DAVID BLOOM

Tectonic evolution of lower Proterozoic rocks, Uinta Mountains, Utah and Colorado

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ABSTRACT

Rocks of the early Proterozoic orogenic system that fringes the Archean-aged Wyoming province are exposed along the Uinta fault in the northeastern Uinta Mountains of Utah and Colorado. Exposed here are the Red Creek Quartzite, an early Proterozoic-type miogeoclinal metasedimentary sequence more than 4 km thick, and an underlying, newly recognized, Archean gneiss complex more than 2.7 b.y. old. During the Hudsonian orogenic period, the miogeoclinal sequence was emplaced northward over the Archean complex by tectonic translation along a thick mylonite zone in the waning phases of upper amphibolite metamorphism. The orogen was disrupted by east-trending block faults with several kilometres displacement during initiation of the Uinta aulacogen and was buried by more than 7 km of middle Proterozoic sediments of the Uinta Mountain Group. The middle Proterozoic block faults were reactivated with reversed sense of displacement during the Laramide uplift of the Uinta Mountain block.

INTRODUCTION

An orogenic system of late Archean and early Proterozoic age fringes the Archean-aged Wyoming province on three sides (Houston and Karlstrom, 1979; King, 1976). This paper addresses the tectonic evolution of a small but complex segment of the orogenic system exposed in the Red Creek area of the northeastern Uinta Mountains of Utah and Colorado (Fig. 1). Because of its small areal exposure, this segment of the orogenic system is discussed in the framework of a better-preserved segment of the same system exposed in the mountains of southeastern Wyoming (Hills and Houston, 1979; Karlstrom and Houston, 1979; Graff, 1978).

Exposures of early Precambrian rocks in the Red Creek area are discontinuous and total less than 40 km^2. However, a surprisingly large vertical interval of the orogen, more than 4 km, is exposed because of large-scale post-orogenic block faulting and tilting. The exposed section indicates that as much as 3 km may have been removed by faulting.

Two major early Precambrian lithotectonic units are exposed in the Red Creek area: the Red Creek Quartzite (Hansen, 1965), a ± 4-km-thick miogeoclinal sequence of early Proterozoic type (Houston and Karlstrom, 1979), and the underlying Owiyukuts Complex (named here), which is a high-grade gneissic terrane of Archean age.

The metamorphic grade of the Red Creek rocks spans the amphibolite facies of regional metamorphism at pressures near the aluminum-silicate triple point. Pressure-temperature–sensitive metamorphic mineral assemblages and down-plunge projections provide control in the vertical arrangement of the disrupted fault blocks of the orogen.

A composite section of the orogen indicates that the Red Creek Quartzite was thrust northward on a ductile décollement zone over the Owiyukuts Complex, in a manner somewhat analogous to the emplacement of the early Proterozoic Libby Creek Group over older rocks in the Medicine Bow Mountains of southeastern Wyoming (Karlstrom and Houston, 1979).

The Red Creek area was block-faulted and deeply eroded and was overlapped unconformably by the middle Proterozoic Uinta Mountain Group, which was deposited in an east-west–trending aulacogen-related rift that opened the Cordilleran ocean basin farther west (Burke and Dewey, 1973; Sears and Price, 1978). The deep crustal faults related to this disturbance were in part reactivated and in part decapitated during uplift of the Uinta Mountain block during the Laramide Orogeny.

STRUCTURAL SETTING

Early Precambrian rocks are exposed in seven areas in the hanging wall of the east-west–trending Laramide Uinta Fault, which places Precambrian rocks over rocks as young as Eocene (Hansen, 1965). The exposures are isolated from one another by the unconformably overlying Uinta Mountain Group and by faults related to both the Laramide Orogeny and formation of the Uinta aulacogen.

The exposed early Precambrian rocks in the Red Creek area are parts of at least four major tilted fault blocks truncated by the unconformity at the base of the Uinta Mountain Group. Different metamorphic facies and structural styles preserved in each of these blocks may indicate that these blocks represent different tectonic levels of the orogen. Faults bounding parts of the blocks were clearly reactivated, and the fault pattern in the Uinta Mountain Group is here interpreted to partly correspond to the outlines of the fault blocks of early Precambrian rocks (Fig. 1).

The largest continuous exposure of the metamorphic rocks is in the vicinity of Red Creek Canyon and is dominated by a large, easterly plunging box-shaped fold of schistosity, the Garnet Canyon anticline (Hansen, 1965). The exposures of the orogen in Jesse Ewing Canyon 1,500 m to the east appear to be part of the same coherent fault block, because (a) the two areas are separated by physically continuous Uinta Mountain Group rocks in depositional contact with the Red Creek Quartzite, (b) the Red Creek rocks at Jesse Ewing Canyon are structurally aligned with the

