McNamara-Garnet Range transition (Precambrian Missoula Group)

Donald I. Bleiwas

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THE McNAMARA-GARNET RANGE TRANSITION
(Precambrian Missoula Group)

by

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Master of Science

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The transition of the McNamara Formation to the overlying Garnet Range Formation in five measured and described sections reveals a change in depositional environment from the arid to subhumid oxidizing braided fan delta environment of the McNamara, to a higher energy braided fan delta with diagenetic reducing conditions in the overlying Garnet Range Formation. The succession of environments may be a result of tectonic or climatic change.

The uppermost McNamara is dominantly a hematitic, red, highly feldspathic, subrounded quartzite that fines northward. The southernmost section displays abundant northward dipping pink crossbeds approximately 20 centimeters high that grade upward into red siltites which are frequently scoured. Toward the north, a lower stream gradient resulted in sheet flow and very shallow braided streams. Sediments are commonly mudcracked. The northernmost section is very thinly bedded mudcracked red siltite and interbedded green siltite. These sediments locally contain oolites, gypsum casts, and calcite probably deposited along the margins of an alkaline body of water.

The lowermost Garnet Range Formation is characteristically angular to subangular gray to gray-green highly micaceous feldspathic quartzite which weathers with a limonitic stain. A matrix of illite probably results from diagenetic alteration of feldspar. The southernmost section contains unidirectional northward dipping one meter high crossbeds, representing straight braided stream channels. As sediments fine fairly northward, sedimentary structures decrease in scale reflecting shallow braided stream channels. These pass laterally into fine grained siltites deposited in shallow water, possibly an embayment.
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CHAPTER I

INTRODUCTION

Stratigraphic Setting

The Missoula Group of Clapp and Deiss (1931) is the uppermost group within the Precambrian Belt Supergroup. It has been described in eastern Washington, northern Idaho, and western Montana, and consists of a thick sequence of clastic rocks. The Missoula Group has been divided into seven formations (Fig. 1): the Snowslip; the Shepard; the Mount Shields; the Bonner; the McNamara; the Garnet Range; and the Pilcher. The contact between the McNamara and overlying Garnet Range, one of the sharpest in the Belt, takes place in a maximum of a few tens of meters. It is marked by an increase in detrital mica and a change from the dominant red beds of the upper McNamara to the gray to gray-green sediments of the Garnet Range. The lithic differences between the Garnet Range and the underlying formations of the Missoula Group denote a prominent change in depositional environment of the Belt.

Purpose of Study

This thesis reports on a study of the transition of the McNamara into the overlying Garnet Range Formation. The principal goals were as follows: 1) to record vertical and horizontal variations of mineralogy, sedimentary structures, color, grain shape and grain size; 2) to correlate the McNamara-Garnet Range transition over a wide geo-
Figure 1. Stratigraphic section of Missoula Group near Alberton, Montana. (Adapted from Wells '74 & Winston '77)
graphic area; 3) to interpret the change in environments that caused the lithic changes; 4) to determine, using stratigraphic relationships, any great tectonic displacements that may have taken place.

**Methods of Study**

Reconnaissance and collection of field data was completed during the summer of 1975 and fall of 1976 over mountainous terrain in northwestern Montana and northeastern Idaho (Fig. 2). The transition of the McNamara-Garnet Range was measured and described in five stratigraphic sections (Appendix I). Sedimentary structures, grain size and color were noted in detail. Samples collected from the transition were studied in thin section for mineralogy and microstructures. Where mineralogy was in doubt, x-ray diffraction was utilized. Some cherts were studied by use of a scanning electron microscope.

**Previous Work**

Generalized descriptions and estimated thicknesses of the McNamara and Garnet Range formations have been described by Nelson and Dobell (1961), Harrison and Jobin (1963), Harrison and Campbell (1963), Harrison (1972), Campbell (1960), and Wells (1974). Unpublished work has also been completed by Winston (personal communication), Desormier (1973), and Hall (1968). No specific regional correlations, detailed stratigraphic sections or models of depositional environment of this specific interval have previously been attempted.
Figure 2. Index map to study areas.
CHAPTER II

DEPOSITIONAL SETTING

Sand Transport Direction

Directional orientations of sedimentary structures were recorded throughout the stratigraphic sections where possible. Measurements were taken on cross-beds, asymmetrical climbing ripples and imbricated mudclasts.

Data from the broad study area indicates that from the upper McNamara to the lower Garnet Range formations, dominant transport direction was northward with an obvious northward decrease in grain size. This agrees with data presented by Winston (1973) for the Bonner Formation.

Source Area

Sedimentary structures indicate a northward direction of transport for the uppermost McNamara and the lowermost Garnet Range formations. The highly feldspatic sediments of the upper McNamara and the micaeous feldspatic nature of the Garnet Range suggest a crystalline and metamorphic source terrain. The contribution of sediment from a metamorphic source becomes increasingly apparent in the Garnet Range.

It has been previously suggested (Winston, 1973; Calbeck, 1975; McMannis, 1963) that sediments derived from pre-Beltian crystalline-metamorphic terrain of the Dillon block were shed on the north downthrown side of the Willow Creek fault which was intermittently active
throughout the Precambrian. The high orthoclase content (up to 30%) of the McNamara and Garnet Range may have been derived from aplitic gneisses of the pre-Cherry Creek Group (pre-Beltian) or aplites of the Dillon granite gneiss some of which consists almost wholly of quartz and orthoclase (Heinrich, 1960).

**Age of Sedimentation**

Very little age dating has been done on the Missoula Group. There are, however, two dates determined by Obradovich and Peterman (1968) on the Garnet Range Formation in the Alberton area. Biotite in a mafic sill intruding the Garnet Range revealed a date of 760 million years. This date represents only a minimum age. Another date of 930 million years, on detrital mica, is suggested to represent a maximum age of sedimentation for the Garnet Range. These dates should be applied cautiously due to diagenetic alteration of detrital micas and subsequent metamorphic events.
CHAPTER III

TEXTURE AND MINERALOGY

Mineralogy

The upper McNamara is generally a highly feldspathic subrounded to rounded quartzite, siltite or argillite. Quartz, rarely rutilated, comprises up to 80% of the sediment and feldspar, and is as high as 40% at Porters Corners. Orthoclase makes up to 30% and is slightly to moderately altered. Plagioclase and microcline reach 5% respectively and are also slightly to moderately altered. Some feldspar grains, especially orthoclase, are larger than quartz grains and represent a textural inversion (Folk, 1968), suggesting a feldspar source that was very close by or closer than that of much of the quartz. Rare detrital tourmaline, zircon, metachert, mica, leucoxene, and chlorite are also present. The uppermost McNamara contains up to 2% mica, consisting of muscovite and probably leached biotite. Leached biotite is golden brown and commonly has a hematitic weathering rind. The red and maroon colors which are characteristic of much of the upper McNamara are produced by disseminated hematite "dust", hematitic grain coatings, and hematitic mud clasts. The fine grained green sediments of the McNamara consist of quartz, feldspar, and rare detrital micas, sometimes "floating" in a very fine grained matrix of chlorite and illite.

