle / Lower)	Aldridge Fm.	Lower part / Argillite member / Quartzite member	
		(Low) Fort Steele Fm.		

Figure 4. Table of formations for the Purcell Supergroup and their correlative units within the western Belt Supergroup of Idaho and Mortana. Nelson East Half from Reesor (1981, 1983); Fernie West Half from Leech (1958); Idaho and Montana from Harrison et al. (1992) and Harrison and Cressman (1993). ** The transitional member of the Prichard Formation (Cressman, 1989) correlates with lower Creston of the Yahk map area.

Purcell sedimentation may have ended with the onset of the East Kootenay orogeny, a contractional tectonic event between 1350 and 1300 Ma (McMechan and Price, 1982). A Late Proterozoic extensional event, the Goat River orogeny (circa 800 Ma), resulted in continental rifting and initiation of the Cordilleran miogeocline with deposition of the Windermere Supergroup (Höy, 1993). The Laramide orogeny (100-70 Ma) produced the dominant folds and thrust faults in the map area. Strata of the Purcell anticlinorium were transported to the east on west-dipping imbricate thrust faults that extend into cratonic basement. Reactivation of some of these faults to form listric normal faults during an Eocene extension event is locally important, especially southwest of the map area (Newport fault and Priest River complex; Harms and Price, 1992).

STRATIGRAPHY

The map area is underlain almost entirely by the Purcell Supergroup, a thick succession of siliciclastic and lesser carbonate rocks of Middle Proterozoic age (Figure 5). The Aldridge Formation (Schofield, 1915), the lowermost division of the Purcell Supergroup and the dominant unit in the map area, is more than 3500 metres thick. The correlative Prichard Formation in western Montana reaches a thickness of at least 6000 metres, including the gabbro sills (Cressman, 1985). The lower and middle Aldridge (Prichard) formations differ from the overlying Purcell Supergroup strata in that they were deposited in deeper water as turbidites, are intruded by numerous gabbro sills, contain extensive and distinctive marker units and have disseminated pyrrhotite throughout (Cressman, 1989). The Creston Formation (about 2300 metres thick; Reesor, 1983) gradationally overlies the Aldridge Formation. It is exposed in the footwall of the Moyie fault in the eastern part of the Yahk map area, on the west side of the Carroll Creek/Kid fault in the central part, and in the northwest corner of the sheet. The overlying Kitchener Formation includes the lowermost significant carbonate accumulations in the Purcell succession. A small, possibly fault-bounded block of Kitchener Formation is exposed in the northeast part of the map area in the footwall of the Moyie fault.

ALDRIDGE FORMATION

The Aldridge Formation comprises a thick succession of dominantly turbiditic silicic clastic rocks, including quartz wackes and arenites, siltstones and mudstones deposited in a middle to lower submarine fan setting. Although greenschist grade metamorphic mineral assemblages in these rocks are consistent with the use of metamorphic rock names (quartzite, siltite and argillite), sedimentary rock names are retained here because of the low level of deformation. East of the Yahk area, the Aldridge Formation has been subdivided into three units, the lower, middle and upper Aldridge, based on lithological characteristics and stratigraphic position. Mineralogic and chemical data for the Aldridge Formation are given by Edmunds (1977a). The lower and middle Aldridge are intruded by the Moyie sills, a suite of gabbroic sills which have been interpreted by Höy (1989) to be coeval with sedimentation in the Aldridge.
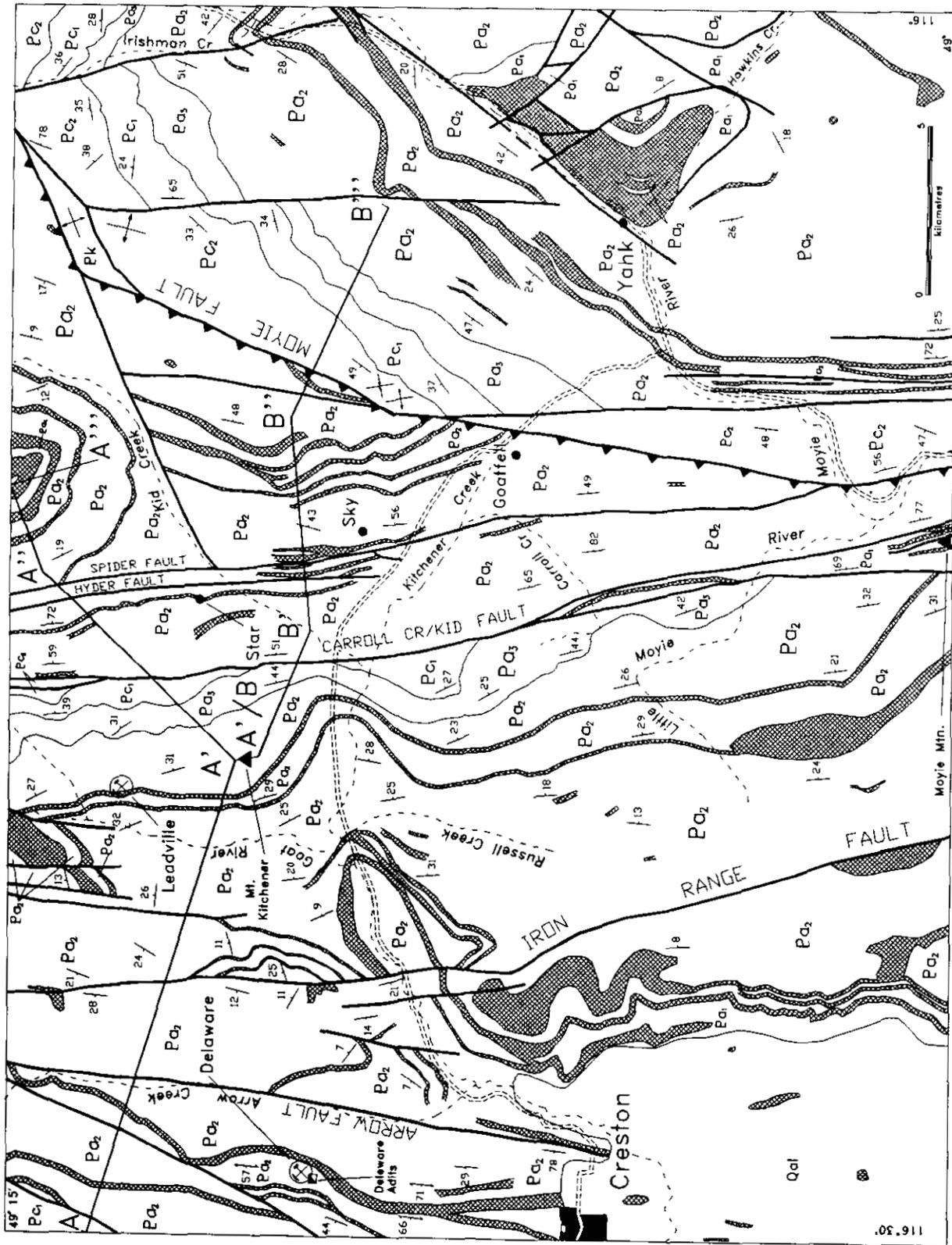
Figure 5. Simplified preliminary geology of the Yahk map area (82F/01), incorporating unpublished geology from Reesor and locations of selected mineral occurrences. Legend is included on Figure 8.

Total thickness of the Aldridge in the southern Purcell Mountains has been estimated to be over 4200 metres (Edmunds, 1977a, b; Höy and Diakow, 1981); its base is not exposed. Its age is constrained by the age of the Moyie sills (circa 1445-1480 Ma) and basement (1600 to 1700 Ma; Burwash et al., 1962; Cressman, 1989). Recent zircon U-Pb dates of two Moyie sills in the Kimberley area are about 1480 Ma (Anderson and Parrish, 1993). A third sill in the same area yielded a zircon date of 1468.0 ± 1.5 Ma (D. Davis, personal communication, 1993). The Cooper Lake granophyre; part of a gabbro sill 90 metres thick, located north of the present map area, yielded a 1425 to 1457 Ma zircon U-Pb date (Ross et al., 1992). Slightly younger dates were reported for the Lumberton sill near Moyie Lake (1445 ± 11 Ma; Höy, 1989) and for the Crossport C sill in Idaho (1433 ± 10 Ma; Zartman et al., 1982). Geochronometric and geochemical studies of the sills are ongoing by H.E. Anderson (GSC, Ottawa) and E. Schandl (University of Toronto) as part of the Sullivan-Aldridge project.

LOWER ALDRIDGE (Pa₁)

The upper part of the lower Aldridge in the Cranbrook-Kimberley area consists mainly of rusty weathering thinly bedded siltstone and argillite, interpreted as distal turbidites (Höy, 1993). The base of the middle Aldridge is placed below blocky, grey-weathering quartz wacke beds. The Sullivan deposit occurs at the transition from lower to middle Aldridge. This lithological transition is indistinct or is not seen in the Yahk-Creston map area. Possible lower Aldridge has been mapped in the southeast corner of 82F/01 by Höy (1993), where it occurs in the core of the Moyie anticline. Lower Aldridge has also been inferred in the hangingwall of the Carroll Creek/Kid fault in the south-central part of the map area (Figure 5). A thick succession of dominantly arenite and wacke, intruded by numerous thick sills and exposed in the Ramparts east of Creston, may also represent lower Aldridge, based on its structural position in the core of a regional anticline (Goat River anticline).

RAMPART FACIES

Lithologically, rocks included in the upper lower Aldridge in the Yahk map area are distinct from the thinly bedded, siltstone-dominated sequences mapped by Höy (1993) to the northeast. They are informally referred to as the "Rampart facies" and consist primarily of distinct, light grey to buff, thick to medium-bedded quartz wacke with lesser green-grey siltstone. The thick beds form prominent cliffs or ribs along hillsides. Beds tend to weather with rounded edges. The sequence is notably non-rusty weathering, lacking pyrrhotite. Locally, the arenite is crossbedded, graded and/or laminated. Some beds are visibly lenticular in outcrop

and show cut-and-fill features at the base, suggestive of channel deposits. Beds tend to form amalgamated sets that fine upward. Between the sets are sequences of more thinly bedded quartzites with siltstones and wacke mudstone. Bedding is wavy and lenticular, showing features of current activity (ripple crosslamination) and loading (load ripples). Typical of the lower Aldridge, numerous Moyie intrusions are present in the Rampart sequence.

