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Vertical Distributions of Carbonite Lithologies, Bedding Features, and Macrofossils in the Broken Rib Member of the Upper Devonian Dyer Formation Near Monument Lake, Garfield County, Colorado

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VERTICAL DISTRIBUTIONS OF CARBONATE LITHOLOGIES, BEDDING FEATURES, AND MACROFOSSILS IN THE BROKEN RIB MEMBER OF THE UPPER DEVONIAN DYER FORMATION NEAR MONUMENT LAKE, GARFIELD COUNTY, COLORADO

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has been approved as meeting the requirement for the Degree of Master of Arts in College of Natural and Health Sciences in School of Earth Sciences and Physics, Program of Earth Sciences

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ABSTRACT

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The Broken Rib Member of the Upper Devonian Dyer Formation is a series of fossiliferous limestone beds deposited during the Famennian stage of the Late Devonian. The limestone units are well-exposed near Monument Lake in the White River National Forest of west-central Colorado, where they weather into a series of step-like, laterally continuous surfaces. A graphic log, recorded in the field, reveals that lithologies vary from carbonate mudstones to wackestones and reflect the fluctuating water depth associated with a transgressing and regressing sea. The fossil assemblages consist of well-preserved, identifiable brachiopods, bryozoans, pelmatozoans, and other minor taxa that occur in a micrite and fossil fragment matrix. These taxa indicate the Broken Rib Member formed in a sublittoral, marine environment with well-oxygenated water of normal salinity, with a slow accumulation of lime mud. Well-preserved identifiable fossils are uncommon in micritic limestones near the bottom of the section and were likely deposited during a peak transgression during the Famennian stage under

storm wave base. Identifiable fossils are more abundant at the top of the section where storms periodically winnowed away mud and deposited fossil fragments. Further investigations that identify marker beds would correlate the findings of this study with other exposures of the Broken Rib Member. Additional analysis of patterns of faunal diversity through the section would allow a more precise reconstruction of the conditions during deposition of the Broken Rib Member.

ACKNOWLEDGEMENTS

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CHAPTER I

INTRODUCTION

This study presents data collected from detailed observation of a section of the Broken Rib Member of the Dyer Formation near Monument Lake in the White River National Forest in west-central Colorado. It reveals vertical variations in the lithology and fauna of the Broken Rib Member. This study also includes a taphonomic and paleoecological interpretation of the environment that formed the limestone layers and fossil assemblages of the Broken Rib Member.

During the Devonian, a shallow sea repeatedly transgressed and regressed over most of present day Colorado and deposited sandstones and carbonates (Campbell, 1970; Sandberg and Poole, 1977). Mississippian erosion removed most of these deposits but the Chaffee Group, a Late Devonian sequence, remains (Campbell, 1970). The Chaffee Group consists of the basal Parting Formation and the upper Dyer Formation. The Parting is composed of calcareous quartz-sandstone beds; the Dyer consists of the basal Broken Rib Member, a series of fossiliferous limestone beds, and the upper Coffee Pot Member, a series of tan, unfossiliferous, dolostone beds.

Deposition of the Broken Rib Member took place during the Famennian stage of the Devonian. This stage immediately follows one of the five largest known extinction events that occurred at the Frasnian-Famennian boundary (McGhee, 1996). About 75% of brachiopod genera were lost during this extinction event including the Pentamerida and Atrypida orders (McGhee, 1996). Strophomenida, Spiriferida, and Rhynchonellida are among the survivors that persist and diversify during the Famennian (Johnson, 1979; McGhee, 1996) and comprise many of the genera found at Monument Lake.

Previous work consists of lithological descriptions, and subdivision, ranking, and chemostratigraphic correlation of the formations and members. Emmons (1882) named the Parting Quartzite after the Parting Spur in Lake County, Colorado. In 1931, Kirk named the Chaffee Formation in Chaffee County, Colorado. Behre (1932) named the Dyer Dolomite for the West Dyer and Dyer mountains in Lake County, Colorado. Bass and Northrop (1963) were the first to map in detail the Devonian rocks in the White River Plateau in Colorado. Campbell (1970) further described these rocks, elevated the Chaffee Formation to Group status, changing the name Parting Quartzite to the Parting Formation, and divided the Parting into unnamed units A, B, and C. He also changed the name of the Dyer Dolomite to the Dyer Formation and designated the lower fossiliferous limestone unit the Broken Rib Member and the upper dolostone unit the Coffee Pot Member. Additionally, Campbell (1970) logged 31 measured sections of the Chaffee Group, creating a regional synthesis of the Devonian rocks in west-central Colorado. Finally, Myrow and others (2011) recorded a strong positive carbon isotope excursion and correlated it to the latest Devonian Hangenberg Isotopic Excursion in Europe.

Other previous work includes paleontological studies. Girty (1900) described the fauna of the Ouray Limestone in southwestern Colorado, the equivalent of the Dyer Formation in Garfield County, and Kindle (1909) described additional species from the Ouray Limestone. In Garfield County, G.A. Cooper described a fauna from the Broken Rib Member (Bass and Northrop, 1963, table 1). Also from Garfield County, Sandberg and Poole (1977) and Sandberg and Ziegler (1996) described microfossils from the Chaffee Group and used them to establish a biochronology and biostratigraphy of the Late Devonian including assigning the Broken Rib Member to the early *expansa* conodont zone.

General marine regression characterizes the Famennian stage of the Late Devonian during which the Broken Rib Member formed. A series of smaller scale transgressions and regressions occurred as shown in figure 1 (Sandberg and Poole, 1977; Johnson and others, 1985; Johnson and Sandberg, 1988; Sandberg and Ziegler, 1996; Sandberg and others, 2002). The Broken Rib Member formed during one of the largest of these smaller-scale transgressions (Sandberg and Dreesen, 1984; Sandberg and others, 1989).

All of these studies document critically important information about the Dyer Formation, but do not describe the details of the lithologies and fossil assemblages that occur within the Broken Rib Member of the Dyer Formation. For example, Bass and Northrop (1963), Campbell (1970), and Ross and Tweto (1980) grouped many of the limestone beds in the Broken Rib into thick, fossiliferous, dolomitic, limestone beds. These workers did not document the detailed changes in bedding and faunas that occur in the member. This stratigraphic variability is readily observed near Monument Lake in the White River National Forest, where the limestone units form a series of step-like, laterally continuous surfaces. This study takes place on these surfaces where the fossil assemblages change from the bottom to the top of the section and reflect the fluctuating environmental conditions associated with the eustatic events.

