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Re-evaluation of the Jesse Ewing Canyon Formation : Implications for Neoproterozoic Paleogeography and Tectonic Setting of Northeastern Utah

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RE-EVALUATION OF THE JESSE EWING CANYON FORMATION: IMPLICATIONS FOR NEOPROTEROZOIC PALEOGEOGRAPHY AND TECTONIC SETTING OF NORTHEASTERN UTAH

by

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ABSTRACT

Re-evaluation of the Jesse Ewing Canyon Formation: Implications for Neoproterozoic Paleogeography and Tectonic Setting of Northeastern Utah

by

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Detailed analysis of the basal unit of the Uinta Mountain Group, the Jesse Ewing Canyon Formation, of northeastern Utah and northwestern Colorado, expands on previous work by further documenting the character of the unit and proposing a revision of the description of the formation and interpretation. The Jesse Ewing Canyon Formation is ~≤1,000 meters thick as opposed to ≤225 meters thick, and the dominant lithology is not conglomerate, but rather finer-grained facies. The Jesse Ewing Canyon Formation reveals multiple alluvial fan point sources feeding a shallow body of water in an active rift basin at ~781 Ma.

Stratigraphic mapping, measured sections, and facies analysis of the Jesse Ewing Canyon Formation have allowed the designation of two members defined by changes in lithology. The coarse-grained Head of Cottonwood member (~0-200 meters thick) represents alluvial fan deposition along the basin bounding faults to the north. The fine-grained Willow Creek member (~150-1,000 meters thick) represents distal alluvial fan, braided stream, fan delta, and nearshore deposition and records the complex interaction of transverse and longitudinal alluvial systems with an intermittent shallow body of water.

The stratigraphy and distribution of the two members of the Jesse Ewing Canyon Formation suggest sedimentation along the basin-bounding east-west trending fault system was dominated by alluvial fans that graded laterally into finer sediments basinward. Changes in thickness and (or) lithology across Laramide and younger structures are attributed to synextensional deposition. A crude, overall fining-upward trend within the Willow Creek member suggests alluvial fan retrogradation that was likely controlled by coincident northward transition in fault slip along related structures.

Preliminary subdivisions were made within the overlying Uinta Mountain Group based on the presence of a middle shale and conglomeratic unit. The designation of the lower, middle, and upper Uinta Mountain Group establishes a stratigraphic framework for the correlation between the northern and southern margins of Browns Park, and ultimately the eastern and western domes of the Uinta Mountains. Repetition of the lithostratigraphic units in the overlying undifferentiated Uinta Mountain Group may be due to a blind thrust fault as opposed to deposition.

(232 pages)

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CHAPTER 1

INTRODUCTION

1.1 - Location and General Geologic Background

The Uinta Mountain Group of northeastern Utah and northwestern Colorado is one of the best preserved successions of Neoproterozoic strata in North America (Fig. 1). It is exposed in the core of the Uinta Mountains as a doubly plunging anticline flanked by younger Paleozoic and Mesozoic strata that range from the Cambrian Lodore Formation to the Lower Cretaceous Mowry Shale and underlain by the Paleoproterozoic (?) Red Creek Quartzite (Hansen, 1965; Hansen et al., 1983; Gregson and Chure, 2000). Though these strata may answer many questions associated with the Neoproterozoic, such as the timing of the breakup of Rodinia and pre-Sturtian paleoclimate (Karlstrom et al., 1999; Dehler et al., 2005b), it has received little attention by the Precambrian research community. This project focuses on the basal unit of the Uinta Mountain Group, the Jesse Ewing Canyon Formation (~225 meters thick; Sanderson and Wiley, 1986), exposed in an approximately 56 km^2 area in the eastern Uinta Mountains along the Utah-Colorado border (Fig. 1).

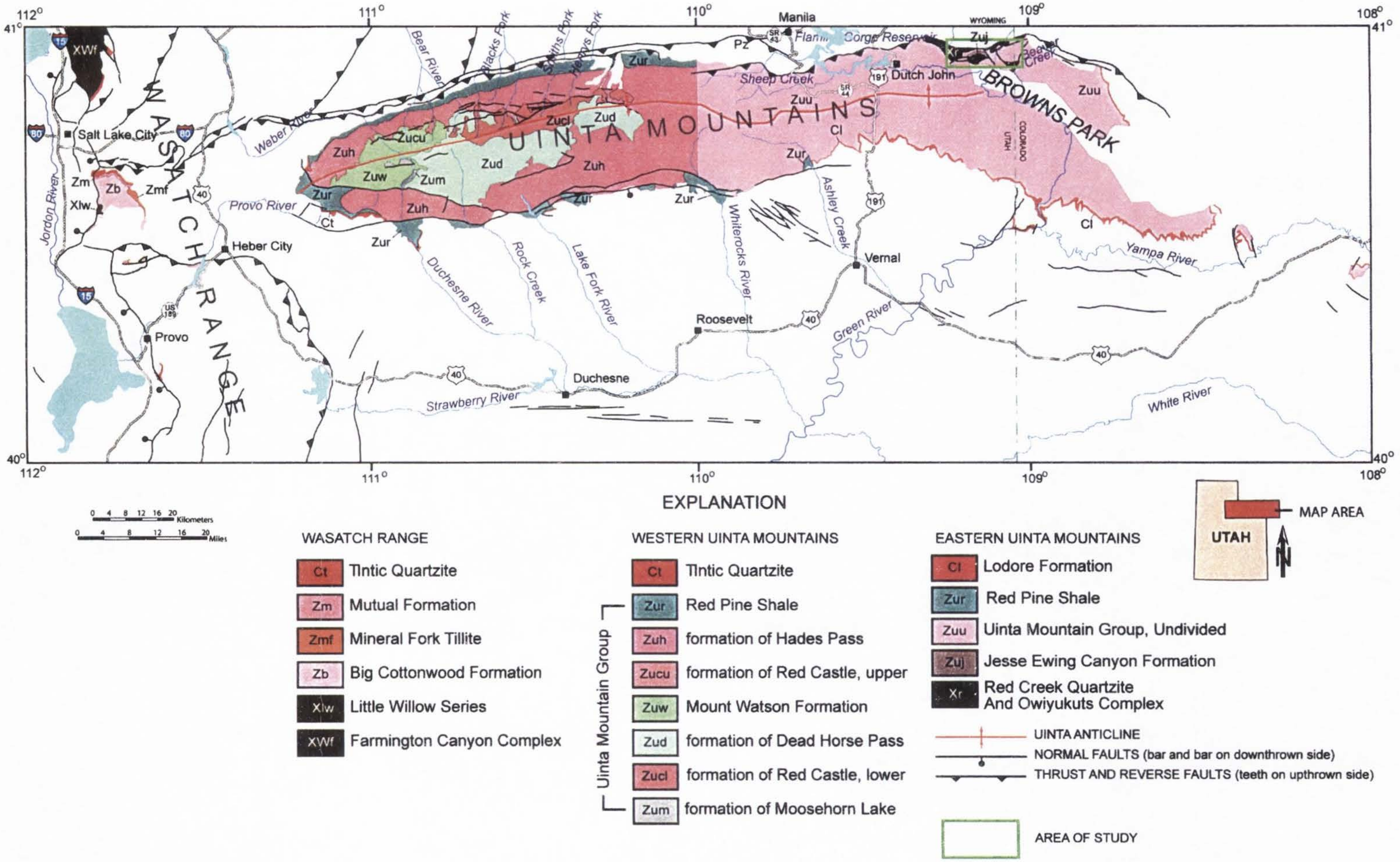


Figure 1. Simplified geologic map of the Uinta Mountains and surrounding area (from Dehler et al., 2005b). Note area of study along the eastern margin of the current range.

1.2 - Significance and Purpose

The basal unit of the Uinta Mountain Group, the Jesse Ewing Canyon Formation, has the potential for addressing many of the key questions about active surficial, tectonic, and climatic processes in northern Utah during Neoproterozoic time. Thoroughly interpreting the depositional environments, structural setting, and age of the Jesse Ewing Canyon Formation is critical for understanding the regional paleogeography and tectonic setting of northeastern Utah and northwestern Colorado during Neoproterozoic time. Previously interpreted as an alluvial fan deposit (Sanderson and Wiley, 1986), the Jesse Ewing Canyon Formation likely represents additional depositional environments based on field observations of this study. For example, the presence of potentially marine acritarchs and the abundance of organic-rich shale requires re-evaluation of this unit. Also, the presence of Neoproterozoic (?) diamictites, especially in light of the Snowball Earth hypothesis (Hoffman and Schrag, 2002), requires a re-evaluation of previous work which states that these deposits are non-glacial in origin (Sanderson and Wiley, 1986). Additionally, further documentation of syntectonic deformation is necessary towards the understanding of Uinta Mountain Group basin evolution (e.g., Sanderson and Wiley, 1986). Lastly, the age of this unit is only known from relative dating—it is younger than the Paleoproterozoic (?) Red Creek Quartzite (Hansen, 1965; Sanderson and Wiley, 1986), and it is older than the <770 Ma formation of

Outlaw Trail in the middle Uinta Mountain Group in the eastern Uinta Mountains (U-Pb date on 4 detrital zircon grains; Fanning and Dehler, 2005).

Detailed characterization of the Jesse Ewing Canyon Formation has both regional and disciplinary importance. Regionally, detailed mapping of this formation adds to the Precambrian database, and measured sections establish a stratigraphic framework for this and other studies. These data will aid in correlation between the east and west structural domes of the Uinta Mountain Group, and with the Big Cottonwood and overlying Mineral Fork formations to the west in the Wasatch Range (Link et al., 1993; Condie et al., 2001; Dehler et al., 2005b). The results of this research will ultimately contribute to clarifying the paleogeographic setting of northeast Utah during the Neoproterozoic (e.g., Wallace and Crittenden, 1969; Condie et al., 2001).

This work also makes several disciplinary contributions in the tectonic and Precambrian realm. First, it helps us to understand the tectonic framework of western Laurentia during the time between the amalgamation of Rodinia and the onset of the Cordilleran miogeocline (i.e., during the Neoproterozoic breakup of Rodinia) (Karlstrom et al., 1999; Sears and Price, 2003). By constraining the age and structural setting of the Uinta Mountain Group, we can add to the understanding of the nature and timing of basin formation during the pre-miogeoclinal phase of western Laurentia and test current models that suggest different styles and timing of rifting (Prave, 1999; Colpron et al., 2002; Eyles and Januszczak, 2004; Fanning and Link, 2004). Secondly, by interpreting the depositional environments of the Jesse Ewing Canyon Formation, contributions can also be made towards understanding regional or even global pre-Sturtian (≥~ 750 Ma) paleoclimate (e.g.; Hoffman and Schrag, 2002; Dehler et al., 2005a).

This project focuses on stratigraphic mapping to demonstrate that the Jesse Ewing Canyon Formation 1) records, in part, fan delta deposition, 2) records syntectonic deposition at 800-750 Ma, related to a rifting event that precedes the two major rift episodes of Neoproterozoic western Laurentia; and 3) records non-glacial deposition along a storm-affected clastic shoreline.

1.3 - Previous Work

With the exception of the Jesse Ewing Canyon Formation, the eastern strata of the Uinta Mountain Group have received relatively little work and remains undifferentiated. Work by Connor et al. (1988) made the first attempt at subdividing the eastern Uinta Mountain Group, suggesting the first stratigraphic subdivisions. Recent work by De Grey (2005) made further contributions by informally subdividing the eastern Uinta Mountain Group into three distinct divisions based on facies assemblages.

Hansen (1965) was the first to recognize the significance of the basal conglomerate of the Uinta Mountain Group. Hansen (1965) documented the aerial distribution of the unit and indicated that the most significant accumulations of conglomerate are located near the Jesse Ewing Canyon area. He also points out that the conglomerate thins to the east and is absent on a depositional contact with the Red Creek Quartzite on O-Wi-Yu-Kuts Mountain (plate 1).

Sanderson and Wiley (1986) formally described and named this basal conglomeratic unit as the Jesse Ewing Canyon Formation. Through seven measured sections and paleocurrent analysis, Sanderson and Wiley (1986) identified seven facies within the Jesse Ewing Canyon Formation and defined upper and lower contacts of the unit. Since the work by Sanderson and Wiley (1986), no other analysis of the Jesse Ewing Canyon Formation has been performed.

Two distinct paleogeographic models have been proposed for the Uinta Mountain Group. Wallace and Crittenden (1969) proposed that the Uinta Mountain Group was deposited in a narrow east-west trending trough dominated by fluvial environments that opened into a marine body of water to the west. This marine basin might be associated with the Big Cottonwood Formation of the Wasatch Mountains. Sanderson (1984) and Sanderson and Wiley (1986) suggest no marine influence, but rather that the entire group is represented by braided fluvial deposition. More recent work by DeGrey (2005) interprets the eastern Uinta Mountain Group to represent a braided fluvial system with intermittent marine (?) incursion from the west. The details of each model in the context of the Jesse Ewing Canyon Formation will be discussed in Chapter 7.

Geochemical work by Ball and Farmer (1998) suggest sediment provenance and paleogeographic reconstructions based on Nd isotope and trace element data. This work was supplemented by Condie et al. (2001) who built on their paleogeographic model, and illustrated that the Uinta Mountain Group was deposited in an intracratonic rift rather than an aulacogen. Regional work by Dehler et al. (2001) used microfossil assemblages and C-isotope data to suggest that the Uinta Mountain Group is correlative with other Neoproterozoic successions such as the Big Cottonwood Formation in the Wasatch Range, Chuar Group in Grand Canyon, and Pahrump Group in Death Valley.

1.4 - Scope of Project

The main objective of this research is to accurately identify all facies assemblages and interpret depositional environments associated with the Jesse Ewing Canyon Formation by stratigraphic mapping and measured sections. By using detailed mapping (1:12,000), measured sections, petrographic analysis, facies analysis, and paleocurrent analysis, this research can offer key insight into the active processes during the initiation of basin formation and subsequent deposition of the Uinta Mountain Group. The main questions to be addressed by this research are: 1) Does the Jesse Ewing Canyon Formation record deposition other than alluvial fan processes as observed by Sanderson and Wiley (1986)? 2) Does Jesse Ewing Canyon Formation show any evidence for glacial deposition? 3) Is there any evidence for syn-tectonic deposition that can be used to better understand the timing and style of rifting and basin formation? 4) Can stratigraphic mapping above the Jesse Ewing Canyon Formation lead to further subdivision of the undifferentiated Uinta Mountain Group in the eastern Uinta Mountains? 5) Can the maximum age of the Uinta Mountain Group be obtained by detrital zircon analysis from sandstones in the basal Jesse Ewing Canyon

Formation? 6) What paleogeographic reconstructions can be made or modified based on stratigraphic mapping and facies analysis?

CHAPTER 2

GEOLOGIC BACKGROUND

2.1 – Regional Tectonic Setting

The Uinta Mountain Group is exposed only in the Uinta Mountains of northeastern Utah and northwestern Colorado (Fig. 1). The Uinta Mountains are a Laramide age uplift approximately 260 km long from east to west and ~50 km wide from north to south that follows the same trend as the Cheyenne suture between the Wyoming Craton and the Yavapai Province (Hansen, 1965; Stone, 1993; Condie et al., 2001) (Fig. 2). The range is exposed as a doubly-plunging anticline that consists of two elongate domes separated by a shallow structural saddle that crosses the fold axis (Fig. 3) (Hansen, 1965; Hansen, 1984). The two domes are expressed structurally by a change in strike and dip of the Uinta Mountain Group (Hansen, 1984). Both domes underwent similar Laramide deformation, though the eastern dome experienced more uplift (Hansen, 1984). In the Oligocene, uplift of the domes ceased and the eastern dome began to collapse and now displays lower topographic relief, but deeper structural displacement as compared to the western dome (Hansen, 1984). Total axial length of the fold is ~320 km, though the Uinta anticline is only ~260 km long. The fold axis extends westward to the Wasatch front where it is exposed in the Cottonwood uplift, and continues eastward until it dives beneath the Tertiary Browns Park Formation in Colorado. The anticline is asymmetric as demonstrated by steeper structural dips on the northern limb compared to those

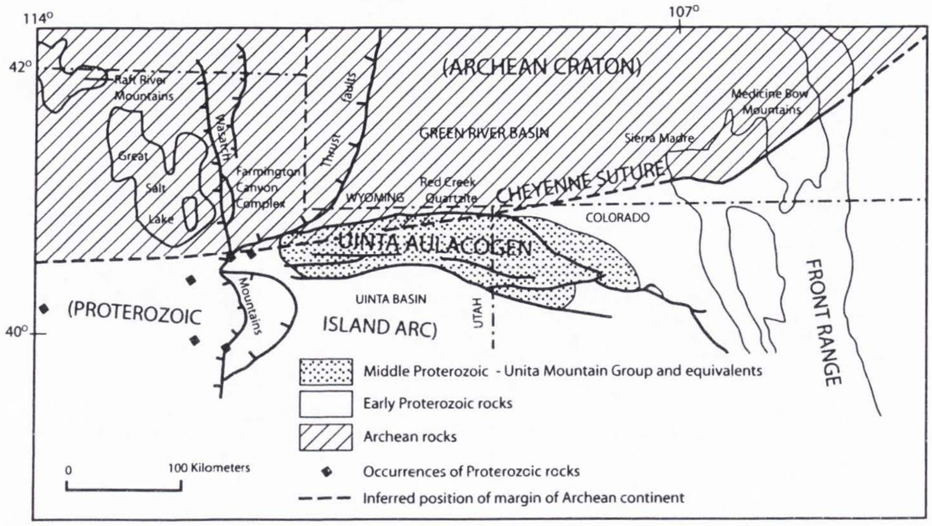


Figure 2. Reconstructed tectonic regime showing the location of the Uinta Mountain Group paleobasin in relation to the Cheyenne Suture (from Stone, 1993).

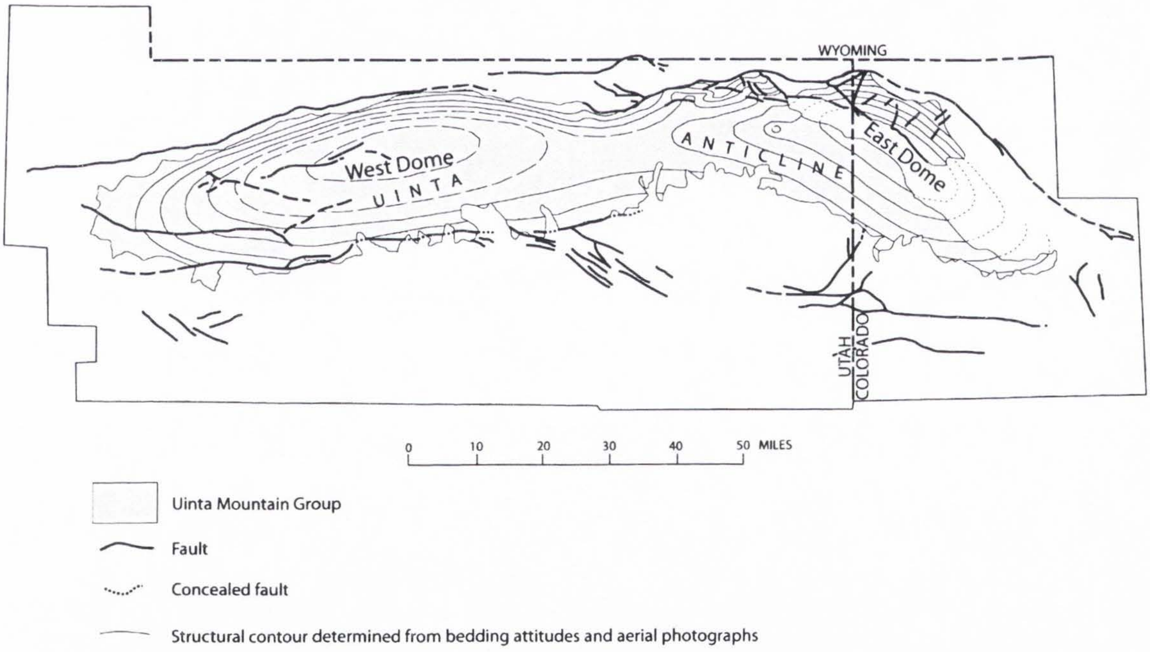


Figure 3. Structure map of the Uinta Mountains illustrating the doubly plunging anticline and eastern and western domes separated by a shallow structural swell (from Hansen, 1965). The Uinta Mountain Group is characteristically different in the two domes and different levels of the stratigraphy are exposed. The Jesse Ewing Canyon Formation is only exposed in the eastern dome.

those on the southern limb, and the crestline of the range is much closer to the range-bounding fault to the north (Hansen, 1965).

2.2 - Geologic History

The Red Creek Quartzite, which underlies the Jesse Ewing Canyon Formation, is a unit of moderately high metamorphic grade spanning the amphibolite facies. It is composed of three main rock types; metaquartzite, amphibolite, and mica schist (Hansen, 1965). Sedimentary protoliths have been interpreted as a ~4 km thick succession of clean quartz sand and clay deposited on a slowly-subsiding shelf (Hansen, 1965; Sears et al., 1982). Possibly underlying the Red Creek Quartzite is the O-Wi-Yu-Kuts complex originally described by Sears et al. (1982). Additional work by Swayze and Holden (1984) propose that the O-Wi-Yu-Kuts complex is simply metasomatized Red Creek Quartzite and not an older and distinguishable terrane.

Following the deposition and burial of the Red Creek protolithic sediments, a period of deformation and metamorphism and shortening produced a synmetamorphic recumbent syncline that closes to the south (Hansen, 1965; Sears et al., 1982). This deformation is the result of compression as the Red Creek strata were thrust northward during Paleoproterozoic accretion of the Yavapai Province to the Wyoming Province along the Cheyenne Suture (Sears et al., 1982; Duebendorfer and Houston, 1987; Bryant and Nichols, 1988; Ball and Farmer, 1991; Stone, 1993).

A second stage of deformation resulted in tight folds and high grade metamorphism followed by mafic injection (Hansen, 1965). This deformation led to pegmatization and albitization, though given the degree of metamorphism, there is surprisingly little pegmatite (Hansen, 1965).

At approximately 1,550 Ma, large normal faults with displacements of several kilometers placed the Red Creek Quartzite in contact with the Owiyukuts Complex, a 2,700 Ma (Rb-Sr whole-rock) medium to fine-grained granitic gneiss (Sears et al., 1982). The Red Creek Quartzite was subsequently uplifted and deeply eroded leading to the deposition of the Uinta Mountain Group (Hansen, 1965; Sears et al., 1982).

Two primary ages have been reported from the Red Creek Quartzite. An age of 2,320 Ma was obtained from Rb/Sr dating of the muscovite-schist facies of the Red Creek Quartzite and is thought to indicate the earliest stage of metamorphism (Hansen, 1965). A younger age of roughly 1,500 Ma has been obtained using the K-Ar analysis on the schist and younger pegmatite in the Red Creek Quartzite, and is suspected of reflecting a younger metamorphic event (Hansen, 1965).

The Uinta Mountain Group was deposited on the Red Creek Quartzite in a rapidly subsiding, shallow water, east-west trending basin (Hansen, 1965; Sanderson and Wiley, 1986; Ball and Farmer, 1998; Condie et al., 2001). There is still some question as the extent and basin type in which the Uinta Mountain Group was deposited (Sanderson and Wiley, 1986; Sears et al., 1982; Stone, 1993), but recent work suggests that it is some form of intracratonic basin that crudely follows the Cheyenne Suture (Condie et al., 2001; Dehler et al., 2007).

Deposition and burial of the Uinta Mountain Group was followed by broad regional uplift which persisted during most of Paleozoic and Mesozoic time. This is demonstrated by thinning of Paleozoic and Mesozoic strata onto the flanks of the long-lived topographic high (Hansen, 1965). This uplift started after the deposition of the Red Pine Shale (~742 Ma) and before deposition of the Lodore/Tintic formations (Middle to Late Cambrian) (Dehler et al., 2007).

Laramide deformation occurred during two distinct time periods. The first and most intense period of deformation occurred in Late Cretaceous to earliest Tertiary times, which resulted in dragging and flexing of the adjacent fault blocks (Hansen, 1965, 1984). A second period of movement took place in the Tertiary along pre-existing fault planes. This deformation resulted in normal gravity faulting that displaced overlying Tertiary rocks without deforming the adjacent fault blocks (Hansen, 1965).

The Laramide reverse faults likely follow inherited planes of weakness produced from Precambrian normal faulting (Sears et al., 1982, Stone 1993). These faults are the largest and longest faults and bound the range to the north and south (Hansen, 1965). The largest of these faults is the Uinta-Sparks fault which separates Precambrian rocks to the south and Paleozoic and Mesozoic rocks to the north (Fig. 4a) (Hansen, 1965; Stone, 1986; 1993). This fault is dominantly responsible for the uplift of the Uinta Mountains and, cumulatively, is

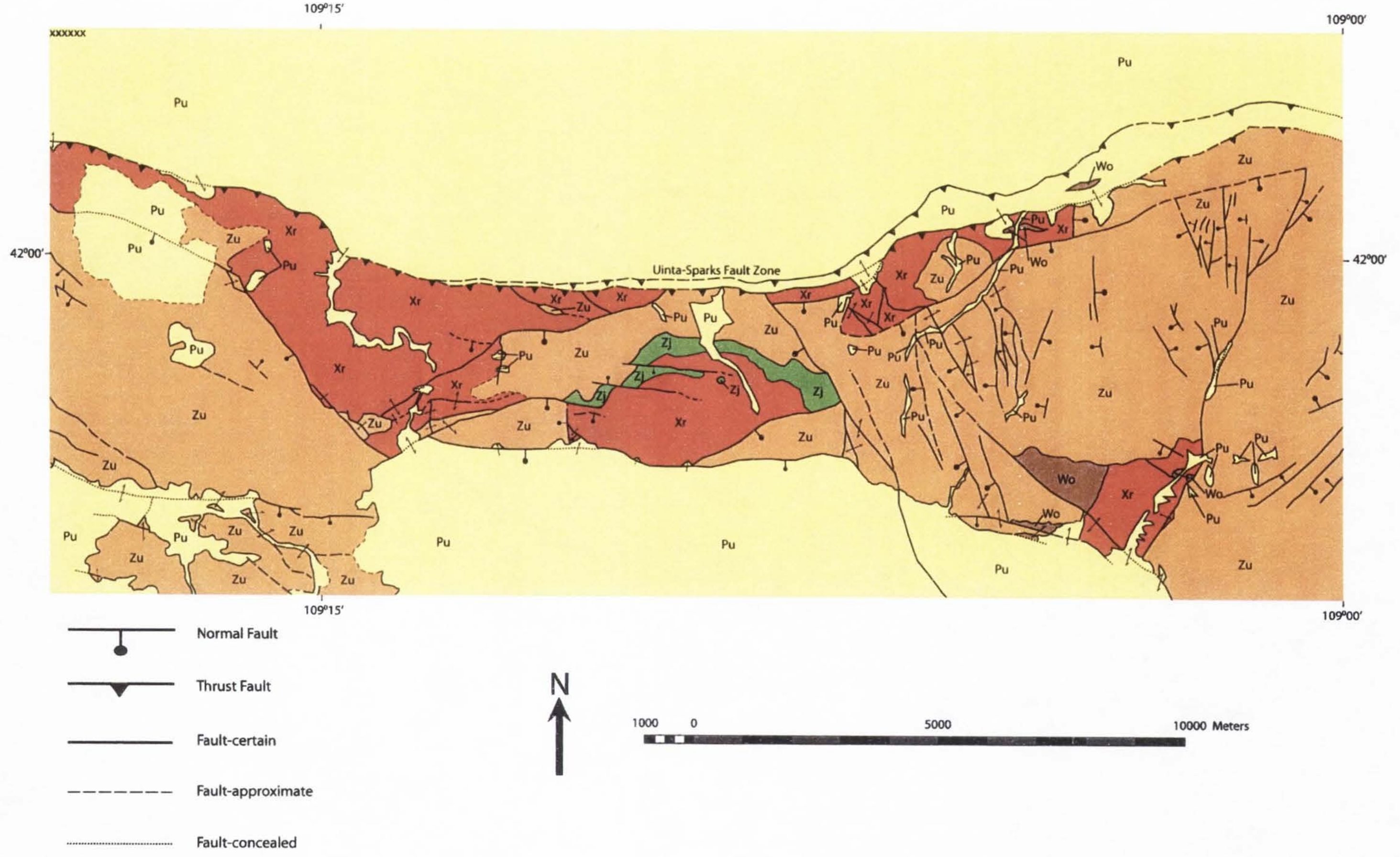


Figure 4a. Geologic map showing outcrop distribution of the Jesse Ewing Canyon Formation, Uinta Mountain Group, and major structures in the eastern Uinta Mountains (from Sprinkel, 2002). See figure 3b for description of map units.

Pu Phanerozoic rocks

Undifferentiated Phanerozoic rocks. Surficial fine- to coarse-grained sand to boulder sized Quaternary deposits. Tertiary Browns Park formation, a dominately white to tan fine-grained tuffaceous sandstone. Cretaceous shales and fine- to coarse-grained sandstones.

Zu Uinta Mountain Group, undivided (Neoproterozoic) (as much as 3,500 meters)

Undifferentiated Uinta Mountain Group. Dark- to light-red, fine- to coarse-grained quartz and lithic arenite. Thick- to medium-bedded, planar-, cross-, and contorted bedding with ripples and mudcracks. Contains considerable amounts of red, green, and dark-gray micaceous shale and conglomerate with associated pebble lags.

Zj Jesse Ewing Canyon Formation (Neoproterozoic?) (225 meters)

Dark- to light-red, brown and reddish-purple pebble to boulder conglomerate interbedded with quartz and lithic arenite and shale. Clasts primarily from underlying Red Creek Quartzite displayed as white, pale green, and pink quartzite. Basal unit of the formation dominated by conglomerate where upper units are primiarly finer grained green micaceous sandstones and maroon shales.

Xr Red Creek Quartzite (Paleoproterozoic?)

Contains metaquartzite, mica schist, and amphilbolite.

Metaquartzite - resistant white, gran, tan, and light-green metaquartzite.

Mica Schist - Quartz-muscovite schist that grades between metaquartzite and mica schist.

Amphibolite - Dark-gray to black, fine- to medium-grained amphilbolite composed of strongly foliated mafic rocks associated with the Red Creek Quartzite as numerous small bodies.

Wo Owiyukuts Complex (Paleoproterozoic?)

High-grade, metamorphosed potassium-rich granitic gneiss with lesser amounts of quartzofeldspathic gneiss.

Figure 4b. Description of map units in Figure 4a (from Sprinkel, 2002)

161 km long (Hansen, 1965). The Uinta-Sparks fault is associated with a 1.6 km wide fault zone and shows drag on both fault blocks of Laramide and pre-Laramide age (Hansen, 1965).

Normal faulting commenced with the cessation of Laramide deformation (Hansen, 1965). These faults are the most common type of fault in the eastern Uinta Mountains, but are shorter and show less displacement than those produced during the Laramide Orogeny (Hansen, 1984). These faults were also active over much longer periods of time and have two phases of movement. The first phase coincided with the gravitational collapse of the eastern dome in the Oligocene. The second phase of slip was during and following the deposition of the Miocene Browns Park Formation (Hansen, 1965, 1984).

2.3 - Stratigraphy, Age, and Basin Type of the Uinta Mountain Group

Just as the east and west domes of the Uinta Anticline separate the range structurally, these features also expose different intervals and units of the Uinta Mountain Group stratigraphy. The Uinta Mountain Group is a ≤7 km thick deposit of dark to light red medium to coarse grained, massive to cross-bedded quartz-rich (defined in this study as containing greater than 90% quartz) sandstone with lesser shale and conglomerate (Figs. 5, 6) (Hansen, 1965; Wallace and Crittenden, 1972). The western dome exposes the upper ~4km of Uinta Mountain Group stratigraphy. This part of the stratigraphy has received the majority of the work performed on the Uinta Mountain Group and has resulted in

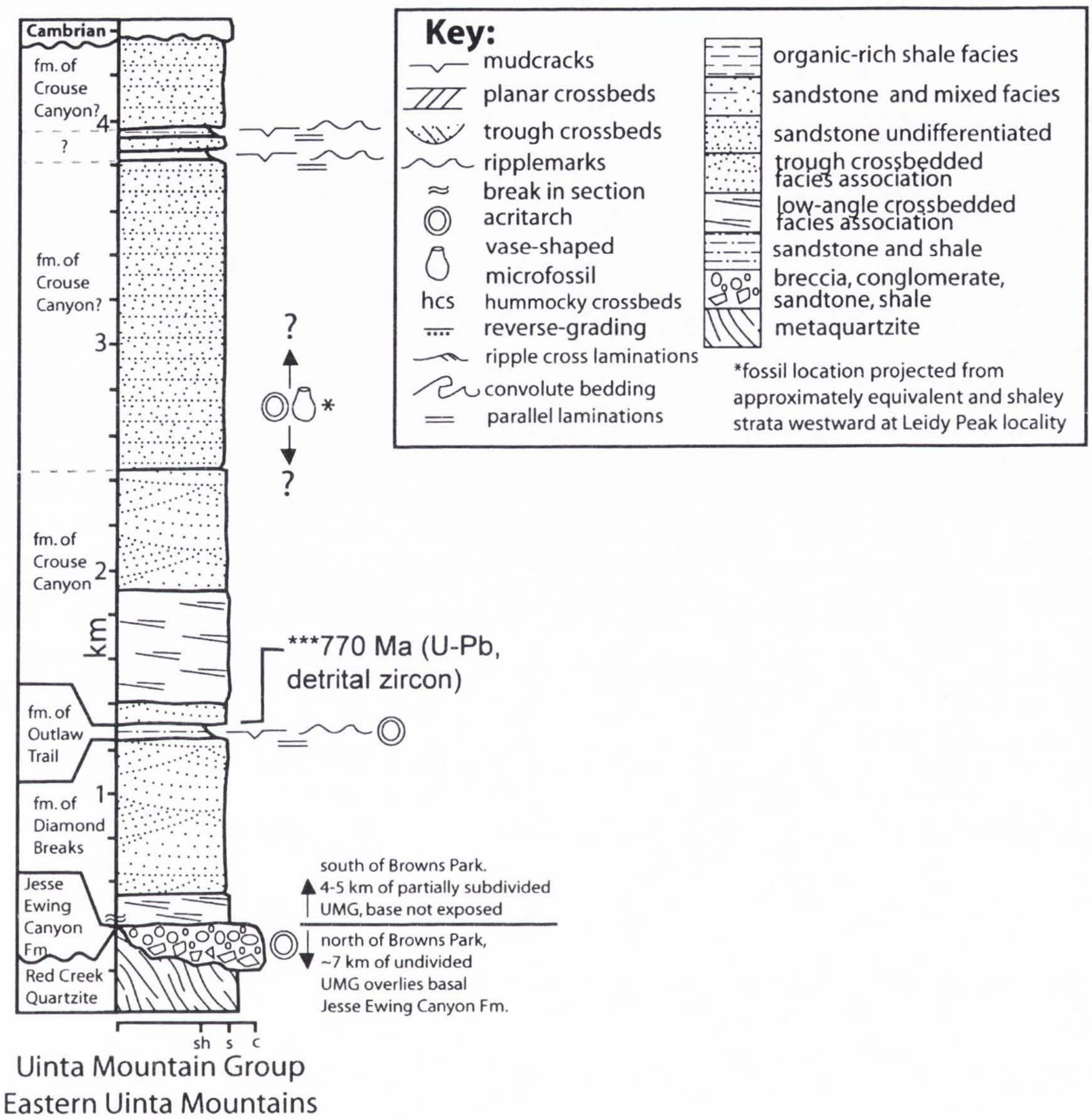
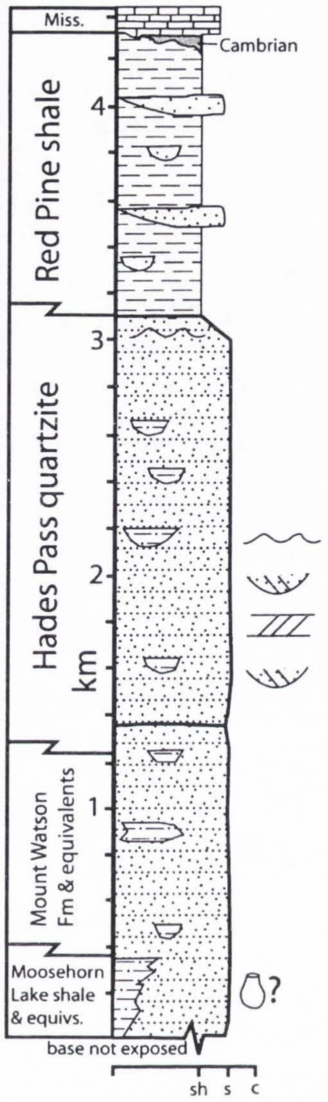


Figure 5. Generalized stratigraphy of the eastern Uinta Mountain Group prior to the work of this study (from Dehler et al., 2005b). Note thickness and lithologic character of the Jesse Ewing Canyon Formation. Key is for Figures 5, 6, and 11.



Uinta Mountain Group
Western Uinta Mountains

Figure 6. Generalized stratigraphy of the western Uinta Mountain Group (from Dehler et al., 2005b). Note that the base of the Uinta Mountain Group is not exposed. See Figure 5 for key to lithologic units and symbols. Compare with Figure 5 stratigraphy where majority of strata are yet to be differentiated.

formal and informal subdivisions of the strata (Wallace, 1972; Sanderson, 1984). Approximately 7 km of strata is exposed in the eastern dome, and yet it has received little attention from the Precambrian research community. With the exception of the Jesse Ewing Canyon Formation, the entire eastern Uinta Mountain Group remains formally undivided with no correlation between the eastern and western parts of the range.

Sediment provenance studies illustrate two distinct sources for the Uinta Mountain Group (Wallace, 1972; Sanderson, 1984; Ball and Farmer, 1998; Condie et al., 2001). Arkosic sandstone has a source from dominantly granites enriched in Th, U, Y, Zr, Hf, and REE with signatures suggesting the Wyoming Craton to the north as the primary source (Ball and Farmer, 1998; Condie et al., 2001). Quartz arenite was mainly derived from Paleoproterozoic crust east of the Uinta Mountain Group basin, though some additional quartz-rich sediment has been shown to be sourced from the north (Ball and Farmer, 1998; Condie et al., 2001; De Grey, 2005; Dehler et al., 2007).

Accurate dating of the Uinta Mountain Group has proven difficult and in many cases relative dating is the only age constraint on certain rock units. The Uinta Mountain Group unconformably overlies the Paleoproterozoic (?) Red Creek Quartzite (Fig. 5) (Hansen, 1965). The contact between the basal Jesse Ewing Canyon Formation and the overlying undivided Uinta Mountain Group has been assigned an age between 1.4 and 0.9 Ga using wholerock Rb/Sr dating (Hedge et al. 1986). Furthermore, the formation of Outlaw Trail in the middle eastern UMG can be no older than 770 Ma based on U-Pb dating of 4 detrital zircon grains (Fanning and Dehler, 2005). The uppermost unit of the Uinta Mountain Group, the Red Pine Shale, has previously been assigned an age of 950 Ma based on wholerock Rb/Sr dating (Fig. 6) (Crittenden and Peterman, 1975). More recent research, however, correlates the Red Pine Shale with the Chuar Group, Grand Canyon at ~742 Ma (Vidal and Ford, 1985; Karlstrom et al., 2000; Dehler et al., in press). The Uinta Mountain Group is also broadly correlative with the Pahrump Group of Death Valley and the Big Cottonwood Formation of the Wasatch Range (Wallace, 1972; Link et al., 1993; Condie et al., 2001; Dehler et al., 2005b).

Previous workers propose that the Uinta Mountain Group was deposited in an east-west trending aulacogen related to the rifting of the Laurentian margin (e.g., Sears et al., 1982), but others suggest that sediments were instead deposited in an intracratonic rift (Link et al., 1993; Condie et al., 2001). The later hypothesis is based on the fact that Proterozoic and Archean continental basement is found as far west as northeast Nevada with no appearance of oceanic crust. This then places the Uinta Mountain Group at least 500 km east of the developing continental shelf with no evidence for continental crust rupture or a passive continental margin (Condie et al., 2001). The intracratonic rift proposed by Condie et al. (2001) would still allow the Uinta Mountain Group to be deposited in an east-west trending rift basin that potentially was part of a larger interior seaway to the west and/or south (Fig. 7) (Wallace and Crittenden, 1969;

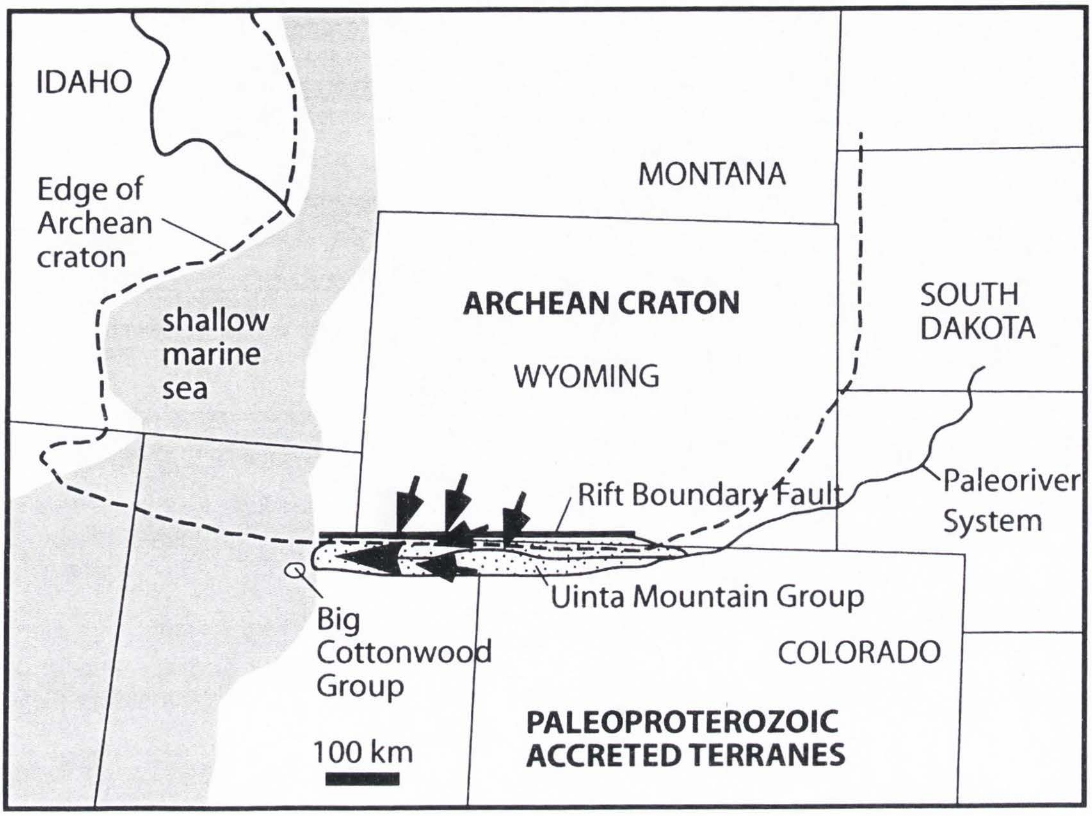


Figure 7. Paleogeographic map based on provenance studies of the Uinta Mountain and the Big Cottonwood successions (from Condie et al., 2001). Note that the Uinta Mountain Group basin is interpreted as a narrow intracratonic trough dominated by fluvial environments. Large black arrows indicate flow direction of Uinta Mountain Group sediments. Compare with Figure 8.

Condie et al., 2001; Dehler et al., 2007). This intracratonic rift model is also consistent with work by Wallace and Crittenden (1969) who describe a change from west flowing fluvial sediments in the east to deltaic sediments in the west (Fig. 8).

2.3.1 - Western Uinta Mountain Group

The stratigraphically highest interval including the uppermost member of the Uinta Mountain Group, is exposed in the western dome (Fig. 6). The lower formations in the western dome including the formations of Red Castle, Moosehorn Lake, Hades Pass, and Mt. Watson were described and interpreted informally (Wallace and Crittenden, 1969; Wallace, 1972). Sanderson (1984) characterized and formally named the Mount Watson Formation in his study of the western Uinta Mountains. Although the Red Pine Shale is formally named (Williams, 1953), it is only now being described in detail (Dehler et al., 2007).

The formation of Red Castle (>600m) is the lowest recognized formation in the western Uinta Mountains. It consists of rhythmically alternating intervals of cross-bedded dark-red to brownish-red coarse-grained arkosic sandstone to micaceous arkosic siltstone to shale. The lower part of the formation is dominated by massive cross-bedded, well-indurated pebbly arkose showing abundant channeling separated by thin shale and conglomerate units. Typical primary sedimentary structures include planar and small-scale trough cross-bedding and ripplemarks with shale-clast conglomerate (Wallace and Crittenden,

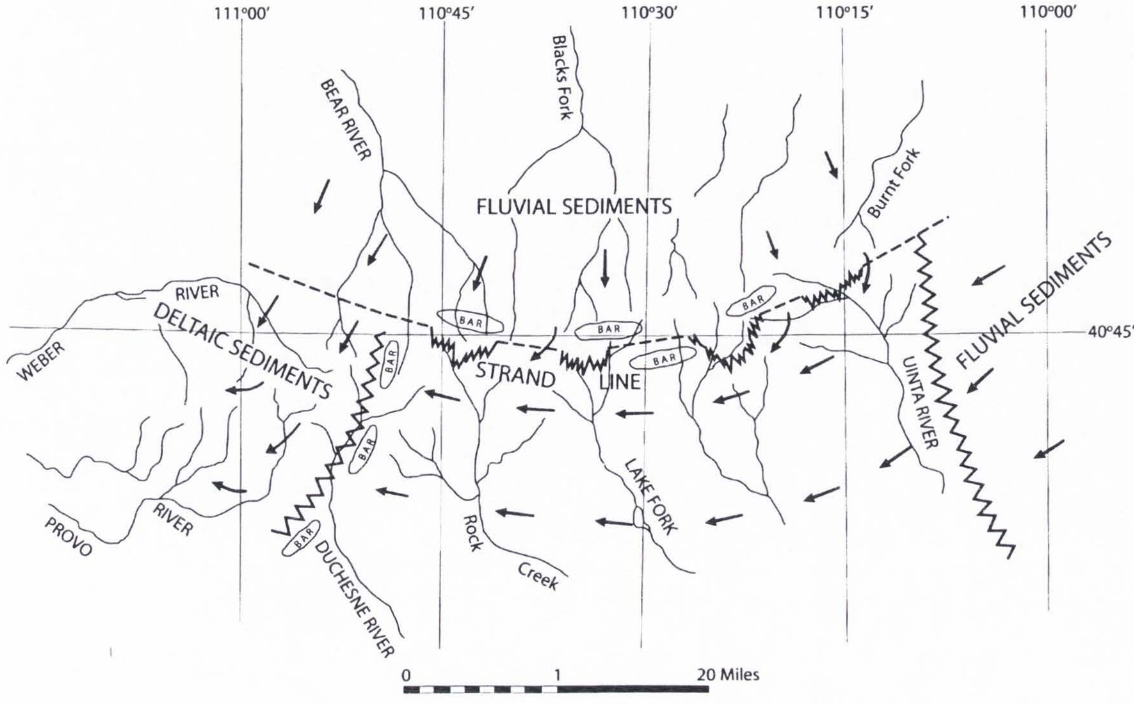


Figure 8. Paleogeographic map showing sediment transport directions of west and central Uinta Mountain Group depositional systems as interpreted by Wallace and Crittenden (1969). Note the strandline coincides roughly with modern range divide. Wallace and Crittenden (1969) interpret mature quartz sand brought into the basin from the east and immature arkosic sand brought in from the north (from Wallace and Crittenden, 1969). Compare to Figure 7.

1969). The formation of Red Castle has been interpreted to have been deposited in a fluvial environment (Wallace and Crittenden; 1969).

In the southern part of the western dome, the arkosic sandstone of the formation of Red Castle grades laterally into quartz arenite of the equivalent Mount Watson Formation (>600m). Underling the Mount Watson Formation is the formation of Moosehorn Lake comprised of arkosic shale only exposed in a small area along the northern Duchesne River. The transition between the formation of Red Castle and Mount Watson Formation is hard to distinguish due to lack of traceable shale intervals that extend across both units.

The Mount Watson Formation is characterized primarily by sandstone wedges composed of light-gray to pink well sorted, well rounded quartz arenite that thicken to the south. These sandstone wedges typically display small- and medium-scale planar and trough cross-beds, soft-sediment deformation structures, ripplemarks, and parting lineations (Wallace and Crittenden, 1969). The sandstone in the formation of Mount Watson has been interpreted to represent a fluvial environment (Wallace and Crittenden, 1969; Sanderson, 1984) that intertongues with deltaic and marine shale (Wallace and Crittenden, 1969).

Overlying the formation of Red Castle and Mount Watson Formation is the formation of Hades Pass (~2100 meters). The formation of Hades Pass is composed of coarse-grained, reddish to purplish quartz sandstone with alternating beds of arkosic sandstone and conglomerate and small amounts of shale. This thins westward and is characterized by a finer grain size and thick-bedded cross-bed cosets and an increase in quartz arenite relative to underlying units (Wallace, 1972). This has been interpreted as a fluvial environment (Wallace and Crittenden, 1969).

The Red Pine Shale (<1200 meters; eroded top) is the uppermost unit of the Uinta Mountain Group and signifies the end of preserved Neoproterozoic deposition in the area. The Red Pine Shale exhibits three distinct facies: an olive-drab to black shale facies, shale and sandstone facies, and sandstone facies (Dehler et al., 2007). The shale facies constitutes about 70% of the entire unit and contains 1-100 meters thick intervals of organic rich parallel and ripple-laminated shale. The shale and sandstone facies makes up approximately 20% of the unit and is characterized by organic-rich gray to black siltshale interbedded with thinly bedded fine to coarse-grained quartz arenite to arkosic arenite. This interval displays slump folds, load structures, hummocky-cross stratification, symmetric ripples, parallel to ripple laminations, climbing ripples, and silica concretions. The sandstone facies contains fine grained to granule quartz arenite to arkosic arenite characterized by normal and reverse graded beds, hummocky cross stratification, cut and fill structures, asymmetric and symmetric ripples, parallel to ripple laminations, load structures, and planar to tabular cross-beds (Dehler et al., 2007). The Red Pine Shale has been interpreted to represent a deltaic environment that opened into a marine body of water to the south and west (Dehler et al., 2001; Dehler et al., 2007).

2.3.2 - Eastern Uinta Mountain Group

The eastern dome of the Uinta anticline exposes a relatively lower stratigraphic interval of the Uinta Mountain Group, including the basal member, the Jesse Ewing Canyon Formation (Fig. 5); however, it is still unclear how the Uinta Mountain Group strata between the domes correlate. The Jesse Ewing Canyon Formation was deposited unconformably on the Red Creek Quartzite illustrating the greatest amount of missing time in the Uinta Mountains (>1.5 Ga Hansen, 1965; Sprinkel, 2002). Relief on this surface generally is in excess of several hundred feet, where conglomeratic beds of Jesse Ewing Canyon Formation fill paleotopographic lows. Far to the east near the Colorado border, this surface is near-planar, but the conglomeratic beds of the Jesse Ewing Canyon Formation are absent (Hansen, 1965).

Overall, the Jesse Ewing Canyon Formation contains interbedded dark-reddish-brown to dark gray conglomerate and breccia with considerable amounts of quartz arenite and maroon shale (Sanderson and Wiley, 1986). Sediment source for the northern Jesse Ewing Canyon Formation is derived mainly from the Archean basement of the Wyoming craton and Proterozoic crust to the north and east respectively, with reworked Red Creek Quartzite (Ball and Farmer, 1998; Condie et al., 2001). This suggests that the Wyoming Province,the Red Creek Quartzite, and Proterozoic crust were uplifted and supplying sediment during deposition of the Uinta Mountain Group (Ball and Farmer, 1998). The finer sediments of the southern portion of the Jesse Ewing Canyon Formation and overlying undivided Uinta Mountain Group were derived from Proterozoic crust to the east and several Archean and Proterozoic (?) sources to the north and are thought to have been transported by a major west and south flowing fluvial system (Figs. 7, 8) (Ball and Farmer, 1998; Condie et al., 2001; De Grey, 2005).

Sanderson and Wiley (1986) interpreted the Jesse Ewing Canyon Formation as an alluvial fan environment located along the northern boundary of the basin, sourcing sediment from the Wyoming craton. The alluvial fans were adjacent to faults that formed in a stair-step fashion that marked the northern edge of the basin. Within the alluvial fan, they identified seven genetically related facies (A-G). According to their descriptions, overall morphology of the fan fines upward with the coarsest, clast-supported conglomerate at the base in Facies A, evolving to a sandstone-dominated facies with subordinate lenses of conglomerate and shale in Facies G. Also associated with alluvial fan deposition are deposits thought to be the result of a braided stream adjacent to the fan and distal fan environments such as playa and distal sheet flood deposits.

Sanderson and Wiley (1986) define the Jesse Ewing Canyon Formation as an association of thick conglomerate and shale that is easily distinguished from the overlying Uinta Mountain Group. The base of the unit is defined as the unconformable contact with the underlying Red Creek Quartzite. The upper contact is defined as the uppermost major shale bed, or conglomerate bed in localities where shale is absent. Three sections (JE-3, JE-4, and JE-5) were measured along the southern portion of Jesse Ewing Canyon that capture thick intervals of shale and conglomerate with associated sandstone that all belong to the Jesse Ewing Canyon Formation. While reported as incomplete sections, they serve as a proxy for defining the unit beyond the immediate Jesse Ewing Canyon area.

Additionally, Sanderson and Wiley (1986) interpret the Jesse Ewing Canyon Formation as recording syn-tectonic deposition associated with the rifting of an aulacogen. They report an unnamed fault in Jesse Ewing Canyon to display a Precambrian history related to the deposition of the Jesse Ewing Canyon Formation. They describe an older sequence that is confined to the south of the fault and is overlain by a younger sequence that progrades across the fault (Fig. 9). They report an angular unconformity between the two sequences that separates the older more intensely folded older sequence below from the younger gently dipping sequence above.