In most locales, the change from Rampart facies to middle Aldridge occurs approximately where the lower to middle Aldridge contact would be predicted on the basis of marker laminites (see below). The quartz wackes interbed upward into more quartzofeldspathic and locally calcareous beds of the middle Aldridge Formation. Lithologically the transition is subtle. Quartzitic beds of the Rampart facies and the middle Aldridge Formation are not distinguishable, if compared by individual bed.

CORRELATION AND EXTENT

The Rampart facies thickens toward the U.S. border and thins eastward. At Creston the facies is estimated to be 700 metres thick. Eastward, Rampart facies can be recognized on the Canam property at America Creek and in drill core on the Eng property at Yahk ddh E90-03, Stephenson, 1990a). Pale blue-grey quartzites dominate the cored interval at Yahk. The cored interval is believed to extend stratigraphically across Sullivan time, based on stratigraphic distance to marker laminites

The facies has not been recognized on Mount Mahon immediately east of Yahk and north of America Creek. At Mount Mahon, an interbedded sequence of quartzites, sandstones, siltstones and argillites occupies approximately the same stratigraphic position as the Rampart facies. It is ascribed to a slightly quartzitic variation of typical lower Aldridge (Schiarizza, 1984). Drilling by Chevron Minerals Limited between Mount Mahon and America Creek, intersected fine-grained sedimentary rocks in possible lower Aldridge (ddh MM87-1, Edmunds, 1988). Edmunds interpreted the features as indicating a rather quiet part of the basin. Drilling by Minnova Inc. on east Mount Mahon (ddh MM 91-02, Burge, 1992) intersected intervals dominated by quartz wackes in fining-upward sequences with cut-and-fill features. This may possibly be Rampart facies. Work needs to be done in this area to determine the eastern limit of the facies.

The Rampart facies in the Yahk area may correlate with a thickened middle Aldridge facies, or with the lower Aldridge footwall quartzite exposed in the Sullivan area. Both interpretations imply more proximal parts of turbidite fans in the Yahk area compared to the Sullivan area. Correlation with middle Aldridge facies implies that typical thin-bedded upper lower Aldridge sedimentary rocks occur at lower stratigraphic levels not exposed in the Yahk area. Correlation of the Rampart facies with footwall quartzite implies that the upper

siltstone of the Sullivan area, the more distal turbidites of the lower Aldridge, are replaced to the southwest by proximal middle fan turbidites of the Ramparts facies.

MIDDLE ALDRIDGE (Pa$_2$)

The middle Aldridge underlies most of the map area. It comprises a thick sequence of fine clastic rocks, dominantly planar-bedded, fine-grained quartzofeldspathic wacke to arenite, with lesser siltstone and mudstone. Medium-grained sandstone is uncommon, and coarse-grained sandstone and conglomerate are rare. Total thickness is at least 3000 metres, and may be as much as 4000 metres, based on estimates from map distribution. In contrast, the middle Aldridge in the Cranbrook area is about 2500 metres thick (Höy, 1993) and farther north at the Sullivan mine area, only 2100 metres thick.

Outcrop occurrences of "fragmentals" have been reported by D. Pighin and others. Sheet-like slumps and debris flows, as well as localized, crosscutting, dewatering-type fragmentals have been identified. One locality along the Goat River road is interesting because the fragmental unit forms a prominent, resistant knob just east of the road. Similar breccias in other parts of the Aldridge and Prichard formations are attributed to dewatering features (Höy, 1993; Cressman, 1989).

Typically, the middle Aldridge consists of rusty brown weathering quartzofeldspathic wacke beds, 0.2 to 1.0 metre thick, separated by thinner intervals (typically 0.05 - 0.3 m) of siltstone and argillaceous siltstone (Plate 1). Both thicker and thinner sandstone beds are less common. The sandstone beds are even, planar and laterally continuous, massive to indistinctly graded, locally with coarse (<1 - 2 cm) dark and pale grey laminae. Flute casts, longitudinal and crescentic scour marks and load structures at the base of beds are ubiquitous but unfortunately best seen in talus blocks. Ripple marks and ball-and-pillow structures are rare.

Typical sandstones contain 40 to 60% quartz, 10 to 15% feldspar, 10 to 45% muscovite, up to 15% biotite and/or chlorite, and minor garnet, pyrrhotite, ilmenite, carbonate, titanite, tourmaline, epidote and zircon (J. Getsinger, Appendix III in Rebic, 1989). Siltstone intervals may include fine-grained wacke to mudstone, and are generally parallel laminated, sometimes with pale and dark grey laminae. Siltstone rip-ups are rare; crosslaminae may also be present. The interbedded sandstone and siltstone include variably developed A, AE and ACE Bouma turbidite sequences. Some sequences lack fine siltstone intervals and form thick sandstone units separated only by bedding planes, suggesting that fine material was either eroded or not deposited.

Rare facies variations within the middle Aldridge locally constitute mappable subunits within the thick turbidite succession. A relatively mudstone-rich facies contains numerous thin (<1-10 cm) mudstone beds interbedded with wacke and siltstone. This facies typically contains abundant soft-sediment deformation features, such as argillite rip-ups, mud-chip breccias (Plate 2) and load structures, and may contain wavy or lenticular bedding. Mudstone and siltstone beds are commonly platy, and may preserve excellent flutes and longitudinal scour marks. A second distinct facies
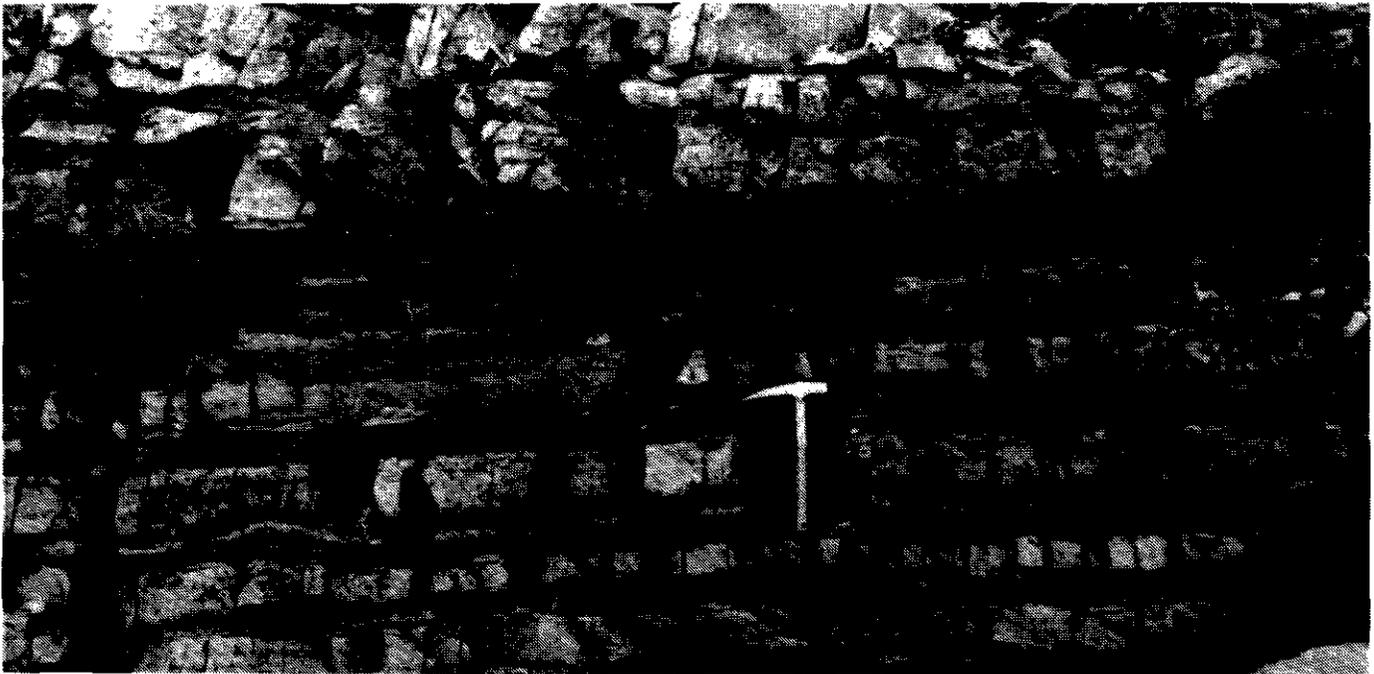

Plate 1. Typical outcrop of the middle Aldridge Formation displaying even, planar bedding (JBR93-78).
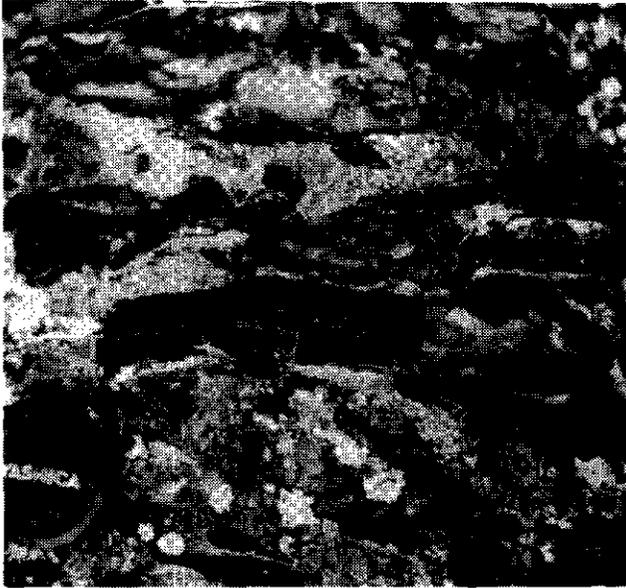
Plate 2. Sedimentary mudchip breccia within the middle Aldridge Formation on the Star Property (JBR93-26).
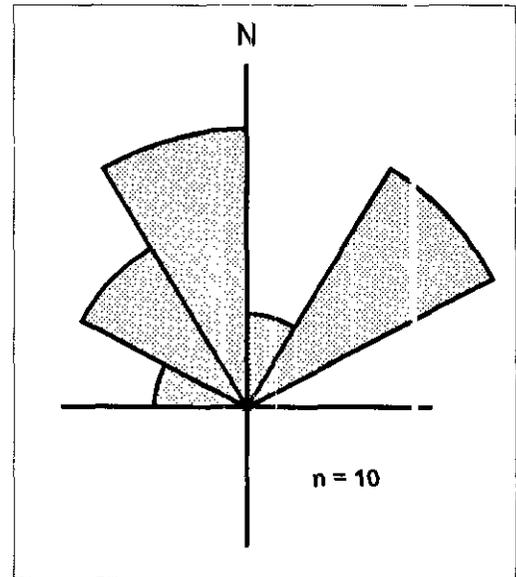