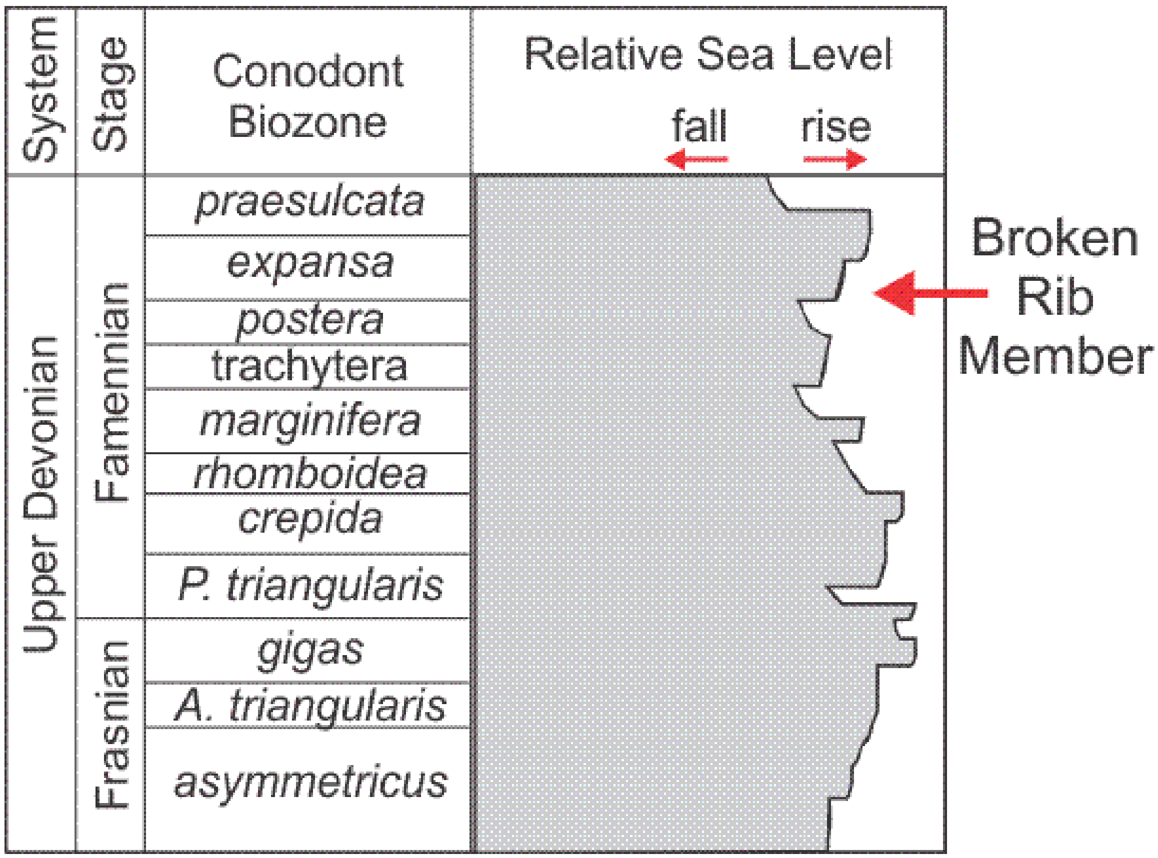


Figure 1. Sea level curve. Shows general Famennian regression and smaller-scale transgression during deposition of the Broken Rib Member (after Johnson and others, 1985, fig. 12 and Henderson and others, 2002, fig. 4).

Location

Monument Lake is located in the Flat Tops area of the White River National Forest, approximately 20 miles north of Glenwood Springs in west-central Colorado (fig. 2a). Access is via the gravel Deep Creek Road/Coffee Pot Road (Forest Service Road 600) to the light duty White Owl Lake Road to the four-wheel drive Transfer Trail Road to Monument Lake. The contact of the Broken Rib Member with the underlying Parting Formation is about 30.0 m above the road at the southwest end of Monument Lake in the NE ¼ sec. 23, T. 4 S., R. 89 W. and the SE ¼ sec. 23, T. 4 S., R. 89 W. of the Garfield County, County Map Series (fig. 2b).