Conformably overlying the Jesse Ewing Canyon Formation is undifferentiated massive and cross-bedded, coarse to medium grained silica-cemented quartz sandstone with interbedded red shale and conglomerate of the Uinta Mountain Group (Fig. 5) (Hansen, 1965). The entire eastern undifferentiated Uinta Mountain Group is characterized by poorly to well sorted, fine- to coarse-grained quartz sandstone with minor additions of feldspar and lithic fragments. The majority of bedding is tabular to lenticular with planar to undulose bedding. Typical primary sedimentary structures include trough and

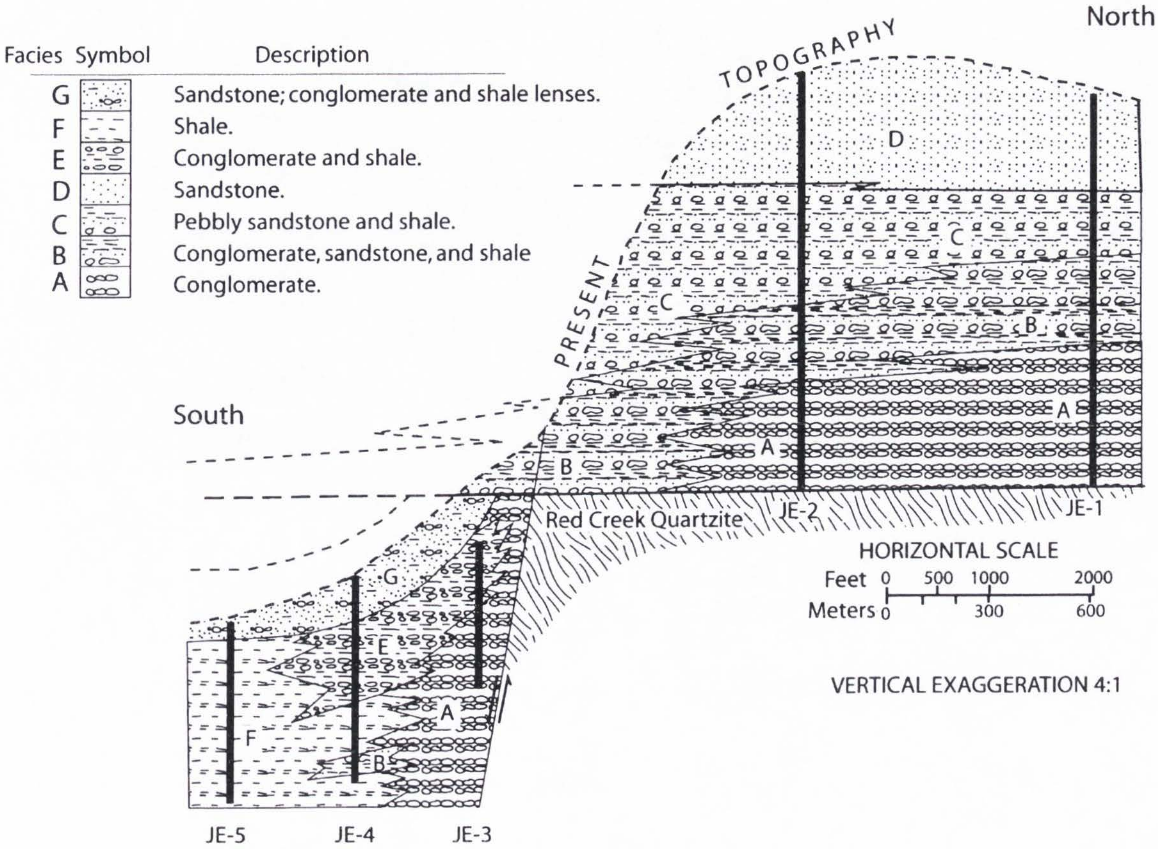


Figure 9. Syntectonic figure showing Sanderson and Wiley's (1986) angular unconformity between an older deformed sequence and younger sequence. Dark lines also show relative locations of Sanderson and Wiley's (1986) measured sections. From Sanderson and Wiley (1986).

low-angle cross-beds, graded bedding, symmetric to asymmetric ripples, and soft-sediment deformation structures (Connor et al., 1988; DeGrey, 2005; e.g., McKenny et al., in review).

Connor et al. (1988) separated the eastern Uinta Mountain Group into three units: a lower sandstone unit, a middle shale unit, and an upper sandstone unit. The lower sandstone unit is characterized by red to reddish-purple, fine- to medium-grained, thickly bedded quartz arenite with crossbedding. The middle shale unit is composed of red, green, and grey, thinly bedded, interbedded mud-cracked siltstone and very fine-grained sandstone. The upper sandstone unit is very similar to the lower sandstone unit, the main difference being that the upper sandstone unit is more arkosic (Connor et al., 1988).

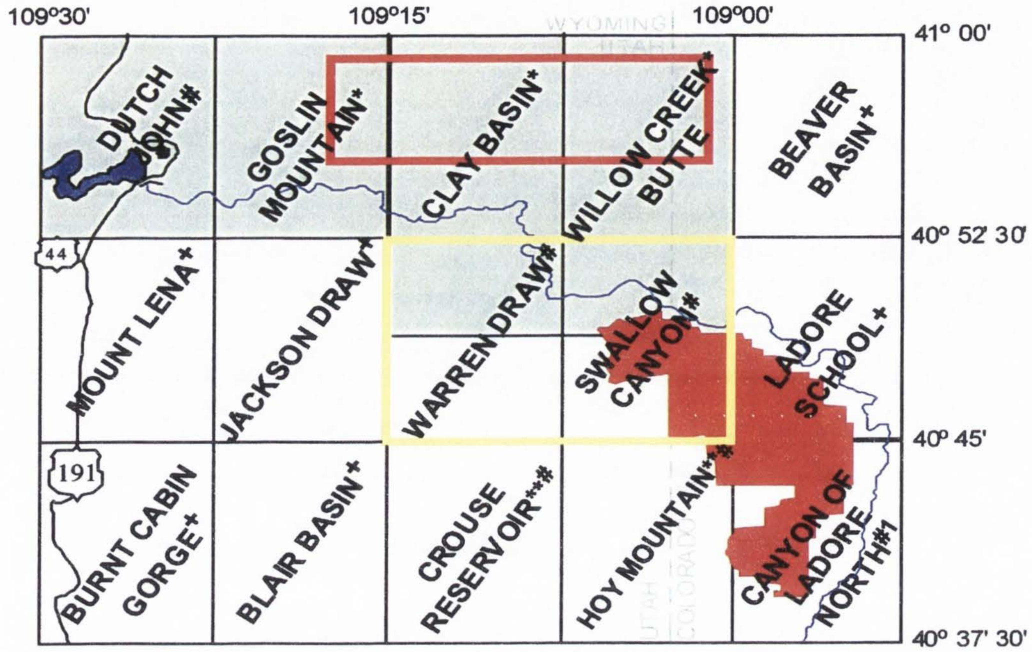
De Grey (2005) proposed that these units be designated as formations within the larger undifferentiated Uinta Mountain Group and are only mappable by the presence of the middle shale unit. De Grey (2005) has informally named the middle shale unit the formation of Outlaw Trail and, thus, separates the lower sandstone unit (formation of Diamond Breaks) from the upper sandstone unit (formation of Crouse Canyon) (Fig. 5). De Grey (2005) interpreted the lower sandstone unit, the Diamond Breaks, as being deposited in a braided river environment with flow direction to the southwest. The middle shale unit has been interpreted as a low energy, interdistributary environment of proximal to medial delta plain (De Grey, 2005). The uppermost sandstone unit demonstrates an increase in energy and is interpreted as a braided river system flowing to the southwest (De Grey, 2005).

CHAPTER 3

METHODS

3.1 – Mapping

Field mapping took place over the summers of 2005 and 2006 using the traditional map and compass method with the aid of areal photograph interpretation and GPS (strike and dip data in appendix B). Detailed mapping was conducted at 1:12,000 scale with special attention given to depositional contacts (stratigraphic mapping) to better understand sedimentological and depositional relationships, although the final map product is shown at 1:24,000 scale (plate 1). The map area consists of a ~56 km^2 area that encompasses the Goslin Mountain, Clay Basin, and Willow Creek Butte 7.5-minute quadrangles (Figs. 4a, 10) (Sprinkel, 2002). The primary focus of the mapping was the basal Precambrian strata of the mountainous area on the northern edge of Browns Park north of the Green River (Fig. 1; plate 1). This map area also exposes the majority of the overlying undifferentiated Uinta Mountain Group leading to one of the only places in the range where a minimum thickness can be calculated for the entire Uinta Mountain Group (e.g., Hansen, 1965). This area is also an important place to start building a stratigraphic framework where correlations can be made with, not only the strata exposed on the southern edge of Browns Park, but also between the eastern and western structural domes of the Uinta Mountains. As mentioned above, the mapping was focused on the Precambrian stratigraphy. Therefore all older crystalline



Area mapped by Hansen (1965, and references therein)

Diamond Breaks Wilderness Study Area mapped by Connor et al. (1988)

Area mapped by Dehler and students for EDMAP 2002, 2004 (De Grey, 2005; McKenney et al. (in review)

Area mapped for EDMAP, 2006 (Brehm and Dehler, 2006, in prep)

* Only quadrangles where basal UMG has been observed and mapped

** Unconformable upper contact of UMG mapped in these quadrangles (Hansen, et al. 1981; Hansen and Rowley, 1991)

\+ Not mapped at 1:24,000 scale

1 Hansen et al. (1982)

\# Shale units subdivided in UMG

Figure 10. Location map showing mapped area on surrounding topographic map base.

basement units were not mapped, nor were any overlying or adjacent Phanerozoic units.

3.2 - Stratigraphic Characterization and Measured Sections

Stratigraphic characterization of the Jesse Ewing Canyon Formation was accomplished through detailed field mapping and measured sections. Eight measured sections (<40-~1,000 meters thick) were measured and used to determine the spatial relationships of the observed facies within the map area (Figs. 7, 8; appendix A). Stratigraphic characterization was based primarily on two distinct facies associations: the comparison of the relative amounts of conglomerate to shale that led to the designation of two members within the Jesse Ewing Canyon Formation. Further work within these two members led to a more detailed characterization of the individual facies based on grain size, sedimentary structures, bedding, and the ratio between shale and the coarser grained fraction of a specific interval.

Based on observations during field mapping, type locations were selected to obtain a detailed description of each member. The locations of these measured sections are shown on plate 1 and the full detailed descriptions are displayed in appendix A. Cross sections showing calculated thickness are also shown on plate 1.

3.3 – Samples

A sample suite was collected using a stratified approach within the measured sections for petrographic analysis and to insure stratigraphic context for future work. Eighty-two samples were collected whenever there was an obvious change in lithology or sedimentary structures, and consisted primarily of sandstone and lesser shale populations. Hand samples were described in the field for composition, sorting, rounding, grain size, and sedimentary structures. Shale samples were collected for future carbon, XRD, and XRF analyses. Sandstone billets were cut for thin sections at the facilities at Utah State University and were sent to Quality Thin Sections, Tucson, Arizona to have 19 sandstone thin sections made.

Heavy mineral separation was conducted by Paul Link in the laboratories of Mark Schmitz at Idaho State University. Paul Link also analyzed the 72 detrital zircon grains using the SHRIMP in the laboratory of Mark Fanning at Australian National University.

3.4 - Paleocurrent Analysis

Paleocurrent data were collected in the field during mapping and measuring section for the primary purpose of determining the general trend of current flow direction and sediment transport. A thorough paleocurrent analysis was out of the scope of the project and was not performed. A total of 39 paleocurrent readings were collected at 21 stations within the map area.

Paleocurrent readings were taken dominately from planar- and trough-cross-bedded sandstone, with lesser readings taken on tangential crossbeds, symmetric ripple crests, and imbricated clasts. All readings that yielded a dip greater than 25° were corrected for dip (Collinson and Thompson, 1982). With the exception of one station, the paleocurrent measurements in section H are only presented showing the trend of transport. Since no plunge was measured in the field, all indicators were given an average plunge of 22°. Those stations where an average plunge was used are marked accordingly in appendix A and plate 2. The raw data including locations can be found in appendix C.

3.5 - Petrographic Analysis

Petrographic analysis of 19 samples was conducted using the traditional method. Each thin section was point counted at 300 counts per slide under 20x or 10x power depending on the average grain size for each particular section (raw data in appendix D). The point count categories are as follows: polycrystalline quartz, monocrystalline non-undulose quartz, monocrystalline undulose quartz, weathered feldspar, sedimentary lithic, accessory mineral, cement, and matrix. These data were then normalized for Qm, F, and Lt categories for compositional analysis and data presentation on a QFL diagram (appendix E). For this normalization, polycrystalline quartz was included in the lithic category.

In addition to point counting, each thin section was also analyzed for average grain size, grain size range, sorting, rounding, and grain boundaries along with any additional comments (appendix F). All thin section work was conducted at the facilities at Utah State University.

CHAPTER 4

GEOLOGIC MAPPING WITHIN THE GOSLIN MOUNTIAN, CLAY BASIN, AND WILLOW CREEK BUTTE QUADRANGLES

4.1 - Geographic Features

The map area for this project is contained within the Goslin Mountain, Clay Basin, and Willow Creek Butte 7.5' quadrangles of the eastern Uinta Mountains of northeastern Utah and northwestern Colorado. This area is accessible via US Highway 191 to Browns Park Road through Jesse Ewing Canyon (also part of the Browns Park Scenic Byway). There are no paved roads in the area with the exception of Colorado Highway 318, which begins at the Utah-Colorado border.

The main geographic feature of the area is the Green River, which flows roughly east-west through Browns Park just south of the bedrock exposure and area of primary focus of this project (Fig. 1, plate 1). The mountainous region north of Browns Park is dissected by several small streams that flow from north to south, and eventually joining the Green River. Some of the larger of these streams are, from east to west, Red Creek (the type section for the Red Creek Quartzite), Willow Creek, and Beaver Creek which appear from west to east, respectively.

Other perennial drainages worth mentioning are the Mountain Home Draw, Cottonwood Draw, Bender Draw, Galloway Creek, and Little Beaver Creek (plate 1). Mountain Home Draw begins near the top of Mountain Home at an unnamed spring and dissects the landscape in such a way that exposes one of the few complete sections of Jesse Ewing Canyon Formation in the area. Cottonwood Draw's headwaters are from Cottonwood Spring near the top of Head of Cottonwood on the east side of Jesse Ewing Canyon, which exposes, potentially the largest, most complete section in the area. Bender Draw is a small tributary to Willow Creek, which exposes some of the lowermost Jesse Ewing Canyon Formation in the area. Like Bender Draw, Galloway Creek is also a tributary to Willow Creek and allows access to some of the most northern exposures of the Jesse Ewing Canyon Formation. Lastly, Little Beaver Creek is a small tributary to Beaver Creek originating from Honeymoon Spring near O-Wi-Yu-Kuts Flats and penetrates the heart of the undifferentiated Uinta Mountain Group to the east (plate 1).

Other geographic features that occupy the area are the large broad plateaus that comprise the northwestern margin of Browns Park and dominate the central portion of the map area. These plateaus account for most of the exposure in the area and are divided into four distinct regions. From west to east they are: Goslin Mountain, Mountain Home, Head of Cottonwood, and O-Wi-Yu-Kuts Mountain (plate 1).

4.2 - Overview of Geologic Units

The focus of this project is the Precambrian stratigraphy, specifically the Jesse Ewing Canyon Formation (plate 1). The map area was defined in such a way as to emphasize the Precambrian exposure, specifically the Jesse Ewing Canyon Formation and related undivided Uinta Mountain Group. The major geologic units have been divided as follows: Red Creek Quartzite, Jesse Ewing Canyon Formation (Head of Cottonwood member and Willow Creek member), Uinta Mountain Group (lower, middle, and lower) (Fig. 11; plate 1).

The lowermost and oldest unit in the map area is the O-Wi-Yu-Kuts complex though some argue that this unit is actually metasomatized Red Creek Quartzite (Swayze and Holden, 1984). For the purposes of this project, there has been no differentiation of the O-Wi-Yu-Kuts complex from the Red Creek Quartzite and all crystalline basement has been mapped as Red Creek Quartzite. The Red Creek Quartzite displays three main rock types: metaquartzite, amphibolite, and mica schist (Hansen, 1965). Unconformably overlying the Red Creek Quartzite is the Jesse Ewing Canyon Formation which has been divided into an interbedded-shale-and-sandstone member and a conglomeratic member (this study) (plate 1). Stratigraphically above the Jesse Ewing Canyon Formation is the undivided Uinta Mountain Group which has been *preliminarily* subdivided into three informal formations (this study). The lower Uinta Mountain Group consists of dominantly thickly bedded trough cross-bedded sandstones. Above this is the middle Uinta Mountain Group, which in places resembles the Jesse Ewing Canyon Formation as a shale-dominated formation with interbedded conglomerate and sandstone. Overlying the middle unit is the upper Uinta Mountain Group which is predominately quartz-rich sandstones with lesser amounts of shale (plate 1). This upper unit is truncated by the Uinta-Sparks fault zone just northeast of the northern edge of the map area (see Hansen, 1965).

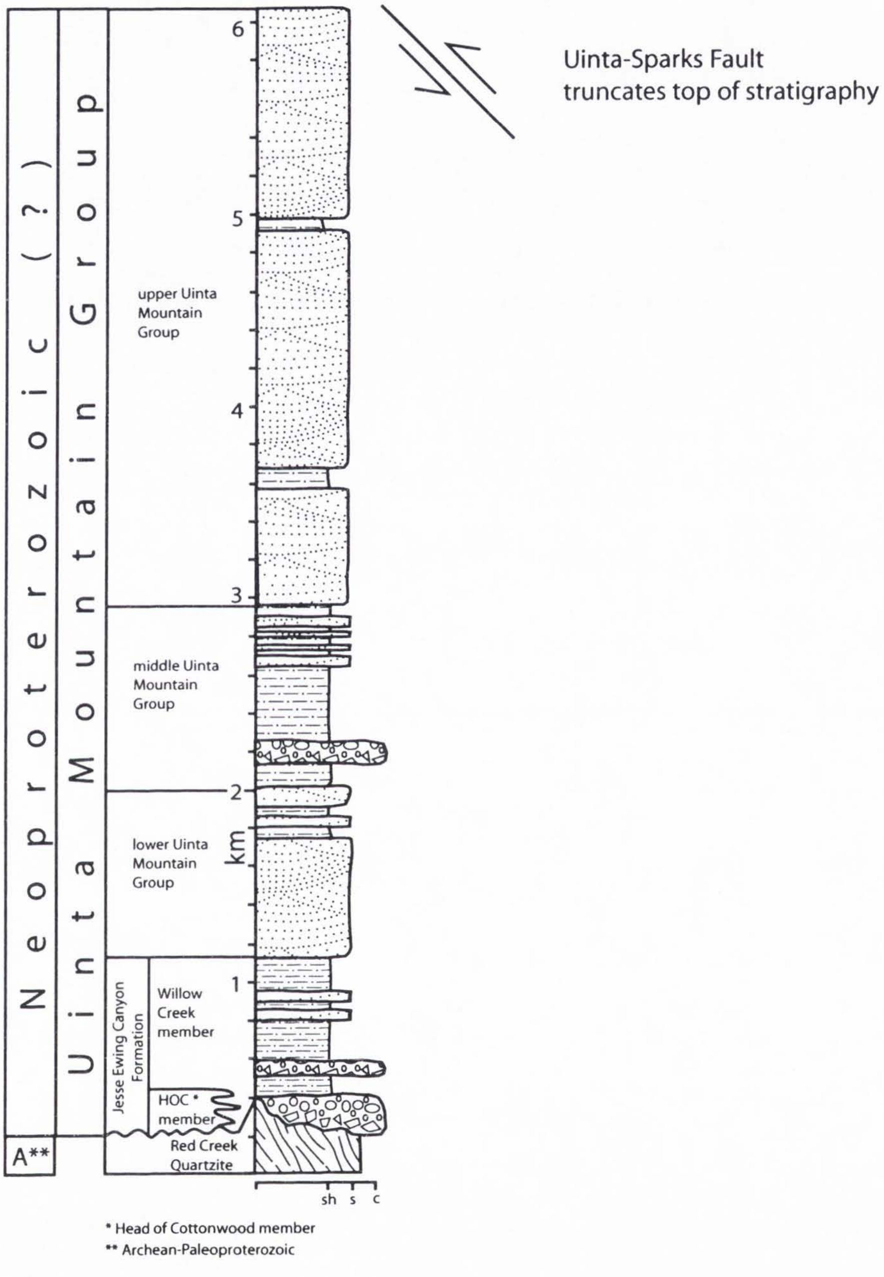


Figure 11. Generalized eastern Uinta Mountain Group stratigraphy based on the results of this study. Note the subdivision into members and greater thickness increase of the Jesse Ewing Canyon Formation. Compare to Figure 5.

The Phanerozoic strata in the area were not mapped though special symbols have been used to illustrate their presence (plate 1). These rocks span from Cretaceous to Quaternary in age and dominately occupy the lowlands of the map area.

4.3 - Mapping Units

Detailed stratigraphic mapping of the mountainous region north of Browns Park has allowed further subdivision within the Jesse Ewing Canyon Formation and differentiation of the overlying undivided Uinta Mountain Group (compare Fig. 4a with plate 1) (Hansen, 1965; Sanderson and Wiley, 1986; Sprinkel, 2002). These new map units are important for characterization and interpretation of the Uinta Mountain Group as a whole. Additionally, the differentiation of the previously undifferentiated Uinta Mountain Group is important for designation of a stratigraphic framework that can be used for correlation between the northern and southern margins of Browns Park. This then can be the building block for formally subdividing the entire Uinta Mountain Group, and help with understanding how the strata of the strata of the east and west structural domes of the range correlate.

4.3.1 - Subdivision of the Jesse Ewing Canyon Formation

The Jesse Ewing Canyon Formation has been subdivided into two members based on grain size and stratigraphic relationships. The coarse member is named the Head of Cottonwood member for the excellent exposures on the southern slope on the Head of Cottonwood (plate 1, plate 2; Section C, appendix A). At this locality Section C is comprised entirely of the Head of Cottonwood member. At its type locality, the Head of Cottonwood member rests unconformably on the Red Creek Quartzite and is in fault contact with the overlying Willow Creek member. At the type section, the Head of Cottonwood member demonstrates a minimum (faulted upper contact) thickness of approximately 190 meters (plate 2; Section C, appendix A). While at this locality the Head of Cottonwood member is faulted and only a minimum thickness can be obtained, this is the only location that exhibits considerable amounts (>100 meters) of laterally continuous conglomerate in depositional contact with the Red Creek Quartzite. This member is characterized by considerable amounts of conglomerate with lesser amounts of interbedded shale and sandstone. The conglomerate is generally massive, and has little to no clast imbrication. Bedding geometry is either lenticular or tabular and is generally medium to very thickly bedded. The upper contact for this member is sharp or gradual depending on the locality, but in all cases the contact has been mapped at the last significant (2 meters) conglomerate and first significantly thick (>3 meters) sandstone.

The second member of the Jesse Ewing Canyon Formation has been named the Willow Creek member due to the excellent exposure, relatively insignificant structure, and extreme thickness along the southern reaches of Willow Creek (plates 1, 2). At this locality, the coarse Head of Cottonwood member is absent and the Jesse Ewing Canyon Formation is represented entirely by the finer Willow Creek member and rests directly on the Red Creek Quartzite (Hansen, 1965) (plates 1,2). This member is characterized by substantial thicknesses of shale and sandstone (~370-995 meters) with lesser interbedded conglomerate. The abundance of shale relative to sandstone and conglomerate is the primary mapping characteristic of this unit. The upper contact with the undivided Uinta Mountain Group has been identified as the break between dominantly shale to dominantly sandstone. The contact between these two units is sharp and will be discussed further in 4.3.2. While this member consists primairly of shale and sandstone, it has been included in the Jesse Ewing Canyon Formation due to its genetic association with the Head of Cottonwood member. This relationship is best displayed in the southern parts of Jesse Ewing Canyon where thick (>100 meters) accumulations of the Head of Cottonwood member thin rapidly into the shale of the Willow Creek member. While this area does display evidence for small scale faulting, the offset of these faults is considered minimal due to the coherent and consistent stratigraphy of the area.

The majority of the shale is maroon, silty, and slightly micaceous. Sandstone beds are generally tabular, well sorted, and well rounded with thicknesses of 2 meters, though thicknesses can exceed 80 meters in some localities (appendix A, Section H; plate 1). Also housed within this finer member is a green sandstone and shale interval (10-~80 meters thick). This part of the section represents the finest-grained facies in the entire formation ranging from claystone to fine-grained sandstone. This interval is of special interest for its potential in correlation due to unique sedimentary structures, color, and detrital zircon populations. The Willow Creek member has been measured to have a thickness of 997 meters, though different locations are expected to vary in thickness and stratigraphic character due to paleotopography and tectonic influences during deposition (appendix A, Section H).

4.3.2 - Differentiation of the Undivided Uinta Mountain Group North of Brows Park

Though the focus of this project was the Jesse Ewing Canyon Formation, mapping the surrounding area led to the observation of three distinct units of mappable proportions that will aid in the subdivision of eastern stratigraphy of the Uinta Mountain Group. While formal designation of these units is out of the scope of this project, it establishes a framework for future workers to build upon.

The unit directly overlying the Jesse Ewing Canyon Formation has been designated the lower Uinta Mountain Group (~850 meters thick, map thickness). The basal contact of this unit marks the sharp boundary between the shale of the Willow Creek member of the Jesse Ewing Canyon Formation and the more resistant cliff-forming sandstone of the lower Uinta Mountain Group (plate 1). The most characteristic feature of the lower Uinta Mountain Group, and the trait used for mapping, is the drastic increase of sandstone relative to shale. This contact is defined where shale is totally absent and sandstone persists for a stratigraphic thickness greater than 80 meters. Above this thick basal interval of sandstone, shale may be present, but in much lesser quantities than sandstone such that the entire unit is viewed as dominantly sandstone with lesser shale. This contact is easily discernible by aerial photograph and marks a drastic change in depositional systems during this time. The lower Uinta Mountain Group is dominantly medium- to coarse-grained quartz-rich sandstone that is moderately well-sorted. Beds are typically medium-bedded, and dominantly lenticular with lesser tabular bedding. The majority of the sandstone is trough cross-stratified and planar cross-stratified with occasional well rounded pebble lags of Red Creek Quartzite.

Overlying the lower Uinta Mountain Group lies the middle Uinta Mountain Group (~880 meters thick, map thickness). This unit strongly resembles the Jesse Ewing Canyon Formation and is thought to represent similar depositional processes and environments. Further work on this unit would most likely result in a member scheme similar to the member criteria defined in the Jesse Ewing Canyon Formation. The basal contact between the lower and middle Uinta Mountain Group is characterized as the lithologic change from dominantly sandstone to dominately shale. This is defined as the change from an overall sandstone unit (sandstone intervals on average ≥ 20 meters) to a unit that is predominately shale with thinner (~5 meter thick) sandstone intervals. This contact is easily seen on aerial photographs and in many places can be identified by topography alone where significant changes in slope can be discerned as a result of a greater percentage of shale. The contact is best observed near O-Wi-

Yu-Kuts Mountain north of Cold Spring Mountain near the Utah-Colorado border (plate 1). Here Beaver Creek cuts to the east along a dip slope between lower and middle Uinta Mountain Group. At this locality, the middle Uinta Mountain Group (~880 meters) is composed mainly of shale with interbedded sandstone, but farther north and west just south of Galloway Creek on the west side of the O-Wi-Yu-Kuts Fault, it becomes much more conglomeratic. This interval was initially observed by Hansen (1965), where he used the sandstone intervals as marker beds for calculating the stratigraphic throw across the O-Wi-Yu-Kuts Fault and calculating a minimum thickness of the Uinta Mountain Group.

The final unit designated as a result of this mapping is the upper Uinta Mountain Group (~3120 meters minimum thickness, map thickness). This contact is very similar to the contact between the Jesse Ewing Canyon Formation and the lower Uinta Mountain Group. The contact is defined as the lithologic change from predominately shale to dominately sandstone. The lower Uinta Mountain Group contact has been defined where the last significant shale interval (shale > 20 meters) is replaced by sandstone intervals with a thickness greater than 50 meters. Like the lower Uinta Mountain Group, the upper Uinta Mountain Group does contain interbedded shale, but the unit is dominated and characterized by the greater amount of sandstone. Though an in depth characterization of the upper Uinta Mountain Group has yet to be performed, preliminary observations show the upper Uinta Mountain Group to display medium grained quartz-rich sandstone organized in medium to thick trough cross-stratified beds. Thinner (<15 meter) shale intervals are interbedded within this dominantly sandstone unit.

4.4 - Structural Overview

The structural style of the entire map area can be generally summarized by fault orientation. The map area is dominated by west and northwest trending thrust and reverse faults and north to northeast trending normal faults.

East-west trending faults dominate the map area and account for the majority of the displacement. The present day configuration of these faults are high angle reverse faults likely modified by Laramide deformation. These fault planes accommodated much of the reverse movement associated with the uplift of the Uinta Mountains. Starting in the Oligocene the faults accommodated normal movement associated with the gravitational collapse of the eastern part of the range. While these faults show some sense of normal movement, the dominate direction is reverse.

The majority of north-northeast trending normal faults show mainly dip-slip displacement with a minimal strike-slip component. The exception to this is the O-Wi-Yu-Kuts Fault which has a calculated stratigraphic throw of 7,000 feet and approximately 2.25 miles of strike-slip motion (Hansen, 1965). Other north-south striking faults generally dissect the structural trend of the area and minimally displace the east-west trending faults.

Hansen (1965) produced an excellent report of the structural evolution of this area, therefore much of the structural mapping reflected in this study originated from his work. Hansen (1965) divided the project area into four structurally distinct areas based on fault orientation and sense of movement. Additional structures were mapped in Hansen's (1965) second area during the course of this project.

The first area is located along the western border of the map area on the eastern edge of Goslin Mountain (plate 1). This area is bound by the steeply dipping Uinta-Sparks fault zone to the north and the north-dipping northwest trending Goslin Fault to the south and southwest, which Hansen (1965) suggests is actually a rotated thrust fault. In the heart of this area is the Garnet Canyon anticline, which Hansen (1965) interprets to be an overturned fold in the Red Creek Quartzite. To the northwest of the Garnet Canyon anticline lies a small section of basal Jesse Ewing Canyon Formation folded into a small syncline that is encased in a syncline with steeper dips in the Red Creek Quartzite. It is thus inferred that the Red Creek Quartzite was folded prior to the deposition of the Jesse Ewing Canyon Formation, which was then folded post-deposition (Hansen, 1965).

Hansen's second structural area is located between Jesse Ewing Canyon and Mountain Home Draw. Here there is good structural continuity with the first area and Hansen (1965) suggests that this is simply an extension of area one that displays homoclinal dips.

Additional faults were mapped in Hansen's second area during this study. The newly mapped Willow Creek Fault, just east of Jesse Ewing Canyon and south of Bender Draw, is likely associated with the previously mapped, but unnamed Jesse Ewing Canyon Fault (plate 1). This structure is a splay off the Bender Fault, and generally parallels the Bender Fault for ~1.7 km before dying out on the east side of Jesse Ewing Canyon. West of the intersection between the Bender and Willow Creek faults, the Bender Fault appears to transfer displacement to the Willow Creek Fault which accommodates the majority of movement beyond this point. The Willow Creek Fault is likely an extension of the Jesse Ewing Canyon Fault because it displays similar geometry and orientation.

The Red Creek Quartzite and the Jesse Ewing Canyon Formation are exposed in a block between the Uinta-Sparks Fault and Bender Fault just to the south of Galloway Creek. On the south side of the Bender Fault, a conglomeratic unit similar to the Jesse Ewing Canyon was mapped. Initial interpretation concluded that this conglomeratic unit was the Jesse Ewing Canyon Formation, but stratigraphic and structural relationships suggest otherwise. If this new conglomeratic unit is indeed Jesse Ewing Canyon Formation, this would require a significant (>2000 meters of stratigraphic throw) structure to the south to juxtapose Jesse Ewing Canyon Formation against stratigraphically-high undifferentiated Uinta Mountain Group. Without this significant structure, the Bender Fault must accommodate all of the slip in the area and this conglomeratic unit could not be part of the Jesse Ewing Canyon Formation, rather a conglomeratic interval stratigraphically high within the undifferentiated Uinta Mountain Group. Since the Bender Fault in the Bender Draw area seems to have little stratigraphic displacement and only displays the Jesse Ewing Canyon Formation, a new structure was needed to account for stratigraphically low Jesse Ewing Canyon Formation to be adjacent to stratigraphically high undifferentiated Uinta Mountain Group. Large displacement along the Willow Creek Fault satisfies such criteria and preserves all stratigraphic relationships.

The Mountain Home, Jesse Ewing Canyon, and Willow Creek faults have a long and complicated history that is suspected to date back to at least Neoproterozoic time. Changes in thickness that are observed across these structures suggest a Neoproterozoic history of this fault system separating two Precambrian fault blocks that record two different sedimentologic and stratigraphic histories during Jesse Ewing Canyon Formation time (compare measured sections G and H, plate 2). While their present orientation reflects high angle reverse movement, most likely modified from Laramide compressional forces, these faults show a normal sense of movement during Neoproterozoic time (see following chapters).

Loosely associated with the Jesse Ewing Canyon and Willow Creek faults is a north-northwest trending normal fault that cuts these two larger faults. This structure roughly parallels the southern edge of the Head of Cottonwood and is displaced by smaller northeast trending faults (plate 1). The normal fault is important in explaining the thinning beds of the Willow Creek member on the top of Head of Cottonwood and the overturned beds at the northwest end of Head of Cottonwood. This fault truncates the top of the Head of Cottonwood member in measured section C.

Evidence for Precambrian folding is documented in the Head of Cottonwood member, just west of Band Box Butte on the west side of Jesse Ewing Canyon. Closely associated with the depositional contact with the Red Creek Quartzite, the Head of Cottonwood member is folded into a syncline, similar to that seen on Goslin Mountain. This timing of this folding can be constrained to only Head of Cottonwood time and the overlying Willow Creek member has not been effected.

The third area is located within Bender Draw and east of Bender Mountain. This is one of the most structurally complex areas and is entirely enclosed by faults. Here the high-angle north-dipping Bender Fault serves as a back thrust against the Uinta-Sparks Fault. North of the Bender Fault, is a similar synclinal structure to that as seen on Goslin Mountain. Here, the Jesse Ewing Canyon Formation has a slightly different character and is hard to differentiate from Red Creek Quartzite at first glance.

The fourth and final area described by Hansen (1965) is located on the southern slope of O-Wi-Yu-Kuts Mountain. In contrast to area three to the west, area four is the least structurally complex region in the map area. Here dips are nearly homoclinal dipping roughly 35° to the north. The only major faults in the area are the Beaver Fault, along the southwestern margin, and the O-Wi-Yu-Kuts

Fault to the east. Both faults are normal. This area does have numerous small normal faults and associated folds, none of which displace strata substantially (plate 1).

This area is also the site for a possible major north-dipping thrust fault that might repeat the the basal Uinta Mountain Group stratigraphy (plate 1). The similar character and thickness of the middle Uinta Mountain Group and the Jesse Ewing Canyon Formation may suggest that these two units are the same unit, instead of distinct stratigraphic units separated in both space and time. While data is lacking to prove or disprove its existence at this point, the possibility of such a structure must be considered. The implications of this structure are discussed in detail in section 7.6.

4.5 - Geologic Cross Sections

Two north-south geologic cross sections were made within the field area with an emphasis on stratigraphic relationships while also demonstrating structural complexity. Section line A-A' runs along the east side of Jesse Ewing Canyon, beginning north of the Uinta-Sparks Fault zone and ending just south of the Mountain Home Fault in Browns Park. Section B-B' begins north of the Bender Fault, continuing southwest to the Red Creek Quartzite exposure on O-Wi-Yu-Kuts Mountain.

Cross section A-A' is important for understanding the structural complexity of the Jesse Ewing Canyon while giving additional insight into the stratigraphic relationships of the lowermost Uinta Mountain Group. To the north, the Head of

Cottonwood member of the Jesse Ewing Canyon Formation is in fault contact (shown as the Uinta-Sparks Fault Zone in this area) with undifferentiated Phanerozoic units. A sliver of the Willow Creek member of the Jesse Ewing Canyon Formation lies stratigraphically above the Head of Cottonwood member and is faulted against lower Uinta Mountain Group along the northern slope of Head of Cottonwood. Across this fault, beds of the Jesse Ewing Canyon Formation and the lower Uinta Mountain Group are folded into an overturned syncline. This syncline is downdropped between and dissected by three unnamed faults on the northern and southern slopes of Head of Cottonwood. This syncline could be the pair to an anticline mapped just south of the Uinta-Sparks Fault zone. This anticline-syncline pair is likely the product of drag associated with east-west striking faults in the area. These faults offset and truncate these folds.

Further south on the Head of Cottonwood, the basal Head of Cottonwood member is in depositional contact with the Red Creek Quartzite. Near the southern end of Jesse Ewing Canyon, the Jesse Ewing Canyon Fault displaces Red Creek Quartzite adjacent to a sliver of the Head of Cottonwood member. The area proximal to the Jesse Ewing Canyon Fault is heavily faulted by numerous small scale faults with unknown but suspected minimal (~25-50 meters) displacement. The exact geometry, orientation, and displacement of these faults is unknown. In this area, the Head of Cottonwood member grades southward into the Willow Creek member, which is folded into an asymmetric anticline with steeper dips shown on the southern limb. This fold was identified by Hansen (1965) to be associated with movement along the Jesse Ewing Canyon Fault. The Willow Creek member is truncated by the Mountain Home Fault to the south adjacent to the Tertiary Browns Park Formation.

The second cross section, B-B', located atop O-Wi-Yu-Kuts Mountain, roughly parallels the O-Wu-Yu-Kuts Fault and displays the most complete stratigraphy in the area. In the south, a depositional contact of the Jesse Ewing Canyon Formation with the Red Creek Quartzite is observed. Here the Head of Cottonwood member is absent and the Willow Creek member directly overlies the Red Creek Quartzite. Directly above a thick (~1,000 meters) section of Willow Creek member lies the lower Uinta Mountain Group. Two faults with minimal displacement interrupt otherwise continuous stratigraphy. Above the lower Uinta Mountain Group lies the middle Uinta Mountain Group that also displays a small fault that only slightly disturbs bedding orientation. The middle Uinta Mountain Group grades upwards into the upper Uinta Mountain Group representing the stratigraphically highest interval in the mapping area. This unit is truncated by the Bender Fault that brings up the Head of Cottonwood member against upper Uinta Mountain Group.

Both cross sections show high angle normal and reverse faults that displace the stratigraphy with little strike-slip motion. With the exception of the Uinta-Sparks Fault zone and the Jesse Ewing Canyon Fault, all faults that cross these sections display dips greater than 85°. Though the top of O-Wi-Yu-Kuts

Mountain is dissected by several minor faults, this is the only area where the most complete stratigraphy is exposed.

CHAPTER 5

FACIES ANALYSIS

5.1 - Introduction

Four facies have been identified within the Jesse Ewing Canyon Formation, the focal point of this project, and an additional facies has been identified within the lower Uinta Mountain Group. Facies have been identified by their grain size, composition, sedimentary structures, bedding geometry, bedding thickness, color, and sorting (Table 1). The facies described herein are primarily those found within the newly informally named Head of Cottonwood and Willow Creek members of the Jesse Ewing Canyon Formation as well as a generalized facies representative of the lower Uinta Mountain Group. The middle and upper Uinta Mountain Group have been omitted from this analysis as they are out of the scope of this project. A summary of these facies along with interpretation is displayed in table 1. To assist facies identification, normalized point count data were placed in a QFL ternary diagram to determine composition (Fig. 12). In addition to collecting lithologic and sedimentologic data, paleocurrent measurements were collected to help identify facies and processes. The results of the paleocurrent analysis are displayed in Figure 13.

5.2 - Conglomerate Facies

5.2.1 - Description of the Conglomerate Facies

The conglomerate facies is primarily characterized by a coarse clast- and

Table 1. Facies table showing the five defined facies of this study. Facies 1-4 are entirely contained within the Jesse Ewing Canyon Formation. Facies 5 represents the overlying Uinta Mountain Group

Facies	Informal Identificaion	Description	Facies Definition	Interpretation
1	Conglomerate	Massive, thickly bedded (~1-3m) clast-supported conglomerate to breccia, subangular to moderately well rounded Red Creek Quartzite clasts; interbedded silty maroon shale	Predominately conglomerate with subordinate shale and sandstone interbeds, conglomerate beds no less than 1 meter thick with lesser amounts of interbedded sandstone and shale	Alluvial fan, proximal fan delta
2	Maroon Shale	Micaceous, silty organic-rich shale, mudcracks; interbedded arkosic- and quartz-rich tabular bedded sandstone and quartzite conglomerate, scoured tops and bases	Predominately maroon shale with interbedded sandstone and conglomerate, sandstone and conglomerate beds not to exceed 1 meter in thickness and overall interval is dominated by shale	Shallow subaqueous to exposed mudflat interbedded with sheetflood and turbidite; distal fan delta
3	Sandstone	Medium grained purple and pink quartz and lesser arkosic and lithic arenite, moderately to well rounded, moderately to well sorted, trough-cross stratified with planar and tangential foresets, planar tabular cross stratification, fining-upward foresets, mud-draped ripples, soft-sediment deformation, symmetric and asymmetirc ripples and ladder/interference ripples, pebble lags, plane beds; interbedded with maroon silty micaceous shale and mudstone	Predominately sandstones with lesser interbedded shale, sandstone beds no less than 1.5 meters thick and overall interval is dominated by sandstone	Primarily braided fluvial and nearshore with subordinate sheetflood
4	Green Sandstone and Shale	Green micaceous well rounded, fine grained sandstone and shale, planar tabular cross-stratification, tangential cross-stratification, hummocky cross stratification, wavy bedding, mudcracks, interferrence ripples, symmetric ripples	Green fine-grained sandstone, siltstone, and shale, small (<0.5 m thick) conglomerate with green sandstone matrix; no maroon shale, purple or pink sandstone, or large (bedding greater than 0.5 m thick and clasts larger than 5 cm) conglomerate beds	Shoreface/Offshore bars, below FWB, shallow water-sometimes exposed, storm affected
5	lower Uinta Mountain Group	Massive to trough cross stratified quartz arenite, pebble lags, fining upward sequences, intervals of interbedded red shale, few interbedded clast supported conglomerate with average clast size ~5 cm	Predominately sandstones with lesser interbedded shales, sandstone intervals exceed 20 meters in thickness with shale intervals not exceeding 10 meters in thickness	Braided fluvial

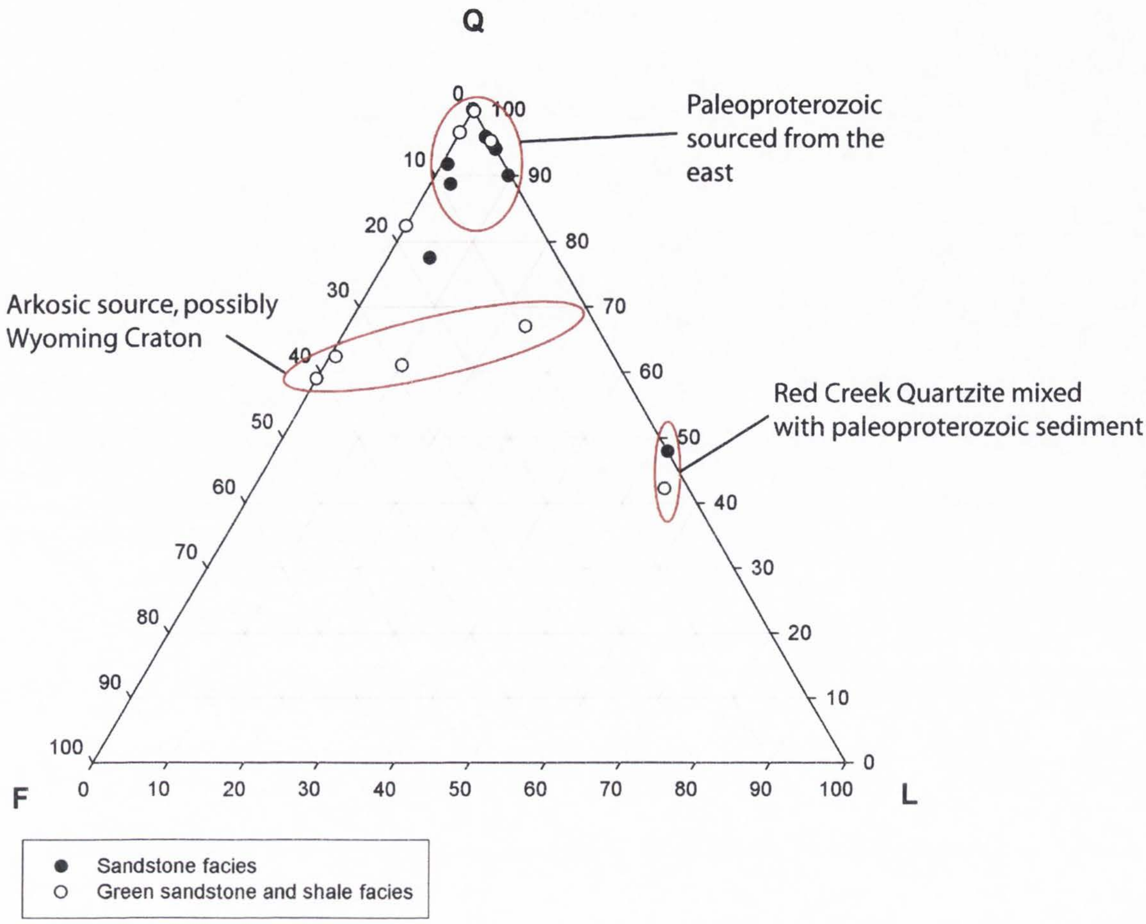


Figure 12. Ternary diagram showing point count data normalized for quartz, feldspar, and quartz (see table 4). All samples were taken from the sandstone or green sandstone and shale facies to determine compositional nature of facies for provenance work. Note the green sandstone and shale facies shows a greater spread, suggesting sediment mixing from a quartz-rich and feldspathic source and both facies also show mixing with proposed Red Creek Quartzite (L) source. Q=Qm, L=Qp and other lithics, F=feldspar.

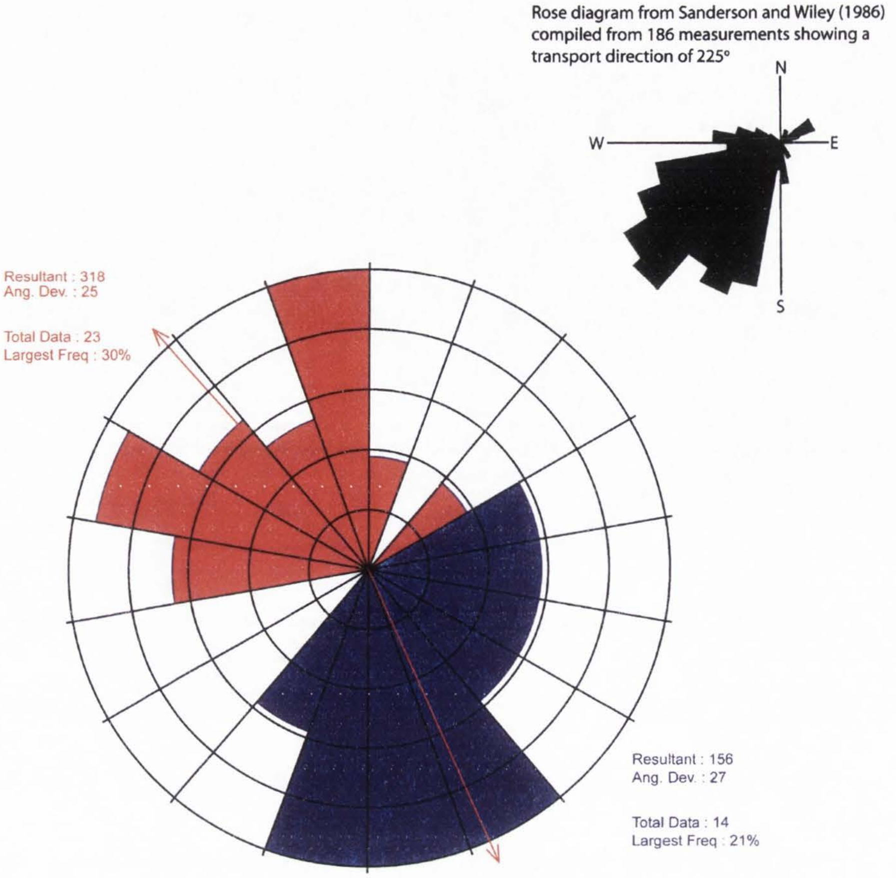


Figure 13. Rose diagrams comparing the inferred paleocurrent directions of the Jesse Ewing Canyon Formation based on the results of this study and those of Sanderson and Wiley (1986). Due to lack of sufficient paleocurrent indicators in the conglomerate facies, the majority of indicators measured for this study were taken from the sandstone facies and the thinner sandstone beds within the maroon shale facies. Red represents data for northwest directed measurements, blue represents data from east-southeast directed measurements. Upper right hand corner inset show paleocurrent data from clast imbrication in the Jesse Ewing Canyon Formation by Sanderson and Wiley (1986). Note how the sandstone paleocurrent data is bipolar, and the different trend compared to the imbrication paleocurrent data. Rose diagram generated in Geoplot v. 1.2.

matrix-supported conglomerate that comprises the majority of the Head of Cottonwood member. As defined by this study, conglomerate beds must be at least 1 meter in thickness to classify as the conglomerate facies. The outcrops of this facies are limited to five separate areas and appear as follows from west to east: Goslin Mountain, mouth of Red Creek, Jesse Ewing Canyon (including the type section at Head of Cottonwood), Bender Draw, and south of Galloway Creek (plate 1). Clasts within the Head of Cottonwood member are generally subangular to moderately well rounded. Maximum clast diameters within this facies were measured at 53 cm. All large clasts (> 5 cm) are derived from the underlying Red Creek Quartzite, and are predominately from the metaquartzite facies of Hansen (1965). This facies reflects a strong relationship between clasts preserved in the Jesse Ewing Canyon Formation and nearby outcrop of the Red Creek Quartzite. As noted above, the predominate clast population is the metaquartzite facies of the Red Creek Quartzite. The few outcrops in the mapping area that display a suite of Red Creek clasts other than metaquartzite match present day outcrops of Red Creek Quartzite that display the same metamorphic facies suite suggesting short transport distances. Some intervals within this facies also illustrate a fair amount (~30% of observed beds) of sorting for such a coarse unit. Field observation also suggests a relationship between average clast size preserved and the fracture patterns within nearby Red Creek Quartzite. It is hypothesized that the fracture patterns in the Red Creek Quartzite controls the clast size in the Jesse Ewing Canyon Formation.

The conglomerate facies as a whole is generally massive in nature. There have been some documented primary sedimentary structures but their occurrences are rare. Among these structures are weak clast imbrication and both normal and reverse graded bedding (Fig. 14). Beds are generally 1-3 meters in thickness though some 5 meter beds have been observed (Fig. 15). The unit is overall clast-supported, but matrix supported beds can be found on a bed-to-bed basis (Fig. 16). Within the thicker conglomeratic intervals, beds can be hard to discern due to their massive nature, but these deposits seem to show both lenticular and tabular bedding (Figs. 17, 18).

Interbedded within the conglomerate facies are lesser amounts of shale and sandstone. The shale and sandstone are commonly interbedded with each other and compose non-conglomeratic intervals between conglomerate outcrops. At the type section, the shale and sandstone interbeds form covered intervals with noticeable slope change (Fig. 19). These covered intervals appear to be lenticular and form between outcrops of conglomerate. Though exposure at the type section is less than ideal, it is the only location within the map area where laterally continuous outcrops of conglomerate are found. Shale comprises most of the covered intervals and is generally silty and slightly micaceous.

5.2.2 - Interpretation of the Conglomerate Facies

It is in agreement with Sanderson and Wiley (1986) that the conglomerate facies represents alluvial fan deposition, and additionally is interpreted as a

Figure 14. Field photograph of the conglomerate facies showing reverse grading. Pencil for scale.

Figure 15. Field photograph of the conglomerate facies along the eastern side of Jesse Ewing Canyon. Unit in the upper left hand corner is the Red Creek Quartzite adjacent to the Head of Cottonwood member separated by the Jesse Ewing Canyon Fault. Note the tabular nature of the beds near the top of the outcrop. Near the bottom of the outcrop beds are harder to discern but show lenticular bedding. “Tang” the suburban for scale.

Figure 16. Field photograph showing clast-support in the conglomerate facies. Note the predominate clast is the white metaquartzite facies of the Red Creek Quartzite. Pencil for scale.

Figure 17. Field photograph showing the conglomerate facies of the Head of Cottonwood member. Notice the generally massive and tabular nature of the beds. Boston Red Sox hat for scale.

Figure 18. Field photograph of the conglomerate facies showing bot lenticular and tabular bedding. Note how this particular outcrop is housed in shale and underlying the conglomerate there are thin tabular sandstone beds also housed in shale. Boston Red Sox hat for scale.