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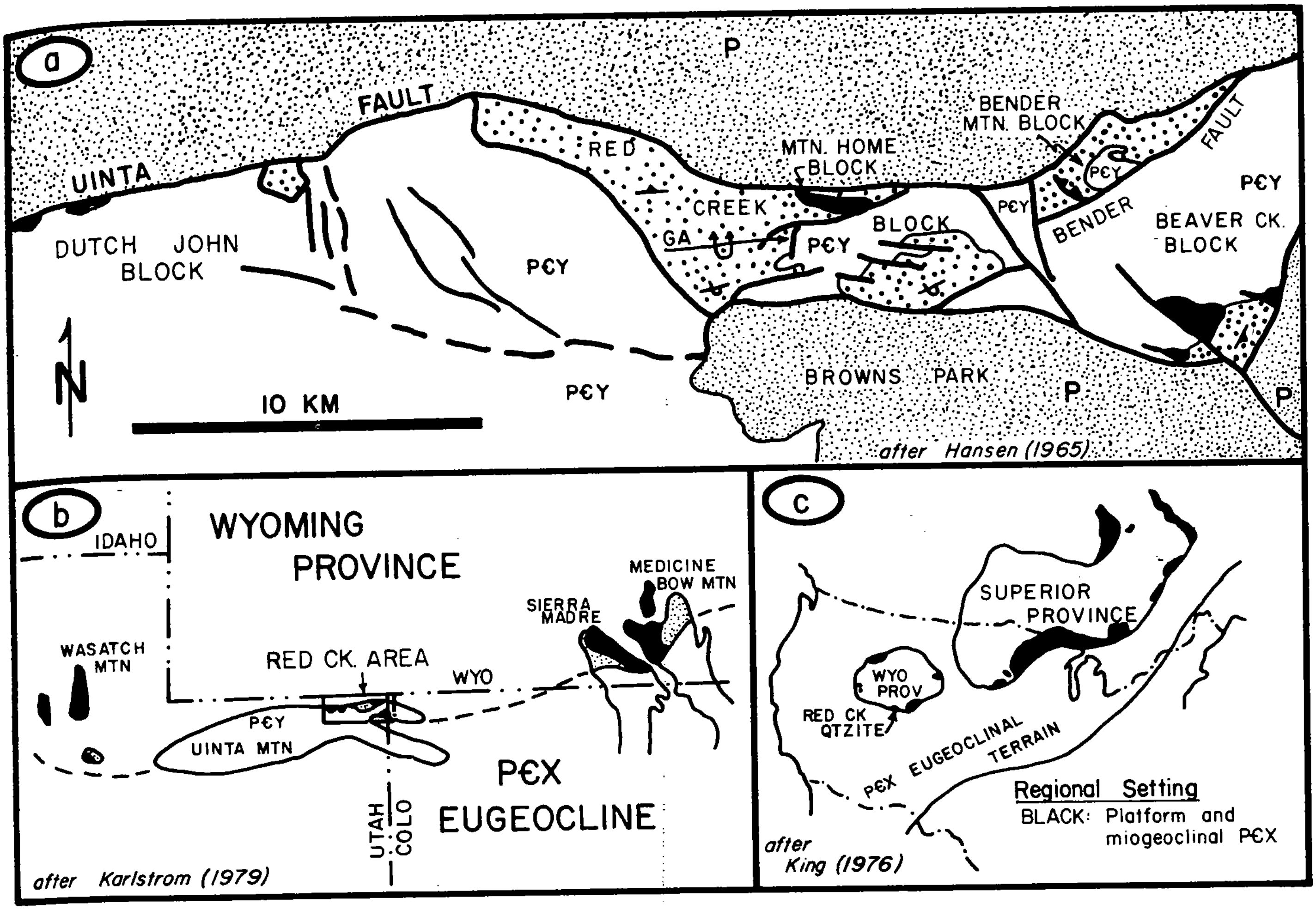


Figure 1. a. Sketch map of Red Creek area, showing major fault blocks of early Precambrian rocks discussed in text. Large, sparse stipple, Red Creek Quartzite; black, Owiyukuts Complex; Clear (PЄY), Uinta Mountain Group; dense, fine stipple (P), Phanerozoic sediments; GA, Garnet Canyon anticline. b. Location of Red Creek area. Stipple, PЄX miogeoclinal sediments; black, Archean rocks. c. Regional setting of early Precambrian rocks, northeast Utah.

southern limb of the Garnet Canyon anticline, and (c) metamorphic assemblages from the two areas are compatible. This block, here called the Red Creek block, contains more than one-half of the exposed section of metamorphic rocks and provides the control for much of the lithostratigraphic column presented below (see Fig. 3).

The exposures in the vicinity of Bender Mountain constitute a second major fault block, the Bender Mountain block, which differs from the Red Creek block in structural style, lithostratigraphy, and metamorphic grade. These blocks are separated by a system of northwest-trending, steep, post–Uinta Mountain Group faults. Metamorphic mineral assemblages from the Bender Mountain block suggest that it is a downfaulted, higher level of the orogen than the Red Creek block.

A third major fault block is exposed along Beaver Creek at the southern end of O-Wi-Yu-Kuts Mountain and is here called the Beaver Creek block. It contains the highest-grade metamorphic mineral assemblages and the most ductile deformational features of any of the fault blocks. Also exposed in this block is the largest outcrop of the Owiyukuts Complex, which structurally underlies the Red Creek Quartzite. The Beaver Creek block is separated from the Bender Mountain block by the Bender Fault, a post–Uinta Mountain Group fault with more than 2 km of vertical displacement, and is separated from the Red Creek block by a system of steep, northwest-trending post–Uinta Mountain Group faults.

Three small areas underlain by early Precambrian rocks of the orogen occur along the Uinta Fault south of Dutch John Mountain, as structural horses between the Uinta Mountain Group and Phanerozoic sediments. These horses include both Owiyukuts gneisses and Red Creek metasediments and may be decapitated remnants of a single larger fault block of the deeper levels of the orogen.

A small fault block at the head of Mountain Home Draw, the Mountain Home block, contains Owiyukuts gneisses in fault contact with Red Creek Quartzite, overlapped by the Uinta Mountain Group. In this area, the evidence for post–Uinta Mountain Group reactivation of basement faults is exceptionally well exposed.

METAMORPHISM

The supracrustal sequence of the Proterozoic orogenic system contains metamorphosed quartzites, pelites, calc-silicates, and mafic rocks. Metapelites have so far been most useful in establishing variations in metamorphic grade between the various fault blocks of the orogen (Fig. 2).