The transition into the Garnet Range Formation is marked by a conspicuous increase in detrital mica, decrease in hematitic pigment-
Figure 3. Diagenetically altered feldspar squeezed between quartz grains in Garnet Range.
tation, increased alteration of detrital feldspar and development of a chlorite-illite matrix as determined by x-ray diffraction and less mature sediments. The Garnet Range is comprised of subangular to sub-rounded quartz grains which make up to 80% of the sediment and feldspars which make up to 25%. Orthoclase content is as high as 15%, and plagioclase and microcline make up to 5% respectively. Microcline is generally more abundant than plagioclase. The illite-rich matrix of the Garnet Range consists of up to 10% of the total rock and most is derived from the diagenetic alteration of feldspar (Fig. 3), primarily orthoclase. Minor amounts of matrix material may result from alteration of other unstable minerals. The chlorite and illite of the Garnet Range is responsible for the green tints which typify it. Detrital mica, muscovite, and leached biotite, up to 1.5 mm. long, make up to 5% of the sediment and are characteristically concentrated along bedding planes. Trace amounts of rutilated quartz, metachert, tourmaline, leucoxene (possibly an alteration product of sphene, rutile, or ilmenite), sphene and zircon are also present. Disseminated pyrite cubes up to 1 mm. and very fine grained cubes of magnetite are rare.

Coloration of Sediment

The red and green colored sediment of the McNamara and Garnet Range of the Missoula Group share much in common with the sediments of the Torrodonian Group (Precambrian) of Scotland (Selley, 1965, 1970) and the Difunta Group (Cretaceous-Paleocene) in northeastern Mexico (McBride, 1975) in that the colors reflect both depositional and diagenetic environments.
Figure 4  Coexisting red and green clasts in upper McNamara.
The red sediments of the McNamara, Torrodonian Group and the Difunta Group are colored by hematite intergrown with clays, as coatings on grains and as hematitic mudclasts.

The green colored sediments in all of the groups is produced by chlorite, green illite and the paucity of hematite. Pyrite imparts a gray color to the sediment.

The iron in the red sediments was probably transported and deposited in the oxidized state mostly as limonitic muds. The red sediment of the McNamara display abundant well developed polygonal mudcracks, salt casts, gypsum casts, mudclasts and pervasive hematite suggesting subaerial exposure in an oxidizing environment.

The thinly bedded green sediments of the upper McNamara were probably initially deposited as oxidized sediments, but were subsequently reduced below the depositional interface in shallow ponds. McBride (1975) reports coexisting red and green clasts in channel sands in the Difunta Group, indicating that the oxidized or reduced nature of the iron resulted shortly after deposition and was available to erosion on the delta plain. Coexisting red and green intraclasts are present in quartzites of the upper McNamara (Fig. 4).

Much of the Garnet Range is gray to gray-green pyritic quartzite with numerous dark gray to black mudcracked surfaces and mudclasts which suggest post-depositional reduction of red beds. The overlying Pilcher Formation is a red hematitic quartzite, implying that reduction was confined to the Garnet Range perhaps resulting from a reducing water table.
CHAPTER IV

CHERT AND CHERTY SILTITE OF THE UPPER McNAMARA
AND LOWERMOST GARNET RANGE

Description

Cherts and cherty siltites are rare in the Belt Supergroup of northwestern Montana. They have been observed in the Prichard Formation and the Middle Belt carbonate but are most common in the Missoula Group. Chert is present in every section of the uppermost McNamara and becomes rarer in the lowermost Garnet Range.

The chert of the uppermost McNamara and lowermost Garnet Range is hard, harder than a hammer, and commonly breaks into small conchooidal fragments. Color ranges from mostly green to gray-green, although some is brown. Thickness of individual beds ranges from microscopic to 15 cm. In some sections, individual beds can be followed the length of available outcrop (20 m.). Cherty sediments occur throughout the same interval within the McNamara-Garnet Range transition for a horizontal distance of 250 km. Chert clasts up to 5 cm. long occur in crossbedded quartzite in the Flint Creek section.

Petrographically, the cherts and cherty siltites consist of detrital grains in a partly to totally silicified microcrystalline quartz or chalcedony matrix (Fig. 5). Matrix supported detrital grains are mostly quartz, feldspar, mica, and chloritic (?) clasts. Occasional quartz grains are embayed (Fig. 6). Diagenetic pyrite is also present. Spherules and filaments, possibly algal in origin, are well preserved.
Origin of Chert

Theories suggesting the origin of the chert beds of the upper McNamara and lower Garnet Range can only be considered speculative at this point.

Throughout the stratigraphic record occur cherts formed by devitrification of volcanic ash and subsequent release and precipitation of hydrated silica (opal), which converts to chalcedony or microcrystalline quartz. Cherts of the Duchesne Formation (Anderson and Picard, 1974) and the Arkansas Novaculites (Goldstein, 1959) are believed to have formed in this manner. The very thinly bedded appearance of some cherty argillites in the upper McNamara and lower Garnet Range suggest that they were deposited in shallow intermittent ponds. Other chert beds at the tops of graded sequences may have resulted from reworked ash. A similar process has been suggested for silicified ash of the Duchesne Formation (Anderson and Picard, 1974). In thin section, embayed quartz and possible ghosts of coarse-grained detrital clasts appear identical to devitrified tuff fragments in the Cretaceous Dunkleberg Group of Montana and the Silurian of Maine (Horodyski, personal communication).

The only known volcanic activity in the Belt region within the available time framework of the McNamara and Garnet Range are greenstones in eastern Washington (Leola Volcanics) and southern British Columbia (Irene Volcanics) which are Windermere in age. Due to sedimentary reworking, later metamorphism, and lack of any concrete evidence connecting them with known volcanism, it is highly speculative
Figure 5. Fine grained cherts at Trout Creek section.

Figure 6. Embayed quartz grain in chert (Rainbow Bend section).
to say that the cherts of the McNamara and lower Garnet Range are volcanic in origin.

A simpler way to explain the origin of the cherty sediments results from the conversion of smectite to illite during diagenesis. It has been suggested (Hower, et al., 1976) that the smectite to illite reaction yields silica (smectite + Al\(^{3+}\) + K = illite + Si\(^{4+}\)). The alteration of orthoclase in the uppermost McNamara and Garnet Range could supply aluminum and potassium for the clay reaction and also release free silica. The abundance of mature mudcracks, occasional gypsum casts, and red beds in the upper McNamara suggests that a subhumid to arid environment existed which would be favorable for the formation of smectite. The character of the Garnet Range suggests a wetter environment and might explain the sudden decrease in cherts.
CHAPTER V

SECTION DESCRIPTION AND INTERPRETATION

Porters Corner Section (P.C.)

Description

The salient features of the stratigraphic section at Porters Corner are described below. For more detail, see Appendix I.

The 380 meter thick section at Porters Corner is described in four segments.

The lowermost 34 meters consist mostly of repeated graded sequences from 10-45 centimeters thick. At the base of each graded sequence are medium to coarse grained high angle tangentially cross-bedded quartzites up to 10 centimeters high with imbricated mudchips. These grade upward in each sequence into horizontally laminated red siltites. The tops of most sequences are scoured below the base of the next overlying graded sequence. Crossbeds throughout this sequence are rather unidirectional to the north.

The second unit, from 34-135 meters, is mostly tangentially cross-bedded coarse quartzite up to 25 centimeters high and tabular cross-beds up to 10 centimeters. Silt beds are significantly fewer than in the underlying unit. Some are cut by scours up to 1.2 meters deep and filled by crossbedded sand. An interval of brown chert clasts up to 5 centimeters long occurs between 42-46 meters.
The third unit (135-170 meters), the highest unit of the McNamara, is dominantly coarse-grained pink quartzites with high angle tangential crossbeds, up to 1 meter high, containing large imbricated mud-chips. Detrital mica becomes conspicuous in the upper part of this segment.

The uppermost unit (170-380 meters) is dominantly a gray micaceous planar to crossbedded quartzite with rare red beds in the lower part of the sequence. The base of this unit marks the base of the Garnet Range Formation. An interval of limonite stained quartzite, which is deeply weathered, is cut and overlain by planar crossbedded quartzite with relatively fresh, unweathered feldspar and mica grains.

