PETROLOGY AND SEDIMENTOLOGY OF THE MORRISSEY FORMATION (KOOTENAY GROUP), SOUTHEAST BRITISH COLUMBIA - SOUTHWEST ALBERTA

Petrology and Sedimentology of the
Morrissey Formation (Kootenay Group),
Southeast British Columbia - Southwest Alberta

by

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Abstract

The Morrissey Formation of the Kootenay Group was mapped and sampled in three outcrops in southwestern Alberta and southeastern British Columbia; Burnt Ridge and Sparwood Ridge in British Columbia and Adanac Mine sight in Alberta.

The lowest unit mapped was within the upper Fernie Formation (Passage beds) and consists of interbeds of sandstone and siltstone that were deposited as shallow water marine sediments.

The Morrissey Formation conformably overlies the Fernie Formation and contains two members; the Weary Ridge Member and the Moose Mountain Member. The Weary Ridge Member consists of fine to medium grain, parallel and trough crossbedded sandstone, that was deposited as a delta-front-sand facies produced by coalescing of delta-sands from three to four delta complexes. The overlying Moose Mountain Member consists of high angle trough crossbedded, coarse grain, "salt and pepper" sandstone representing a distributary mouth bar environment. The Moose Mountain Member is unconventional in that the upper portion contains two units not seen in other sections. A marine trace fossil unit and a beach unit are both found within the upper portion of the member. These two units represent a transgression caused by channel switching and a regression and reworking of sediments into a beach respectively.

Above the Morrissey Formation are the continental coals and fluvial systems of the Mist Mountain Formation.

Petrographic studies on twenty-five thin sections show two sedimentary sources for the Formation. The first source being chert rich Upper Paleozoic carbonates and the second source is Lower Paleozoic clastics that have previously been derived from a metamorphic complex of the Canadian Shield. The sandstones are cemented by quartz syntaxial overgrowths implying that there was a moderate degree of pressure solution, indicating a fairly high overburden pressure during diagenesis.

Acknowledgements

I would like to thank Dr. G.V. Middleton for his supervision, both in the summer field season and throughout the year.

Thanks also to Mr. L.B. Samuelson of Kaiser Resources for allowing the use of a four wheel drive truck on weekends to locate and map outcrops.

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Chapter 1

Introduction

The Jurassic-Cretaceous Kootenay Group consists of three formations: the Morrissey Formation, the Mist Mountain Formation, and the Elk Formation (Gibson, 1979). Figure 1-1 shows the correlation of the Kootenay Group with the equivalent in northeast British Columbia.

The studies reported in this thesis were mainly concerned with the Morrissey Formation. The Morrissey Formation consists of two members: the Moose Mountain Member and the Weary Ridge Member. These members correlated with Unit A and Unit B respectively of Gibson (1977).

The Morrissey Formation marks the beginning of the Cretaceous marine regression that closed up a large portion of the seaway in western Alberta (Nelson, 1970). The Morrissey Formation consists of a thick sandstone formation with no major breaks. The sandstone ranges from 20 metres to 80 metres thick and thins eastward. It contains a distinct coarsening upward sequence at all localities. The contact with the Fernie Formation is sharp but conformable. The upper Fernie Formation consists of very fine grained sandstones interbedded with shales and mudstones. The upper contact with the Mist Mountain Formation is found to be sharp but conformable.

The contact between the Weary Ridge Member and the Moose Mountain Member is a sharp transition. The sandstone of Moose Mountain is better

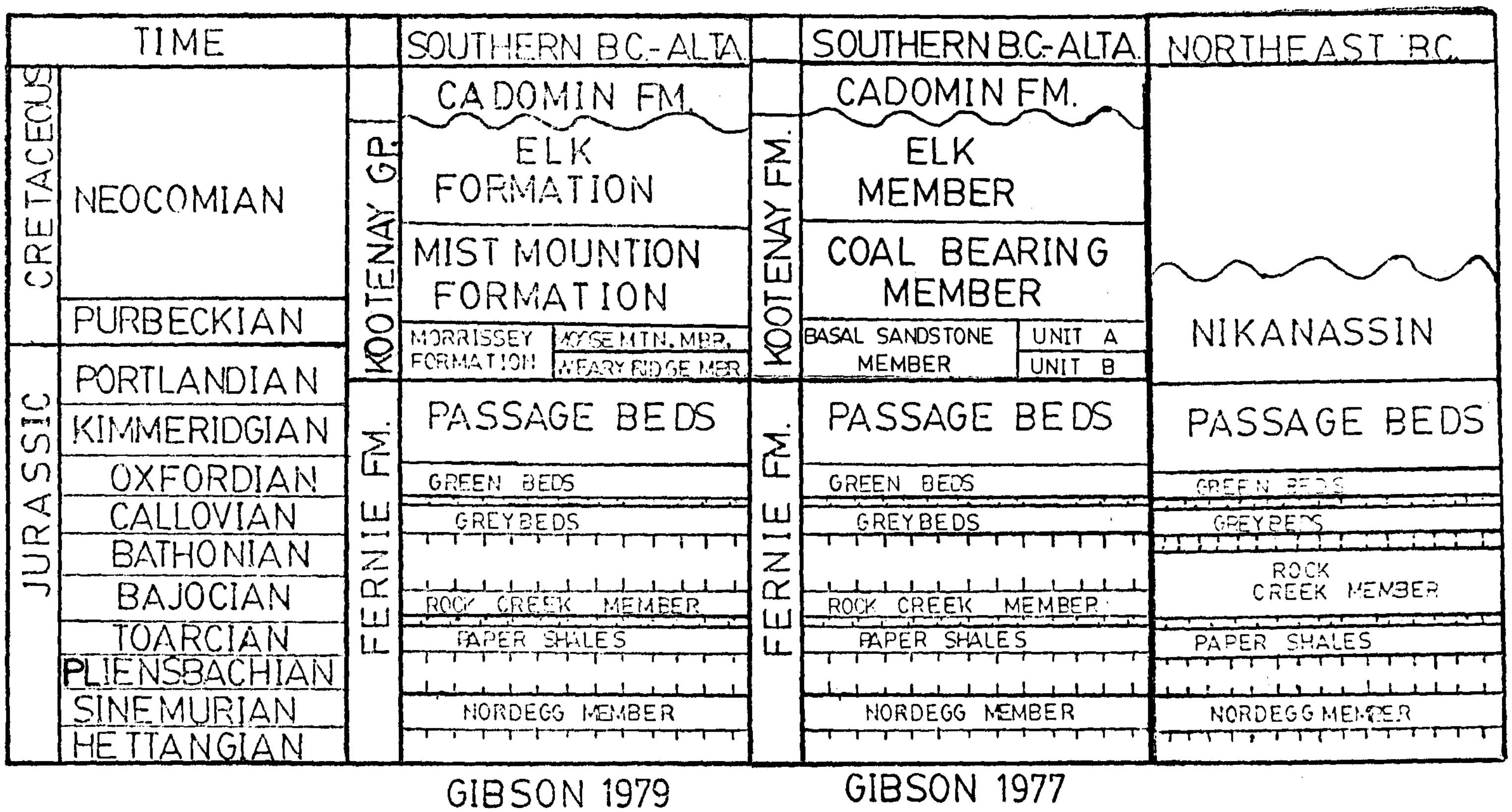


Figure 1-1: Stratigraphic correlation of the Fernie Formation-Kootenay Formation southeast British Columbia northeastern British Columbia. Adapted from Gibson (1979, 1977).

indurated, coarser grained, darker grey (on a weathered surface) and less argillaceous. The Weary Ridge Member sandstones are finer grained, more argillaceous, not as well indurated, orange-brown-grey weathered sandstone. There is also a difference in sedimentary structure between the two members.

High angle (35-40°) trough cross-bedding is the dominant structure in the Moose Mountain Member, whereas in the Weary Ridge Member, although trough cross-bedding is found, it is not as abundant and it frequently dips at relatively low angles (10-20°).

The formation above the Morrissey Formation is the Mist Mountain Formation. The Mist Mountain Formation was previously named the Coal Bearing Member of the Kootenay Formation (Jansa, 1972; Gibson, 1977). The Mist Mountain Formation consists of thick interbedded sequences of grey-brown to dark grey weathered siltstone, shale, conglomeratic to fine grained light grey weathering sandstones, dark grey to organic black concretionary mudstones, and thin to very thick seams of low- to high-volatile bituminous to semi-anthracite - anthracite coals. The thickness of the Mist Mountain Formation in the study area ranges from 80 metres at Adanac Mine to approximately 675 metres at Burnt Ridge. Coal seam thicknesses of up to and over 10 metres were found by the author during summer field work with Kaiser Resources.

To the north within the southern part of Jasper National Park, the Morrissey Formation grades into the lower Nikanassin Formation. The Nikanassian Formation is composed of a sequence of medium to dark grey to yellow-brown weathering siltstone, sandstone, mudstone, shale, and minor thin seams of coal in the more westerly section (Gibson, 1978). The Nikanassian does not show a sharp contact with the Fernie Formation but consists of a thick succession of interbedded sandstone, siltstone, and shale, similar in appearance to strata of the underlying Fernie Formation (Gibson, 1978). The Nikanassian Formation is the marine equivalent of the Morrissey Formation in the northern part of the Rockies and shows that the seaway had not totally disappeared in lowermost Cretaceous time.

Location

The Morrissey Formation outcrops studied are all found in the southern Front Ranges of the Rocky Mountains of southwestern Alberta and southeastern British Columbia. Three outcrops were measured during the summer field season. Figure 1-2 shows the location of outcrops of the Kootenay Group which were mapped and sampled.

Section 1 is located on Burnt Ridge (latitude 50° 00'N, longitude 114° 48' W) in southeastern British Columbia. Burnt Ridge is located on the west side of a north-south trending syncline. Regional strike and dip of the ridge are approximately 10°/40°E. The Ridge contains a complete section of the Kootenay Group. Plate 1-1 shows the entire section from the top of the Morrissey Formation.

Section 2 is Sparwood Ridge (latitude 49° 43'N, longitude 114° 52'W) in southeastern British Columbia. This section is almost directly southeast of Sparwood, British Columbia. Sparwood Ridge is located on the west side of a north-south trending syncline. Minor normal faulting can be

Figure 1-2: Location map showing approximate location of the three section measured.

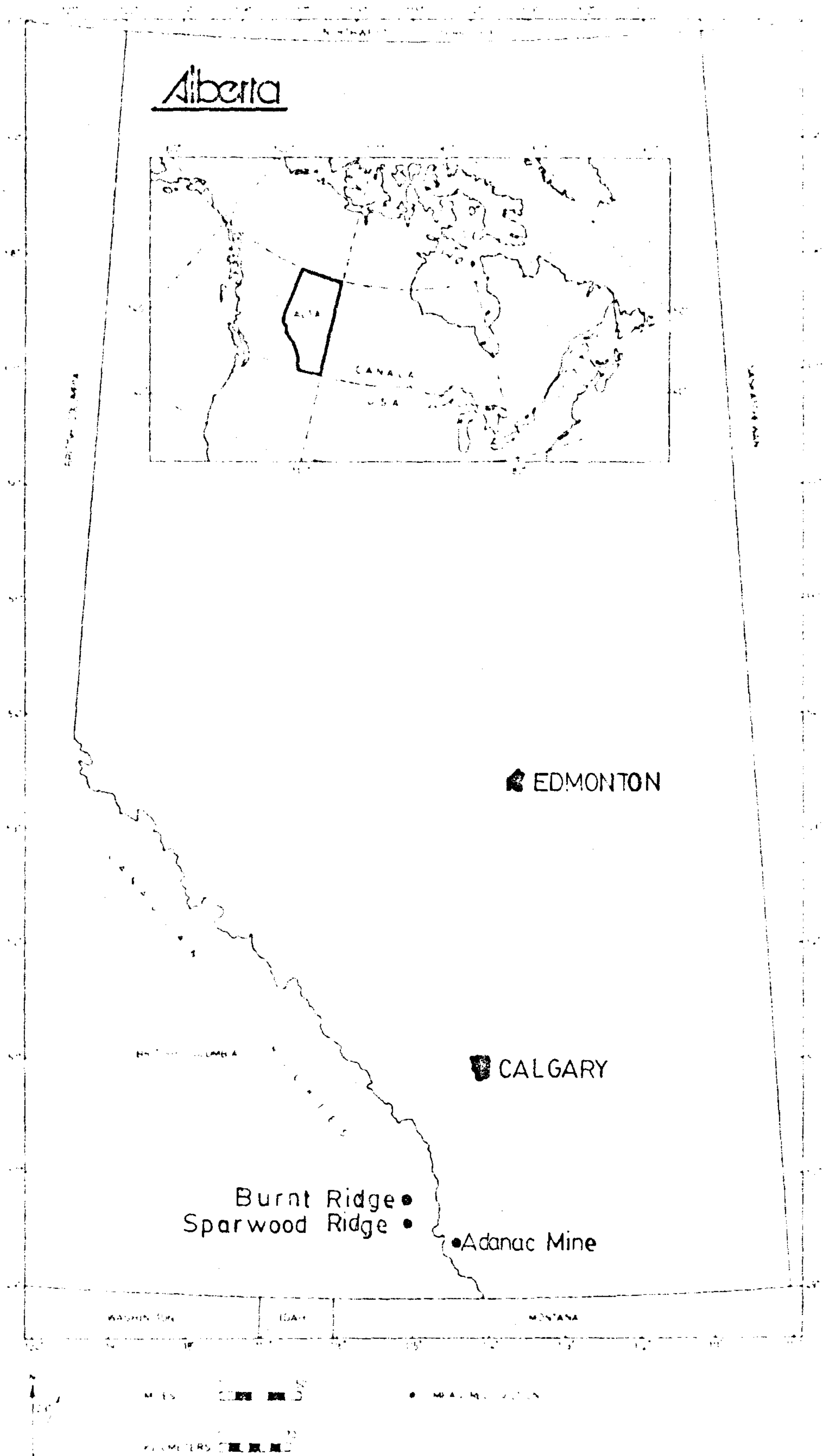

Alberta
CANADA
EDMONTON
CALGARY
Burnt Ridge
Sparwood Ridge
Adanac Mine
MONTANA

Plate 1-1: Morrissey Formation section at Burnt Ridge, British Columbia. Truck in background for scale.

seen in the section: as the displacement by the fault is small, the thickness of the section can be measured accurately. The regional strike and dip of the Sparwood Ridge section is 179°/39°E. Plate 1-2 shows the complete measured section on Sparwood Ridge.

The third measured section is found at an old coal mine in southwestern Alberta. Adanac Mine is located 15 km southwest of Hillcrest, Alberta. Adanac Mine is at latitude 49° 30'N and longitude 114° 24'W. The Adanac Mine section is located on the southern part of the west limb of the north-south trending anticline plunging to the south. This section is overlaid unconformably by the Cadomin Formation of the Blarimore Group: the Elk Formation of the Kootenay Group has been eroded away. The regional strike and dip of the Adanac Mine section is 155°/34° SW. The section is shown in Plate 1-3.

Of the three outcrops, Sparwood Ridge and Burnt Ridge are located on the Lewis thrust sheet, whereas the Adanac Mine outcrop is located on the Livingstone thrust sheet to the east. A palinspastic reconstruction of the original area of deposition would suggest movement of the thrust sheet 60 to 70 kilometres for the Livingstone thrust sheet and 100 to 110 kilometres for the Lewis thrust sheet (Jansa, 1972).

Objectives

The basic objective of this study is to examine the petrology of the Morrissey Formation and thus be able to determine the provenance of the formation.

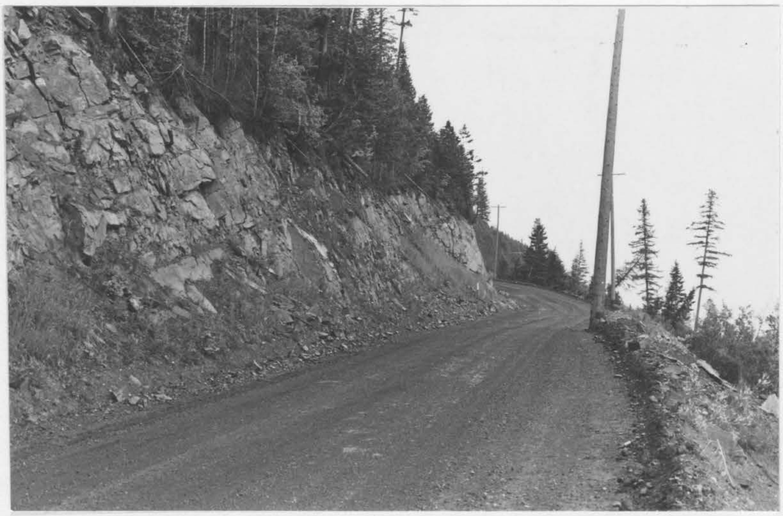


Plate 1-2: Morrissey Formation section at Sparwood Ridge, British Columbia.

