Paleoenvironmental interpretation of the Middle Cambrian Flathead Sandstone and Wolsey Shale, Clarks Fork region, Wyoming

Dawn Morgan
Department of Geology, Beloit College, 700 College St., Beloit, WI 53511-5595
Faculty sponsor: Carl Mendelson, Beloit College

INTRODUCTION

The Flathead Sandstone and Wolsey Shale located in the Clarks Fork Valley, Park County, Wyoming, represent a classic example of a Middle Cambrian transgressive succession. Transgression occurred from west to east with an approximate north-south shoreline. Formation thickness is dependent upon east-west position and locally upon the topography of the underlying 2.7-Ga Precambrian granite. During the Middle Cambrian these crystalline highs were islands in an epeiric sea (Middleton, 1980). The purpose of this study is to make a paleoenvironmental interpretation of the Flathead Sandstone and Wolsey Shale on the basis of sedimentology, ichnology, and depositional history.

METHODS OF STUDY

On the basis of thickness, stratigraphic continuity, and degree of visible exposure, I selected five outcrops of Flathead Sandstone and one of the Wolsey Shale as the focus of the study (Fig. 1). Reconnaissance was conducted at three additional localities. Previous work by Beebee (1996) provided mineralogical data and a basis for locating the outcrops of study. Due to the large size and horizontal variability of the recently exposed Sunlight Creek gorge outcrop, I constructed three stratigraphic sections at this locality.

In describing the Flathead, I concentrated on the lithology; bed thickness; texture; geometry of cross-stratification; degree of bioturbation; and presence, size, and abundance of trace fossils. Three outcrop faces displaying well-preserved sandwave stratification were measured, sketched, and described. Focus was placed on the presence of foresets, superimposed foresets, and erosion and reactivation surfaces. The degree of bioturbation was determined using the ichnofabric index of Droser and Bottjer (1989). The stratigraphic section constructed for the Wolsey Shale includes detailed description of lithology, color, grain size, sedimentary structures (ripples, starved ripples), and presence, size, and abundance of trace fossils.

In situ vertical burrows were collected from Flathead outcrops; samples of horizontal feeding traces were collected from float material of both formations. In the laboratory I identified, photographed, and, in some cases, sketched these traces. Examples of coarser grained sandstone deposits containing ripples and gutter casts were collected for further examination.

DISCUSSION

Flathead Sandstone. On the basis of characteristic combinations of lithology, sedimentary structures, and trace-fossil assemblages, the Flathead can be divided into 4 depositional facies. Unfortunately, due to a lack of lateral continuity and the small number of outcrops studied, it is not possible to correlate outcrops. The lowermost facies is a poorly sorted, sub-angular conglomerate with a very coarse sand to granule-size matrix, supporting clasts as large as pebbles. This facies contains alternating coarser and finer beds with widely spaced layers of cross-bedding. Based on the absence of trace fossils and lack of compositional and textural maturity, this unit is interpreted to be fluvial. Coarse-grained horizontally bedded units may represent plane-bed transport in upper flow regime during high-energy events (Miall, 1977), whereas the low-angle cross-bedding may be the result of the migration of longitudinal bars (Hein and Walker,1977), or grain avalanching down the lee side of bars in a coarse-grained braided system (e.g., Cant and Walker, 1978). This facies probably is identical with the Arkose-Conglomerate facies of Middleton (1980). Only the Clarks Fork Canyon Mouth outcrop contained this basal facies (about 71 cm thick); elsewhere the nonconformity with the crystalline basement was not exposed, although I estimate that this surface was within two metres of the base of all outcrops except that along the Chief Joseph Highway.

The second facies is divided into two subfacies. Facies 2a is composed of interbedded small-scale trough cross-bedding, medium- to coarse-grained horizons containing well-defined vertical burrows (including *Skolithos* and U-shaped burrows), and 1.5- to 22-cm-thick layers of localized shale-siltstone of variable thickness (Fig 2, metres 0-7). Facies 2b is very similar to the underlying strata, but lacks the well-defined vertical burrows and repetition of cross-beds, burrowed surfaces, and shale lenses. It is composed of medium- to very coarse grained trough- and horizontally laminated sandstone. There are some vertical burrows, but they are small and poorly defined. Facies 2b also contains large-scale trough cross-bedding (Fig. 2, metres 7-16). It is possible that these two subfacies record the same depositional environment; however, they are different enough in character that they may be divided. The coarse grain size; trough cross-bedding; and presence of the vertical burrows identified as *Skolithos, Arenicolites,* and possibly *Diplocraterion* support the interpretation of facies 2 as a high-energy wave- or current-dominated environment. In Ekdale's (1984) energy-depth zonation of trace fossils in a classic beach-to-offshore succession, facies 2 is represented by the sandy to sublittoral zone.