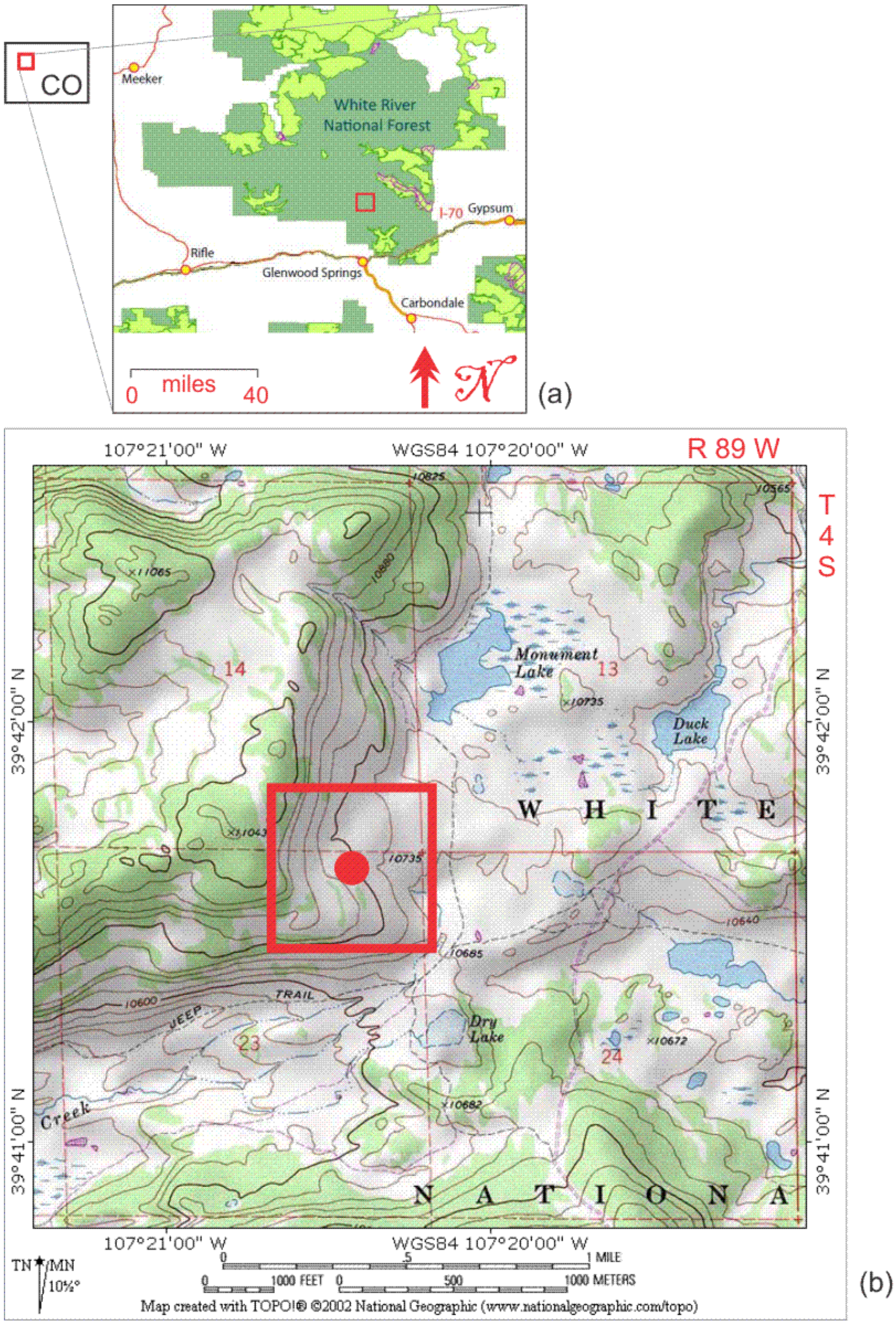


Figure 2. Location of study area. (a) Monument Lake located in the Flat Tops area of the White River National Forest, north of Glenwood Springs, CO (From http://coloradodeservesmore.org/find-out-more/maps/); (b) Study area southwest of Monument Lake indicated by square, measured section indicated by circle.

CHAPTER II

METHODS

In the Flat Tops area of the White River Plateau, the Broken Rib Member of the Dyer Formation occurs as mostly poorly exposed outcrops and vertical cliffs that are not easily accessible, and are often too steep for close examination. However, during the summer of 2010, Jim Bullecks of the Western Interior Paleontological Society and I used Bass and Northrop's (1963) Geologic and Structure Contour Map of the Glenwood Springs Quadrangle to locate a complete, well-exposed, and conformable section of the Broken Rib Member. The study area is located southwest of Monument Lake where the limestones have weathered into six distinct, laterally continuous, fossiliferous ledges that are easily accessible. The upper surfaces of these ledges are ideal for collecting detailed information about the fauna and lithology that shows variation from the top to the bottom of the section. In order to characterize these changes, during the summers of 2011, and 2012, I recorded one stratigraphic column and made a lithological and paleontological description of each weathered surface that I titled "surface 1". I then labeled three sites on each surface where descriptions that are more detailed were made. At each of these sites, I conducted point counts, estimated fossil abundances, and noted brachiopod occurrences and frequencies. A detailed description of these methods follows, and the collected data is included in the appendixes.

Fauna and lithology vary both laterally and vertically throughout the Broken Rib Member at Monument Lake. The stratigraphic section describes a sequence of 19.1 m of 26 limestone beds and details the vertical changes in lithology from bottom to top. The described section reveals the thickness of each bed, the nature of bedding, the characteristics of the contacts, weathering characteristics, and the location of the weathered surfaces.

General descriptions include all the characteristics that are readily observable on each weathered surface in the field. The only magnification used was a 10X hand lens. Rock descriptions are after Dunham’s (1962) classification of carbonate rocks and grain sizes are after the Wentworth particle-size classification (1922). Faunal identifications are after Girty (1900) and Kindle (1909) with updated brachiopod taxonomy from Jim Bullecks (C.J. Bullecks, oral and written communs., 2011, 2012). Only macrofossils were studied, the identification and analysis of microfossils is beyond the scope of this study.

Point counts of fossil abundances estimate the type of fossils and the frequencies with which they occur on each weathered surface. A 51 cm square wooden frame strung with thread created a grid pattern with 289 points located 3.0 cm apart. The point count recorded the unidentifiable fossil fragments (fossil fragments) and identifiable fossils to phylum that occurred at each point at three sites on each weathered surface.

Estimates of fossil abundances by area are another way to record fossil taxa abundance and diversity. This areal estimate indicates the percentage that each fossil fragment, identifiable fossil type, and micrite occurs in a 10.0 cm square area of the weathered surface, as determined by visual estimates. Three areal estimates were conducted at different sites on each of the six weathered surfaces.

Brachiopods are the most diverse of all the identifiable fossils at Monument Lake and previous workers have identified over 30 species from the Broken Rib Member and its correlative formations (Girty, 1900; Kindle, 1909; Stainbrook, 1947; Bass and Northrop, 1963). In this study, I attempted to identify 100 brachiopod specimens to genus and species on each weathered surface to account for species diversity. However, complete, articulated brachiopod shells are rare at Monument Lake and therefore I was unable to identify 100 brachiopods on each surface. On the surfaces where 100 brachiopods were not identifiable, the number of each species that could be identifiable was recorded. The above-described methods determined the diversity and abundance of fauna and lithologies on each weathered surface.

CHAPTER III

EXPOSURES AND LITHOLOGIES

The graphic log (plate 1) illustrates the position and thickness of lithologic packages, and their color, bed thickness, weathering features, fossil content, and contacts, as well as the location of the weathered surfaces. The Broken Rib Member is a series of light gray to dark gray, fossiliferous carbonate mudstones and wackestones. It conformably overlies the Parting Sandstone and is conformably capped by the Coffee Pot Member (Campbell, 1970). The Parting Sandstone is a light-tan, well-indurated, calcareous sandstone that is easily distinguished from the Broken Rib Member by its color and lithology. The Coffee Pot Member is a dolostone that is also easy to distinguish from the Broken Rib Member because it is light-tan and unfossiliferous. The Mississippian Leadville Limestone unconformably caps the Dyer Formation.