Plate 1-3: Morrisey Formation section at Adanac Mine, Alberta. Austin Mini in background for scale.

The second objective of the study was to map the Formation sedimentologically and to make a detailed facies analysis of the outcrops studied in order to determine the ancient environment of deposition of the Morrissey Formation. During the summer, the sections were measured and described. At the same time samples were taken at known intervals for thin section analysis. In total, 25 thin sections were analyzed.

Previous Work

The Kootenay Formation was first described by its position relative to the higher formations of the Cretaceous system, and by the fossil plants which it contained (Dawson, 1886). After this time, there have been countless classifications and reclassifications of the Kootenay. Cairnes (1914) defined the base of the Kootenay Formation as a "Brown prominent sandstone bed". This description of the Kootenay, if used today, would define the base of the Kootenay as the base of the Weary Ridge Member of the Morrissey Formation. Again in 1917, the area was mapped, and the base of the Kootenay was defined as the base of the massive grey sandstone (Rose, 1917). The basal sandstone of the Kootenay was named the Moose Mountain member of Beach (1943) but this definition of the Moose Mountain member is equivalent to todays entire Morrissey Formation (Gibson, 1979). This can be seen by a quotation from Beach (1943): "The Moose Mountain Member varies in thickness from 40 to 60 feet and rests upon the eroded surface of the Fernie Formation". Beach described the Moose Mountain as "essentially one massive bed of very dark grey to dull black medium to coarse grained bituminous sandstone, having little or no bedding".

The first good indication of the age of the Moose Mountain Member was made by Bell (1944) as a result of a paleobotanical investigation. Further evidence of the age of the Kootenay resulted from identification of pelecypods 8 metres above the base of the Moose Mountain Member by Allen and Carr (1947). The data collected showed the age to be Late Jurassic.

In 1953, an extensive report on the coal fields of southeastern British Columbia was published (Newmarch, 1953). In this report the Kootenay Formation was divided into the basal sand and the coal bearing members. For reasons unknown, the contact of the Basal Sandstone Member with the Fernie Formation below was placed within the thick sandstone and not at its base.

A large amonite was also found by Newmarch (1953) and identified as Titanites occidentalis by Frebold (1957); the age was determined to be Jurassic (Portlandian). Westermann (1966) re-examined the amonite and re-confirmed the age to be Portlandian. Norris (1959) divided the Kootenary into four distinct members: Mutz, Hillcrest, Adanac, and Moose Mountain. Once again the Moose Mountain contact with the Fernie passage beds was placed somewhere within the large basal sandstone and not at the base of it. The members proposed by Norris (1959) were found by later workers not to be distinct throughout all of the southern Rockies.

Pocock (1964) stated that only the Moose Mountain member can be consistently identified away from the type section at Grassy Mountain. The other members have no significance except in the area around Grassy

Mountain. Norris (1964) suggested a shallow-water marine (beach?) environment for the Moose Mountain of the Kootenay.

Jansa (1972) produced the first intensive study of the facies of the Kootenay Formation. Once again, for no apparent reason, the base of the Kootenay (Moose Mountain Member) was assigned to a position within the passage beds of the Fernie Formation. Jansa also placed the top of the Moose Mountain within the Coal Bearing Member as he descirbed shales. In the upper Moose Mountain (Jansa, 1972), the facies interpretation put forward for the Kooenay was channel fill and point bar systems for the upper Moose Mountain and the lower Moose Mountain Member represented delta front sheet sands (Jansa, 1972). The Fernie passage beds below represent pro-delta environments, indicating shallow neritic conditions (Jansa, 1972).

Gibson (1977) re-defined the base of the Kootenay as the first sandstone with no siltstone, shale or mudstone breaks. This allows for easy subsuface and outcrop identification of the Moose Mountain Member. He also re-named the Member the Basal Sandstone Member and broke the Member into two distinct units, A and B. Lithological differences have been discussed previously. Sedimentologically, his facies interpretation of the Basal Sandstone Member was as a distributary-mouth bar delta front sheet sand deposit, due to the large geographical extent of the Member. The lower sandstone of the Basal Sandstone was then re-interpreted by Hamblin (1978) and Hamblin and Walker (1979) as a beach deposit. The upper units was thought to represent a fluvial braided river system (Hamblin and Walker, 1978). The latest published work (Gibson, 1979) redefined the nomenclature of the Kootenay Formation. The formation has become a Group with the Moose Mountain-Basal Sandstone Member becoming the Morrissey Formation comprised of the Weary Ridge Member and the Moose Mountain Member. The Coal Bearing Member is now defined as the Mist Mountain Formation and the Elk Member is now the Elk Formation (Gibson, 1979).

Geological Setting

The Jurassic-Cretaceous Kootenay Group was deposited as a result of the tectonic uplift of the Coast Range Orogeny. The orogeny caused the uplift of all of the Paleozoic and Lower Mesozoic sediments above sea level and started the erosion which produced all of the clastic supply of the Cretaceous period. The Nikanassian Sea that had covered most of the southern parts of Alberta and British Columbia since the Proterozoic, retreated northwards due to the advance of the thick clastic wedge of the Kootenay which prograded into the basin. The Jurassic-Cretaceous climate was tropical. The paleolatitude of southern Alberta was somewhere between 40°and 50°N (Couillard and Irving, 1975). The wind direction of the time was estimated to be temperate westerly wind belt (Gordon, 1974). Land plants and trees fluorished in the swampy lands behind the regressing seas producing the thick coals of the Mist Mountain Formation.

Chapter 2

Facies Descriptions

The facies descriptions presented in this thesis are a result of field data collected from all sections. Facies are based on lithology, grain size and sedimentary structures including bioturbation.

The vertical sections of each of the three outcrops in Figure 2-1 show grain size variations, lithology, sedimentary structures, and bioturbation present within each of the facies.

In the following descriptions, colour refers to weathered outcrops unless otherwise specified.

Facies A: Sandstone-Siltstone Facies - Fernie

Facies A is the lowest encountered in all three sections. This unit consists of dark grey to rust coloured sandstone units interbedded with dark brown siltstones (Plates 2-1, 2-2). The sandstone units range from one to three metres thick with an average thickness of 1.5 metres. The sandstone:siltstone ratio increases from 1:4 at the base to 4:1 at the top of the facies. This transition occurs within 15 metres of the measured section of this facies. The grain size of this unit is very fine (10-12 grains/mm) with abundant clay matrix (10-15%). Minor calcite is also present in these sandstones. Sandstone beds in the lower outcrops of the facies have sharp bases and contain incomplete Bouma sequences

Figure 2-1 : Vertical sections and correlations of the Morrissey Formation, southern Rocky Mountains.

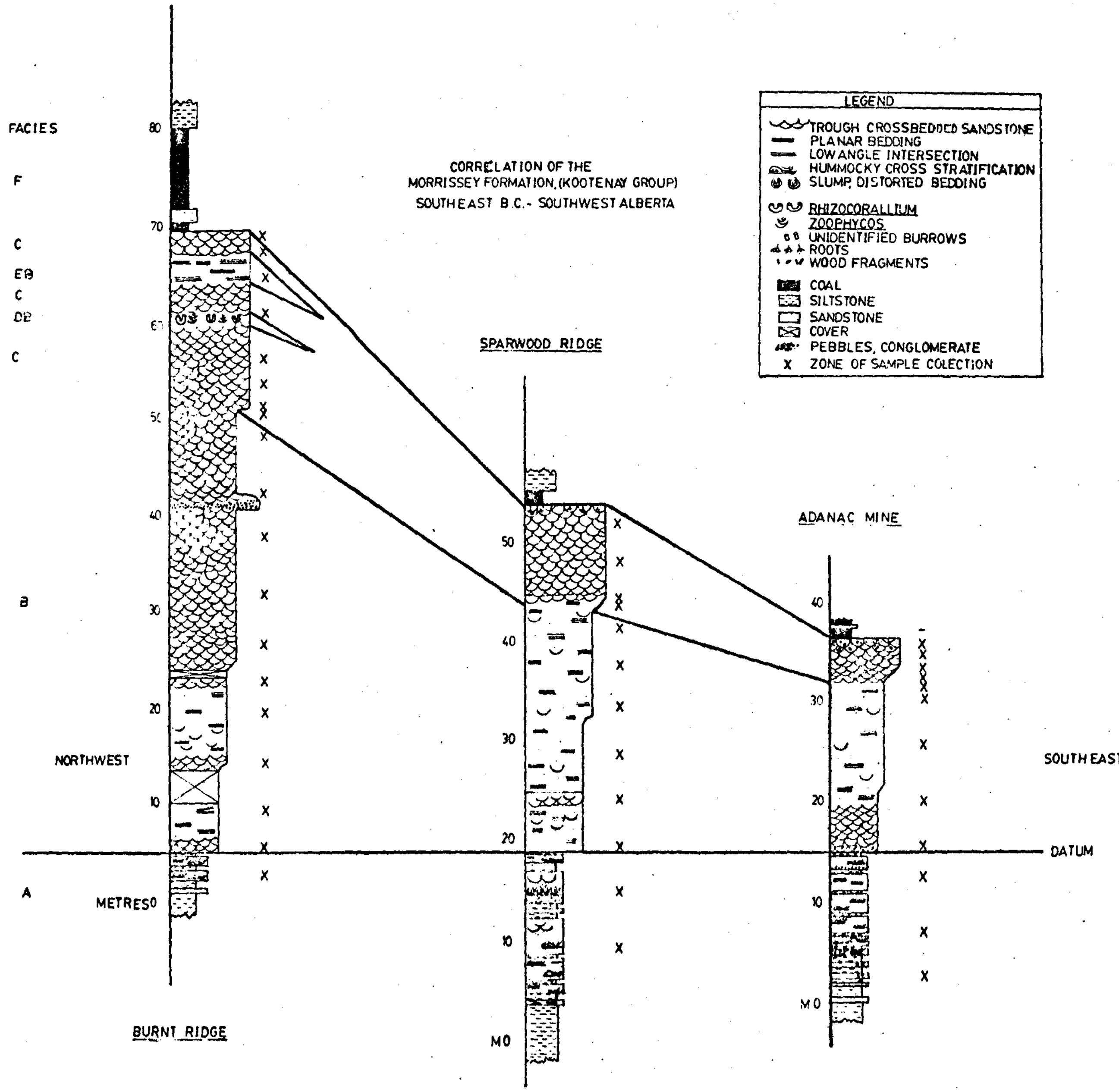

CORRELATION OF THE
MORRISSEY FORMATION, (KOOTENAY GROUP)
SOUTHEAST B.C.- SOUTHWEST ALBERTA
LEGEND
TROUGH CROSSBEDDED SANDSTONE
PLANAR BEDDING
LOWANGLE INTERSECTION
HUMMOCKY CROSS STRATIFICATION
SLUMP, DISTORTED BEDDING
RHIZOCORALLIUM
ZOOPHYCOS
UNIDENTIFIED BURROWS
ROOTS
WOOD FRAGMENTS
COAL
SILTSTONE
SANDSTONE
COVER
PEBBLES, CONGLOMERATE
X ZONE OF SAMPLE COLECTION
FACIES
F
C
EB
C
DB
C
B
A
NORTHWEST
METRES
BURNT RIDGE
SPARWOOD RIDGE
ADANAC MINE
SOUTH EAST
DATUM

Plate 2-1: Facies A. Location is Adanac Mine section. Thin interbeds of siltstone and sandstone. Field book for scale.

Plate 2-2: Facies A. Location is on Burnt Ridge. Thicker sandstone interbeded with siltstone. Hammer is used for scale.

(divisions B and C, i.e. plane parallel laminae and ripples, wavy or convoluted laminae respectively: Bouma, 1962).

All of the sandstone units show a fining upward sequence and at the top of the bed they grade into siltstones and the cylce repeats itself. Sole marks were found on the bases of some of these beds. The sole marks consisted of woodchips, grooves and prod marks but no orientations could be determined on any of the ones found.

The top three to four metres of sandstone contain, as previously stated, much higher ratios of sandstone:siltstone (4:1). Sedimentary structures present in these sandstones include parallel to low angle divergence sets and broadly curving sets of laminations (Plates 2-3, 2-4).

The broadly curing sets of laminations are termed Hummocky Cross Stratification (Fig. 2-2) and the major characteristics of this structure are described by Harms et al. (1975) as follows:

1) lower boundary surface of sets are erosional and commonly slope at angles less than 10 degrees with a maximum of 15 degrees.

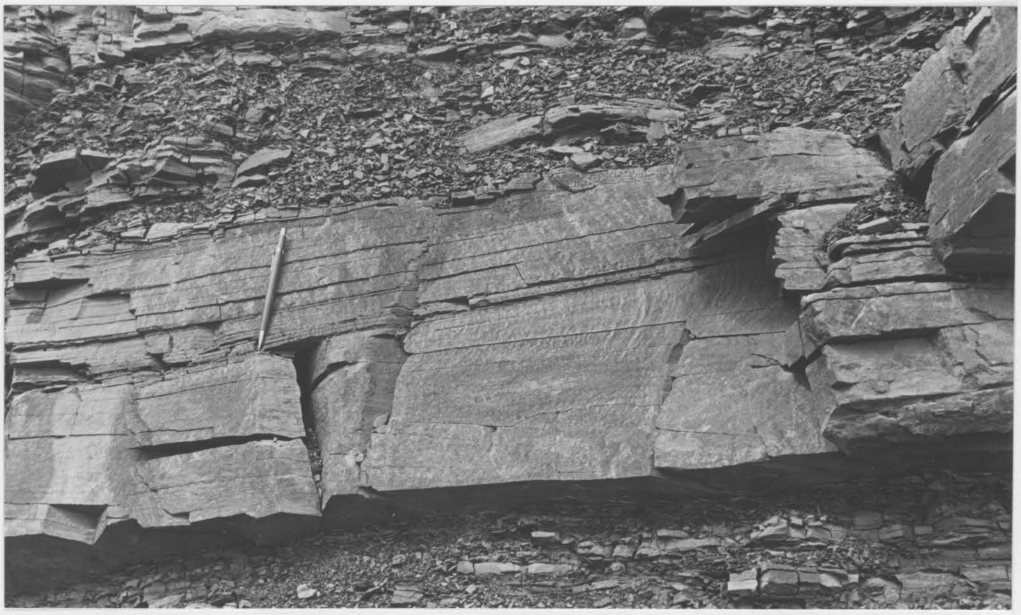
2) laminae above these erosional sets boundaries are parallel to the surface, or nearly so.

3) laminae can systematically thicken laterally in a set, so that their traces on a vertical surface are fan like and dip diminishes regularly.

4) the dip directions of the erosional sets boundaries and of the overlying laminae are scattered. The characteristics suggest that during deposition the bed was scoured into low hummocks and shallow swales not well organized in orientation. This topography

Plate 2-3: Facies A. Hummocky cross-stratification. Note broadly curving sets of lamination. Location is Adanac Mine sight. Scale is one metre.

Plate 2-4: Facies A. Hummocky cross-stratification. Pencil is used for scale. Tip of pencil defines large hummock. Location is Adanac Mine sight.