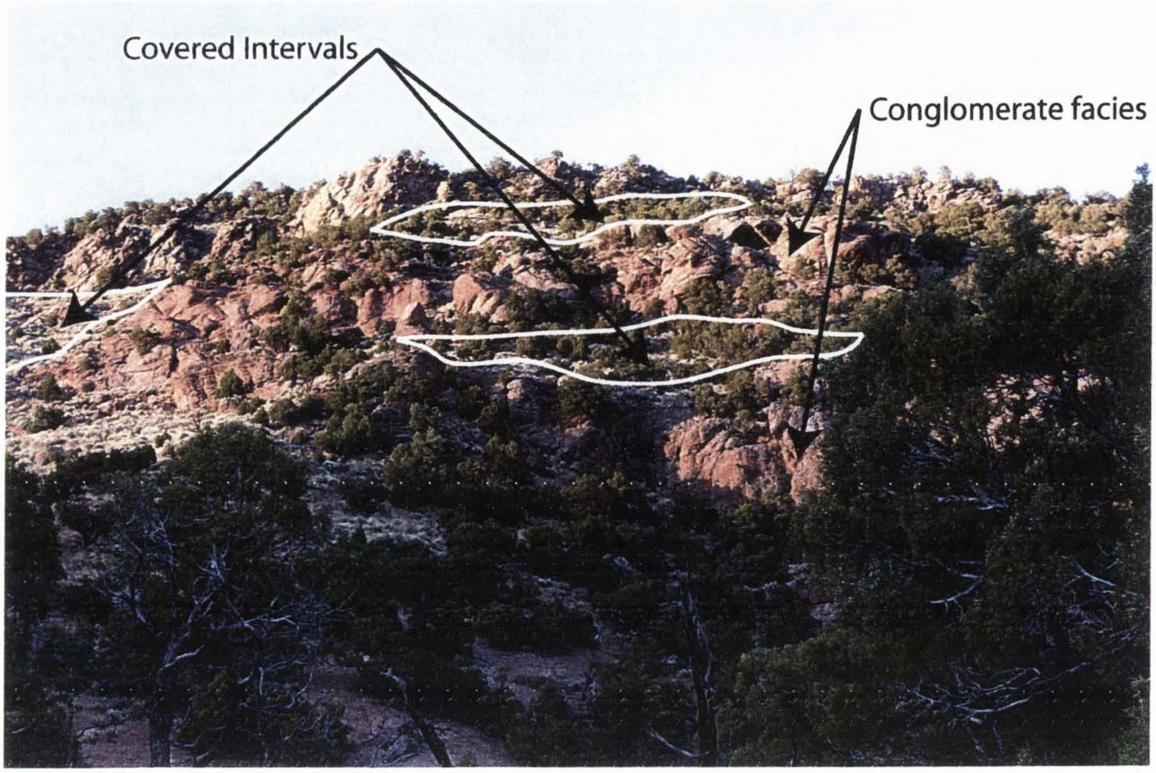


Figure 19. Field photograph near measured section C showing the outcrop character of the conglomerate facies on the southern slope of Head of Cottonwood. Note how sandstone and shale form discontinuous lenticular intervals between laterally continuous conglomerate outcrop (expressed as covered intervals). Base of section obscured by trees. Juniper trees for scale.

proximal fan delta. The conglomerate facies records the later stages (stage 2 and 3) of alluvial fan development as characterized by Blair and McPherson (1994) by the absence of discernible talus, rockfall, rockslide, or rock avalanche deposits (Fig. 20). This interpretation is strengthened by the comparison of conglomerate facies features with modern alluvial fan features (e.g., Blair and McPherson, 1994).

The first line of evidence used for recognizing the conglomerate facies as an alluvial fan deposit is the grain-size variability and provenance of these deposits. Bull (1964, 1972) illustrates that alluvial fans obtain their sediment from a close, identifiable source. Nearly all of the clasts within the conglomerate facies are directly derived from the underlying/adjacent Red Creek Quartzite. Further, alluvial fans have been documented to consist primarily of coarse-grained conglomerate and breccia with finer interbedded detritus that increases downfan (Blissenbach, 1954; Bull, 1972, 1977). At the type section of the Head of Cottonwood member, where the best exposures of the conglomerate facies are found, finer deposits are interbedded with the conglomerate. Additionally, south of the Jesse Ewing Canyon Fault coarse beds of conglomerate fine southward, the inferred direction of sediment transport based on facies architecture and minimal (8) clast imbrication measurements (i.e. conglomerate facies) (Fig. 21). The cyclic nature of facies in the Jesse Ewing Canyon Formation is consistent with the development of alluvial fans and related environments in an arid to semi-arid region experiencing flash floods, a common

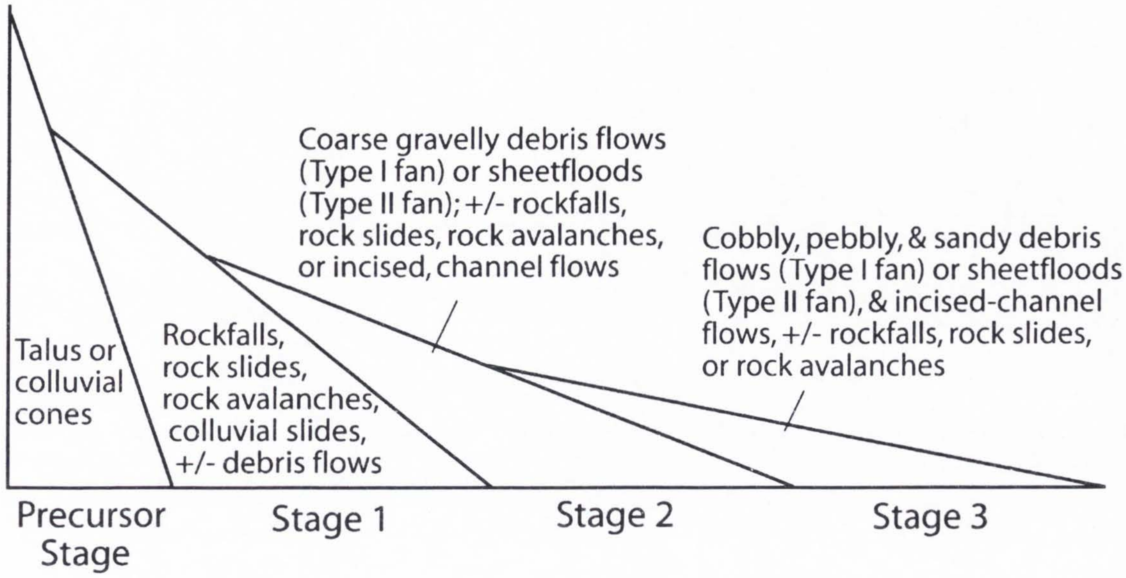


Figure 20. Stage of alluvial fan development as reported by Blair and McPherson (1994) (from Blair and McPherson, 1994). The conglomerate facies within the Jesse Ewing Canyon Formation represents Stage 2 and Stage 3 development.

environment for alluvial fans (Horton, 1945; Strahler, 1957, 1964).

Previous research on alluvial fans found that they commonly interfinger with adjacent compatible environments (Blissnebach, 1954; Bull, 1972, 1977). The conglomerate south of the Jesse Ewing Canyon Fault is found to interfinger with the maroon shale facies. The majority of shale associated with conglomerate is maroon in color and is suggestive of oxidizing conditions at time of deposition. These red beds can be characteristic of arid to semiarid alluvial fans (Walker, 1967; Bull, 1972).

Sedimentary structures and bed geometry in the conglomerate facies suggest alluvial fan deposition. Clast-supported to matrix-supported massive conglomerate beds with scoured bases are suggestive of stacked debris flow

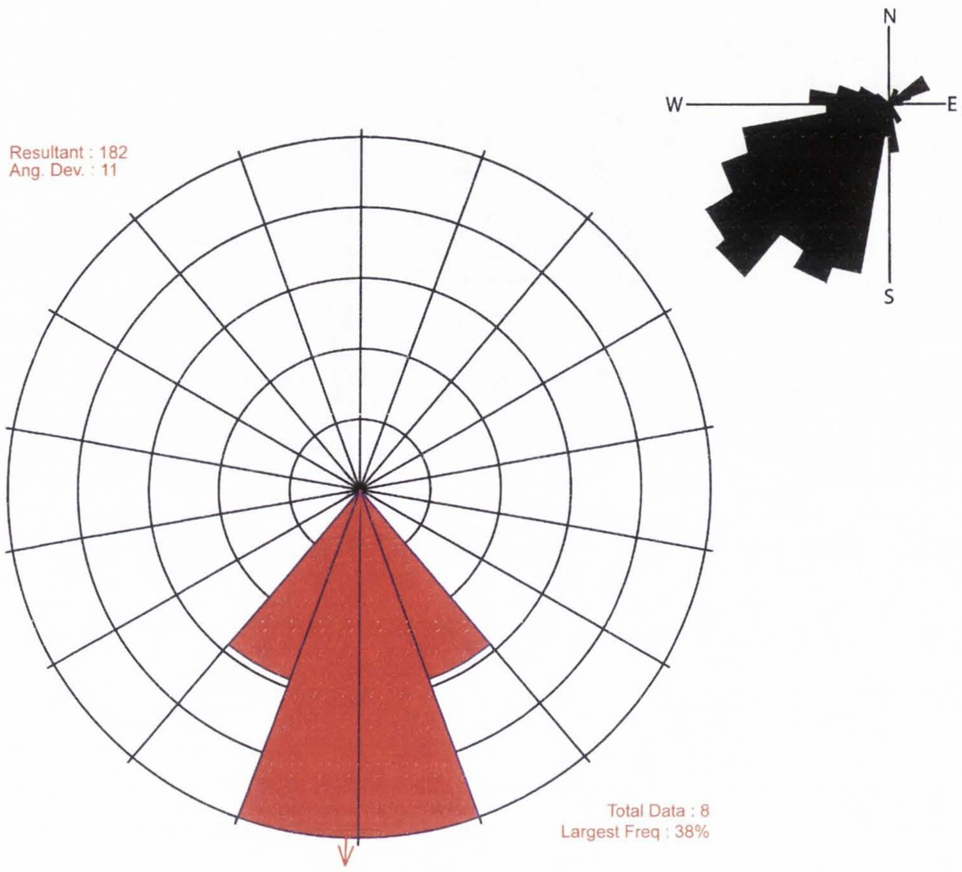


Figure 21. Rose diagram showing direction of clast imbrication within the conglomerate facies of the Head of Cottonwood member. This transport direction is consistent with work by Sanderson and Wiley (1986) (shown in upper right) and DeGrey (2005).

lobes (Blair and McPherson, 1994). Laterally continuous, tabular, graded beds of conglomerate and (or) sandstone, interbedded with the maroon mudstone, with sharp tops and bases are suggestive of sheet floods and also possibly turbidity flow in shallow water (Hogg, 1982; Blair, 1985, 1987; Wells and Harvey, 1987).

The massive nature of the Jesse Ewing Canyon conglomerate facies, as well as the lack of imbrication and channelization, suggests a rapidly aggrading alluvial fan system dominated by primary processes with little reworking. Blair and McPherson (1994) document a suite of features on alluvial fans suggesting secondary reworking of the alluvial fan surface. Very few of these secondary features were recognized in the Jesse Ewing Canyon Formation, and massive bedding suggests that these deposits were buried before background overland flow could rework them into secondary features (Blair and McPherson, 1994). This is consistent with the syn-tectonic nature of alluvial fan deposition that predicts the rapid accumulation of sediment along a tectonically active basin margin fault (Blissenbach, 1954; Bull, 1964, 1977). Precambrian movement along the Jesse Ewing Canyon Fault allowed accommodation space for conglomerate aggradation as well as the rest of the formation (cf. section C and section H).

Lateral thickness changes of the conglomerate facies are typical of alluvial fan and fan delta deposition (Blissenbach, 1954; Bull, 1972, 1977). Changes in lateral variability and thickness are suggestive of alluvial fan(s) with a steep alluvial slope of 5° or greater (Blair and McPherson, 1994). The lateral facies changes seen in the Jesse Ewing Canyon Formation, despite faulting (cf. Section G with Section C), suggest deposition distal and proximal to the point source, respectively (plate 2). Large-scale thickness variability and facies changes seen in the north-south stratigraphic correlation, again, despite faulting, (compare sections G and H, Plate 2) suggests syntectonic deposition.

5.3 - Maroon Shale Facies

5.3.1 - Description of the Maroon Shale Facies

The maroon shale facies is the single most important facies for defining/mapping the Jesse Ewing Canyon Formation. It is the principal component of the Willow Creek member and defines the contact between the Jesse Ewing Canyon Formation and the lower Uinta Mountain Group. The facies has been defined as a predominately shale interval with interbedded sandstone and conglomerate, where sandstone and conglomerate beds do not exceed 1.5 meters in thickness and the overall interval is dominantly shale (Fig. 22). The shale is micaceous, silty, locally organic-rich with intervals that show mudcracks.

Interbedded within the maroon shale facies are thinner beds of sandstone and conglomerate (2-150 cm) (Fig. 23). Sandstone alternate in composition between arkosic- and quartz-rich, and are generally tabular bedded and laterally continuous for at least 25 meters. Both upper and basal contacts with the shale are sharp, and few beds show evidence for scouring. Sandstone beds generally exhibit plane beds and planar tabular cross-stratification with occasional

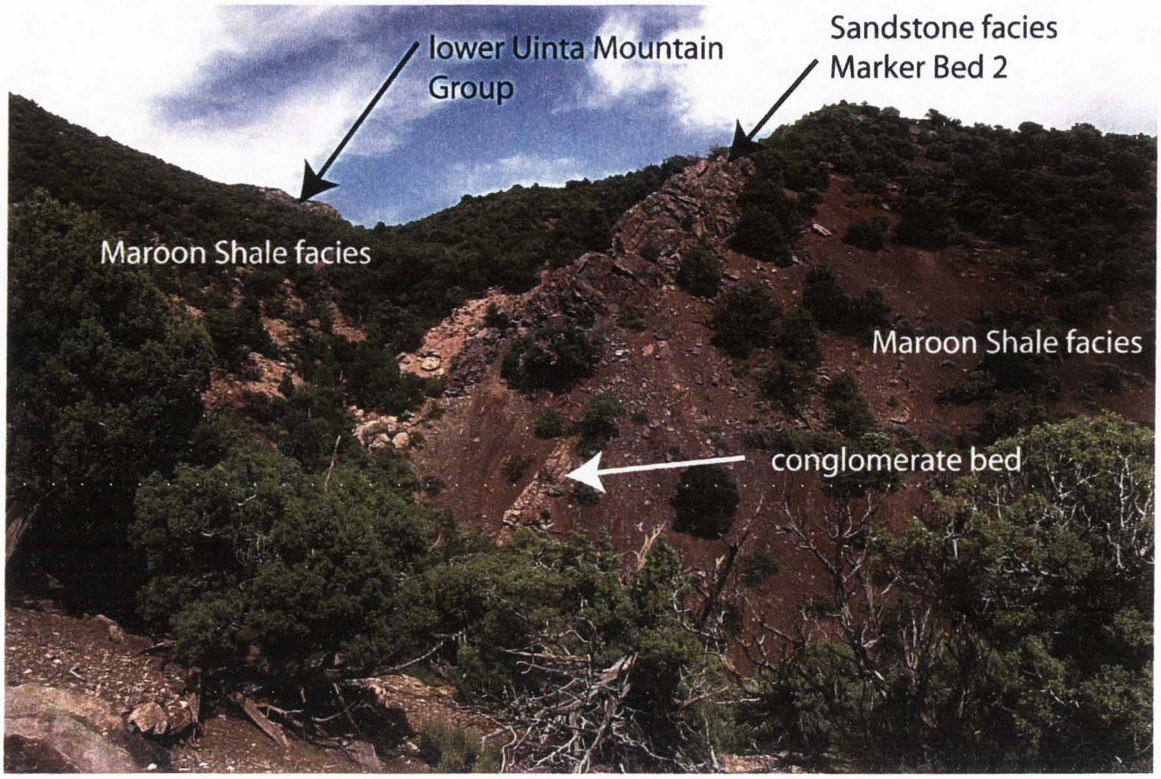


Figure 22. Field photograph showing the relationships of the maroon shale facies with other facies in the Jesse Ewing Canyon Formation.

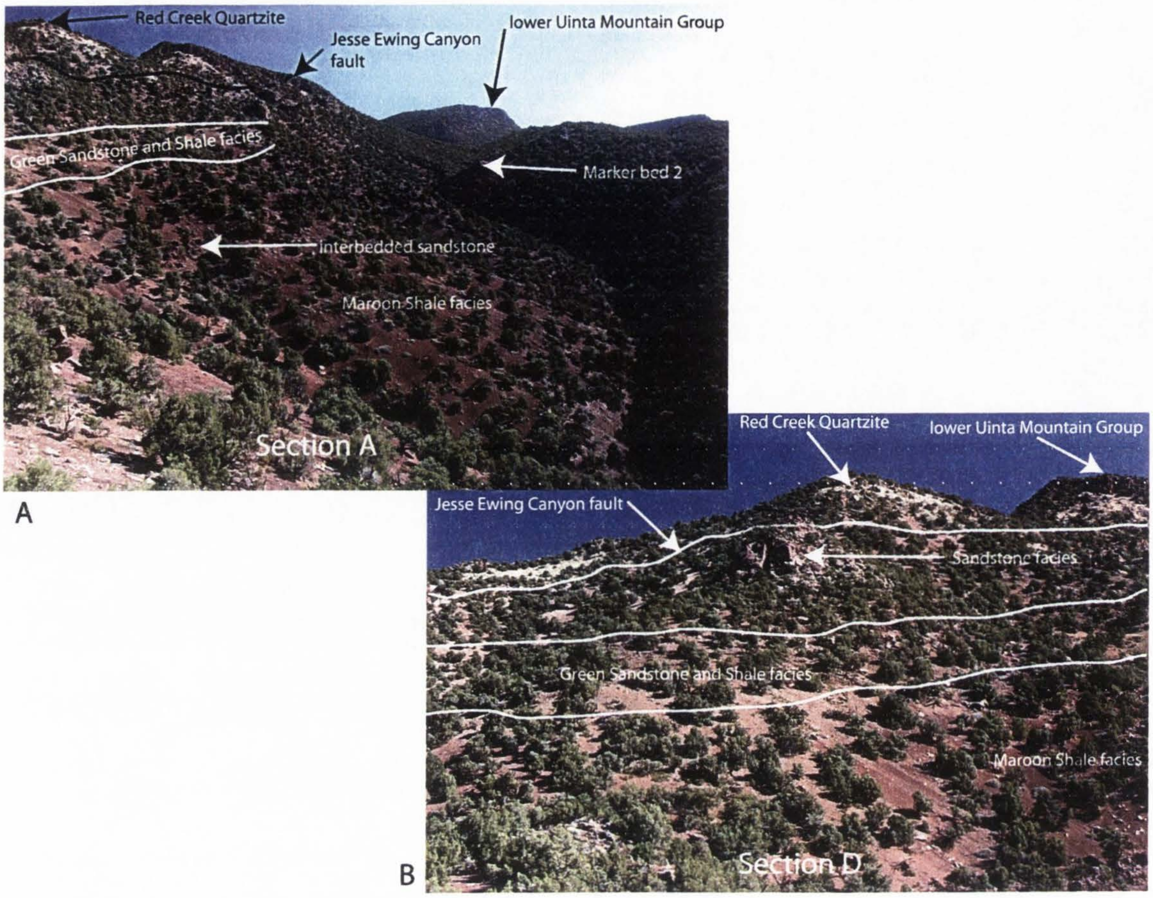


Figure 23. A. Field photograph looking east and showing overview of measured section A illustrating facies relationships. B. Field photograph looking north showing overview of section D and illustrating facies relationships.

asymmetric ripples and graded bedding (<30 cm). Thinner (<40 cm) sandstone beds are commonly obscured by extensive slope wash.

Occasional conglomerate beds, thinner than 1 meter, are also observed within the maroon shale facies (Fig. 24). These conglomerate beds contain much smaller clasts than those in the conglomerate facies, generally on the order of 5 cm in diameter. Conglomerate beds are typically massive, though some show weak imbrication and fining upward. Like the sandstone beds, conglomerate beds are generally tabular (though some are lenticular) and laterally continuous (≥25 meters) at outcrop scale (see Section E in appendix A).

5.3.2 - Interpretation of the Maroon Shale Facies

The fine-grained nature and lateral continuity of the maroon shale facies suggests that it records suspension settling in a playa, lake, or shallow marine environment. Deposition took place in a large, low energy silt and clay dominated environment and records background sedimentation. Periodically water levels retreated, leaving the basin floor subaerially exposed, cracking the silty muds that were deposited. The mud was likely sourced from the Red Creek Quartzite and/or other extrabasinal source(s). This mud represents distal alluvial fan to fan delta deposition.

The thin tabular-bedded laterally-continuous sandstone and conglomerate beds in the Jesse Ewing Canyon Formation reflect sheetflood, turbidite, or near-shore deposition (Fig. 25). Sheet-like deposits commonly represent sheetfloods

Figure 24. Maroon shale facies with interbedded thinner (<100 cm) conglomerate beds. Note the tabular geometry and sharp contacts of the conglomerate beds.

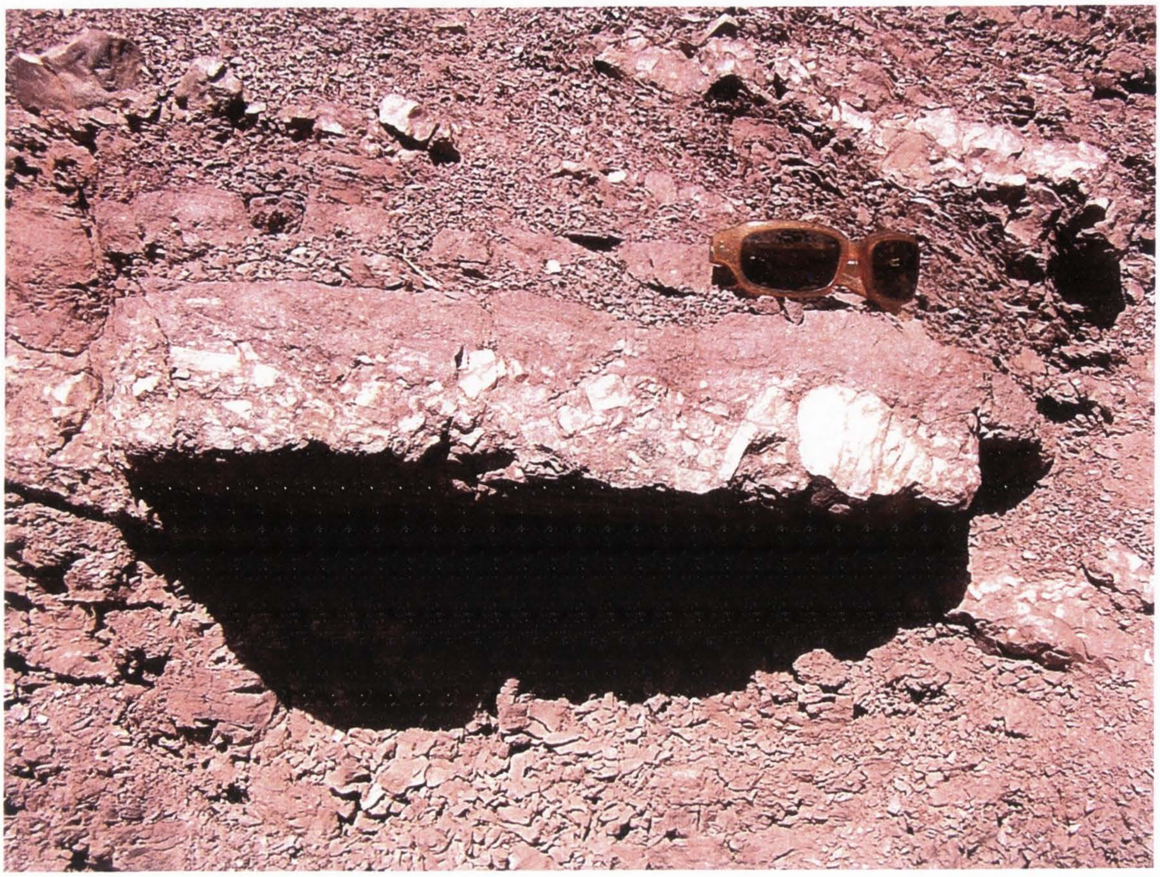


Figure 25. Field photograph of a turbidite/sheetflood in the maroon shale facies. Note the fining upward sequence and tabular bedding geometry. Also notice all clasts are white metaquartzite clasts derived from the Red Creek Quartzite.

on the distal parts of an alluvial fan or alluvial plain (Steel and Aasheim, 1978; Turnbridge, 1981, 1984; Hubert and Hyde, 1983; McKee et al, 1967; Stear, 1985). Further evidence is given by Reading (1996) who describes sheetflood deposits as sandstone bodies that are 20 cm to 2 meters in thickness, show graded bedding, and have sharp bases with little erosive relief. Asymmetric ripples within the sandstone beds record the decelerating flow in the later stages of episodic sheetflood deposition (Reading, 1996).

A second process interpreted for the thin sandstone beds within the maroon shale facies are turbidity currents. Reading (1996) illustrates the importance of density currents in the distribution of sediment into offshore areas where there is adequate clastic sediment supply. Turbidity currents are important in delivering coarser sediment to lake bottoms where rivers enter lakes (Reading, 1996). While some of these sandstone deposits have been interpreted as turbidities, these deposits do not reflect deposition on a continental slope, rather a delta slope.

Sedimentary structures observed within the thin sandstone beds within the maroon shale facies are also consistent with a turbidite interpretation. The thickness, grain size ranges, graded bedding, sharp bases, parallel laminations, crossbeds, and ripples in these deposits are all consistent with turbidites (Bouma, 1962; Reading, 1996). The sandstone in the sandstone facies exhibit all of these sedimentary structures, but not always within the same bed, though Reading (1996) demonstrates that a turbidite sequences is rarely preserved in its entirety. Turbidities have also been documented to occur as a result of tectonic activity (Bouroullec et al., 1991; Tiercelin et al., 1992). Seeing that the Jesse Ewing Canyon Formation is a syn-tectonic deposit, the likelihood of tectonically triggered turbidities is high, and may also explain some of the observed soft sediment deformation. East-southeast directed paleocurrents in the sandstones within the maroon shale facies likely reflect deposition by turbidites or sheetfloods, depending on base level (Fig. 26).

5.4 - Sandstone Facies

5.4.1 - Description of the Sandstone Facies

The sandstone facies is characterized by a higher percentage of sandstone relative to shale. Along with the maroon shale facies, the sandstone facies is an important component in the fine-grained Willow Creek member of the Jesse Ewing Canyon Formation. The sandstone facies is arbitrarily designated where sandstone beds or sets of sandstone beds exceeds 150 cm. The sandstone facies contains quartz- and arkosic-arenite interbedded with lesser shale (<150 cm) in an interval that is overall dominated by sandstone (appendix A, Section G, meter 120-150). Petrographic analysis shows that the sandstone facies is predominately quartz arenite with lesser arkosic and lithic arenite (Fig. 12). Shale within the sandstone facies is the same maroon micaceous silty shale that comprises the maroon shale facies, only in lesser quantities (<150 cm). Bedding is generally tabular, though some localities (namely those high in the section and to the north) show lenticular bedding. Bedding contacts are sharp

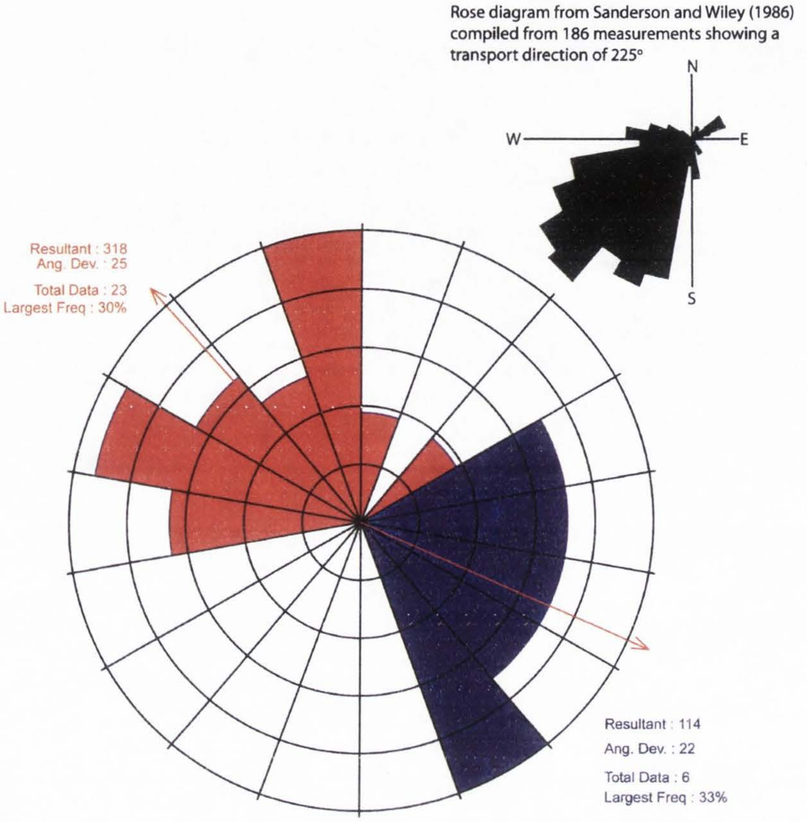


Figure 26. Rose diagram showing transport direction within the sandstone facies and thin (<1.5 meters) sandstones within the maroon shale facies of the Jesse Ewing Canyon Formation. Note the wide distribution of paleocurrent directions as a result of the range of depositional processes responsible for the deposition of the sandstone facies (i.e., fluvial W-NW and sheetflood/turbidite E-SE). Compare to Sanderson and Wiley's (1986) plot in upper right corner. Red=NW directed paleocurrents, Blue=SE directed paleocurrents. Imbrication data removed.

along both top and bottom with little erosive relief (appendix A, Section A, meter 102-106).

The sandstone facies displays a wide range of sedimentary structures, though not all of them are represented in every bed. Most commonly the sand grains are moderately to well rounded and moderately to well sorted. Beds typically show plane beds and planar-tabular cross-bedding, though trough cross-bedding and tangential foresets have been observed (appendix A) (Figs. 27, 28). Many sandstone beds also display fining-upward and well rounded pebble lags with clasts derived from the Red Creek Quartzite (Fig. 29). Less commonly, sandstone intervals are observed to have mud-draped ripples, soft sediment deformation, symmetric and asymmetric ripples, and ladder/interference ripples.

Because of this extensive suite of sedimentary structures, and the lack of sedimentary structures in other facies, the majority of paleocurrent data were collected from the sandstone facies, although some paleocurrent data is from the thinner sandstone beds within the maroon shale facies. The results of this preliminary paleocurrent are displayed in Figure 11 (also see appendix C). Interestingly, the paleocurrent distribution is bimodal: there is both a northwest and a south-southeast averaged flow direction, which in either case is nearly 90° off from the previously reported average flow direction to the southwest (Sanderson and Wiley, 1986).

There is agreement between the dominant paleoflow directions of

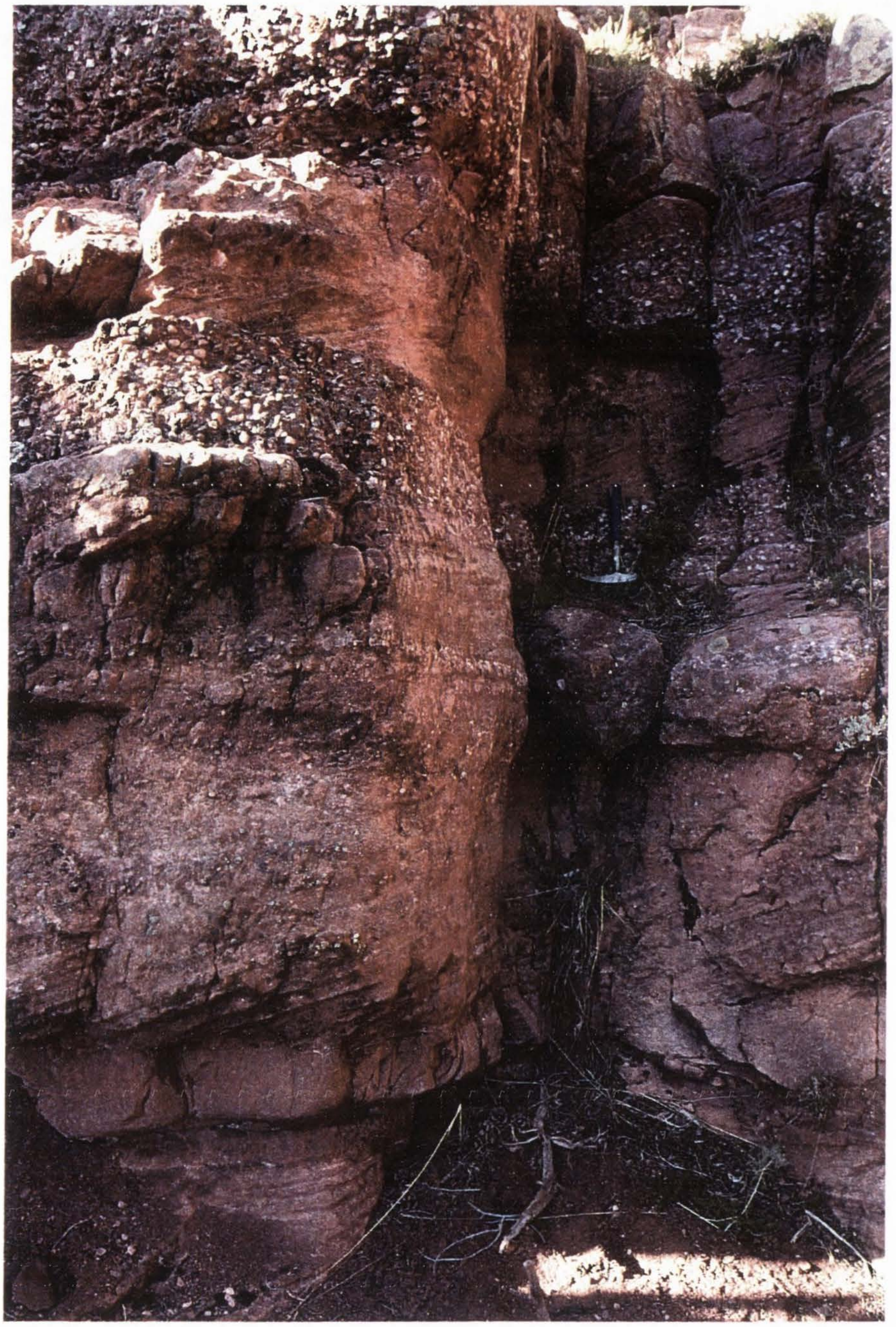


Figure 27. Field photograph of the sandstone facies. Note the planar tabular crossbeds and interbedded tabular conglomerate. Also notice the cyclicity of this interval. This has been interpreted as a nearshore deposit that likely reworked preexisting braided fluvial deposits. Hammer for scale.

Figure 28. Field photograph of trough crossbeds in the sandstone facies within the Willow Creek member of the Jesse Ewing Canyon Formation. Note how the troughs are defined by pebble lags of Red Creek Quartzite. Hammer for scale.

Figure 29. Field photograph of the sandstone facies with interbedded conglomerate. Note the tabular nature of the conglomerate bed interbedded within the sandstone.

Sanderson and Wiley (1986) and DeGrey (2005), which both show southwesterly directed paleocurrents. Paleocurrent data of DeGrey (2005) is from the Uinta Mountain Group strata above the Jesse Ewing Canyon Formation south of Browns Park. If Sanderson and Wiley (1986) included the lower Uinta Mountain Group (with the definition of this study) within their paleocurrent analysis, this could account for some of the similarities between Sanderson and Wiley's (1986) and DeGrey's (2005) data. Sanderson and Wiley (1986) also focused on the conglomerate facies, and the paleocurrent data in this study was taken from three additional facies.

5.4.2 - Interpretation of the Sandstone facies

The sandstone facies illustrates the greatest complexity of depositional environments and represents at least three separate depositional processes that all converged over a common area, resulting in vertically stacked sandstone beds that can be hard to differentiate. The sandstone facies likely records fluvial, nearshore, and sheetflood deposition that all occurred within an intersecting area. Many of the individual sedimentary structures used in the identification of these deposits are common in many depositional environments making it hard to discern one environment from another. Sedimentary structures, bedding geometry and thickness, sandstone composition, and paleocurrent data have all been applied towards the identification of these deposits.

The collective suite of sedimentary structures within the sandstone facies (Table 1) suggests that many of these deposits are not directly related to the alluvial fan deposits. The presence of soft sediment deformation, symmetric ripples, ladder structures, and mud-draped ripples suggest subaqueous deposition in a nearshore environment with multiple directions of paleoflow. While not unique to any single depositional system planar tabular cross-stratification, trough cross-stratification, and lag deposits are generally associated with braided fluvial and nearshore environments while fining upward sequences and crossbedding are observed in sheetflood and turbidite deposits.

Bedding geometry and thickness has allowed further separation of the sandstone facies. Tabular bedding geometry is pervasive in the sandstone facies and indicates that these deposits were not confined to single channels, rather spread throughout the area with great lateral continuity. This type of bedding geometry is commonly associated with braided fluvial, nearshore, sheetflood, and turbidite environments (Ramos et al., 1986; Reading, 1996). Additionally, similar bedding geometries have been observed in the Molina Member of the Wasatch in Colorado where braided streams have been interpreted to have been deposited in a muddy depositional setting (Lorenz and Nadon, 2002).

Bedding thickness and thickness of the bedding sets have also been useful in determining depositional environment. Thicker beds (>1.5 meters) stacked in sets that achieve considerable thicknesses (>20 meters) have been classified as the braidplain of a braided fluvial system that dissected mudflats of the maroon shale facies at the distal margin of the alluvial fans during lowstands.

Alternatively, these thicker sandstone deposits could reflect a nearshore environment that separates the coarse conglomerates of the alluvial fans from the finer-grained shale deposition in a subaqueous environment. Thinner beds (<2 meters) that are not stacked in larger sets and are encased in maroon shale represent periodic deposition by either sheetfloods or turbidites (base level dependent) at the distal reaches of the alluvial fans.

The thicker sandstone beds (>1.5 meters) within the sandstone facies have been identified as braided fluvial deposits (appendix A, Section H, meterage 62-134). The bed thickness, grain size, bedding geometry, flat bases, trough and planar cross-stratification, and planar laminations are all consistent with braided fluvial deposition (Ramos et al., 1986 ; Røe, 1987; Reading, 1996).

The thinner sandstone beds (<2 meters) within the sandstone facies have been interpreted as sheetflood or turbidite deposits dependent on base level (appendix A, Section G, meterage 114-132). During lowstands these thinner beds would represent sheetfloods associated with the alluvial fans. These thinner beds share the same characteristics as the sandstone beds within the maroon shale facies. These sandstone beds are consistent with observations that sheetflood deposits are generally 20 cm to 2 meters in thickness and have sharp bases with little erosive relief (Reading, 1996). Graded bedding is common in sheetflood deposits where thicker beds may show cross-bedding (Reading, 1996). Due to their unconfined nature, sheetfloods commonly cover large areas and display tabular bedding geometry (Blair and McPherson, 1994).

Sheetfloods are an important gravity flow deposit common in alluvial fan settings especially near the distal reaches of the fan (Steel and Aashiem, 1978; Turnbridge, 1981; Hogg, 1982; Hubert and Hyde, 1983; Turnbridge, 1984; Blair, 1985, 1987; Wells and Harvey, 1987). The southwesterly and southeasterly directed paleocurrents likely reflect sheetflood deposition associated with the alluvial fan (Fig. 26).

Another possible process represented by the thinner (<2 meters) sandstones is ephemeral streams. Ephemeral stream deposits are generally around 2 meters in thickness (Reading, 1996) and their features can mimic those of sheetflood and turbidite deposits with a few subtle differences. The main difference between these deposits is the lenticular nature of ephemeral stream deposits (Reading, 1996). This can be hard to distinguish in the field though, as they appear tabular (Turnbridge, 1981) but extensive exposure demonstrates their lenticular nature (Leeder, 1974; Mjøs et al., 1993). As with sheetflood deposits, ephemeral stream deposits show little erosive relief (Reading, 1996), and thus consistent to what is observed in the field.

Petrographic data from the sandstone facies suggests that the majority of the sand that makes up the sandstone facies is extrabasinal in origin. Figure 12 shows three potential sources of sediment for the sandstone facies. The local Red Creek Quartzite source does not supply arkosic or monocrystalline quartz sediment, therefore this sediment must be extrabasinal in origin. The quartz-rich sediment is believed to have been sourced from Paleoproterozoic terranes to the east, while arkosic sediment is thought to have been derived from the Wyoming Craton to the north.

Paleocurrent data has also assisted in the identification of the sandstone facies. Figure 13 demonstrates that the primary direction of paleoflow was to the northwest while a small percentage of flow is to the east-southeast. The majority of the paleocurrent indicators measured were taken within the sandstone facies with few measurements taken in the thinner sandstones within the maroon shale facies. The majority of these measurements were taken during mapping so these data do not directly link to measured sections though GPS locations mark their exact locations. The few measurements that are directly linked to a measured section are found in section H (appendix A). These measurements are only plotted on the section and not incorporated within the rose diagram as they only contain the trend of paleoflow. What can be said from these data though is that the paleoflow is bimodal. The northwest paleoflow direction likely represents braided fluvial or nearshore environments where longshore drift reworks the braided fluvial sands in to bars. The east-southeast directed paleoflow could be related to the distal parts of the alluvial fan/fan delta by process of sheetfloods/turbidites.

Additionally, some of these sands were likely reworked by shoreline processes. The presence of symmetric and interference ripples imply two dominant directions of current suggestive of wave action associated with shorelines (Prothero and Schwab, 1996; Boggs, 2001a). Mud-draped ripples, as found in the sandstone facies, are also suggestive of a nearshore environment, where suspended mud is deposited in times of slack water (Boggs, 2001b).

5.5 - Green Sandstone and Shale Facies

5.5.1 - Description of the Green Sandstone and Shale Facies

The best exposure of the green sandstone and shale facies is found in and around the areas of sections A and D (plate 1) (appendix A, Section A, meterage 224-306, Section D, meterage 70-166). The green sandstone and shale facies consistently displays the most unique sedimentary structures, grain size, and color of all of the observed facies. Initially the green sandstone and shale facies was identified by the obvious change in color. In a formation dominated by maroon shale, conglomerate, and sandstone, the green color of this facies make it an easily identifiable unit. Unfortunately, weathering characteristics are such that this unit, while relatively thick (5-97 meters), is often obscured by cover and is easily overlooked. Generally speaking, this unit is primarily found by float then walking laterally to good exposure. Another strong characteristic of this unit is the overall finer nature of the deposits. Unlike the maroon shale facies that is silty shale and interbedded medium grained sandstone, the green sandstone and shale facies is characterized by mudstone to slightly silty green shale and fine-grained sandstone to siltstone. Petrographic analysis shows that the green sandstone and shale facies varies considerably in composition (spanning quartz, arkosic, and lithic arenite), showing only a slight dominance of arkosic arenite (Fig. 12). This interval lacks interbedded coarser sandstone or maroon shale, and has one 1.5 meters thick matrix-supported conglomerate (average clast size ~3-4 cm), that is interbedded with black to green shale (Fig. 30) (appendix A, Section A, meterage 278).

The green sandstone and shale facies also displays the most unique sedimentary structures of any facies in the map area. This facies commonly shows planar tabular cross-stratification, tangential cross-stratification, hummocky cross-stratification, mudcracks, graded bedding, and both interference and symmetrical ripples and occasional trough cross-stratification (Figs. 31, 32, 33, 34, 35). The sandstone and siltstone grains in this facies are generally well rounded and well sorted, and are organized into laminated to thin lenticular, tabular, and wavy beds. Intervals within the green sandstone and shale facies also show a cyclic nature to deposition displayed as coarsening upward sequences from mudstone to fine-grained sandstone on a 1.5 meter scale (Fig. 36).

5.5.2 – Interpretation of the Green Sandstone and Shale Facies

The green sandstone and shale facies was likely deposited on a shallow storm-dominated clastic coast resembling a delta front, and represents the furthest recognized basinward deposits preserved in the Jesse Ewing Canyon

Figure 30. Field photograph of coarse-grained turbidite within the green sandstone and shale facies. Note the sharp basal contact with the underlying green to black mudstone and reverse grading in lowermost conglomerate bed.

Figure 31. Field photograph of planar tabular cross-stratification and wavy bedding in the green sandstone and shale facies. Pencil for scale.

Figure 32. Field photograph of tangential cross-stratification in the green sandstone and shale facies. Pencil for scale.

Figure 33. Field photograph of mudcracks in the green sandstone and shale facies. Pencil for scale.

Figure 34. Field photograph of interference ripples on the underside of a sandstone bed in the green sandstone and shale facies. Pencil for scale.

Figure 35. Field photograph of small scale trough cross-stratification in the green sandstone and shale facies. Pencil for scale.

Figure 36. Field photograph of the cyclicity of the green sandstone and shale facies. Note the appearance of the fine-grained sandstone every 1.5 meter scale. Also note the tabular nature and relative amount of sandstone to mudstone.

Formation. This facies represents deposition in a relatively low-energy environment, consistent with the previous interpretation of an alluvial fan systemfeeding into a large body of water (i.e. fan delta).

Primary sedimentary structures in the sandstone beds within the green sandstone and shale facies indicate that this facies was deposited on a storm-dominated coast. The predominant sedimentary structures found on storm-dominated coasts identified by Aigner (1985) are as follows: 1) wave ripples and wave ripple cross-lamination, 2) hummocky cross-stratification, 3) swaley cross-stratification, 4) tabular and trough cross-stratification, and 5) graded bedding. Of these, 1,2,4, and 5 have been observed within the green sandstone and shale facies.

The strongest evidence for storm deposits within the green sandstone and shale facies of the Jesse Ewing Canyon Formation is the presence of hummocky cross-stratification (Fig. 37)(see appendix A sections A, D, and G). These features form from high-energy currents with an oscillatory component (Harms et al., 1982; Boggs, 2001a) typically associated with storms. These features also give indication of water depth. Though it is not known exactly how deep the water must have been during deposition, we do know that this location was below fair weather wave base (Reading, 1996).

The green mudstone of this facies gives additional information with regards to depositional environment, specifically water depth. These mudstones require suspension settling in a low-energy environment, but at the same time,

Figure 37. Field photograph showing small scale hummocky cross-stratification in the green sandstone and shale facies. This is the primary structure used for a storm effected shoreline interpretation of the green sandstone and shale facies. Also note symmetric ripples bellow the hummocky cross-stratification. Pencil for scale.

the mudcracks indicate that this area was intermittently exposed subaerially (Boggs, 2001a). Given this criteria, the green sandstone and shale facies was deposited on a storm-dominated coast that had a very shallow gradient leading into the body of water and thus, a very shallow wave base. Small changes in base level would then expose or flood this coast allowing for intermittent exposure of the sediment.

5.5.3 - Detrital Zircon and Petrographic Analysis of Sample B2

Detrital zircon sample B2 was collected in measured section B (meter 1) with the goal of obtaining a maximum depositional age in addition to provenance information. Figure 38 shows the resultant detrital zircon populations obtained from 72 zircon grains within sample B2.

Several grain populations indicate a complex provenance history for this unit and the youngest grain may indicate a maximum depositional age for the Uinta Mountain Group. The most significant population is the 2.6 Ga peak which represents Late Archean to Early Proterozoic input, likely from the Wyoming craton, but possibly form other cratons further east. A smattering of Paleoproterozoic grains likely represents the Yavapai-Mazatzal provinces. There is a Grenville-age peak at about 1.1 Ga. These grains could be coming transcontinent from the east, or from the southeast (Llanoria). The two Neoproterozoic ages represent two different analyses from the same grain

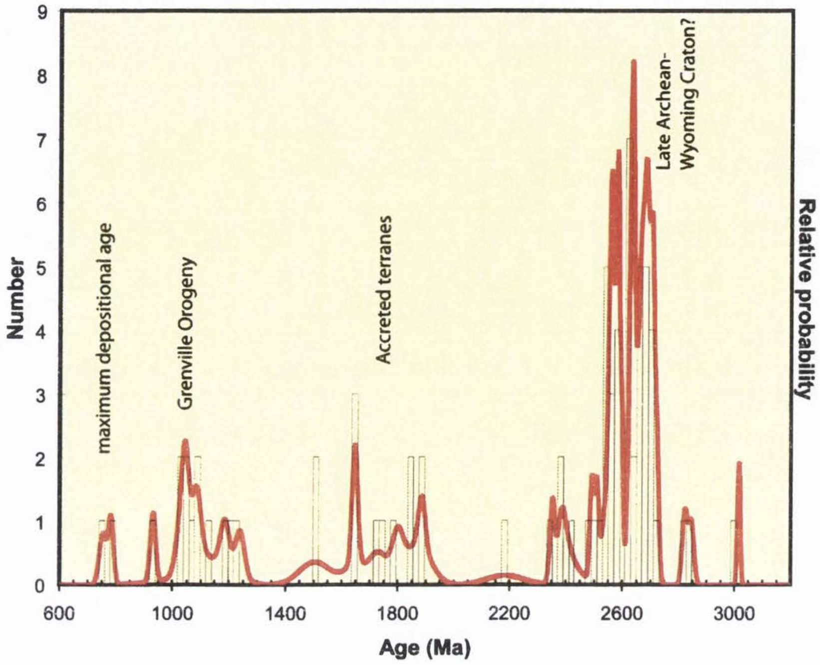


Figure 38. Probability density plot of sample B2 for the ages of 72 detrital zircon grains within the green sandstone and shale facies. Note the peak at 781Ma.

yielding ages of 753 and 781 Ma. It turns out that the 753 Ma spot was too close to the edge of the grain and is therefore unreliable data point (Fanning, pers. comm., 2006). The 781 Ma spot is a robust measurement and, not only suggests a felsic volcanic Neoproterozoic provenance (likely from similar areas as the Grenville grains), yet also hints that the basal Uinta Mountain Group can be no older than ~781 Ma. More grains need to be found (at least 3 more) before the population will be considered statistically significant. This possible depositional age is consistent with work by DeGrey (2005) who reported ~770 Ma single detrital zircon grain within an arkosic sandstone of the formation of Outlaw Trail. Fanning and Dehler (2005) have since analyzed a total of 128 grains from the formation of Outlaw Trail, four grains of which yield a concordia age of 770 Ma. This work refines dates obtained from Mueller et al. (2005) who report dominately Grenvillian concordia (0.95-1.35 Ga).

The new detrital zircon analysis reported here yielded a more complex provenance history compared to previous provenance work on this unit (Ball and Farmer, 1998; Condie et al., 2001). Ball and Farmer (1998) reported Nd isotope values from different facies in the Jesse Ewing Canyon Formation that indicated Archean and Paleoproterozoic influences from the Wyoming craton and the Red Creek Quartzite coming from the north, as well as a Paleoproterozoic source coming from the east. They did not, however, report any younger populations.

The detrital zircon analysis is consistent with the petrographic analysis of the green sandstone and shale facies which demonstrates that this facies represents sediment mixing from several sources (seven total). Interestingly Figure 12 demonstrates that the green sandstone and shale facies is the only facies with an arkosic source. This observation is consistent with work by DeGrey (2005) that reports the formation of Outlaw Trail as being arkosic. The striking similarity of the green sandstone and shale facies and the formation of Outlaw Trail suggests that these two units acquired sediment from similar sources.

5.6 - Lower Uinta Mountain Group Facies

5.6.1 – Description of the Lower Uinta Mountain Group facies

The lower Uinta Mountain Group is characterized by a drastic increase of quartz-rich sandstone beds, associated with a decrease in shale. This increase is best seen at the contact of the Jesse Ewing Canyon Formation and the lower Uinta Mountain Group. Here the maroon shale of the Jesse Ewing Canyon Formation ends abruptly, and is replaced by cliff-forming quartz-rich sandstone of the lower Uinta Mountain Group for an interval no less than 20 meters in thickness. The initial pulse of sandstone (>20 meters) has no interbedded shale, though above this interval lesser (<20 meters) amounts of shale are observed while the unit is overall dominated by sandstone.

The lower Uinta Mountain Group facies is the most homogeneous in terms of sedimentary structures and lithology of all the facies observed. The dominant sedimentary structure in the lower Uinta Mountain Group is trough cross-stratification, though some beds are massive. Pebble lags of well rounded Red Creek Quartzite are common and mark the base of many of the beds that fine upward from there. The sandstone of the lower Uinta Mountain Group is medium- to coarse-grained, moderately to well rounded, and moderately to well sorted. This unit is generally medium- to thickly-bedded with lenticular bed geometry. Occasional clast-supported conglomerate is interbedded with the sandstone, yet it is not associated with the shale like in the Jesse Ewing Canyon Formation. These beds are typically up to 1 meter in thickness, lenticular to tabular, and have sharp contacts with the surrounding sandstone. The shale within the lower Uinta Mountain Group is similar, though not identical to those found in the Jesse Ewing Canyon Formation. The shale is a maroon mudstone, with a very small silty component, is non-micaceous, and generally occurs in intervals no thicker than ~10 meters.

5.6.2 - Interpretation of the lower Uinta Mountain Group facies

The lower Uinta Mountain Group represents deposition in a braided fluvial environment that was not encroached upon by other subenvironments as seen in the Jesse Ewing Canyon Formation. The trough cross-stratification, fining-upward sequences, and truncation of bedding suggests deposition in a braided fluvial environment (Rust, 1978; Miall, 1992; Reading, 1996). This interpretation is also consistent with De Grey (2005) that designates the formation of Diamond

Breaks, the lowermost unit in the Uinta Mountain Group stratigraphy south of Browns Park, as a braided fluvial system based on the observation of the same sedimentary structures. The sandstone of the lower Uinta Mountain Group also resembles the thicker sandstones within the Jesse Ewing Canyon Formation, previously interpreted as fluvial. Conglomerate beds within the sandstone of the lower Uinta Mountain Group represent the coarsest bedload of the main channel of this system (Reading, 1996). This also indicates that Red Creek Quartzite was available as a source at this time either as outcrop, or, more likely, recycled as clasts. Mudstone represents low-energy overbank deposits adjacent to the braided channels consistent with reports by Reading (1996) and Boggs (2001b). alternatively, some mudstone intervals could represent a mudflat environment similar to the maroon shale facies of the Jesse Ewing Canyon Formation only on a smaller scale.

CHAPTER 6

STRATIGRAPHY AND PALEOGEOGRAPHY

6.1 - Introduction/Subdivision of Units

The eastern Uinta Mountain Group strata in the mountainous region north of Browns Park has been subdivided into five informal mappable units. The Jesse Ewing Canyon Formation has been subdivided into two informal members; a coarse-grained member (Head of Cottonwood member) and fine-grained member (Willow Creek member). The recognition of the Willow Creek member as a part of the Jesse Ewing Canyon Formation has effectively quadrupled the maximum thickness from 225 meters reported by Sanderson and Wiley (1996) to nearly 1000 meters as measured in section H (appendix A). Additional, very *preliminary* subdivisions have been made to the overlying undifferentiated Uinta Mountain Group. Differentiation of the Uinta Mountain Group is dependent solely on the presence of a shaley unit east of O-Wi-Yu-Kuts Mountain and a correlative, genetically-related conglomerate unit just south of the Bender Fault (plate 1). This shaley unit and correlative conglomerate unit has been designated as the middle Uinta Mountain Group and allows for the designation of the lower and upper Uinta Mountain Group below and above this unit, respectively. These subdivisions within the Uinta Mountain Group are only preliminary observations that set a stratigraphic framework for future workers.