Figure 6. Paleocurrent rose diagram for the middle Aldridge Formation in the project area.
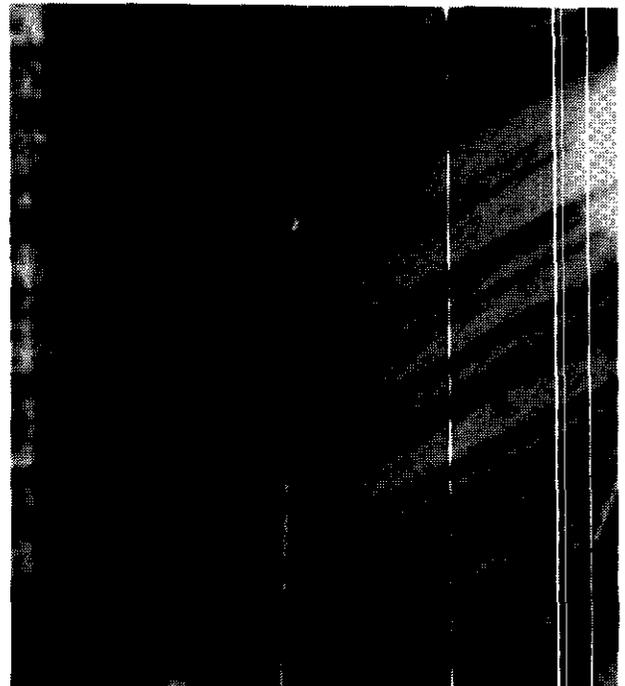

Plate 3. Marker unit from two localities 70 kilometres apart. Sample provided by D. Pighin, Consolidated Ramrod Gold Corporation.

consists almost entirely of clean quartz arenite beds averaging 1.0 to 1.5 metres thick. Intervening siltstone intervals are absent or thin.

The upper part of the middle Aldridge is characterized by thinner wacke beds (0.05 - 0.5 m thick) which are more widely separated within grey to dark grey, thin-bedded to laminated siltstone and mudstone. Thin-bedded, argillaceous siltstone-dominated sequences in this part of the section can be easily interpreted as upper Aldridge in areas lacking good exposure. Sills are generally not found in the upper middle Aldridge. This distinct interbedded wacke and dark grey siltstone grades upward over about 100 metres into the upper Aldridge.

Limited paleocurrent data suggest northeasterly to northwesterly current directions (Figure 6). These trends are consistent in a general sense with those in the Fernie West-half area (82G W1/2: Höy, 1993), and in the central Belt basin in Montana (Finch and Baldwin, 1984), supporting a northwest-trending basin. A northwesterly trend probably parallels the topographic axis of the basin in middle Aldridge time (Winston *et al.*, 1984).

MARKER UNITS

Laminated siltstone marker units are present in numerous locations in the middle Aldridge. A stratigraphy comprising at least twenty markers developed by Cominco geologists and others has been found to be useful for stratigraphic control across the Purcell (Belt) basin (Edmunds, 1977b; Huebschman, 1972, 1973; D. Pighin, personal communication, 1993). South of the project area Cressman (1989, p. 30) refers to

a series of "key beds" (*a* through *f* on his Section 11) that may correlate in part with this marker stratigraphy.

Each marker unit comprises a distinct sequence of alternating light and dark grey, parallel siltite laminae that can be correlated over distances up to several hundred kilometres (Huebschman, 1973; Edmunds, 1977b; Plate 3). The layers consist of quartz and feldspar grains with disseminated biotite, muscovite and pyrrhotite (Huebschman, 1973). One to three % carbon provides the coloration difference between layers. The

marker units range in total thickness from a few centimetres to over 12 metres. Turbidite-derived wacke between markers varies from about 15 to 200 metres thick (Cominco Ltd., unpublished data). Intervals over which individual marker sequences occur can be greatly expanded or locally even partially eroded by wackes related to turbidite deposition.

The origin of these enigmatic units is a matter of debate. They may record episodic surface algal blooms producing the dark, organic-rich laminae with dust storms distributing silt over large areas of the basin (Huebschman, 1973). Alternatively, the pale laminae may record episodic sedimentation of terrigenous material from dust storms (Turner et al., 1992) as has been recorded in the Gulf of California (Baumgartner et al., 1991). The Black Sea may present a modern analogue of light and dark layered beds correlated across the entire basin. Although they are not directly comparable, because grain sizes vary between layers from silt to mud, unlike the Aldridge marker units. A third possible explanation for marker laminae could be that a large river supplied silt to the body of water and the silt was widely dispersed because density contrasts in the water column prevented rapid settling of the particles.

Individual laminae and sets of laminae within the marker intervals thicken slightly and proportionately over large areas. It is difficult to imagine a point sediment-source distributing sediment so uniformly and thinly, not only at one time but over a period of time represented by laminae sets. It seems necessary to invoke a feature fundamental to the body of water itself to explain the uniformity and continuity of the marker laminae. Individual pale laminae of the marker interval tend to have sharp bases and gradational tops. This suggests that the onset of deposition of the pale laminae is triggered by specific, basin-wide events. The pale laminae tend to be massive but the dark laminae are comprised of even finer microlaminae. Such fine laminations suggest a chemical control. Deposition of the marker laminites appears to have occurred in a bottom environment devoid of current activity. Perhaps physiochemical or biochemical changes in stagnant bottom waters controlled deposition from suspension. Further work is needed on the marker laminites.

UPPER ALDRIDGE (Pa₃)

The upper Aldridge Formation is distinguished by its rusty dark brown weathering, grey to dark grey, platy to fissile, thin and parallel-bedded to laminated siltstone and silty mudstone couplets. Ripple marks are rare. Characteristic white siltstone laminae are noted by Reesor (1981) and in the United States informally called "lined rock" (Cressman, 1989). Quartzofeldspathic wacke beds are very rare and thin (<10 cm). Commonly, the forest covered hillsides typical of the region turn to open grassy patches in areas underlain by upper Aldridge

argillite. Presumably this is due to disseminated sulphide in the argillaceous member that inhibits tree growth. Talus derived from the fissile upper Aldridge forms chip size fragments. Moyie sills are absent.

The contact between the middle Aldridge and upper Aldridge is transitional over at least 100 metres, as wacke beds become thinner and more widely separated up-section. The gradational contact leads to imprecise determination of thickness, but it is estimated to be about 400 to 500 metres in the Yahk map area. This is thicker than that suggested by Reesor (300 m; 1981) but comparable to that in the Fernie area (about 500 m; Höy, 1993). The gradational upper contact with the Creston Formation is placed where pale green colours, shrinkage (syneresis) cracks and other shallow-water sedimentary features first appear. Cressman (1985) uses similar features to divide the Prichard and Burke formations. A massive, thick bedded siltstone or wacke occurs at the base of the Creston Formation. It is also exposed in the Moyie Lake area.

The upper Aldridge reflects waning input of sandstone turbidites and final pelagic sedimentation prior to the shallowing of the Purcell (Belt) basin as represented by the Creston Formation.

MOYIE INTRUSIONS (Pm)

The term Moyie sills was first used by Daly (1912a, b) to describe sills on "Moyie Mountain" along the International border 2 kilometres west of Kingsgate (Figure 5). Moyie intrusions, dominantly sills but also dikes, are more common west of the Rocky Mountain Trench, where they can comprise 30% of the section. There are two main episodes of sill emplacment important within the Aldridge Formation (Gorton et al., in preparation; R. Turner, personal communication, 1993). No distinct features were recognized to differentiate the sills in the field. In the Lamb Creek area, west of Moyie Lake, the cumulative thickness of the sills is about 1300 metres (Höy, 1993).

The Moyie sills are widespread in the lower and middle Aldridge in the Yahk map area. They extend laterally over tens of kilometres, crosscutting bedding at small angles and, therefore, some can be used for gross stratigraphic correlation. Locally they are dikes cutting stratigraphy. The sills are fine to medium grained, and range in composition from hornblende (± pyroxene) gabbro to hornblende quartz diorite and hornblendite. Mafic phenocryst contents vary up to 70%. Some of the thicker sills (> 20 m) contain irregular patches of coarse pegmatitic hornblende and feldspar. Zones of granophyre, as described in the uppermost sill at the Sullivan mine, were not observed in the map area.

The sills vary greatly in thickness; typically they are 15 to 30 metres thick, although they reach up to 300 metres or more in thickness (Cressman, 1989, reports

sills up to 600 m thick). As in the Cranbrook area to the east, a conspicuous section in the middle part of the middle Aldridge contains from two to six prominent sills. Sills are absent in the underlying 1000 metres, and few if any occur above it. This upper sill succession is well exposed south of Kid Creek, where a sequence of four or five sills is repeated by faulting. To the west, on Mount Kitchener, the same stratigraphic section contains only two sills (Figures 5 and 8).

Sill margins are typically sharp and locally chilled. The variability in contact metamorphic effects, from a wide biotite hornfels to absent, has been attributed to differences in the level of emplacement that would have controlled the ambient temperature and pore water contents of the hostrocks (Cressman, 1989). Höy (1989, 1993) proposed that some of the sills intruded wet sediments coeval with deposition of the lower and middle Aldridge formations. Supportive evidence for this can be seen along Highway 3 near Kitchener, where a narrow zone of conglomerate with no bedding contains oblong, rounded quartz-sandstone cobbles and boulders in a matrix of the same composition (Turner et al., 1992, Stop 1-7). This is interpreted as evidence of fluid streaming through wet sediments trapped between two sills, one exposed above the conglomerate in the outcrop and a lower sill exposed just to the east in a roadcut. An example of soft-sediment deformation along a Moyie sill margin occurs near trenches in the Iron Range. Bleached, albite-altered metasedimentary rocks occur locally, such as on the Goat River road near Highway 93 (Turner et al., 1992; Stop 1-8), and may be due to sill emplacement.