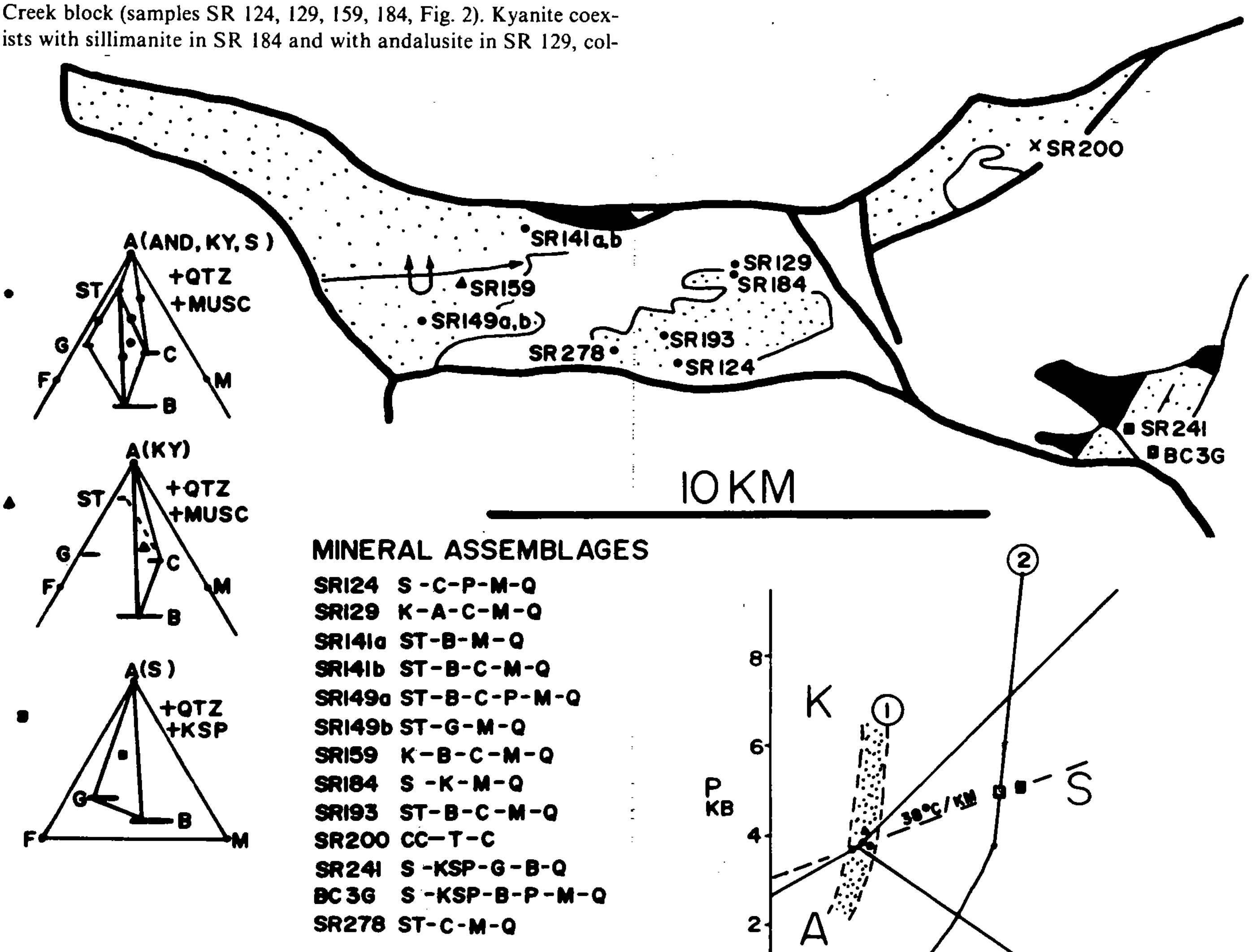
The Red Creek block contains mineral assemblages that define the reaction:

$$\text{staurolite + chlorite + muscovite + quartz} = \text{kyanite + biotite} + H_2O. \quad (1)$$

The product assemblage is represented by sample SR 159 (Fig. 2), which was collected in the core of the postmetamorphic Garnet Canyon anticline. The reactant assemblage is represented on both limbs of the anticline and in both exposure areas of the Red Creek block (samples SR 141b, 149a, 193, 278). This distribution suggests that the P-T surface defining reaction 1 was subparallel to schistosity and compositional layering and was folded with them in the Garnet Canyon anticline.

All three aluminum-silicates have been identified in the Red Creek block (samples SR 124, 129, 159, 184, Fig. 2). Kyanite coexists with sillimanite in SR 184 and with andalusite in SR 129, collected 300 m to the north. This spatial relationship implies that metamorphic conditions were very close to the triple point in the eastern part of the Red Creek block. Sillimanite coexists with chlorite in SR 124, about 300 m southeast of SR 193, which contains the reactant assemblage staurolite-chlorite-muscovite-quartz for reaction 1. This suggests that reaction 1 may cross the sillimanite stability field or occupy a divariant zone near the triple point, as shown in Figure 2. If so, the product assemblage SR 159 required pressures somewhat above the triple point, as kyanite is the aluminum silicate that was produced. This interpretation is consistent with the easterly plunge of the Garnet Canyon anticline and correspondingly lower pressures to the east.

The Red Creek block was thus metamorphosed at ± 500 °C, ± 3.8 kb (triple point of Holdaway, 1971).



MINERAL ASSEMBLAGES

SR124	S-C-P-M-Q
SR129	K-A-C-M-Q
SR141a	ST-B-M-Q
SR141b	ST-B-C-M-Q
SR149a	ST-B-C-P-M-Q
SR149b	ST-G-M-Q
SR159	K-B-C-M-Q
SR184	S-K-M-Q
SR193	ST-B-C-M-Q
SR200	CC-T-C
SR241	S-KSP-G-B-Q
BC3G	S-KSP-B-P-M-Q
SR278	ST-C-M-Q

Figure 2. Metamorphic mineral assemblages of the Precambrian rocks, Red Creek area, Utah. Symbol at sample location indexed to Thompson projections and P-T grid. Aluminum-silicate triple point after Holdaway (1971). Location of reaction 1 inferred; reactions 2 and 3 from Carmichael (1978). Abbreviations: S, sillimanite; K, kyanite; A, andalusite; ST, staurolite; G, garnet; C, chlorite; B, biotite; KSP, K-feldspar; P, plagioclase; M, muscovite; Q, quartz; CC, calcite; T, tremolite.