The following section is in preparation to fulfill the requirement of the North American Stratigraphic Code in order to formalize the Head of Cottonwood and Willow Creek members of the Jesse Ewing Canyon:

This study intends to formalize the Head of Cottonwood member and the Willow Creek member as part of the Jesse Ewing Canyon Formation. These member subdivisions are subordinate to the Jesse Ewing Canyon Formation and are genetically liked to each other.

The Head of Cottonwood member derives its name from the excellent exposures of conglomerate along the southern slope of Head of Cottonwood (see Section C, Plate 1). While this locality contains faults that truncate the upper portion of the section exposing only a minimum thickness, it is the only location that illustrates the thickest, most laterally continuous, and most structurally coherent outcrop of the Head of Cottonwood member. It is proposed that the stratotype of the Head of Cottonwood member is located along the southern slope of Head of Cottonwood on the east side of Jesse Ewing Canyon.

The Head of Cottonwood member is defined as a clast- to matrix-supported pebble- to cobble-conglomerate or breccia. Predominate clast composition is white to pale gray metaquartzite with lesser amphibolite and schist. Maximum clast diameter is ~60 cm. The conglomerate commonly displays graded (normal and reverse) bedding and tabular to lenticular bedding (1-4 meters thick). Scours are common and beds are generally massive with rare instances of weakly developed clast imbrication. Conglomerate is interbedded with medium-grained to granule lithic- to sublithic-arenite and micaceous maroon clay- to mudshale. Lithic- to sublithic-arenite is maroon on a weathered surface, and pink on fresh surfaces. Arenites are generally moderately- to moderately poorly sorted and subangular to subrounded. Arenites are generally lenticular bedded, normally graded, and trough cross-stratified. Clay- to mud shale is maroon on weathered surfaces, and gray to black on fresh surfaces and laminated. The conglomerate thins laterally abruptly (in <0.5 km) into micaceous maroon clay- to mudshale.

The Head of Cottonwood member has a stratigraphic thickness of 0-190 meters. In the type section, the Head of Cottonwood member reaches its maximum exposed thickness of 190 meters. The Head of Cottonwood member is observed in four primary areas including Goslin Mountain, Jesse Ewing Canyon, Bender Draw, and Galloway Creek.

The Willow Creek member derives its name from the excellent exposures along Willow Creek (see Section H, Plate 1). At this locality the Willow Creek member is ~1,000 meters thick with no observed faulting. The stratotype of the Willow Creek member is located along the Willow Creek drainage south of Bender Mountain.

The Willow Creek member is defined as a shale and sandstone unit with lesser interbedded conglomerate. Micaceous laminated maroon clay- to mudshale is maroon on weathered surfaces, and gray to black on fresh surfaces. Sandstones are purple to pink moderately well to moderately poorly sorted, subangular to moderately well rounded lithic, arkosic, to quartz arenite. Arenites are commonly tabular bedded with lesser lenticular beds. Common sedimentary structures include planar-tabular crossbedding, trough crossbedding, pebble lags, asymmetric and symmetric ripples, normal grading, and plane beds with lesser interference ripples, mud-draped ripples, and soft-sediment deformation.

The Willow Creek member is profuse in the mountainous region north of Browns Park and can reach thicknesses up to 1,000 meters. The most westward exposure is located just west of Red Creek and shale of the Willow Creek member can be continuously traced well into Colorado with no significant interruption.

When present, the Head of Cottonwood member is in sharp unconformable contact with the underlying Red Creek Quartzite (see Plate 1). The upper contact with the Willow Creek member is defined as the last significant (>3 meters thick) conglomerate and first significant (>10 meters) shale interval. This contact is generally gradational with the overlying Willow Creek member. The Willow Creek member is observed in sharp depositional contact with the Red Creek Quartzite, laterally equivalent to the Head of Cottonwood member, and in gradational contact overlying the Head of Cottonwood member. The basal contact of the Willow Creek member, when the Head of Cottonwood member is present, is marked by the first >10 meters interval of shale and lesser interbedded sandstone and last significant (>3 meters) conglomerate. The upper contact between the Willow Creek member and the overlying Uinta Mountain

Group is sharp and is marked by the lack of interbedded shale in a sandstone dominated interval that exceeds 100 meters.

The Willow Creek member is profuse in the mountainous region north of Browns Park and can reach thicknesses up to 1,000 meters. The most westward exposure is located just west of Red Creek and shales of the Willow Creek member can be continuously traced well into Colorado with no significant interruption.

The Jesse Ewing Canyon Formation and related herein proposed Head of Cottonwood and Willow Creek members were first described by Hansen (1965) who documented the significance of a basal conglomerate in the Uinta Mountain Group. Sanderson and Wiley (1986) formally named the Jesse Ewing Canyon Formation, documenting a composite stratotype on the eastern side of Jesse Ewing Canyon based on the work of Wiley (1984). Their characterization of the formation was incomplete inasmuch that they did not characterize the finer-grained interval (in their measured section JE-5) identified by this study as the Willow Creek member. Furthermore, some of their sections were measured through faulted strata and the faults were not addressed in their data presentation. Sanderson and Wiley (1986) report that further work was needed to properly characterize the formations aerial extent and occurrence of the formation.

While good geochronolgoic control has yet to be obtained for the Jesse Ewing Canyon Formation, the detrital zircon analysis of this study produced a single grain with a reported age of 781 Ma within the Willow Creek member. A statistically significant population is still needed to confirm this age to the Jesse Ewing Canyon Formation, although it can be said that the Jesse Ewing Canyon formation is younger than the next youngest grain population (1.1 Ga) and is likely older than the 770 Ma formation of Outlaw Trail (Fanning and Dehler, 2005).

Limited data prohibit direct correlation of the Head of Cottonwood and Willow Creek members to other regional units. A larger detrital zircon population in the Willow Creek member producing an age of ~781 Ma, could lead to possible correlation to the 770-742 Ma Chuar Group of the Grand Canyon (Karlstrom et al., 2000; Dehler et al., 2005a). Locally, there are no known correlations of the Jesse Ewing Canyon Formation, though it is speculated that correlative units are in the subsurface of the western Uinta Mountains.

6.2 – Description of the Head of Cottonwood Member of the Jesse Ewing Canyon Formation

The Head of Cottonwood member of the Jesse Ewing Canyon Formation has been subdivided on the basis of its coarse-grained nature. This member is composed entirely of the conglomerate facies which contains lesser amounts of interbedded sandstone and shale. The Head of Cottonwood member is seen in several localities within the map area, and in many cases is closely associated with the basal contact with the underlying Red Creek Quartzite (plate 1). Where the basal contact is exposed, the Head of Cottonwood member unconformably overlies the Red Creek Quartzite and fills in paleotopographic lows in excess of 30 meters (southern slope of Head of Cottonwood, plate 1). The upper contact is gradational as conglomerate grades into the finer shale and sandstone of the Willow Creek member (appendix A, Section G). Along the southern part of Jesse Ewing Canyon the Head of Cottonwood member has been documented to grade into the Willow Creek member demonstrating that the Willow Creek member can exist stratigraphically below, above, and laterally equivalent to the Head of Cottonwood member (Fig. 39). A minimum thickness of 190 meters is seen at the type locality on the southern slope of Head of Cottonwood where the uppermost exposed Head of Cottonwood member is in fault contact with the Willow Creek member (appendix A, Section C).

Distribution of the Head of Cottonwood member varies greatly within the map area. Lateral thickness is highly variable and in places the unit is absent and the Willow Creek member rests directly on the Red Creek Quartzite (plate 1 and 2). Lateral thinning is well documented by comparing measured section C with section G (plate 2). While only separated by ~3 km the Head of Cottonwood member thins from ~190 meters in section C to ~84 meters in section G.

Vertically, the Head of Cottonwood member is less variable. Generally only lenticular beds of shale and sandstone interrupt an otherwise continuous outcrop of conglomerate. A transect through the Head of Cottonwood member demonstrates only crude cyclicity seen as the alternation between conglomerate and shale intervals on a 10 meter scale (appendix A, Section C).

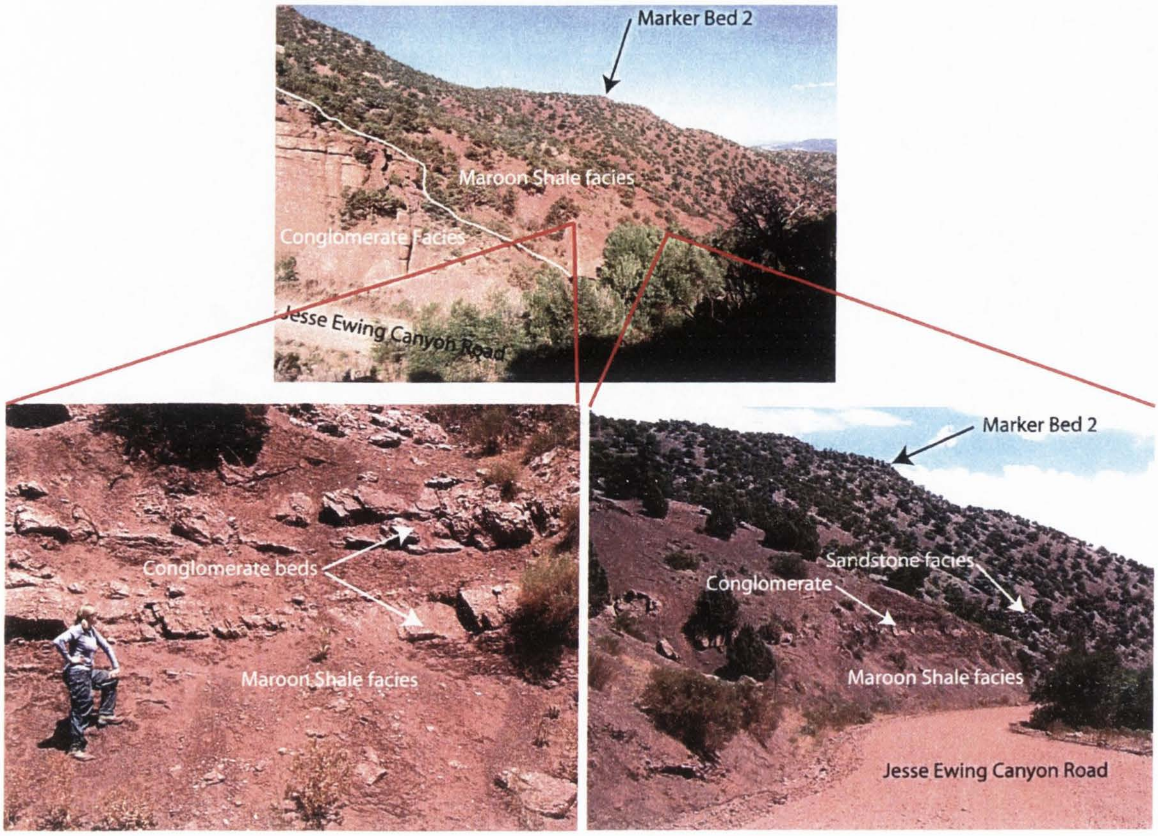


Figure 39. Field photograph demonstrating stratigraphic relationships of the Head of Cottonwood member (conglomerate on the left) and Willow Creek member (shales to the right) of the Jesse Ewing Canyon Formation along the eastern side of Jesse Ewing Canyon. In this case, the Head of Cottonwood member grades into the Willow Creek member. Note the abruptness of conglomerate thinning into the shale as you move from left to right. Lower most photographs display the transition from conglomerate dominated facies to shale dominated facies.

6.3 – Description of the Willow Creek Member of the Jesse Ewing Canyon Formation

The Willow Creek member of the Jesse Ewing Canyon Formation consists predominately of the maroon shale facies as well as the sandstone and green sandstone and shale facies and reaches a thickness of up to 1,000 meters. This member accounts for the majority of the Jesse Ewing Canyon Formation and the greatest thicknesses are found east of Jesse Ewing Canyon and west of O-Wi-Yu-Kuts Mountain (see section H, plates 1 and 2)(appendix A, Section H). This member overlies the Head of Cottonwood member when present, or, when absent is in depositional contact with the Red Creek Quartzite (see O-Wi-Yu-Kuts Mountain on plate 1). As previously described, this member is also laterally equivalent to the Head of Cottonwood member (Fig. 39). This lower contact with the Red Creek Quartzite is generally poorly exposed and shows paleotopographic relief in excess of 30 meters (Hansen, 1965). The upper contact is sharp with the lower Uinta Mountain Group, and in most cases, is easily identifiable in aerial photograph.

The Willow Creek member is very laterally continuous and appears to retain its general thickness in all places where there is good stratigraphic control. This lateral continuity is best displayed between Jesse Ewing Canyon and O-Wi-Yu-Kuts Mountain (plate 1).

The Willow Creek member demonstrates two different scales of vertical cyclicity (1 meter scale and >10 meters scale). Within the maroon shale facies, small scale (<3 meters) cyclicity is observed. As part of the definition of the maroon shale facies, it contains numerous <1.5 meters beds of sandstone and rare conglomerate that are interbedded within the maroon shale. Generally these <1.5 meters beds of sandstone appear every 3-5 meters separated by maroon shale. Similar cyclicity is observed in the green sandstone and shale facies and shows <1.5 meters beds of sandstone that coarsen upward separated by ~3 meters of green mudstone (appendix A, Section D, meterage 104-136) (Fig. 36).

On a larger scale (>10 meters scale) the Willow Creek member seems to demonstrate some stratigraphic trends, but varies somewhat from section to section. Section G shows no unique trends and is most unlike the other measured sections. The of the section crudely fines upward from conglomerates at the base to sandstone and shale near the top. Above the Head of Cottonwood/Willow Creek contact, the section coarsens upward from shale at the base to sandstone near the top (plate 2). The green sandstone and shale facies makes only one appearance for a relatively thin (~8 meters) interval and it is difficult to correlate between sections due to thickness changes and stratigraphic positioning.

Measured sections A, B, D, and H are similar in that they are composed entirely of the Willow Creek member and probable correlations can be made between them. All sections show at least one interval of green sandstone and shale facies. The uppermost green sandstone and shale facies can be seen in sections A, D, and H and can be correlated with considerable certainty (plate 2).

Stratigraphically lower green sandstone and shale facies intervals are observed, yet they are not easily correlative between measured sections. Section D has one interval of green sandstone and shale that is not observed in any of the other nearby sections (plate 2). Section B contains one interval below marker bed 1 that is not seen in section H, the only other measured section that contains the same stratigraphic interval (plate 2).

6.4 – Description of the Uinta Mountain Group

As detailed description of the undifferentiated Uinta Mountain Group was not the focus of this study, only generalized formation descriptions have been documented. These observations were made during mapping and in rare instances, the measuring of section above the Jesse Ewing Canyon Formation contact. Reported thicknesses were calculated from the map (plate 1). For complete descriptions of the lower, middle, and upper Uinta Mountain Group see Chapter 4.

The lower, middle, and upper Uinta Mountain Group represent 1 kilometer-scale informal formations that are persistent throughout the field area. These formations represent the most continuous stratigraphy in the map area and can be traced laterally for tens of kilometers. The lower Uinta Mountain Group is predominately a sandstone unit with lesser interbedded shale. Conformably overlying the lower Uinta Mountain Group is the shaley and conglomeratic middle Uinta Mountain Group. The conglomeratic interval of the middle Uinta Mountain Group on the west side of the O-Wi-Yu-Kuts fault can be traced into shaley lateral equivalent found on both the east and west side of the O-Wi-Yu-Kuts fault (plate 1). The basal contact is sharp and is best displayed as a dip slope north of Cold Spring Mountain and atop O-Wi-Yu-Kuts Mountain. The upper contact with the upper Uinta Mountain Group appears to be gradational on a 10-meter-scale and has been picked primarily by the transition from shale to sandstone corresponding to a change in slope. The middle Uinta Mountain Group is conformably overlain by the upper Uinta Mountain Group, a predominately sandstone unit with lesser interbedded shale. No vertical cyclicity has been observed in these informal formations, though little time was spent documenting each formations characteristics. The descriptions here are presented only as general trends observed during mapping.

6.5 - Stratigraphic Interpretation and Paleogeography

The Uinta Mountain Group stratigraphy represented in the mountainous region north of Browns Park can crudely be divided into two primary facies associations that represent drastically different depositional environments. The first association is represented by the Jesse Ewing Canyon Formation and the middle Uinta Mountain Group. Nearly identical lithology, facies architecture, and relative proportions of observed facies suggest that depositional process for these two separate units were the same. The second association consists of the lower and upper Uinta Mountain Group. Though it is suspected that the facies architecture of these two formations are not identical based on preliminary observations of dominant sedimentary structures and the relative abundance of sandstone to shale, they share a strong relationship in lithology, outcrop character, and lateral variability.

6.5.1 – Stratigraphic Interpretation of the Head of Cottonwood Member

The Head of Cottonwood member represents proximal to medial alluvial fan deposition along the northern margin of the Uinta Mountain Group basin. Measured section C indicates solely proximal to medial alluvial fan deposition (appendix A, Section C) (plate 2). The lateral change in the Head of Cottonwood member between section C and section G documents the transition to more distal environments (~190 meters in section C compared to ~84 meters in section G) (plate 1 and 2) (appendix A, Section H). Section G records the transition from medial alluvial fan to distal alluvial fan or possibly fan delta (appendix A, Section G) (plate 2). Since both section C and section G have faults that dissect them, thickness variations between sections C and G are not conclusive. However, the relative amounts of conglomerate at each section do give an indication to their position relative to the alluvial fan. Using this logic, this would position section G between alluvial fans (Fig. 40 block A).

Documentation of the Head of Cottonwood member east and west of Jesse Ewing Canyon gives insight into the number of alluvial fans present in the field area. A minimum of three point sources were identified within the map area. These separate fans can be seen on Goslin Mountain, the Jesse Ewing Canyon

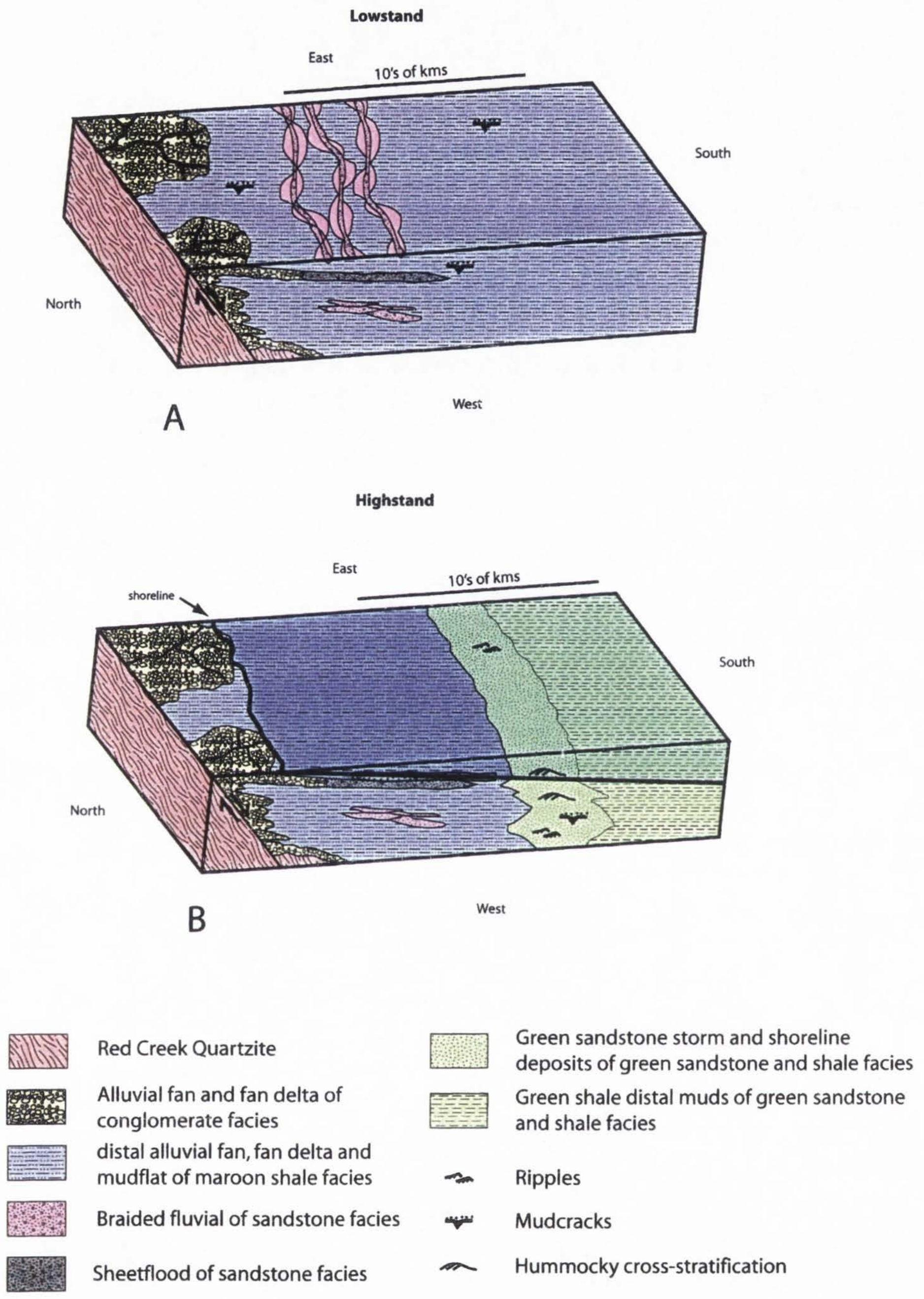


Figure 40. Block diagram showing lowstand and highstand conditions of shallow body of water that occupied the main basin during Jesse Ewing Canyon Formation time. A. During lowstands, the braided fluvial system dominated the distal fan/mudflat. B. During highstands, deltaic turbidite deposits and braided fluvial sediments get reworked into shoreline sands.

area, and Bender Draw, from west to east. Longitudinal thinning of conglomerate beds to the south was also observed, which defines a wedge-shaped profile characteristic of alluvial fans (Blair and McPherson, 1994). These fans record basin initiation given their coarse nature and close association with the basal contact.

The grain size and massive nature of the conglomerate suggests that the deposits preserved in the Head of Cottonwood member were proximal and fed sediment to adjacent environments basinward (mostly southward). Transport direction has been inferred from north to south-southeast based on the distribution of the coarsest conglomerates found along the northern reaches of the map area and thinning abruptly southward where they pinch out into the maroon shale facies. This is consistent with the findings of Sanderson and Wiley (1986) (Fig. 39). The massive nature of the conglomerates suggests that they were primarily deposited by primary mass flow processes and were quickly buried before they could be organized (Blair and McPherson, 1994). This is consistent with the tabular nature of the conglomerate beds.

The position of the alluvial fans within the basin was strongly influenced by local tectonics. The alluvial fans developed along the basin margin near the basin bounding extensional faults to the north. Continued extension along the northern basin margin produced several parallel faults created in sequence stair-step fashion originating from the south and propagating northward (Fig. 41) (Sanderson and Wiley, 1986). As this extension continued, alluvial fan

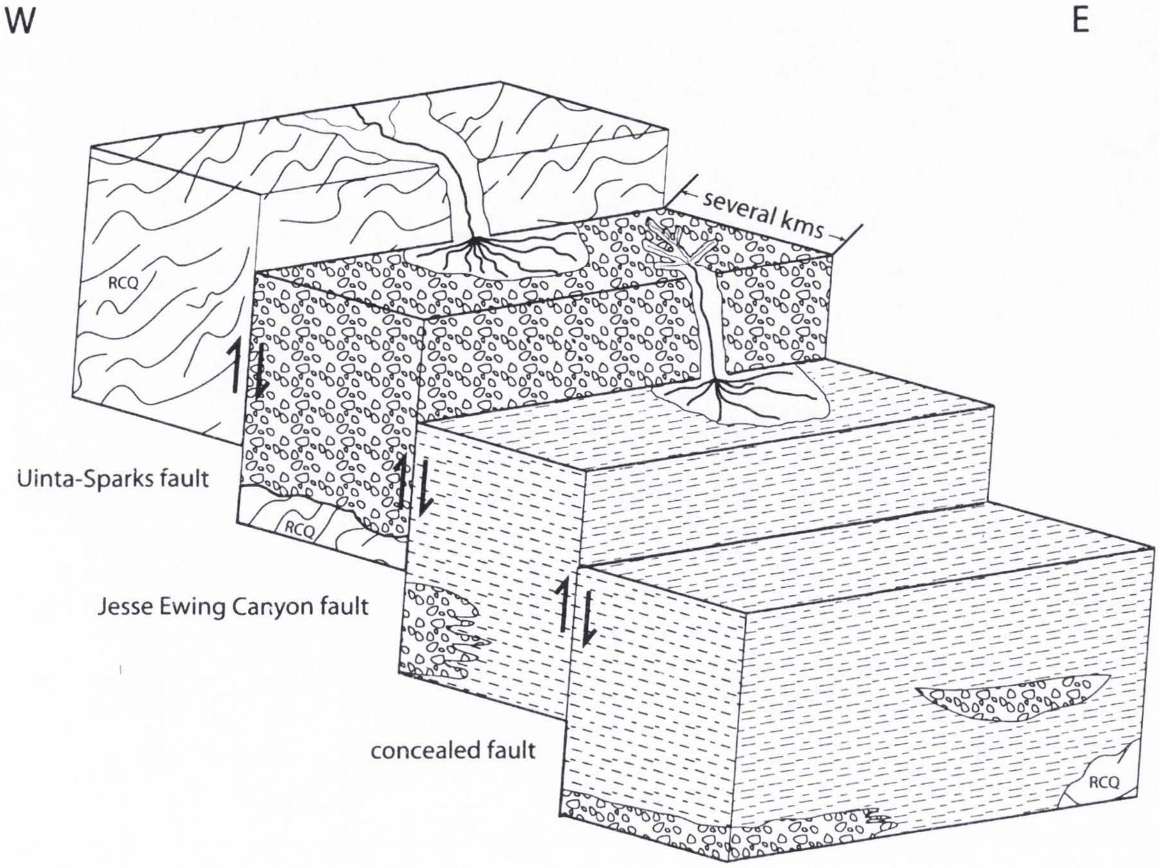


Figure 41. Idealized stair-step diagram showing fault orientation and style that marked the northern basin margin during Jesse Ewing Canyon Formation extension. Note syntectonic nature of these faults and how they control facies distribution throughout the basin. No implied fault dip. RCQ= Archean-Paleoproterozoic Red Creek Quartzite.

deposition retreated northward.

6.5.2 – Stratigraphic Interpretation and Paleogeography of the Willow Creek member

The Willow Creek member represents the convergence of multiple depositional systems within a common area and illustrates the complexity of interactions between depositional environments. Contained within the Willow Creek member are fluvial, shoreline, and alluvial fan environments where sediments were deposited by storm, sheetflood, turbidite, and background suspension settling processes. All of these environments occur basinward of the alluvial fans that mark the basin margin and are in a dynamic equilibrium with each other where the dominant depositional process changes through time. The result is a depositional unit that displays great heterogeneity and complex intertounging relationships.

The Willow Creek member stratigraphy shows many changes from mud-rich environments (distal alluvial fan, fan delta, mud flat) to more distal environments near wavebase (appendix A, Sections A,B,D, and H) (plate 2). The large scale (>10 meters) cyclicity indicates multiple changes in base level through time, where small scale (<3 meters) cyclicity reflects short term base level changes or storm events. Correlation between the Willow Creek member sections indicates some facies are laterally continuous (marker bed 1 and 2, green sandstone and shale facies, maroon shale facies) for at least 5-10 kilometers. This suggests that these environments were also widespread which is reasonable for braided stream and nearshore environments (Fig. 40).

Intertonguing of the conglomerate facies and the maroon shale facies (boundary between the Head of Cottonwood member and Willow Creek member) is best exposed along the southern end of Jesse Ewing Canyon. This marks the transition from alluvial fan to fan delta deposits that occurred on a very low gradient surface. Here, the micaceous silty maroon mud was deposited in a shallow-water basin that was intermittently exposed. The interbedded sandstone beds of varying thickness represent sheetflood, turbidite, shoreline and fluvial deposition basinward of the fan system, though their deposition was not always coeval. These sand bodies were deposited on the distal alluvial fan and proximal to distal fan delta or mudflats, dependent on water depth. During lowstands, sheetfloods and fluvial processes were responsible for deposition of the sandstone and maroon shale facies on the distal alluvial fan/mud flat. During highstands, these processes were absent leaving nearshore and distal fan processes responsible for deposition of the sandstone and maroon shale facies (Fig. 40). Basinward, the green sandstone and shale facies represents the most distal environment. Beyond the shoreline, below and near fair weather wave base, the green sands were deposited on a very shallow storm-effected coast. These sandstone beds intertongue with the green micaceous and sometimes organic-rich mudstones that represent the finest deposits in the local basin. Meter-scale coarsening-upward cyclicity in the green sandstone and shale facies reflects climatically-driven sedimentation of sandstone punctuating mudstone deposition (Reading, 1996).

Primary sedimentary structures and paleocurrent data aid in the differentiation of sandstone deposits and probable depositional process. Sharp-based fining-upward sheet-like deposits that grade from pebble to medium sand, inferred to flow southward, represent distal sheet flood deposits which sourced the alluvial fan system. Sharp-based moderately well sorted quartz-rich sandstone beds that are plane-bedded and tabular cross-bedded were deposited by fine-grained turbidities and longshore currents during highstands and were sourced from the east. The slight majority of the paleocurrent data indicate northwesterly directed flow direction (Fig. 13), and petrographic analysis and detrital zircon analysis of sample B2 indicate that this sediment was sourced outside the basin and probably brought in by a major fluvial system from the east or southeast (Fig. 12) (Ball and Farmer, 1998; Condie et al., 2001). The thickest trough cross-stratified sandstone intervals represent deposition by fluvial processes during lowstands (Ramos et al., 1986). These were smaller streams that reworked and deposited sediment brought into the basin by the larger fluvial system to the east.

Vertical stacking of these facies is similar at all locations where there is good stratigraphic control and illustrate the transition to overall more basinward deposits through time. Coincident with the retrogradation of alluvial fan deposition was the movement of basin deposits northward. The overall sequence shows the retreat of alluvial fans as the basinal facies migrate northward. A re-emergence of the maroon shale facies is shown overlying the green sandstone and shale facies possibly representing the retreat of the shoreline southward. This transition documents the dominance of basinal deposits in the Jesse Ewing Canyon Formation through time.

6.5.3 – Stratigraphic Interpretation and Paleogeography of the Uinta Mountain Group

The lower Uinta Mountain Group represents a braided fluvial system that dominated deposition after Jesse Ewing Canyon Formation time. The precursor to this fluvial-dominated system was observed in the sandstone facies of the Jesse Ewing Canyon Formation, where the sandstone deposits reflect braided fluvial and possibly nearshore environments. The abruptness of the contact between the Jesse Ewing Canyon Formation and the lower Uinta Mountain Group signals a drastic change in depositional processes and environment as a result of major basin reorganization and possible sub-basin integration. A dominant braided fluvial environment is consistent with previous workers paleogeographic reconstructions that show the majority of the eastern Uinta Mountain Group representing braided fluvial conditions (Wallace and Crittenden, 1969; Condie et al., 2001; DeGrey, 2005). This fluvial system is also responsible for supplying the basin with the extrabasinal sediment that makes up the quartz-rich sandstone in the Jesse Ewing Canyon Formation (e.g., Condie et al., 2001).

Little can be said with absolute certainty about the Uinta Mountain Group stratigraphy at this point as a through facies analysis was never performed. It can be determined though, with considerable certainty, that the the overall stratigraphy records a transition from high energy quartz-rich sand deposition to low energy mud deposition before reverting back to a high energy sand dominated system. If any analogues for DeGrey's (2005) work can can be used to the stratigraphy north of Browns Park, it is predicted that the lower and upper Uinta Mountain Group record varying environments associated with a braided fluvial system that is punctuated by a return to Jesse-Ewing-Canyon-Formation-like deposition.

6.6 - Syntectonic deposition in the Jesse Ewing Canyon Formation

The Jesse Ewing Canyon Formation records syntectonic deposition related to rifting of the Uinta Mountain Group basin. The best preserved example of this is in Jesse Ewing Canyon where thickness and lithology changes occur within the Jesse Ewing Canyon Formation across the Jesse Ewing Canyon Fault system (see measured sections G and H, plate 2). Comparing measured sections G and H (plate 2), a thickness change on the order of 600 meters is observed. The abundance of fine-grained sediments southward in section H illustrates that alluvial fan deposition was primarily contained to the north along the basin-bounding faults and basinal deposits occupied the southern portion of the basin accumulating in great thickness due to abundant sediment supply and rapid subsidence associated with fault movement. Conglomerate north of the Jesse Ewing Canyon Fault suggests that there was another similar fault to the north that uplifted Red Creek Quartzite. This demonstrates faults arranged in a stair-step like fashion that marked the northern margin of the basin (Fig. 41). While locally thicker deposits tend to be on the southern (footwall) side of these faults, the basin showed asymmetric sediment distribution resulting in thicker overall sediment accumulation along the northern basin margin (Sanderson, 1984; Sanderson and Wiley, 1986; Stone, 1993) (Fig. 42). While post-Precambrian faulting in the area of section G exists, the displacement of this fault is minimal and not significant enough to account for the drastic stratigraphic changes seen between section G and H.

Additional evidence for syntectonic deposition is demonstrated by growth folding between members of the Jesse Ewing Canyon Formation. Southeast of Mountain Home and west of Jesse Ewing Canyon there is a small syncline that steeply folds the Head of Cottonwood member. Westward this fold terminates at the Head of Cottonwood/Willow Creek contact indicating folding associated only with the deposition of the Head of Cottonwood member. Stratigraphically above this contact undeformed beds of the Willow Creek member dip gently to the north-northwest.

While Sanderson and Wiley (1986) also interpret the Jesse Ewing Canyon Formation to record syntectonic deposition, they do so for different reasons. Sanderson and Wiley (1986) interpret that the Jesse Ewing Canyon Formation

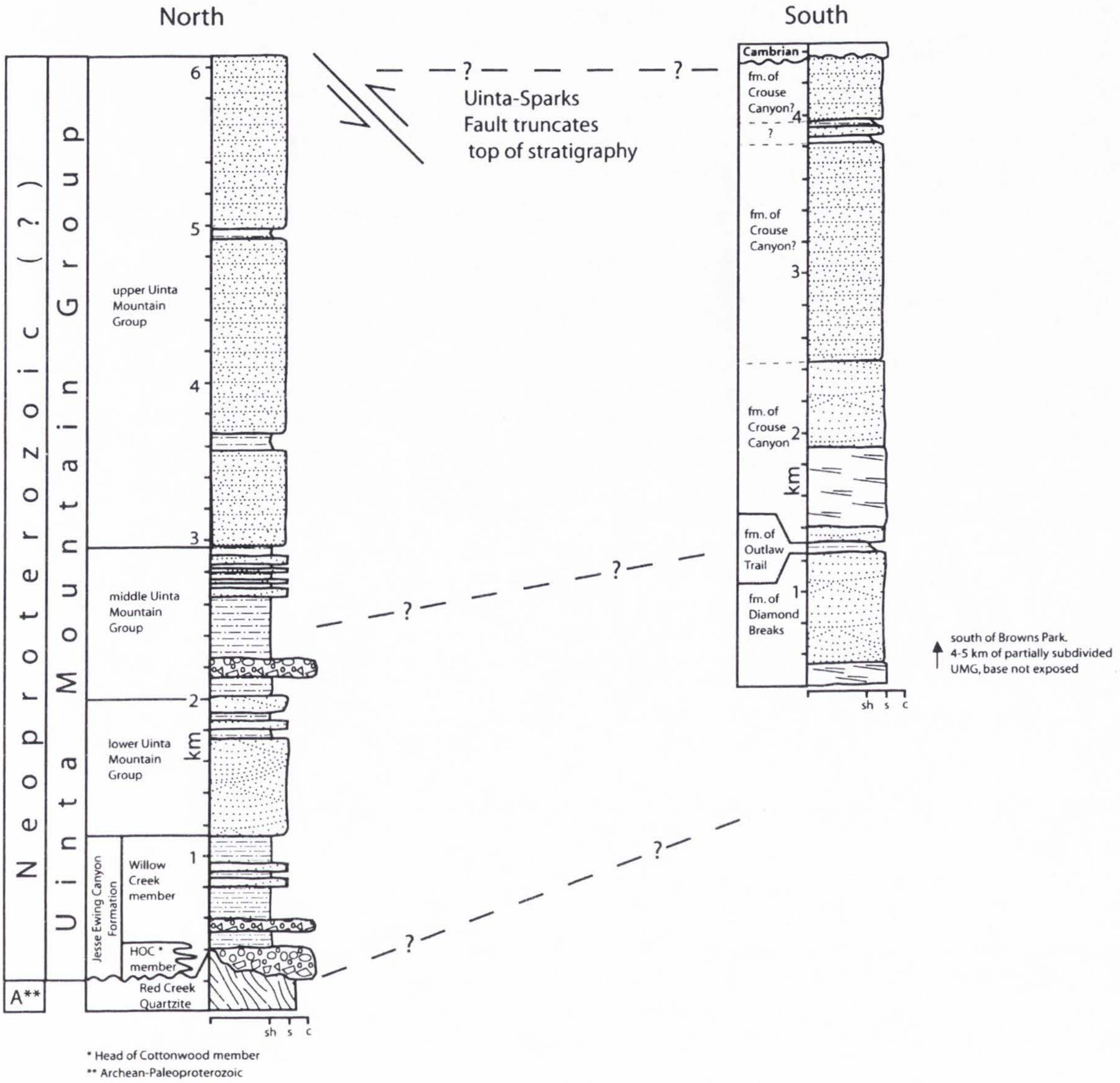


Figure 42. Generalized eastern Uinta Mountain Group stratigraphy north and south of Browns Park (southern stratigraphy from DeGrey, 2005). Note the greater exposed thickness of strata to the north and likely correlations suggest an asymmetric basin during deposition that thickened northward consistent with Hansen (1965), Sanderson (1984), and Stone (1993).

south of the Jesse Ewing Canyon Fault is older and is in angular discordance with the overlying younger Jesse Ewing Canyon Formation (dominately conglomerate) mostly north, but also south, of the fault (Fig. 9). Sanderson and Wiley's (1986) angular unconformity was not located, yet in the vicinity where they interpret an unconformity, the bedding orientation is highly variable due to Cenozoic(?) drag on the Jesse Ewing Canyon Fault. No evidence was found suggesting two stratigraphic packages with different deformational histories.

6.7 - Controls on Stratigraphy on the Jesse Ewing Canyon Formation

The primary stratigraphic controls on the Jesse Ewing Canyon Formation were likely a combination of tectonic and climatic, depending on stratigraphic scale. Although parts of the Jesse Ewing Canyon Formation are cyclic on different scales, the majority of the unit is best described as acyclic. This acyclic nature likely reflects differential subsidence rates through time in concert with a variety of different climatic effects. The small scale (<~3 meters thick) cyclicity found in the maroon shale and green sandstone and shale facies are likely the products of high-frequency climatic change (Heckel, 1986; Reading, 1996). Thicker (100's meters scale) cycles are more likely attributed to changes in local subsidence rates due to tectonism (e.g. Wescott, 1988; Gawthorpe and Colella, 1990).

In the maroon shale facies, the meter-scale cyclicity is likely the result of storm events punctuating otherwise quiet background sedimentation. The sandstone and conglomerate beds within this facies represent sedimentation events (sheetfloods, turbidites) that were likely the result of high precipitation rates over a relatively short period of time (Blair and McPherson, 1994; Reading, 1996), whereas the shale represents suspension settling between storms. This would suggest that the Uinta Mountain Group basin was in a semi-arid to arid environment that periodically experienced severe flash flooding events. This type of climate also had an important impact on the construction of the related conglomerate facies (debris flow deposits). Another possible control on meter-scale cycles in this facies could be short-term changes in base level. This is however, not likely, since the sandstone and conglomerate beds represent both subaerial and subaqueous deposition. Although base level controlled whether the deposit was subaqueous or not, it did not control the cyclic nature of the deposits.

In the green sandstone and shale facies, repetition of sandstone and shale on a meter scale could also represent storm events in an otherwise quiet part of the basin. Alternatively, these cycles could represent high-frequency changes in base level associated with changing lake or ocean levels. If lacustrine, the changes would reflect humid-to-arid climate change fluctuations (Van Houten, 1962, 1964). If marine, these cycles could represent short-term glacioeustatic fluctuations (Heckel, 1994; Read, 1995).

Another possible control on the meter-scale cycles could be episodic tectonism associated with the syndepositional faults (e.g. Cisne, 1986). Due to the lateral continuity of many of the cycles in these two facies, short-term tectonism is probably not responsible for the cyclicity, yet is responsible for providing accommodation space for the cycles.

Tectonic subsidence is probably the greatest control over the larger stratigraphic scales (100-1,000 meters scale) (e.g., Reading, 1996; Gawthorpe and Colella, 1990). Movement on faults not only creates accommodation space for sediment accumulation but also lifts the highlands that locally supply sediment to the alluvial fans. The interplay of sediment source and accommodation space allows for the rapid burial as evidenced by the conglomeratic deposits.

The large scale (~1,000 meters) overall crude fining-upward trend in the Jesse Ewing Canyon Formation likely reflects basin-scale tectonic subsidence and the concomitant northward retrogradation of alluvial fans and related basinal deposits (e.g., Gawthorpe and Colella, 1990). Crude intermediate cyclicity (100 meters scale, plate 2), namely alterations between intervals of green sandstone and shale facies and maroon facies, could be attributed to changes in subsidence rates related to the Jesse Ewing Canyon fault system, or, to non-tectonic changes in base level such as lake- or sea-level fluctuations related to climate (e.g. Wescott, 1988; Read, 1995). Due to lack of laterally continuous exposure, this is difficult to test.

CHAPTER 7

DISCUSSION

7.1 – Paleogeographic and Tectonic Implications

The results of this research are in agreement that Jesse Ewing Canyon Formation sediments were deposited in an intracratonic rift that was fed by alluvial fans from the north, fluvial or deltaic systems from the east, and that there was an intermittent shallow body of water in the axis of the basin. Limited paleocurrent data show one paleoflow direction within the Jesse Ewing Canyon Formation is to the northwest and another paleoflow direction to the south-southeast (Fig. 13). It is unknown whether this shallow body of water was marine or lacustrine; however, marine-type acritarchs have recently been reported from this unit (Nagy and Porter, 2005; Sprinkel and Waanders, 2005), and other workers have proposed that parts of the western UMG are marine (Wallace and Crittenden, 1969; Dehler et al., 2005a,b, 2007).

Paleocurrent data from this study shows very different trends than those from Sanderson and Wiley (1986). The results of this study show a transport direction nearly 90° from that reported by Sanderson and Wiley (1986) (Fig. 13). Though the dataset for this study is small (n=37), it represents dominantly the sandstone facies transport direction. This would reflect transport of sediment by transverse (alluvial fan/fan delta) and axial (braided streams, longshore drift) systems.

This study is in agreement with Condie et al. (2001) that the Uinta Mountain Group basin was not an aulacogen, but an intracratonic rift. No volcanic deposits were observed in the only basal deposits exposed within the Uinta Mountain Group basin. This study documents syntectonic extension associated with the deposition of the Jesse Ewing Canyon Formation. Growth folding in the Head of Cottonwood member and thickness changes in the Willow Creek member all suggest that syntectonic deposition occurred during Jesse Ewing Canyon Formation time.

Stratigraphic relationships indicate that subsidence and sediment accumulation rates within the Uinta Mountain Group basin were strongly afected by local tectonics. Hansen (1965) was the first to make this observation stating that the Uinta Mountain Group was deposited in a rapidly subsiding, east-west trending trough. This has been inferred through the use of sedimentology where many primary structures are preserved indicating rapid subsidence and burial by overlying sediment. This is excellently displayed in the conglomerate facies of the Jesse Ewing Canyon Formation where large mass flow deposits that constructed the alluvial fans were quickly buried and experienced little reworking by secondary processes. Additionally, only subordinate distal deposits show any indication of long-lived residence time at the surface where quartz-rich sand would have been reworked by shoreline processes.

There are at least two documented stages of tectonism recorded within the eastern Uinta Mountain Group stratigraphy. Facies changes in the Jesse

Ewing Canyon Formation show a retrogradation of alluvial fans through time, suggesting that this period experienced continual rifting as the basin margin migrated northward. Continued rifting is also seen by thickness changes within the Jesse Ewing Canyon Formation, where areas to the south show thicker accumulation of sediment during this time (compare measured sections G and H on plate 2). Lastly, growth folding in the Head of Cottonwood member that creates a angular unconformity between the Willow Creek member (plate 1). A second stage of tectonism is documented by the conglomerates of the middle Uinta Mountain Group. While further work is required to properly document the occurrence of these deposits, the similarity with the conglomerates of the Jesse Ewing Canyon Formation suggests similar tectonic regimes.

7.2 – Age and Provenance Implications

Recent work by Fanning and Dehler (2005) resulted in an age of 770 Ma for the formation of Outlaw Trail of the eastern Uinta Mountain Group based on the analysis of 4 detrital zircon grains. The exact stratigraphic position of the formation of Outlaw Trail in relation to the Jesse Ewing Canyon Formation is unknown. Tentative correlation of the formation of Outlaw Trail with the middle Uinta Mountain Group north of Browns Park (this study) suggests that the data obtained by Fanning and Dehler (2005) would be put in context as being ~2,650 meters above the Jesse Ewing Canyon Formation.

Detrital zircon analysis of the green sandstone and shale facies from this work suggests an age of approximately 781 Ma (Chapter 5), although this is based on only one zircon grain. This result could limit the timing of deposition of the basal Uinta Mountain Group to no older than 781 Ma and suggests that the ~781 Ma source was exposed multiple times throughout the deposition of the Uinta Mountain Group. This analysis also documents 5 distinct sources of sediment for the Uinta Mountain Group. Additionally, this age also suggests that significant volumes of sediment were deposited rapidly in this basin.

Other detrital zircon populations in the analyzed sample indicate that, not only were there several local sediment sources, but also one or more transcontinental sources. The Grenville and 781 Ma grain populations likely came from Texas and (or) from the east.

The presence of ~781 Ma grains in the Uinta Mountain Group basin also signals the earliest documented rifting of Rodinia. This date can be used to further refine the protracted rifting model proposed by Prave (1999) that suggests rifting of Rodinia was not contained in a single event, rather a prolonged event that appears to have occurred over several hundred million years.

Petrographic analysis in combination with field work, suggests that the sediment source for the quartz-rich sandstone was extrabasinal, in agreement with previous workers (Sanderson, 1984; Ball and Farmer, 1998; Condie et al., 2001) and implies that these sands were brought in from the east by the proposed fluvial system (Fig. 40). The dominant clastic composition derived from the north is metaquartzite and lithic arenite. A major arkosic component was not observed, indicating that the Wyoming Craton, a likely source for arkosic sediment, was not a major source during Jesse Ewing time.

7.3 – Stratigraphic Implications

The provisional subdivision of lower, middle, and upper Uinta Mountain Group allows for a preliminary correlation of eastern Uinta Mountain Group stratigraphy north of Browns Park with the three informal formations suggested by De Grey (2005) (Fig. 42). If this is true, then lower, middle, and upper Uinta Mountain Group would be equivalent to the formation of Diamond Breaks, the formation of Outlaw trail, and formation of Crouse Canyon respectively (Fig. 42). This correlation could allow a common stratigraphic framework north and south of Browns Park and an eventual link between the eastern and western domes of the entire range.

7.4 – Modification of the Jesse Ewing Canyon Formation as a Unit

This research modifies the Jesse Ewing Canyon Formation from its original description and interpretation by Sanderson and Wiley (1986). These modifications allow for a more complete understanding of the thickness, areal extent, and depositional environments of the Jesse Ewing Canyon Formation. Modifications have been made to the maximum thickness and characterization of the unit. These modifications resulted in the subdivision of the formation into the two distinct members, the Head of Cottonwood member and Willow Creek member.

Originally interpreted as an alluvial fan, the Jesse Ewing Canyon Formation is more fully represented by what Sanderson and Wiley (1986) classify as “compatible adjacent environments.” This study expanded on this interpretation by stratigraphic mapping of the Jesse Ewing Canyon Formation in great detail and thus integrating all facies associated with this formation. The results of this study recognize the importance of the finer-grained facies as the most representative part of the Jesse Ewing Canyon Formation and that the coarser grained deposits are relatively minimal (in preserved areal extent and thickness). The Jesse Ewing Canyon Formation has been redefined to include all the finer-grained deposits that interbed or correlate with the coarser-grained facies, and are stratigraphically below the undifferentiated Uinta Mountain Group proper. This increases the maximum thickness of the formation from 225 meters as reported by Sanderson and Wiley (1986) to 1,000 meters in this study (see Section H in appendix A) and also allows for the subdivision of the formation based on coarse- and fine-grained lithology (Head of Cottonwood member and Willow Creek member, respectively). This study demonstrates that the Jesse Ewing Canyon Formation is generally a shale and sandstone unit representing alternating low energy suspension settling deposition with punctuated sheetflood, turbidite, nearshore, and braided fluvial deposition. Alluvial fans, represented by conglomerate, marked the northern margin of the basin, but were not representative of the overall deposition of the basin.

7.5 - Alternative Interpretations

Alternative stratigraphic interpretation is possible based on general stratigraphic trends seen on the map in the greater O-Wi-Yu-Kuts area. This interpretation would have significant stratigraphic implications regarding correlation within the Uinta Mountain Group and basin configuration during deposition. Preliminary map relationship observations comparing the similarity between the Jesse Ewing Canyon Formation and middle Uinta Mountain Group suggest that the section could be structurally repeated making the contact between the lower and middle Uinta Mountain Group a thrust fault rather than a depositional contact (see plate 1). Arguments can be made for both a depositional and fault contact, and while future work will resolve this issue, the implications of both interpretations are discussed below.

7.5.1 - Stratigraphic Interpretation

There are several lines of evidence that support a coherent stratigraphy interpretation for the area near O-Wi-Yu-Kuts Mountain. 1) The stratigraphic interpretation is in good agreement with Hansen (1965) and Sanderson (1984) that the Uinta Mountain Group paleobasin was asymmetric, resulting in thicker sediment accumulations to the north. 2) A stratigraphic interpretation is also consistent with work by DeGrey (2005) and proposes a good correlation with units along the southern margin of Browns Park. 3) The contact between the middle and upper Uinta Mountain Group appears to be gradational in the location with the best exposure north of Cold Spring Mountain. In contrast, the Jesse

Ewing Canyon Formation and the lower Uinta Mountain Group contact is sharp in all places where there is good exposure. 4) The repetitive nature and dominant lithotypes of the Uinta Mountain Group would predict a re-emergence of a facies through time. 5) As described in Chapter 4, this proposed thrust fault was suspected based on the close spatial relationship of the Head of Cottonwood member and the middle Uinta Mountain Group. The lack of sufficient field evidence led to the conclusion that these were indeed two distinct and separate units, and the fact that present day exposures of the Head of Cottonwood and middle Uinta Mountain Group are juxtaposed to one another is merely a coincidence. 6) The proposed thrust fault would not follow the structural trend of the area. This thrust fault would be parallel to bedding for the majority of its length at a relatively low-angle whereas most other faults in the area are reverse faults that truncate bedding. 7) Lastly, a structural ramp to the north is required to cut up through the the UMG and repeat the section of JECF and lower UMG. This would require 10s of kms of lateral and vertical displacement, that, when restored, would put the displaced UMG strata well to the north of the major Uinta-Sparks fault zone. All structural and basinal models suggest that there is little to no UMG strata north of this major structure (e.g. Sears et al., 1982; Stone, 1993) (Fig. 2). The potential thrust fault is not an impossibility, yet does go against all previous data sets and models for the shape of the UMG basin.

7.5.2 - Structural Interpretation

There are several lines of evidence that favor a thrust fault interpretation for the contact between the lower and middle Uinta Mountain Group. 1) The close spatial relationship of the Head of Cottonwood member and the middle Uinta Mountain Group in the Bender Draw area is suggestive that these lithologically similar units are indeed the same formation. 2) Aerial photographic interpretation suggests that there is little to no displacement on the Bender Fault north of O-Wi-Yu-Kuts Mountain and that beds north of the Bender Fault are of the same formation as those south of the Bender Fault. 3) A repeated section on O-Wi-Yu-Kuts Mountain would effectively reduce the total calculated thickness of the Uinta Mountain Group by half (~4.2 km), which would be consistent with work by Sprinkel and Waanders (2005) that suggests a thinner total thickness based on thermal index of alteration (TAI) work. 4) If a thrust fault exists between the lower and middle Uinta Mountain Group this would be an eastward continuation of the previously mapped Willow Creek Fault. 5) Lastly, the observed stratigraphy of the middle Uinta Mountain Group so closely matches the Jesse Ewing Canyon Formation stratigraphy that they could be the same unit instead of two separate units with similar depositional settings. This is strengthened by nearly identical detrital zircon populations that are found within the Willow Creek member and the formation of Outlaw Trail (Fanning and Dehler, 2005).

This second interpretation would have several stratigraphic implications that are inconsistent with previous work and would rely on future work to properly understand. Work by Hansen (1965) and Sanderson (1984) independently suggest that the Uinta Mountain Group was deposited in an asymmetric basin that thickened to the north in both the eastern and western domes respectively. If the stratigraphy north of Brows Park exposed near O-Wi-Yu-Kuts Mountain demonstrates a repeated section through thrust faulting, then the this would suggest a much more symmetric basin that was not controlled by a dominant fault immediately to the north. Secondly the thrust fault interpretation proposes inconsistent stratigraphy for the southern margin of Browns Park in comparison with work by DeGrey (2005). This interpretation would imply that the Jesse Ewing Canyon Formation would be equivalent to the formation of Diamond Breaks and formation of Outlaw Trail. This interpretation also implies that these shales are replaced by sandstones with southwesterly directed paleocurrents, nearly 90° off from those observed within the Jesse Ewing Canyon Formation sandstones. For this to be true then there must be basin partitioning within the Uinta Mountain Group paleobasin that separates Jesse Ewing Canyon Formation deposition on the north side from deposition on the south side while still maintaining similar thicknesses. This divide within the basin would allow a shallow body of water to exist on the northern margin but not along the southern margin.