All limestone beds of the Broken Rib Member are gray, bioturbated, with scattered fossils and are either mudstones or wackestones. However, variations in fossil content, bedding, and weathering features define four distinct lithologic packages. The most recognizable lithologic package is a gray, fossiliferous wackestone comprised of individual beds that are wavy, roughly horizontal, and pinch out to form small lenses (fig. 3a) that weather into small, flattened, nodular pieces. This bed geometry was termed “knobbly” by Bass and Northrop (1963, p. 18). Campbell (1970) uses the term “knobby” to describe the bed geometry and knobby is the term used in this study. Knobby package forms rounded cliffs and occurs repeatedly without a recognizable pattern throughout the section. Another lithologic package is a structureless, gray, fossiliferous mudstone with horizontal, slightly wavy, parallel beds that weather blocky to knobby (fig. 3b). Another lithologic package is a well-indurated, structureless, gray, fossiliferous wackestone that weathers blocky and smooth (fig. 3c). The last distinct lithologic package forms the uppermost unit of the Broken Rib Member. This package consists of lenses of gray, fossiliferous wackestone up to about 3.0 cm thick interbedded with lenses of tan, unfossiliferous dolostone of about the same thickness. This alternating limestone and dolostone lithologic package weathers blocky, smooth (fig. 3d), and forms a gradational contact with the overlying Coffee Pot Member. The four lithologic packages described above recur intermittently throughout the section as seen in the graphic log and in figure 4.

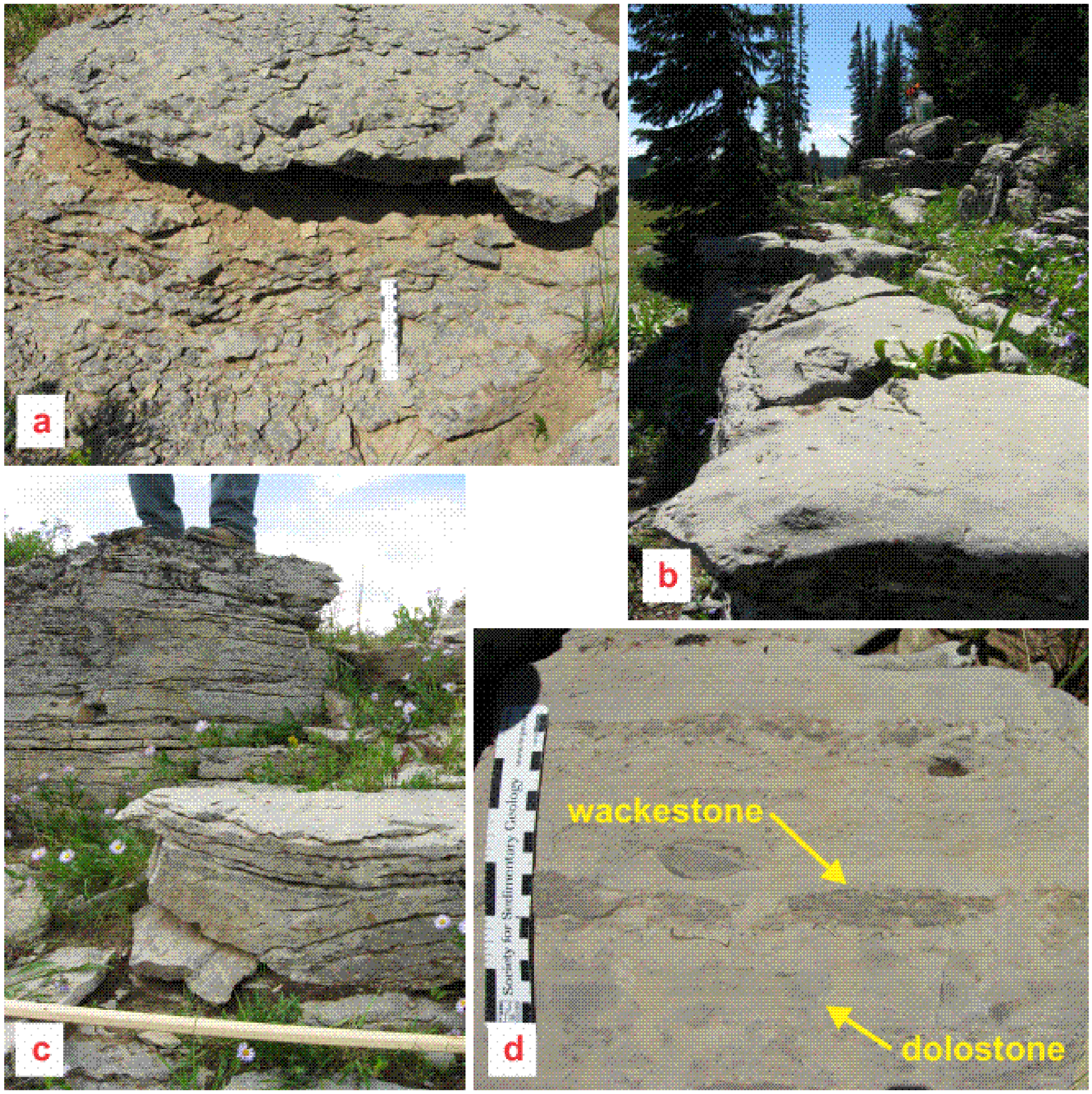


Figure 3. Lithologic packages. (a) Knobby wackestone (Bass and Northrop, p. 18, 1963); (b) Structureless mudstone; (c) Structureless wackestone; (d) Interbedded wackestone and dolostone.