Environmental Interpretation of the Porters Corner Section

Porters Corner is the southernmost section studied and contains the coarsest grain sizes and the largest scale sedimentary structures in this study. It is, therefore, probably closest to the original source area.

The lowermost unit in the Porters Corner section (0-34 meters) probably represents shallow, fairly straight, northward-flowing braided stream channels in the lower flow regime. The silts at the top of graded sequences were probably deposited from suspended load as channels shifted. The shifting channels scoured underlying silts, leaving them as discontinuous lenses. Some of the silt was reworked into mudclasts in the overlying sands.

The second and third units represent the progressive incursion of larger and deeper braided stream channels which ultimately formed,
crossbeds up to 1 meter thick. The fine silts which are so common in the lowermost unit are all but absent because of high channel density and reworking. The obvious increase in detrital mica toward the top of the third unit represents the increased contribution from a metamorphic source.

The uppermost unit (170-380 meters) is consistently more micaeous than the underlying sequences and represents the firm establishment of a metamorphic source area. The development of gray beds probably results from rapid sediment burial without oxidation or from diagenetic reduction of sediment. Abundant planar crossbedded quart-zites were deposited as longitudinal and/or transverse bars with planar bedded sediments deposited on top in upper flow regime. The horizon of limonitic stained quartzite may represent a Precambrian weathering horizon, suggesting a period of non-deposition.

Rainbow Bend Section (R.C.)

Description

The Rainbow Bend section consists of four definable units. For a more detailed description, see Appendix I.

Unit one (0-19 meters) consists of slightly micaceous medium-to fine-grained quartzite and siltite. The lowermost part of the unit is dominantly fine-grained quartzite and siltite, forming up to 7.5 centimeter graded couplets with mudcracked surfaces. Rare thin beds of green siltite up to 2.5 centimeters occur throughout the lower part of this unit.
The remaining upper part of the unit is dominantly red medium-grained quartzite to siltite forming graded sequences up to 20 centimeters thick. Scours up to 13 centimeters deep and planar beds with imbricated mudchips at the base pass up into asymmetrical climbing ripples and horizontally laminated silts. Rare mudcracks and raindrop impressions occur sporadically throughout the upper part of the unit. A 30 centimeter thick bed of brown cherty siltite occurs at about 13 meters in the section.

Unit two (20-49 meters) is comprised of dominantly medium- to coarse-grained 36 centimeter graded sequences with deep scours at the base up to 46 centimeters long and 15 centimeters deep, filled and overlain by high angle crossbeds up to 10 centimeters high, passing up to abundant asymmetrical ripples and thin beds of horizontally laminated siltites. No mudcracked surfaces were observed.

Unit three (60-112 meters) is mainly red and purple medium- to fine-grained micaceous quartzite and siltite with rare gray-green quartzites. Planar beds and climbing ripples up to 5 centimeters high and sand to silt graded beds up to 30 centimeters thick are common. Some thin beds at the tops of graded sequences contain up to 15% detrital mica and weather to a crumbly brown.

Unit four (112-140 meters) consists of graded sequences up to 60 centimeters thick that are medium- to coarse-grained micaceous gray and very micaceous gray-green limonitic stained quartzite with abundant planar beds at the base overlain by climbing ripples up to 5 centimeters high. Abundant planar beds and rare massive gray quartzites
up to 1 meter thick are present throughout the unit. No mudcracks or red mudclasts were observed. The transition of the red sediments of unit three to the dominantly gray and gray-green micaceous sediments of unit four marks the contact between the McNamara and the Garnet Range.

Environmental Interpretation

The lower part of unit one probably represents deposition of sediment either between lobes of the braided fan similar to those described by McGowan (1971) for the Gum Hollow Fan, or overbank deposition adjacent to shallow braided streams on a delta plain. Rare thin green beds lacking mudcracks were probably deposited in temporary shallow ponds and subsequently reduced below the depositional interface.

The remaining upper part of the unit represents development of larger and deeper braided streams resulting from increased discharge or possibly from the lateral migration of the main part of the fan. Graded sequences probably represent waning discharge rates and infilling of channels. The slight increase in detrital mica results from the higher contribution from a metamorphic source.

Unit two probably represents the establishment of development of larger more competent streams forming deep scours. The lack of mudcracks in the tops of graded sequences is probably a result of high channel activity or high humidity, preventing the formation of well-developed polygonal mudcracks.

Unit three demonstrates the interbedded nature of the transition. Planar bedding passing into climbing ripples in graded sequences are
similar to those developed in the Bonner Formation (Winston, 1973). Winston (1973) suggested that planar beds were probably deposited in upper flow regime across broad and very shallow channels, possibly during sheet floods. The transition from higher to lower flow regime did not produce dunes because the streams were too shallow, and as a result, climbing ripples formed. The high percentage of detrital mica associated with fine grained quartzite demonstrates that they behave as smaller grains due to their platy nature.

Unit four marks the stratigraphic contact of the McNamara with the Garnet Range. The larger sedimentary structures, gray to gray-green colors and high detrital mica content are characteristic of the lowermost Garnet Range Formation. Massive structureless gray quartzites up to one meter thick are very similar to sands deposited by lateral accretion in distributary channels in shallow fast-flowing braided streams (Shaw, 1975, p. 299). Planar beds in overlain by climbing ripples probably formed similarly to those described in unit three. Sedimentary structures in the Garnet Range and the gray to gray-green color suggest higher discharge, more rapid deposition and diagenetic reduction of sediment.

Ellis Mountain Section (E.M.)

Description

The salient features of the 68 meter Ellis Mountain section near Alberton, Montana, are described in four sedimentary packages. A detailed description is presented in Appendix I.
The lowermost part of the section (0-12 meters) is medium grained red to maroon slightly micaceous quartzite and siltite. Graded couplets from 15-30 centimeters thick are common and have small imbricated mudclasts and asymmetrical climbing ripples at the base which grade into mudcracked horizontally laminated siltite. Horizontally laminated siltites are abundantly scoured and supply mudchips in overlying quartzites. Seven centimeter lenticular lenses of pink medium grained quartzite occur sporadically.

The second part of the section (12-18 meters) is dominantly red to maroon slightly micaceous medium grained quartzite and siltite. Abundant asymmetrical climbing ripples up to 2.5 centimeters thick form sequences up to 1.8 meters thick. Graded couplets between 2.5 and 5 centimeters thick are common. Rare horizontally laminated fine grained green siltite occur intermittently.

The third unit (18-42 meters) is a relatively thick interval of micaceous, coarser, gray and purple quartzites interbedded with rare fine grained red quartzites. Many of the gray beds display limonitic weathering. This interval contains numerous beds of low angle planar crossbed sets up to 10 centimeters thick which are planed off by upper regime planar beds containing abundant imbricated mudclasts forming sequences up to 70 centimeters thick. An 18 meter thick sequence of cherty siltites overlain and underlain by quartzites is prominent at the top of this interval. It is intensely fractured and sedimentary structures are obscured. In thin section they appear thinly bedded.
The base of the fourth and uppermost unit (42-68 meters) is marked by the contact of the dominantly red McNamara with the dominantly gray to gray-green Garnet Range. Sediments are medium to coarse grained very micaceous gray to gray-green quartzites that commonly weather reddish brown. Abundant planar beds with mica concentrated along bedding planes are very common. Less common are unidirectional (northward) sets of tangential crossbeds up to 30 centimeters high. Graded sequences up to 45 centimeters thick commonly have planar beds at the base which pass upward into asymmetrical climbing ripples up to 5 centimeters high and horizontally gray to dark gray horizontally laminated siltites. Some planar crossbeds overlain by planar beds are bordered by channel scours. Disseminated pyrite was found intermittently throughout this unit. Mudcracks are very rare and are mostly poorly developed. Very thin cherty beds and clasts occur only in the lowermost part of the interval. Patches of calcite as fracture fillings between detrital grains present in quartzites occur sporadically throughout this unit.