7.6 – Greater Implications

Detrital zircon work and detailed stratigraphic analysis of the Jesse Ewing Canyon Formation has regional implications that further constrain our understanding of Neoproterozoic processes at ~781 Ma. No glacial deposits were observed within the JECF, therefore no glacial deposition took place in this area at ~781 Ma. Additionally, the JECF records a rifting event that precedes the development of the passive continental margin in this area.

CHAPTER 8

CONCLUSIONS

Through stratigraphic mapping, facies, paleocurrent, and petrographic and detrital zircon analysis of the mountainous region north of Browns Park, a better understanding has been gained of the eastern Uinta Mountain Group stratigraphy.

A focus on the Jesse Ewing Canyon Formation provides insight into the active depositional processes and allows for modification of previous depositional and paleogeographic models. The model proposed by this research suggests alluvial fan deposition along an active northern basin margin that graded basinward into a very low gradient west flowing braidplain and mudflat periodically submerged by a shallow, possibly marine, body of water. This braidplain was punctuated by episodic deposition of sheetfloods originating from the north off the alluvial fans and, when submerged, turbidites originating from the north. Flow direction of the braidplain may reflect hangingwall tilt to the west-northwest. Past the distal reaches of this braidplain lies a storm-effected shallow body of water that periodically transgresses and regresses dependent on local tectonic activity and possibly regional climate.

Stratigraphic mapping of this region allowed for the subdivision of the Jesse Ewing Canyon Formation into two members and the division of the previously undifferentiated Uinta Mountain Group into three preliminary formations. Based primarily on lithology and facies, the Jesse Ewing Canyon

Formation has been subdivided into a coarse-grained Head of Cottonwood member and a fine-grained Willow Creek member. Subdivisions within the Uinta Mountain Group are dependent on a shaley to conglomeratic middle unit referred to as the middle Uinta Mountain Group bounded by the lower and upper Uinta Mountain Group below and above, respectively.

The Jesse Ewing Canyon Formation is now informally divided two distinct members that represent very different depositional systems. The Head of Cottonwood member is a conglomeratic unit and is generally near the basal contact with the underlying Red Creek Quartzite. This member represents alluvial fan deposition along the northern margin of the Uinta Mountain Group basin whereby the majority of sediment of this member was locally derived from the Red Creek Quartzite. Three alluvial fans have been identified within the map area, distinguished by the systematic lateral thinning of conglomerate in three different areas. This member also contains lesser amounts of interbedded shale and sandstone representing interfan-lobe environments.

The Willow Creek member is composed of finer-grained strata that represent the distal margins of the alluvial fans or, where submergent, fan deltas. This member consists predominately of shale and sandstone with lesser amounts of conglomerate. The maroon shale facies represents deposition in a proximal fan delta or distal alluvial fan that received periodic sand deposition. These sands were deposited by two main processes: sheetflood and turbidite. The sandstone facies represents deposition by braided fluvial and nearshore environments that reworded braided fluvial deposits. The well sorted, moderately well rounded nature of all these deposits reflects an extrabasinal system proposed to be a west flowing braided fluvial system (Wallace and Crittenden, 1969; Sanderson, 1984; Ball and Farmer, 1998; Condie et al., 2001). Also in the Willow Creek member is the green sandstone and shale facies which represents deposition near and below fair weather wave base on a storm-effected coast. The vertical stacking of these facies suggests shifting of basinal environments northward as the basin continued to widen.

Preliminary detrital zircon data and petrographic data show that the Jesse Ewing Canyon Formation indicates basin initiation in the area at about 781 Ma and that there were at least five different sediment populations. These populations include: two late Late Archean sources, Paleoproterozoic, Grenville, and a single 781 Ma grain. The maximum depositional age indicates that initial rifting could have started no later than ~781 Ma in this area. This is the earliest Neoproterozoic rifting that has been geochronologically documented in the western US and represents an earlier phase of rifting of Rodinia; making the protracted rifting of Neoproterozoic western Laurentia even more so (Prave, 1999; Colpron et al., 2002).

Provenance data combined with paleocurrent and facies data suggest that the sediment derived from the north consisted primarily of Red Creek Quartzite with feldspathic sands transported in after headward erosion through the uplands captured streams that derived sediment from the Wyoming Craton. Other sources of arkosic and quartz-rich sediment likely came from the southeast to east via a west traveling fluvial system (Wallace and Crittenden, 1969; Ball and Farmer, 1998; Condie et al., 2001). Though initially brought into the basin through a fluvial system, these sediments were ultimately deposited as a combination of alluvial, fluvial, turbidite, and shoreline processes.

Climatic and tectonic controls are observed on different scales within the stratigraphy of the Jesse Ewing Canyon Formation. Small scale (1-10 meter-scale) cyclicity within the JECF is likely climatically influenced. Cycles may be the result of short-lived intense storms or short-term changes in base level. Intermediate cyclicity (10s to 100s of meters) may indicate base-level rise and fall associated with regional or global climate change. Larger cyclicity (1,000 meter scale) and the overall fining upward within the JECF is likely the result of tectonic activity along basin margin faults. Times that show conglomeratic facies and little reworking by secondary processes indicate rapid subsidence and times of increased tectonic activity. This is best displayed in the Head of Cottonwood member and the middle Uinta Mountain Group.

The undivided Uinta Mountain Group has been subdivided based on the presence of a middle shale unit. The lower Uinta Mountain Group likely represents relative tectonic quiescence where a major braided fluvial system occupied the center of the basin and dominated deposition. The middle Uinta Mountain Group marks the re-emergence of Jesse Ewing Canyon-like deposition displaying similar facies associations. This demonstrates renewed tectonic activity and subsequent uplift of Red Creek Quartzite outcrop evidenced by the large (40 cm) subangular Red Creek Quartzite clasts housed within the conglomerate. Another period of likely relative tectonic quiescence followed resulting in the reintroduction of a major fluvial system in the area.

Similar stratigraphy has been observed on the south side of Browns Park by De Grey (2005) where designations of two dominantly sandstone formations are separated by a shaley interval thus subdividing the Uinta Mountain Group into the formation of Diamond Breaks, the formation of Outlaw Trail, and the formation of Crouse Canyon from bottom to top, respectively. Preliminary correlations have been made using the terminology of De Grey (2005) in attempts to build a stratigraphic framework for the eastern Uinta Mountain Group stratigraphy. If this work holds true, then the lower, middle, and upper Uinta Mountain Group would correlate with the formation of Diamond Breaks, the formation of Outlaw Trail, and the formation of Crouse Canyon, respectively (Fig. 42). Further characterization of the Uinta Mountain Group above the Jesse Ewing Canyon Formation would be needed to properly correlate these units.

Controls of the eastern undivided UMG stratigraphy are similar to those in the JECF. Small scale (1-10 meter-scale) cyclicity is likely driven by climate and large scale cyclicity (1,000 meter scale) are likely driven by local tectonics. The middle Uinta Mountain Group most likely records a time of increased tectonic activity while the time represented by the lower and upper Uinta Mountain Group record relatively less (though still tectonically active) periods of tectonic activity.

An alternative to the stratigraphic interpretation of the stratigraphy exposed on O-Wi-Yu-Kuts Mountain would suggest a major thrust fault that is bedding parallel along the lower and middle Uinta Mountain Group contact. This would imply that the stratigraphy exposed near O-Wi-Yu-Kuts Mountain is not coherent as previously thought, but rather demonstrates a repeated section. This would effectively eliminate the middle and upper Uinta Mountain Group and replace them with the repeated Jesse Ewing Canyon and lower Uinta Mountain Group stratigraphy, respectively. While circumstantial evidence suggests that this thrust fault does not exist, this interpretation cannot be dismissed. The close spatial relationships and similarities of the Head of Cottonwood member and the middle Uinta Mountain Group suggest that these two units may indeed be the same.

While the results of this study have advanced the understanding and correlation of the eastern Uinta Mountain Group stratigraphy, it is still premature to determine how the eastern and western Uinta Mountain Group stratigraphy correlate. This study is in agreement with Sanderson and Wiley (1986), who suggest that the basal facies in the western formation of Red Castle represent similar depositional environments as those observed in the eastern Uinta Mountain Group (lower and upper Uinta Mountain Group, this study). This is only a preliminary correlation as it is equally likely that western units in the subsurface correlate to the eastern stratigraphy. At this time, correlation with the Big Cottonwood Formation of the Wasatch is not possible, but work in progress by

Dehler et al. (2001, 2007) will hopefully make advancements correlating the Neoproterozoic strata of northern Utah.

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APPENDICES

APPENDIX A
Measured stratigraphic sections

Key to measured sections

Break in section

Hummocky Cross-stratification

Lense

Ripples

Plane beds

Planar cross bedding

Trough cross bedding

Scour cast

Graded bedding

Mudcracks

Channel

Tangential cross beds

Soft sediment deformation

Pebble lag

Laminations

Paleocurrent direction

Paleocurrent trend with unmeasured plunge

A-2 (15m)	Sample location
A-1 (7.5m)ts	Sample location with petrographic data
B-2* (1m)	Detrital zircon sample
PC-H1 (3 m)	Paleocurrent Station
M 1	Marker bed interval used for correlation between measured sections
4	Interpreted facies, see Table 1 for facies description

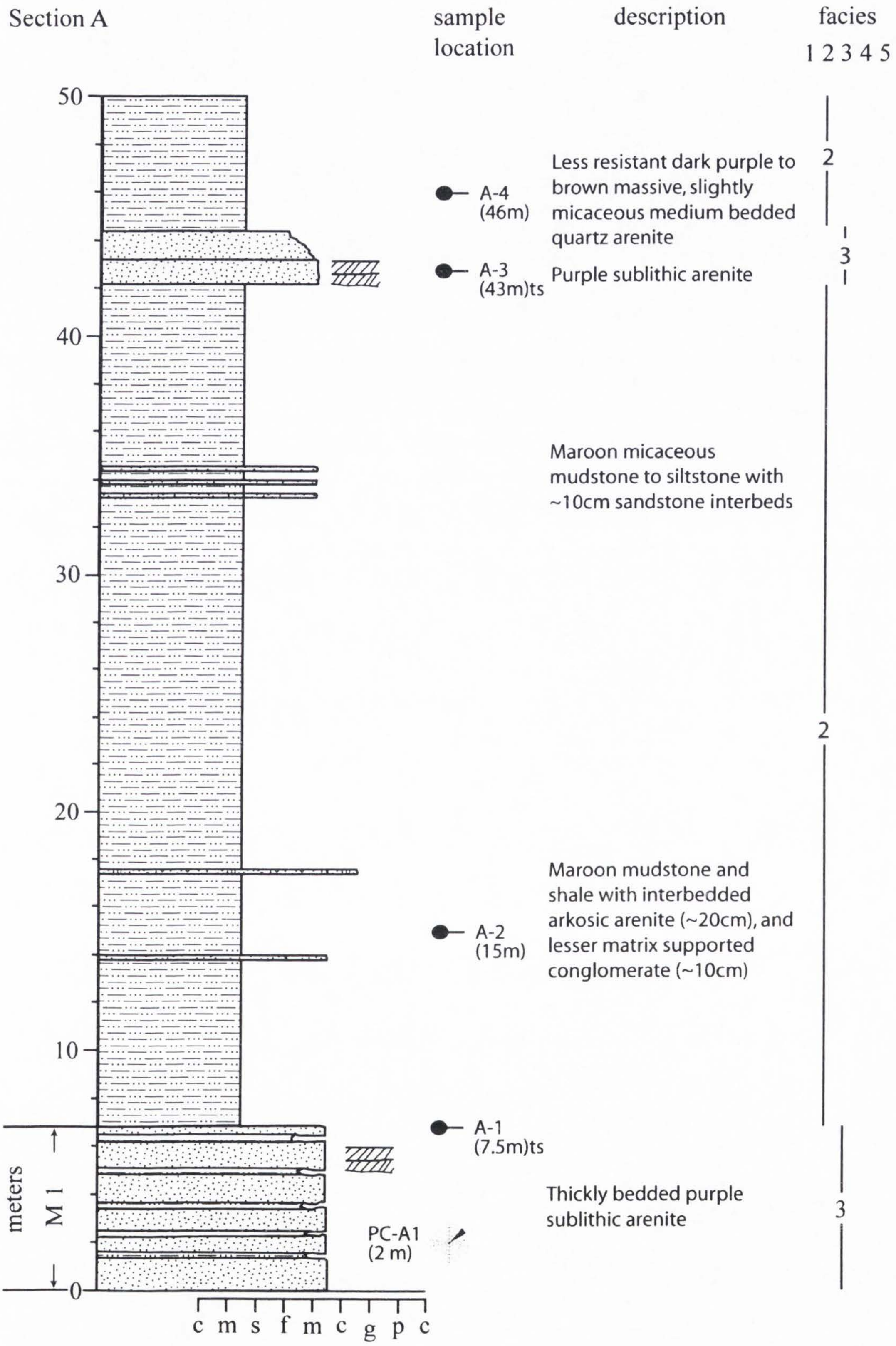
Sandstone with granules

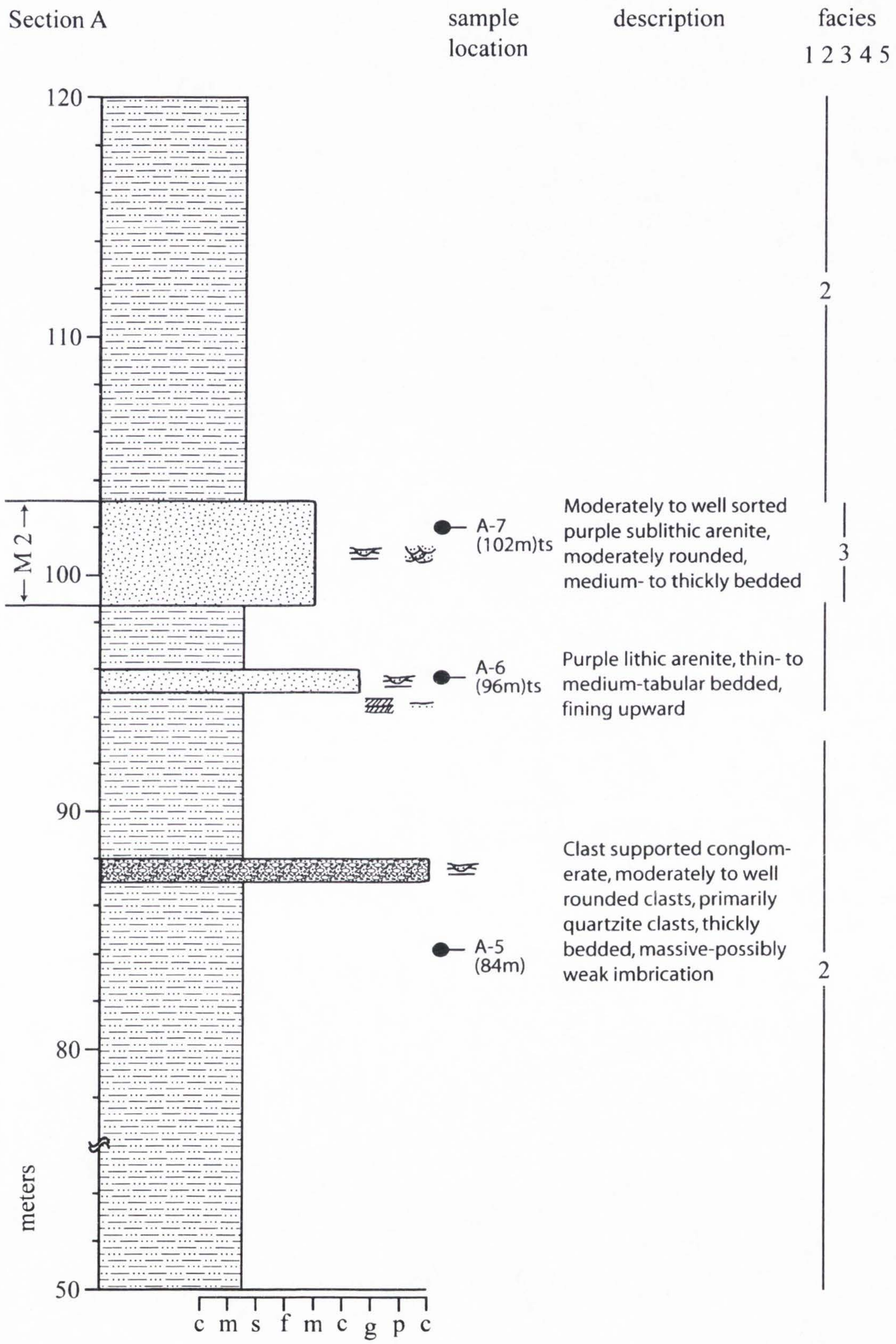
Sandstone

Mudstone

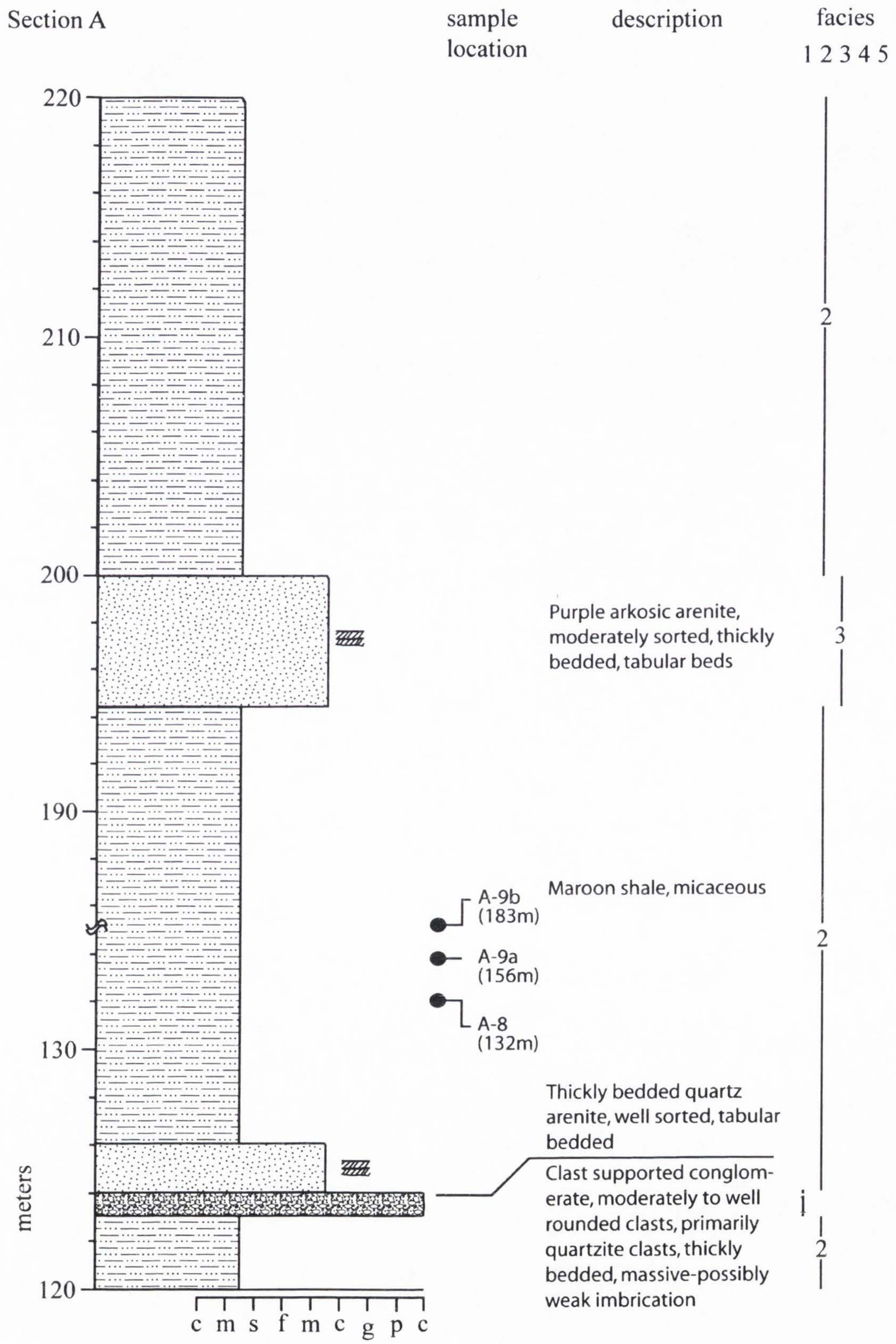
Silty shale

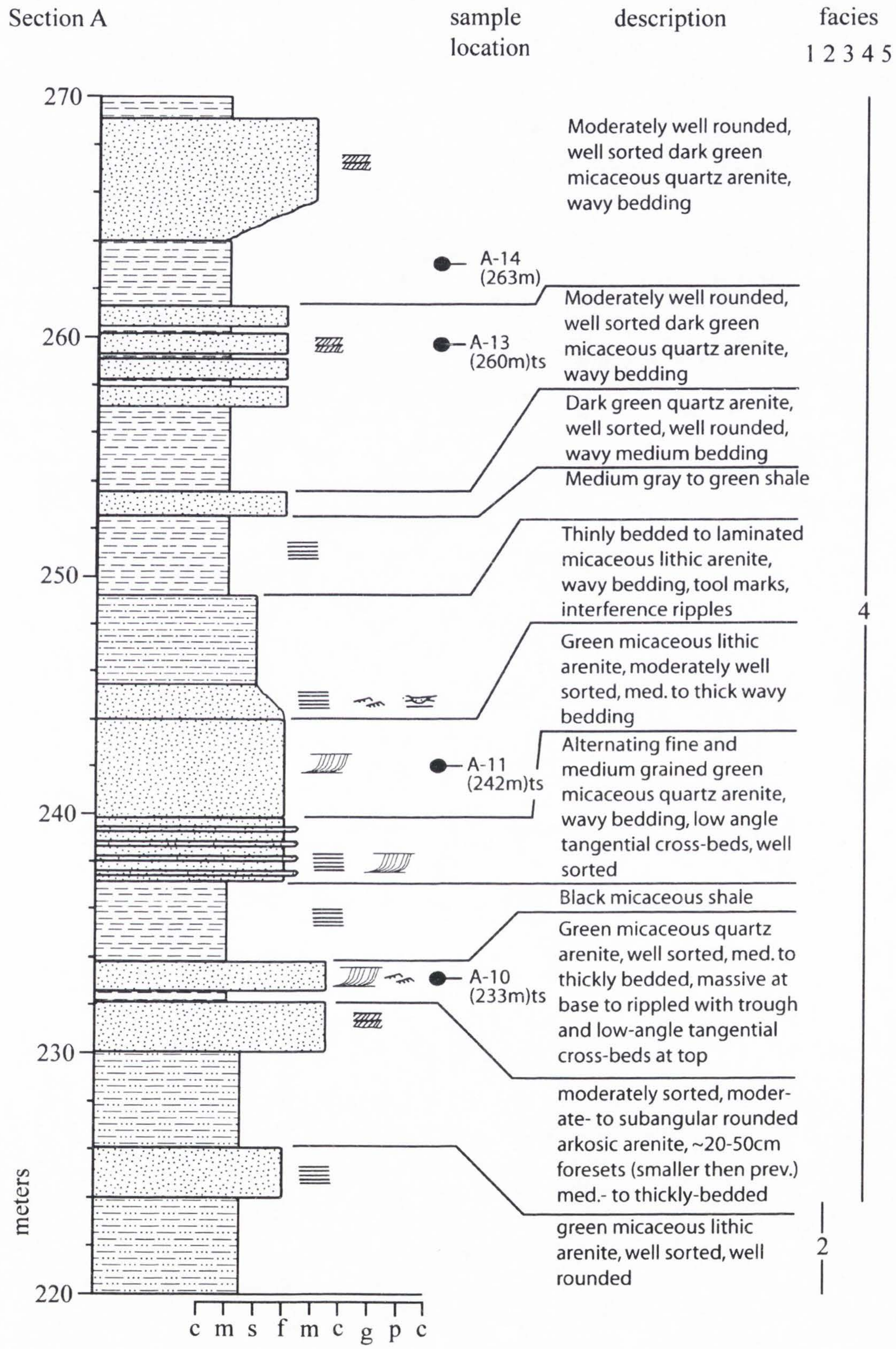
Conglomerate

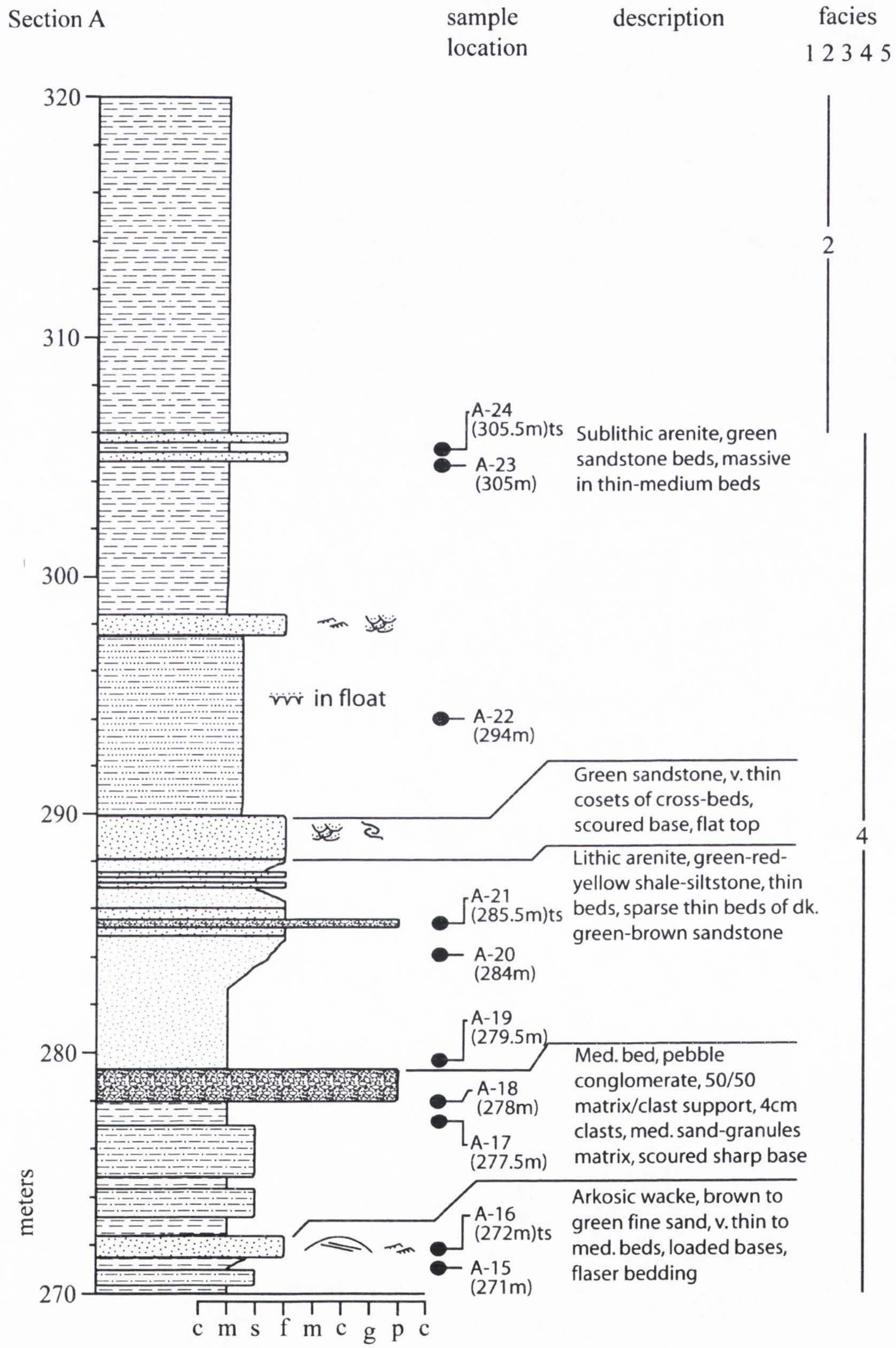

Section A
sample location
description
facies
1 2 3 4 5
50
40
30
20
10
0
meters
M 1
A-4 (46m)
Less resistant dark purple to brown massive, slightly micaceous medium bedded quartz arenite
2
A-3 (43m)ts
Purple sublithic arenite
3
Maroon micaceous mudstone to siltstone with ~10cm sandstone interbeds
2
A-2 (15m)
Maroon mudstone and shale with interbedded arkosic arenite (~20cm), and lesser matrix supported conglomerate (~10cm)
A-1 (7.5m)ts
Thickly bedded purple sublithic arenite
3
PC-A1 (2 m)
c m s f m c g p c

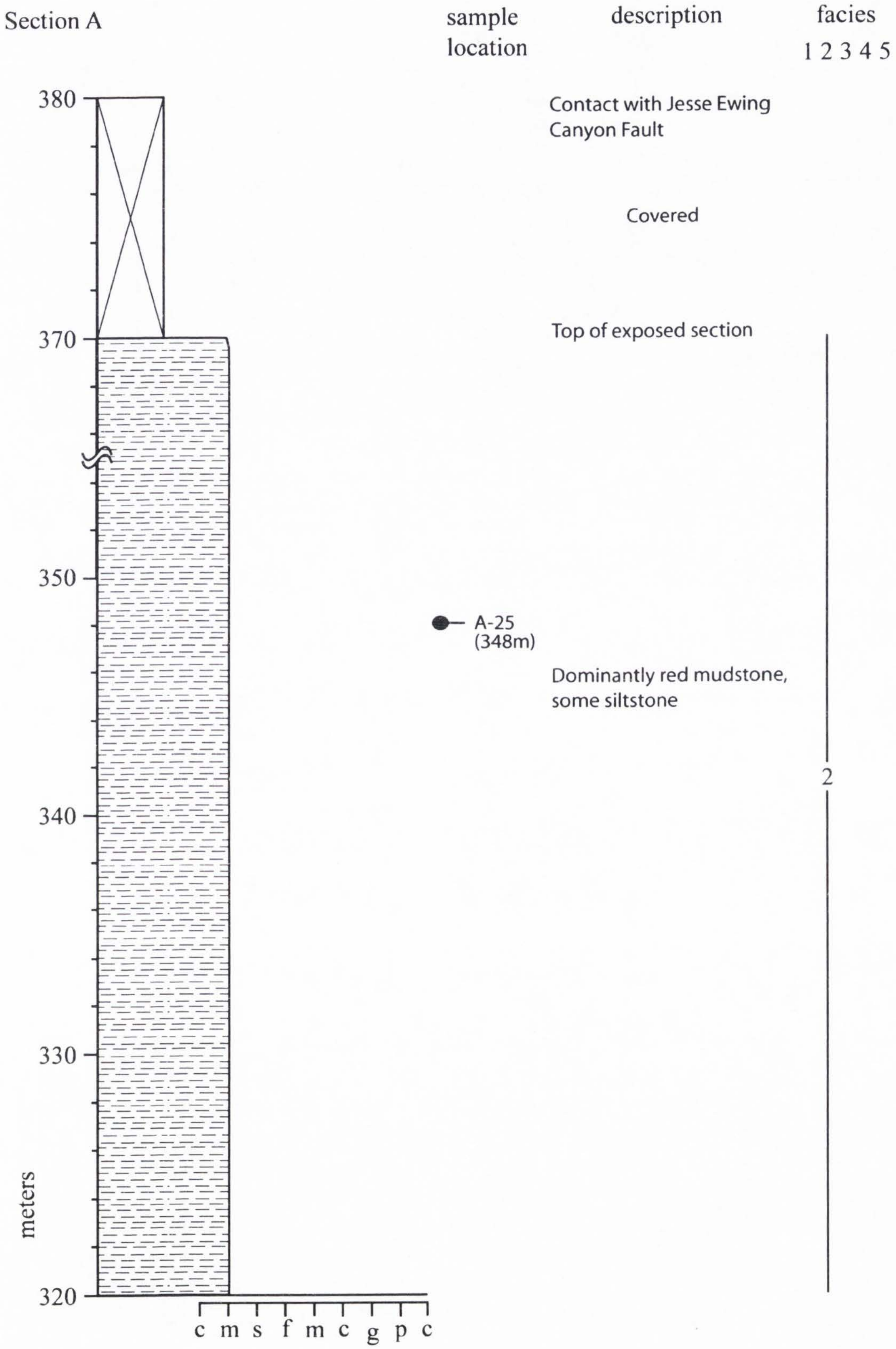


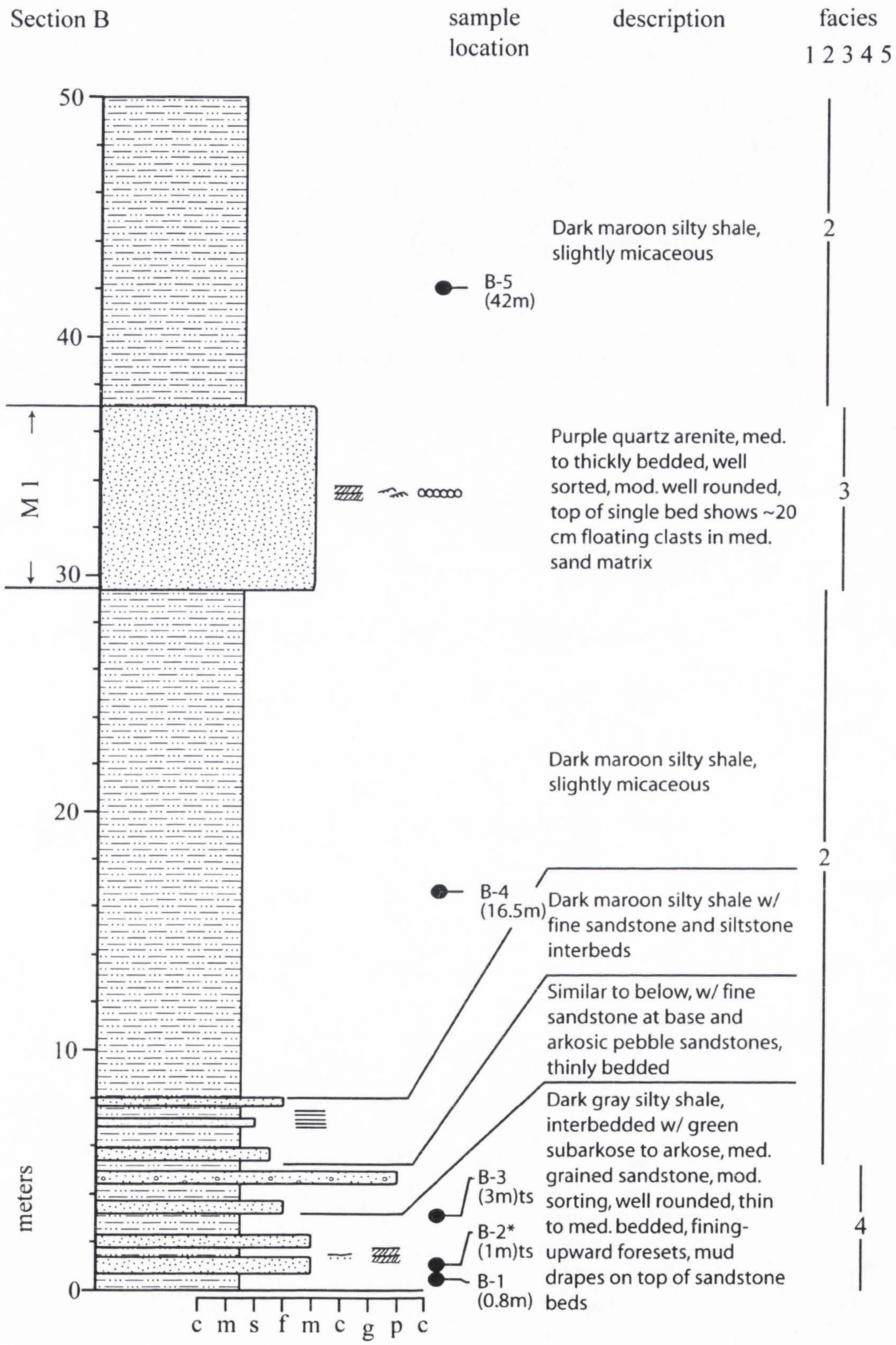
Section A
sample location
description
facies
1 2 3 4 5
120
110
100
90
80
50
meters
M 2
A-7 (102m)ts
Moderately to well sorted purple sublithic arenite, moderately rounded, medium- to thickly bedded
A-6 (96m)ts
Purple lithic arenite, thin- to medium-tabular bedded, fining upward
Clast supported conglomerate, moderately to well rounded clasts, primarily quartzite clasts, thickly bedded, massive-possibly weak imbrication
A-5 (84m)
2
3
2
c m s f m c g p c

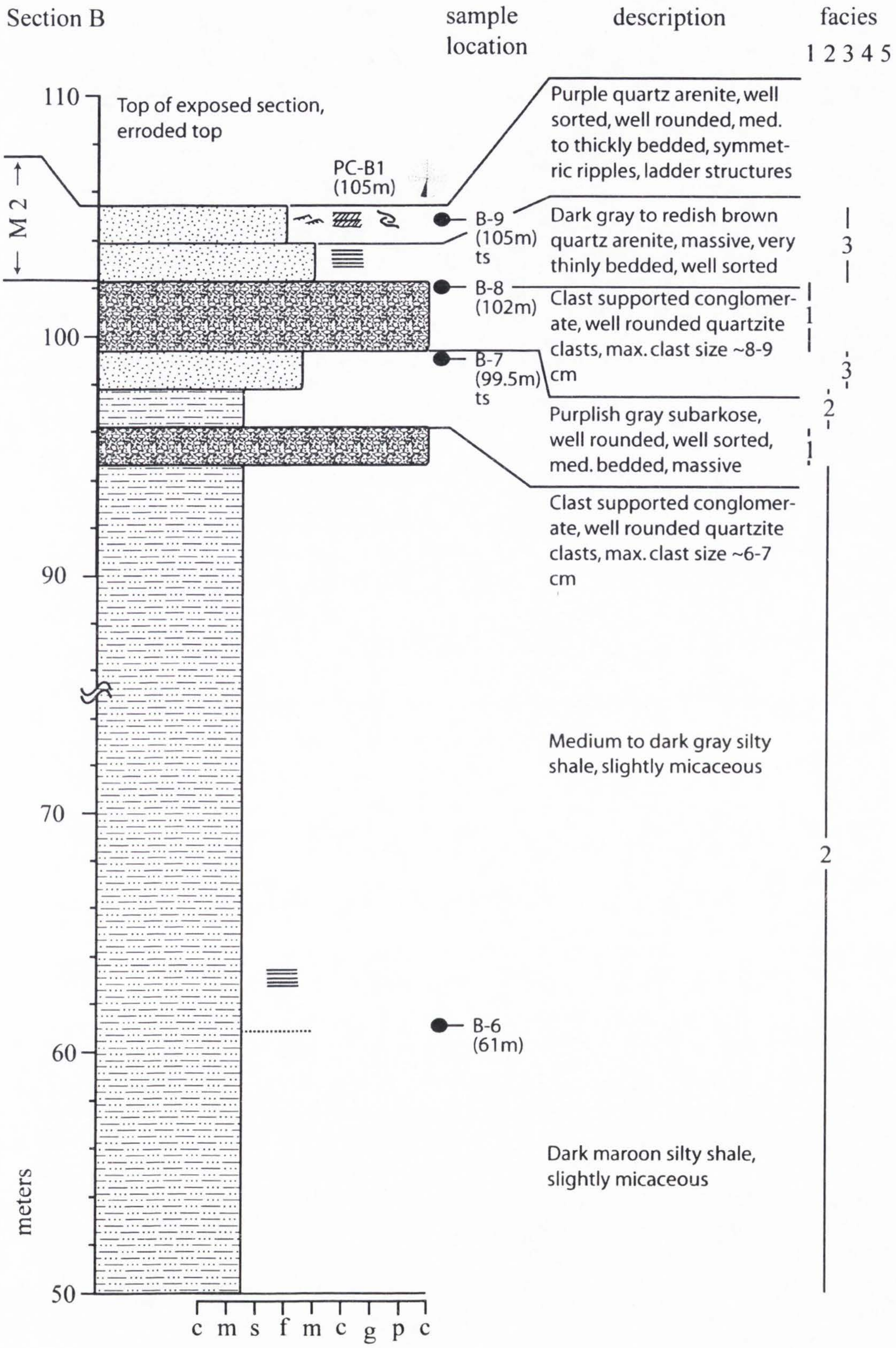

Section A
sample location
description
facies
1 2 3 4 5
220
210
200
190
130
120
meters
c m s f m c g p c
2
Purple arkosic arenite, moderately sorted, thickly bedded, tabular beds
3
A-9b (183m)
A-9a (156m)
A-8 (132m)
Maroon shale, micaceous
2
Thickly bedded quartz arenite, well sorted, tabular bedded
Clast supported conglomerate, moderately to well rounded clasts, primarily quartzite clasts, thickly bedded, massive-possibly weak imbrication
i
2


Section A
sample location
description
facies
1 2 3 4 5
270
260
250
240
230
220
meters
c m s f m c g p c
A-14 (263m)
A-13 (260m)ts
A-11 (242m)ts
A-10 (233m)ts
Moderately well rounded, well sorted dark green micaceous quartz arenite, wavy bedding
Moderately well rounded, well sorted dark green micaceous quartz arenite, wavy bedding
Dark green quartz arenite, well sorted, well rounded, wavy medium bedding
Medium gray to green shale
Thinly bedded to laminated micaceous lithic arenite, wavy bedding, tool marks, interference ripples
Green micaceous lithic arenite, moderately well sorted, med. to thick wavy bedding
Alternating fine and medium grained green micaceous quartz arenite, wavy bedding, low angle tangential cross-beds, well sorted
Black micaceous shale
Green micaceous quartz arenite, well sorted, med. to thickly bedded, massive at base to rippled with trough and low-angle tangential cross-beds at top
moderately sorted, moder-ate- to subangular rounded arkosic arenite, ~20-50cm foresets (smaller then prev.) med.- to thickly-bedded
green micaceous lithic arenite, well sorted, well rounded
4
2

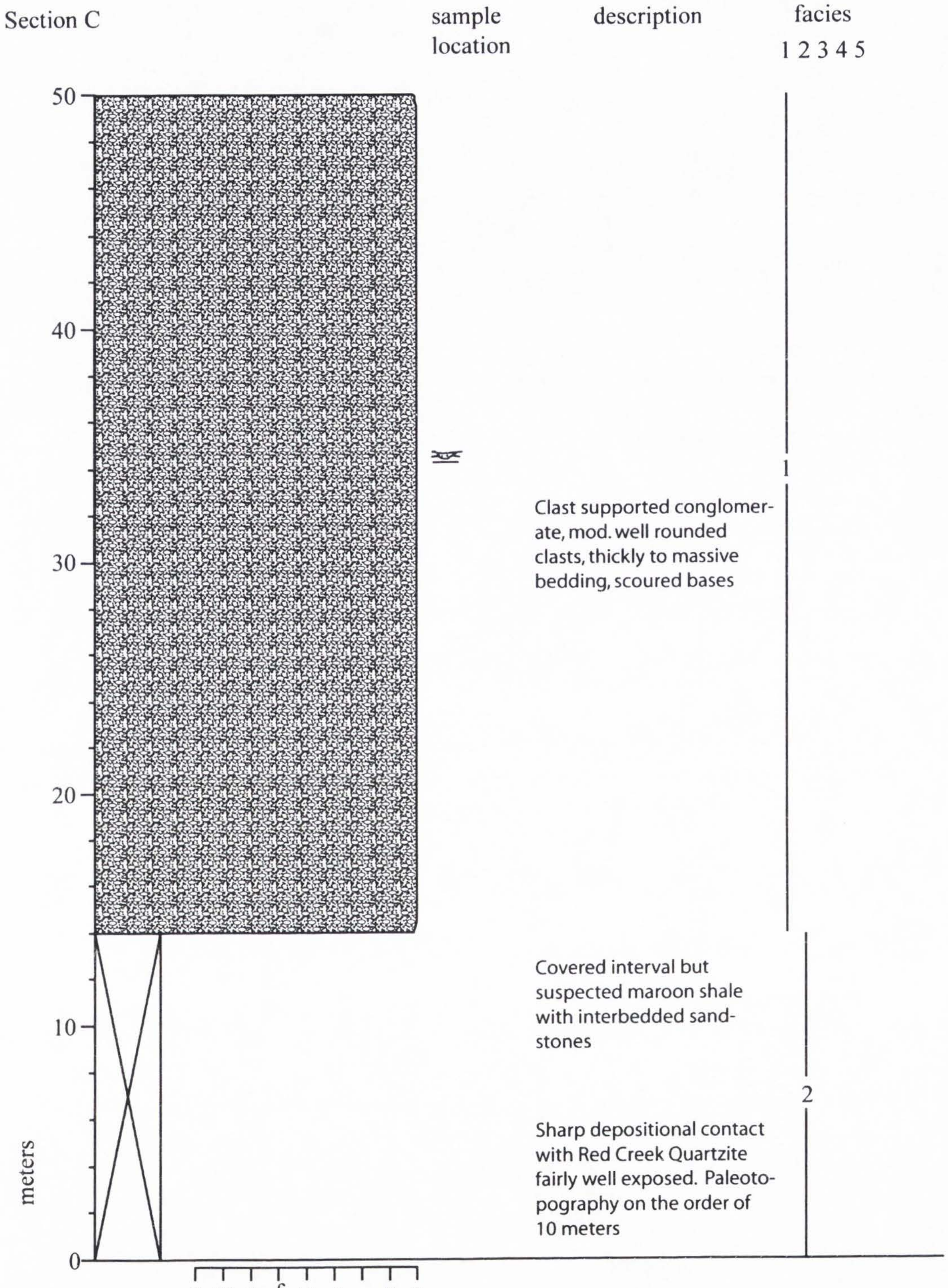

Section A
sample location
description
facies
1 2 3 4 5
320
310
300
290
280
270
meters
c m s f m c g p c
2
4
A-24 (305.5m)ts
A-23 (305m)
Sublithic arenite, green sandstone beds, massive in thin-medium beds
in float
A-22 (294m)
Green sandstone, v. thin cosets of cross-beds, scoured base, flat top
Lithic arenite, green-red-yellow shale-siltstone, thin beds, sparse thin beds of dk. green-brown sandstone
A-21 (285.5m)ts
A-20 (284m)
A-19 (279.5m)
Med. bed, pebble conglomerate, 50/50 matrix/clast support, 4cm clasts, med. sand-granules matrix, scoured sharp base
A-18 (278m)
A-17 (277.5m)
Arkosic wacke, brown to green fine sand, v. thin to med. beds, loaded bases, flaser bedding
A-16 (272m)ts
A-15 (271m)

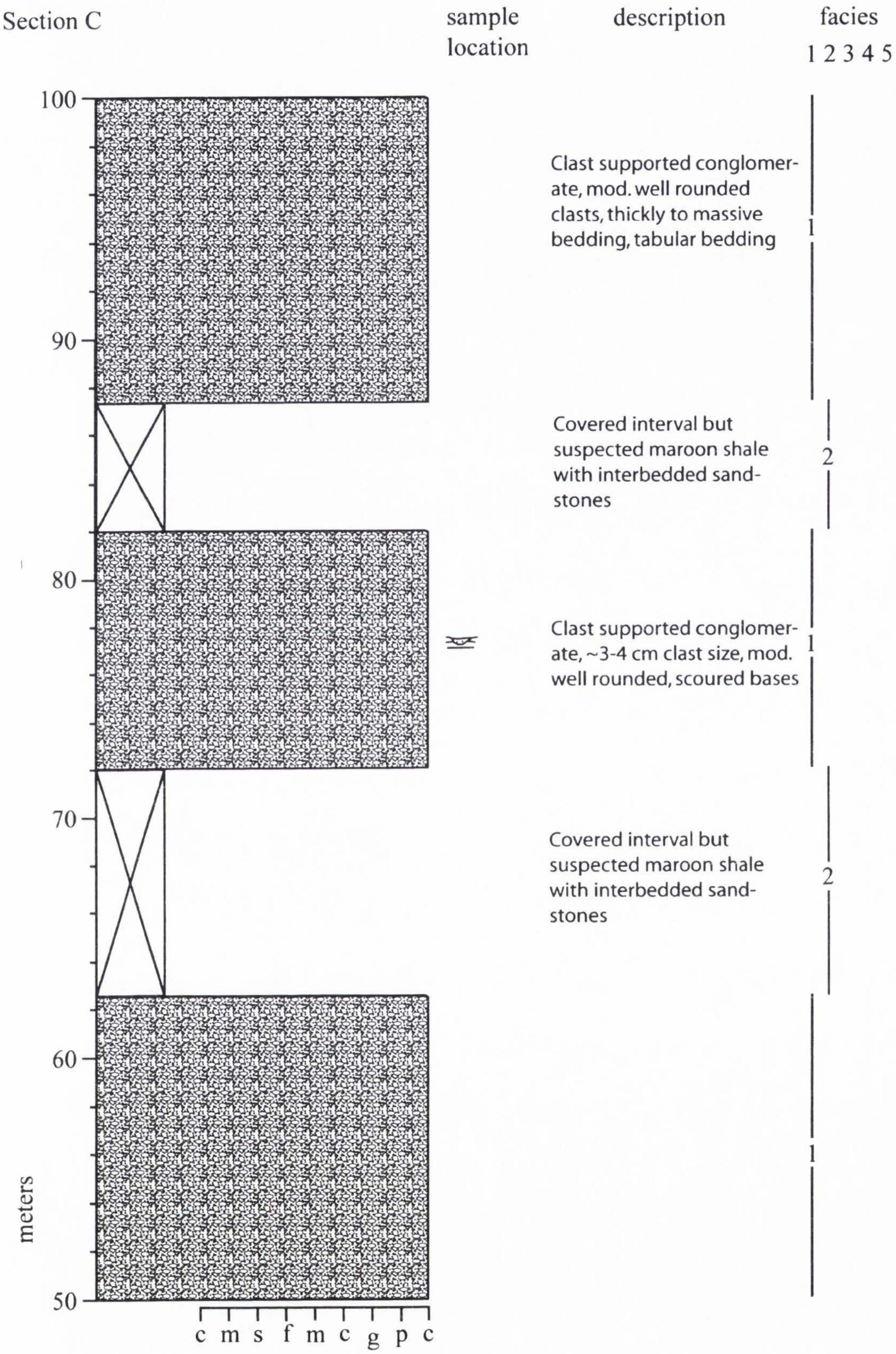

Section A
sample location
description
facies
1 2 3 4 5
380
370
350
340
330
320
meters
c m s f m c g p c
Contact with Jesse Ewing Canyon Fault
Covered
Top of exposed section
A-25 (348m)
Dominantly red mudstone, some siltstone
2

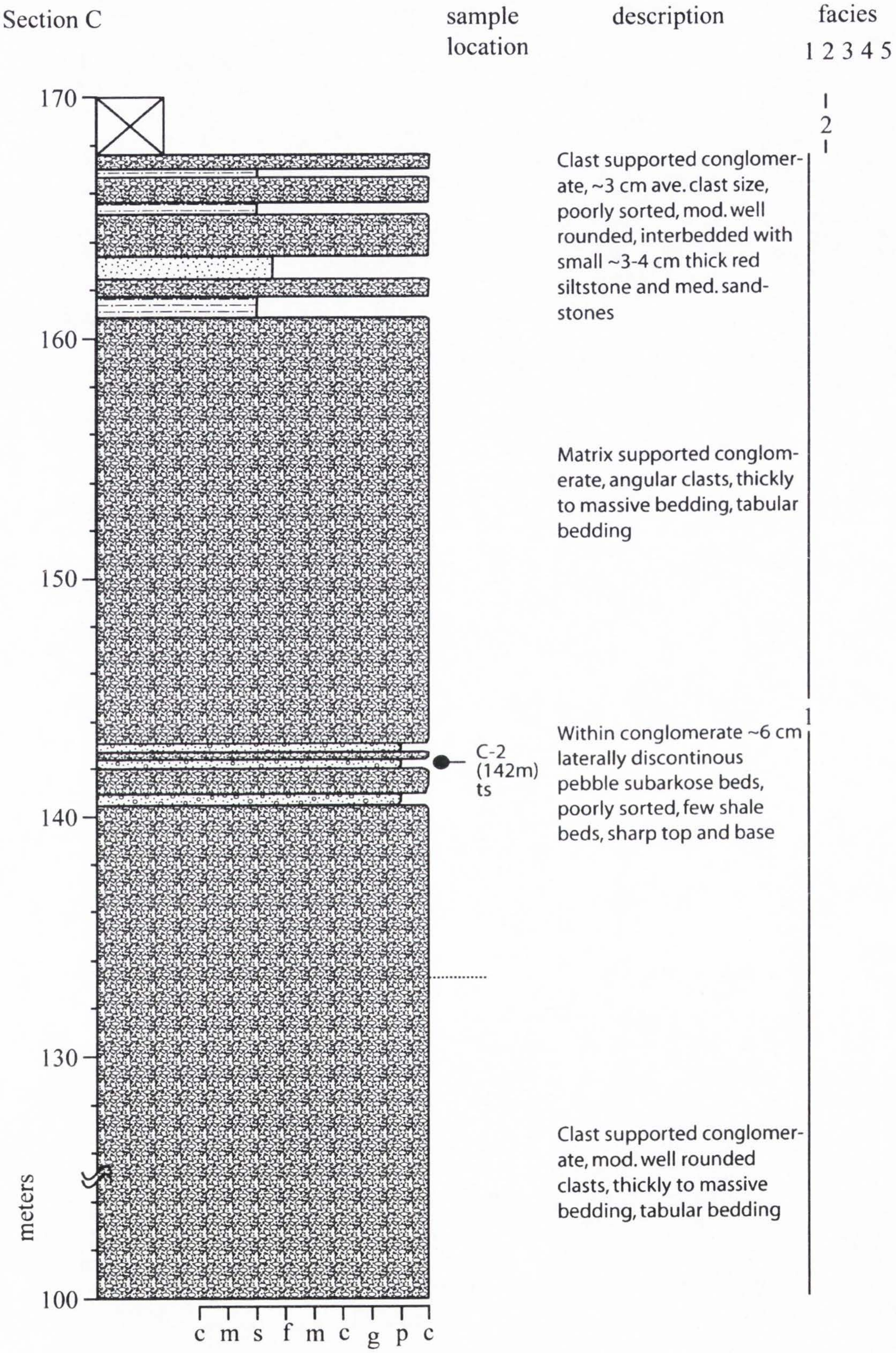

Section B
sample location
description
facies
1 2 3 4 5
50
40
30
20
10
0
meters
M 1
c m s f m c g p c
B-5
(42m)
B-4
(16.5m)
B-3
(3m)ts
B-2*
(1m)ts
B-1
(0.8m)
Dark maroon silty shale, slightly micaceous
Purple quartz arenite, med. to thickly bedded, well sorted, mod. well rounded, top of single bed shows ~20 cm floating clasts in med. sand matrix
Dark maroon silty shale, slightly micaceous
Dark maroon silty shale w/ fine sandstone and siltstone interbeds
Similar to below, w/ fine sandstone at base and arkosic pebble sandstones, thinly bedded
Dark gray silty shale, interbedded w/ green subarkose to arkose, med. grained sandstone, mod. sorting, well rounded, thin to med. bedded, fining-upward foresets, mud drapes on top of sandstone beds
2
3
2
4