The Beaver Creek block contains mineral assemblages that define the reaction:

$$\text{quartz} + \text{muscovite} + \text{plagioclase} = \text{K-feldspar} + \text{sillimanite} + \text{liquid.} \qquad (2)$$

The assemblage of BC 3G lies on the univariant curve (Fig. 2), while SR 241, collected from deeper structural levels, contains the product assemblage. The Beaver Creek block contains abundant massive quartz-feldspar-muscovite pegmatite bodies, implying that the breakdown of muscovite + quartz occurred at pressures greater than those of the liquid-absent reaction:

$$\text{quartz} + \text{muscovite} = \text{K-feldspar} + \text{sillimanite} + H_2O \qquad (3)$$

but less than those of the kyanite stability field.

The positions of reactions 2 and 3 in Figure 2 are taken from Carmichael (1978). A constant geothermal gradient of 28 °C/km projected through the triple point determined by Holdaway (1971) intersects reaction 2 in the sillimanite field. If the supracrustal rocks of the Red Creek and Beaver Creek blocks were quenched during the same metamorphic episode, as implied by similar K-Ar ages of amphibolites from the two blocks (Graff and others, 1980), and if the geothermal gradient was constant, then the metamorphic conditions of the Beaver Creek block were 650–700 °C at $\sim$5–5.5 kb. This implies a pressure difference of $\sim$1.2 kb between SR 129–SR 184 and BC 3G, which corresponds to a vertical rock interval of $\sim$4 km (3.4 km/kb). One kilometre of section exposed in the Red Creek block underlies SR 129–SR 184. If these differences are interpreted as the result of vertical placement in the orogen and are not due to thermal-dynamic effects, then $\sim$3 km of section is faulted out of the exposed Red Creek Quartzite section.

A single sample of calc-silicate from the Bender block (SR 200) with the assemblage: chlorite-tremolite-calcite may indicate that part of the Bender block is in the greenschist facies, if the breakdown of the chlorite-calcite tie line was not surpassed by high CO_2 pressures. Other parts of the Bender block contain amphibolites and granitic gneisses in what are here interpreted to be fault slices related to the Uinta Fault. If SR 200 does represent greenschist-facies conditions, the Bender Fault, separating the Bender Mountain and Beaver Creek blocks, must have more pre–Uinta Mountain Group displacement than does the fault separating the Beaver Creek and Red Creek blocks.

LITHOSTRATIGRAPHY

Red Creek Quartzite

The Red Creek Quartzite (Powell, 1876; Hansen, 1965) comprises the miogeoclinal, supracrustal part of the Proterozoic orogen. Metamorphic assemblages suggest that the lowest part of the miogeoclinal sequence is exposed in the Beaver Creek block, intermediate levels are exposed in the Red Creek block, and uppermost levels occur in the Bender Mountain block. Rocks exposed in the disrupted Dutch John block are similar to those of the Beaver Creek block.

The lowest rocks of the Red Creek Quartzite (Fig. 3) are feldspathic quartzites which have been deformed into mylonites in a thick, ductile 1-km fault zone above the gneisses of the Owiyukuts Complex. The quartzites are vitreous and very fine grained; the feldspar occurs as augen dispersed in a quartz matrix. The quartzite is interleaved with garnet amphibolite layers on a scale of centimetres to metres over a thickness of hundreds of metres along Beaver Creek as a result of imbricate ductile faulting under upper-amphibolite–facies conditions.

If the interpretations presented in structural and metamorphic sections of this paper are valid, then $\sim$3 km of stratigraphic section is not exposed or has been removed by faulting. This gap occurs between the exposures of the Red Creek Quartzite of the Beaver Creek block and the lowest stratigraphic levels of the Red Creek block.

A section of Red Creek Quartzite more than 3 km thick is exposed in the Red Creek block, in Red Creek Canyon, and in Jesse Ewing Canyon. Rarely preserved graded bedding, a set of truncated cross-beds, and a possible channel indicate that the base of this section is exposed in the core of the Garnet Canyon anticline and that the top is exposed on the south limb of the fold in lower Jesse Ewing Canyon. A stratigraphic gap of unknown, but probably small, magnitude occurs between the sequences exposed in the two areas. The section in the Red Creek block consists of four thick orthoquartzite units separated by pelitic units with marble and calc-silicate members.

Orthoquartzite units are 300 to 600 m thick and are dominated by very clean, massively bedded, fine- to medium-grained, recrystallized, vitreous white quartzite. The upper-middle quartzite unit

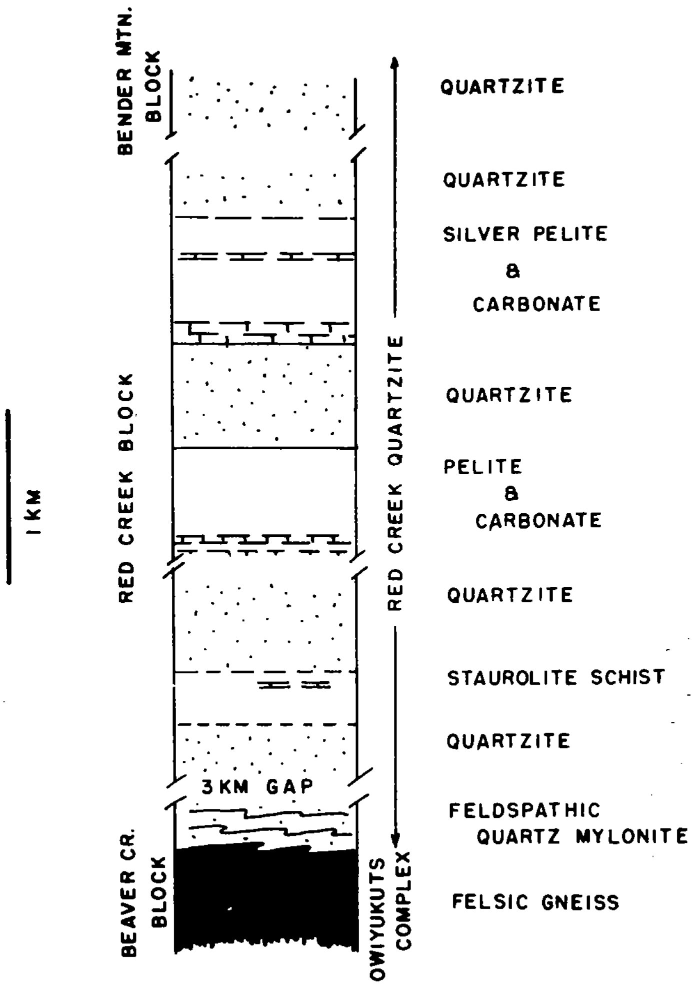


Figure 3. Columnar section of early Precambrian rocks, Uinta Mountains, Utah.