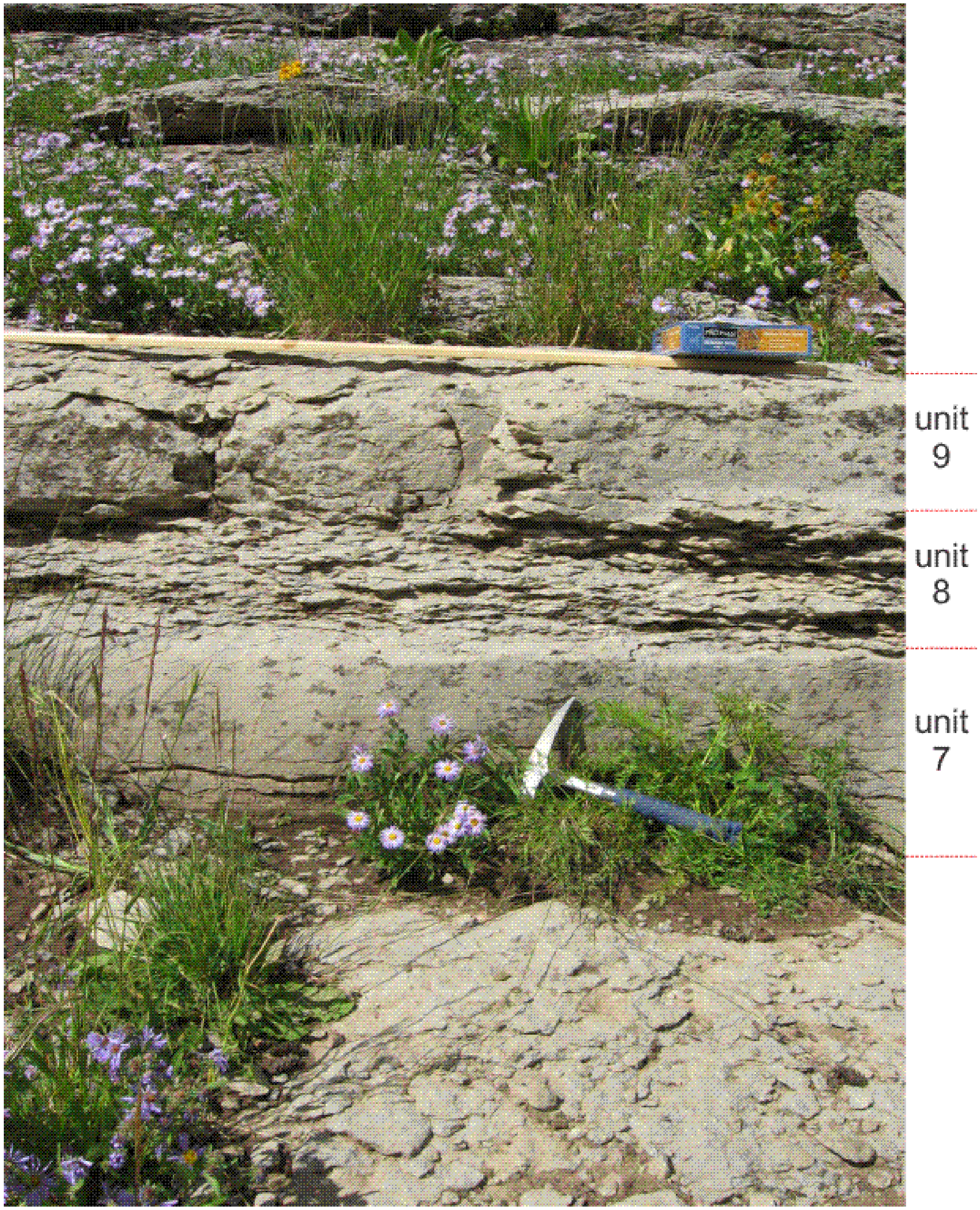


Figure 4. Recurring lithologies. Units 7, 8, and 9 of the measured section at Monument Lake.

CHAPTER IV

DESCRIPTION OF FOSSILIFEROUS SURFACES

At the Monument Lake study area, the Broken Rib Member crops out in a series of six, step-like, east-facing ledges which are laterally continuous for approximately 25 to 400 m (fig. 5). The upper weathered surfaces of these ledges provide large exposed areas of rock on which to observe the lithology and fauna (fig. 6). The surfaces appear to be similar, but detailed observation reveals their fossil abundances, lithology, and sedimentary structures are different. The following descriptions detail the characteristics of each weathered surface and highlight the features that make each one unique.

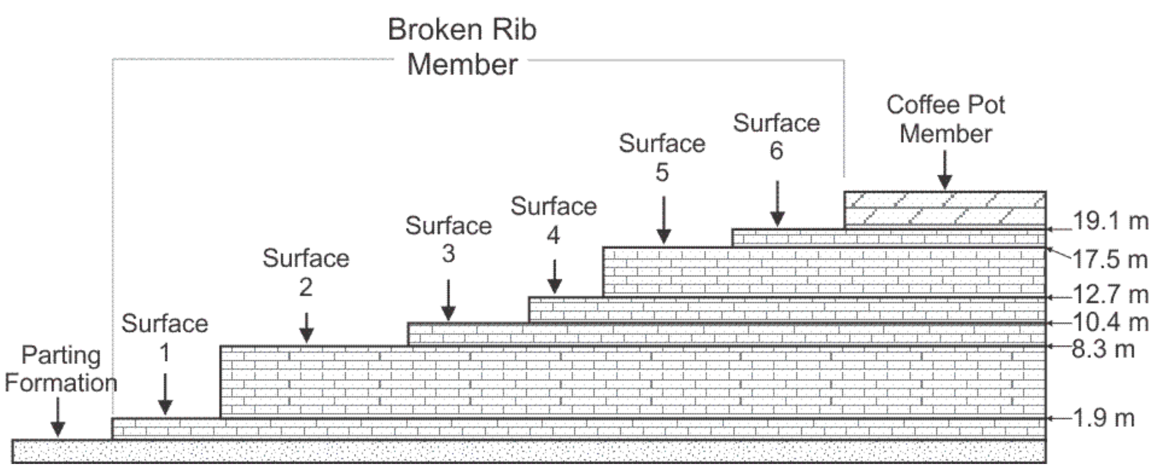


Figure 5. Limestone surfaces illustration. Six, step-like, limestone surfaces of the Broken Rib Member at Monument Lake.