Facies 3 is characterized by large-scale sandwave deposits composed of medium- to very coarse grained sandstone. Many sets are bounded by reactivation surfaces; these are the result of a change in activity of the bedform. Sandwaves indicate depositional environments of tide-dominated shelves; they range up to 20 metres in height with wavelengths of tens to hundreds of metres (Boggs,1995). Due to outcrop constraint and erosional surfaces, the maximum size of sandwaves in the Flathead is unknown. Superimposed foresets dip toward, as well as away from, the large-scale dip direction; these observations suggest unequal ebb and flood tides.

Facies 4, the uppermost facies, represents a deepening transition from the Flathead Sandstone into the Wolsey Shale and is best represented by 4 metres of section at the Chief Joseph Highway outcrop. It is characterized by interbedded, poorly sorted, and highly bioturbated sandstone and silty shale. The degree of bioturbation ranges from 2-5 on Droser and Bottjer's (1989) ichnofabric indices, although most layers are in the 4-5 range. In high-energy and wave-dominated environments, inorganic structures predominate because biogenic structures are either not developed or have been eroded away. In low-energy settings, biogenic reworking is often so thorough that the sediment becomes homogeneous, poorly sorted, and virtually structureless (Apgar, 1986). The latter is most likely the explanation for facies 4, because beds are composed of medium- to very coarse grained sandstone with biogenically incorporated clay. Original bedding is rare, but when it does occur, it is horizontally laminated, thus inferring a deeper (below wave base?) environment of deposition.

Wolsey Shale. The Wolsey Shale is composed of thin layers of shale and siltstone with interbedded very fine to medium-grained sandstone. The shale is soft and fissile; the sandstone, typically differentially weathered, contains cross-bedding. The wide variation in color is probably not indicative of diagenetic alteration (Lebauer, 1964), and thus may reflect a stratigraphic change in the degree of oxidation. Abundant primary sedimentary structures include ripple marks, starved ripples, graded bedding, and prod and scour marks. Bioturbation and horizontal feeding traces are common. The degree of bioturbation was noted using the ichnofabric index diagram for every stratigraphic layer. Many layers were so highly bioturbated that individual burrows were not recognizable. Small burrows, oval in cross-section and with an average diameter of 0.5 cm, are abundant in the Wolsey Formation; it is difficult to determine their taxonomic affinity. *Teichichnus*, a horizontal burrow with a vertical component, was most prevalent and most easily identified. Its concave-upward spreite make it easily distinguished from surrounding sediment. The highly bioturbated layers and complex networks of horizontal feeding traces indicate slow sedimentation. The Wolsey is interpreted to be a transitional unit between the underlying clastic Flathead and overlying Meagher Limestone; it apparently formed on a storm-influenced shallow shelf.

CONCLUSIONS

The Flathead Sandstone and Wolsey Shale represent a deepening succession deposited during the Middle Cambrian. Facies 1 is the least mature unit of the Flathead; it represents the initial stages of transgression and is interpreted to be fluvial in origin. Facies 2, consisting of well-rounded, cross-bedded, quartz sandstone with abundant vertical burrows, is thought to have been deposited in upper shoreface to foreshore environments. The sandwave facies (facies 3) is also thought to represent lower-shoreface deposition where tidal action was prevalent. The uppermost facies of the Flathead (facies 4) is the highly bioturbated and poorly sorted transitional phase into the overlying Wolsey Shale; this facies most likely represents the transitional environment from the lower shoreface to the inner shelf.

In modern settings, the abundance of benthic marine invertebrate organisms increases with decreasing grain size. This can be attributed to a number of different factors, including lower physical energy, deeper water conditions, an increase in food availability, and substrate preference. A trend of increased biogenic activity is coupled with a decrease in the amount of physical sedimentary structures (Davis, 1983). The Wolsey records a dramatic change from sandy substrate to the muddy offshore substrate; this transition occurs at fairweather wave base. Although sand layers were incorporated into the Wolsey during periods of increased wave energy associated with storms, it is predominantly finer grained.