The dark green to black sills look remarkably fresh and locally have planar, polygonal joints (Plate 4). Joint surfaces typically weather rusty brown. Sporadic white bull quartz veins, quartz-epidote veins and pods

containing minor chalcopyrite occur within some sills.

The chemistry of the Moyie sills has been reviewed by Höy (1993) and Gorton et al. (in preparation). They comprise two distinct populations: alkaline and transitional sills, only recognized in the Mount Mahon area just south of Yahk; and subalkaline tholeiitic sills elsewhere. Detailed petrography and geochemistry of correlative sills to the south, near Crosspoint, Idaho are presented by Bishop (1973). Continuing work on sill petrography, geochemistry and dating is in progress by H.E. Anderson as part of the Sullivan-Aldridge project

OTHER SILLS AND DIKES (Pb)

Rare mafic sills and dikes, outwardly similar to the Moyie sills, intrude rocks as young as Kitchener Formation (Höy, 1993). In the Yahk map area, one such dike cuts lower Creston Formation on the ridge east of Leadville Creek. The dike is about 10 metres wide and intrudes Creston siltstone.

CRESTON FORMATION

The Creston Formation underlies about 10% of the Yahk map area. It crops out in four areas The best exposures are on the northwest limb of the Moyie anticline and along a north-trending graben that extends southward into Idaho and Montana. Creston strata also underlie the eastern and western limbs of the Goat River anticline; the latter was not mapped in 1993 (Rice, 1941).

The Creston Formation in the Nelson East Half map area is divided into a lower argillaceous member (~1000 m thick), a middle quartzitic member (~100 m thick)
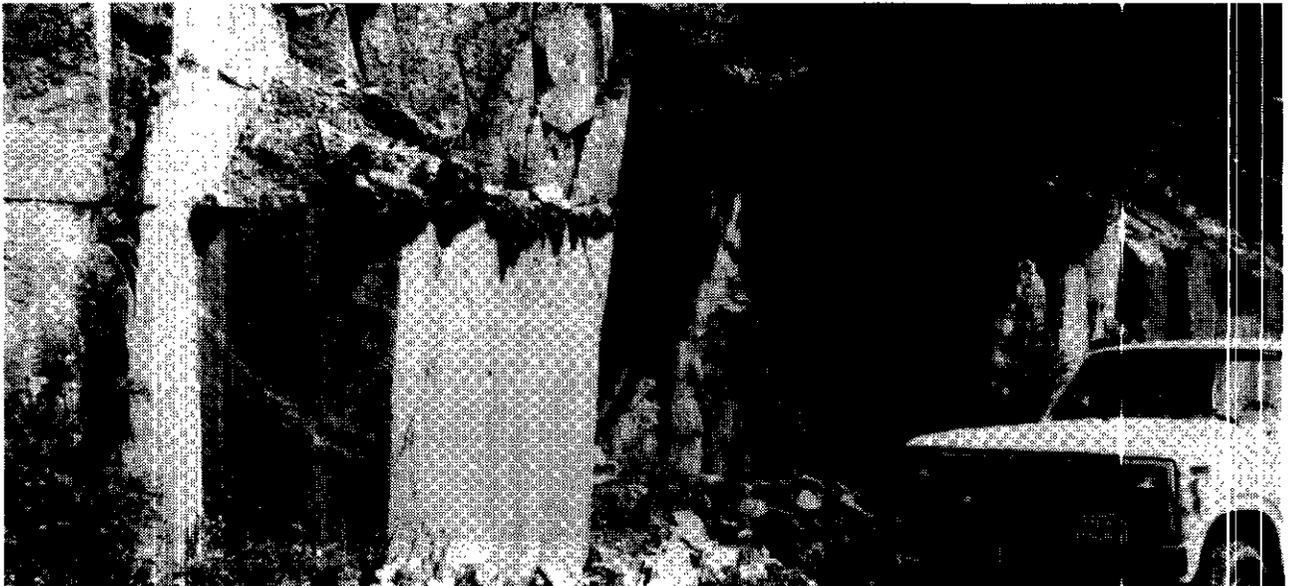

Plate 4. Moyie sill with prominent planar joints, on the Mount Thompson lookout road.

and an upper siltite and argillite (< 300 m thick). They correlate with the Burke, Revett, St. Regis and Empire formations of the Ravalli Group in the United States (Figure 4). The transitional member, in the upper part of the Prichard Formation of Cressman (1989) is correlative with lower Creston Formation in the Yahk area. The Creston Formation represents shallow-water, reworked deposits accumulated on prograding (from the south) deltas or fans (Hrabar, 1973), possibly in a tide-dominated delta as proposed by Kopp (1973). The Revett Formation hosts numerous important copper-silver deposits and occurrences in western Montana (see below).

Only the lower and middle Creston have been recognized in the Yahk map area. Disseminated magnetite and local veins within the Creston Formation produce prominent aeromagnetic anomalies which conform to the mapped distribution of the unit. Speckled argillite with small euhedral magnetite crystals is common in the Burke Formation.

LOWER CRESTON (Pc₁)

The lower Creston consists of thin-bedded, laminated siltstone, argillite and lesser fine-grained quartz wacke. Total thickness of the lower Creston in the Yahk map area is about 650 metres, best exposed northeast of Mount Kitchener. The contact with underlying upper Aldridge rocks is gradational, reflecting a gradual shallowing of the Purcell basin. Lower Creston Formation is distinguished from the Aldridge Formation by colour, bedforms and sedimentary structures. Lower Creston rocks are generally waxy pale green to olive, with tan weathered surfaces, although pale grey and mauve to purple siltstone and argillite are common. Wavy to lenticular bedding (Plate 5) and typically sub-phyllitic to phyllitic (sericitic, therefore soft) rocks are common, in contrast to planar, unfoliated Aldridge beds. Graded, fining-upward couplets of siltstone and mudstone are widespread. The most

characteristic and diagnostic sedimentary structures are subaqueous shrinkage cracks (syneresis cracks) and asymmetric and symmetric ripples. The discontinuous cracks, developed in argillaceous beds, are a few centimetres long and consist of one to four irregular cracks. Unlike subaerial mudcracks, they do not form closed polygons. Other subaerial indicators, like raindrop imprints, are also lacking. Ripples have wavelengths of 3 to 10 centimetres and amplitudes of 3 to 10 millimetres, with about a 10:1 ratio (Plate 6); the ripple crests are commonly sinuous.

An intertidal to shallow subtidal mudflat setting is interpreted from these sedimentary structures and based on regional correlations. Winston (1986) has argued for a lacustrine setting for the upper Belt strata.

MIDDLE CRESTON (Pc₂)

The middle Creston overlies the lower Creston gradationally. It comprises at least 900 metres of thin to medium and less commonly thick-bedded, laminated quartz arenite to quartz wacke, siltstone and mudstone. Excellent exposures occur in the northeast corner of the map area, north of Leadville Creek and in the Kingsgate graben (Figure 5). In contrast to the lower Creston, it is characterized by mauve to purplish sequences which are interbedded with greenish sediments. Light grey to white medium-grained quartz arenite with commonly concordant but locally discordant mauve colour laminations or rings is a distinctive lithotype (Plate 7). Sandstone beds generally appear to be cleaner and more quartz rich than Aldridge sandstones. Bedding is planar to wavy; planar and trough crosslaminations, scour and fill, and graded fining-upward sequences are common. Bidirectional cross bedding, common in tidal flats (Davis, 1983), can be seen in places. Sedimentary structures are abundant, including load casts, ball-and-pillow structures and ripples (Plate 6). Desiccation cracks (mudcracks), which are not found in the lower Creston, indicate subaerial exposure, suggesting

Plate 5. Typical wavy bedding with flame structures developed in the Creston Formation (DBR93-102).

Plate 6. View southwest to curve-crested, asymmetric ripples within maroon siltstone of the middle Creston Formation (DBR93-406).
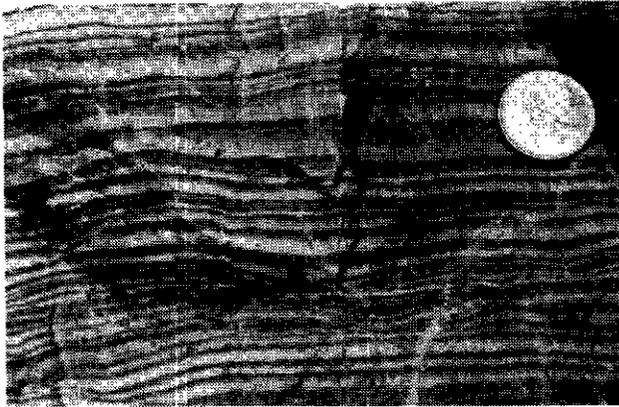
Plate 7. Distinctive mauve, laminated white quartz arenite of the middle Creston Formation (DBR93-102).

Plate 8. Middle Creston Formation mud-chip breccia consisting of maroon argillite chips within white quartz arenite (DBR93-184). The arenite beds are interpreted to represent repeated storm deposits across a mudflat.

continued shallowing during deposition of the Creston. Mud-chip breccia horizons with dark grey to brick-red mudstone fragments within white medium-grained quartz arenite are common; the bases of these beds are planar and the tops are rippled, perhaps indicating storm events in a shallow subtidal or intertidal environment (Plate 8).

The middle Creston is correlative, in part, with the deltaic facies of the Revett Formation in Montana, supporting a model of prograding fans from a southerly source.

UPPER CRESTON (Pc₃)

The upper Creston Formation comprises green siltstone, light and dark, thinly laminated argillite and siltstone and purple argillite (Reesor, 1983). No definitive upper Creston was mapped in the project area.

KITCHENER FORMATION (Pk)

The Kitchener Formation, defined by Daly (1905) and Schofield (1915), overlies the Creston Formation and

comprises green dolomitic siltite, argillite and carbonaceous dolomite and limestone. It forms a succession 1800 metres thick (in the Nelson East Half area where mapped by Reesor, 1983) of shallow-water deposits that correlate with the middle Belt carbonate, the Wallace Formation to the south and the Helena Formation to the southeast (Figure 4). Uncommon stromatolites are locally important.