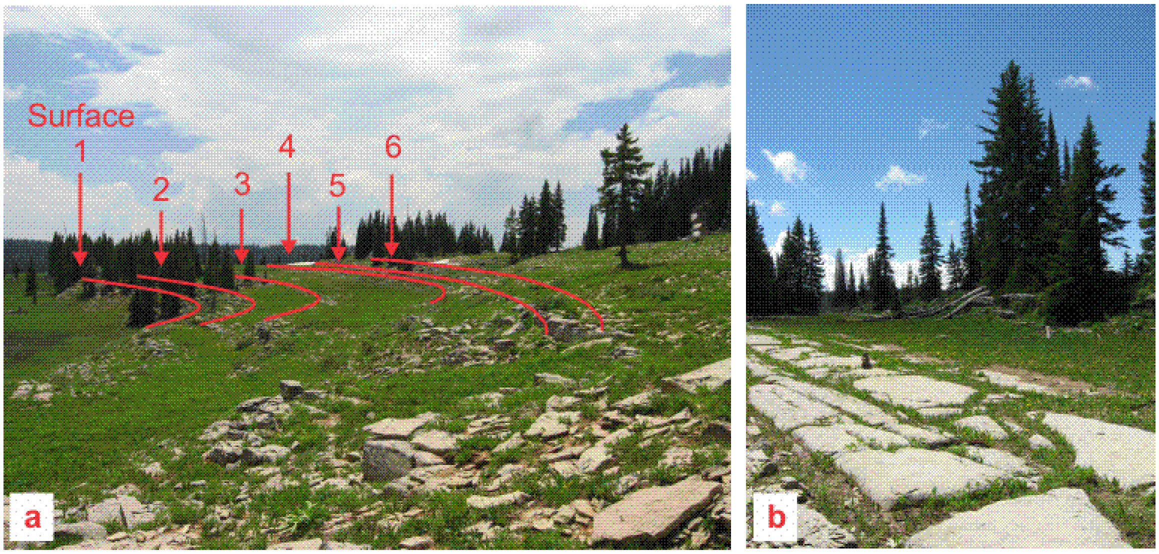


Figure 6. Limestone surfaces. (a) Six, step-like, limestone surfaces of the Broken Rib Member occur at Monument Lake, view to southeast; (b) Weathered limestone surface 3 is an ideal setting on which to observe the lithology and fossil assemblages, view to southeast.

The matrix of all the weathered surfaces is primarily micrite and secondarily fossil fragments. Fossil fragments are subangular to subrounded, sand-sized, and range in size between 3.5 to -1.0 Ø. Identifiable fossils measure about 2.0 mm to about 8.0 cm at their longest dimension. The most common identifiable fossils found are disarticulated fragments of pelmatozoan columnals. Other common identifiable fossils consist of fragments of bryozoan zoaria and brachiopod shells; internal molds of brachiopod shells; articulated segments of pelmatozoan columnals; and gastropod steinkerns. Rare identifiable fossils are solitary rugosan corallites (horn coral corallites), fragments of straight nautiloid internal molds, and disarticulated fragments of pelmatozoan calyxes. Figure 7 shows representative identifiable fossils at Monument Lake.

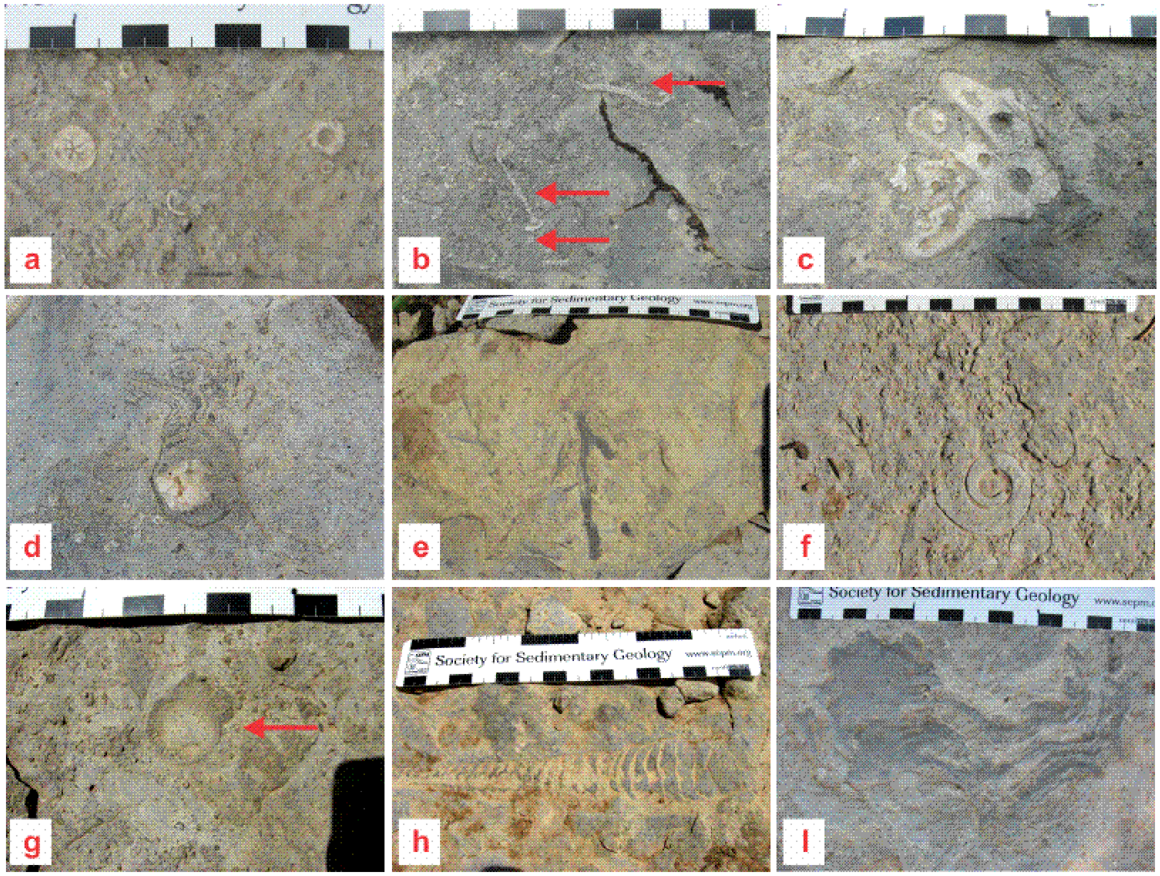


Figure 7. Representative fossils. Fossils found at Monument Lake include (a) Disarticulated pelmatozoan ossicles; (b) Articulated pelmatozoan stem segment; (c) Pelmatozoan calyx; (d) Brachiopod shell; (e) Bryozoan zoaria; (f) Gastropod steinkern; (g) Rugosan coral corallite; (h) Nautiloid steinkern; and (i) Stromatoporoid coenosteum.