Environmental Interpretation

The lowermost part of the Ellis Mountain section probably represents overbank deposition adjacent to stream channels or sheet flooding along an extensive delta plain. The abundance of asymmetrical climbing ripples indicate rapid deposition by sediment laden water in lower flow regime. Planar beds containing large numbers of mudchips were deposited in upper flow regime possibly during sheet flooding.
The most prominent features of the second interval are thick sequences of asymmetrical climbing ripples which are similar to those described from Walker (1963). He interpreted the sequences to have been from overbank flood waters high in suspended sediment load deposited in abandoned stream channels by a rather steady current. Thinly bedded green siltites were probably deposited in small intermittent ponds with reducing conditions below the depositional interface.

Unit three represents the northward advance of larger braided streams forming longitudinal or transverse bars, approximately 1 meter high, which were frequently scoured by upper regime flow. Limonitic coatings staining the gray quartzites represent weathering of ferrous iron. The interbeds of gray quartzite with reduced iron and red quartzite with oxidized iron reflect the gradation of Mc-Namara transition into the overlying Garnet Range. The cherts are discussed separately, p.

The uppermost part of the section is totally within the Garnet Range. The increase in detrital mica concentrated along bedding planes results from the increasing dominance from a metamorphic source. The greater number of planar beds represents a higher incidence of upper regime flow. Planar crossbeds overlain by planar beds and cut by transverse crossbeds are characteristic of transverse or longitudinal bars cut by small braided streams (Boothroyd and Ashley, 1975, p. 214). The scarcity of mudcracks and sedimentary features indicates high discharge rates with rapid deposition. The presence of pyrite suggests reducing conditions possibly generated by a high water table.
Description

The prominent features of the Trout Creek section are described below as three distinct packages. For a more detailed description, see Appendix I.

The lowermost part of the section (0-20 meters) is characterized by fine grained red siltites forming up to 5 centimeter graded sequences with mudcracked surfaces. Within the red bed sequence, thin beds of green siltites less than 2.5 centimeters thick are common with rarer beds of fine grained quartzite up to 10 centimeters. Some of the graded red beds contain pink quartzite, that is planar bedded, at the base and passes up into asymmetrical climbing ripples up to 5 centimeters high, followed by horizontally laminated red siltite. Gray to gray-green cherty siltites with rare dewatering structures and small soft sediment folds occur throughout the upper part of this interval.

The section from 20-50 meters thick is mostly pink to red medium grained quartzites and siltites forming graded sequences up to 23 centimeters thick with 7.5 centimeter high sets of tangential cross-beds containing imbricated mudclasts up to 5 centimeters long that pass up into asymmetrical climbing ripples up to 5 centimeters high. The tops of most graded sequences are extensively mudcracked and sometimes exhibit raindrop impressions. Rare green siltites up to 7 centimeters thick of uniform thickness occur throughout this interval. In the upper part of this interval, detrital mica increases noticeably.
The uppermost segment of the section (39-75 meters) is micaceous pink, red, and purple siltites to medium grained quartzite which abruptly passes upward into the micaceous gray to gray-green quartzite and siltite of the Garnet Range Formation. At 56 meters in the section, both planar beds 10-15 centimeters thick and tangential crossbeds up to 10 centimeters high indicate a northward direction of transport are common. Asymmetrical climbing ripples up to 5 centimeters high occur throughout the unit. Rare cherty siltites up to .65 centimeters thick and very rare mudcracked surfaces are found in the upper part of the section.

Environment of Deposition

The lowermost interval of the Trout Creek section probably represents deposition of fine grained sediments on a very low gradient delta plain followed by extensive dessication resulting in abundant polygonal mudcracks. McGowan (1971) describes very well-developed mudcracked surfaces between various lobes in the distal parts of the Gum Hollow Fan in Texas. The green finely bedded siltites lacking mudcracks and fine-grained quartzite were probably deposited in shallow ponds or along the margin of a larger body of water that occasionally advanced and receded. The water cover reduced ferric to ferrous iron below the depositional interface. The influx of slightly coarser pink sand in 10 centimeter couplets that pass from planar beds to asymmetrical climbing ripples covered with very fine grained sediments of uniform thickness represents advance incursion of shallow
braided stream channels which overflowed their channels. The transition of planar beds to asymmetrical ripples probably took place in shallow streams or distributaries which limited the size of bedforms.

The middle part of the section represents development of deeper and more competent streams which deposited northward dipping unidirectional crossbeds. Large imbricated mudclasts within fine grained quartzites and siltites suggests that the competency of the streams was greater than the grain size available. Perhaps rainstorms that left raindrop impressions on numerous bedding surfaces swelled the streams. Uniform green siltites were probably deposited in intermittent ponds.

The uppermost unit is increasingly micaceous and represents greater contribution from a metamorphic source deposited by braided stream channels. The gray to gray-green colors of the Garnet Range represent diagenetic reduction of sediment. Fine-grained green siltites with very rare mudcracks probably represent deposition in shallow ponds or in an embayment by adjacent braided streams.

**Thompson Falls Section (T.F.)**

**Description**

The Thompson Falls section is described in three separate units. For a more detailed description, see Appendix I.

Unit one (0-79 meters) consists of a relatively thick sequence of fine-grained green slightly calcareous siltite that is very thinly bedded (7 millimeters) horizontally laminated with very rare sub-
Figure 7 Oolites in green siltite (Thompson Falls section).
aerial mudcracks. A thin (7.5 centimeters) bed of cherty siltite, 7 meters upsection, consists of chalcedony (probably replacing calcite), and displays fenestral fabric (birdseye structures) and matrix supported oolites (Fig. 7). Occasional linear, discontinuous probably subaqueous mudcracks, and water expulsion structures occur in the more thinly laminated sediments which have very sharp upper and lower contacts. Slightly coarser sediment with small scours, asymmetrical ripple marks, and polygonal subaerial mudcracks become increasingly common toward the top of this unit.

Unit two (79-97 meters) is comprised of coarser (medium grained) slightly micaceous red quartzite and siltite with northward migrating climbing ripples and imbricated mudclasts. The quartzite forms graded sequences up to 15 centimeters thick with tangential (5 centimeter) crossbeds at the base that pass up into climbing ripples and horizontally laminated mudcracked sediments at the top. Some bedding surfaces contain gypsum casts (Fig. 8).

The base of unit three (97-121 meters) marks the contact of the upper McNamara and the Garnet Range. The sediments are generally micaceous medium to fine grained gray to gray-green, sometimes weathered to limonitic sandstone, that commonly form up to 10 centimeter thick graded couplets with asymmetrical ripple marks up to 5 centimeters high. No mudcracks were observed.

Environment of Deposition

The lowermost unit of the Thompson Falls section was probably deposited in a progressively filled alkaline body of water, perhaps
Figure 8  Gypsum casts in uppermost McNamara (Thompson Falls section).
a protected embayment. The thinly laminated nature of the sediments at the base of the section probably represents the quietest and deepest environment of all the sections studied. The presence of matrix supported oolites suggest influx of sediments from offshore bars or adjacent beaches. Fenestral fabric (birdseye structures) suggest a period of subaerial exposure as the sediments prograded similarly to those of the coast of Abu Dhabi (Purser, 1973). The uppermost part of unit one consists of sediment deposited on a delta plain or marginal sand flat, cut by shallow braided stream channels.