(third unit above base) contains a thick section of red and purple quartzite. Bedding is defined by thin micaceous partings and thin heavy mineral segregations, and beds range from a few centimetres to 2 m in thickness, with 0.5 m generally average. Bedding generally parallels schistosity. Quartzites grade with increasing mica content into pelitic schists.

The pelitic units vary in thickness because of tectonic effects and disruption by abundant intrusive amphibolites. Each of the pelitic units has distinctive lithologic features. The lower pelite is as much as 300 m thick and contains thin, alternating layers of micaceous quartzite and staurolite schist near the base, garnetiferous chlorite schists, and calc-silicate and reddish calcite-marble beds near the top. The middle pelite is as much as 800 m thick, but its base is not exposed. It contains a 50-m section of distinctive, thickly bedded red and purple calcitic marble with interbedded dark gray quartzites near the base of the exposed section. This pelite unit grades upward into the purple and red quartzites of the upper-middle quartzite unit. The upper pelite, as much as 700 m thick, contains much distinctive silvery-gray and light green magnetite-bearing schist with thin interbeds of chloritic quartzite with locally preserved graded bedding. Its base is marked by a 25-m-thick, white, siliceous dolomitic-marble unit. The upper pelite unit contains abundant thick amphibolite bodies in the form of lenses or sheets that were emplaced parallel to the schistosity.

The Bender Mountain block contains a thick sequence of clean, massive orthoquartzites indistinguishable from those of the Red Creek block, except in lacking thick, interlayered pelites. Limited data suggest that these rocks are of a lower metamorphic grade than any others in the orogen, and they may represent the uppermost exposed part of the Red Creek Quartzite section. Structural relations are complex, but at least several hundred metres of quartzite is exposed.

Total thickness of the Red Creek Quartzite may exceed 7 km. This estimate is based on ~4 km of exposed section and on the interpretation that metamorphic isograds approximately parallel compositional layering and that no major synmetamorphic nappes are present, which provides the possibility that ~3 km of section is missing. An undetermined amount of the section may be faulted out in the basal ductile shear zone.

Owiyukuts Complex

The Owiyukuts Complex underlies an area less than 3 km^2 and is best observed along the south flank of O-Wi-Yu-Kuts Mountain. These exposures compose part of the Beaver Creek block and are in the only area in which the contact between the Owiyukuts Complex and the Red Creek Quartzite parallels the layering within the Red Creek Quartzite. Rocks here assigned to the Owiyukuts Complex also occur in the Mountain Home block and Dutch John block and as horses in the Bender Mountain block. The rocks of the Owiyukuts Complex were included with the Red Creek Quartzite by Hansen (1965).

The Owiyukuts Complex is dominated by medium- to fine-grained potassium-feldspar–rich granitic gneiss interfaced with quartzofeldspathic gneiss, garnet gneiss, migmatitic gneiss, fine-grained biotite gneiss, and garnet amphibolite. It encloses massive, coarse-grained bodies of quartz-muscovite-feldspar pegmatite. In the Mountain Home and Dutch John fault blocks, the gneissic rocks are highly altered and disrupted into breccias, microbreccias, and cataclastic gneisses with chloritized shear surfaces, and they weather readily to reddish arkosic soil.

The Owiyukuts Complex is here interpreted to unconformably underlie the Red Creek Quartzite along a surface which became the locus of ductile shearing during the deformation and metamorphism of the Red Creek Quartzite. Carl Hedge (1980, personal commun.) has recently obtained a Rb-Sr whole-rock isochron age of 2.7 b.y. for Owiyukuts gneisses from Beaver Creek.

STRUCTURAL ANALYSIS

Structural surfaces preserved in the early Precambrian rocks of the Red Creek area include bedding, schistosity, crenulation cleavage, cataclastic foliation, and gneissic schistosity. Rocks of the Red Creek block are considerably less intensely deformed than those of the Beaver Creek block, in accordance with their lower metamorphic grade.

Primary bedding is rarely preserved but does occur along the south limb of the Garnet Canyon anticline and is consistently overturned to the south. It is marked by a gradation from quartzite to schist at a small angle to schistosity.

Schistosity is defined by the alignment of metamorphic mica and chlorite. Some quartzites are so pure that they do not have measurable schistosity. The thicker amphibolite bodies of the Red Creek block are schistose only along their contacts with the enclosing metasediments, as noted by Hansen (1965). The schistosity of the Red Creek block is warped into the broad, box-shaped Garnet Canyon anticline, which plunges gently to the east. Mesoscopic flexural slip folds and chevron folds are related to formation of the anticline.

Surfaces of schistosity and bedding in quartzites contain a prominent intersection lineation which plunges gently to the east and northeast in the Red Creek block (Hansen, 1965, p. 142.) and is clearly related to the development of the Garnet Canyon anticline.

Crenulation cleavage occurs locally in some pelitic units but has not been studied systematically.

Mylonitic foliation is the dominant structural surface in the quartzites of the Beaver Creek block and in the cataclastic gneisses of the Mountain Home block. In the Beaver Creek block, foliation has been deformed into open to isoclinal, north-facing folds in a spectacular display on the east wall of Beaver Creek Canyon. These folds have moderately to steeply southeasterly plunging axes. The cataclastic foliation of the Owiyukuts gneisses in the Mountain Home block is deformed into open folds which plunge gently to the southeast.

The Owiyukuts Complex of the Beaver Creek block has an easterly dipping gneissic schistosity, subparallel to the mylonitic schistosity of the overlying Red Creek Quartzite.

Cataclastic textures are very common in the quartzites of the orogen but are notably lacking in associated pelites.