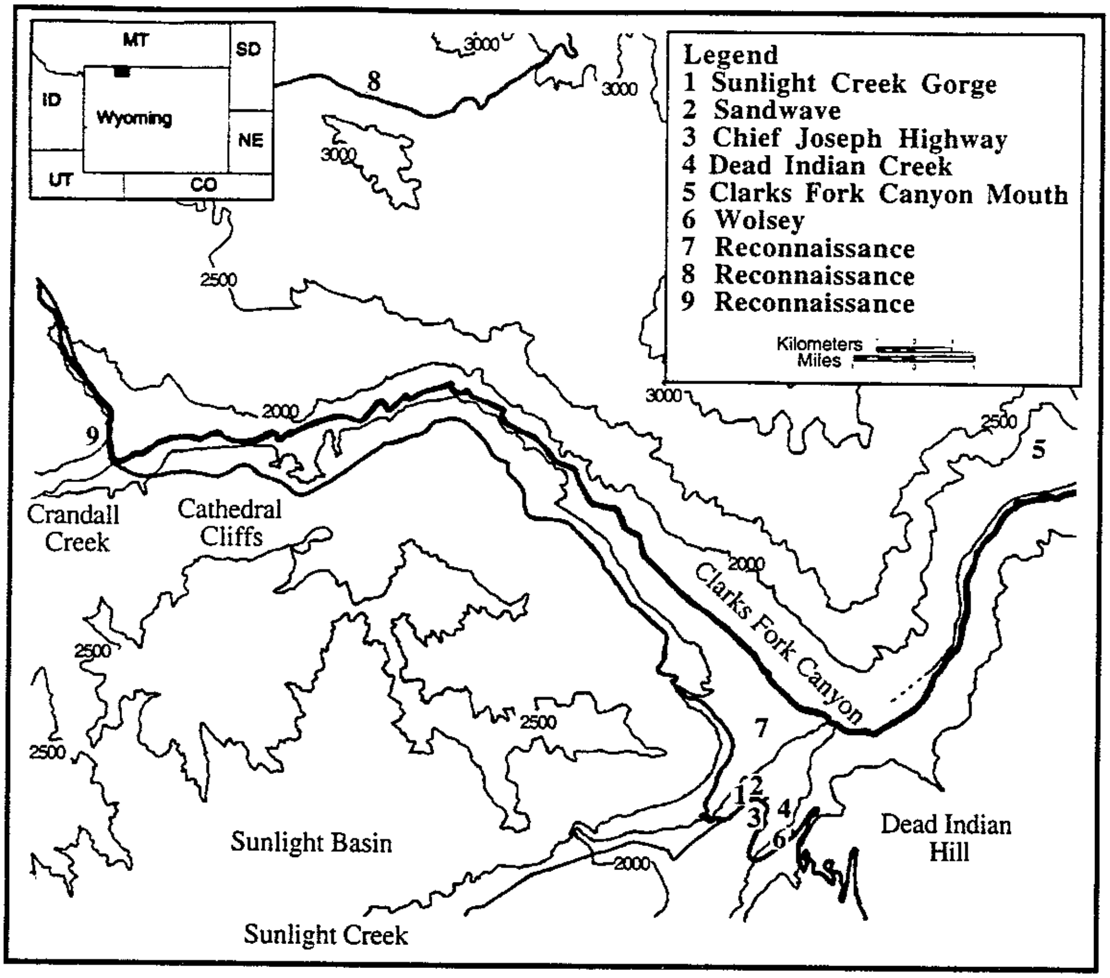

Figure 1. Location map of Clarks Fork Region.