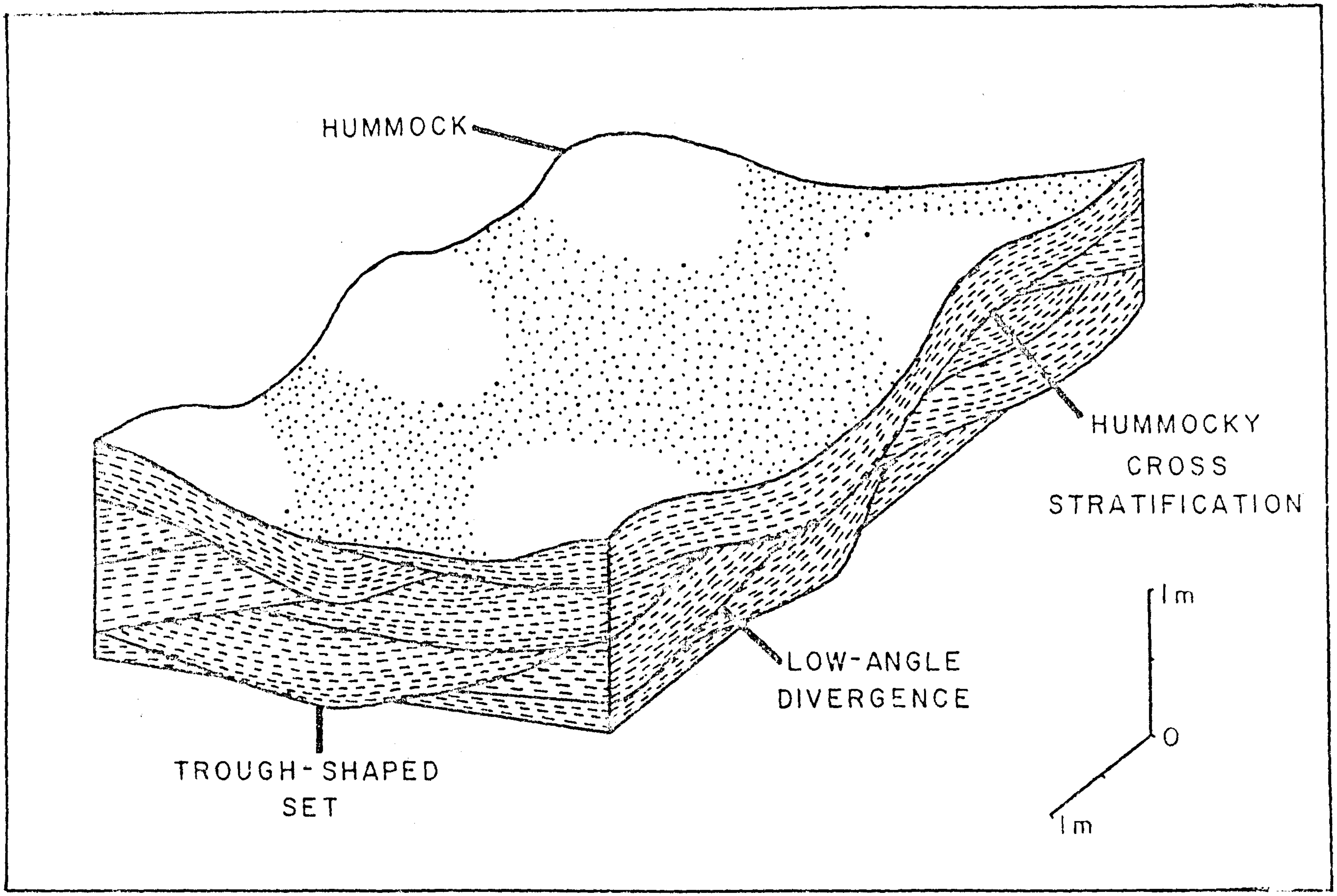


Figure 2-2: Schematic block diagram of Hummock Cross Stratification. Adapted from Hamblin, 1978.

was then mantled by laminae of material swept over the hummocks and swales. In terms of scale, hummocks are 10 to 50 cm high and spaced one to a few metres apart. The base of hummocky cross stratified layers are commonly sharp and may have drag or prod marks at contacts with underlying clay rick beds. The tops may have ripples.

No ripples were found in the sections measured. All the tops of the beds were sharp except for minor ones which were bioturbated and thus had gradational boundaries.

At the Sparwood Ridge section a unit of ball-and-pillow soft sedimentary deformation is found within one of the hummocky cross-stratification units (Plate 2-5). This structure was not found at the other two sections measured but has been found in the same facies at a section north of the study area (Hamblin, 1978).

Facies B: Planar-Trough Cross Bedded Sandstone

This facies is the thickest one in all three sections. Its thickness is 46 metres at Burnt Ridge, 19 metres at Adamac Mines, and 25 metres at Sparwood Ridge. The facies is a solid sandstone with no siltstone or mudstone breaks (Plates 2-6, 2-7). The sandstone itself is fine grained at the base and increasing to medium grained at the top. It is light-dark grey sandstone which weathers to a rust colour. It has fairly high induration and calcite is also present in the lower portions of this facies.

Plate 2-5: Facies A. Soft sedimentary deformation. Pencil is located on the top of the structure. Location is Sparwood Ridge.

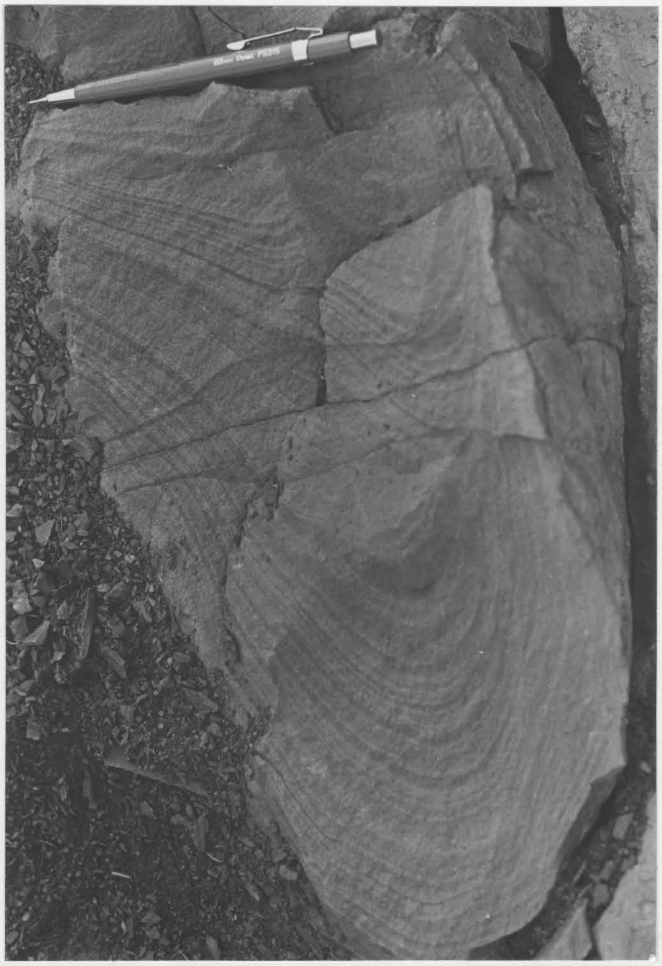


Plate 2-6: Facies B. Planer-trough crossbedded sandstone. Location is at Adanac Mine sight. Field note book is for scale.

Plate 2-7: Facies B. Planer-trough crossbedded sandstone. Location is on Sparwood Ridge. Thickness of section seen is 10 metres.

The lower boundary with facies A is sharp at all three sections. At this boundary there is a slight increase in grain size. Sedimentary structures found in this unit are not extremely abundant in the Adanac Mine or Sparwood Ridge sections but are abundant in the Burnt Ridge section. In the Sparwood Ridge and Adanac Mine sections there are planar to low angle divergent sets and also found are small to medium scale trough cross-beds. In these two sections, there are many more planar to low angle divergent beds than there are trough cross-beds.

In the Burnt Ridge section we see the reverse case. Trough cross-bedding (Plate 2-8) is the primary sedimentary structure found and planar low-angle divergent beds are much less common. Also found in the Burnt Ridge section are two conglomerate layers (Plates 2-9 and 2-10). The maximum thickness of the major conglomerate layer is 20 cm and the conglomerate is laterally consistent. No bioturbation was found in this facies. Minor coal fragments were found at both the Adamac Mine and the Burnt Ridge sections. Clay rip-up clasts were also found in the lower portion of the Adanac Mine section.

The upper boundary of this facies is sharp but conformable. The change is accompanied by distinct changes such as colour changes, grain size change from medium to coarse, and a great change in induration.

Facies C: Trough Cross-Bedded Sandstone

This facies consists of medium to coarse grained rock. The rock is dark grey in colour and still weathers to rust colour but the rust colour is not concentrated as in the lower facies. This rock is much better

Plate 2-8: Facies B. Large trough within the facies. Location is on Burnt Ridge. Metre stick is used for scale.

Plate 2-9: Facies B. Conglomeratic bed. Note sharp base and fining upward. Location is on Burnt Ridge. Field book for scale.

Plate 2-10: Facies B. Another view of conglomeratic bed. Note that bed is fairly uniform in thickness. Field book is used for scale.


6
5
4
3
2
1
335-8360
FIELD
BOOK

indurated and pebbles are occasionally found throughout the section with minor conglomeratic stringers at the top of the facies at each unit. The lithology of this facies is a "salt and pepper", which, by definition, is composed almost entirely of quartz and chert. The sedimentary structures present within this unit are medium to large scale trough cross-bedding (Plate 2-11). This trough cross-bedding is at a much higher angel than in the lower facies. No fining upward sequences were recorded at any of the outcrops measured. At lower contact with facies B, there is a change in grain size, induration, and sedimentary structure but there is no break in the sandstone: it is continuous.

Bioturbation cannot be seen in any of the sections. Rootlets were found at Sparwood Ridge and Adanac Mine right at the very top of the facies, but not at Burnt Ridge.

A large ammonite of genus <u>Titanites sp</u>. was found at the top of the facies by Newmarch (1953) at a section on Coal Creek about 18 km to the west of the Sparwood Ridge section. Ammonite fragments were also found by Hamblin (1978) and are believed to be from the same genus as the ones found at Coal Creek. Contact with the upper facies is abrupt. Coarse grained sandstone ends and is followed by coal of facies F.

Burnt Ridge is unusual in that it contains the two facies described below, which are not found in the other two measured sections nor in sections published by other authors.

Facies DB: Marine Trace Fossil

This facies is present only within the Burnt Ridge section. The facies is 75 cm thick and there is no lithologic change from facies C.

Plate 2-11: Facies C. Trough crossbedding. Note minor pebbles also seen in the photograph. Pencil indicates top. Location is on Burnt Ridge.

Two distinct trace fossils are found within this facies. Zoophycos (Plate 2-12) is found along with Rizochrallium (Plates 2-13, 2-14). These two fauna are found together, possibly with other unidentified worm burrows. Well preserved fossils were found only in the lower 50 cm of the section although bioturbation can be seen through the entire 75 cm of the facies. The lower contact is abrupt with the underlying facies. The upper contact is gradational back into two metres of facies C.

Facies EB: Parallel Bedded Sandstone

The next facies up in the Burnt Ridge section has the same lithology as facies C - coarse grained with a few pebbles. The sedimentary structures present in this facies are parallel beds with occasional very low angle divergence in some areas of the facies (Plates 2-15 and 2-16). The lower contact is sharp with only a change in sedimentary structure present. The upper boundary is also sharp and goes back into facies C. The thickness of the facies is 3 m. Wood fragments are found in this facies along with bioturbation in one portion of the facies by unidentified worms (Plate 2-17).

Facies F: Coal, Siltstone, Mudstone, Sandstone

This facies consists of coal, siltstone, mudstone, and sandstone beds. The lower contact with facies C is abrupt at all three sections and proceeds into a coal unit 2 m in thickness. This is followed by a siltstone-mudstone unit. The coal in this facies consists of Durain and Clarian with occasional Vitrain bands within the beds. The coal

Plate 2-12: Facies DB. _Zoophycos_ burrow. Note the definite direction of movement downward. Pencil is used for scale. Location is on Burnt Ridge.


0.5mm Pentel PS315

Plate 2-13: Facies DB. *Rizochrallium* burrow. Pencil is lying on the bottom of the bed. Location is on Burnt Ridge.

Plate 2-14: Facies DB. *Rizochrallium* burrows. The photograph is of the base of the bed. Pencil is used for scale. Location is on Burnt Ridge.

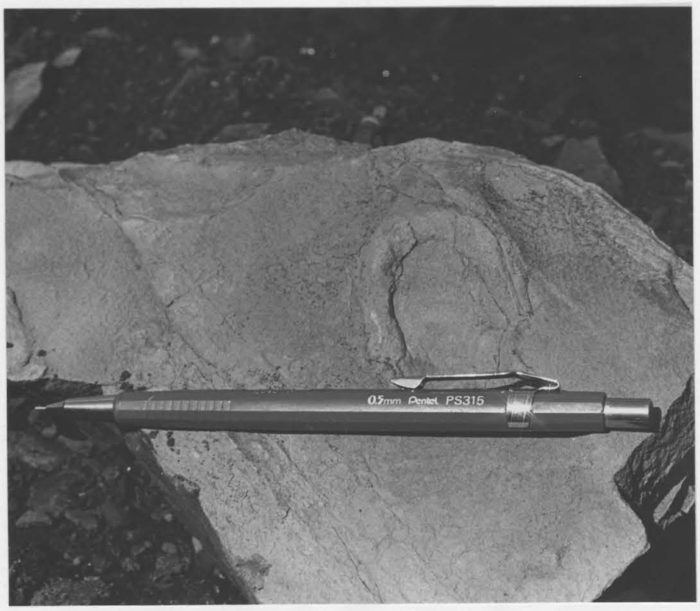

0.5mm Pentel PS315

Plate 2-15: Facies EB. Parallel bedded sandstone. Pencil indicates up direction. Location is on Burnt Ridge.

Plate 2-16: Facies EB. Parallel bedded sandstone. Pencil indicates up direction. Note pebbles present in sandstone. Location is on Burnt Ridge.

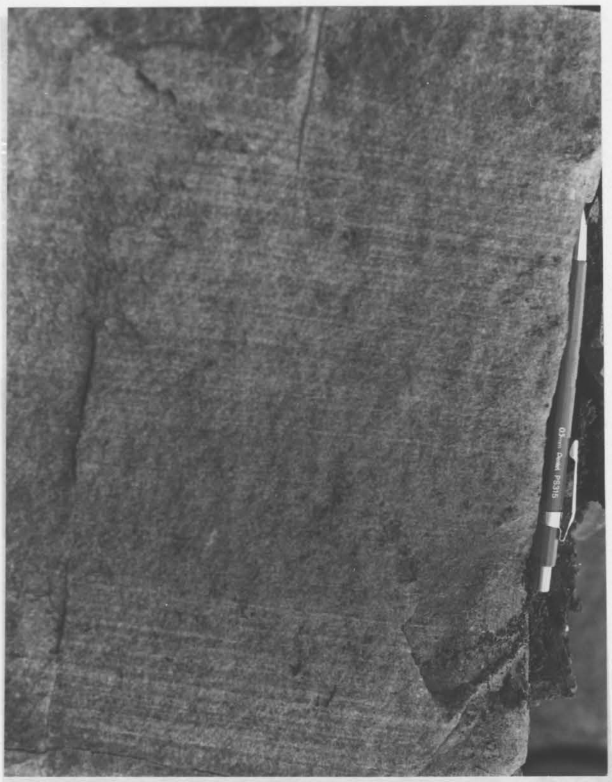
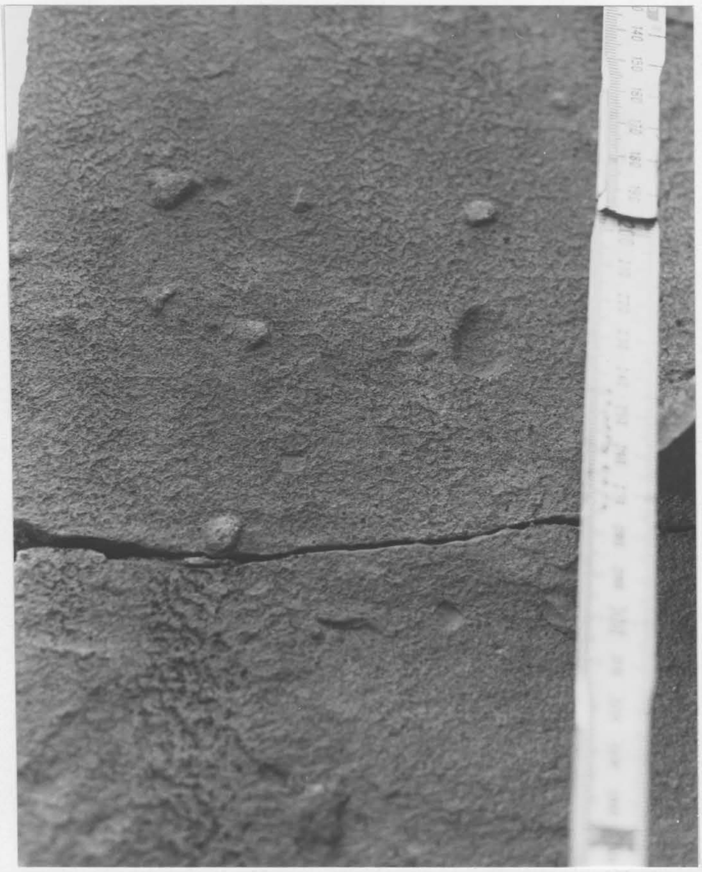


Plate 2-17: Facies EB. Unidentified warm burrows. Photograph is from base of bed. Location is on Burnt Ridge. Metre stick for scale.



is low to medium volatile bituminous. The rank of the coal decreases with height in the section just as the volatile amount increases with the height in the section.

Siltstones-mudstones range from brown to organic black with or without carbonaceous material. In the siltstones, wood fragments, fern impressions, grasses, leaves, and even tree imprints have been observed.

Bioturbation by animals also occurs in the siltstones-mudstones of this facies. Concretions can also be found in some of the units.

Sandstones of the facies range from very coarse grained conglomeratic to very fine grained. The lithology of all sandstones is salt and pepper. Within some of the sandstone are conglomerate lenses with green chert pebbles as the major constituent.

Chapter 3

Petrology

Method

Fourty-four samples were collected in the field from all three sections mapped. Thin sections of 25 of these samples were made. The thin sections were all cut normal to the bedding.

Several types of petrographic studies were used as the basis for the determination of providence. The major study was to determine the composition of the thin sections and percentages of each mineral.