Section B
sample location
description
facies
1 2 3 4 5
110
100
90
70
60
50
meters
M 2
Top of exposed section, erroded top
PC-B1 (105m)
B-9 (105m) ts
B-8 (102m)
B-7 (99.5m) ts
B-6 (61m)
Purple quartz arenite, well sorted, well rounded, med. to thickly bedded, symmetric ripples, ladder structures
Dark gray to redish brown quartz arenite, massive, very thinly bedded, well sorted
Clast supported conglomerate, well rounded quartzite clasts, max. clast size ~8-9 cm
Purplish gray subarkose, well rounded, well sorted, med. bedded, massive
Clast supported conglomerate, well rounded quartzite clasts, max. clast size ~6-7 cm
Medium to dark gray silty shale, slightly micaceous
Dark maroon silty shale, slightly micaceous
3
1
3
2
1
2
c m s f m c g p c

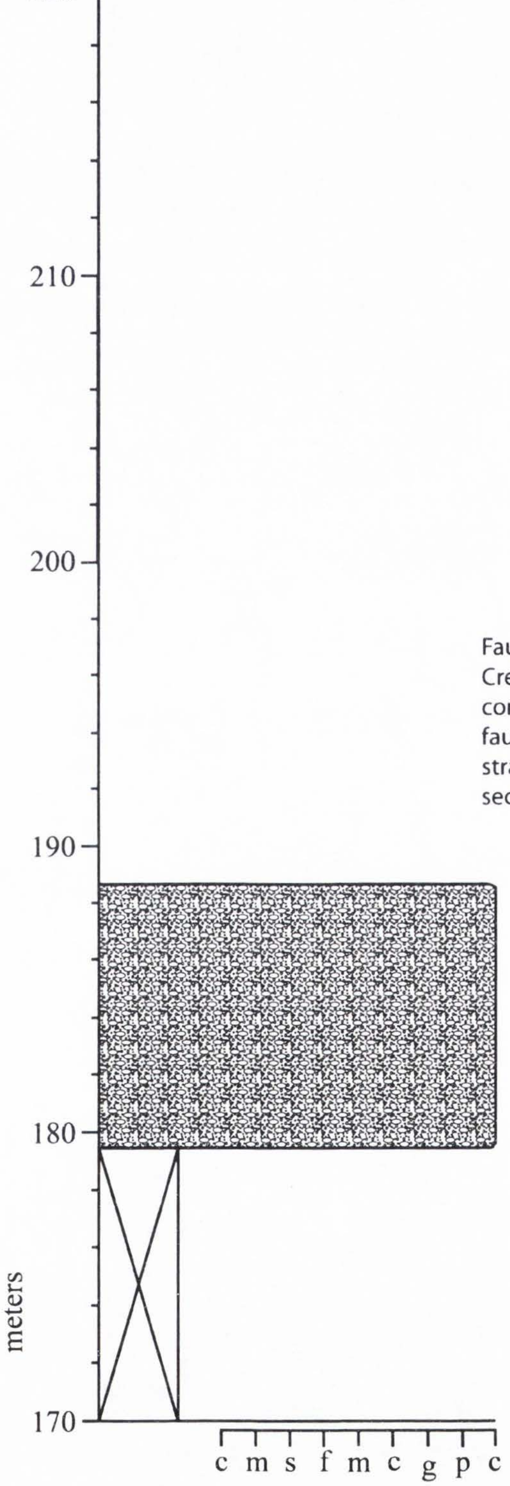

Section C
sample location
description
facies
1 2 3 4 5
50
40
30
20
10
0
meters
Clast supported conglomerate, mod. well rounded clasts, thickly to massive bedding, scoured bases
1
Covered interval but suspected maroon shale with interbedded sandstones
2
Sharp depositional contact with Red Creek Quartzite fairly well exposed. Paleotopography on the order of 10 meters
c m s f m c g p c


Section C
sample location
description
facies
1 2 3 4 5
100
90
80
70
60
50
meters
c m s f m c g p c
Clast supported conglomerate, mod. well rounded clasts, thickly to massive bedding, tabular bedding
1
Covered interval but suspected maroon shale with interbedded sandstones
2
Clast supported conglomerate, ~3-4 cm clast size, mod. well rounded, scoured bases
1
Covered interval but suspected maroon shale with interbedded sandstones
2
1


Section C
sample location
description
facies
1 2 3 4 5
170
160
150
140
130
100
meters
2
1
Clast supported conglomerate, ~3 cm ave. clast size, poorly sorted, mod. well rounded, interbedded with small ~3-4 cm thick red siltstone and med. sandstones
Matrix supported conglomerate, angular clasts, thickly to massive bedding, tabular bedding
C-2
(142m)
ts
Within conglomerate ~6 cm laterally discontinous pebble subarkose beds, poorly sorted, few shale beds, sharp top and base
Clast supported conglomerate, mod. well rounded clasts, thickly to massive bedding, tabular bedding
c m s f m c g p c

Section C

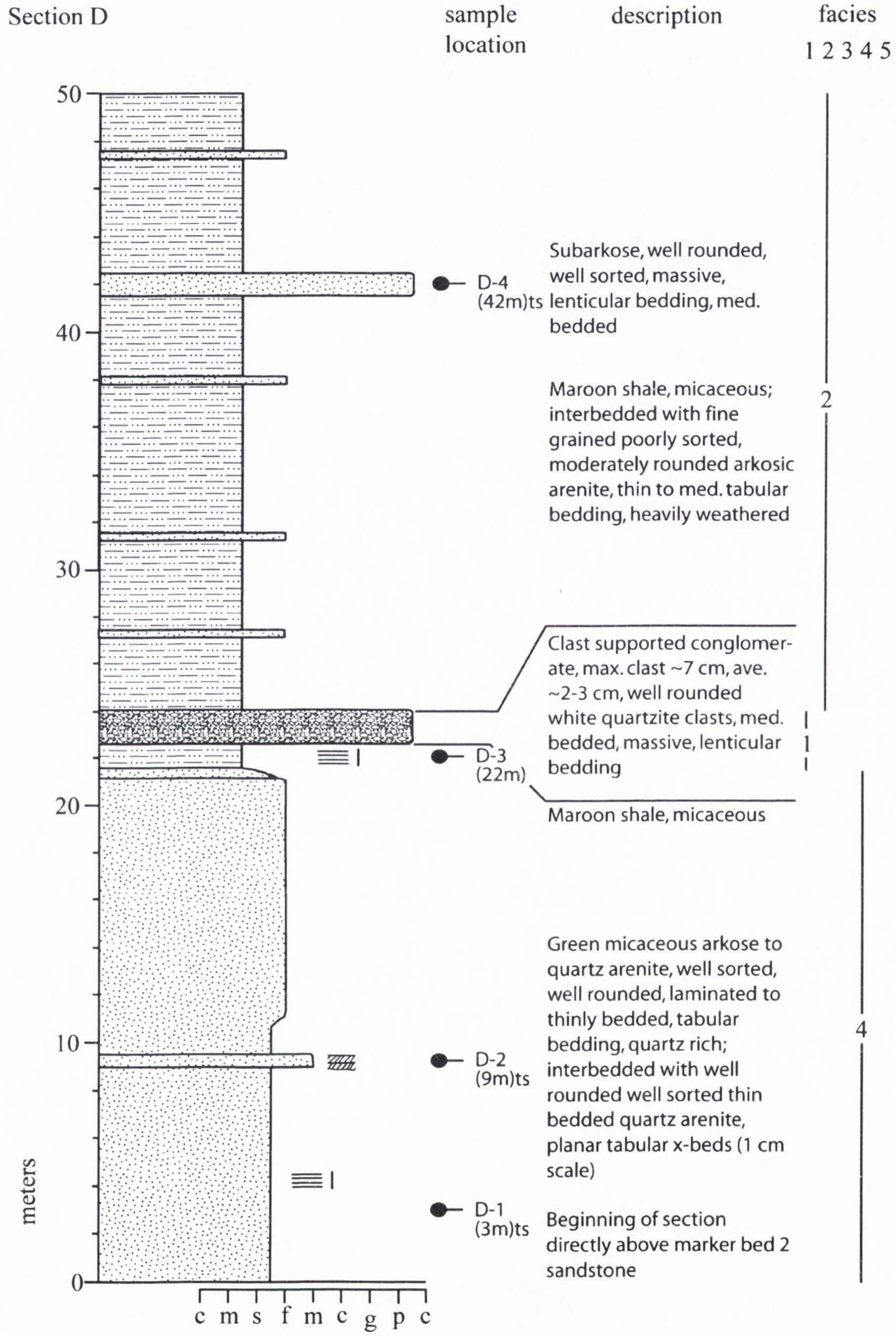
sample location | description | facies 1 2 3 4 5



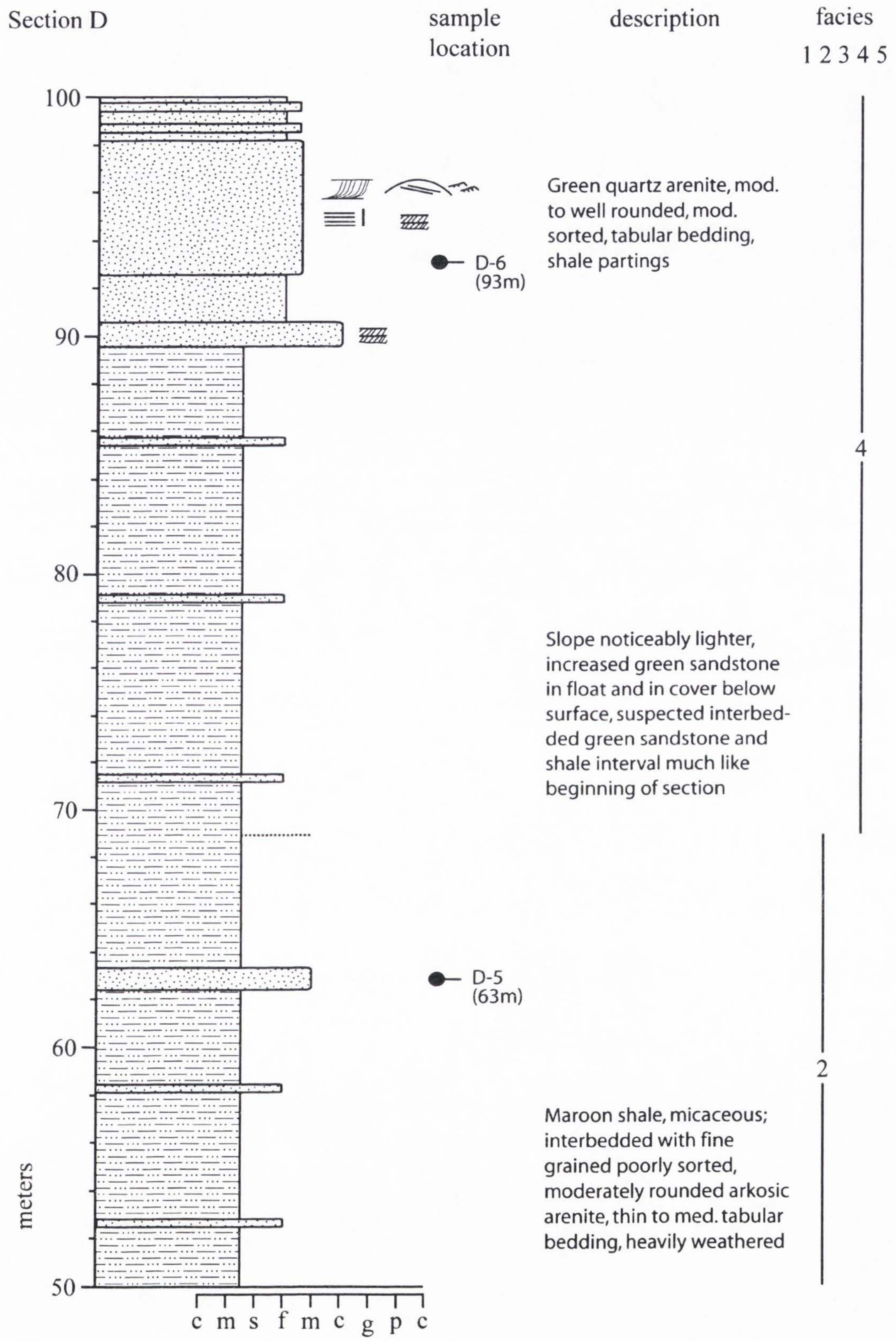
Fault contact with Willow Creek member. Structural complexities above this fault prohibit detailed stratigraphic measured sections.

Clast supported conglomerate, thickly to massive bedding, scoured bases, mod. well rounded to angular clasts, few matrix supported beds, ave. clast size ~5 cm — facies 1

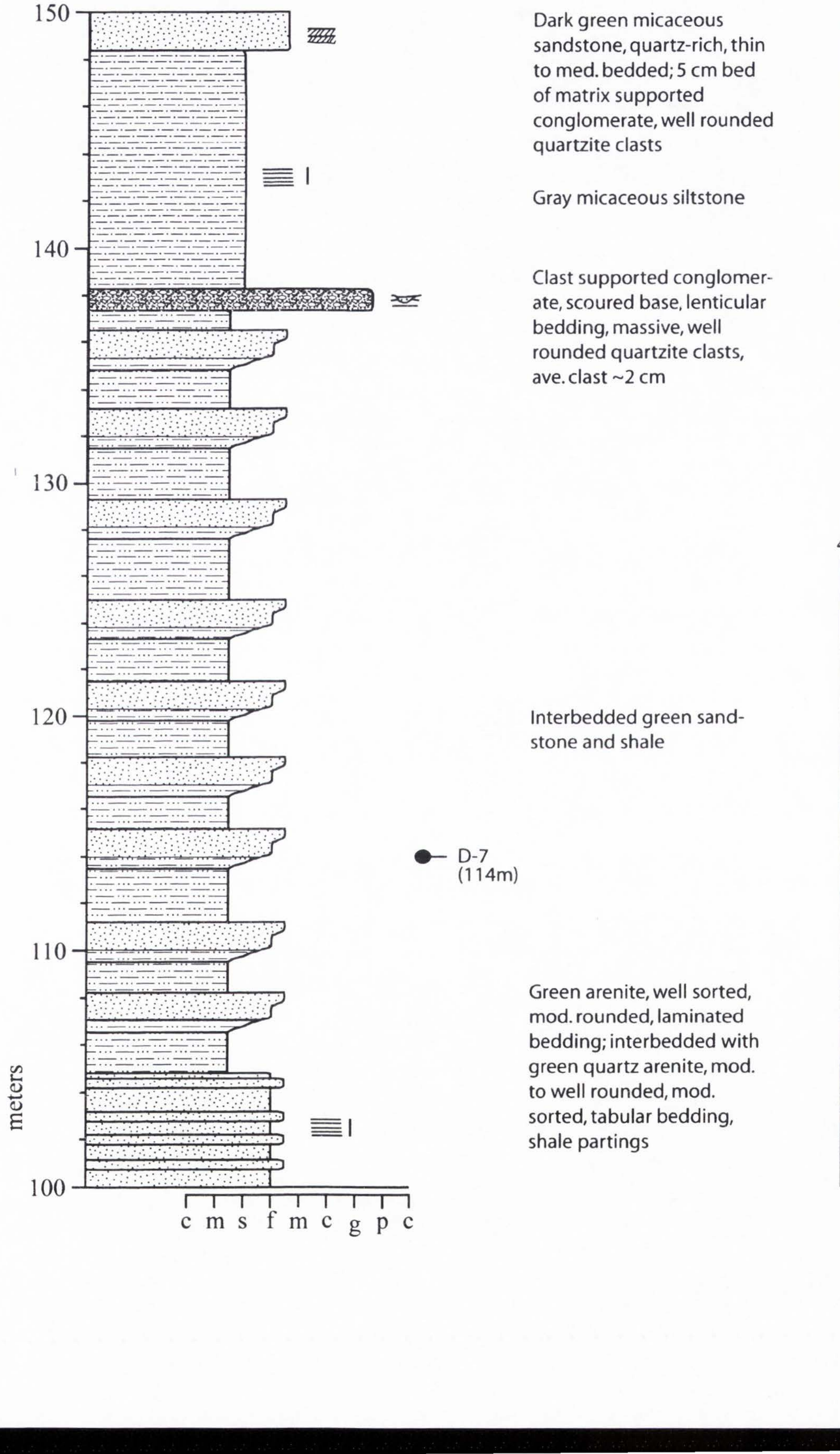
Covered interval but suspected maroon shale with interbedded sandstones — facies 2



Section D
sample location
description
facies
1 2 3 4 5
50
40
30
20
10
0
meters
c m s f m c g p c
D-4 (42m)ts
Subarkose, well rounded, well sorted, massive, lenticular bedding, med. bedded
Maroon shale, micaceous; interbedded with fine grained poorly sorted, moderately rounded arkosic arenite, thin to med. tabular bedding, heavily weathered
2
Clast supported conglomer-ate, max. clast ~7 cm, ave. ~2-3 cm, well rounded white quartzite clasts, med. bedded, massive, lenticular bedding
D-3 (22m)
Maroon shale, micaceous
Green micaceous arkose to quartz arenite, well sorted, well rounded, laminated to thinly bedded, tabular bedding, quartz rich; interbedded with well rounded well sorted thin bedded quartz arenite, planar tabular x-beds (1 cm scale)
4
D-2 (9m)ts
D-1 (3m)ts
Beginning of section directly above marker bed 2 sandstone


Section D
sample location
description
facies
1 2 3 4 5
100
90
80
70
60
50
meters
c m s f m c g p c
D-6 (93m)
D-5 (63m)
Green quartz arenite, mod. to well rounded, mod. sorted, tabular bedding, shale partings
Slope noticeably lighter, increased green sandstone in float and in cover below surface, suspected interbedded green sandstone and shale interval much like beginning of section
Maroon shale, micaceous; interbedded with fine grained poorly sorted, moderately rounded arkosic arenite, thin to med. tabular bedding, heavily weathered
4
2

Section D | sample location | description | facies 1 2 3 4 5



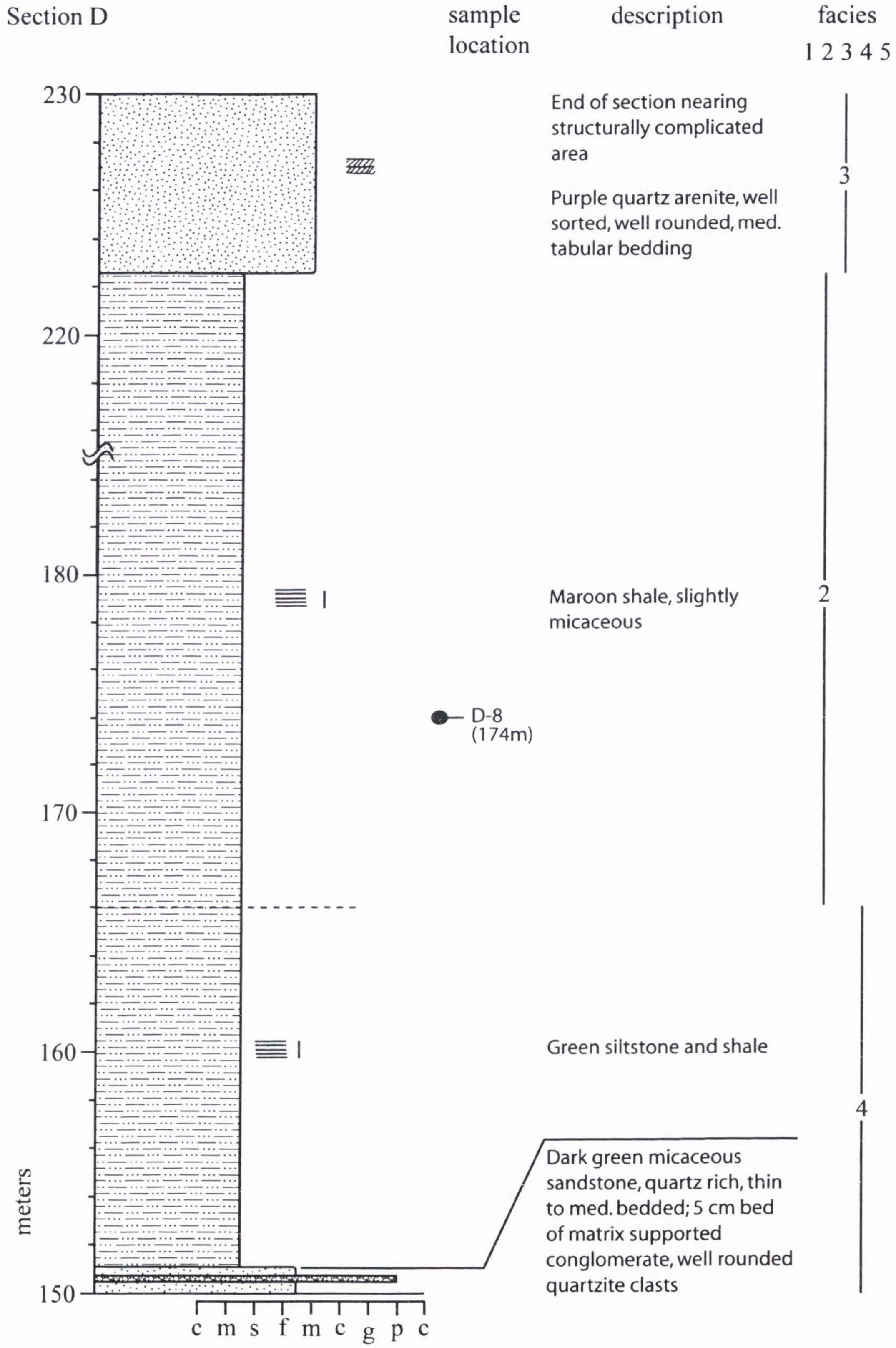
Dark green micaceous sandstone, quartz-rich, thin to med. bedded; 5 cm bed of matrix supported conglomerate, well rounded quartzite clasts

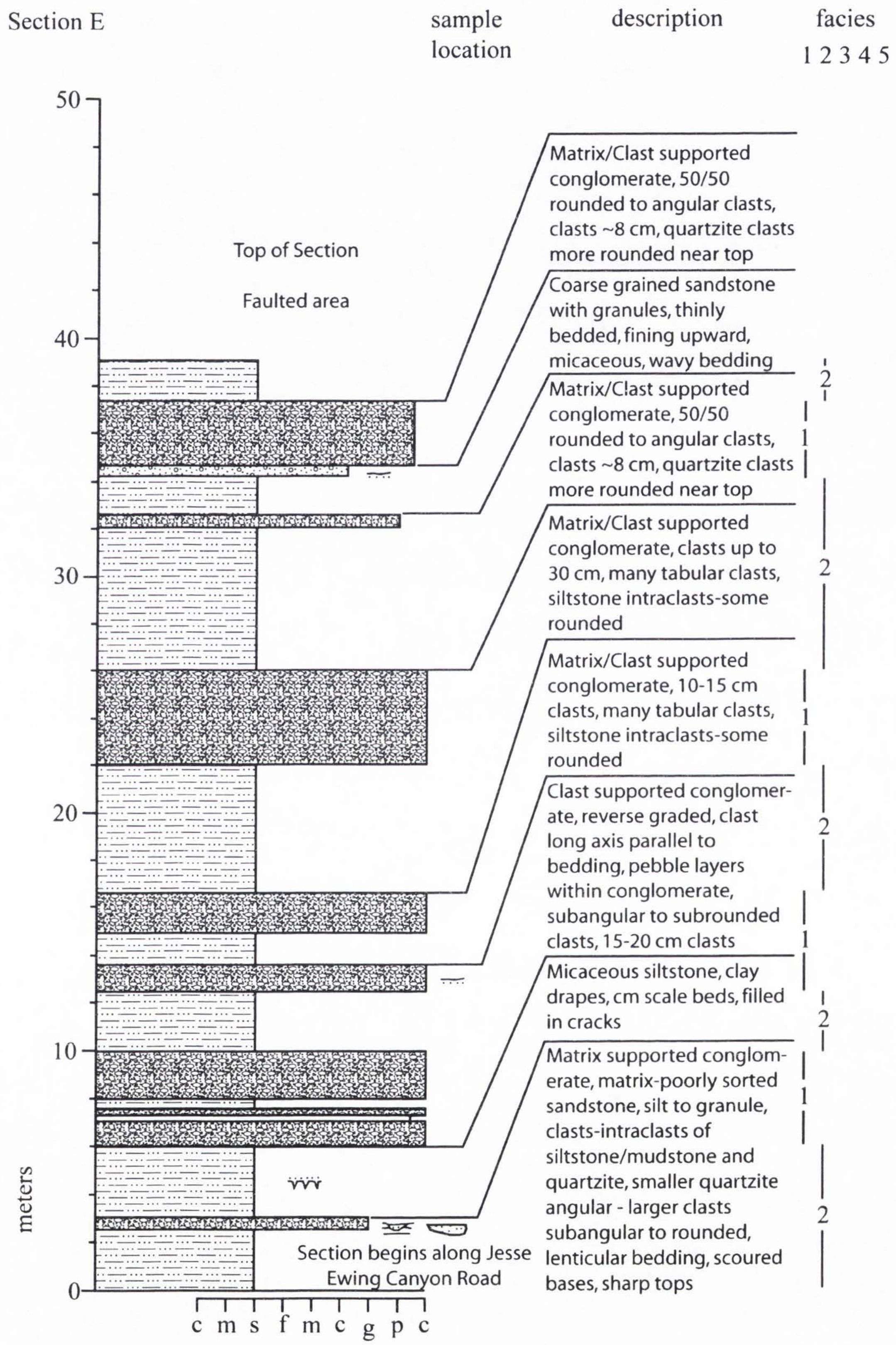
Gray micaceous siltstone

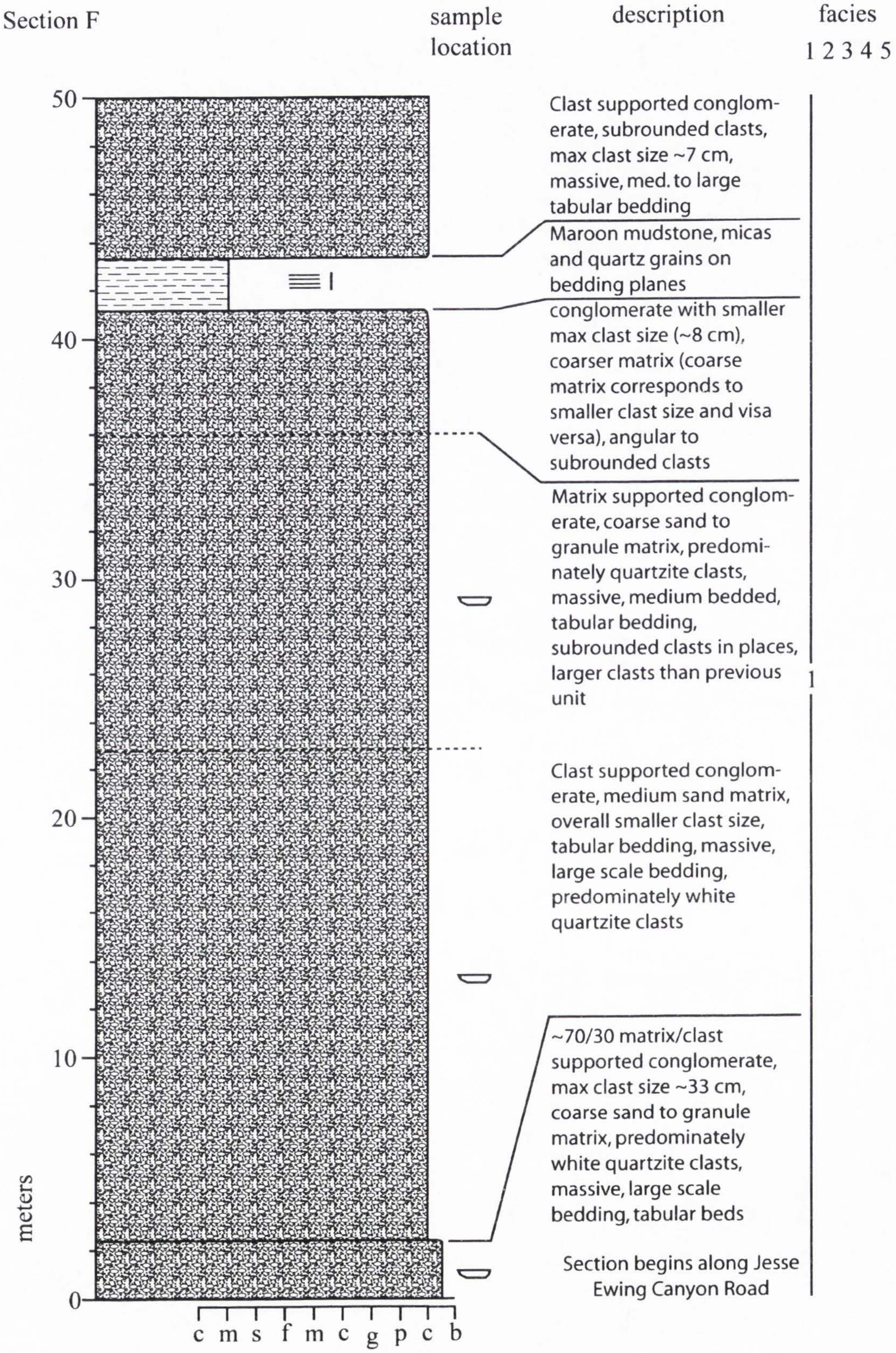
Clast supported conglomerate, scoured base, lenticular bedding, massive, well rounded quartzite clasts, ave. clast ~2 cm

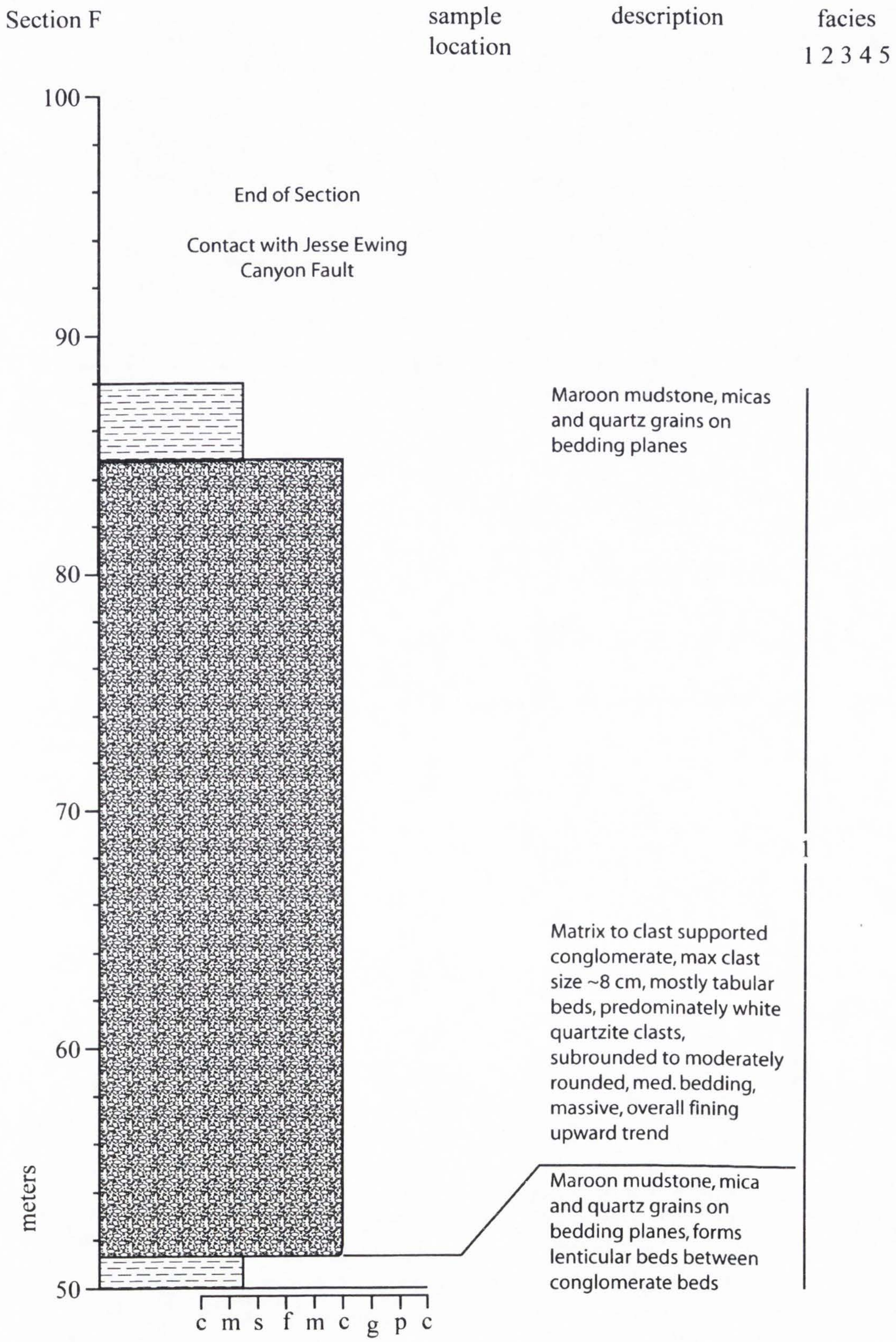
Interbedded green sandstone and shale

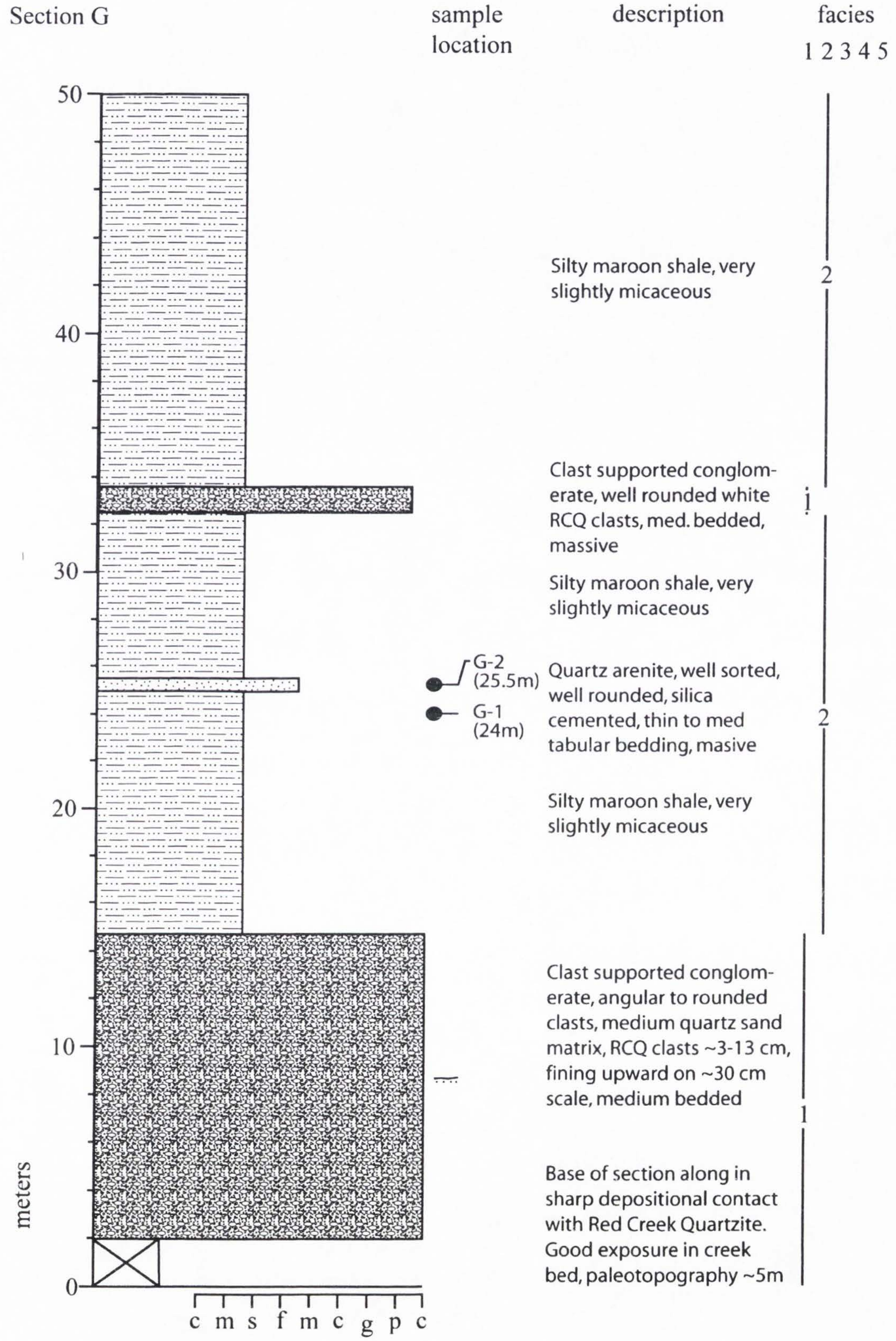
Green arenite, well sorted, mod. rounded, laminated bedding; interbedded with green quartz arenite, mod. to well rounded, mod. sorted, tabular bedding, shale partings

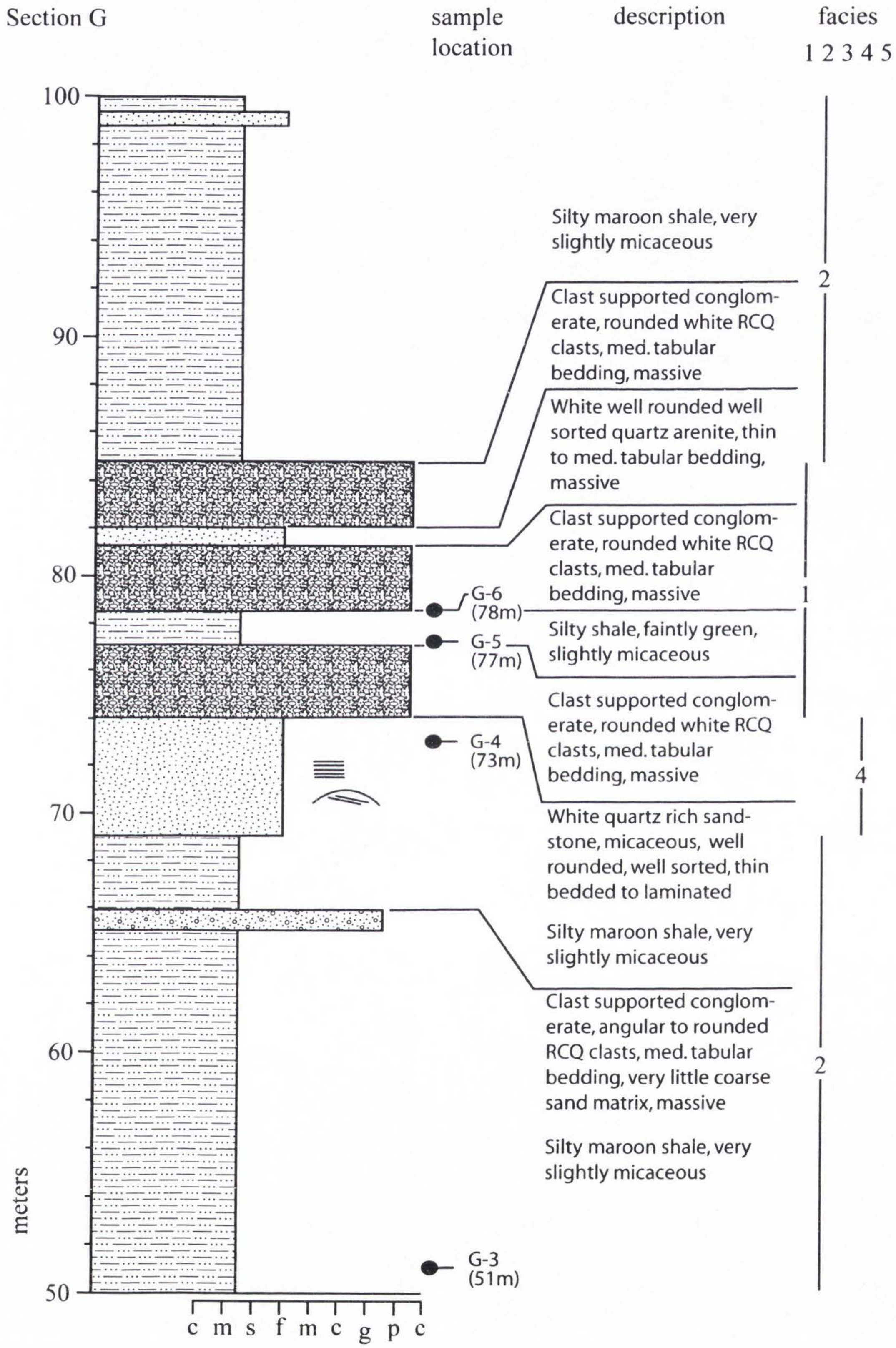

Section D
sample location
description
facies
1 2 3 4 5
230
220
180
170
160
150
meters
c m s f m c g p c
D-8 (174m)
End of section nearing structurally complicated area
Purple quartz arenite, well sorted, well rounded, med. tabular bedding
3
Maroon shale, slightly micaceous
2
Green siltstone and shale
4
Dark green micaceous sandstone, quartz rich, thin to med. bedded; 5 cm bed of matrix supported conglomerate, well rounded quartzite clasts

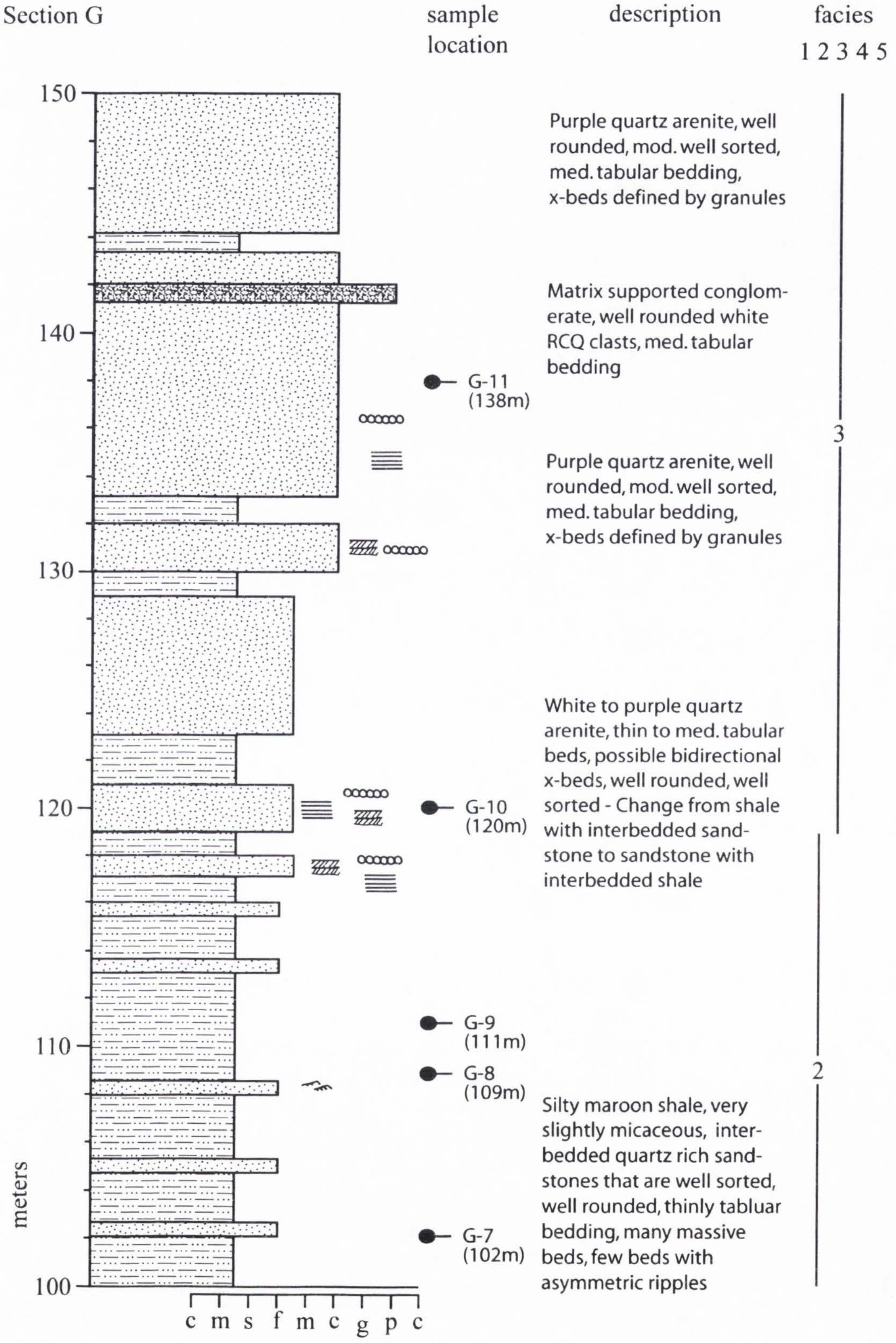

Section E
sample location
description
facies
1 2 3 4 5
50
40
30
20
10
0
meters
Top of Section
Faulted area
Section begins along Jesse Ewing Canyon Road
c m s f m c g p c
Matrix/Clast supported conglomerate, 50/50 rounded to angular clasts, clasts ~8 cm, quartzite clasts more rounded near top
Coarse grained sandstone with granules, thinly bedded, fining upward, micaceous, wavy bedding
Matrix/Clast supported conglomerate, 50/50 rounded to angular clasts, clasts ~8 cm, quartzite clasts more rounded near top
Matrix/Clast supported conglomerate, clasts up to 30 cm, many tabular clasts, siltstone intraclasts-some rounded
Matrix/Clast supported conglomerate, 10-15 cm clasts, many tabular clasts, siltstone intraclasts-some rounded
Clast supported conglomerate, reverse graded, clast long axis parallel to bedding, pebble layers within conglomerate, subangular to subrounded clasts, 15-20 cm clasts
Micaceous siltstone, clay drapes, cm scale beds, filled in cracks
Matrix supported conglomerate, matrix-poorly sorted sandstone, silt to granule, clasts-intraclasts of siltstone/mudstone and quartzite, smaller quartzite angular - larger clasts subangular to rounded, lenticular bedding, scoured bases, sharp tops
2
1
2
1
2
1
2
1
2

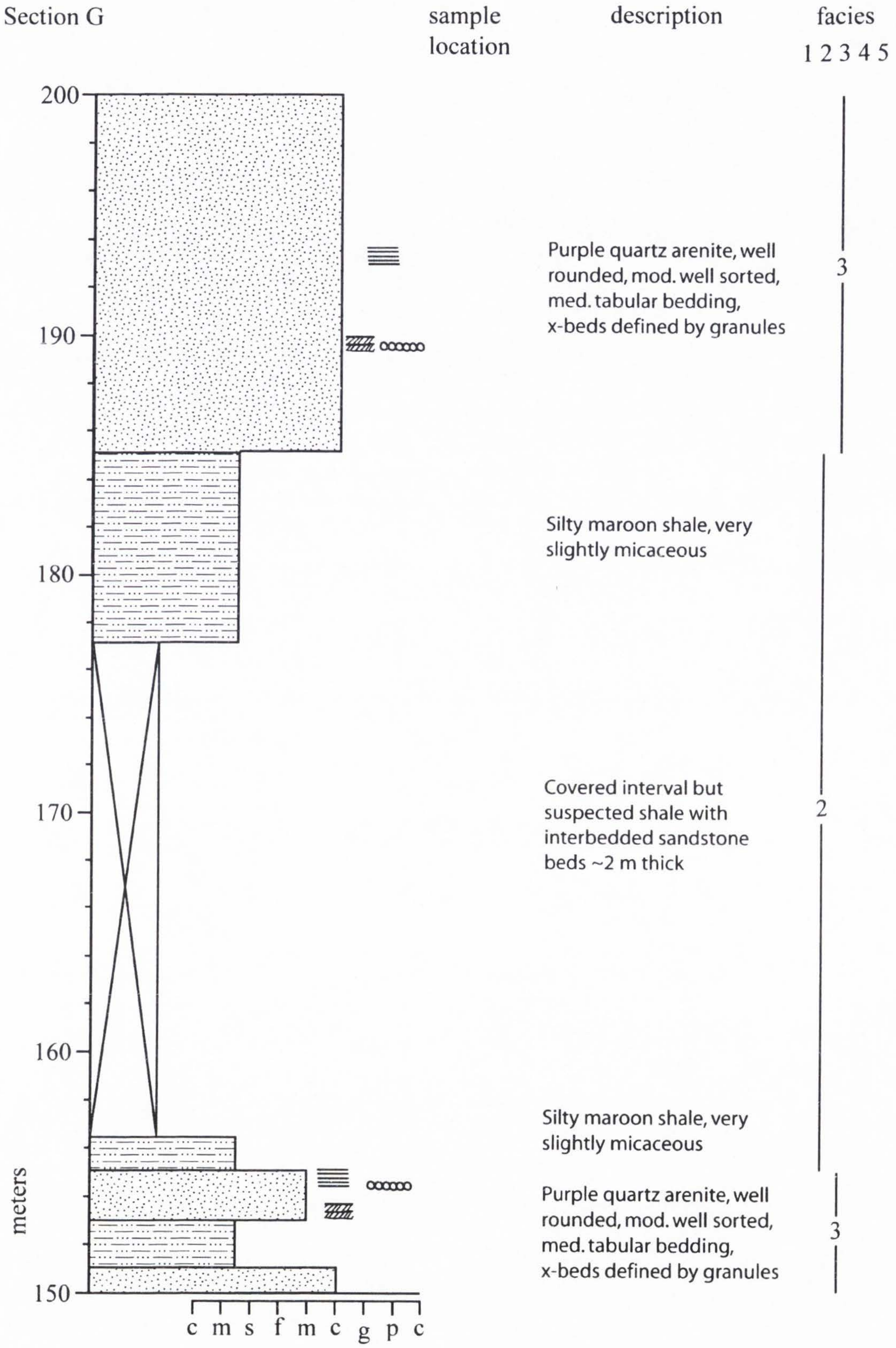

Section F
sample location
description
facies
1 2 3 4 5
50
40
30
20
10
0
meters
c m s f m c g p c b
Clast supported conglomerate, subrounded clasts, max clast size ~7 cm, massive, med. to large tabular bedding
Maroon mudstone, micas and quartz grains on bedding planes
conglomerate with smaller max clast size (~8 cm), coarser matrix (coarse matrix corresponds to smaller clast size and visa versa), angular to subrounded clasts
Matrix supported conglomerate, coarse sand to granule matrix, predominately quartzite clasts, massive, medium bedded, tabular bedding, subrounded clasts in places, larger clasts than previous unit
1
Clast supported conglomerate, medium sand matrix, overall smaller clast size, tabular bedding, massive, large scale bedding, predominately white quartzite clasts
~70/30 matrix/clast supported conglomerate, max clast size ~33 cm, coarse sand to granule matrix, predominately white quartzite clasts, massive, large scale bedding, tabular beds
Section begins along Jesse Ewing Canyon Road


Section F
sample location
description
facies
1 2 3 4 5
100
90
80
70
60
50
meters
End of Section
Contact with Jesse Ewing Canyon Fault
Maroon mudstone, micas and quartz grains on bedding planes
1
Matrix to clast supported conglomerate, max clast size ~8 cm, mostly tabular beds, predominately white quartzite clasts, subrounded to moderately rounded, med. bedding, massive, overall fining upward trend
Maroon mudstone, mica and quartz grains on bedding planes, forms lenticular beds between conglomerate beds
c m s f m c g p c


Section G
sample location
description
facies
1 2 3 4 5
50
40
30
20
10
0
meters
c m s f m c g p c
Silty maroon shale, very slightly micaceous
2
Clast supported conglomerate, well rounded white RCQ clasts, med. bedded, massive
1
Silty maroon shale, very slightly micaceous
G-2 (25.5m)
G-1 (24m)
Quartz arenite, well sorted, well rounded, silica cemented, thin to med tabular bedding, masive
2
Silty maroon shale, very slightly micaceous
Clast supported conglomerate, angular to rounded clasts, medium quartz sand matrix, RCQ clasts ~3-13 cm, fining upward on ~30 cm scale, medium bedded
1
Base of section along in sharp depositional contact with Red Creek Quartzite. Good exposure in creek bed, paleotopography ~5m