Most identifiable fossils float in matrix (fig. 8a) and rarely occur as concentrations of shells (fig. 8b). Identifiable fossils also exhibit no preferred orientation or grouping by phylum or species. Burrows are the only sedimentary structure observed and they vary in abundance from less than 20% by area on some weathered surfaces to about 80% on others. Detailed observations reveal that each weathered surface possesses a unique ratio of identifiable fossils to fragments, a unique frequency of large burrows, and a unique set of identifiable fossils that distinguishes each surface from the others.

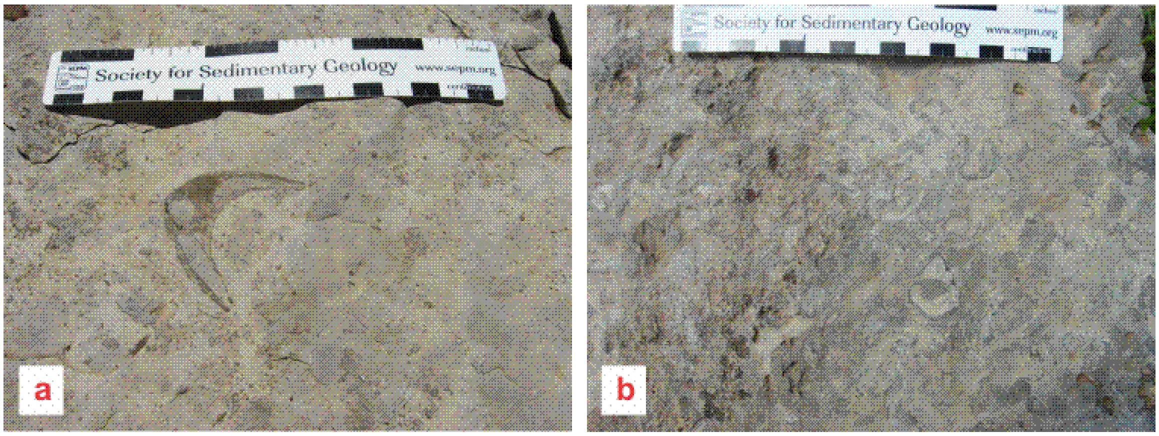


Figure 8. Fossils in matrix. (a) *Paurorynchа endlichi* shell surrounded by muddy matrix; (b) Concentration of unidentified brachiopod shells.

Surface 1 is the lowermost surface, 1.9 m above the top contact of the Parting Formation. The surface 1 limestone bed is a light-gray to tannish-gray, structureless, fossiliferous, mudstone that weathers knobby. Fossil fragments are abundant and range in size from 2.5 to 1.5 Ø. Identifiable fossils are uncommon, are 2 mm to 4.0 cm at their longest dimension, and consist mostly of disarticulated pelmatozoan columnals. Articulated pelmatozoan stems, fragments of brachiopod shells, internal brachiopod molds, and fragments of bryozoan zoaria also occur. Gastropod steinkerns and horn coral corallites rarely occur in surface 1. Distinct from the others, surface 1 contains mostly fossil fragments with rare identifiable fossils.

Surface 2 is 8.3 m above the Parting and its limestone bed is a light-gray, bioturbated, mudstone that weathers smooth. The size range of fossil fragments is from 2.0 to 1.5 Ø. Rare identifiable fossil fragments occur in the matrix, are between 3 mm to 3.2 cm at their longest dimension, and are most commonly disarticulated pelmatozoan columnals. Other common identifiable fossils consist of fragments of bryozoan zoaria, fragments of brachiopod shells, and internal brachiopod molds. No brachiopod fossil fragments can be identified to genus on surface 2. Gastropod steinkerns occur, but are rare. Surface 2 is about 20% bioturbated with small, hallow, calcite-lined vugs thought to be burrows. These cavities have a maximum width of 1.5 cm and a maximum length of 4.0 cm (fig. 9). Additionally, the burrows are horizontal, irregular in shape, and are the distinguishing characteristic of this limestone surface.

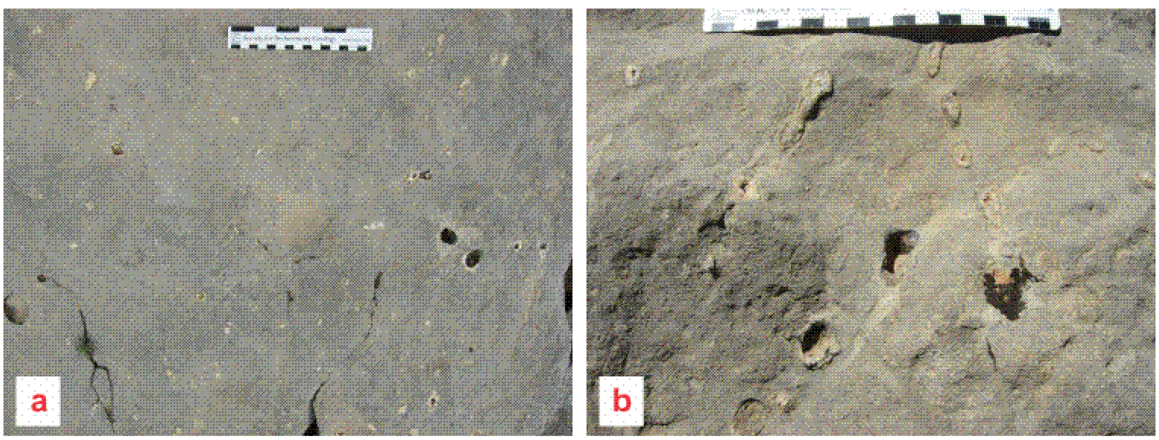


Figure 9. Small burrows. (a) Small, hallow, calcite-lined vugs on surface 2 at Monument Lake; (b) Close up of vugs.