The Kitchener Formation is poorly exposed in the northeast corner of the map area, in the footwall of the Moyie fault. Farther northeast the formation outlines the northwest limb of the Moyie anticline. Prominent but thin, brown-weathering dolomitic siltstone beds distinguish Kitchener Formation from Creston Formation. They pit-out and produce rough and irregular weathered surfaces. Otherwise, the wavy bedded, pale green siltstone and argillaceous siltstone are similar to the Creston Formation. Isolated outcrops, faulting and tight folding preclude estimates of total thickness. Strata are phyllitic with local transposed bedding in this area.

LAMPROPHYRE DIKES AND SILLS

Biotite lamprophyre intrusions outcrop in several areas, north of Kid Creek (Star property), near Goatfell and in the Iron Range. These are brown weathering, medium to coarse grained, and contain biotite, hornblende and possibly olivine. They occur as sills as well as steeply dipping dikes. Similar intrusions are found in the Cranbrook-Kimberley area, where they are inferred to be Early Cretaceous (Höy, 1993).

STRUCTURE

REGIONAL STRUCTURAL FEATURES

The map area lies on the western flank of the Purcell anticlinorium, the westernmost component of the Cordilleran fold and thrust belt. The anticlinorium, itself allochthonous and transported eastward with respect to North American basement, is bounded on the east by the Rocky Mountain Trench. To the west, the Purcell Supergroup strata become progressively more deformed and metamorphosed within the Kootenay Arc (Figure 3). Southwest of Creston is the northern extension of the Purcell Trench, defined as a north-trending topographic depression and, in part, a graben in northern Idaho (Harrison et al., 1972). Here, the Priest River Complex includes metamorphic rocks and Late Cretaceous granitic rocks (Kaniksu batholith) in the hangingwall of an inferred east-dipping normal fault (Purcell Trench fault, Yoos et al., 1991). Farther east, the eastern margin of the Sylvanite anticline is the Libby thrust belt, a series of

west-dipping thrust faults that projects to a basal décollement 10 to 15 kilometres below the map area (Harrison et al., 1992; Harrison and Cressman, 1993).

Much of the project area lies between the southwestern projections of the St. Mary and Moyie faults. These faults strike across the northern part of the Purcell (Belt) basin and have Proterozoic (St. Mary) and Paleozoic (Moyie) histories (Höy, 1979, 1993; McMechan, 1979, 1981). This transverse trend projects southwesterly toward the Yahk map area from a marked flexure in the eastern margin of the Purcell (Belt) basin. This flexure is reflected in isopachs of the middle Aldridge (Höy, 1993), and therefore is an original feature of the basin margin, and not a later tectonic feature. The transverse structures probably reflect structures and/or topography of the underlying continental basement.

SEISMIC DATA

Moyie sills form prominent seismic reflectors on profiles acquired in southern British Columbia and the northern United States by LITHOPROBE, COCORP and industry (F.A. Cook, personal communication, 1993; Yoos et al., 1991). The data also suggest that Aldridge Formation basement is involved in the folding and thrusting.

FOLDING EVENTS

There are three ages of folding evident within the Purcell (Belt) strata: doubly plunging Late(?) Proterozoic folds, complex Cretaceous to Paleocene folds and thrusts (Laramide orogeny) and Eocene extension related folds (Benvenuto and Price, 1979; Harrison and Cressman, 1993). The broad to open Proterozoic folding was accompanied by greenschist grade metamorphism as indicated by metamorphic biotite cooling dates of 1330 ± 45 Ma in Montana (Obradovich and Peterman, 1968). A

pegmatitic phase of the Hellroaring Creek stock, recently dated at 1365 ± 2 Ma (U-Pb monazite; J. Mortenson, personal communication, 1992), provides a younger age constraint for this deformational event because the stock intrudes folded Aldridge Formation (Leech, 1962). A rapikivi granite of the same age (ca. 1365 Ma) intrudes greenschist-grade rocks of the Yellowjacket Formation (Aldridge Formation equivalent) in the Salmon River arch in east-central Idaho (Chamberlain and Doughty, 1993).

PROJECT AREA STRUCTURAL FEATURES

The Yahk map area can be divided into three structural domains separated by high-angle faults. Bedding attitudes in the three domains are shown in Figure 7. The eastern and western domains are dominated by broad, north-trending and north-plunging folds, the Moyie and the Goat River anticlines (Figure 9). The southern extension of the Moyie anticline is called the Sylvanite anticline in western Montana (Harrison et al., 1992). The Moyie fault and related structures truncate the western limb of the Moyie anticline in the east-central part of the map area, while the Carroll Creek/Kid fault cuts the eastern limb of the Goat River anticline (Figures 5 and 8).

Between the Moyie and Carroll Creek/Kid faults is a structurally complex, internally faulted horst-like panel, here called the central domain, which is entirely underlain by lower and middle Aldridge Formation. Tighter and more intense folding, with steeply plunging fold axes, is common adjacent to major faults like the Moyie and Carroll Creek. The lack of strata younger than Kitchener Formation precludes any definitive evidence for the timing of deformation in the map area; constraints from other regional studies are used.

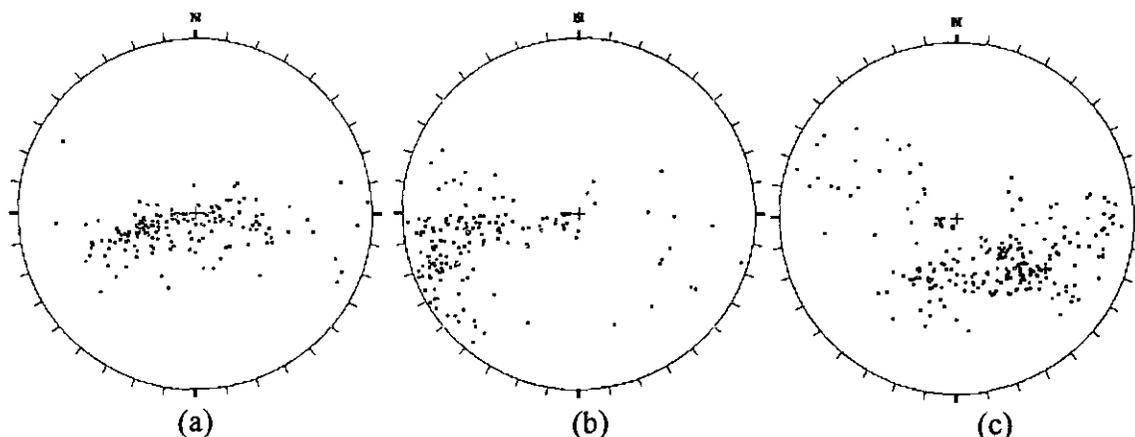Structural style of the Yahk map area is characterized by broad open folds and steep faults.

Figure 7: Stereonet plots of poles to bedding for (a) the Goat River antiform, west of the Carroll Creek/Kid fault (170 data points); (b) the central domain, between the Moyie and Carroll Creek/Kid faults (182 data points); (c) the Moyie antiform, east and south of the Moyie fault (236 data points). Equal area projection.

While a weak, spaced cleavage is present throughout the map area, penetrative fabrics are seen only within a broad zone adjacent to the Moyie fault and related structures, and within narrower zones along other faults.

An intense penetrative cleavage is present in the northwestern corner of the map area, in the west limb of the Goat River anticline. Gabbro sills are foliated with discrete shear zones (chlorite schist), west of Arrow Creek, that are possibly part of the St. Mary fault or related splays. Phyllitic (sericite-rich) siltite and foliated diorite are also present near the Delaware adits (Figure 5). The overall gradational increase in strain and metamorphism westward corresponds to the transition from the Purcell anticlinorium into the eastern fringe of the Kootenay Arc.

Metamorphic mineral assemblages in the metasedimentary rocks include muscovite-biotite-garnet-quartz-(k-spar-albite) and possibly muscovite-chloritoid-biotite-quartz-(k-spar-albite). Greenschist to lower amphibolite grade metamorphism accompanied Late Jurassic to Paleocene (Laramide) deformation, although this probably overprinted Proterozoic deformation and metamorphism during the East Kootenay orogeny (Höy, 1993).

MOYIE FAULT

The Moyie and related faults extend from the east side of the Rocky Mountain Trench (Dibble Creek fault) through to the eastern part of the Yahk map area and into northern Idaho (Höy, 1993; Reesor, 1981; Harrison et al., 1992). A complex history for the northwest-dipping Dibble Creek fault includes pre-Devonian north-side-down and younger oblique reverse movement (Leech, 1958). Devonian gypsum served as the locus of movement in the footwalls of both the Dibble Creek and Moyie faults In the Moyie Lake area, the fault cuts the western limb of the Moyie anticline (Höy and Diakow, 1982). The Moyie fault is also a right-lateral reverse fault with about 12 kilometres of displacement (Benvenuto and Price, 1979; Höy, 1993).