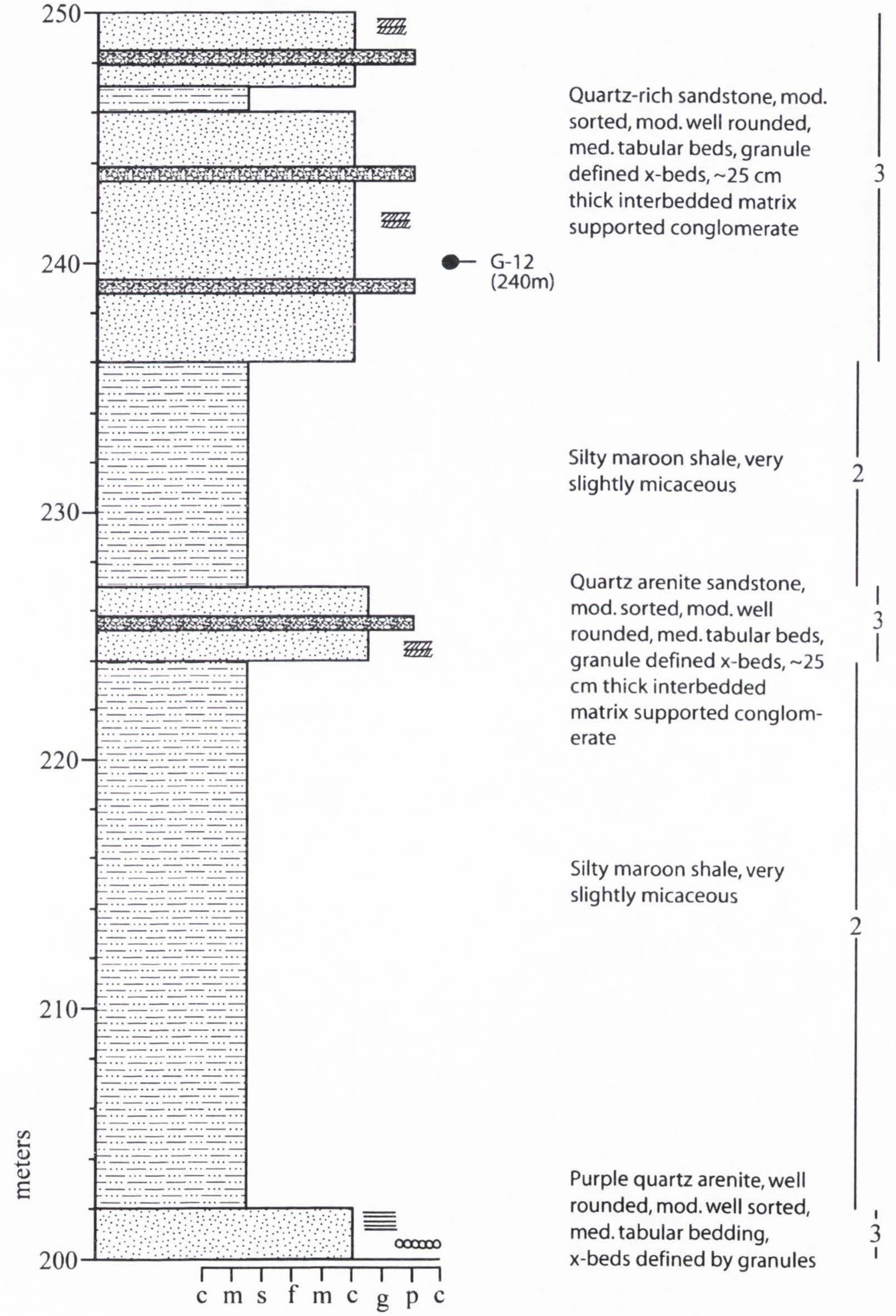

Section G
sample location
description
facies
1 2 3 4 5
100
90
80
70
60
50
meters
c m s f m c g p c
Silty maroon shale, very slightly micaceous
Clast supported conglomerate, rounded white RCQ clasts, med. tabular bedding, massive
White well rounded well sorted quartz arenite, thin to med. tabular bedding, massive
Clast supported conglomerate, rounded white RCQ clasts, med. tabular bedding, massive
G-6 (78m)
Silty shale, faintly green, slightly micaceous
G-5 (77m)
Clast supported conglomerate, rounded white RCQ clasts, med. tabular bedding, massive
G-4 (73m)
White quartz rich sandstone, micaceous, well rounded, well sorted, thin bedded to laminated
Silty maroon shale, very slightly micaceous
Clast supported conglomerate, angular to rounded RCQ clasts, med. tabular bedding, very little coarse sand matrix, massive
Silty maroon shale, very slightly micaceous
G-3 (51m)
2
1
4
2


Section G
sample location
description
facies
1 2 3 4 5
150
140
130
120
110
100
meters
c m s f m c g p c
G-11 (138m)
G-10 (120m)
G-9 (111m)
G-8 (109m)
G-7 (102m)
Purple quartz arenite, well rounded, mod. well sorted, med. tabular bedding, x-beds defined by granules
Matrix supported conglomerate, well rounded white RCQ clasts, med. tabular bedding
Purple quartz arenite, well rounded, mod. well sorted, med. tabular bedding, x-beds defined by granules
White to purple quartz arenite, thin to med. tabular beds, possible bidirectional x-beds, well rounded, well sorted - Change from shale with interbedded sandstone to sandstone with interbedded shale
Silty maroon shale, very slightly micaceous, interbedded quartz rich sandstones that are well sorted, well rounded, thinly tabluar bedding, many massive beds, few beds with asymmetric ripples
3
2


Section G
sample location
description
facies
1 2 3 4 5
200
190
180
170
160
150
meters
c m s f m c g p c
Purple quartz arenite, well rounded, mod. well sorted, med. tabular bedding, x-beds defined by granules
3
Silty maroon shale, very slightly micaceous
Covered interval but suspected shale with interbedded sandstone beds ~2 m thick
2
Silty maroon shale, very slightly micaceous
Purple quartz arenite, well rounded, mod. well sorted, med. tabular bedding, x-beds defined by granules
3

Section G

sample location | description | facies 1 2 3 4 5



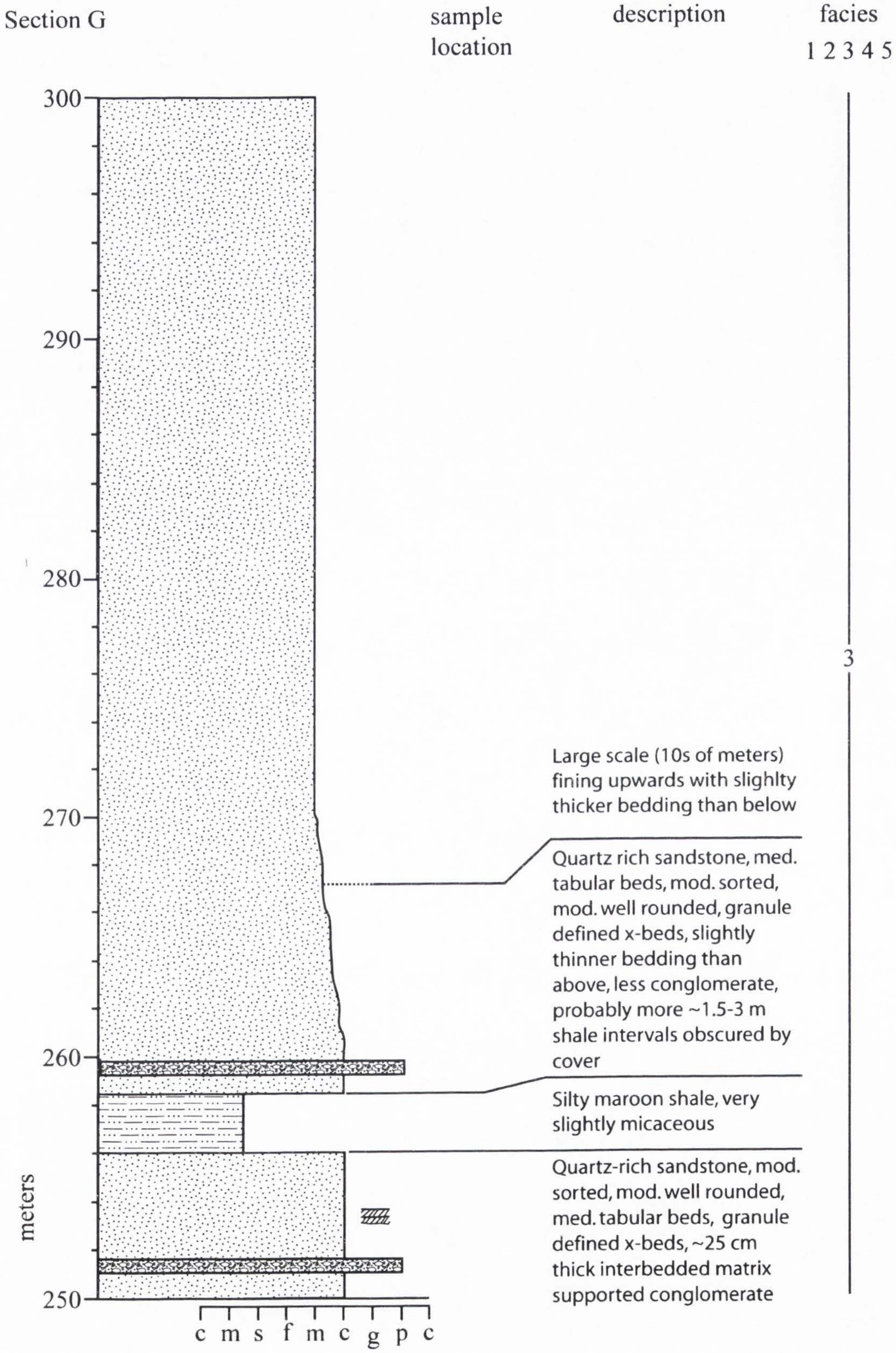
Quartz-rich sandstone, mod. sorted, mod. well rounded, med. tabular beds, granule defined x-beds, ~25 cm thick interbedded matrix supported conglomerate

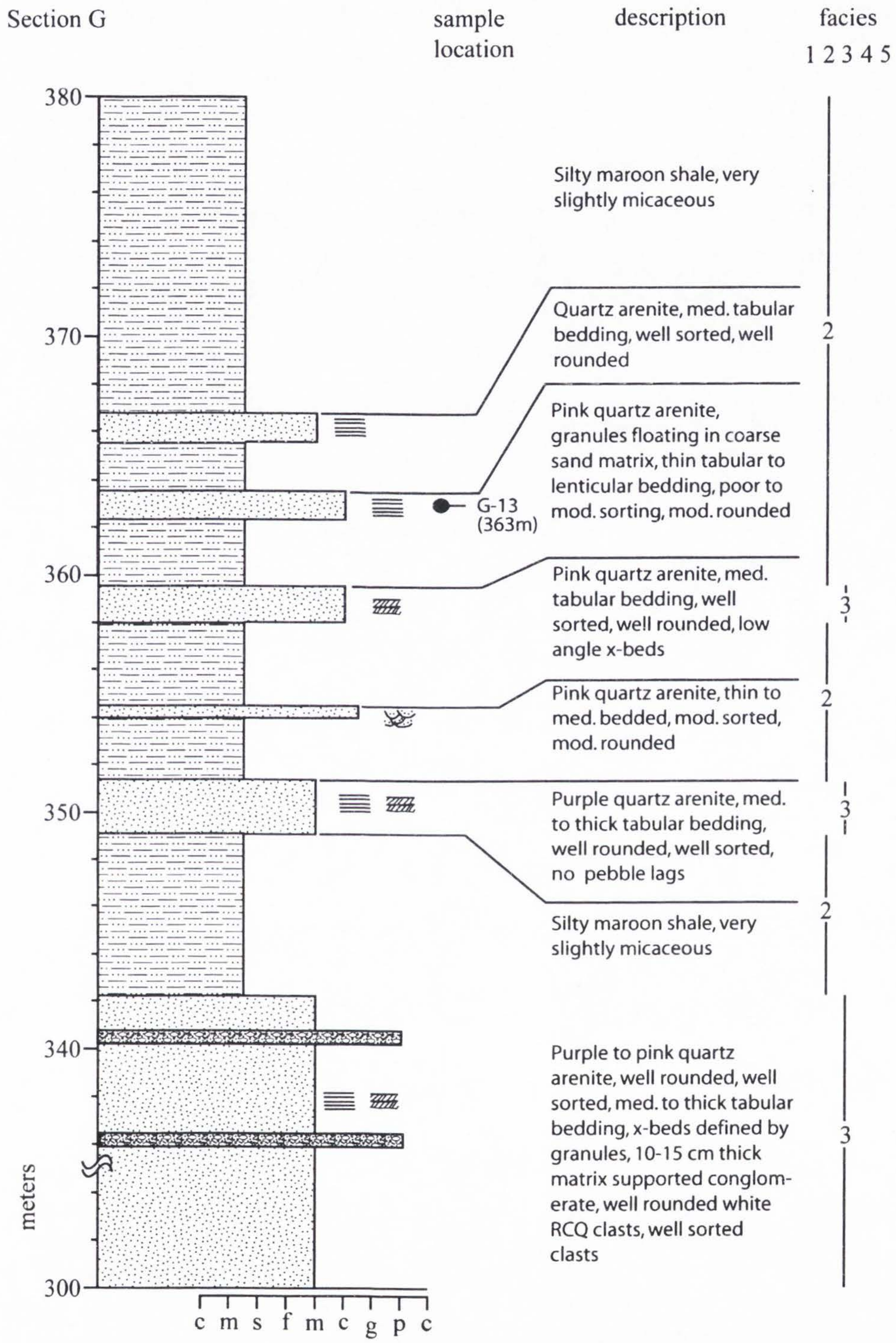
Silty maroon shale, very slightly micaceous

Quartz arenite sandstone, mod. sorted, mod. well rounded, med. tabular beds, granule defined x-beds, ~25 cm thick interbedded matrix supported conglom-erate

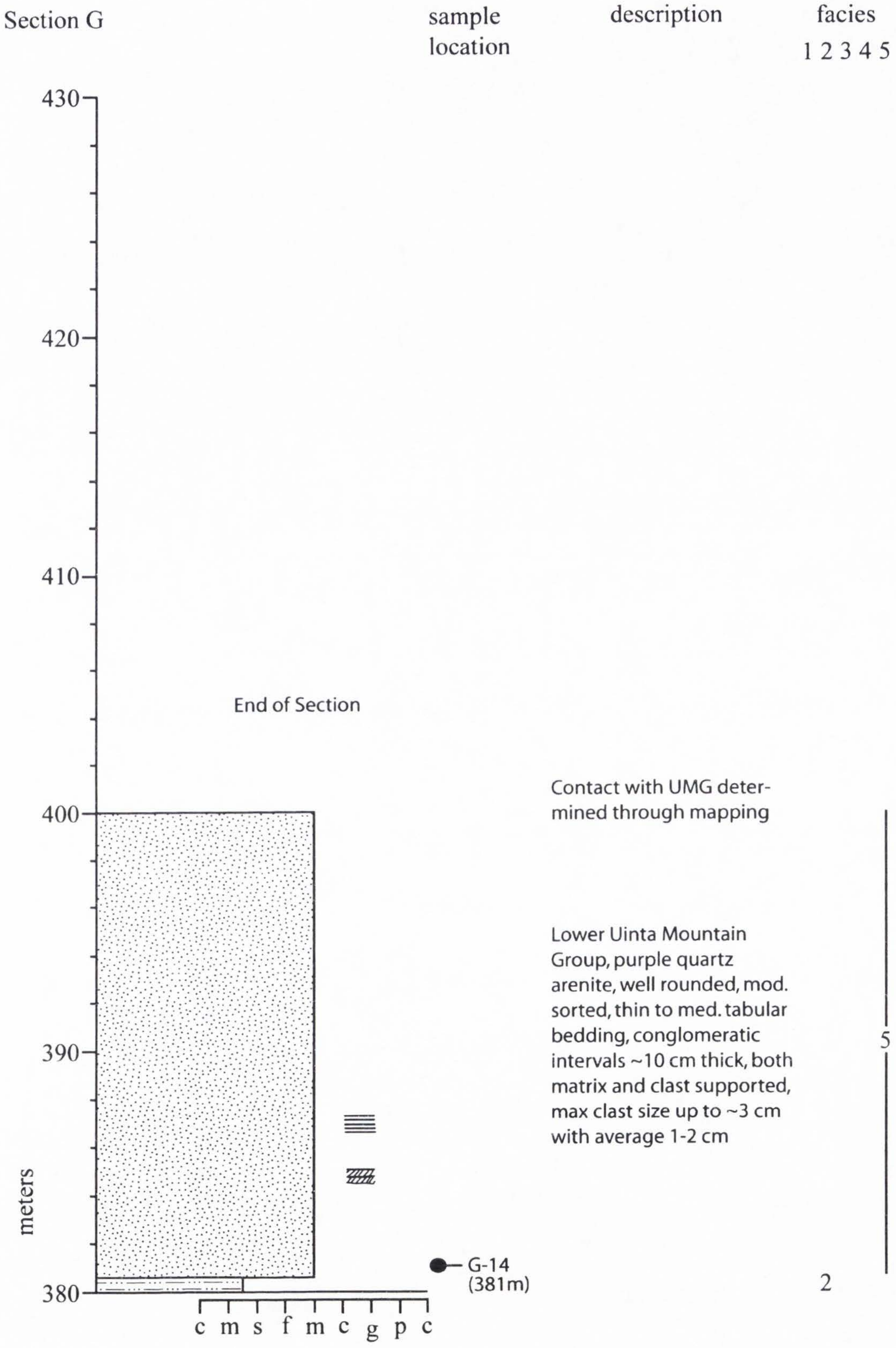
Silty maroon shale, very slightly micaceous

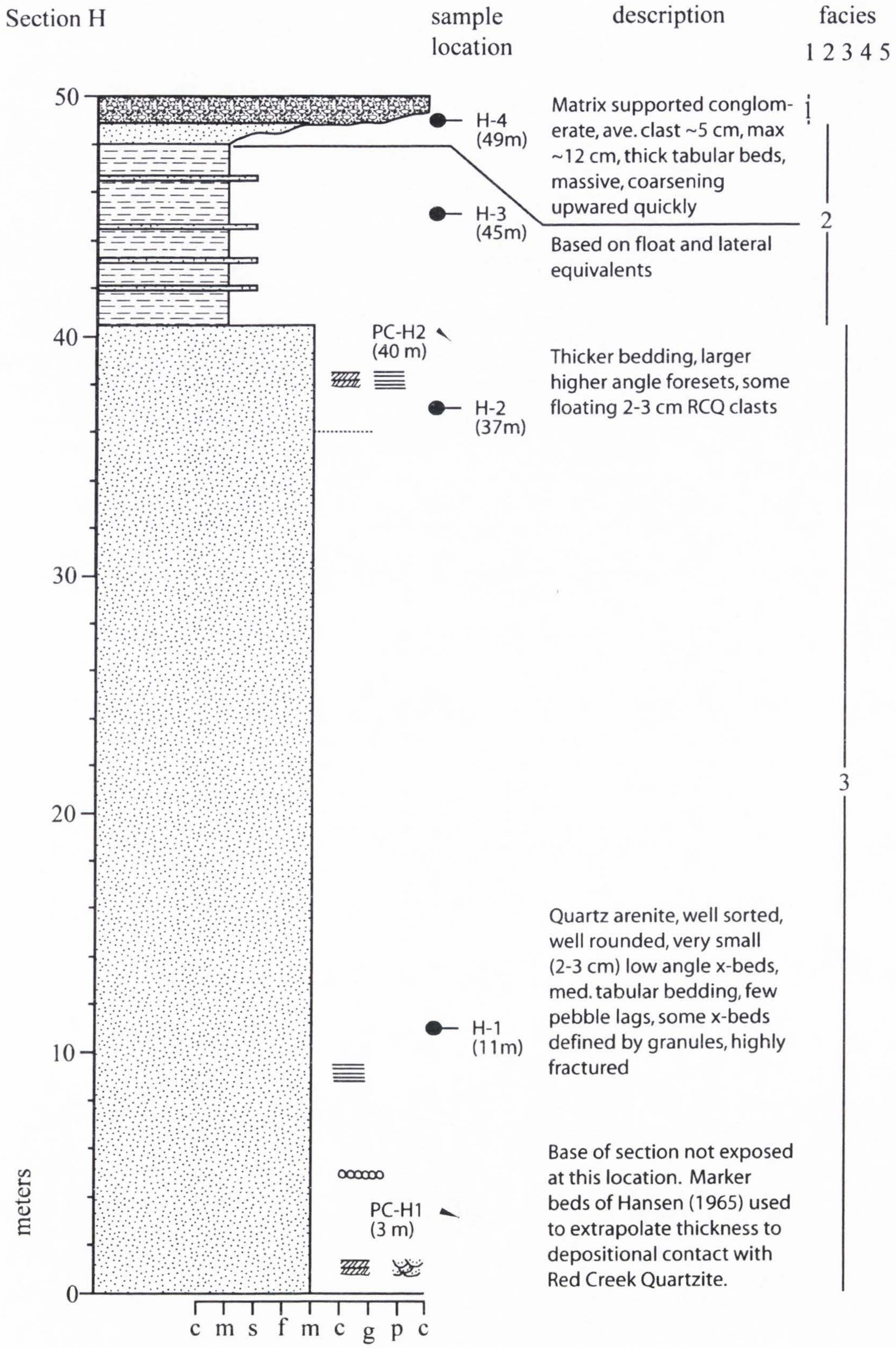
Purple quartz arenite, well rounded, mod. well sorted, med. tabular bedding, x-beds defined by granules

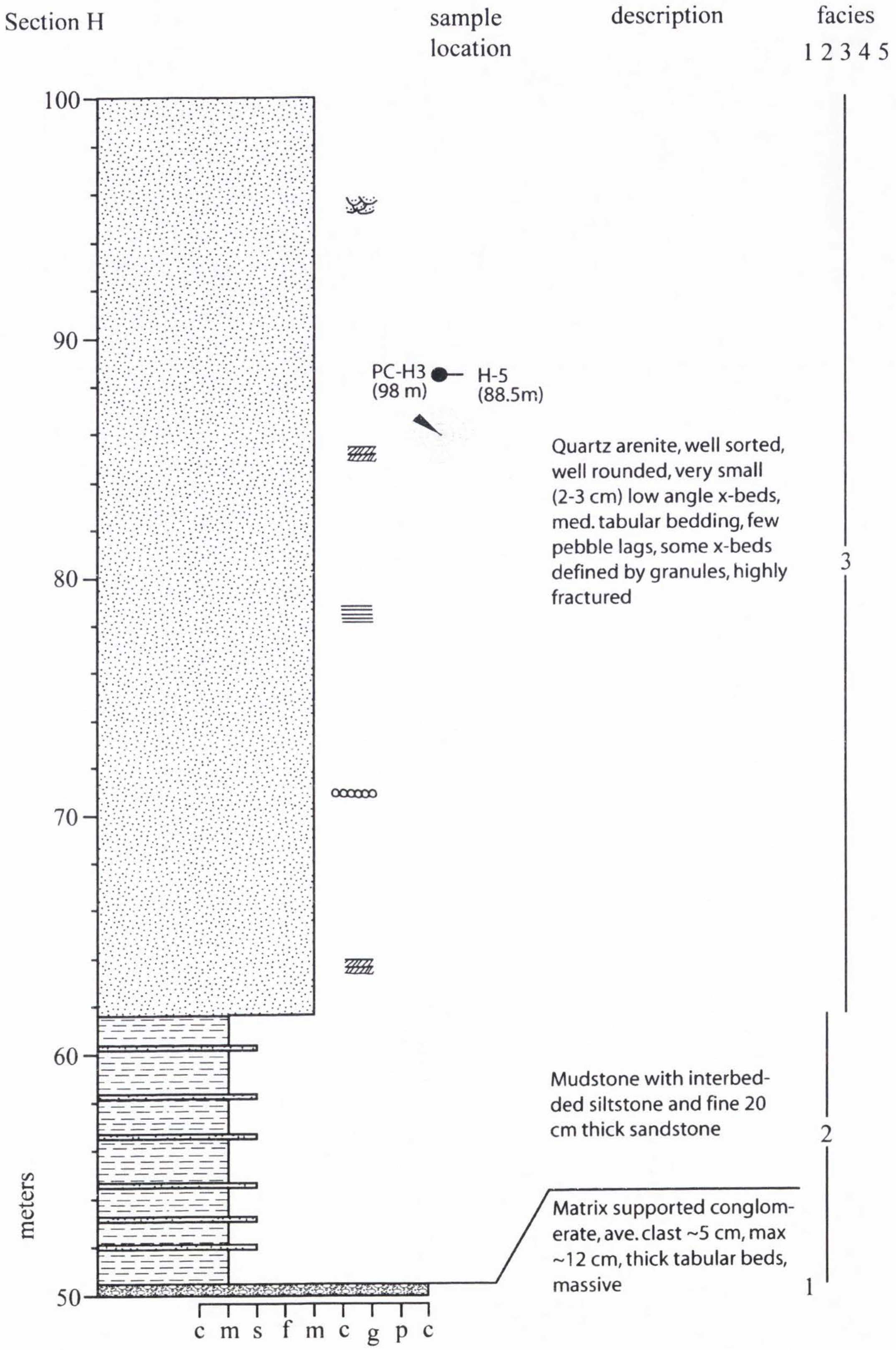

Section G
sample location
description
facies
1 2 3 4 5
300
290
280
270
260
250
meters
c m s f m c g p c
3
Large scale (10s of meters) fining upwards with slighlty thicker bedding than below
Quartz rich sandstone, med. tabular beds, mod. sorted, mod. well rounded, granule defined x-beds, slightly thinner bedding than above, less conglomerate, probably more ~1.5-3 m shale intervals obscured by cover
Silty maroon shale, very slightly micaceous
Quartz-rich sandstone, mod. sorted, mod. well rounded, med. tabular beds, granule defined x-beds, ~25 cm thick interbedded matrix supported conglomerate



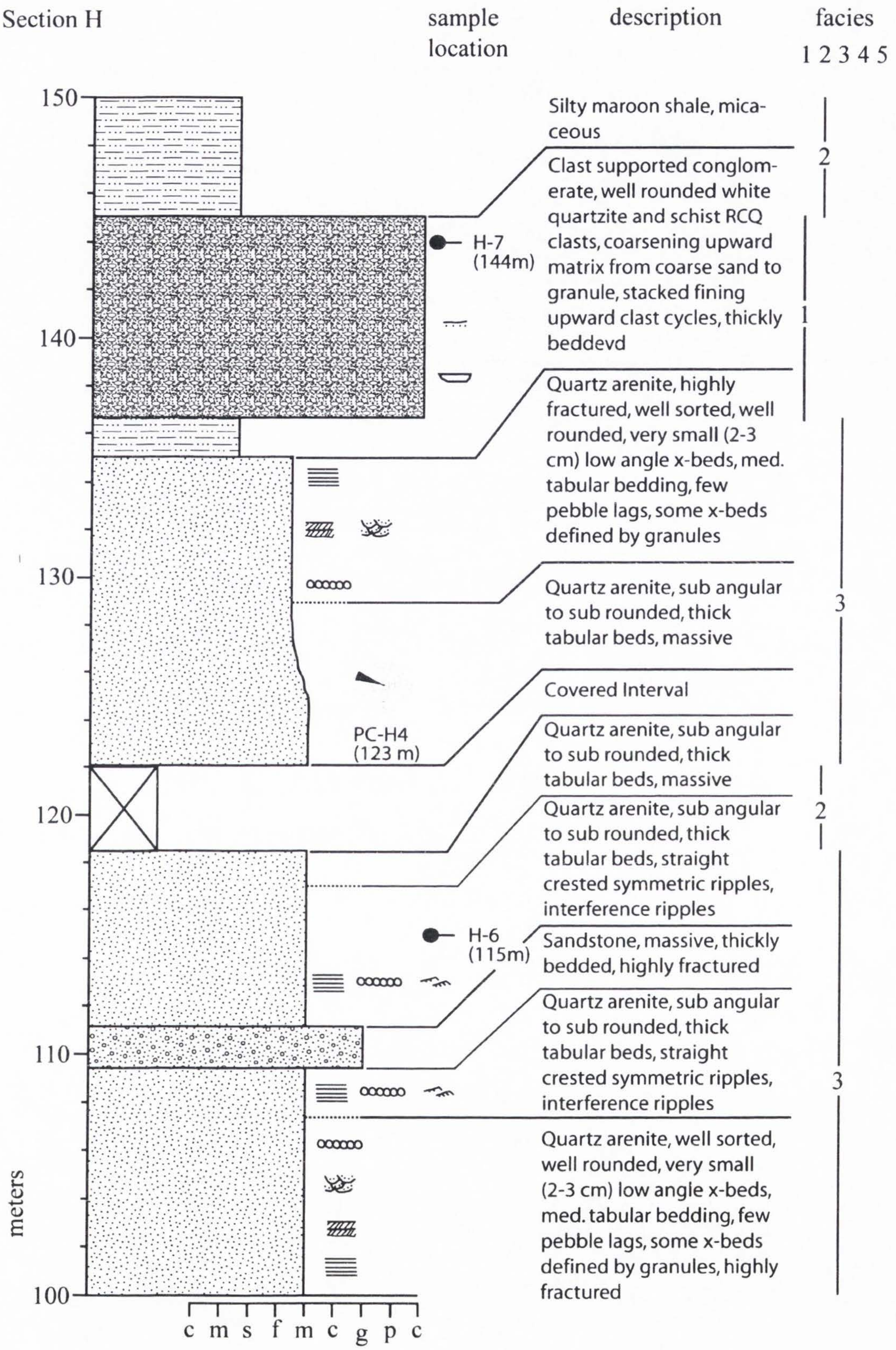
Section G
sample location
description
facies
1 2 3 4 5
380
370
360
350
340
300
meters
c m s f m c g p c
G-13 (363m)
Silty maroon shale, very slightly micaceous
Quartz arenite, med. tabular bedding, well sorted, well rounded
Pink quartz arenite, granules floating in coarse sand matrix, thin tabular to lenticular bedding, poor to mod. sorting, mod. rounded
Pink quartz arenite, med. tabular bedding, well sorted, well rounded, low angle x-beds
Pink quartz arenite, thin to med. bedded, mod. sorted, mod. rounded
Purple quartz arenite, med. to thick tabular bedding, well rounded, well sorted, no pebble lags
Silty maroon shale, very slightly micaceous
Purple to pink quartz arenite, well rounded, well sorted, med. to thick tabular bedding, x-beds defined by granules, 10-15 cm thick matrix supported conglomerate, well rounded white RCQ clasts, well sorted clasts
2
3
2
3
2
3

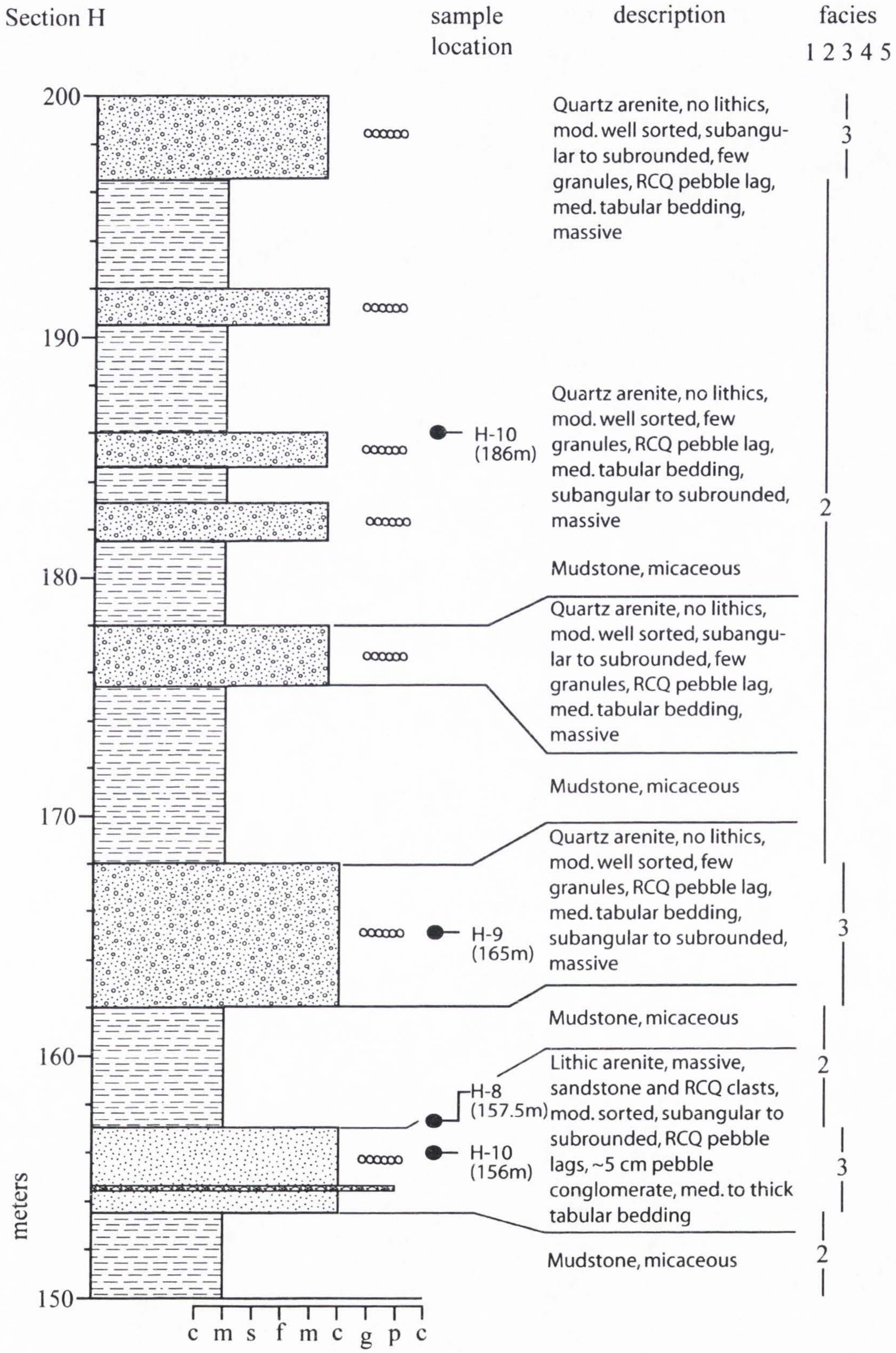

Section G
sample location
description
facies
1 2 3 4 5
430
420
410
400
390
380
meters
End of Section
Contact with UMG determined through mapping
Lower Uinta Mountain Group, purple quartz arenite, well rounded, mod. sorted, thin to med. tabular bedding, conglomeratic intervals ~10 cm thick, both matrix and clast supported, max clast size up to ~3 cm with average 1-2 cm
5
2
G-14
(381m)
c m s f m c g p c

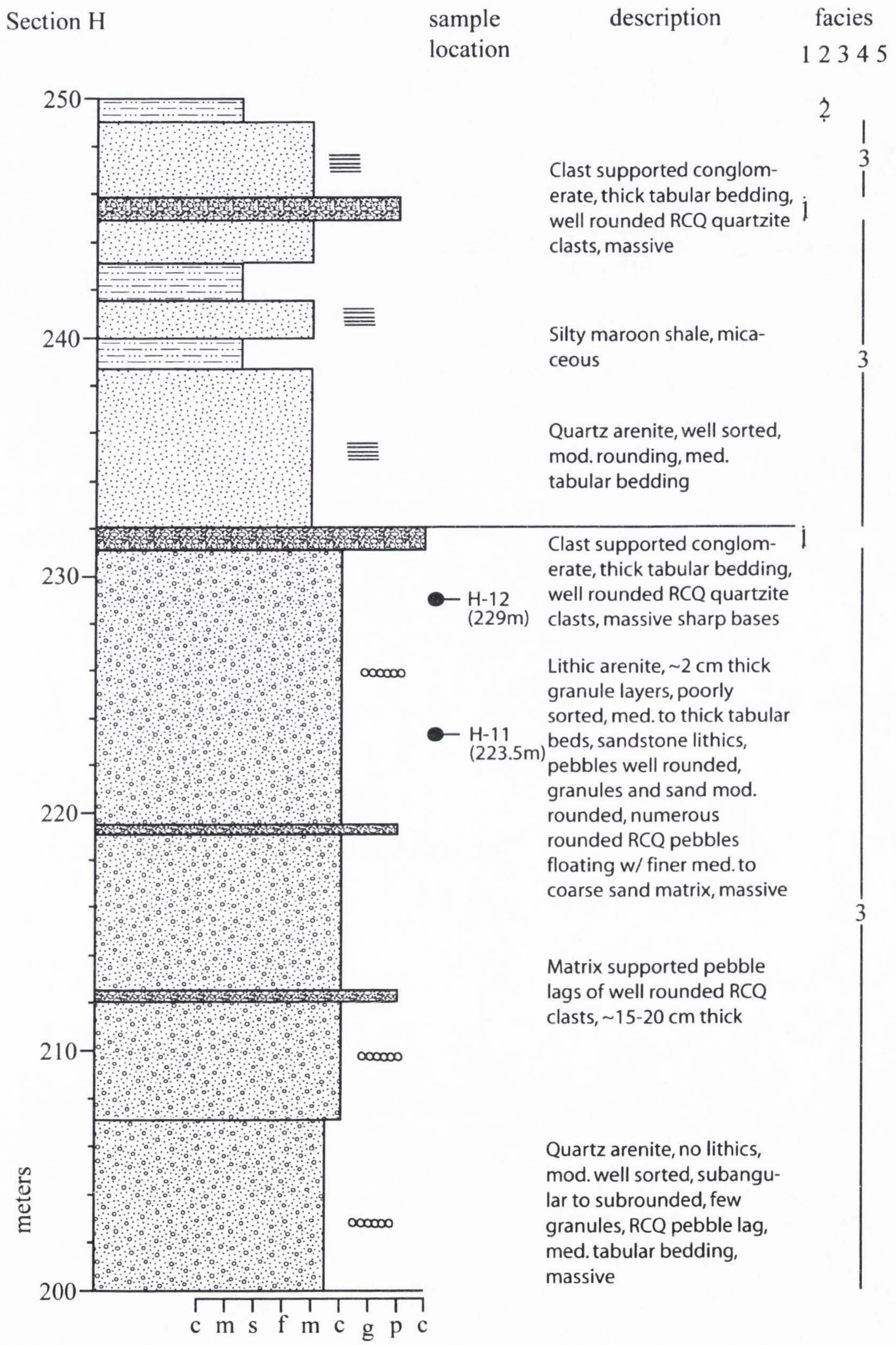

Section H
sample location
description
facies
1 2 3 4 5
50
40
30
20
10
0
meters
c m s f m c g p c
H-4 (49m)
H-3 (45m)
PC-H2 (40 m)
H-2 (37m)
H-1 (11m)
PC-H1 (3 m)
Matrix supported conglomerate, ave. clast ~5 cm, max ~12 cm, thick tabular beds, massive, coarsening upwared quickly
Based on float and lateral equivalents
Thicker bedding, larger higher angle foresets, some floating 2-3 cm RCQ clasts
Quartz arenite, well sorted, well rounded, very small (2-3 cm) low angle x-beds, med. tabular bedding, few pebble lags, some x-beds defined by granules, highly fractured
Base of section not exposed at this location. Marker beds of Hansen (1965) used to extrapolate thickness to depositional contact with Red Creek Quartzite.
1
2
3

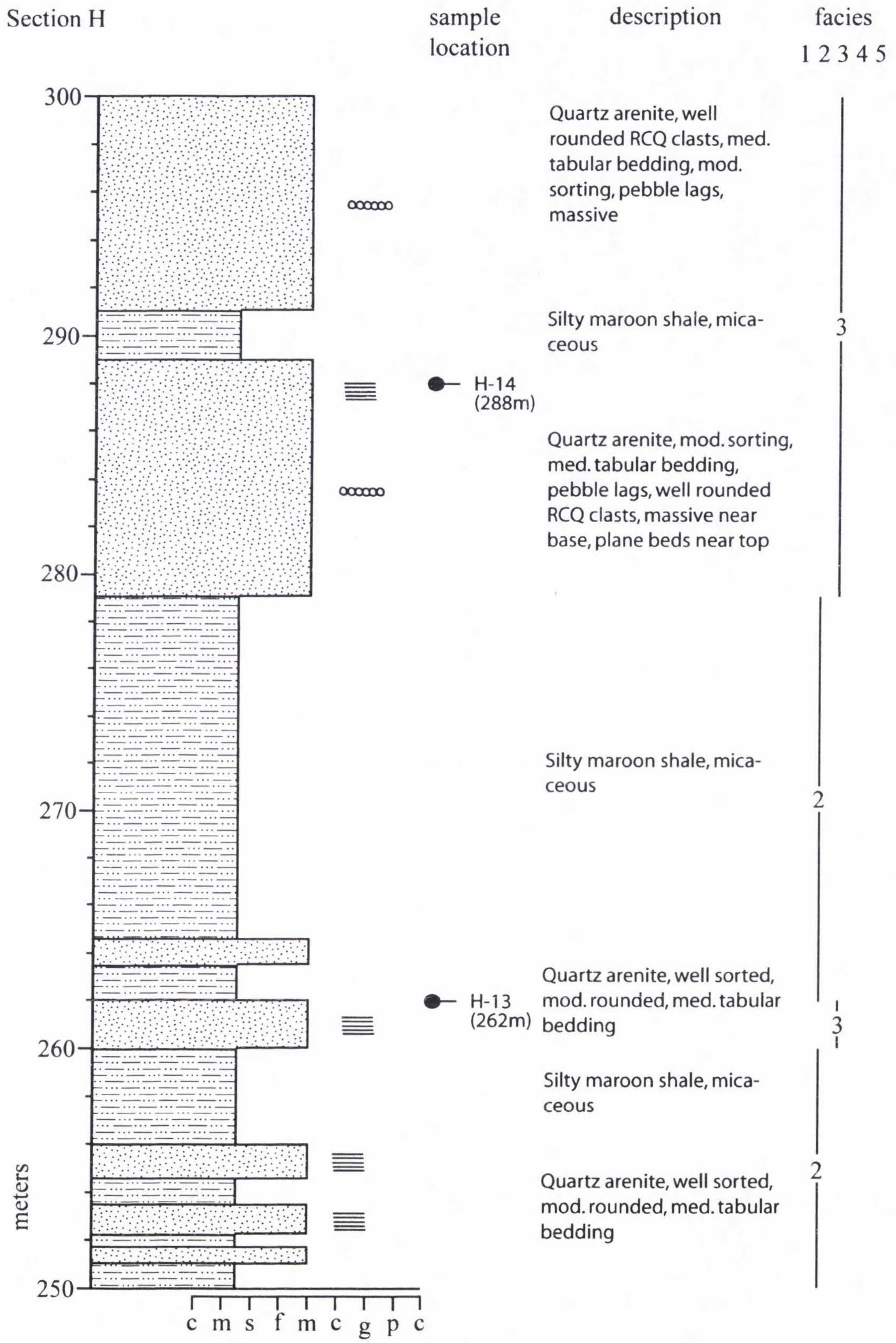


Section H
sample location
description
facies
1 2 3 4 5
100
90
80
70
60
50
meters
PC-H3 (98 m)
H-5 (88.5m)
Quartz arenite, well sorted, well rounded, very small (2-3 cm) low angle x-beds, med. tabular bedding, few pebble lags, some x-beds defined by granules, highly fractured
3
Mudstone with interbedded siltstone and fine 20 cm thick sandstone
2
Matrix supported conglomerate, ave. clast ~5 cm, max ~12 cm, thick tabular beds, massive
1
c m s f m c g p c


Section H
sample location
description
facies
1 2 3 4 5
150
140
130
120
110
100
meters
c m s f m c g p c
H-7 (144m)
PC-H4 (123 m)
H-6 (115m)
Silty maroon shale, micaceous
Clast supported conglomerate, well rounded white quartzite and schist RCQ clasts, coarsening upward matrix from coarse sand to granule, stacked fining upward clast cycles, thickly beddevd
Quartz arenite, highly fractured, well sorted, well rounded, very small (2-3 cm) low angle x-beds, med. tabular bedding, few pebble lags, some x-beds defined by granules
Quartz arenite, sub angular to sub rounded, thick tabular beds, massive
Covered Interval
Quartz arenite, sub angular to sub rounded, thick tabular beds, massive
Quartz arenite, sub angular to sub rounded, thick tabular beds, straight crested symmetric ripples, interference ripples
Sandstone, massive, thickly bedded, highly fractured
Quartz arenite, sub angular to sub rounded, thick tabular beds, straight crested symmetric ripples, interference ripples
Quartz arenite, well sorted, well rounded, very small (2-3 cm) low angle x-beds, med. tabular bedding, few pebble lags, some x-beds defined by granules, highly fractured
2
1
3
2
3


Section H
sample location
description
facies
1 2 3 4 5
200
190
180
170
160
150
meters
c m s f m c g p c
H-10 (186m)
H-9 (165m)
H-8 (157.5m)
H-10 (156m)
Quartz arenite, no lithics, mod. well sorted, subangular to subrounded, few granules, RCQ pebble lag, med. tabular bedding, massive
Quartz arenite, no lithics, mod. well sorted, few granules, RCQ pebble lag, med. tabular bedding, subangular to subrounded, massive
Mudstone, micaceous
Quartz arenite, no lithics, mod. well sorted, subangular to subrounded, few granules, RCQ pebble lag, med. tabular bedding, massive
Mudstone, micaceous
Quartz arenite, no lithics, mod. well sorted, few granules, RCQ pebble lag, med. tabular bedding, subangular to subrounded, massive
Mudstone, micaceous
Lithic arenite, massive, sandstone and RCQ clasts, mod. sorted, subangular to subrounded, RCQ pebble lags, ~5 cm pebble conglomerate, med. to thick tabular bedding
Mudstone, micaceous
3
2
3
2
3
2

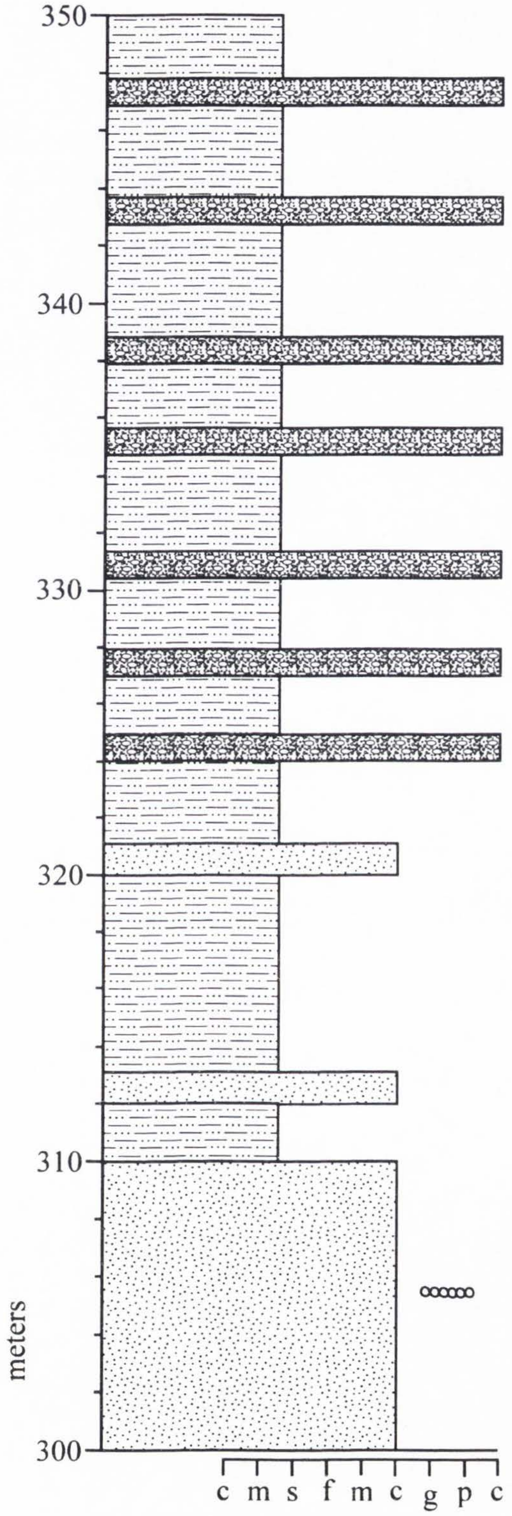

Section H
sample location
description
facies
1 2 3 4 5
250
240
230
220
210
200
meters
c m s f m c g p c
Clast supported conglomerate, thick tabular bedding, well rounded RCQ quartzite clasts, massive
Silty maroon shale, micaceous
Quartz arenite, well sorted, mod. rounding, med. tabular bedding
Clast supported conglomerate, thick tabular bedding, well rounded RCQ quartzite clasts, massive sharp bases
H-12 (229m)
Lithic arenite, ~2 cm thick granule layers, poorly sorted, med. to thick tabular beds, sandstone lithics, pebbles well rounded, granules and sand mod. rounded, numerous rounded RCQ pebbles floating w/ finer med. to coarse sand matrix, massive
H-11 (223.5m)
Matrix supported pebble lags of well rounded RCQ clasts, ~15-20 cm thick
Quartz arenite, no lithics, mod. well sorted, subangular to subrounded, few granules, RCQ pebble lag, med. tabular bedding, massive
2
3
1
3
1
3



Section H
sample location
description
facies
1 2 3 4 5
300
290
280
270
260
250
meters
c m s f m c g p c
Quartz arenite, well rounded RCQ clasts, med. tabular bedding, mod. sorting, pebble lags, massive
Silty maroon shale, micaceous
H-14 (288m)
Quartz arenite, mod. sorting, med. tabular bedding, pebble lags, well rounded RCQ clasts, massive near base, plane beds near top
3
Silty maroon shale, micaceous
2
Quartz arenite, well sorted, mod. rounded, med. tabular bedding
H-13 (262m)
3
Silty maroon shale, micaceous
Quartz arenite, well sorted, mod. rounded, med. tabular bedding
2

Section H

sample location | description | facies 1 2 3 4 5



Conglomerate and shale interval with no sandstone

- Silty micaceous maroon shale

-Clast supported conglomerate, ave. clast ~5 cm, max. clast size 50 cm, well rounded white RCQ clasts, some intervals very micaceous, massive

Quartz arenite, med. tabular bedding, mod. sorting, pebble lags, well rounded RCQ clasts, massive

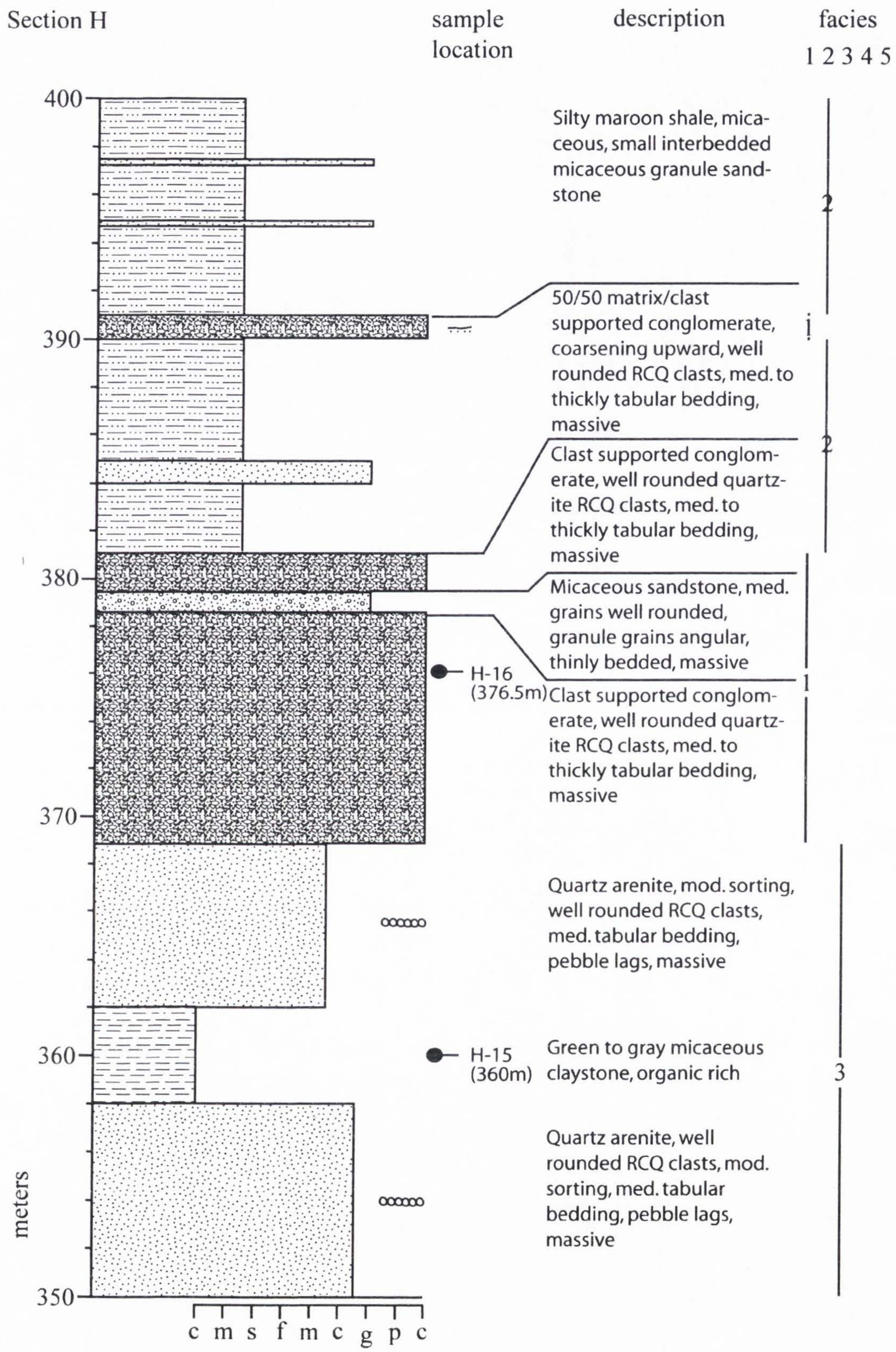
Silty maroon shale, micaceous

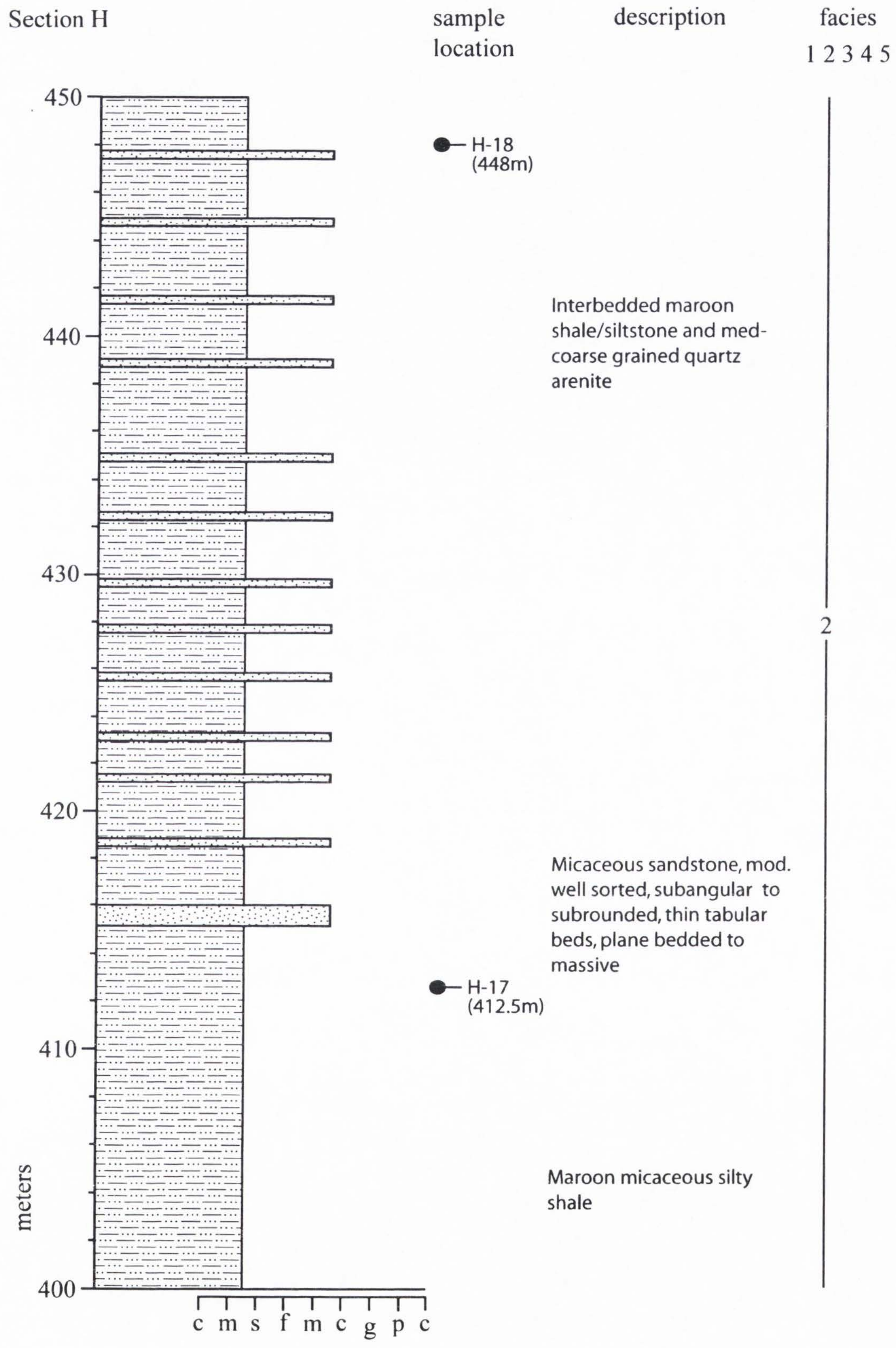
Quartz arenite, med. tabular bedding, mod. sorting, pebble lags, well rounded RCQ clasts, massive