The petrographic composition of each slide was determined by microscopic identification of 500 points using a stage point counter.

The next analysis of the thin sections was to count only quartz grains. This procedure was to count the four basic types of quartz grains found in sedimentary rocks (Basu et al., 1975). The four types of quartz are as follows: 1) non undulose quartz is quartz that requires less than 5 degrees of stage rotation to cause all parts of the grain to become optically extinct; 2) undulose quartz is quartz which needs more than 5 degrees of stage movement for all parts of the grain to become optically extinct; 3) polycrystalline quartz which is distinguished from quartz by containing numerous small crystals within the original grains. The number of crystal units within the polycrystalline grains is related to the source rocks of the polycrystalline quartz. Polycrystalline quartz grains containing two to three crystal units per grain have been shown to be most probably derived from a plutonic source (Basu et al., 1975). Most quartz grains derived from a polycrystalline gneissic rock contain more than three crystal units per grain. A double triangular diagram can be constructed consisting of the four variables: undulose, non-undulose, polycrystalline (2-3 crystal units per grain) and, polycrystalline (more than 3 crystal units per grain). Plotting a sandstone on this diagram indicates the probable source rock as metamorphic or plutonic.

Other studies made on the sections include research of the heavy mineral content of the rock in order to determine roughly the zircon-tourmaline-rutile (ZTR) index (Hubert, 1962) of the Morrissey Formation. The ZTR index is the ratio between the abundance of the mineral species zircon, tormaline, and rutile and the total abundance of non-opaque heavy minerals found within the rock. Thus the relationship SX/ST x 100% where: SX = abundance of ZTR minerals, ST = total abundance of non-opaque heavy minerals. The ZTR index allows a classification of sandstone based on the maturity of the accessory heavy mineral suite which is present.

Average grain sizes were estimated for all of the thin sections and also for the samples which were not cut for thin sections. This information shows a consistent grain size increase vertically in the section. Textural aspects of the thin sections were also observed. The framework grains of eight thin sections were point counted to 100 points. The relationship between the grain boundaries is directly related to the type of compaction and cementation involved with the rock (Pettijohn et al., 1972).

Results

Components. The estimated mineral types and their abundances are found in Table 3-1. The rock is composed of quartz, chert, sedimentary rock fragments, clays, and heavy minerals.

Rock Fragments. There are three major types of rock fragments found in the thin sections. Mudstone/shale rock fragments are by far the most common fragments found (Plate 3-1). They consists of brown translucent grains that are well rounded and very fine grained. Also found are siltstone rock fragments which are lighter in colour and are a coarser grain size than the mudstone fragments (Plate 3-2). There are considerably fewer of these types of fragments found in all of the sections. The third type of rock fragment found is carbonate rock fragments (Plate 3-3). These are composed of high birefringent grains of carbonate which often contain abundant secondary hematite staining. Some euhedral crystals are present in some of the grains. No evidence of fossils was found in any of the carbonate grains.

Chert is the most abundant of all of the sedimentary rock fragments (Plate 3-4). The chert present ranges from coarse crystalline to cryptocrystalline with minor amount of microcrystalline chalcedony present in every thin section studies (Plate 3-5). No fossiliferous spicules were seen in any of the chert. The chert is well rounded and often is iron stained on the outer surface of the grain. Minor amounts of light brown to dark brown phosphatic chert are also found in some of the thin sections. Chert content increases with grain size in the section.

Table 3-1

Pointcounts: Per Cent Minerals

	quartz	chert	clays	carb. R.F.	MDSN, SLSN, R.F.	matrix	heavies	hem.	total %
				Burnt Ridge					
BR-19	63.2	23.0	2.4	0	11.0	0.2	0	0.2	100
BR-18	58.8	29.8	2.0	0	8.1	0	0.2	0.2	100
BR-17	44.0	40.4	4.0	0.2	10.8	0.2	0	0.6	100
BR-13	35.8	45.0	4.0	3.6	10.0	1.0	0.2	0.4	100
BR-12	52.6	24.8	9.0	0	9.6	1.0	0.4	3.6	100
BR-10	50.8	20.0	17.4	.6	7.0	1.8	0.2	1.4	100
BR-8	53.4	9.0	20.2	4.6	6.6	3.0	0.2	2.4	100
BR-6	51.6	11.8	16.8	12.0	5.2	1.2	0.4	1.0	100
BR-4	56.2	7.0	16.0	10.8	4.6	3.6	1.0	0.8	100
BR-2	43.6	4.4	28.4	10.0	6.4	3.0	.6	3.6	100
				Adanac Mine					
AM-12	62.6	23.2	6.8	0	7.2	0	0.2	0	100
AM-11	48.2	36.6	2.4	0	12.2	0	0.2	0.6	100
AM-10	66.8	10.6	10.8	0	7.4	0.6	0.2	3.6	100
AM-9	55.0	26.0	4.4	0.2	13.2	0.4	0	0.2	100
AM-8	39.2	38.2	6.2	0	14.6	1.0	0	0.8	100
AM-7	48.4	19.6	23.8	0	3.4	2.4	0	2.4	100
AM-6	56.4	10.6	20.5	0.2	7.0	3.2	0.2	0.8	100
AM-5	60.0	7.2	23.2	0	3.6	0.4	0.4	4.4	100
AM-4	63.4	4.0	24.0	0.2	2.4	2.0	0.4	3.6	100
AM-2	63.0	6.6	20.0	1.6	1.4	3.2	1.0	3.0	100

Table 3-1

(cont'd)

Poincounts: Per Cent Minerals

	quartz	chert	clays	carb. R.F.	MDSN, SLSN, R.F.	matrix	heavies	hem.	total %
				Sparwood Ridge					
SR-12	43.2	33.0	4.6	0	19.0	0	0	0.2	100
SR-11	50.4	18.0	5.0	8.8	14.3	1.0	1.0	1.6	100
SR-10	61.2	11.2	9.2	9.2	7.0	1.0	0	1.2	100
SR-6	54.6	3.0	13.0	20.0	5.6	1.0	0.4	2.2	100
SR-3	49.2	9.4	11.8	12.4	12.0	0.2	1.0	2.2	100

Plate 3-1: Mudstone rock fragments in centre of photograph. Thin section number SR-6. Magnification 250.

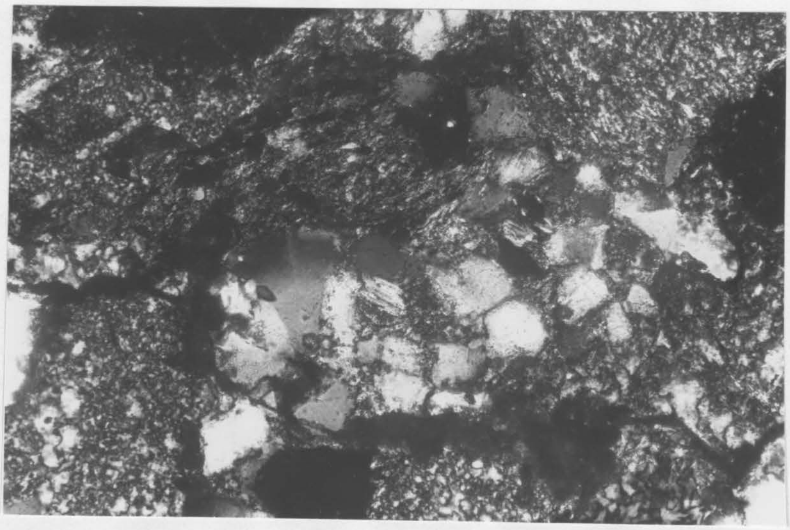


Plate 3-2: Siltstone rock fragment in centre of photograph. Surrounded by chert and mudstone rock fragments. Thin section number AM-9. Magnification 63.

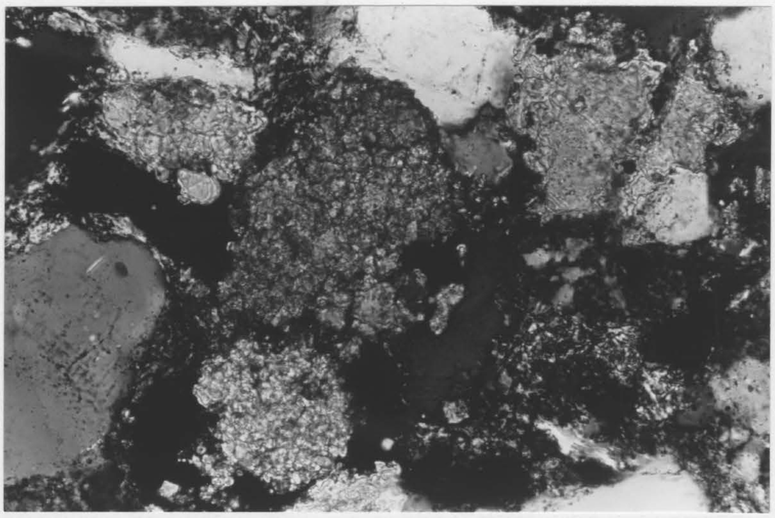


Plate 3-3: Carbonate rock fragments in centre of photograph. Around rims of fragments is secondary hematite staining. Thin section number SR-6. Magnification 250.

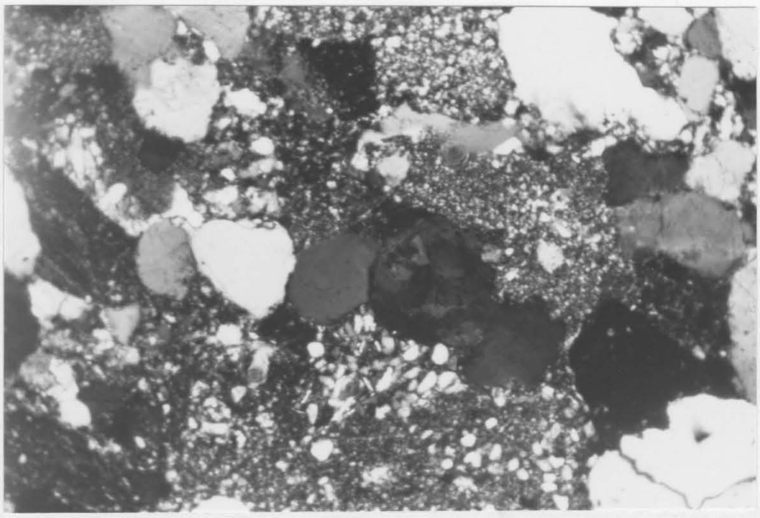


Plate 3-4: Chert. Found throughout photograph. Thin section number SR-6. Magnification 250.

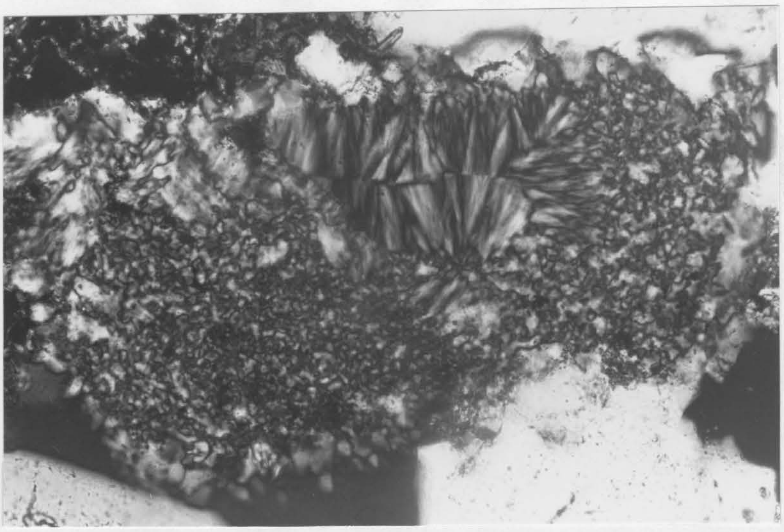


Plate 3-5: Chert variety. Chalcedony within large chert grain. Radiating structure is indicative of Chalcedony. Thin section number SR-11. Magnification 250.

The clay content of these thin sections is fairly large and thus detrital and authigenic clays are undistinguishable from one another in most cases. Detrital clays are found crushed around and between grains. They are usually compacted and thus can be shown to be primary. Authigenic clays fill the interstices of the rock not previously filled before diagenesis. The authigenic clays found in the thin sections include kaolinite, illite, and chlorite.

The kaolinite (Plate 3-6) can be distinguished by its low birefringence (first order grey white) and by the booklet shape seen in some of the grains. Illite (Plate 3-7) can be distinguished by high birefringence, and a very unstructured nature. Chlorite (Plate 3-8) is distinguished by its pleochroism (green) and also its very low birefringence allows for distinguishing it from high birefringent glauconite.

Quartz occurs in many forms in the Morrissey Formation. Grains of quartz are the most common mineral found, but along with the grains of quartz are syntaxial overgrowth cement. In all of the thin section studies, many overgrowths were found (Plate 3-9). The quartz grains themselves consist of three major types: non-undulose (Plate 3-10), undulose (Plate 3-10), polycrystalline (Plate 3-11). Other features of the quartz are the amount of vacuoles and inclusions. Inclusions of rutile needles were found in a few of the quartz grains. Inclusions of heavy minerals were found in some of the grains but are not very common. The apparent roundness of the grains, is, in general, angular to subangular but it is not indicative of the true nature of the grains. Because syntaxial overgrowths are such a

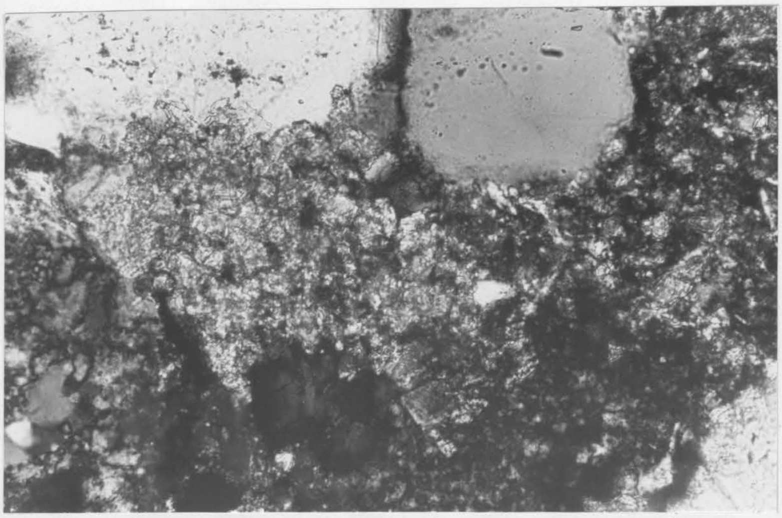


Plate 3-6: Authigenic kaolinite. Can be seen in this photograph. Thin section number SR-11. Magnification 250.

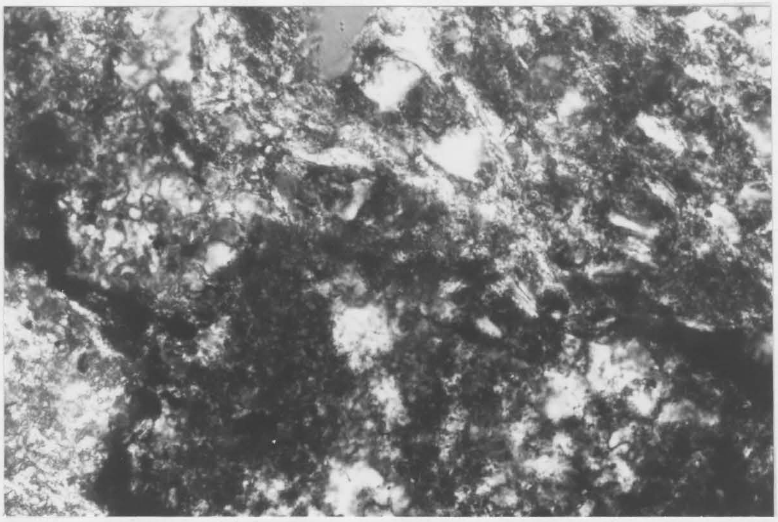


Plate 3-7: Illite. High birefingence and unstructured. It is found in the centre of the photograph. Thin section number SR-11. Magnification 400.