The middle unit appears to have been deposited on delta plains or possibly tidal flats with very well developed mudcracked red (oxidized) sediments. Gypsum casts (Fig. 8) suggest that evaporative alkaline conditions existed at least locally.

The uppermost part of the section marks the contact with the Garnet Range. The obvious increase in detrital mica and green to gray-green colors with limonitic staining are characteristic of the lowermost Garnet Range. The sediments represent deposition by more competent braided streams in shallow waters of the delta front or in adjacent bodies of water where subaerial exposure was very rare. Subaqueous deposition produced reducing conditions below the depositional interface.
CHAPTER VI

SUMMARY

Integrated Interpretation

In the Precambrian, optimum conditions existed for the development of alluvial fan deltas due to the absence of vegetation (McGowen and Groat, 1971). Sedimentary structures in the uppermost McNamara and lowermost Garnet Range strongly suggest deposition by braided stream channels on prograding fan deltas. The northward decrease in grain size and scale of sedimentary structures suggest that most sediment was derived from pre-Beltian highlands to south of the Willow Creek Fault, consisting of igneous and metamorphic terrains.

The uppermost McNamara is interpreted to have been a northward prograding braided fan delta deposited in an arid to subhumid environment (Fig. 10). Gypsum casts, well preserved rounded feldspars, extensive well developed polygonal mudcracks and red beds suggest evaporative conditions with a well developed zone of oxidation possibly resulting from a low water table. Salt casts found slightly lower in section than those studied adds support.

The most proximal part of the fan examined, at Porters Corner (Figs. 9, 10) contains the largest scale sedimentary structures and coarsest grain size of the McNamara studied. Northward dipping 1 meter high tangential crossbeds and channel scoured siltites were deposited by braided streams as they flowed north and decreased in energy with a decrease in gradient.
Sand bars (transverse & longitudinal), Intermittent lakes.

Figure 10. Upper McNamara. (Vertical scale greatly exaggerated.)
The Rainbow Bend section (Figs. 9, 10) probably represents deposition by shallow braided streams in interlobe areas that occasionally filled with water passing up to sheet flow sedimentation in upper flow regime in higher parts of the section.

The lowest part of the Ellis Mountain section (Figs. 9, 10) may represent deposition on the low gradient delta plain or perhaps in interlobe areas. Higher up section as the delta prograded, coarser sediments and larger scale sedimentary structures were deposited followed by development of bars.

Between the Ellis Mountain section and Trout Creek, the decreasing gradient is very evident. The medium to coarse grained quartzite at Ellis Mountain fines northward to interbedded red and green fine grained quartzites and siltites at Trout Creek. The McNamara at Trout Creek was probably deposited on the delta plain by small braided streams which commonly overflowed their channels and followed by extreme dessication. Deposition was also in temporary ponds or along the margins of a larger body of water that frequently advanced and receded.

The most distal segment of the fan delta examined, near Thompson Falls (Figs. 9, 10), demonstrates the progradational nature of the upper McNamara. The lowermost part of the section reflects deposition of sediment in a relatively quiet environment, possibly an embayment, overlain by sediment with oolites deposited from off-shore bars or adjacent beaches. The oolitic sediments pass upward to mudcracked red sediments with gypsum casts suggesting subaerial exposure and
Figure 11  Transition. (Vertical scale greatly exaggerated.)
evaporative conditions possibly along the margins of a "Belt" sea or an alkaline body of water.

The transition into the overlying Garnet Range Formation (Fig. 11) is characteristically marked by a change from the red colors of the uppermost McNamara to the gray to gray-green colors of the Garnet Range, accompanied by coarser more micaceous less mature sediment in larger scale structure, reflecting higher discharge and probably more rapid deposition (Fig. 11). The change in color represents reduction of iron, possibly resulting from high water saturation of sediment.

Overlying the upper McNamara fan delta are the sediments of the Garnet Range (Fig. 12). The rarity of well developed mudcracks and gypsum casts in the Garnet Range may reflect either short periods of subaerial evaporation or higher humidity than the McNamara. Reduction of iron in the transition may result from diagenetic reducing conditions brought about by high water saturation.

The lowermost Garnet Range at Porters Corner (Fig. 9) is similar to the underlying McNamara in that it contains the largest sedimentary structures and coarsest grain size of all sections and is also the most proximal section of Garnet Range examined. The Garnet Range differs from the McNamara in color, type of sedimentary structures, and mineralogy. The lowermost Garnet Range at Porters Corner represents development of northward migrating longitudinal bars overlain by planar bedded sands deposited in upper flow regime. The sediments were rapidly deposited and subsequently reduced diagenetically.
Figure 12. Lowermost Garnet Range. (Vertical scale greatly exaggerated.)
The Rainbow Bend section (Figs. 9, 12) represent deposition down fan by rapidly flowing braided streams and planar bedded sediment deposited in upper flow regime.

The Ellis Mountain section (Figs. 9, 12) reflects the development of longitudinal bars cut by small braided streams and overlain by micaceous planar bedded quartzite deposited in upper flow regime.

The Garnet Range in Trout Creek probably represents deposition in shallow ponds or adjacent to a larger body of water, by sediment laden braided streams (Figs. 9, 12).

The most distal section, near Thompson Falls (Figs. 9, 12), represents deposition in shallow delta from braided streams or in an embayment. The shallow water sediments of the Garnet Range overlying the mudcracked sediment of the McNamara may result from a relative transgression produced by lateral migration of maximum deposition as the delta subsided, overall subsidence or a rise in water level.

Speculative Mechanisms for Transition

Most "Belt" workers would agree that the character of the Garnet Range Formation is unlike any other unit in the Missoula Group. Its great thickness (2,425 meters in Alberton, Wells, 1974), the characteristic gray to gray-green colors and high detrital mica content make it distinctive. The abrupt upward transition from the McNamara to the overlying Garnet Range represents a major change in depositional or source area environments which could have been produced by various mechanisms. Time correlation with any particular climatic or tectonic
event is speculative due to the paucity of radiometric dates.

The upward coarsening grain size in the upper McNamara into the Garnet Range, increased contribution from a metamorphic source and transition from the highly oxidized sediments of the uppermost McNamara to the less oxidized sediment of the Garnet Range may reflect increased surface and subsurface flow of water, which in turn could have been brought about by the following speculative mechanisms: 1) tectonic event; 2) climatic change; 3) modification of climate produced by a tectonic event.

1) A change in tectonic setting in the source area could increase the watershed geometry and the available source area, producing higher discharge and sedimentation rates.

2) A transition to a wetter climatic period can have a profound effect on the depositional environment. Greater precipitation within the source area resulting in high discharge would produce an increase in stream competency and probably change the level of the water table.

To speculate further, evidence supporting late Precambrian glaciation between 800 and 600 million years ago (Eocambrian) can be found in Australia, Africa, Greenland, Spitzbergen, South America, and North America (Harland, 1964). Perhaps the transition of the McNamara into the Garnet Range reflects the development of a braided outwash fan similar to those described by Boothroyd and Ashley (1975) for the Scott and Yana outwash fans in Alaska.
3) A combination of the two mechanisms could also produce changes in depositional environment. With increased elevation produced by mountain building, climate could have been modified. A possible present analog exists on Vancouver Island, Canada, where Pacific fronts are blocked by mountains resulting in more than 160 centimeters of precipitation annually.
REFERENCES CITED


McGowen, J.H., 1970, Gum Hollow Fan Delta, Nueces Bay; Texas report of Inv., no. 69, Bureau of Econ. Geol., Univ. of Texas, 91 p.


APPENDIX I

LOCATION AND WRITTEN DESCRIPTION OF SECTIONS

The procedure for measuring stratigraphic sections was as follows: 1. to measure the section with a Jacob's staff and mark off thickness with spray paint, and 2. to describe the section and collect samples for thin sectioning.