In the Yahk map area, the Moyie fault places middle Creston and possible Kitchener formations against middle Aldridge Formation (Figure 5). This requires an apparent vertical throw, with the west-side-up, on the order of 1.0 to 1.5 kilometres (similar to that estimated by Reesor, 1991). In the northeastern corner of the Yahk sheet, major displacement is transferred from a northeasterly trending segment to a north-trending segment, with an isolated block of Kitchener Formation occurring near the fault flexure. A possible extension of
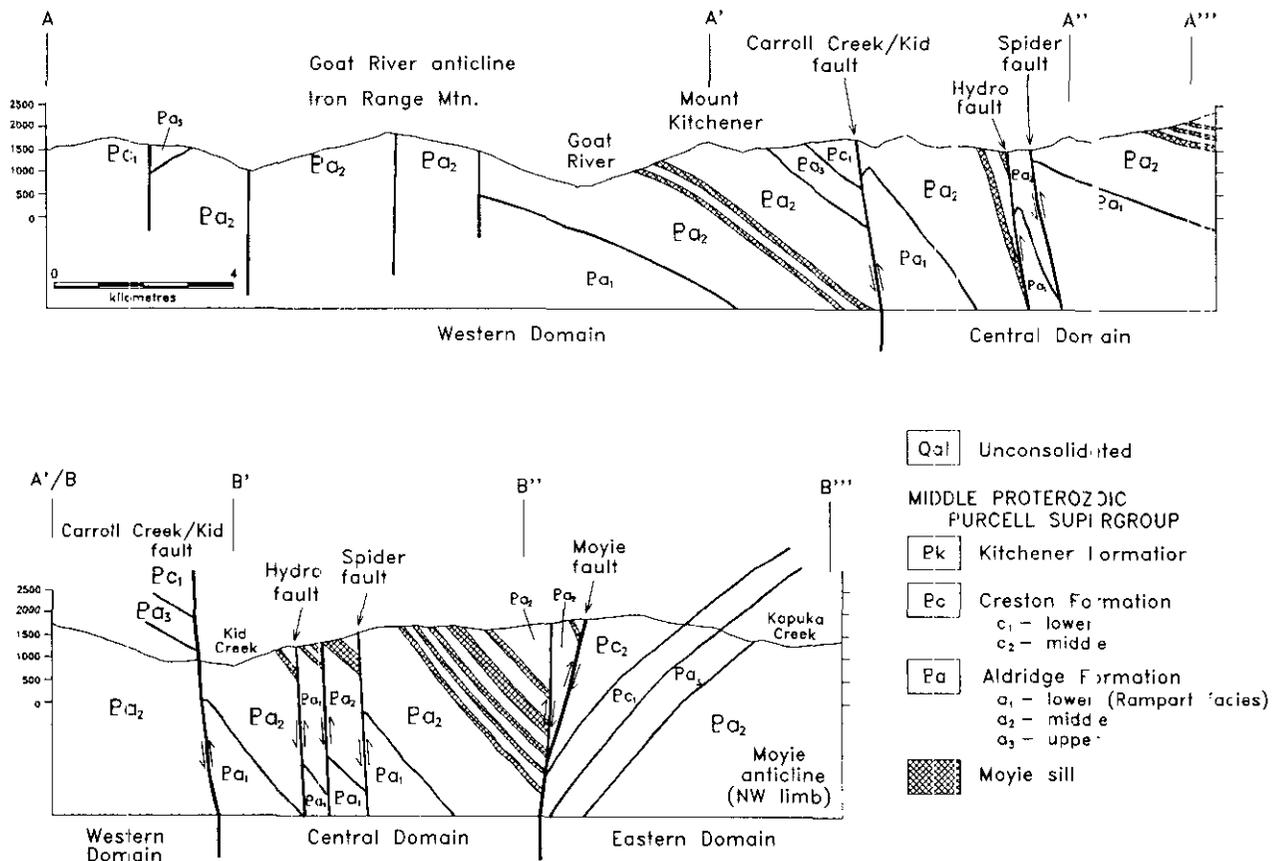

Figure 8(a). Cross-section A-A'-A"-A"'; (b) Cross-section B-B'-B"-B"'. Vertical exaggeration 2x.

the northeasterly trending segment strikes southwest from this point along Kid Creek, separating a block of moderately to steeply dipping middle Aldridge Formation from a block of flat-lying rocks to the north. Both northeast-trending and north-trending fault segments are included as part of the Moyie fault system by Reesor (1993), although the relationship between them is unclear.

The Moyie fault dips steeply throughout the Yahk area. Tight folds and a penetrative cleavage are developed in thin-bedded footwall Creston and Kitchener Formation (Plate 9), while a weaker cleavage and broader folds occur in hangingwall middle Aldridge. The fault is a broad zone (up to 500 m wide) of intense brittle-ductile shearing.

CENTRAL DOMAIN

The central domain is bounded by the Carroll Creek/Kid fault on the west and by the Moyie fault system on the east. Due to the southerly convergence of its bounding faults it is roughly funnel-shaped in map view, broadening from a width of about 3 kilometres at the Canada - U.S.A. border to over 12 kilometres north of Kid Creek. The central domain comprises a series of narrow, north-trending panels separated by steep faults, the most important of which are the Carroll Creek, Spider and Hydro faults. The latter two are east-dipping reverse faults which repeat a sequence of sills and marker laminates, the latter identified by detailed Cominco mapping. Dips within the block are moderate to steep, except for a flat-lying panel east of the Spider fault on the north side of Kid Creek. The Carroll Creek fault, juxtaposes lower Creston with middle Aldridge formation. It consists of a bleached, clay-altered mylonitic rock that was exposed across a zone 2 metres wide by road building on the Star Property (P. Ransom, personal communication, 1993). Minor folds are essentially absent and cleavage is poorly developed, except adjacent to the bounding faults.

KINGSGATE GRABEN

The Kingsgate graben preserves middle Creston Formation in a north-trending belt that extends southward along the western flank of the Moyie-Sylvanite anticline. Bedding-cleavage intersections across the graben indicate most of it is on the east limb of a broad faulted syncline.

IRON RANGE FAULT

The Iron Range fault zone, a series of faults across about a 1-kilometre width, trends subparallel to the axis of the Goat River anticline, and cuts gently dipping Aldridge Formation sedimentary rocks. A well-developed north-northeast-striking, steeply northwesterly

Plate 9. Open to close minor folds developed within thin-bedded to laminated, pale green phyllitic argillite, Kitchener Formation in the Moyie fault zone (DBR93-322).

dipping spaced to penetrative cleavage occurs within 100 metres of the fault zone. Individual faults consist of sheared rock 5 to 10 metres wide, with steeply dipping fault lineations representing latest motion. Bedding attitudes steepen within the fault zone and tight folds are common. Intense hematite-magnetite-quartz alteration zones occur along the fault zone, as discussed below.

Based on the correlation of marker laminites across the fault zone there is little vertical displacement at Iron Range Mountain. However, the fault zone is complex and it is interpreted to be deep-seated because of the abundant evidence of hydrothermal alteration along it. To the north, the fault projects into the St. Mary - Hall Lake system as mapped by Reesor (1981).

MINERAL OCCURRENCES

The Sullivan-type sedex deposit has remained the prime exploration target throughout the Purcell (Belt) basin. The Sullivan deposit has been described by Hamilton *et al.* (1983) and Höy (1984). Recent studies by Leitch *et al.* (1991), Turner and Leitch (1992) and Leitch and Turner (1992) have refined the Sullivan model. Massive sulphide mineralization, tourmalinite, albite and muscovite alteration, manganese-rich garnet, sedimentary fragmental units and syndepositional sedimentary structures (slumps) and faults are characteristic features. Co-existing brown and black tourmalinite are considered to be an indication of high fluid to rock ratios and therefore may discriminate potentially mineralized from barren tourmalinite showings (Slack, 1993).

Characteristics of mineral occurrences in the Yahk map area are summarized in Table 1 and locations are
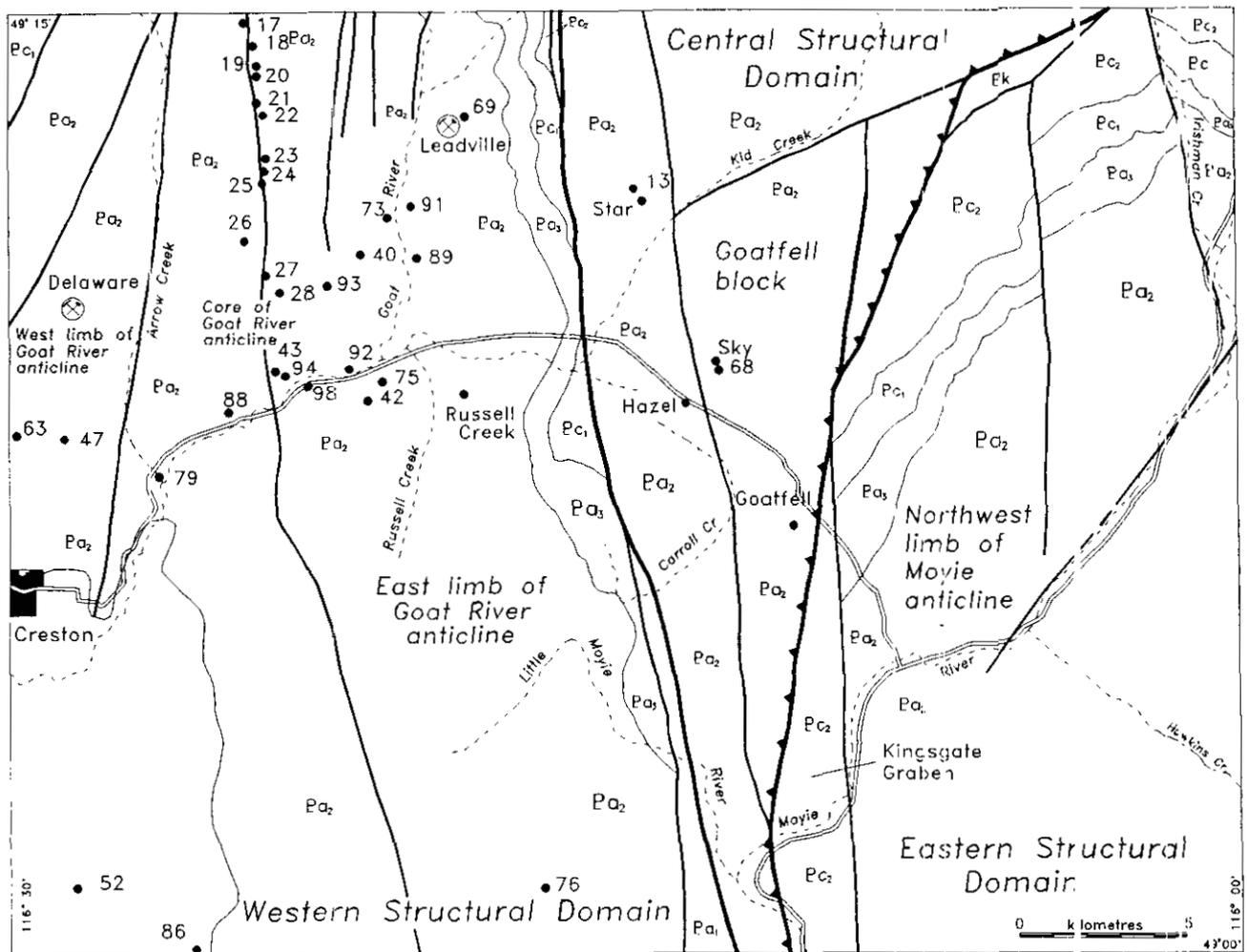
Figure 9. Mineral occurrence localities from MINFILE database and structural domains. Occurrences are described in Table 1. Central domain is shown by stippled pattern.

plotted on Figure 9. Lead-zinc mineralization is widespread in quartz veins in the middle Aldridge. Lead and silver production came from the Leadville and Delaware mines. Stratiform sedex mineralization has been discovered nearby at the Fors property west of Moyie lake. The lower-middle Aldridge contact, the stratigraphic position of the Sullivan deposit, is exposed at relatively shallow depth in the cores of the Moyie and Goat River anticlines, and in uplifted fault panels in the central domain.