Amphibolites serve as both time and strain markers. In the Red Creek block, amphibolites form massive bodies emplaced both parallel to and across the layer-parallel schistosity of the metasediments and contain rotated, foliated quartzite xenoliths. These relationships, discussed by Hansen (1965), show that the amphibolites were intruded after the rocks of the Red Creek block had acquired a metamorphic foliation. However, they were metamorphosed to an assemblage compatible with the enclosing metasediments and were deformed by open folds related to the development of the Garnet Canyon anticline. The margins of the amphibolites were probably foliated during the late folding episode, both by flexural slip along contacts and by hydration from the enclosing metasediments. Staurolite porphyroblasts in enclosing metapelites contain rotated inclusion trails which could be related to flexural slip folding after or near the end of their growth.

In the Beaver Creek block, amphibolites are thin and rarely cross foliation of the enclosing mylonitic metasediments; instead,

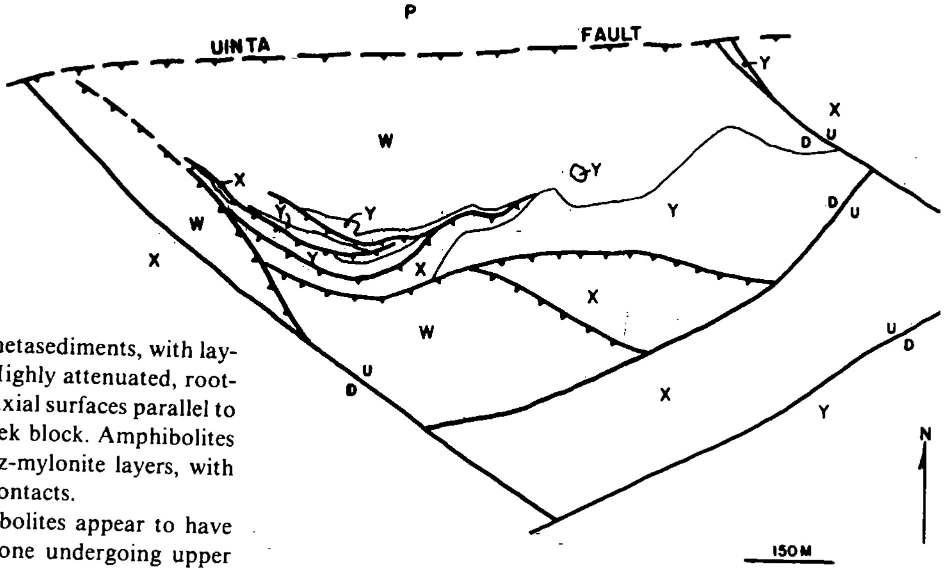


Figure 4. Detailed map of Mountain Home fault block. W, Owiyukuts gneiss; X, Red Creek Quartzite; Y, Uinta Mountain Group; P, Phanerozoic rocks.

they form a lit-par-lit alternation with the metasediments, with layering on a scale of centimetres to metres. Highly attenuated, rootless isoclinal folds of quartz stringers, with axial surfaces parallel to the layering, are common in the Beaver Creek block. Amphibolites are tightly folded with the enclosing quartz-mylonite layers, with thin, crenulated chloritic selvages near the contacts.

In the Beaver Creek block, the amphibolites appear to have been intruded into a thick ductile shear zone undergoing upper amphibolite facies metamorphism and imbricate faulting. In the Red Creek block, they were intruded into a sequence that was not undergoing wholesale penetrative strain but was still near its middle-amphibolite–quenching temperature, and the amphibolite bodies were autometamorphosed by reacting with fluids produced by dehydration reactions within the enclosing or underlying metasediments. During this process, they were folded with enclosing metasediments into the Garnet Canyon anticline and acquired marginal foliation. Meanwhile, at depth in the Red Creek block, the rocks remained hot and ductile longer but were finally deformed into north-facing folds of schistosity. This is a diachronous model of a ductile strain boundary migrating downward through a cooling metamorphic orogen undergoing northerly tectonic transport.

The Bender Mountain block is distinguished by a prominent thrust fault (mapped by Hansen, 1965) which places quartzite over quartzite, truncates schistosity, and disrupts lineations. It is a postmetamorphic feature and yet is clearly pre–Uinta Mountain Group because it is folded into a synform that is truncated by the basal Uinta Mountain Group (Hansen, 1965). The thrust fault itself is rootless; it is cut off to the south by the Bender Fault and to the north by the Uinta Fault. It is here considered to be a high-level manifestation of the postmetamorphic tectonic translation of the Red Creek Quartzite.

BLOCK FAULTING

Best estimates based on metamorphic grade and structural configuration indicate that the Beaver Creek block was uplifted 4 km to 7 km relative to the Red Creek block prior to deposition of the Uinta Mountain Group. The upper estimate assumes that a constant 30° southeast dip of the metamorphic layering in the Beaver Creek block can be projected to the fault zone separating the blocks. The Beaver Creek block was uplifted somewhat more than this relative to the Bender Mountain block in pre–Uinta Mountain Group time. The Red Creek block was uplifted relative to the Bender Mountain block by an unknown amount. The Mountain Home block is a horst of Owiyukuts gneisses with at least 4-km uplift relative to the Red Creek block and is bounded by a system of branching, curved faults (Fig. 4). Pre–Uinta Mountain Group displacement of the Dutch John block relative to the Red Creek block is unknown, as the rocks deformed by the Hudsonian Orogeny are not in depositional contact with the Uinta Mountain Group in the Dutch John block, but at present, the rocks of the orogenic system in the Dutch John block are a few kilometres higher than in the Red Creek block.

The locations of post-Uinta faults have been mapped by Hansen (1965). The Bender Fault displaces the base of the Uinta Mountain Group at least 2 km, with the Beaver Creek block relatively downthrown. The Uinta Mountain Group of the Beaver Creek block is downthrown ~1.5 km with respect to the Red Creek block. These displacements are opposite in sense to the pre–Uinta Mountain Group faulting and so should be added to the net displacement of the early Precambrian rocks for determination of total pre–Uinta Mountain Group displacement. The Beaver Creek block may have thus been uplifted as much as 10 km relative to the Red Creek and Bender Mountain blocks prior to deposition of the Uinta Mountain Group. This faulting is of crustal dimensions and is probably related to the origin of the Uinta aulacogen.