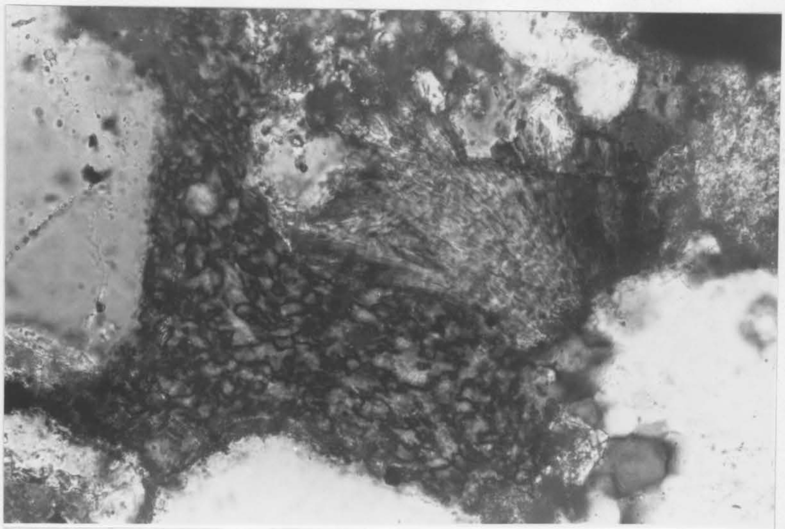


Plate 3-8: Authigenic chlorite. Can be identified by pleochrosim and radiating nature. Chlorite is in the centre of the photograph. Thin section number BR-12. Magnification 400.

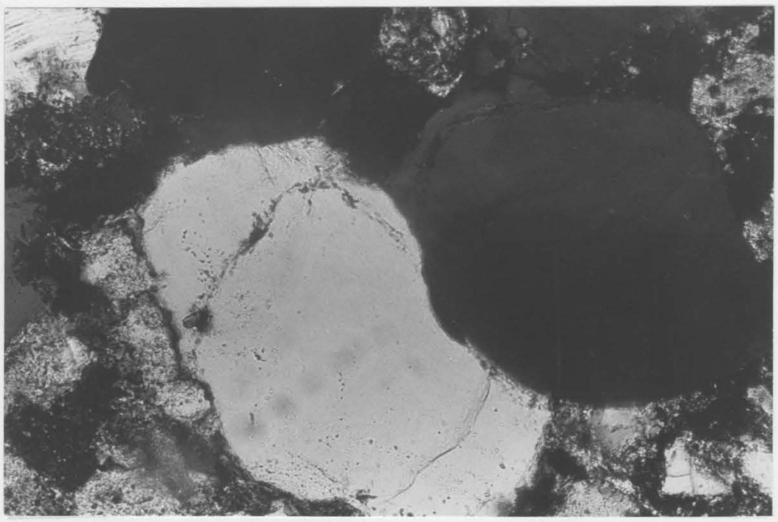


Plate 3-9: Syntax overgrowths on quartz grains. These overgrowths are fairly large and the contact between quartz grains is concavo-convex. Also note the possibility of second generation overgrowths on the rims of the larger quartz grain. Thin section number SR-11. Magnification 160.

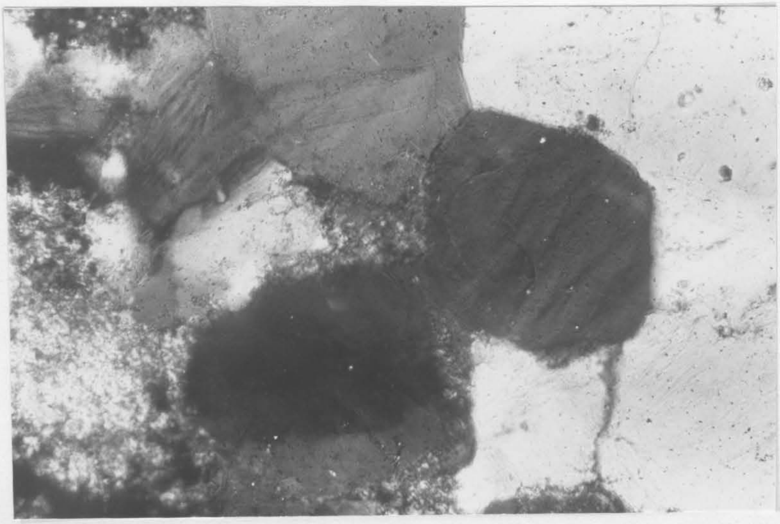


Plate 3-10: Quartz grains. Quartz in this photograph shows undulose and nonundulose extinction. Thin section number BR-10. Magnification 250.

Plate 3-11: Polycrystalline quartz. In centre of photograph, all crystals within the grain contain suture contacts. Thin section number BR-18. Magnification 160.

large part of the diagenesis of this sandstone the true roundness cannot be accurately estimated by ordinary petrographic observations.

Heavy minerals in the Morrissey Formation are very rare. They account for less than one per cent of each thin section. The heavy minerals found are zircon, tourmaline and very minor amounts of magntitite, apatite, and rutile (in quartz). All of these heavy minerals, except the rutile needles enclosed in quartz grains are well rounded and show no signs of overgrowths.

There are a few accessory minerals found within the thin sections. Muscovite flakes occur in minor amounts (Plate 3-12). The muscovite grains show signs of compaction and they are distinguished by the high birefringence of muscovite compared to most minerals present.

Another group of accessory minerals are the iron oxides of the hematite/limonite group. This group of minerals appears to be authigenic since it occurs as coatings on many of the quartz, carbonate, and chert grains. These minerals occur as crystals and also occur disseminated throughout various areas of the matrix.

Quartz Types and Extinction

As described previously the quartz grains were counted to determine a relationship between the types of grains. Table 3-2 shows the results of the count performed on each of the thin sections. Figure 3-1 shows the relationship between the type of quartz and the nature of the source area (Basu et al., 1975). Inclusions in quartz were point counted (100 points) to examine and classify them according to the

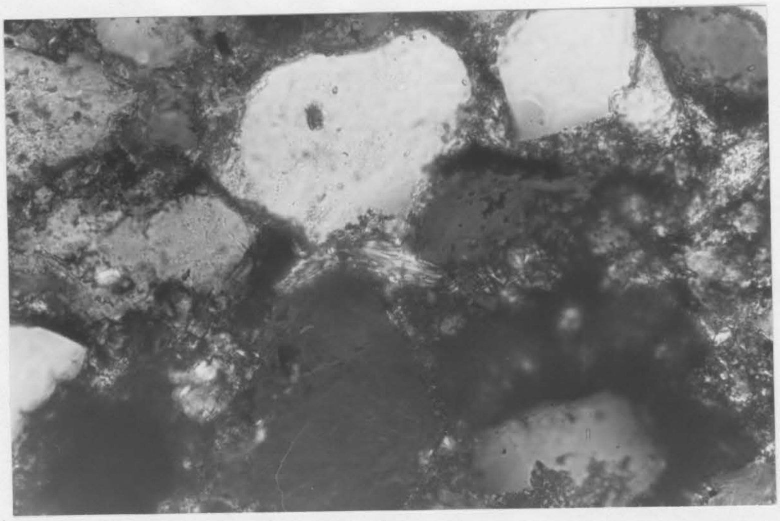


Plate 3-12: Muscovite flake. The flake is found in very centre of photograph. Has suffered distortion due to compaction. Thin section number AM-2. Magnification 400.

Table 3.2

Quartz Point Counts*

	Non-Undulose	Undulose	2-3 crystals/ grain polycrystalline	3 crystals/ grain polycrystalline
BR-19	65	28	0	7
BR-18	66	26	2	6
BR-17	50	33	3	14
BR-13	62	34	0	4
BR-12	67	24	1	8
BR-10	57	36	1	6
BR-8	75	18	1	6
BR-6	59	34	2	5
BR-4	66	25	3	6
BR-2	54	38	1	7
AM-12	59	27	3	11
AM-11	55	38	0	6
AM-10	64	29	1	6
AM-9	58	28	0	14
AM-8	56	29	2	13
AM-7	56	36	2	6
AM-6	58	30	5	7
AM-5	75	14	1	5
AM-4	68	26	2	3
AM-2	70	26	0	4
SR-12	54	31	2	13
SR-11	48	43	3	6
SR-10	50	40	1	10
SR-6	47	48	2	3
SR-3	52	38	1	9

* N = 100

BR - Burnt Ridge AM - Adanac Mine SR - Sparwood Ridge

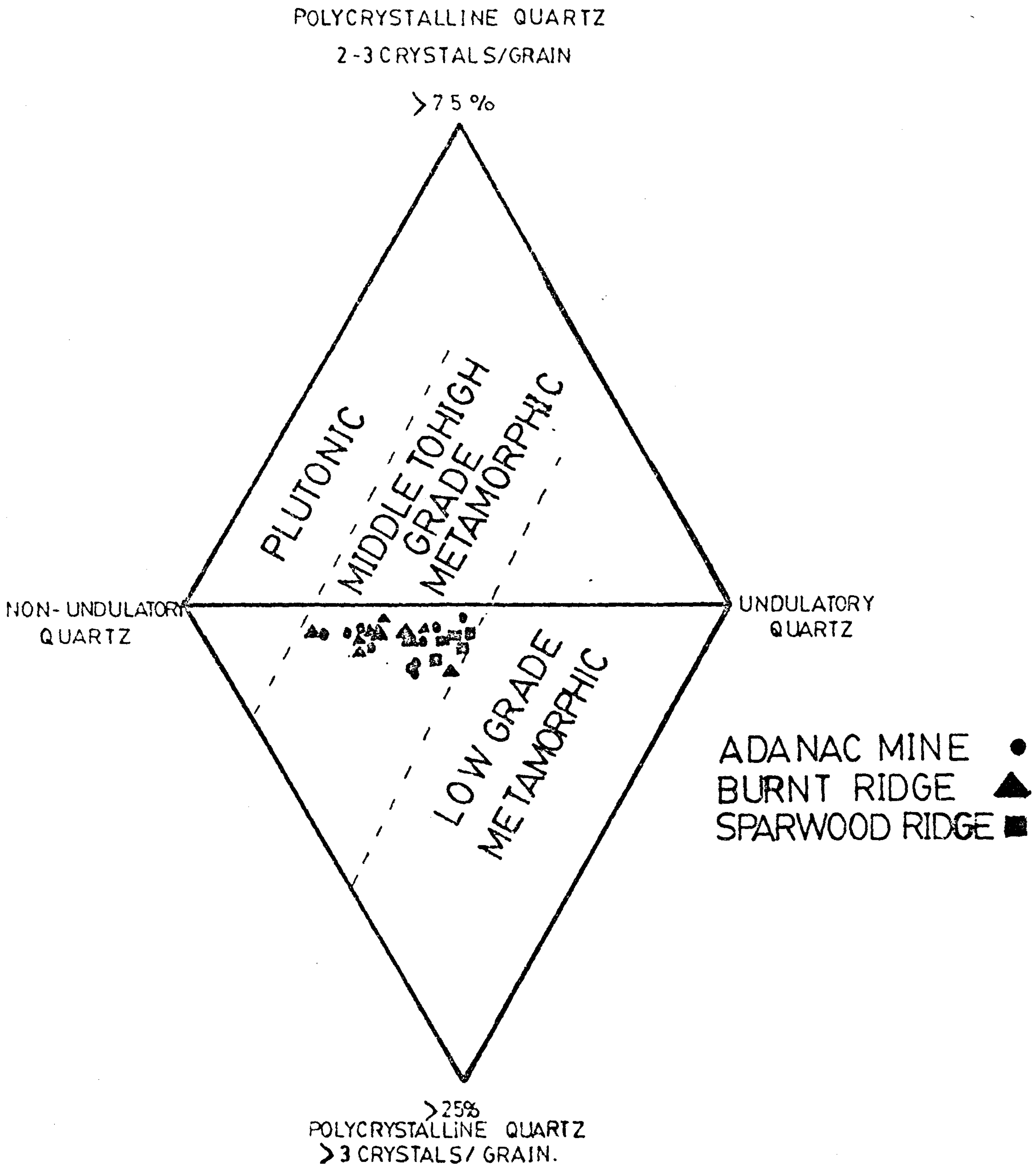


Figure 3-1: Quartz extinction diagram for the Morrissey Formation sandstones. Adapted from Basu et al. (1975).

scheme proposed by Folk (1974). Types of inclusions examined in quartz grains were: abundant vacuoles, rutile needles, few vacuoles, and microlites (other than rutile). The results (Table 3-3) showed that most thin sections had a large amount of quartz with few vacuoles which could represent any source area (Folk, 1974). The majority of the sections tended to have 1 - 5% of the inclusions representing rutile needles: this type of inclusion generally indicates metamorphic terranes, but can also occur in plutonic terranes (Folk, 1974).

Heavy Mineral ZTR Study

The heavy mineral suite found in these sandstones as previously stated, was derived from the information given in Table 3-4. In the five thin sections point counted for heavy minerals, zircon, tourmaline, and rutile composed 97% of all non-opaque heavy minerals. The ZTR index is measured at 97% in the Morrissey Formation.

Interstices Study

The Morrissey Formation interstitial material contains a large percentage of quartz. Most of the quartz within the interstices is found as syntac overgrowth on the quartz grains. Dusty quartz is rarely found in the thin sections (Plate 3-13). The porosity of the sandstone is very low due to the amount of compaction and overgrowths. In Sparwood Ridge slides it is found that calcite pore filling cement is more common than in Burnt Ridge and Adanac Mine sections. No rhombohedral dolomite crystals

Table 3-3

Point Counts of Quartz Inclusions

	Abundant Vacuoles	Few Vacuoles	Rutile Neddles	Microlites	Plain Quartz
BR-19	10	20	0	11	59
BR-18	17	30	0	9	44
BR-17	13	15	2	13	57
BR-13	18	28	0	18	36
BR-12	19	24	0	7	50
BR-10	18	15	2	10	55
BR-8	16	23	2	5	54
BR-6	8	32	0	7	53
BR-4	17	30	0	15	38
BR-2	4	20	0	8	68
AM-12	22	26	2	12	38
AM-11	15	27	1	10	47
AM-10	10	40	0	5	45
AM-9	17	45	0	15	22
AM-8	13	26	1	12	48
AM-7	17	40	0	4	39
AM-6	13	26	3	6	52
AM-5	12	35	0	7	46
AM-4	10	26	1	5	58
AM-2	20	55	0	7	18
SR-12	19	21	3	18	39
SR-11	20	23	4	10	43
SR-10	20	35	2	9	34
SR-6	32	20	2	19	27
SR-3	10	13	2	13	62

N = 100

Table 3-4

Heavy Mineral Study*

Sample	Zircon	Tourmaline	Rutile	Apatite	Magmitite
SR-11	7	3	0	-	-
SR-10	7	3	0	-	-
AM-4	8	1	0	1	-
AM-2	9	1	0	-	-
BR-12	8	2	0	-	-
BR-10	7	2	0	-	1

* N = 10 pt of heavy minerals

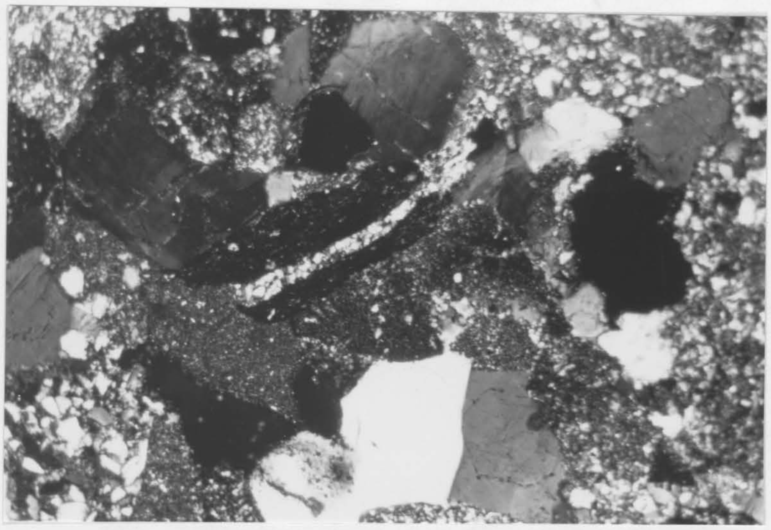


Plate 3-13: Drusty quartz cement. Can be seen in the centre of the fractured mudstone rock fragment. Thin section number BR-13. Magnification 160.

were seen in any of the thin sections.

The clay interstices component is fairly large in the sandstones. The amount of clay present in the sandstone ranges from 2.0 to 28.4%. In all thin sections clay content decreases with increasing grain size. As stated previously, the clays found consist of illite, kaolinite, and minor chlorite. It is not known how much of each clay is authigenic or detrital. If, however, the clay is classified as cement, it is a cementing agent in the sandstone.

Grain Framework

A study was made of the nature of the contacts between grains in the Morrissey Formation. Point counts of 100 points each was prepared for eight samples from the three different sections (sandstone classified as: suture, concavo-convex, long, point, or floating) with the results shown in Table 3-5. It was found from these point counts that more than 50% of all of the contacts within each of the samples are either suture or concavo-convex (Plate 3-9). This indicates that the sandstones were under a moderate overburden pressure during diagenesis and thus the major cementation that should occur would be cementation by quartz overgrowths (Pettijohn et al., 1972).