The core of the Goat River anticline along the Iron Range fault zone is host to an unusual occurrence of iron oxide mineralization. The Iron Range occurrences, form a linear belt of discontinuous mineralization extending from south of the Goat River to the northern edge of the map sheet.

SEDEX AND RELATED DEPOSITS

Occurrences of sedimentary fragmen als, tourmalinite, lead-zinc vein mineralizatic n and soil anomalies within the central domain (Fig are 9) were the target of exploration by Cominco and Chevron in 1987-1989, and by Kokanee Explorations Ltd. now Consolidated Ramrod Gold Inc.) in 1990-1992. Although some exploration within this area focused or determining the location or depth to and esting of the lower-middle Aldridge contact, other work focused on anomalous lead-zinc within a metallogenc interval higher up in the middle Aldridge, near the stratigraphically lowest Moyie sill. This netallogenic event corresponds with a time of increase 1 magmatic activity in the basin, represented by the second pulse of sill emplacement within the middle Aldridge.

Name(s)	MINFILE	UTM (Zone 11)	Description	References
Star, Kid	82FSE 002 82FSE 013	5450050 N 554650 E	ENE-striking and semi-concordant quartz veins with galena, sphalerite, pyrrhotite, chalcopyrite and arsenopyrite in muscovite-chlorite-altered middle Aldridge quartz wackes. Assays of up to 8.29% Pb, 0.71% Zn, 75.09 g/t Ag/ 6.2 m were obtained in drilling.	MacDonald (1978), Simpson (1984), Hagen (1990)
Leadville, Star	82FSE 006	5451550 N 549520 E	Galena with minor sphalerite and chalcopyrite in an ENE-striking quartz vein in middle Aldridge quartz wackes near a gabbro contact. About 9 tonnes of ore was hand cobbed and shipped in the 1920s.	Merrett (1958), Olson (1970)
Iron Range	82FSE 014 to 82FSE 028	5453750 N 543350 E	Hematite with lesser magnetite in steeply dipping veins, narrow stockworks, disseminations and breccia matrix in albitized and locally silicified gabbro and sericitized wackes and siltstones along a north-trending fault.	Young & Uglow (1928)
Empire State	82FSE 040	5447630 N 546885 E	Quartz-calcite veinlets in gabbro with disseminated pyrrhotite and chalcopyrite.	Rice (1941)
Delaware	82FSE 041	5446050 N 538300 E	Galena and minor sphalerite in a quartz vein striking 150/60-70 SW in middle Aldridge quartz wacke. Production from two main adits (1949-1950): 229 t containing 30.08 kg Ag, 21.23 t lead, 498 kg zinc.	Peck (1950), Peck (1951)
Creston Hill	82FSE 042	5443370 N 547160 E	Quartz-calcite veinlets in gabbro with disseminated pyrrhotite and chalcopyrite.	Curry (1953), Rice (1941)
May-Bee	82FSE 043	5444600 N 544360 E	Chalcopyrite in a quartz vein 0.3-1.5 m wide, striking 330/90, in a gabbro sill. Two adits were driven on the vein. Up to 1.81% Cu / 0.7 m.	Merrett (1958) Merrett (1959)
Otto Silver	82FSE 047	5442190 N 538055 E	Galena in a northeasterly striking, steeply dipping quartz vein.	Olson (1970)
Option	82FSE 068	5445450 N 556070 E	Several pits expose at least four quartz veins with pyrite and minor chalcopyrite and scheelite in silicified gabbro and quartz wacke.	McDonald (1960)
Goatfell	-	5441150 N 559250 E	An extensive zone of variably tourmalinized middle Aldridge quartz wacke and siltstone with quartz-muscovite veins with minor pyrite.	
Hazel	-	5443750 N 556700 E	Disseminated sphalerite in a narrow shear zone striking 180/90 in albitized middle Aldridge quartz wacke and siltstone.	
Sky	-	5445000 N 557600 E	Tourmalinized and silicified quartz wacke with pyrite, pyrrhotite, arsenopyrite and chalcopyrite.	Rebic (1989)
Sun	-	5444050 N 550100 E	Galena in east-striking, steeply south-dipping quartz veins up to 0.3 m wide.	

STAR

The Star showing (also known as the Kid: MINFILE 82FSE-002 and 82FSE-013) is in middle Aldridge sedimentary rocks on the west side of Peterson Creek, a tributary of Kid Creek. The showing was discovered in 1967 following up a lead-zinc soil anomaly by surface trenching. The first drill hole by Cominco Ltd. targeted a UTEM anomaly in the late 1980s. Recent work by Kokanee Explorations, Ltd. (1990-1991) has included 5563 metres of diamond drilling in twelve holes.

Surface showings consist of steeply dipping, east to northeast-striking quartz veins with galena and minor sphalerite, in fine-grained quartz wacke. Mineralization intersected over wide intervals in drill core includes values of 4.08% zinc over 1.0 metre and 8.52% lead, 2.38% zinc over 2.0 metres (Stephenson, 1990b). Veins consist of quartz, galena, sphalerite and pyrrhotite, with minor pyrite, chalcopyrite and arsenopyrite. Bedding-parallel quartz-sulphide veins have also been intersected by drilling. Veins are commonly high-strain zones; locally quartz is broken into fragments surrounded by a deformed sulphide matrix of sphalerite and galena (Plate 10). Significant intervals (100 m true thickness) of strongly altered sedimentary rocks occur within the

Plate 10. Quartz-sulphide veins from the Star property illustrating typical textures from drill core of ddh S90-2: (a) quartz vein with intergranular pyrrhotite and galena, the left contact of the vein is brecciated quartz vein fragments within sheared pyrrhotite and galena (354.8 m depth) (b) angular sphalerite within sheared galena and pyrrhotite vein (351.3 m depth), and (c) brecciated chlorite-altered siltstone host and quartz vein fragments within galena, pyrrhotite and rare chalcopyrite vein (352.8 m depth). Abbreviations: C = chalcopyrite, H = hostrock, G = galena, S = sphalerite, Q = quartz.

mineralized zone. Patchy to pervasive chlorite and muscovite, locally associated with quartz-carbonate veining, overprints very fine grained biotite. Numerous lamprophyre sills, believed to be Cretaceous or Tertiary, intrude the mineralized zone.

A distinctive sedimentary facies is exposed in road outcrops and intersected in one drill-hole (ddh S90-5), 2 kilometres north and along strike from the mineralized zone. This facies comprises laminated black siltstone

and mudstone interbedded with dark grey quartz wackes. Wacke beds have rip-ups of black mudstone at their bases, while bedding in mudstone and siltstone is locally wispy to lenticular. A distinctive platy black siltstone, and thin mud-chip and wacke breccia horizons are common within this facies. Flutes and other scoured bedforms are abundant. Local tourmalinization of mudstone beds is evident. Diamond drilling down-dip from surface exposures intersected widespread tourmalinization of argillaceous intervals, as well as a chaotic breccia with quartzite clasts (Hagen, 1990). Similar tourmalinization associated with mudstone beds and abundant sedimentary structures is exposed in roadcuts in the footwall west of the mineralized zone.

Mineralization occurs below the lowest of a group of sills which are repeated by reverse faulting south of Kid Creek. Only the two lowest sills are exposed in the fault block containing the mineralized zone. Dips between the lowermost sill and the Carroll Creek/Kid fault to the west are anomalously steep, averaging 65 to 70°. North-trending bedding is subparallel to the strike of the faults bounding the structural blocks; the faults cut bedding at a low angle both down dip and along strike. Anomalous southeasterly striking bedding crops out just south of the projected surface trace of the mineralized zone, suggesting the possibility of crossfaulting; however, exposures are insufficient to delineate these suspected faults.

GOATFELL

The Goatfell tourmalinite occurrence (Ethier and Campbell, 1977) is in middle Aldridge sediments in the structural panel between the Spider and Moyie faults. The occurrence is exposed along the CPR railway about 1.5 kilometres east of Carroll Creek (Figure 9). The discordant zone crosscuts stratigraphy, and its shape as a resistant knob (less than 500 m in diameter) implies a pipe-like morphology. At the base of the zone thick-bedded, weakly altered quartzites are overlain by massive tourmalinized rock, with tourmalinization apparently having obscured bedding. Alteration appears to be semiconcordant here.

The degree of tourmalinization is variable and seems to reflect original lithologies. Quartz wacke beds tend to be darker grey and harder than unaltered equivalents, whereas argillaceous beds tend to be black, aphanitic and extremely hard, with a conchoidal fracture, reflecting more intense tourmaline replacement. Tourmalinized mud chips in quartzite are abundant. Presumably, the preferential replacement of clay-rich layers occurred because they provided the aluminum required to form tourmaline (Slack, 1993).

Only trace sulphide is associated with tourmaline alteration. Coarse-grained, east to southeast-trending clear to blue-grey quartz veins crosscut tourmalinized

rock, and locally contain pockets of fine to coarse-grained muscovite and 1 to 2% pyrite.

A zone of silicification and muscovite alteration is exposed west of the tourmalinite showing, along the railway tracks east of Carroll Creek. This alteration zone is in the hangingwall of the Spider fault, and may be unrelated to the tourmalinite zone.

Diamond drilling in the footwall of the Goatfell tourmalinite was carried out by Chevron Resources Limited in 1988-1989 (Hitzman, 1989; Rebic, 1989). Four holes were drilled to the Sullivan time horizon. Minor tourmalinite and fracture-controlled sphalerite-galena mineralization was intersected in these holes. No drill holes have been collared in the hangingwall of the Goatfell tourmalinite and its down-plunge extent is unknown.

VEINS AND OTHER SHOWINGS

Several other showings occur within the central domain between the Star showing and the Goatfell tourmalinite:

The **Star South** property (Star 4 and 12 claims), owned by Cominco Ltd., covers an area on the ridge south of Kid Creek in the structural panel between the Spider and Carroll Creek/Kid faults (Figures 5 and 9). This panel contains typical middle Aldridge quartz wacke - siltstone turbidite sequences.