The nature of rejuvenated faults is well displayed in the Mountain Home block (Fig. 4). A veneer of basal Uinta Mountain Group sandstone a few centimetres to tens of metres thick is preserved in the area and overlaps several faults that place Owiyukuts gneisses against Red Creek quartzites. In three cases, the faults were clearly reactivated as small-scale reverse faults related to development of the Uinta Fault and cut the Uinta Mountain Group.

The reversal in sense of displacement of several of the above faults and of others in the area (for example, one mapped by Hansen, 1965, in Red Creek Canyon) is compatible with the replacement of the tensional tectonic regime responsible for the Uinta aulacogen by the compressional tectonic regime of the Laramide Orogeny. The Red Creek–Bender Mountain composite block is a graben lying between the Mountain Home block and the Beaver Creek block. If the bounding faults each had 7 km of vertical displacement and a dip of 45°, a total of 14 km of horizontal crustal extension is required to form the graben. The Uinta Mountain Group is ~7.5 km thick in this area (Hansen, 1965) and has been interpreted to occupy a fault-bounded trough. Accommodation of this body of rock required an additional 15 km of crustal extension in the area, if bounding faults, not exposed, dip 45° (Fig. 5a). With these approximations, a minimum crustal extension of 30 km is required prior to Paleozoic time.

A reasonable, balanced, cross section of the entire Uinta Range drawn through the study area (Fig. 5b) implies that as much as 25 km of crustal shortening may have occurred to form the Laramide Uinta Range. During this shortening, the old faults were reactivated with a reverse sense of displacement. The reverse displacement was

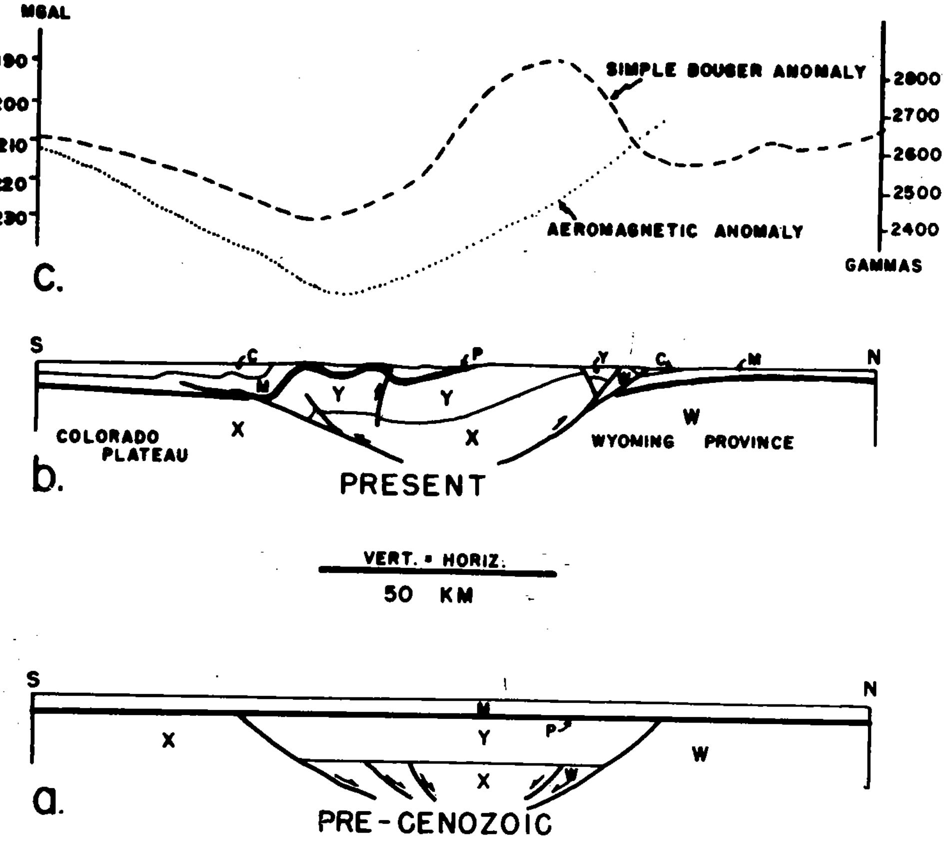


Figure 5. a. Uinta aulacogen prior to Laramide Orogeny. Owiyukuts Complex (W) faulted against Red Creek Quartzite (X). Uinta Mountain Group (Y) occupies aulacogen, overlapped by Paleozoic (P) and Mesozoic (M) rocks. b. Present configuration of Uinta Mountains, no vertical exaggeration. C, Cenozoic. Major faults of 5a were reactivated in Laramide Orogeny. c. Simple Bouger and aeromagnetic anomaly profiles along line of section b, showing effect of uplifted, dense, amphibolite-bearing Red Creek rocks at northern margin of Uinta Mountains. Sources: Cross section b drawn from geologic map of Hansen (1957). Stratigraphic thicknesses from Hansen (1965), Osmond (1964), Garvin (1969). Basement depth from Bayley and Muehlberger (1968). Gravity profile drawn from map of Eaton and others (1978). Magnetic profile drawn from map of Mabey and others (1978). See Figure 1b for location of section.

less than the original normal displacement, so that there is a net normal displacement on the faults today relative to the pre–Uinta Mountain Group rocks. Because the shortening was greater than the 15 km of extension necessary to accommodate the Uinta Mountain Group, the base of the group has been uplifted above the pre–Uinta Mountain Group erosional level, accounting for the exposure of early Precambrian rocks.

If other dips are chosen for the faults, the relationship remains the same, because most movements of both faulting episodes were probably confined to the same fault surfaces.