Evidence of compaction can be seen in other areas of the thin section. Crushed mudstone rock fragments are fairly common in all thin sections. Also present are crinkled muscovite flakes. These flakes tend to be bent around less deformable minerals, as shown in Plate 3-12. Stylolites were found in some samples but were not as common as the

Table 3-5

Grain Framework

Sample	Concave convex	Floating	Long contact	Point	Suture
SR-10	35	11	25	17	17
SR-6	40	9	21	13	20
BR-13	43	1	11	7	32
BR-19	60	0	20	2	18
AM-2	59	6	17	9	9
AM-11	51	0	15	4	30
AM-12	48	0	14	5	33

N = 100

crushed mudstone or muscovite flakes.

Some quartz replacement by calcite is seen in the Sparwood Ridge thin sections. This phenomenon, although rare, is indigenous and seems to be confined to minor areas of the slide.

Quartz grains were also found to contain Boehm lamellae (Plate 3-14) which are the result of intense strain deformation of quartz while in the same rock. They were fairly abundant and found in every sample.

Fractured mudstone grains were found in many thin sections. These mudstone grains were fractured straight through the grain and were cemented back together by dusty quartz cement as shown in Plate 3-15.

Cathodo-luminescence Study

Cathodo-luminescence studies were carried out on the coarse grain samples from Burnt Ridge and Sparwood Ridge. Cathodo-luminescence is the emission of light during electron bombardment from a cold cathode ray tube. The light emissions from the minerals are related to both the chemical composition and the texture of the mineral (Smith and Stenstrong, 1965). The purpose of the study was to determine the true roundness of the quartz grains.

Quartz overgrowths luminesce much less than detrital quartz grains due to differences in composition of the original and the overgrowth, even though the overgrowth is syntaxial in nature. The results of the study show that overgrowths are large in the sandstones. As previously stated, without the use of Cathodo-luminescence the grains appeared to be angular

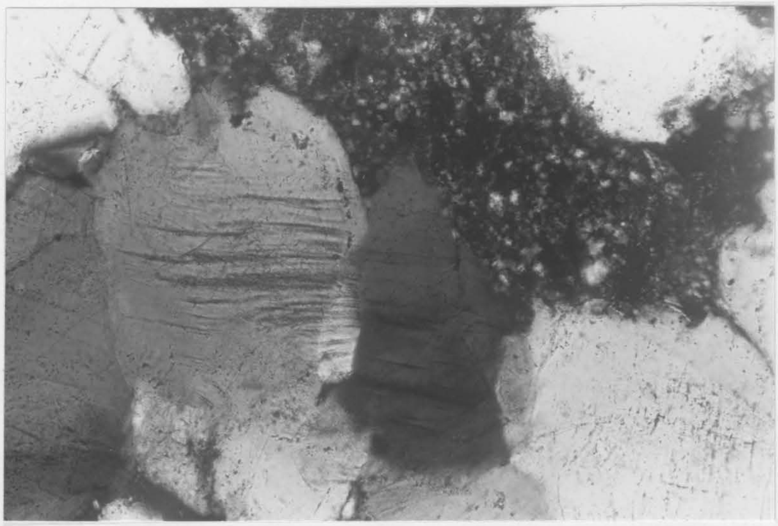


Plate 3-14: Boehm lamellae can be seen in this photograph. Note that the lamellae continue in both of the quartz grains suggesting that deformation took place after diagensis. Thin section number BR-18. Magnification 160.

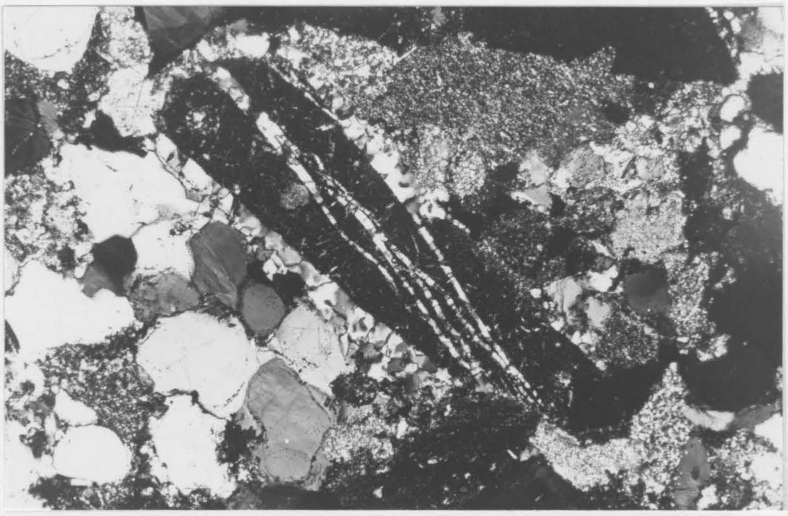


Plate 3-15: Fractured mudstone rock fragment. The rock fragment has obviously suffered severe stress and fractured. The fracture was then infilled with drusty quartz cement.

to subangular (Plate 3-16). By using luminescence the grains can be seen to be subrounded to rounded as shown in Plate 3-17. This was clearly evident in every thin section examined by this technique.

Graphical Analysis

This analysis will start with the classification of the rocks using Folk's classification (Folk, 1968). Table 3-6 shows the recalculation of the rock fragment content. As seen in Figure 3-2, this rock would fall in the Litharenite class and further classified using the second triangle, it is seen that the rock fragments are 100% sedimentary. The third triangle indicates the classification of 21 out of 25 is chert arenites; there are three samples classified as calclithite and one as a shale arenite.

Passega (1957, 1964) suggested that a graph plotting the average grain size (median) against the coarsest one percentile of a sand could be used to indicate the mechanism of deposition. The coarsest one percentile and average grain size, as estimated from thin sections are given in Table 3-7. The one percentile was determined by measuring the 10 largest grains in the thin section. The grain size relationship is plotted on log-log paper with the one percentile on the vertical axis and the median on the horizontal axis (Fig. 3-3). The relationship with these variables shows that the rocks were deposited by tractive currents (Passega, 1964). Tractive currents can be produced by flow in rivers, by marine currents or by waves touching bottom.

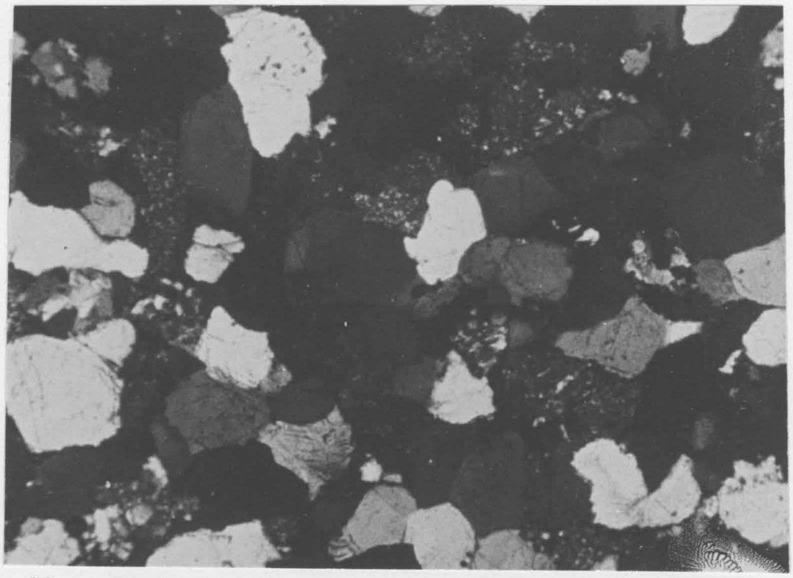


Plate 3-16 : Photograph of area before the cathodoluminescence occured. Thin section number BR-13. Magnification 40.

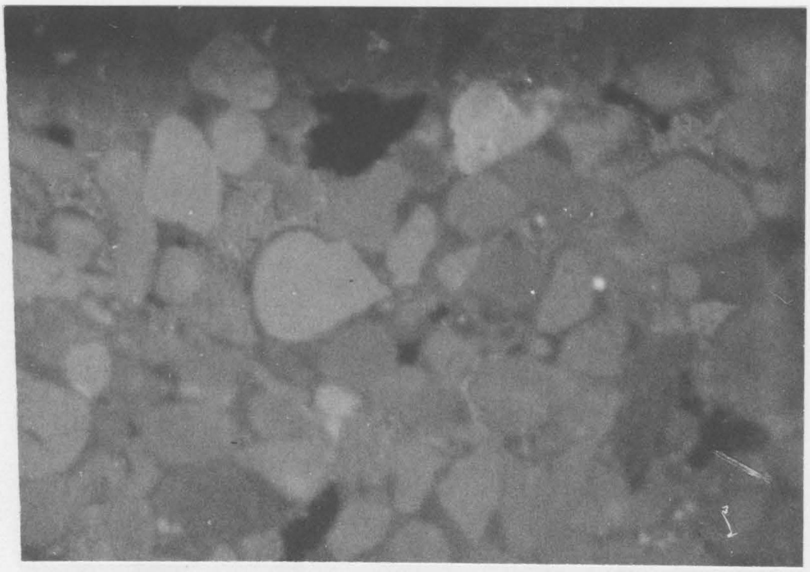


Plate 3-17 : Photograph of area with use of cathodoluminescence effects. Note the roundness of the quartz grains. Thin section number BR-13. Magnification 40.

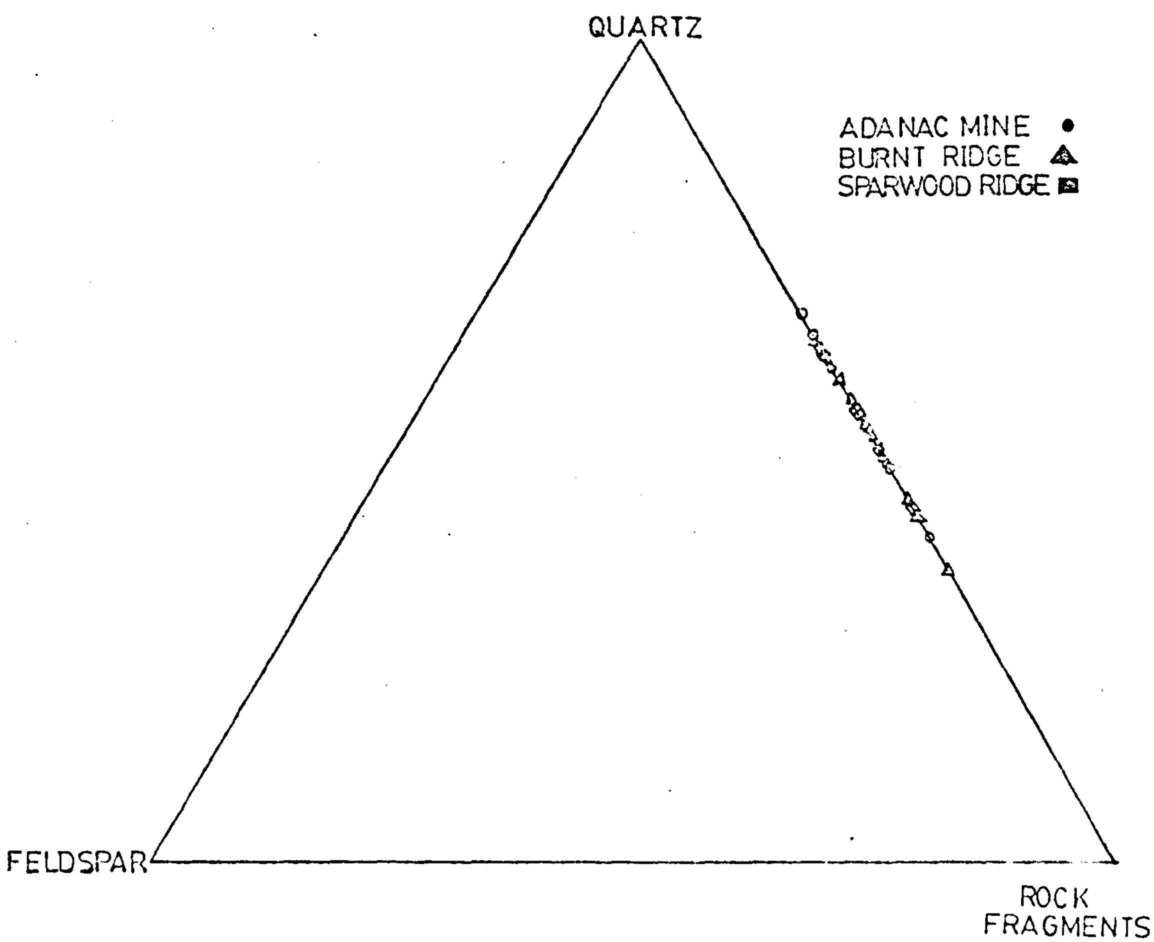
Table 3-6

Percentage of Rock Fragments - Total 100%

	Chert	Carbonate	MDSN
BR-19	67	0	32
BR-18	78	0	22
BR-17	80	0	20
BR-13	76	6	17
BR-12	72	0	28
BR-10	70	1	29
BR-8	44	22	32
BR-6	40.6	41.4	18
BR-4	31	48	21
BR-2	21.3	48	30.7
AM-12	76	0	24
AM-11	75	0	25
AM-10	58	0	42
AM-9	66	0	34
AM-8	72.3	0	28.7
AM-7	85	0	15
AM-6	60	0	40
AM-5	66	0	34
AM-4	60	4	36
AM-2	68	17	15
SR-12	63	0	37
SR-11	43	21	34
SR-10	41	33.5	25.5
SR-6	10	69	19.5
SR-3	27.8	36.6	35.5

BR - Burnt Ridge AM - Adanac Mine SR - Sparwood Ridge

Figure 3-2: Classification of the Morrissey Formation sandstones using Folk,(1968).


QUARTZ
FELDSPAR
ROCK FRAGMENTS
ADANAC MINE
BURNT RIDGE
SPARWOOD RIDGE

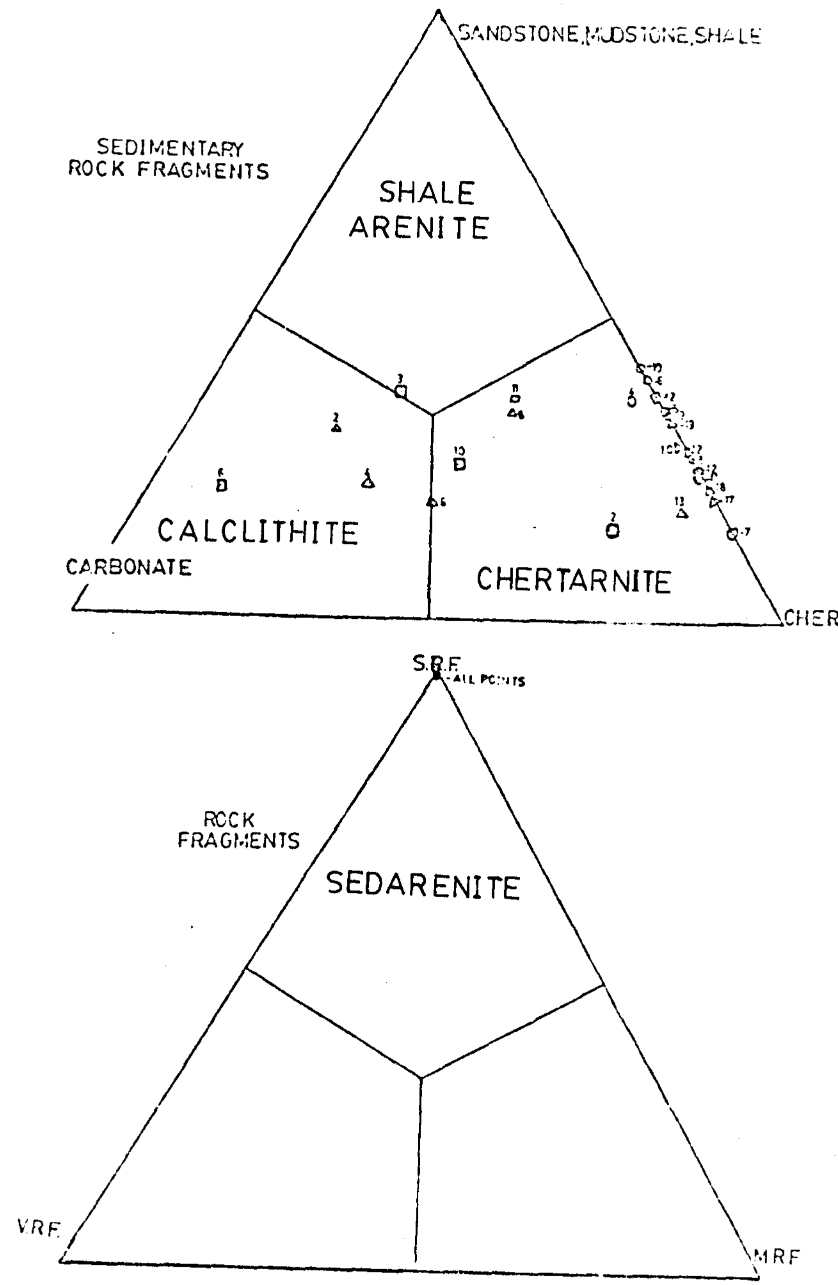

SANDSTONE,MUDSTONE,SHALE
SEDIMENTARY ROCK FRAGMENTS
SHALE ARENITE
CALCLITHITE
CHERTARNITE
CARBONATE
CHERT
S.R.F.
ALL POINTS
ROCK FRAGMENTS
SEDARENITE
V.R.F.
M.R.F.