Work by Kootenay Exploration (Cominco Ltd.) in the late 1980s delineated two lead-zinc soil anomalies west of the Spider fault, with zinc analyses up to 637 ppm and lead to 130 ppm (McCartney, 1990). A small quartz-chlorite-albite alteration zone was mapped adjacent to the Spider fault in the northeast part of the claims (McCartney, 1990). Four sills can be traced across the ridge line within the claim block. The uppermost sill appears to thicken markedly in the area of the largest soil anomaly. It is possible that shearing, localized along the contacts of the upper two sills, provided permeability for fluid flow, remobilizing and concentrating lead and zinc from weakly metalliferous horizons in the sedimentary rocks. Brittle shears can be seen in outcrop along sill contacts in this area. Intersection of sill-sediment contacts with faults at depth would provide a locus for migrating hydrothermal fluids.

The **Hazel** showing is a narrow zone of albitization and silicification with minor pyrite, pyrrhotite and sphalerite along a north-trending fault on the west side of Hazel Creek. The showing is exposed by a small trench of uncertain vintage.

The **Sky** showing was discovered by F.R. Edmunds during a property mapping program for Chevron in 1989. A zone of tourmaline - sulphide and albite alteration 2 to 3 metres wide occurs in medium-bedded wackes and siltstones of the middle Aldridge. Petrographic observations suggest a multi-stage history of alteration

and shearing (Rebic, 1989). Sulphides include pyrite, pyrrhotite, arsenopyrite and chalcopyrite.

The **Option** showing occurs in and immediately adjacent to gabbro sills in the middle Aldridge. Numerous old pits and trenches expose quartz-pyrite vein mineralization in narrow silicified zones. The veins are reported to carry scheelite.

TIMING OF VEIN MINERALIZATION

Galena lead isotope signatures of most veins fall in a cluster that includes stratiform deposits in the lower and middle Aldridge (Sullivan, North Star and Kootenay King: Table 2). The Sullivan orebody has the most radiogenic lead of this cluster and other deposits in the Sullivan corridor plot toward the radiogenic end (North Star, Stemwinder). The similarity of stratiform and vein-lead signatures suggests that the vein mineralization also occurred during the Middle Proterozoic (about Sullivan time). The only exception is the Midway deposit, in the middle Aldridge just east of the Yahk map area, which is distinctly more radiogenic. The Midway orebody also had higher gold grades (7.78 g/t; from Table 12 in Höy, 1993).

Although some of the veins with lead isotope ratios similar to the Sullivan deposit probably represent sedex feeder systems, some may be younger. There are two lines of evidence for this. First, several of the veins (*e.g.* St. Eugene, Star, Leadville) trend roughly orthogonal to regional fold axes. These could be interpreted as filling A-C joints developed during the Proterozoic (Goat River orogeny) or Jura-Cretaceous (Laramide orogeny; Höy, 1993). Second, the Society Girl vein (the eastern extension of the St. Eugene vein system) occurs in quartzite of the lower Creston Formation. Discordant Late Proterozoic K-Ar dates from alteration biotite along the margins of quartz veins at St. Eugene suggest a Proterozoic mineralizing event (Höy *et al.*, 1993).

IRON RANGE

The Iron Range occurrences occur intermittently along the Iron Range fault zone for at least 20 kilometres. They comprise hematite and magnetite zones up to 200 metres wide. The main showings are located along the top of Iron Range Mountain, from about 6 kilometres north of the Goat River to the northern edge of the Yahk map area. Showings south of the Goat River were not visited during the 1993 field season. The northern showings are accessible by a poor four-wheel-drive road which leaves the Goat River road about 10 kilometres north of Highway 3.

The showings were explored in the early part of the century, and excellent detailed descriptions from that era have been published (Young and Uglow, 1928). Extensive trenching (more than 20 trenches) was carried out by Cominco in 1957 to evaluate the iron resource.

Mineralization occurs within the middle Aldridge Formation along a north-trending, subvertical fault zone (Iron Range fault, Figure 5). Aldridge Formation in the vicinity of the northern showings consists of well-bedded quartzofeldspathic wacke and laminated siltstone, which develop a phyllitic sericite foliation near the fault. Locally sericite alteration extends preferentially along specific bedding horizons, presumably due either to permeability or lithologic controls. Mineralization is primarily within sedimentary rocks and less commonly in altered gabbro. A fine-grained, dark green, foliated and mineralized mafic dike outcrops along the fault zone near the northern edge of the map area.

Mineralization consists of hematite and lesser magnetite in steeply dipping veins (0.3 to 0.6 m wide), broader stockworks of thin veinlets, breccia matrix and disseminated grains. Mineralization is sulphide-poor, except in the most northerly showings, where pyrite clots occur within the foliated mafic dike. Mineralized zones pinch and swell along strike, from narrow 0.5 m) veins within sheared rock, to broad (>100 m) zones of multiple veining and alteration.

Hostrocks are strongly albitized, serici ized and/or silicified. Early quartz veins are commonl brecciated, with fragments enclosed in a hematite mat ix. Early albitization is crosscut by hematite veining and angular albitized clasts float in a later hematite matrix in breccia zones. Late-stage white and colourless quartz veinlets commonly crosscut both albite alteration and hematite veining. Depth extent and down-dip variability of the system are unknown due to the lack of diamond drilling. Hematite at the north end of the system could be stratabound, associated with altered siliceous strata; at other exposures the mineralization is cross cutting and appears to be epigenetic.

TABLE 2.
LEAD ISOTOPE VALUES FOR DEPOSITS IN THE YAHK AND KIMBERLEY-CRANBROOK AREAS.

Deposit	NTS	n	Type	Pb206/204	Pb207/204	Pb208/204
Sullivan	82F/09	8	sedex/ms	16.526	15.474	36.174
North Star	82F/09	1	sedex/ms	16.434	15.449	36.052
Stemwinder	82F/09	1	vein	16.444	15.450	36.087
Kootenay King	82G/12	2	sedex/ms	16.394	15.430	36.112
Fors	82G/05	3	vein	16.351	15.408	36.003
Society Girl	82G/05	2	vein	16.309	15.403	35.999
St. Eugene	82G/05	3	vein	16.339	15.395	35.974
Midway	82G/04	1	vein	17.940	15.564	38.593
Mt. Mahon	82G/04	2	vein	16.339	15.403	35.992
Alice	82F/02	1	vein	16.374	15.417	36.073
Kid Creek (Star)	82F/01	1	vein	16.332	15.406	35.985
Leadville	82F/01	1	vein	16.333	15.411	35.997

Data from Godwin *et al.* (1988).
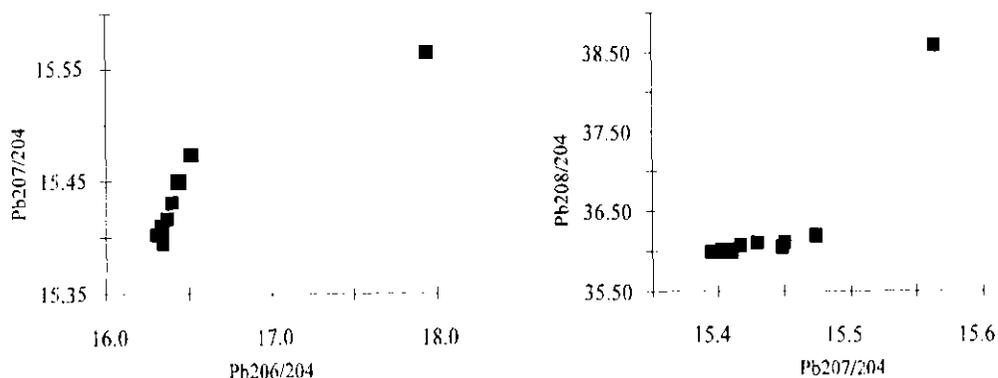
STRATABOUND Cu-Ag DEPOSITS IN MONTANA AND THEIR POTENTIAL IN CRESTON FORMATION

Stratabound copper-silver deposits occur in a narrow belt, the "Western Montana Copper Belt", about 70 kilometres south of Yahk. They include the Spar Lake (Troy), Montanore, and its western extension, the Rock Creek deposit. All three are significant deposits, but only Troy has been mined to date. The regional setting of these low-grade, high-tonnage deposits has been documented by Wells *et al.* (1981). The host Revett Formation, the central part of the Creston Formation, extends northward into the Yahk map area. The deposits formed when warm diagenetic ore solutions migrated laterally through permeable quartz arenite horizons and mixed with cooler pre-ore pore fluids (Hayes *et al.*, 1989). Vertical fluid ascent by water escape structures may also have played a role. Hayes *et al.* discuss the genesis of the Spar Lake deposit in detail.

The **Spar Lake (Troy) mine**, had start-up reserves of 58 million tonnes of 0.76% copper and 54 grams per tonne silver (Balla, 1982). The deposit, discovered in 1963, is hosted by grey-green to white, crosslaminated, well-sorted quartz arenites and siltstones of the Revett Formation, equivalent to the middle Creston. The orebody, 2250 metres long, 550 metres wide and about 20 metres thick, dips gently to the south-southwest (Hamilton and Balla, 1983). A fluviodeltaic environment has been inferred for this sequence. Stratiform and lesser discordant mineralization includes bornite, chalcocite, chalcopyrite, native silver and minor tetrahedrite (Balla, 1982). A pyrite halo surrounds the deposit. Detailed stratigraphy, mineral zonation and sulphur isotope geothermometry are reviewed by Hayes *et al.* (1989).

The continuation of Revett-equivalent stratigraphy north of the border into the Yahk map area indicates the potential for undiscovered deposits in the middle Creston. Although no copper mineralization was noted during the 1993 field season, two occurrences of disseminated hematite and magnetite were discovered. Careful prospecting and analysis of sedimentary facies may well lead to the discovery of significant copper-silver mineralization. Geochemically anomalous copper values are also reported in the eastern part of the basin in the Grinnell Formation, which is correlative with middle Creston Formation (Aitken and McMechan, 1991).

CONCLUSIONS

In summary the study area has:
- atypical lower Aldridge, called Rampart facies, which is indistinct from the middle Aldridge
- deformation and metamorphism that increases to the west of the Arrow Creek fault, marking the transition from the Purcell anticlinorium into the Kootenay Arc
- sedex potential, for example, the nearby Fors occurrence
- a major but unusual iron ore deposit on Iron Range Mountain
- potential for discovery of a stratabound copper-silver deposit in middle Creston stratigraphy

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