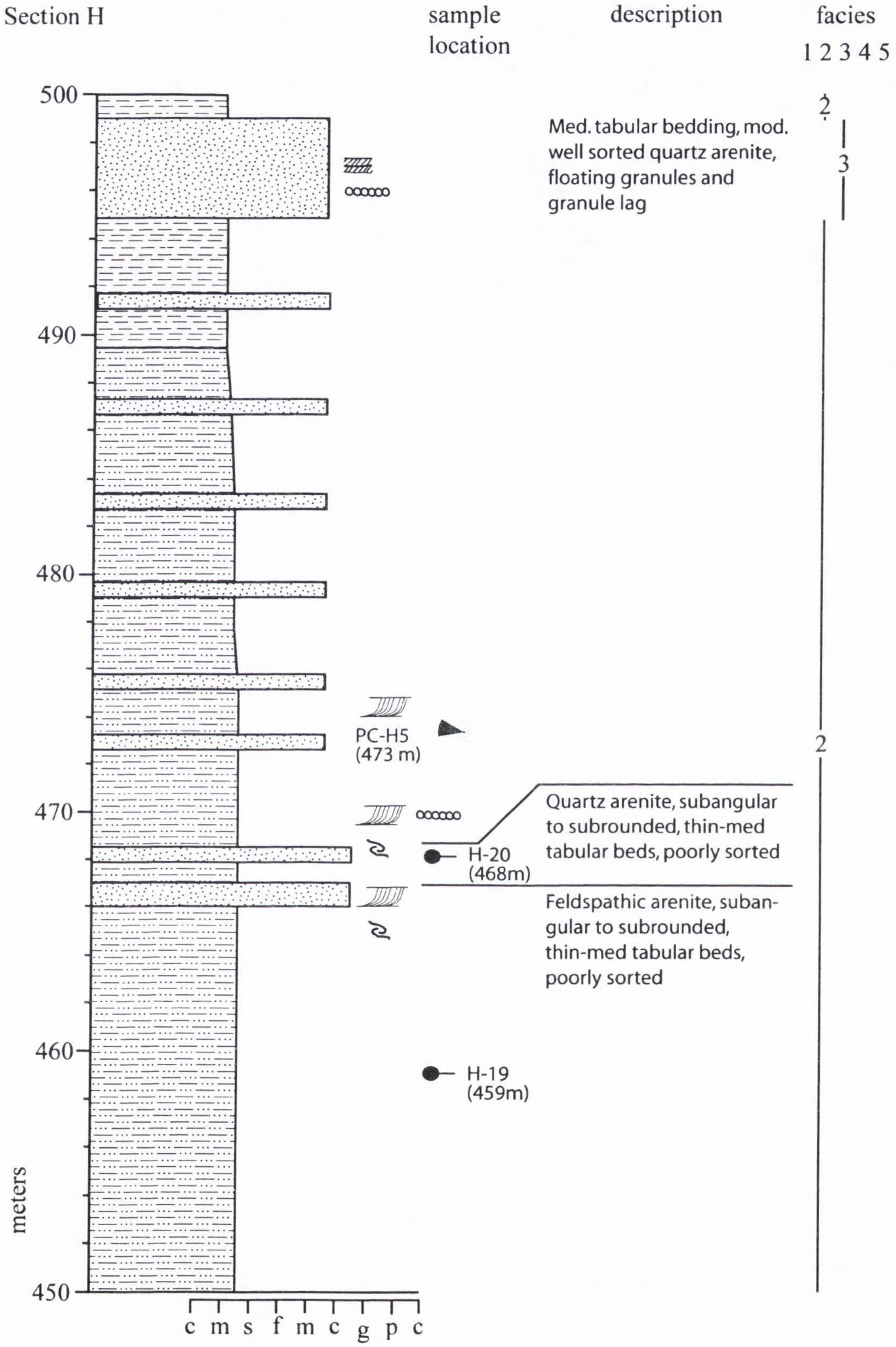
Quartz arenite, mod. sorting, med. tabular bedding, pebble lags, well rounded RCQ clasts, massive

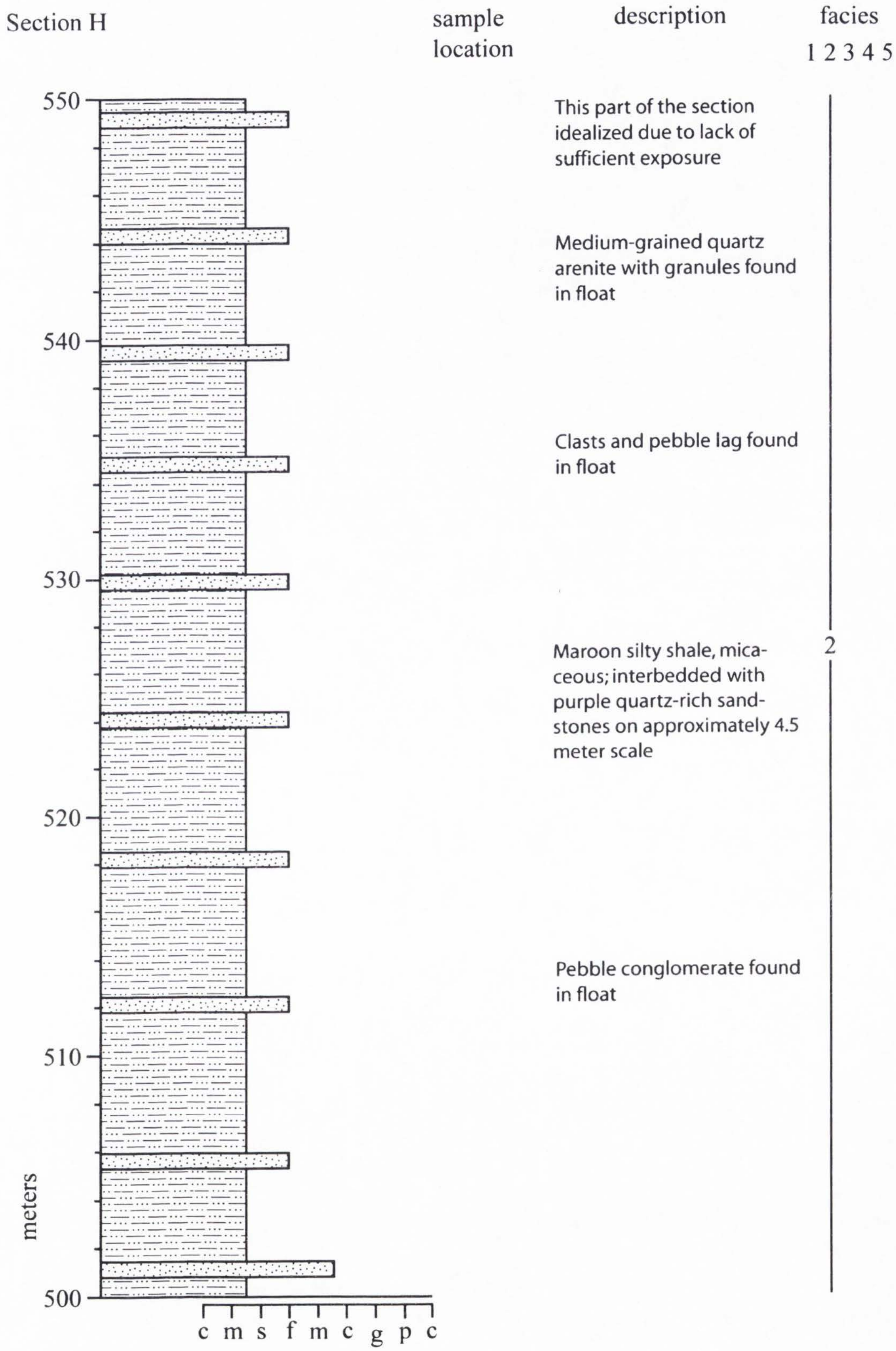
2

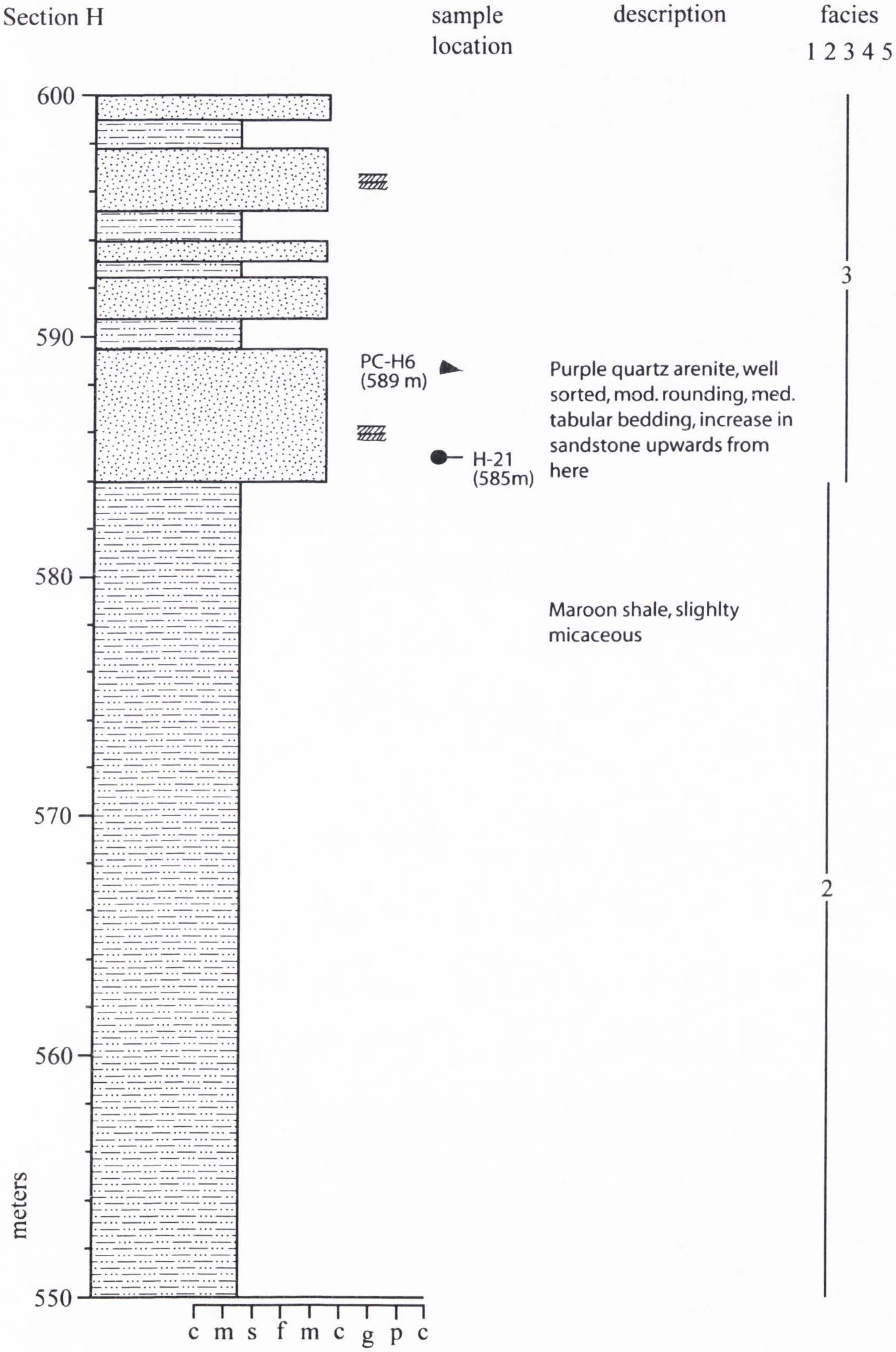
3

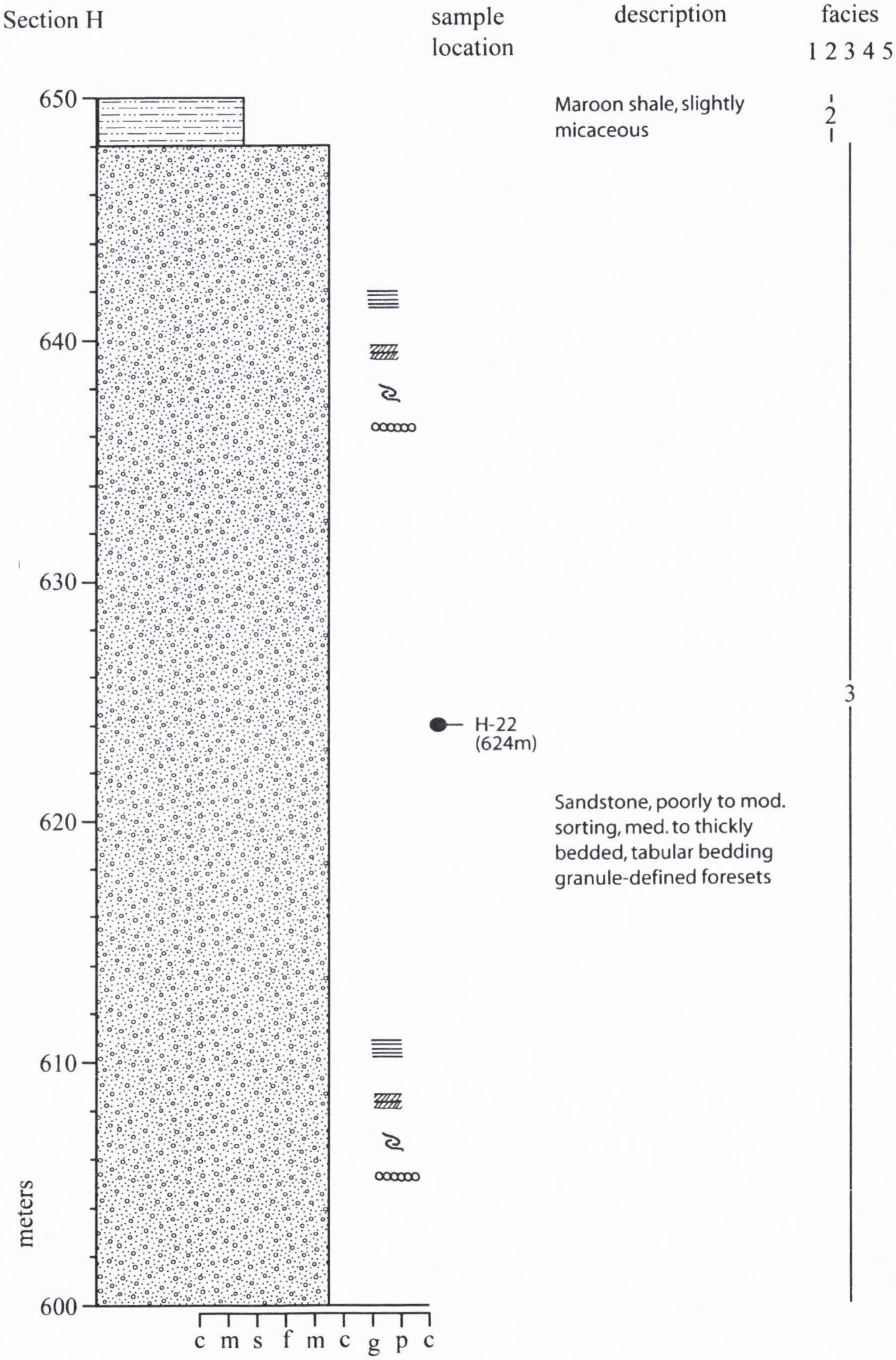

Section H
sample location
description
facies
1 2 3 4 5
400
390
380
370
360
350
meters
c m s f m c g p c
Silty maroon shale, micaceous, small interbedded micaceous granule sandstone
2
50/50 matrix/clast supported conglomerate, coarsening upward, well rounded RCQ clasts, med. to thickly tabular bedding, massive
1
2
Clast supported conglomerate, well rounded quartzite RCQ clasts, med. to thickly tabular bedding, massive
Micaceous sandstone, med. grains well rounded, granule grains angular, thinly bedded, massive
H-16
(376.5m)
1
Clast supported conglomerate, well rounded quartzite RCQ clasts, med. to thickly tabular bedding, massive
Quartz arenite, mod. sorting, well rounded RCQ clasts, med. tabular bedding, pebble lags, massive
H-15
(360m)
Green to gray micaceous claystone, organic rich
3
Quartz arenite, well rounded RCQ clasts, mod. sorting, med. tabular bedding, pebble lags, massive

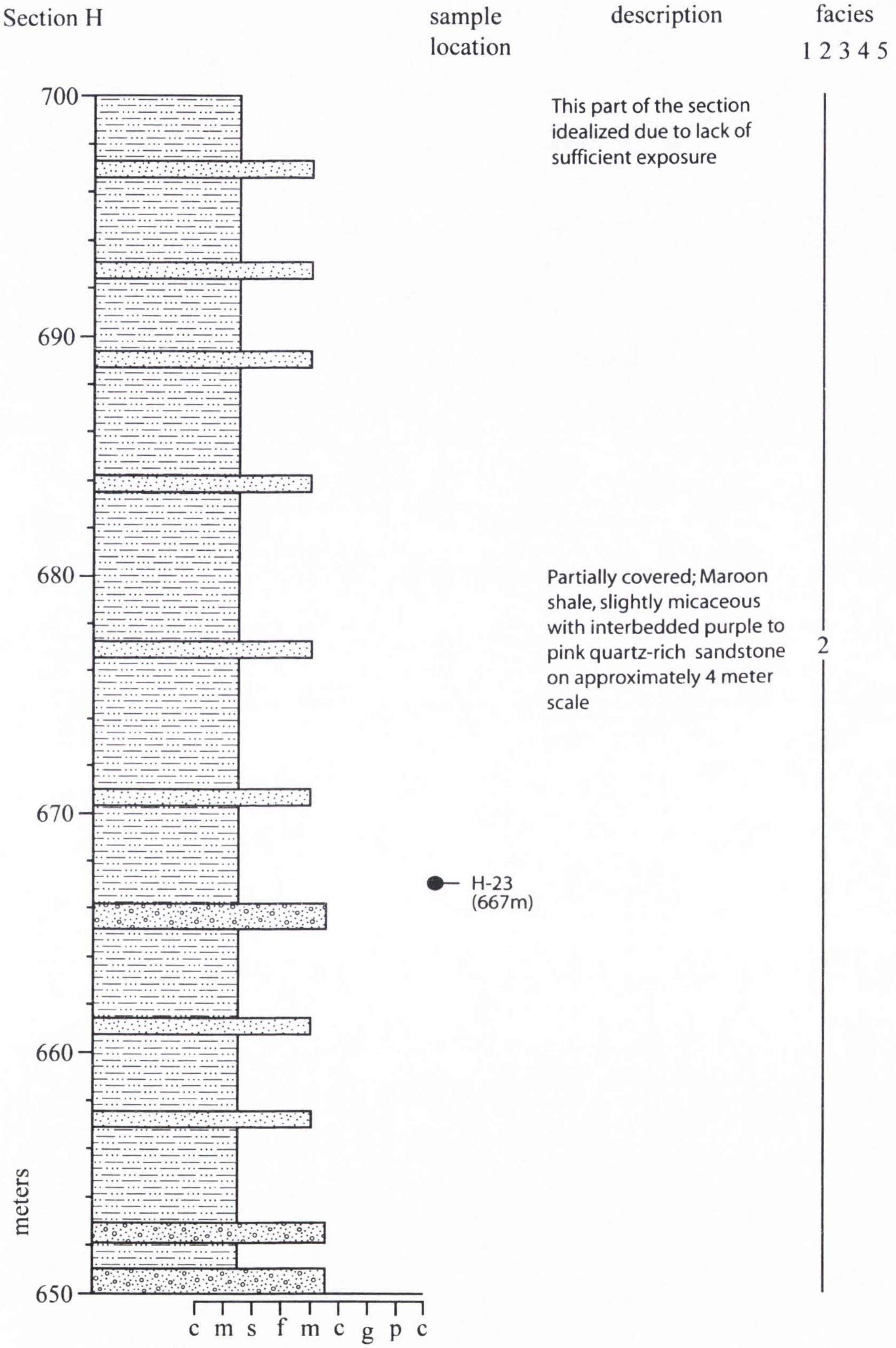

Section H
sample location
description
facies
1 2 3 4 5
450
440
430
420
410
400
meters
H-18 (448m)
H-17 (412.5m)
Interbedded maroon shale/siltstone and med-coarse grained quartz arenite
Micaceous sandstone, mod. well sorted, subangular to subrounded, thin tabular beds, plane bedded to massive
Maroon micaceous silty shale
2
c m s f m c g p c


Section H
sample location
description
facies
1 2 3 4 5
500
490
480
470
460
450
meters
c m s f m c g p c
Med. tabular bedding, mod. well sorted quartz arenite, floating granules and granule lag
3
2
PC-H5
(473 m)
Quartz arenite, subangular to subrounded, thin-med tabular beds, poorly sorted
H-20
(468m)
Feldspathic arenite, subangular to subrounded, thin-med tabular beds, poorly sorted
H-19
(459m)


Section H
sample location
description
facies
1 2 3 4 5
550
540
530
520
510
500
meters
c m s f m c g p c
This part of the section idealized due to lack of sufficient exposure
Medium-grained quartz arenite with granules found in float
Clasts and pebble lag found in float
Maroon silty shale, micaceous; interbedded with purple quartz-rich sandstones on approximately 4.5 meter scale
Pebble conglomerate found in float
2

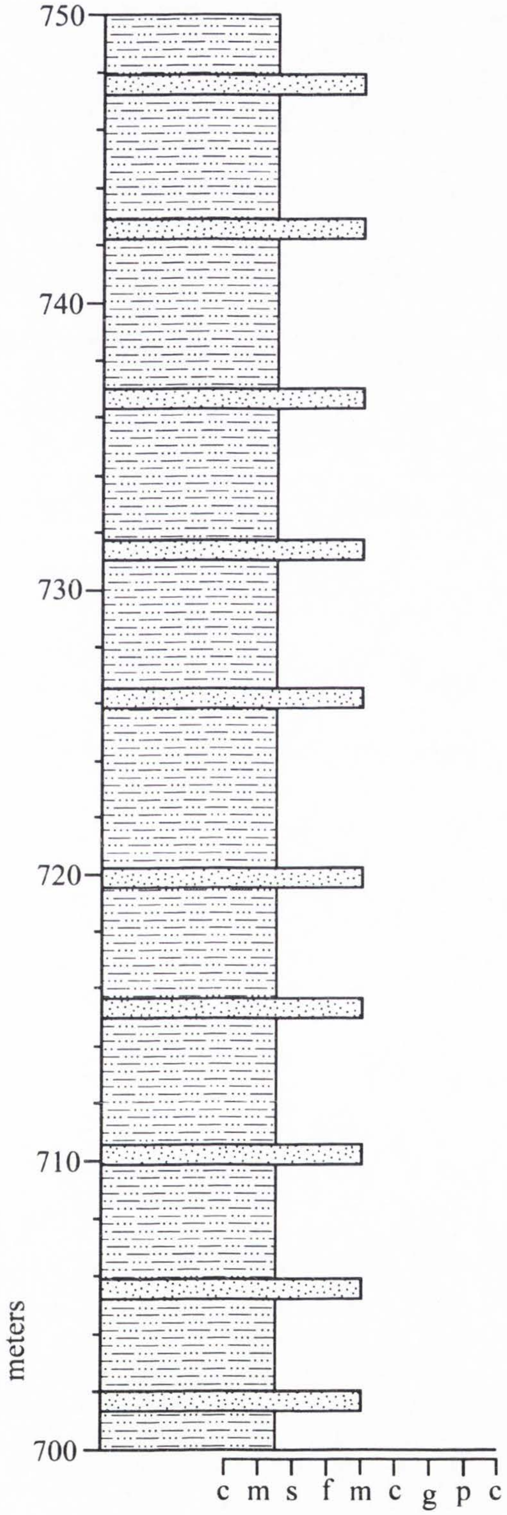

Section H
sample location
description
facies
1 2 3 4 5
600
590
580
570
560
550
meters
PC-H6 (589 m)
H-21 (585m)
Purple quartz arenite, well sorted, mod. rounding, med. tabular bedding, increase in sandstone upwards from here
Maroon shale, slighlty micaceous
3
2
c m s f m c g p c


Section H
sample location
description
facies
1 2 3 4 5
650
640
630
620
610
600
meters
Maroon shale, slightly micaceous
2
3
H-22 (624m)
Sandstone, poorly to mod. sorting, med. to thickly bedded, tabular bedding granule-defined foresets
c m s f m c g p c



Section H
sample location
description
facies
1 2 3 4 5
700
690
680
670
660
650
meters
c m s f m c g p c
This part of the section idealized due to lack of sufficient exposure
Partially covered; Maroon shale, slightly micaceous with interbedded purple to pink quartz-rich sandstone on approximately 4 meter scale
2
H-23 (667m)

Section H | sample location | description | facies 1 2 3 4 5



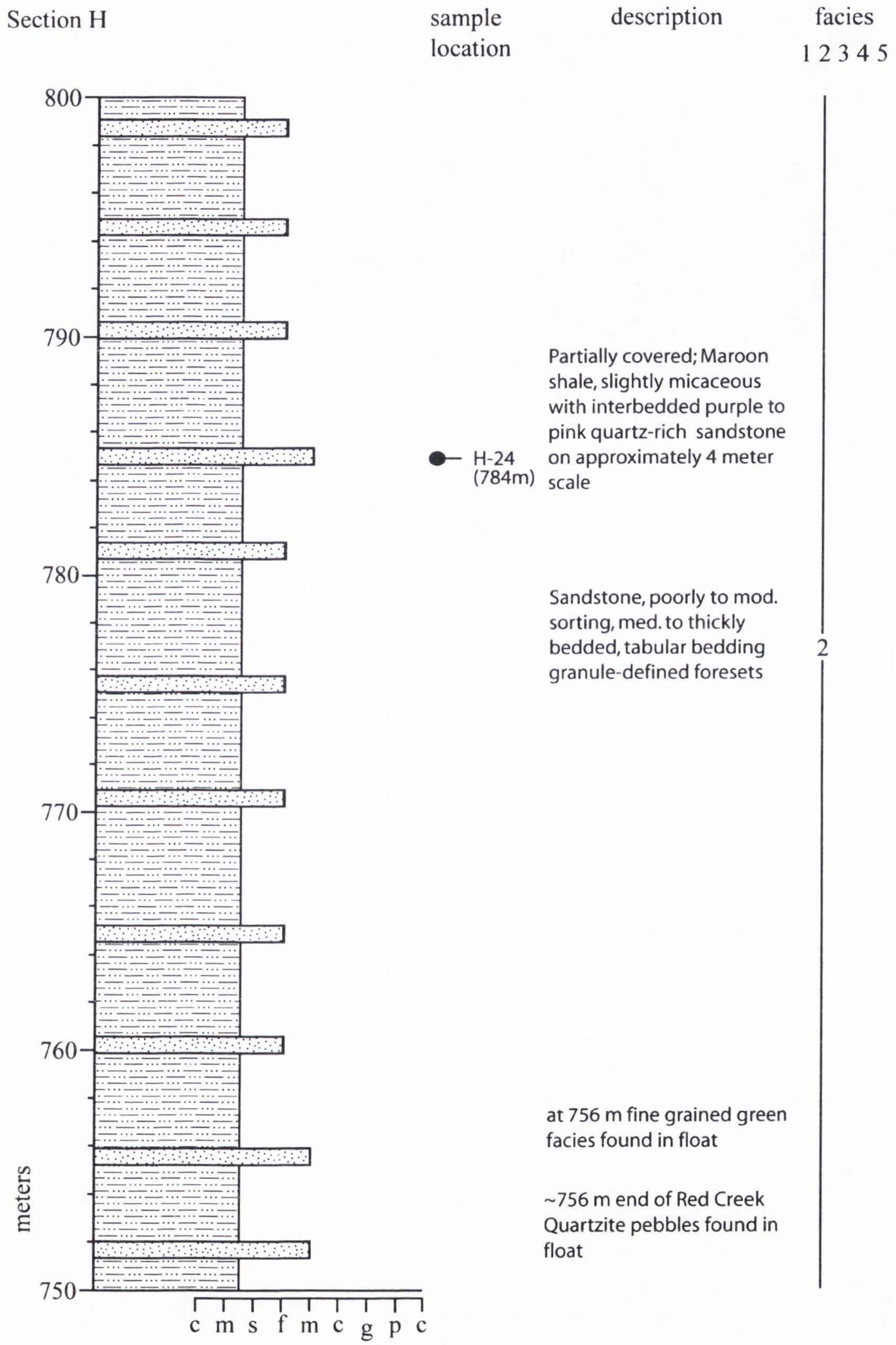
This part of the section idealized due to lack of sufficient exposure

~741 m increased Red Creek Quartzite pebbles found in float

Partially covered; Maroon shale, slightly micaceous with interbedded purple to pink quartz-rich sandstone appearing on 4-5 meter scale

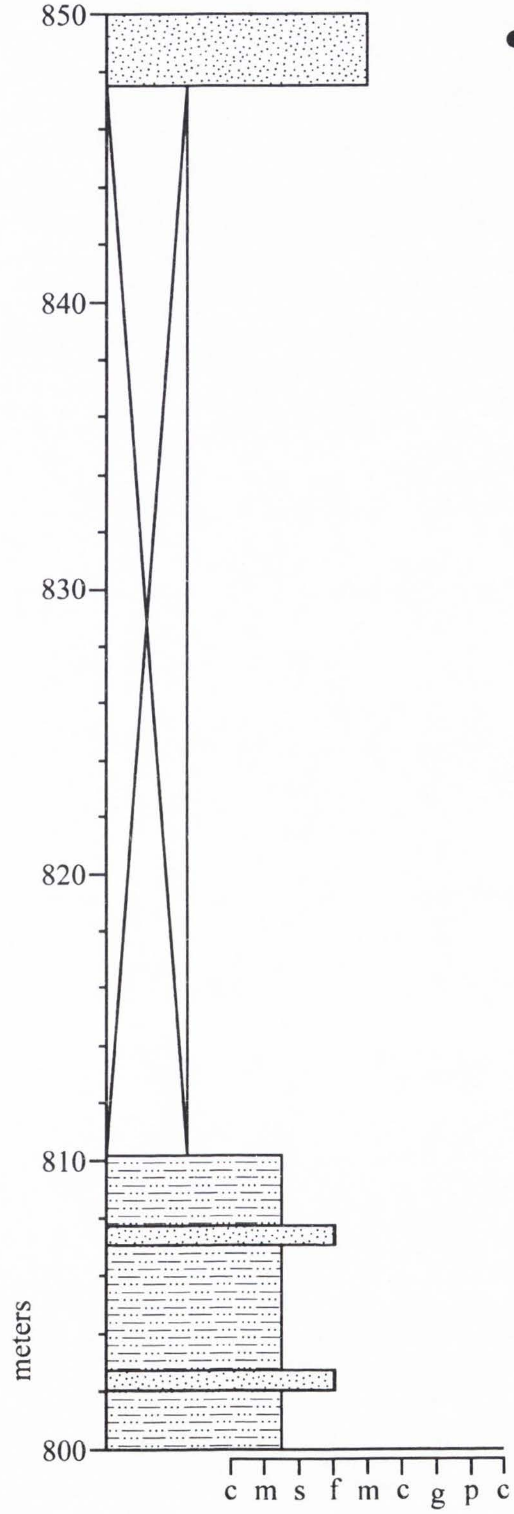
2

Sandstone, poorly to mod. sorting, med. to thickly bedded, tabular bedding granule-defined foresets


Section H
sample location
description
facies
1 2 3 4 5
800
790
780
770
760
750
meters
c m s f m c g p c
H-24 (784m)
Partially covered; Maroon shale, slightly micaceous with interbedded purple to pink quartz-rich sandstone on approximately 4 meter scale
Sandstone, poorly to mod. sorting, med. to thickly bedded, tabular bedding granule-defined foresets
2
at 756 m fine grained green facies found in float
~756 m end of Red Creek Quartzite pebbles found in float

Section H

sample location | description | facies 1 2 3 4 5



H-26 (849m) — Contact with UMG determined through mapping — 5

Quartz arenite, well sorted, mod well rounded, med. tabular bedded, massive

Contact with UMG at 847.5 m

Covered Interval but suspected maroon shale with interbedded sandstones — 2

Decrease in fine-grained green facies and increase of maroon shale

APPENDIX B
Raw strike and dip data

Easting	Northing	Strike	Dip	Dip Direction
655372	4533714	286	78	16
655056	4533292	113	11	203
655656	4533149	298	19	28
654817	4533913	279	71	9
654990	4534221	295	81	25
654693	4533258	279	62	9
654306	4533334	82	49	172
653969	4533208	72	67	162
653955	4533153	265	23	355
653509	4532949	238	25	328
652416	4532079	167	28	257
652568	4532527	278	42	8
652853	4532584	254	15	344
653112	4532404	204	5	294
656660	4532262	54	26	144
657122	4532404	358	20	88
657127	4532389	299	20	29
657005	4532214	294	36	24
655307	4533705	278	84	8
655197	4533633	275	45	5
655332	4533716	92	78	182
655367	4533720	284	83	14
655590	4533726	295	25	25
655646	4533667	284	41	14
656153	4533648	266	34	356
656241	4533620	280	79	10
656534	4533252	5	26	95
656656	4533172	323	34	53
656774	4533162	274	35	4
657441	4532679	355	32	85
657455	4532532	31	42	121
657433	4532469	263	42	353
657439	4532267	261	56	351
657419	4532136	235	26	325
657184	4531953	201	27	291
657196	4531839	121	21	211
657250	4531780	109	45	199
655587	4533926	122	65	212
655610	4533856	120	85	210
655655	4533896	298	81	28
655719	4533965	121	70	211
655943	4533931	116	84	206
656266	4533830	287	41	17
656428	4533632	305	32	35
656509	4533607	225	44	315
656493	4533573	284	61	14
657218	4533463	280	39	10
657193	4533382	272	36	2
657351	4533330	286	39	16

Easting	Northing	Strike	Dip	Dip Direction
657549	4533273	271	35	1
657802	4533137	278	30	8
656748	4532022	10	39	100
656739	4532171	53	54	143
656807	4532046	286	13	16
656842	4532281	39	63	129
656991	4532422	220	76	310
657144	4532374	300	21	30
657105	4532276	292	29	22
657070	4532117	273	13	3
657049	4531950	286	10	16
657063	4531739	111	20	201
656802	4531623	91	43	181
656549	4531701	264	47	354
656508	4531693	250	22	340
656309	4531833	300	30	30
656336	4532015	39	83	129
656345	4531836	323	19	53
656620	4531628	85	31	175
652525	4532187	136	19	226
652487	4532223	175	12	265
652433	4532277	174	16	264
652406	4532302	257	12	347
652486	4532516	216	19	306
652495	4532627	225	17	315
652526	4532641	234	17	324
652595	4532573	260	23	350
653010	4532451	254	21	344
653167	4532817	245	15	335
653217	4533036	215	25	305
653524	4533133	214	20	304
653523	4533217	220	30	310
653541	4533179	200	30	290
654989	4534102	298	60	28
654765	4534065	288	45	18
654139	4534235	61	63	151
653867	4534355	257	77	347
653777	4534185	70	72	160
653677	4534156	57	84	147
653484	4534042	248	60	338
653381	4533839	247	43	337
653593	4533756	250	53	340
653602	4533657	240	49	330
656098	4534339	104	15	194
656067	4534291	78	42	168
648928	4532086	121	32	211
648644	4532170	85	31	175
648743	4532131	88	21	178
660352	4534718	234	43	324

Easting	Northing	Strike	Dip	Dip Direction
660204	4534508	277	31	7
659879	4534280	264	36	354
659543	4533981	244	28	334
657399	4532402	255	52	345
657475	4532713	58	10	148
657040	4531947	295	18	25
654879	4533706	105	90	195
660372	4535054	261	55	351
660400	4534858	280	45	10
656576	4532225	15	30	105
656654	4532264	27	41	117
656718	4532220	25	39	115
656756	4532217	41	58	131
656858	4532170	265	38	355
656651	4532130	10	22	100
656709	4532175	58	47	148
656734	4532146	341	16	71
656517	4532174	135	21	225
664767	4534077	264	24	354
663238	4533016	272	31	2
663164	4532759	265	20	355
663106	4532691	250	22	340
662738	4532448	285	37	15
658082	4533993	210	58	300
658001	4534000	267	78	357
657941	4533950	265	61	355
657962	4533891	262	63	352
658024	4533800	260	60	350
658129	4533585	257	48	347
658298	4533386	262	47	352
658264	4533241	248	44	338
658131	4532925	280	30	10
658227	4532482	270	38	360
658409	4532170	238	20	328
667129	4527712	268	15	358
667167	4527857	266	4	356
667186	4528170	141	20	231
667171	4528196	248	22	338
667148	4528592	225	11	315
666864	4528391	224	18	314
66935	4528277	201	6	291
667027	4528040	142	6	232
666987	4527687	198	8	288
659786	4535305	72	23	162
659796	4535171	276	66	6
659783	4535151	276	60	6
659869	4534937	285	54	15
660262	4535184	268	54	358
660489	4534918	268	44	358

Easting	Northing	Strike	Dip	Dip Direction
662913	4536226	325	22	55
662697	4535786	276	29	6
663980	4536148	266	40	356
652721	4533939	265	39	355
652724	4533769	274	41	4
652661	4533585	278	36	8
652594	4533229	250	25	340
652357	4533110	268	20	358
652305	4532990	259	14	349
652242	4532815	228	11	318
652086	4532576	204	23	294
648002	4530474	230	7	320
651214	4531621	172	14	262
651210	4531707	155	21	245
651241	4531829	167	14	257
645701	4535476	264	53	354
645106	4535726	250	37	340
665955	4533755	255	16	345
666083	4533222	281	22	11
665883	4532976	285	28	15
665870	4532584	301	41	31
664459	4535536	290	35	20
665541	4535583	303	38	33
661201	4535613	259	42	349
661013	4535228	275	38	5
661228	4535183	251	50	341
661250	4535056	256	50	346

APPENDIX C
Raw Paleocurrent Data

PC station	Sedimentary Structure	Bedding	Reading Type	T-P of feature	Orientation	Dip Direction	GPS	Measured Section meter	Rotated Trend-Plunge
1	Imbricated Clasts	298 19	S/D of clasts	356	266 58	north	E 0655656 N 4533149		186 41
	Imbricated Clasts	299 19	S/D of clasts	348	258 54	north			179 38
	Imbricated Clasts	300 19	S/D of clasts	5	275 66	north			194 48
	Imbricated Clasts	301 19	S/D of clasts	16	286 57	north			200 38
2	Planar crossbeds	310 23	S/D of crossbed	71	341 32	east	E 0657204 N 4531867		66 12
	Imbricated Clasts	258 34	S/D of clasts	320	230 45	northwest			148 14
3	Planar crossbeds	255 52	S/D crossbed	320	230 53	northwest	E 0657399 N 4532402		330 4
4	Planar crossbeds	295 18	S/D crossbed	165	75 45	north	E 0657040 N 4531947		148 57
	Planar crossbeds	296 18	S/D crossbed	90	360 12	east			88 4
	Planar crossbeds	297 18	S/D crossbed	140	50 33	north			128 39
PC-A1	Planar crossbeds	298 18	S/D crossbed	43	213 32	northwest		2 m	41 15
PC-B1	Symmetric ripples	140 14	Trend & Plunge	193	193 13	south		105 m	194 2
	Symmetric ripples	141 14	Trend & Plunge	210	210 18	northwest			211 5
5	Planar crossbeds	269 24	S/D crossbed	354	264 34	northwest	E 0664767 N 4534077		355 10
6	Trough crossbed	272 31	Trend & Plunge	270	270 10	west	E 0663238 N 4533016		275 10
7	Planar crossbeds	285 37	S/D crossbed	350	260 47	northwest	E 0662738 N 4532448		358 12
	Planar crossbeds	286 37	S/D crossbed	355	265 48	northwest			1 12
8	Imbricated Clasts	262 63	S/D of clasts	35	305 56	northwest	E 0657962 N 4533891		194 1
	Imbricated Clasts	263 63	S/D of clasts	350	260 77	northwest			172 14
	Imbricated Clasts	264 63	S/D of clasts	20	290 79	northwest			177 17
9	Planar crossbeds	260 60	S/D crossbed	325	235 46	northwest	E 0658024 N 4533800		153 11
10	Planar crossbeds	257 48	S/D crossbed	340	250 70	northwest	E 0658129 N 4533585		344 22
	Planar crossbeds	258 48	S/D crossbed	337	247 54	northwest			341 6
11	Planar crossbeds	268 15	S/D crossbed	308	218 34	northwest	E 0667129 N 4527712		314 24
	Planar crossbeds	269 15	S/D crossbed	331	241 32	northwest			334 18
12	Planar crossbeds	248 22	S/D crossbed	2	272 31	north	E 0667171 N 4528196		359 11
	Planar crossbeds	249 22	S/D crossbed	349	259 27	north			348 5
	Planar crossbeds	250 22	S/D crossbed	344	254 31	north			343 9
13	Planar crossbeds	281 22	S/D crossbed	112	22 23	west	E 0666083 N 4533222		102 25
PC-H1	Trough crossbed	237 19	Trend	*280*	280	northwest	E 0659451 N 4531099		
	Trough crossbed	238 19	Trend	*285*	285	northwest			
	Trough crossbed	239 19	Trend	*290*	290	northwest			
PC-H2	Planar crossbeds	237 19	Dip direction	*310*	310	northwest		40 m	
PC-H3	Planar crossbeds	245 18	Dip direction	*315*	315	northwest		98 m	
PC-H4	Planar crossbeds	264 8	Dip direction	*285*	285	northwest		123 m	
PC-H5	Tangential crossbeds	280 11	Dip direction	*260*	260	west		473 m	
	Tangential crossbeds	281 11	S/D crossbed	*290 22*	290 22	northwest		473 m	
PC-H6	Planar crossbeds	272 13	Dip direction	*280*	280	northwest		589 m	
	Planar crossbeds	273 13	Dip direction	*275*	275	northwest		589 m	

APPENDIX D
Raw Point Count Data

Sample #	Poly Qtz.	Mono. Nonundulose Qtz.	Mono Undulose Qtz.	Weathered Spar	Sed. Lithic	Acc. Mineral	Cement	Matrix	Total
A1	27	154	107	1	1	0	10	0	300
A3	14	130	125	0	0	15	16	0	300
A6	145	28	108	0	3	9	7	0	300
A7	16	100	166	0	1	4	13	0	300
A10	0	28	179	0	0	88	5	0	300
A11	1	7	286	0	0	6	0	0	300
A13	7	34	105	0	0	48	106	0	300
A16	0	16	157	37	0	21	14	55	300
A21	144	2	116	9	9	13	0	7	300
A24	61	26	148	24	0	10	31	0	300
B2	29	42	137	84	1	4	3	0	300
B3	2	21	135	92	0	30	20	0	300
B7	7	65	171	23	0	33	1	0	300
B8	11	108	168	1	0	6	6	0	300
B9	1	128	170	0	0	0	1	0	300
C2	2	35	209	20	0	21	13	0	300
D1	0	2	152	107	0	20	19	0	300
D2	0	61	218	10	0	11	0	0	300
D4	16	15	205	48	0	12	4	0	300

APPENDIX E

Normalized point count data for ternary diagram

Sample #	Facies	Quartz	% Quartz	Feldspar	% Feldspar	Lithics	% Lithics	Total
A1	sandstone	261	90	1	0.3	28	9.7	290
A3	sandstone	255	94.8	0	0.0	14	5.2	269
A6	sandstone	136	47.9	0	0.0	148	52.1	284
A7	sandstone	266	94.0	0	0.0	17	6.0	283
A10	green	207	100.0	0	0.0	0	0.0	207
A11	green	293	99.7	0	0.0	1	0.3	294
A13	green	139	95.2	0	0.0	7	4.8	146
A16	green	173	82.4	37	17.6	0	0.0	210
A21	green	118	42.1	9	3.2	153	54.6	280
A24	green	174	67.2	24	9.3	61	23.6	259
B2	green	179	61.1	84	28.7	30	10.2	293
B3	green	156	62.4	92	36.8	2	0.8	250
B7	sandstone	236	88.7	23	8.6	7	2.6	266
B8	sandstone	276	95.8	1	0.3	11	3.8	288
B9	sandstone	298	99.7	0	0.0	1	0.3	299
C2	sandstone	244	91.7	20	7.5	2	0.8	266
D1	green	154	59.0	107	41.0	0	0.0	261
D2	green	279	96.5	10	3.5	0	0.0	289
D4	sandstone	220	77.5	48	16.9	16	5.6	284

APPENDIX F

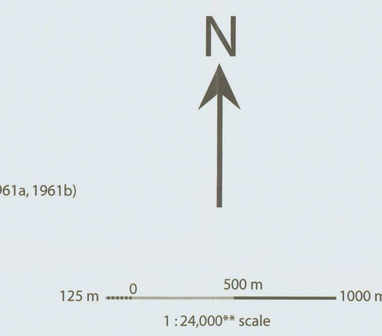
General thin section information

Sample #	Ave. Grain Size	Grain Size Range	Sorting	Rounding	Grain Boundaries	Sandstone Type	Comments
A1	mL	vfL-vcU	well	subangular-subrounded	point	Sublithic arenite	
A3	mL	vfU-vcL	moderate	subangular	point	Sublithic arenite	
A6	mU	fL-vcL	moderate	subangular-rounded	point	Lithic arenite	abundant qtz. overgrowths
A7	mL	fU-cL	well	well rounded	point	Sublithic arenite	
A10	vfU	vfL-fU	well	subrounded	point	Quartz arenite	
A11	mU	mL-cL	well	angular	point	Quartz arenite	
A13	vfU	vfL-fL	well	angular	point	Quartz arenite	
A16	fU	vfU-mL	mod. well	angular	point	Arkosic wacke	
A21	mU	silt-vcU	poor	angular	point	Lithic arenite	
A24	mL	vfU-vcL	poor	subangular-angular	point	Sublithic arenite	
B2	mL	fL-cL	mod. well	subangular-angular	point	Subarkose	
B3	vfU	vfL-cL	moderate	angular	point	Arkose	graded bedding
B7	mL	fU-cL	moderate	moderate	point	Subarkose	
B8	fL	vfU-mL	well	mod. well	point	Quartz arenite	
B9	mL	fU-mU	well	subangular	point	Quartz arenite	
C2	fL	vfU-mL	mod. well	subangular-angular	point	Subarkose	
D1	silt	silt-vfU	well	subangular	point	Arkose	graded bedding
D2	fU	fL-mL	well	subrounded	point	Quartz arenite	
D4	vfU-cL	poor	subangular-angular	point	arenite	Subarkose	

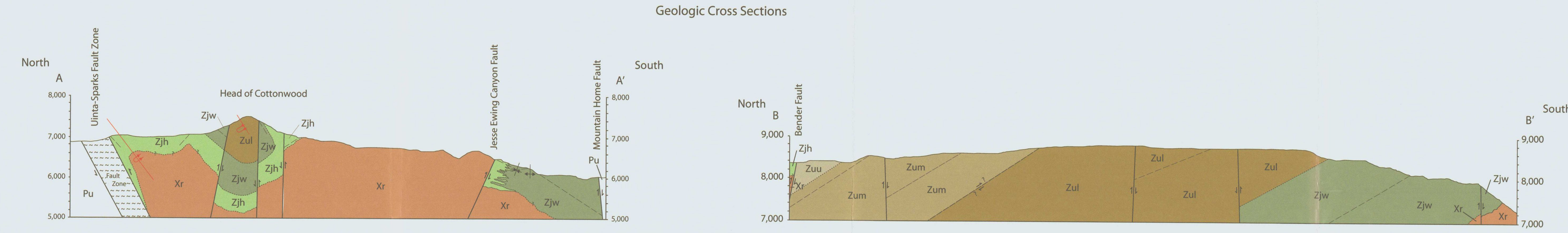
Brehm, 2007
Plate 1 - Map

Pu	**Phanerozoic Rocks** Undifferentiated Phanerozoic rocks. Surficial fine- to coarse-grained sand to boulder sized Quaternary deposits. Tertiary Browns Park formation, a dominately white to tan fine-grained tuffaceous sandstone. Cretaceous shales and fine- to coarse-grained sandstones.
Zuu	**Upper Uinta Mountain Group** Non-formalized Uinta Mountain Group. Dark- to light-red, fine- to coarse-grained quartz and lithic arenite. Thick- to medium-bedded, planar-, cross-, and contorted bedding with ripples and mudcracks. Contains interbedded shale and conglomerate with associated pebble lags.
Zum	**Middle Uinta Mountain Group** Non-formalized Uinta Mountain Group. Dark- to light-red shale with interbedded fine- to coarse-grained quartz and lithic arenite. Thick- to medium-bedded, planar-, cross-bedding with ripples and mudcracks. Upper unit shows red, green, and dark-gray micaceous shale and conglomerate with associated pebble lags.
Zul	**Lower Uinta Mountain Group** Non-formalized Uinta Mountain Group. Dark- to light-red, fine- to coarse-grained quartz and lithic arenite. Thick- to medium-bedded, planar-, cross-, and contorted bedding with ripples and mudcracks. Contains interbedded shale and conglomerate with associated pebble lags.
Zjw	**Jesse Ewing Canyon Formation, Willow Creek Member** Dark- to light-red shale interbedded with brown and reddish-purple quartz, feldspathic, and lithic arenite. Upper units are primiarly finer grained green micaceous sandstones and maroon shales.
Zjh	**Jesse Ewing Canyon Formation, Head of Cottonwood Member** Dark- to light-red, brown and reddish-purple pebble to boulder conglomerate interbedded with quartz and lithic arenite and shale. Clasts primarily from underlying Red Creek Quartzite displayed as white, pale green, and pink quartzite.
Xr	**Red Creek Quartzite** Contains metaquartzite, mica schist, and amphilbolite. Metaquartzite - resistant white, gran, tan, and light-green metaquartzite. Mica Schist - Quartz-muscovite schist that grades between metaquartzite and mica schist. Amphilbolite - Dark-gray to black, fine- to medium-grained amphilbolite composed of strongly foliated mafic rocks associated with the Red Creek Quartzite as numerous small bodies.

Uinta-Sparks Fault Zone
Normal Fault Certain
Normal Fault Approximate
Normal Fault Inferred
Normal Fault Concealed by Tertiary and Quaternary Units
Reverse Fault Certain
Reverse Fault Approximate
Reverse Fault Concealed
Hypothesized Thrust Fault
Fold Axis Approximate
Fold Axis Concealed by Tertiary and Quaternary Units
Axis of overturned anticline
Axis of overturned syncline
Contact Certain
Contact Approximate
Hypothesized Contact
Marker Bed from Hansen (1961b) mapping
Dip of Beds in cross sections
Consealed Contact
Strike and Dip from this study
Strike and Dip from Hansen (1957, 1961a, 1961b) mapping
Location of detrital zircon sample
Location of measured section



Geologic Cross Sections



* O-Wi-Yu-Kuts Complex (Sears et. al., 1982) and facies of the Red Creek Quartzite (Hansen, 1965) not differentiated. Phanerozoic units not mapped.

** Mapped at 1 : 12,000 scale

Plate 1 - Geologic map of the Neoproterozoic Uinta Mountain Group* within the Goslin Mountain, Clay Basin, and Willow Creek Butte 7.5' quadrangles

Plate 2 - Correlation of measured sections

Brehm, 2007
Plate 2 - Correlations