A total of five sections were located, measured, and described. Locations are plotted on Figure 2 and drafted sections in Appendix II.
SECTION P.C. (Porters Corners)

Located 8 km. south of Philipsburg, Montana, along Route 10A; 8 km. past Porters Corners.

<table>
<thead>
<tr>
<th>Unit</th>
<th>Description</th>
<th>Thickness in Meters</th>
<th>Meters Above Base</th>
</tr>
</thead>
<tbody>
<tr>
<td>18</td>
<td>Gold-brown limonite stained micaceous medium-coarse grained quartzite appears deeply weathered with occasional patches of fresh gray micaceous quartzites. Very low-angle unidirectional northward dipping planar crossbeds about 10 cm. thick and abundant planar bedded micaceous gray quartzites.</td>
<td>61</td>
<td>318-379</td>
</tr>
<tr>
<td>17</td>
<td>Very micaceous medium-coarse grained, up to 1 mm., gray quartzite with some finer grained red very micaceous quartzites. Mudchip conglomerates; planar beds common. 10 cm. graded couplets common. Weathered interval scoured by fresh sediment observed.</td>
<td>12</td>
<td>306-318</td>
</tr>
<tr>
<td>16</td>
<td>Red-purple medium-coarse grained slightly micaceous quartzites. 8 cm. high crossbeds.</td>
<td>8</td>
<td>298-306</td>
</tr>
<tr>
<td>15</td>
<td>Covered but float indicates gray quartzites.</td>
<td>28</td>
<td>270-298</td>
</tr>
<tr>
<td>14</td>
<td>Thinly bedded pink, fine-grained quartzites with 8 cm. high northward dipping crossbeds common.</td>
<td>3</td>
<td>267-270</td>
</tr>
<tr>
<td>13</td>
<td>Covered but float indicates gray micaceous quartzites.</td>
<td>34</td>
<td>233-267</td>
</tr>
<tr>
<td>Unit</td>
<td>Description</td>
<td>Thickness in Meters</td>
<td>Meters Above Base</td>
</tr>
<tr>
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<td>---------------------</td>
<td>-------------------</td>
</tr>
<tr>
<td>12</td>
<td>Gray-pink medium-grained quartzite with abundant moderate to high angle 10 cm. high planar and tangential crossbeds. Tops very commonly scoured off. Crossbeds dip northward.</td>
<td>15</td>
<td>218-233</td>
</tr>
<tr>
<td>11</td>
<td>Gray slightly micaceous medium-coarse grained quartzite with high angle crossbeds up to 1 m. high.</td>
<td>3</td>
<td>215-218</td>
</tr>
<tr>
<td>10</td>
<td>Covered</td>
<td>10</td>
<td>205-215</td>
</tr>
<tr>
<td>9</td>
<td>Mostly coarse-grained, up to 1 mm., gray quartzites with some pink and brown quartzites. Low angle crossbeds 13-25 cm. high with tops frequently scoured off. Generally northward dipping crossbeds.</td>
<td>26</td>
<td>179-205</td>
</tr>
<tr>
<td>8</td>
<td>Covered</td>
<td>12</td>
<td>167-179</td>
</tr>
<tr>
<td>7</td>
<td>Pink coarse-grained quartzite, up to 1 mm. with large high angle crossbeds up to 1 m. high, occasionally scoured by planar beds. Occasional matrix supported mudchip conglomerates up to 5 cm. at base of crossbed sets. Crossbeds generally unidirectional, dipping northward.</td>
<td>11</td>
<td>156-167</td>
</tr>
<tr>
<td>6</td>
<td>Pink medium-fine grained quartzites commonly cross-bedded up to 29 cm. and graded horizontal beds up to 15 cm.</td>
<td>17</td>
<td>139-156</td>
</tr>
<tr>
<td>Unit</td>
<td>Description</td>
<td>Thickness in Meters</td>
<td>Meters Above Base</td>
</tr>
<tr>
<td>------</td>
<td>-----------------------------------------------------------------------------</td>
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</tr>
<tr>
<td>5</td>
<td>Pink-red and brown medium grained quartzite up to 1 m. Mudchips common. Directional variation rare.</td>
<td>6</td>
<td>133-139</td>
</tr>
<tr>
<td>4</td>
<td>Pink medium-fine-grained quartzite with purple laminae extensive trough shaped sets of high angle crossbeds. Up to 25 cm. with erosional boundaries between sets and northward dipping unidirectional low angle tabular crossbeds.</td>
<td>3</td>
<td>130-133</td>
</tr>
<tr>
<td>3</td>
<td>Covered</td>
<td>30</td>
<td>100-130</td>
</tr>
<tr>
<td>2</td>
<td>Pink medium-coarse-grained quartzite. Larger graded couplets between 38 and 76 cm., large scours common up to 13 cm. deep with mudchip lags at 100 m., imbricated mudchip conglomerates and 15-20 cm. high low tangential beds and 30 cm. high trough-shaped crossbeds. Brown-red micaceous shaley beds at top of each couplet. Between 42 and 46 m. is a zone of pink quartzite with angular cherty clasts up to 5 cm. long.</td>
<td>66</td>
<td>33-100</td>
</tr>
<tr>
<td>1</td>
<td>Red-pink medium-coarse grained quartzite. Slightly micaceous 23-36 cm. thick graded couplets. High angle tangential crossbeds up to 10 cm. passing upward to climbing ripples and horizontally laminated red silts, scoured red siltites up to 7.5 cm. deep common.</td>
<td>33</td>
<td>0-33</td>
</tr>
</tbody>
</table>
SECTION R.B. (Rainbow Bend)

Section R.B. is located approximately 19.5 km. east of Bonner along the north bank of the Blackfoot River on Route 200.

<table>
<thead>
<tr>
<th>Unit</th>
<th>Description</th>
<th>Thickness in Meters</th>
<th>Meters Above Base</th>
</tr>
</thead>
<tbody>
<tr>
<td>9</td>
<td>Micaceous gray quartzites and very micaceous gray-green siltites with abundant planar beds with occasional 30 cm. deep scours common and 61 cm. thick graded sequences common. Top of graded sequence contain very abundant mica flakes parallel to bedding.</td>
<td>27</td>
<td>109-136</td>
</tr>
<tr>
<td>8</td>
<td>Increasingly micaceous medium grained red and gray quartzites with occasional green-gray and purple micaceous siltites; 30 cm. thick graded couplets common.</td>
<td>26</td>
<td>83-109</td>
</tr>
<tr>
<td>7</td>
<td>Covered</td>
<td>9</td>
<td>74-83</td>
</tr>
<tr>
<td>6</td>
<td>Red and purple medium-coarse micaceous quartzites mostly planar bedded with mudchip clasts common. Occasional graded couplets up to 30 cm. thick.</td>
<td>15</td>
<td>59-74</td>
</tr>
<tr>
<td>5</td>
<td>Covered</td>
<td>11</td>
<td>48-59</td>
</tr>
<tr>
<td>4</td>
<td>Gray, pink and red coarse-grained quartzites and siltites common high angle cross-beds up to 15 cm. with occasional scours up to 46 cm. across and 15 cm. deep, 15-38 cm. thick graded couplets common with common climbing ripples and mudclasts common in coarser grained quartzites.</td>
<td>18</td>
<td>30-48</td>
</tr>
<tr>
<td>Unit</td>
<td>Description</td>
<td>Thickness in Meters</td>
<td>Meters Above Base</td>
</tr>
<tr>
<td>------</td>
<td>-------------</td>
<td>---------------------</td>
<td>-------------------</td>
</tr>
<tr>
<td>3</td>
<td>Influx of coarser planar bedded purple and medium grained 20 cm. high cross-beded gray quartzites with some finer grained red siltites. Increasingly micaceous towards top of interval; mud-clasts common, graded sequences up to 76 cm. in thickness.</td>
<td>12</td>
<td>18-30</td>
</tr>
<tr>
<td>2</td>
<td>Interval of finely bedded slightly micaceous red-maroon fine-grained quartzites and siltites with occasional beds of very fine-grained green siltites. Red siltites frequently mudcracked. Graded couplets up to 2.5 cm. very common.</td>
<td>6</td>
<td>12-18</td>
</tr>
<tr>
<td>1</td>
<td>Fine to medium grained red-maroon slightly micaceous sands with occasional thin green beds of siltites. 15-30 cm. graded sequences with up to 5 cm. asymmetrical climbing ripples, mudchip conglomeritic beds up to 10 cm. thick with clasts as large as 2.5 cm. Planar beds and small lenticular sand lenses common; occasional mudcracked surfaces observed.</td>
<td>12</td>
<td>0-12</td>
</tr>
</tbody>
</table>
**SECTION EM (Ellis Mountain)**