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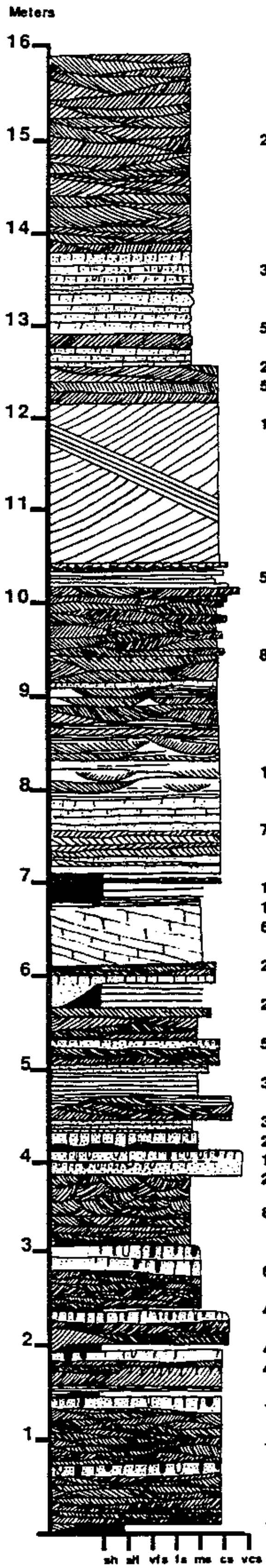

Flathead Sandstone
Sunlight Creek Gorge

	Ichnofabric Index
210 cm of v. c. grained, p. sorted Ss. Trough x-bedded.	1
30 cm of c. grained (ranging from m. to v. c.), p. sorted Ss. Interbeds of <3 mm of sh. #3 of Skolithos, 2 mm in diameter and 1-5 cm in length. Possible U-shape burrows.	3
58 cm of medium grained w/ up to 3 mm clasts, cross-beds at top w/ interbeds of <3 mm sh., #2-3 *Skolithos*.	2-3
25 cm of c. to v. c. grained, p. sorted Ss. 10-15 cm thick trough x-beds.	1
50 cm of c. grained Ss. Trough w/ large scale x-beds.	1
166 cm of m. to v. c. grained Ss. w/ parallel lamination and some thin trough x-beds.	1
54 cm of variable grain size w/ x-bed sets up to 12 cms.	1
87 cm of coarse grain sand with Skolithos and trough x-bedding.	1-2
159 cm of c. grained Ss. w/ parallel lamination and trough x-bedding.	1
71 cm of c. grained Ss. w/ parallel lamination and trough x-beds.	1
17 cm of green sh. w/ a few thin < 3 cm c. grained Ss. beds.	1
10 cm of m. grained Ss. w/ parallel lamination.	1
61 cm of m. grained p. sorted Ss. w/ low angle lamination and #2-3 *Skolithos* on multiple horizons.	2-3
25-47 cm of m. grained, v. p. sorted Ss. w/ *Skolithos*.	2-3
22 cm of sh. w/ a few thin m. grained Ss. interbeds.	1
59 cm of m. to c. grained Ss. w/ trough x-beds and a few possible *Skolithos*.	1-2
32 cm of f. to m. grained, p. sorted Ss. w/ up to pebble size clasts. Parallel lamination.	1
32 cm of c. to v. c. trough x-beds.	1
27 cm f. to m. grained massive Ss.	1
10 cm of m. grained Ss. w/ c. to grn. size particles w/ *Skolithos*	2
21 cm of c. to v. c., p. sorted Ss. w/ *Skolithos*.	2
80 cm of m. grained Ss. w/ parallel lamination. #2 *Skolithos* and U-shape burrows, 2-5 cm in length.	2
68 cm of m to c. grained trough x-bedded Ss. #3.5 *Skolithos* and U-shape burrows in uppermost horizon; 2.5-5 cm in length.	3.5
41 cm of m. to c., x-laminated Ss. # 3.5 *Skolithos* and U-shape burrows in uppermost horizon; 2.5-4 cm in length.	3.5
4 cm of grey-white crumbly sh. w/ some c. grained sand intermixed.	1
48 cm of v. c. grained trough x-beds w/ occasional finer grain interbeds. #2 for 3.5-5 cm *Skolithos* in the m. grained sand horizons.	3.5
1-5 cm of blue-grey, highly-weathered flaky sh.	1
137 cm of m. to v. c. grained Ss. Trough x-bedded w/ an average thickness of 5-10 cm and maximum of 20 cm. #2 *Skolithos* and U-shaped burrows in uppermost horizon. 3-4 cm in length.	2
1.5 cm of blue-grey highly weathered and v. flaky thinly laminated sh.-slt.	1

Figure 2. Stratigraphic Section of Flathead Sandstone: Sunlight Creek Gorge Outcrop.