Hansen (1965) mapped several curious curved faults that juxtapose exposures of the orogenic system and Uinta Mountain Group. In the context of this discussion, these faults are probably the result of reactivation of eroded fault-block monadnocks. The Uinta Mountain Group, which in this area includes massive conglomeratic alluvial fan deposits (Hansen, 1965), could have been deposited on the rounded margins of fault blocks of older Precambrian rocks. Uplift of the fault blocks could have locally produced faults deflected by the configuration of the unconformity. This would imply that deposition of the Uinta Mountain Group began while some topographic relief remained on the block-faulted terrane—an obviously realistic implication supported by the coarseness of clasts in the basal Uinta Mountain Group.

Although the data base for interpretation of the relationship of the Uinta Mountain Group to its basement is small, it strongly supports the concept of deposition in a fault-controlled trough.

TECTONIC SUMMARY

1. Bedding-schistosity intersection relations suggest in a fragmentary way that the earliest structure developed in the Red Creek Quartzite was a synmetamorphic recumbent syncline which closed to the south. A ductile-brittle boundary defined by some combination of variations in strain rate, water content, metamorphic grade, temperature, and confining pressure can be envisioned to have migrated downward in the orogenic pile following the inception of metamorphism. The ductile boundary was located somewhat below the level of reaction 1 at the time of intrusion of the amphibolite bodies, so that deeper levels were highly attenuated by ductile flow after intrusion, while schistosity and isograds of the upper levels were openly folded and thrust-faulted. The box shape of the Garnet Canyon anticline implies that a deeper surface of strain discontinuity must have existed during its formation and may have been represented by the ductile boundary. Finally, the ductile boundary migrated below any presently exposed rocks of the orogen, and the deepest levels were concentrically folded. Sense of vergence was northward as the Red Creek metasediments were thrust over a granitoid authochthon.

2. After cessation of the orogeny, the region was disrupted by block faults with displacements of several kilometres, and different tectonic and metamorphic levels were juxtaposed. This deformation probably occurred about 1,550 m.y. ago and marks initiation of the Uinta aulacogen. The blocks were tilted relative to one another, causing differences in orientation of linear and planar elements.

3. After deep erosion, the fault blocks were overlapped by the middle Proterozoic Uinta Mountain Group, which is more than 7 km thick (Hansen, 1965).

4. During the Laramide Orogeny, the Uinta Mountain block was uplifted by compressive reactivation of deep crustal faults initiated during evolution of the Uinta aulacogen. Some of the faults were decapitated, resulting in the formation of structural horses along the Uinta Fault.

REGIONAL RELATIONSHIPS

Rocks of the Red Creek Quartzite are lithologically similar to the Libby Creek Group (Fig. 1), a 6.8-km-thick miogeoclinal sequence at the top of the early Proterozoic section of the Medicine

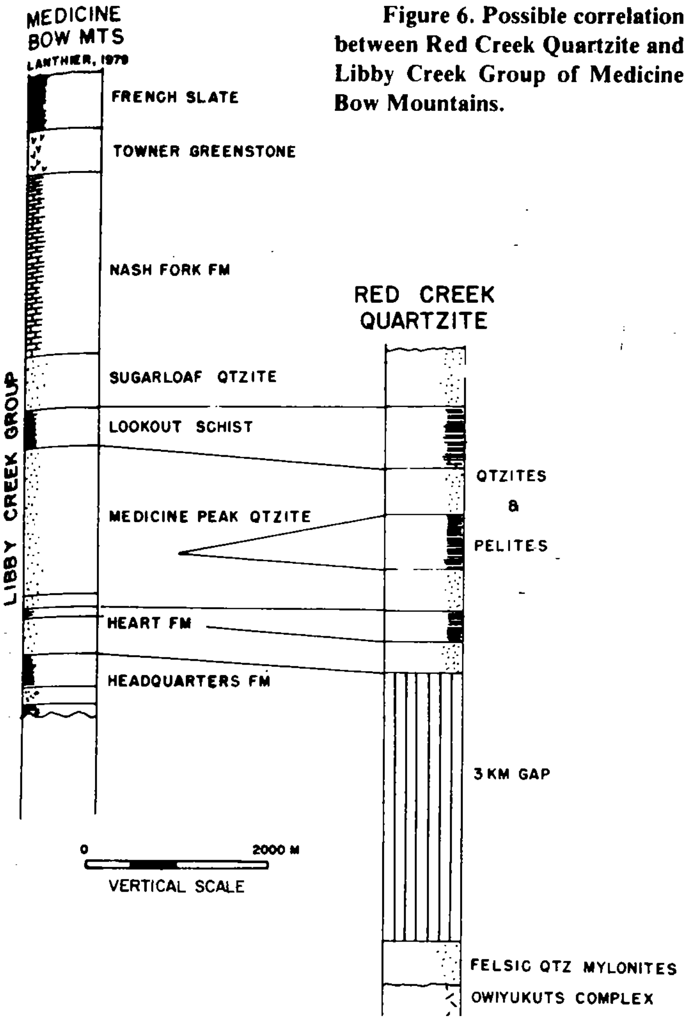


Figure 6. Possible correlation between Red Creek Quartzite and Libby Creek Group of Medicine Bow Mountains.

Bow Mountains of Wyoming (Lanthier, 1979). Although no diamictites are preserved in the Red Creek rocks, a reasonably good correlation can be postulated and is presented in Figure 6.

The Libby Creek Group is more than 1,700 m.y. old, partly overlies Archean feldspathic gneisses, and in part is thrust northward over the early Proterozoic Deep Lake Group (Karlstrom and Houston, 1979). These relationships are like the northward thrusting of the basal Red Creek Quartzite over the Owiyukuts gneisses.

The Libby Creek Group is truncated to the south by a major Precambrian shear zone which also marks the southern limit of Archean ages (~2.5 b.y.) in North America (King, 1976). This boundary can be projected west to the axis of the Uinta Mountains (Karlstrom, 1979), south of which all exposed Precambrian rocks are post-Archean and form part of a vast eugeoclinal terrane (King, 1976).

The Red Creek Quartzite thus correlates well in age, lithologic sequence, tectonic style, and setting with the Libby Creek Group and is probably a continuation of the same Precambrian orogenic system.

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