Table 3-7

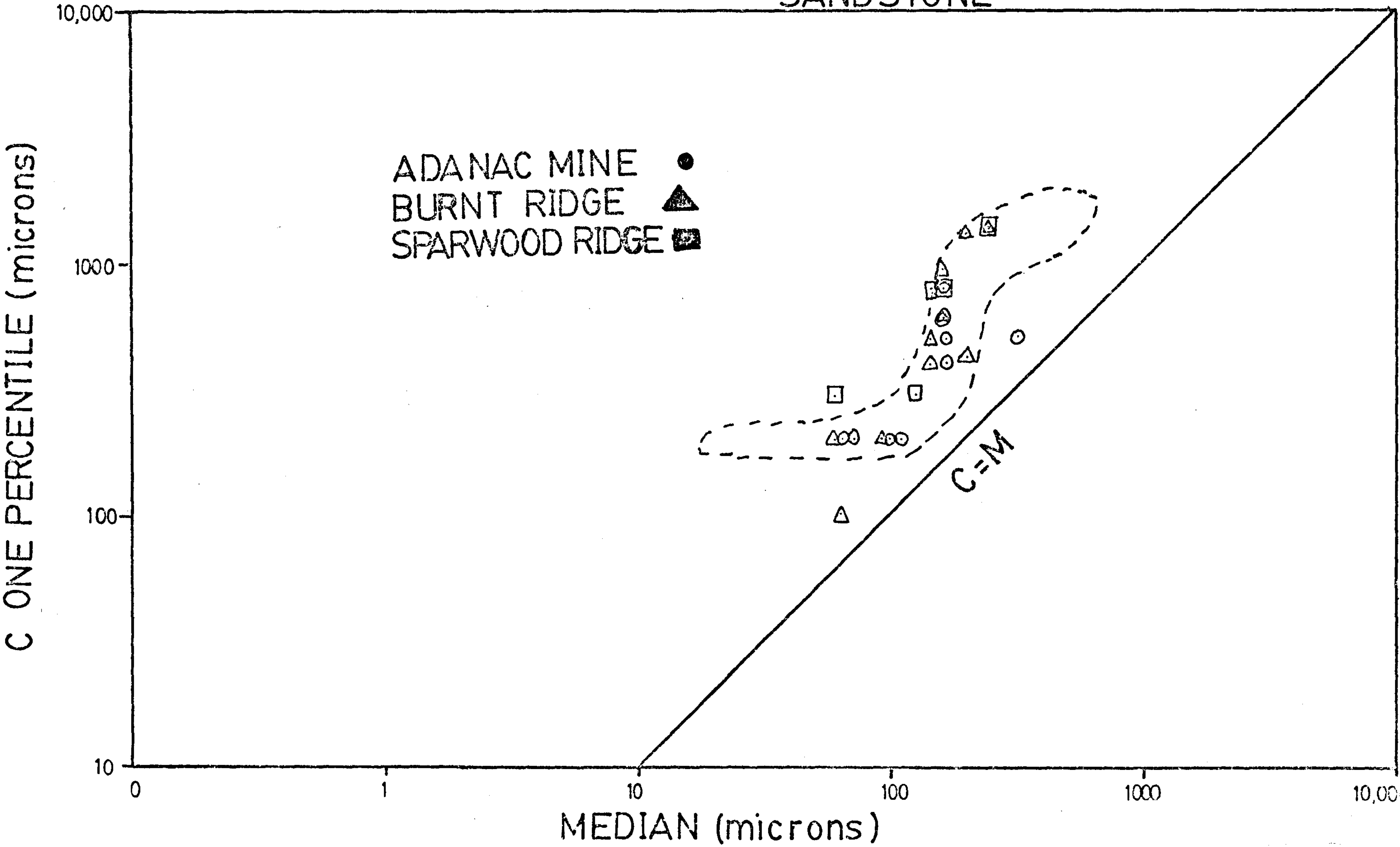
Grain Size

	Median*	One Percentile Coarse Grain*	One Percentile ø
BR-19	200	450	1.15
BR-18	160	950	0.074
BR-17	200	1300	-0.37
BR-13	250	1400	-0.485
BR-12	143	400	1.32
BR-10	163	600	0.73
BR-8	143	500	1.0
BR-6	91	200	2.32
BR-4	60	200	2.32
BR-2	62.5	100	3.32
AM-12	160	400	0.73
AM-11	330	500	1.0
AM-10	160	500	1.0
AM-9	160	600	0.73
AM-8	160	800	0.32
AM-7	100	200	2.32
AM-6	111	200	2.32
AM-5	71	200	2.32
AM-4	71	200	2.32
AM-2	62.5	200	2.32
SR-12	160	800	0.32
SR-11	250	1400	-0.485
SR-10	143	700	0.515
SR-6	125	300	1.37
SR-3	60	300	1.37

* Scale in Microns

Figure 3-3: C-M graph of the Morrissey Formation sandstones. Dotted line indicates area of tractive currents. Adapted from Passega,(1964).

C-M DIAGRAM FOR MORRISSEY FORMATION SANDSTONE



Chapter 4

Discussion and Interpretation

Facies Interpretation

All of the facies described in Chapter 2 can be interpreted with reference to characteristics of lithology and sedimentary structure. The combination of facies found can then be put together to produce an idea of what type of depositional system makes up the ancient environment. The facies discussed range from marine (shales and turbidites) to non-marine fully continental (coals).

Facies A: Sandstone-Siltstone Facies

Sandstones are found interbedded with siltstones in this facies. The deposition of this facies is confined to relatively shallow water marine environments. The major reason for this interpretation is due to the presence of hummocky cross-stratification. Hummocky cross-stratification indirates bottom currents which transported and deposited sands in variable directions from suspension (Hamblin, 1978). This type of sedimentary structure is formed in a marine environment above storm weather wave base but below fair weather wave base as shown in Figure 4-1. This would place facies A in a shallow water marine environment. The sand in this facies was deposited from turbidity flows. This can be seen

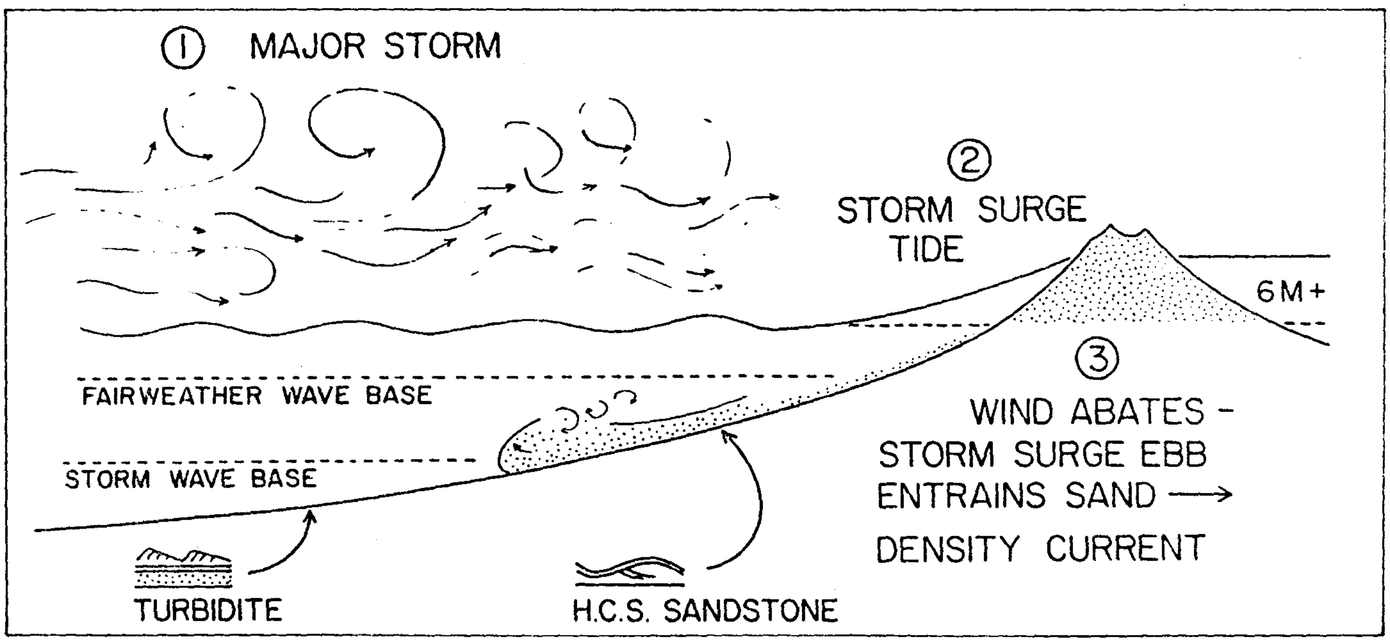


Figure 4-1: Environment of deposition of Hummocky Cross Stratification. Adapted from Walker, 1980.

since the sandbeds do display incomplete Bouma sequences, divisions B and C, suggesting a turbidite origin for the sands. The turbidity currents were possibly generated by severe storms. Differences in thickness of turbidites reflect differences in intensity of storms supplying larger volumes of sediment and allowing the storm weather wave base to be lower. This produces larger and broader hummocks on some turbidites than on others.

The increase in thickness of the sandstones of facies A upwards in the unit reflects the continuous progradation of the clastic wedge and thus the constant shoaling of the waters. The interpretation of this environment, therefore, is shallow marine below fair weather wave base yet above storm weather wave base, within the Nikanassion Sea.

Facies B: Planar-Trough Cross-Bedded Sandstone

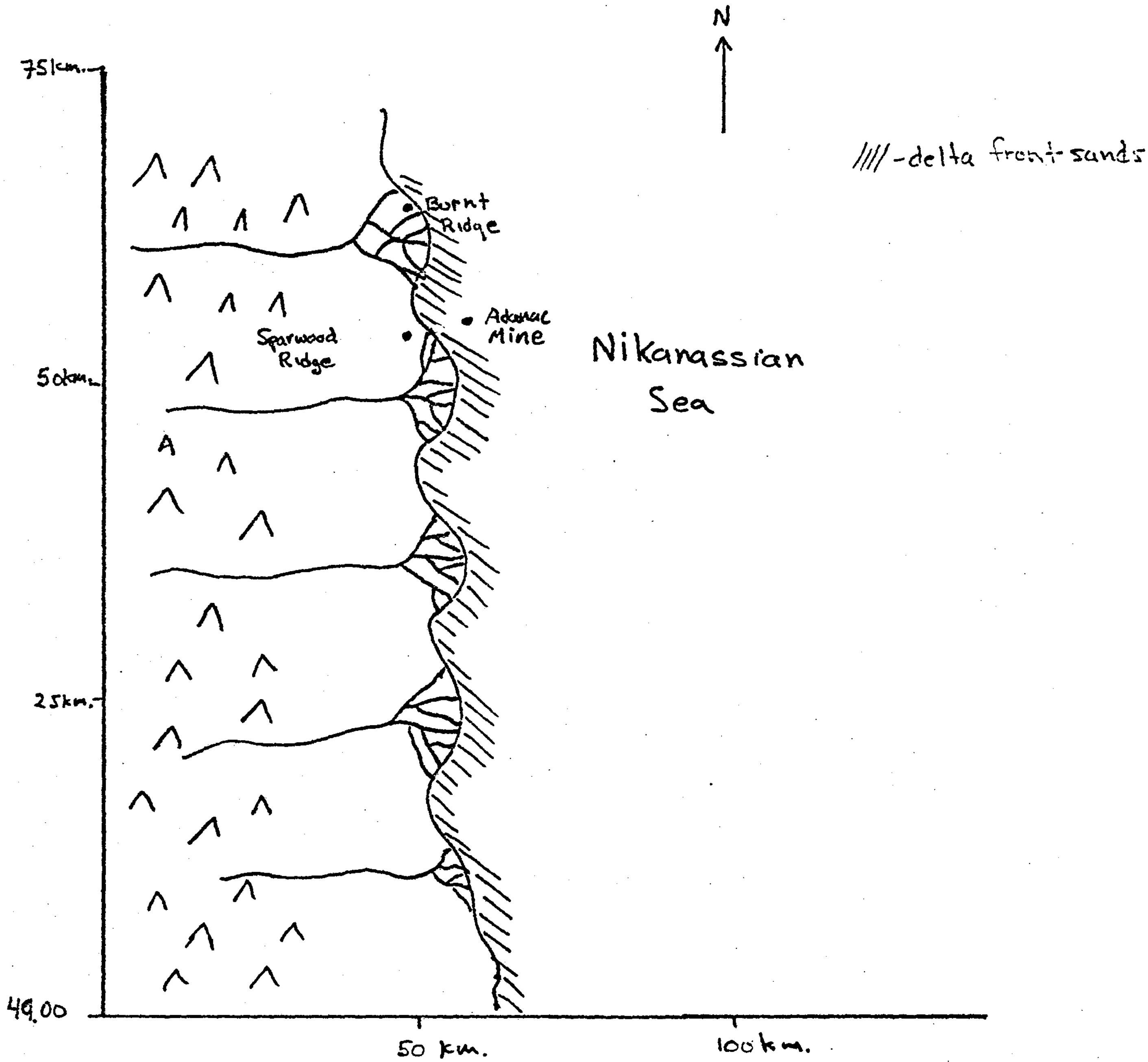
As previsouly stated, this facies abruptly (but conformably) overlies facies A. It is a very thick sandstone ranging from 19 to 46 metres southeast to northwest. The facies is predominantly planar with minor low angle trough cross-beds at the Sparwood Ridge and Adanac Mine sights. The Burnt Ridge section is anomalous to these sections in being almost twice the thickness of the other section and dominated by trough cross-bedding.

The lack of siltstone-mudstone breaks within this facies presents a problem in interpretation. There are reasons why there may be no siltsize particles present within the sandstone. The first reason may be due to the velocity of the river droping the heavier suspended load and bed load (sands) and the lighter suspended load (silts and clays) further out into the basin. The second reason for a total lack of finer grained material may be due to constant winnowing of the sands by waves generated in the sea. The deposition of sand would occur outside of the distributary mouth bar environment and the silts and clays would be deposited in the prodelta environment (Coleman and Gagliano, 1965). After being deposited the sand would then be reworked by a constant unidirectional wave pattern which causes a coalescing of the lobes of the river delta to produce one large sand body. This would result in a continuous delta front sand deposit along the entire river delta (Fisher and McGowen, 1967).

The interpretation of this facies in one of a delta front facies in which sand from just outside the distributary mouth bars of the delta are reworked causing one large delta front sand as seen in Figure 4-2.

The author suggests a large supply of sediment was brought into the southern part of the Rockies by four or five river systems with each river branching out to form a fluvial dominated delta complex. The delta structure will have alunate-cuspate configurations (Figure 4-2). The influx of a large sediment supply due to erosion of the newly uplifted Paleozoic to the west along with the large amount of rainfall would produce a large sediment flow into the basin. Frequent storms will also produce large influxes of sediment into the basin.

These sediments once in the basin were then reworked by wave action which winnowed out much of the very fine grained silts and muds.


N
////-delta front-sands
75km.
50km.
25km.
49.00
50 km.
100km.
Burnt Ridge
Adanac Mine
Sparwood Ridge
Nikanassian Sea

Coalescing of lobes by unidirectional wave action would have allowed the joining of the delta front sands producing a very long delta sand beach deposit system. The wave action, although not extremely severe must to constantly reworking the sediments into the delta front sands. This wave action would have been caused by constant westerly winds (Gordon, 1974).

Continued subsidence of the basin at a rate equal to the rate of sedimentation would allow for a freezing of the progradation of the progradation of the clastic wedge into the basin, thus allowing for the thicknesses of the sections. The Burnt Ridge Section is postulated to be, or very near one of the delta lobes, therefore the thickness is double any other measured section and the amount of trough cross-bedding found in the facies is also much higher than normal.

Further evidence of the Burnt Ridge Section being near the source is a 20 cm fining upward conglomeratic layer present in the middle of the facies. This conglomeratic layer may have been deposited by a turbidity current produced by a severe storm and would be only a localized occurrence.

Facies C: Trough Cross-Bedded Sandstone

The coaser grain size of this facies and the definite appearance of high angle trough cross-bedding might suggest a fluvial interpretation of this facies. However, many of the characteristics of fluvial deposits were not found in any of the sections. No channels, fining upward sequences, over-bank deposits, asymetrical ripple marks, coarse grained lag deposits, or planar tubular cross-stratification were found in the three sections studied. This would suggest to the author that this facies is lacking many of the structures which should be found in a meandering or braided stream (Cant and Walker, 1976).