Located approximately 4.8 km. east of Alberton, Montana, on the south side of Route 90 East on north bank of Clark Fork River.

<table>
<thead>
<tr>
<th>Unit</th>
<th>Description</th>
<th>Thickness in Meters</th>
<th>Meters Above Base</th>
</tr>
</thead>
<tbody>
<tr>
<td>7</td>
<td>Gray to gray-green micaceous dominantly planar bedded quartzite with occasional channel scours up to 60 cm. deep with mudchip lags, crossbeds up to 30 cm. high and asymmetrical climbing ripples. Rare mudcracks, patchy CaCO₃ observed. Weathers rusty brown. Graded sequences up to 30 cm. thick.</td>
<td>18</td>
<td>50-68</td>
</tr>
<tr>
<td>6</td>
<td>Gray to gray-green micaceous medium-grained quartzites with occasional thin chert beds. Mostly planar bedded but with many climbing ripples up to 5 cm. high. Common 30 cm. thick graded sequences of coarse gray sands at base grading into very micaceous grayish brown-green siltites. Sediments weather rusty brown.</td>
<td>8</td>
<td>42-50</td>
</tr>
<tr>
<td>5</td>
<td>Micaceous purple, red, and gray-green quartzites frequently scoured to depths of 8 cm. and common low cross-beds 5-10 cm. high. Numerous green-gray cherty beds 3 mm. thick and thicker cherty green-gray siltites. Sediments characteristically weather rusty brown.</td>
<td>10</td>
<td>32-42</td>
</tr>
<tr>
<td>4</td>
<td>Covered</td>
<td>2</td>
<td>30-32</td>
</tr>
<tr>
<td>Unit</td>
<td>Description</td>
<td>Thickness in Meters</td>
<td>Meters Above Base</td>
</tr>
<tr>
<td>------</td>
<td>-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------</td>
<td>---------------------</td>
<td>-------------------</td>
</tr>
<tr>
<td>3</td>
<td>Dominantly medium-grained red quartzites with occasional planar bedded coarser gray beds and rare fine grained green beds. 30 cm. thick couplets common, convolute beds and common mud-clast conglomerates, noticeable increase in thickness of couplets.</td>
<td>10</td>
<td>20-30</td>
</tr>
<tr>
<td>2</td>
<td>Coarser slightly micaceous red sand, planar bedded red-pink sands up to 10 cm. thick, mudchips up to 8 cm. long and common scours up to 13 cm. deep. Graded couplets up to 20 cm. thick with tops extensively mudcracked and occasionally scoured off. At 12 m. into the section rare cherty very fine grained green and brown beds up to 10 cm. thick; rare rain drop impressions.</td>
<td>17</td>
<td>3-20</td>
</tr>
<tr>
<td>1</td>
<td>Fine-medium grained red quartzite siltites in graded couplets 2.5-8 cm. thick with frequently mudcracked surfaces. Rare very fine grained green beds. Occasional rain drop impressions.</td>
<td>3</td>
<td>0-3</td>
</tr>
</tbody>
</table>
SECTION T.C. (Trout Creek)

Located along Trout Creek 4 km. south of Superior, Montana; and 1.6 km. south of the Diamond Match plant.

<table>
<thead>
<tr>
<th>Unit</th>
<th>Description</th>
<th>Thickness in Meters</th>
<th>Meters Above Base</th>
</tr>
</thead>
<tbody>
<tr>
<td>8</td>
<td>Dominantly micaceous green-gray medium-fine grained quartzites with rarer micaceous purple quartzites at bottom of interval. Mostly planar bedded but climbing ripples up to 5 cm. high are quite common. Numerous thin beds of green-gray cherts 6 mm. and rare immature mudcracked surfaces observed. Some carbonate detected.</td>
<td>32</td>
<td>44-76</td>
</tr>
<tr>
<td>7</td>
<td>Influx of micaceous gray and red quartzites with 10 cm. couplets, scours up to 8 cm. deep and thin inter-beds up to 2.5 cm. thick of green cherts.</td>
<td>5</td>
<td>39-44</td>
</tr>
<tr>
<td>6</td>
<td>Sequences of red to maroon graded 5 cm. quartzites and siltites with large well developed polygonal mudcracked surfaces very common and occasional raindrop impressions; top of graded sequences often scoured forming mudchip conglomerate in overlying beds. Rare green beds.</td>
<td>6</td>
<td>33-39</td>
</tr>
<tr>
<td>5</td>
<td>Dominantly fine-grained red quartzites grading into red to maroon siltites up to 23 cm. couplets. Scoured surfaces common with mudchips up to 5 cm. long.</td>
<td>4</td>
<td>29-33</td>
</tr>
<tr>
<td>Unit</td>
<td>Description</td>
<td>Thickness in Meters</td>
<td>Meters Above Base</td>
</tr>
<tr>
<td>------</td>
<td>-----------------------------------------------------------------------------</td>
<td>---------------------</td>
<td>-------------------</td>
</tr>
<tr>
<td>4</td>
<td>Pink fine-grained quartzites with common climbing ripples up to 2.5 cm.</td>
<td>9</td>
<td>20-29</td>
</tr>
<tr>
<td></td>
<td>high form 5-8 cm. graded sequences with occasional mudcracked surfaces.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Zone of interbedded red and green siltite with red siltites extensively mud-cranked.</td>
<td>3</td>
<td>17-20</td>
</tr>
<tr>
<td>2</td>
<td>Very thin bands .6-1.5 cm. of very hard green to gray chert with thicker bedded 5-8 cm. gray-gray green cherty siltites. Fine-grained green to cherty sediments characteristically break with a conchoidal fracture. Soft sediment structures common. Rare intraformational breccias 5 cm. thick.</td>
<td>3</td>
<td>14-17</td>
</tr>
<tr>
<td>1</td>
<td>Mostly red siltites with interbedded pink quartzites and thin green siltites. Coarser sands commonly form graded sequences up to 10 cm. with occasional climbing ripples; frequently mud-cracked surfaces.</td>
<td>14</td>
<td>0-14</td>
</tr>
</tbody>
</table>
SECTION T.F. (THOMPSON FALLS)

8 km. east of Thompson Falls; 19.4 km. north on Thompson River Road; left on Fishtrap Creek Road for 13 km.; right on Daisy Creek Shale Road for 3.2 km.

<table>
<thead>
<tr>
<th>Unit</th>
<th>Description</th>
<th>Thickness in Meters</th>
<th>Meters Above Base</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>Gray-gray green fine-grained micaceous quartzite and siltite in graded sequences up to 10 cm. thick; asymmetrical current ripples up to 5 cm. high, small scour, no mudcracks.</td>
<td>18</td>
<td>103-121</td>
</tr>
<tr>
<td>4</td>
<td>Covered</td>
<td>6</td>
<td>97-103</td>
</tr>
<tr>
<td>3</td>
<td>Fine-grained slightly micaceous red quartzite and siltite forming graded sequences up to 18 cm. thick; asymmetrical current ripples up to 2.5 cm. high, abundant well developed red polygonal mudcracks with raindrop impressions, gypsum casts; occasional thinly bedded green siltite; occasional calcite cement.</td>
<td>18</td>
<td>79-97</td>
</tr>
<tr>
<td>2</td>
<td>Very thinly bedded 1 cm. green siltite, mostly with sharp contacts; but occasional graded couplets up to 3 cm. thick; very rare mudcracks.</td>
<td>70</td>
<td>9-79</td>
</tr>
<tr>
<td>1</td>
<td>Very thinly bedded $\frac{1}{2}$ cm. thick with sharp contacts, cherty in places, rare syn-eresis(?) mudcracks, very rare lenticular silt lenses 2.5 cm. high; thin bed of cherty siltite with oolites at 7.5 m. intervals</td>
<td>9</td>
<td>0-9</td>
</tr>
</tbody>
</table>
APPENDIX II

STRATIGRAPHIC SECTIONS
PORTERS CORNER (PC)

Red-pink medium-coarse grained quartzite. Slightly micaceous 23-36 cm. (9-14") graded couplets. High angle tangential crossbeds up to 10 cm. (4") high passing up to climbing ripples and horizontally laminated red silts. Scours up to 8cm. deep in silts common.
Medium to coarse grained pink quartzite. Larger graded sequences between 40 and 76 cm (15-30"), scours up to 13 cm (5") deep common with mudchip lags. Trough crossbeds and tangential crossbeds. Angular chert clasts between 42 and 46 m (140-145 feet).
Tangentially crossbedded pink quartzite up to 1 m. (3 ft.) high. Directional variation very rare.

Pink medium grained quartzite with trough crossbeds up to 25 cm. (10"). Low angle planar crossbeds common. Erosional contacts between crossbed sets common.
High angle tangential crossbeds up to 1m. (3ft.) high; occasionally scoured by overlying beds.

Pink medium-fine grained quartzite; tangential cross-bedded 29 cm. (9") high and graded planar beds up to 15cm. (6") thick.
Gray coarse grained quartzite. 
Low angle tangential and planar crossbeds up to 25cm. (10") high.

Garnet Range

McNamara
Mostly gray micaceous medium to coarse grained quartzite with planar and tangential crossbeds up to 10 cm. (4") high. Scoured contacts common.

Gray medium to coarse grained quartzite with high angle tangential crossbeds up to 1 m. (3ft.) high.
Float indicates gray micaceous quartzites

Covered
Float indicates gray micaceous quartzites

Pink to gray medium grained micaceous quartzites with 10 cm. (4") high tangential and planar crossbeds.
Weathered horizon overlain by fresh sediment.

Very micaceous medium to coarse grained, up to 1 mm., gray quartzite with some fine grained red siltites with high mica content. Mudchip conglomerates and planar beds common. 10 cm. graded couplets common.
Gold to brown limonitic micaceous medium to coarse grained quartzite appears deeply weathered with occasional intervals of fresh gray quartzites. Very low angle unidirectional northward dipping planar cross-beds approx. 10 cm. (4") thick and abundant planar bedded micaceous gray quartzites.
Coarser slightly micaceous red quartzite in planar bedded units up to 10 cm. thick. Mudchips and scours common. Graded sequences up to 20 cm. common with mudcracks at the top. Chert bed at 12 m. Rare raindrop impressions.

Fine to medium grained red quartzite and siltite in graded couplets up 8 cm. thick, with common mudcracks. Rare thinly bedded green siltites. Rare raindrop impressions.
Micaceous gray, pink and red coarse grained quartzite to siltite in graded sequences up to 25 cm. thick. Common tangential crossbeds, climbing ripples, scours, mudchips and planar beds.

Dominantly medium grained red quartzite to siltite forming graded couplets up to 30 cm. thick. Coarser gray quartzites form planar beds.
Red and purple medium to coarse grained micaceous quartzites in graded sequences up to 30 cm thick. Very common planar beds with imbricated mudclasts.
Increasingly micaceous medium grained red and gray quartzites with occasional green-gray and purple micaceous quartzites; 30 cm. garned couplets and planar beds common.
20 cm. deep scours.

Tops of some graded sequences are extremely high in detrital micas.

Gry Gry-Grn

Garnet Range

Highly micaceous McNamara

Gry-Grn

Silt fraction in graded sequences often shaley.

Gry
Micaceous gray to gray-green quartzites with abundant planar beds and occasional massive beds and graded sequences up to 60 cm. thick.

1 m. thick massive gray to gray green quartzite.

1 m. thick massive gray to gray green quartzite.

Gry Red
Slightly micaceous fine grained red siltites forming abundant climbing ripple sets up to 2 meters thick. Rare horizontally laminated green siltites.

Fine to medium grained red to maroon slightly micaceous quartzites with interbedded thin green siltites. Assymetrical climbing ripples and rip up clasts common. Rare lenticular lenses of sand. Occasional mud-cracks.
Micaceous purple and gray quartzites with abundant planar beds with common scoured surfaces and low angle planar crossbeds. Chert beds (green) common.

Coarser planar bedded purple and gray micaceous quartzites forming 20 cm. high planar crossbeds cut by planar beds; graded sequences up to 30 cm. common.
Gray to gray-green micaceous quartzite and rare thin beds of chert. Quartzite mostly planar bedded but occasionally cut by tangential crossbeds. Graded sequences up to 30 cm. common. Mud-cracks rare.
Interbedded red and green siltites; with very well developed polygonal mud-cracks in red siltites.

Hard thin beds of green cherts and cherty siltite. Soft sediment deformation, intraformational breccias 5 cm. (2") thick.

Mostly red siltites with red and pink fine grained quartzite. Occasional green siltites. Graded sequences up to 10 cm. (4") and occasional climbing ripples. Very common mudcracks.
Sequences of red to maroon graded (2") (5 cm.) quartzites and siltites with large mature mudcracked surfaces very common and occasional raindrop impressions; top of graded sequences often scoured forming mudchip conglomerate in overlying beds. Rare green chert

Mostly fine grained red quartzites grading into red and maroon siltites up to 23 cm. thick. Mudchips common.

Fine grained pink quartzite; common climbing ripples and graded sequences up to 8 cm. (3") with mudcracked tops.
Dominantly micaceous green to gray-green medium to fine grained quartzite with common climbing ripples, tangential crossbeds up to 10 cm. (4") high, rare chert beds and very rare mudcracks. Weathers reddish brown.
TROUT CREEK
(TC)
THOMPSON FALLS (TF)

- 5-1 cm. thick

Grn

Similar to below except for occasional graded couplets up to 3 cm. (~1""); rare mudcracks.

- 5-1 cm. thick

Grn

1 cm. high

Grn

Very thinly bedded siltites with sharp contacts, cherty in places, rare subaqueous (?) mudcracks. Cherty bed with oolites at 7.5 m.
Float indicates sediments similar to those above and below

Covered

Dk. Grn

-.5 cm.

lt. Grn

-.5 cm.
Fine grained red slightly micaceous fine grained quartzite; graded sequences up to 18 cm. (6"), assymetrical ripples, well developed polygonal mudcracks, raindrop impressions, gypsum casts.
Gray and gray green micaeous quartzites; graded sequences up to 10 cm. (4"), small scours; no mudcracks.