Ruling out a fluvial source for the facies leaves the alternative of another type of deltaic environment. The finding of the trace fossils Rizocrallium and Zoophycos within the Burnt Ridge Section along with the Titanites found by Newmarch (1953) and Hamblin (1978) would also provide evidence that the facies is still within a deltaic environment.

With the progradation of the Kootenay wedge this facies has also become coarser grained than the facies below. The consequence of this facies being coarser grained and possessing higher angle trough cross-bedding would suggest to the author that this facies represents a distributary mouth bar environment (Coleman, 1976).

Distributary mouth bars are commonly clean and well sorted sands that contain multi-directional, trough cross-bedding as the dominant sedimentary structure (Coleman and Gagliano, 1965). This environment for facies C seems to fit well in the area of study. A problem arises in that the lateral extent of this unit is well over 350 km. Over the range of the Morrissey Formation, there may very well be a change in environment of this unit. From the three sections measured and the author's knowledge of the southern part of the Kootenay Group, this environment of deposition seems to be the only possible alternative to the fluvial braided river environment in the southern Rocky Mountains.

Facies DB: Marine Trace Fossil Facies

This facies is a very minor yet important facies. Found abruptly, conformable, above the trough cross-bedded facies, this facies must represent a marine transgression within the river dominated, distributary mouth bar facies in the Burnt Ridge Section. The trace fossils Zoophycos and Rizochrallium both represent a definite marine environment (Weimer, 1978). Zoophycos generally represents deeper neritic to bathyal depths (Seilacher, 1963), but the facies associations indicate a shallow marine environment for the Burnt Ridge occurrance. The presence of a marine transgression high within a wave dominated delta front environment could be explained by channel switching. A cut off of sediment supply combined with continued subsidence would result in a marine transgression. Another switch of the channel back to the area brought about burial and preservation of the main facies and deposition of two metres of facies C above it.

Facies EB: Parallel Bedded Sandstone

This facies overlies the facies C at Burnt Ridge. It consists of parallel bedded sandstones with occassional very low angle divergence beds. Based on the description of the facies and the cleaness of it, the interpretation for the sandstone would be a beach environment (Elliott, 1978). The beach would have been produced by continuous shoaling of the delta with the rate of deposition of sediment greater than the rate of subsidence. Another interpretation may be a minor regression of the

Nikanassian Sea, thus causing the shoaling and the beach to be produced. The upper boundary is sharp with the return to facies C for three metres. This is followed by movement into facies F.

Facies F: Coal, Siltstone, Mudstone, Sandstone

This facies is the first non-marine facies encountered in the sections. The unit represents a non-marine portion of the major delta complex. The sandstone of this facies represents crevasse splays and channel levees, braided rivers and point bar deposits associated with the fluvial portion of the delta. The siltstone, mudstone and coals would all be associated with swampy, deltaic flood plains and marshes. This fluvial environment continues through all of the Mist Mountain Formation depositing less coal and more sandstone and shale, higher in all three sections.

Comparison With Other Sources

The comparison of the facies of the Morrissey Formation with other authors shows many different interpretations of the environments of deposition.

The Fernie "passage beds" are suggested by Hamblin and Walker (1979) to represent hummocky cross-stratified beds with the hummocky cross-stratification being caused by reworking of turbidites that are above storm wave base but below fair weather wave base (Hamblin and Walker, 1979).

The interpretation of facies B as delta front sands is in disagreement with Hamblin and Walker (1979). The Rockdale Delta System of the Wilcox Group of east central Texas provides evidence for the existance of a delta front sand interconnecting delta complexes with large thick (up to 100 m) sandstone bodies (Fisher and McGowen, 1967). To call this facies a beach deposit would require evidence of swash zones and rip current activity, along with some explanation of a thickness of 20 m of sandstone, whereas most ancient examples of beaches are only 3 to 4 metres thick, and the thickest modern beach sand is 7 metres thick (Hamblin, 1978). The interpretation as a delta front sand facies agrees in principle, with Gibson (1977) and to a lesser extent Jansa (1972) who postulates a delta front barrier island system for the facies.

The interpretation of facies C as distributary mouth bar facies is also in disagreement with Hamblin and Walker (1979) who believe the facies is representative of a fluvial braided river system. As previously stated, due to absence of so many of the necessary components of a braided river system and the abundance of characteristics of a distributary mouth bar lead to the conclusion that the system is a distributary mouth bar environment.

What is striking about facies C is its wide lateral extent. Gibson (1977) suggested that this unit (the Moose Mountain Member) might represent a distributary mouth bar-delta front sheet sand-barrier island complex. The observations reported above support the distributary mouth bar-delta front sheet sand interpretation, and it is possible that no evidence of a barrier island complex was not observed simply because of the limited number of outcrops studied.

Facies BD and BE, to the author's knowledge, have not been found at any other outcrop studied. This would suggest that this is an isolated system which is only found in the Burnt Ridge area and is not indicative of the entire Morrissey Formation. The Burnt Ridge section is believed to be very close to one of the major distributaries of the Cretaceous delta system.

The interpretation of facies F as being fluvial braided river, point bar, flood plain, marsh environment agrees with Hamblin and Walker (1979), Gibson (1977) and Jansa (1972).

Petrographic Interpretation

Source

The results of the petrographic data in Chapter 3 lead to the conclusion that the source rocks for the Morrissey Formation sandstones are sedimentary in origin. This is indicated by the total lack of volcanic and metamorphic rock fragments, feldspars, and the absence of a large heavy mineral suite.

The major constituents of the Morrissey sandstone are quartz and chert. The chert found in field and petrographic studies shows many different types: black, green, and white in colour, brownish phospatic polycrystalline, normal polycrystalline, and chalcondonic. This would suggest a deep sea marine environment of formation, probably in a carbonate host rock (Folk, 1974).

The study done on the extinction types of quartz in the thin sections is a direct result of the providence of the rock. Basu et al. (1975) suggests a medium to upper metamorphic grade source area. Considering the total lack of any metamorphic rock fragments in the thin sections, there can be only two possible conclusions. The first conclusion is that the evidence of the quartz types are misleading. If the Morrissey Formation has more than one primary source area for the quartz, the data will not be as accurate (Basu et al., 1975). From the previous discussion, however, it is likely that the Kootenay was derived from a sedimentary source only, and not from a combination of sources.

Assuming evidence of the quartz types is not misleading, it may be concluded that at least one source of the Morrissey sandstone consists of sandstones that were in turn derived from a medium to high grade metamorphic source.

Roundness of quartz grain plays an important role in the determination of the provenence of the Morrissey Formation. The high degree of roundness of the quartz grains observed with the cathodo-luminescence microscope suggests a considerable distance of transport. Since the transport from the Cordillera to the basin of deposition was a maximum of 200 km, it is very doubtful that a single cycle of weathering and transport could produce the roundness seen in the sections. If this is true and the quartz has been derived from a second generation sandstone, there may exist second generation syntaxial overgrowth on some of the quartz grains. Only two grains were observed where this may have been the case (Plate 3-9 shows an example).

The very high ZTR index (97%) within the Morrissey Formation also suggests that the rocks are second generation sandstones (Hubert, 1962). Heavy minerals must be very stable to survive transport, deposition, diagenesis, not once but twice in their history.

The Morrissey Formation sandstones were probably derived from Paleozoic (or Late Protozoic) rock that was eroded in the Cretaceous. In turn, this Paleozoic source rock was earlier derived from a source, probably in the Precambrian Shield, consisting of a high grade metamorphic terrain.

Comparison with Other Authors

Two major source areas, both sedimentary, are most likely to have produced the clastic Kootenay Group. The first source which is agreed upon by most authors is the Upper Paleozoic carbonates of Mississipian, Pennsylvanian, and Permian ages (Rapson, 1964, 1965; Jansa, 1972; Hamblin and Walker, 1979). These Upper Paleozoics are responsible for the influx of chert into the basin. The upper Paleozoic rocks are indicated as the probable source because they contain many times more chert than the Lower and Middle Paleozoic rocks.

The possibility that the chert is derived from the Pennsylvanian-Permian Cache Creek Group of the interior of British Columbia seems slight. If the chert was derived from this source area instead of the Mississipian-Pennsylvanian carbonates of the Banff, Rundle, Rocky Mountain Groups of the Front Ranges, there would need to be a very complex rock fragment suite found in the petrographic sections. Also the accessory minerals and the mineral suites would not be as sparse, because of the mineralogical complexity of the eugeosynclinal assemblage in the interior deposits.

Rapson (1965, 1966) talking about the Upper Kootenay Group - Lower Blairmore Group states that there is an increase in feldspar, volcanic, and metamorphic rock fragments, and heavy minerals from the Lower to Upper Kootenay Group. This suggests a change in source to the western Cache Creek Group which would have been tectonically uplifted since the Late Jurassic, due to the Shuswap Complex of southern central British Columbia (Rapson, 1966).

The increase in chert as a function of the height in the section was interpreted to be an increase in tectonism in the late Jurassic (Hamblin and Walker, 1979). The author, although not disagreeing with the change of source due to tectonic uplift of the Morrissey Formation, suggests that the lack of chert in fine grained sandstones of the Weary Ridge Member is due to the removal of chert grains finer than 100 μm by dissolution (Blatt et al., 1980). The increase in grain size in the Morrissey Formation from fine grained to coarse grained, along with the increase in chert is good evidence that the later theory is valid. This is not to say that there was a lack of tectonism within the late Jurassic deposition of the Morrissey Formation but no conclusive evidence can be found to prove that an increase in tectonism produced the increase in chert in the Upper Morrissey Formation.

The lack of carbonate rock fragments within the Morrissey Formation is also a problem. If the primary source of chert is from limestones of the Late Paleozoic, it might be argued there should also be a large number of carbonate rock fragments in the sandstone, yet this is not the case. Carbonate rock fragments of the sand size are, however, easily removed by dissolution. The climate in the Cretaceous was warm and humid, with a high rainfall and abundant vegetation. Both factors would favour quick dissolution of carbonate.

A second source must be involved to supply the large amounts of quartz into the basin. This would not be supplied by the carbonate source due to the lack of quartz in carbonate rocks (Blatt et al., 1980). The source of this sandstone has been interpreted to be lower Paleozoic sandstones to the west of the area of deposition (Rapson, 1964, 1965; Jansa, 1972; Hamblin and Walker, 1979). Rapson (1965) discussing the providence of the middle to upper Kootenay Group and the Blairmore Group suggests the middle and lower Paleozoic stable sandstones to the west as one source. The author agrees with this analysis. Since the rock was derived from a medium to high grade metamorphic source (Chapter 3), then the Paleozoic clastics which supply the quartz were derived from the Precambrian Shield to the east (Nelson, 1970). The shield rocks would have been the original metamorphic source.

Jansa (1972) suggests an alternative source of the area to the southwest portion of the Shuswap Complex. He is suggesting unmetamorphosed and low grade metamorphic sediments. The author disagrees with this area of providence since there would be some eugeosynclinal input from sources within that area. If the sediments were derived from this area, the rocks would have to contain substantial amounts of feldspar and metamorphic rock fragments along with other material as stated previously. Since this is not found, it is unlikely that the Shuswap area is the source of sediment of the Morrissey Formation sandstones.

The placement of the Morrissey Formation is critical for the provenance study. All indications are that somewhere between the top of the Morrissey Formation and the base of the Blairmore Group there was a change in source from a miogeosynclinal source in the eastern Rockies to a eugeosynclinal source further west in the Cordillera. This source in the west would be the Cache Creek Group of south central British Columbia, along with the plutonic source which is the Shuswap Complex of British Columbia (Rapson, 1965). This change in source of sediments is due to tectonic uplift which continued through the lower Cretaceous.

Diagenesis

Compaction: The compaction of the sandstones of the Morrissey Formation has been substantial. As stated in the previous chapter the majority of grain contacts present are either concavo-convex or suture. Other evidence of compaction found was the presence of crushed and fractured mudstone rock fragments, stylolites, fractured quartz grains, Boehm lamellae in quartz grains, and the amount of syntaxial overgrowths on the quartz grains. All of these factors led to the conclusion that there was a pressure solution. Pettijohn et al. (1972) gives the term moderate pressure solution to rocks with these characteristics. Thus the Morrissey Formation has no porosity or permeability due to the amount of compaction that was placed on the rocks at the time of burial.

Cementation: The major cement within the Morrissey sandstone is a function of the amount of pressure solution within the sandstone (Pettijohn et al., 1972). Since there has been a moderate overburden pressure on the sandstone, syntaxial overgrowths of quartz cement are the major source. Quartz, under fairly high overburden pressures, will preferentially dissolve and then reprecipitate in an area of reduced pressure to form overgrowths. The lack of first generation overgrowths within the sandstone could be a result of the first generation overgrowths being more soluble than the original quartz. Thus, all of the first order overgrowths were slightly dissolved and reprecipitated over top of the primary overgrowth, with no clay boundary present between the two overgrowths and then there would be no way to determine the boundary between the first and second overgrowth.

The second most abundant cement in the rocks would be authigenic clay cement. The clay components, illite-kaolinite, is present in both detrital and authigenic forms. In many cases it is impossible to determine whether the clay is authigenic or detrital. Kaolinite and illite are both found filling intersticies between quartz, chert, and rock fragment grains. Chlorite is a very minor clay present within the samples but is most likely authigenic since it has a sheave like structure that would have been destroyed during compaction. In many areas, the clay cement is very complex and contains hematite-limonite along with the clay component.

The third type of cement found is carbonate. The carbonate cement element is not very abundant in the overall slides, except for the

Sparwood Ridge slides. The carbonate found in most slides seems to be concentrated in one area of the slide and in most cases found near carbonate rock fragments. The carbonate cement is thought to be due to dissolving of some of the carbonate rock fragments and then re-precipitation of the carbonate as cement. The carbonate fragments and cement found contain abundant rims of hematite/limonite iron oxides that may have been derived from iron rich limestones or may have been derived from the detrital clay and mudstone rock fragment components.

Chapter 5

Conclusions

1) The Morrissey Formation within the study area can be divided up into two major facies at all three sections. These facies are based upon characteristic grain size, sedimentary structure, induration, colour, and mineralogical differences within the facies.

2) Facies A, consists of interbeds of fine grain sandstone and siltstone with sharp based beds that are gradational back into the siltstone. The sandstone beds average 1.5 metres thick. This facies is part of the Fernie Formation passage beds and is representative of offshore shallow water marine sandstones, produced by storm-surge-generated-turbidity currents (Hamblin, 1978). Storm generated Hummocky Cross Stratification is found on this sandstone, thus the sandstone was deposited below fair weather wave base.

3) Sparwood Ridge and Adanac Mine sections are typical of the southern Rocky Mountains in terms of facies within the Morrissey Formation. The Burnt Ridge section is atypical of the Formation in possessing two unique facies in the upper portion.

4) Facies B, consists of parallel bedded and minor trough cross-bedded, medium grain sandstone. This facies was produced by a coalescing of

delta sands to produce one large delta front sand facies which is continuous throughout all of southeastern British Columbia-southwestern Alberta.

5) Facies C, consists of high angle trough cross bedded, coarse grained "salt and pepper" sandstone. This facies represents a distributary mouth bar environment of deposition.

6) On Burnt Ridge two extra facies were recorded. The first, Facies DB, is 75 cm thick bioturbated area containing the trace fossils Rhizocarallium and Zoophycos in a course grain sandstone, represents a marine transgression within an overall regressive sequence. The transgression was produced by channel switching which cut off the sediment supply. This combined with continued subsidence resulted in a shallow, open marine environment which allowed the trace fossils to inhabit the area.
Facies EB, a three metre, parallel bedded, coarse grain sandstone, with low angle divergent sets and minor pebbles, was produced by shoaling of the delta, due to a minor regression and reworking of distributary mouth bar sands into a beach.

7) Overall, the Morrissey Formation consists of two members. The Weary Ridge Member, interpreted as coalesced delta-front sands, which make up a continuous sandstone across the southern part of Alberta and British Columbia. The overlying Moose Mountain Member represents a distributary mouth bar facies with progradation of the delta over top of the Delta Front sand.

Sedimentary Petrography

8) The Morrissey Formation sandstones are classified as chert arenites using Folk's classification.

9) The provenance of the sandstones of the Morrissey Formation was from two major sources. The first was the Mississippian-Pennsylvanian-Permian carbonates of the southern front ranges, and accounts for the chert in the rock. The second source was Lower Paleozoic sandstones that were previously derived from a Precambrian complex of medium to high grade metamorphic rocks.

10) The sandstones have undergone a moderate degree of pressure solution, thus indicating a fairly high overburden pressure.

11) The major cement found is quartz syntaxial overgrowth cement. The second most abundant cement found is the clay cement component and the third, and very minor cement, is calcium carbonate.

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