Next highest is surface 3, located 10.4 m above the Parting. The surface 3 limestone bed is a medium-gray, bioturbated, fossiliferous wackestone with a smooth surface. Abundant fossil fragments range in size from 3.0 to 2.0 Ø and identifiable fossils occur commonly from about 2 mm to 4.8 cm at their longest dimension. Similar to surfaces 1 and 2, disarticulated pelmatozoan columnals are the most commonly occurring identifiable fossils, reach a maximum diameter of almost 1.0 cm, and occur with fragments of fenestrate bryozoan zoaria. Internal molds of brachiopods are less common and fragments of nautiloid shells, gastropod steinkerns, horn coral corallites, and fragments of pelmatozoan calyxes are rare. Stromatoporoid coenosteums occur rarely on surface 3 only. About 40 to 60% of the area of this surface is bioturbated with abundant, closely spaced large burrows that have a maximum width of 45 cm and a maximum length of 60 cm long. Burrows are dark-gray, elongated ovals, and backfilled fossil fragments, and make the limestone bed of surface 3 unique (fig. 10).

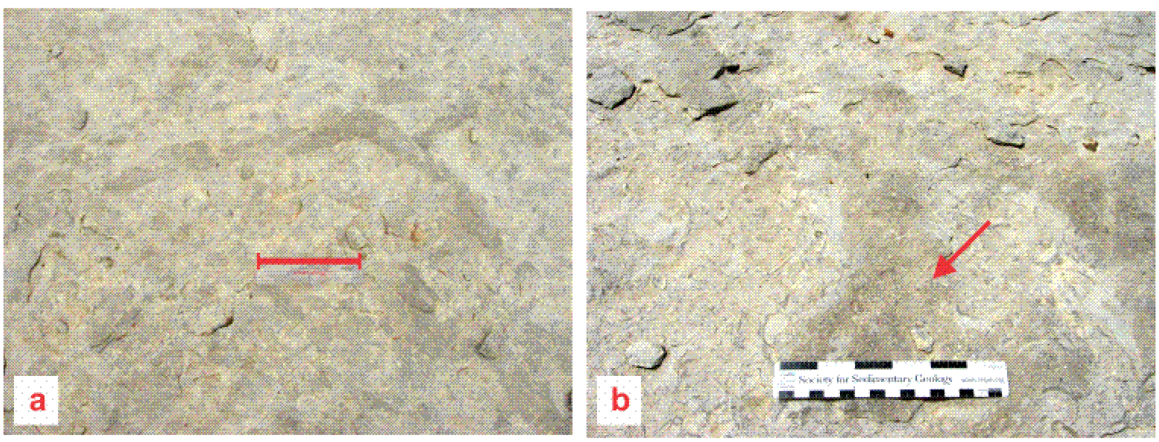


Figure 10. Large burrows. (a) Large burrows are backfilled with fossil fragments on surface 3 at Monument Lake. Red scale is 10 cm; (b) Close up of burrows.

Surface 4 is 12.7 m above the Parting and its limestone bed consists of a light-gray, bioturbated, fossiliferous, wackestone that weathers knobby. Fossil fragment matrix ranges in size from 2.5 to -1.0 Ø. Identifiable fossils are abundant and large with a minimum of 2 mm to 7.5 cm at their longest dimension. Disarticulated pelmatozoan columnals are the most common identifiable fossils and are found with fragments of bryozoan zoaria and brachiopod shells, often in concentrations of shells. Horn coral corallites, gastropod steinkerns, and disarticulated pelmatozoan stem segments and calyx fragments occur rarely (fig. 11). This surface is 30 to 40% bioturbated with small burrows that are a maximum width of about 1 cm, a maximum length of 3.0 cm, and large, dark-gray, fossil fragment-filled burrows are a maximum size of about 7 cm wide and 13 cm long. Although surface 4 contains many features seen in previous ledges, the occurrence of shell concentrations distinguishes its limestone bed from the others.

Figure 11. Pelmatozoan stem. Articulated pelmatozoan stem segment and calyx fragment, rare at Monument Lake.

Weathered surface 5 is 17.5m above the Parting and is developed on a very light-gray, fossiliferous, bioturbated, wackestone limestone bed that weathers knobby. The range in size of fossil fragments is from 2.0 to -1.0 Ø. Fragments of brachiopod shells are the most abundant identifiable fossils on this surface. Other fossils, such as disarticulated pelmatozoan columnals and fragments of bryozoan zoaria, are also abundant and range from 2.0 mm to 8.0 cm at their longest dimension. The largest identifiable fossils on surface 5 are fragments of brachiopod shells (fig. 12). Many brachiopod shells occur with fragments of bryozoan zoaria in concentrated shell pavements. Rarely occurring are horn coral corallites, gastropod steinkerns, and fragments of straight nautiloid shells. Surface 5 is 80% bioturbated with small, horizontal burrows up to 1.0 cm wide and 4.0 cm long. This is the mostly highly bioturbated surface, and the exceptionally large size of the abundant brachiopods is its unique characteristic.

Figure 12. Large brachiopod. Brachiopod shell fragment from surface 5.

Surface 6 is the uppermost surface and occurs 19.1 m above the Parting Formation. The surface 6 limestone bed is a tannish-gray, fossiliferous, bioturbated, wackestone that weathers smooth. Fossil fragment matrix is between 3.0 to 0.5 Ø and identifiable fossils range in size from 2 mm to 3.5 cm at their longest dimension. The most commonly occurring identifiable fossils are disarticulated pelmatozoan columnals followed by fragments of bryozoan zoaria. Fragments of small brachiopod shells averaging about 1.5 cm long occur abundantly, some in shell concentrations, while horn coral corallites and gastropod steinkerns are rare. Surface 6 is about 50% bioturbated with small burrows that occur up to a maximum of about 1.0 cm wide and about 2.0 cm long. Additionally, this uppermost surface shares a gradational contact with the overlying Coffee Pot Member and this is expressed on the surface as laterally discontinuous, discreet areas of the surface that posses Broken Rib Member affinities (dark gray fossiliferous limestone) and other, different, discreet areas of the surface with Coffee Pot affinities (light tan unfossiliferous dolostone) (fig. 13). Finally, this pronounced lateral discontinuity is the unique feature of the limestone bed of surface 6.

The fossils that are exposed in the six weathered surfaces of the Broken Rib Member at Monument Lake have many similarities such as: the kinds of identifiable fossils that occur; grain size of the fossil fragments; and degree of bioturbation. However, these multiple, laterally continuous surfaces provide a rare opportunity to study the vertical changes in the lithology and fauna.

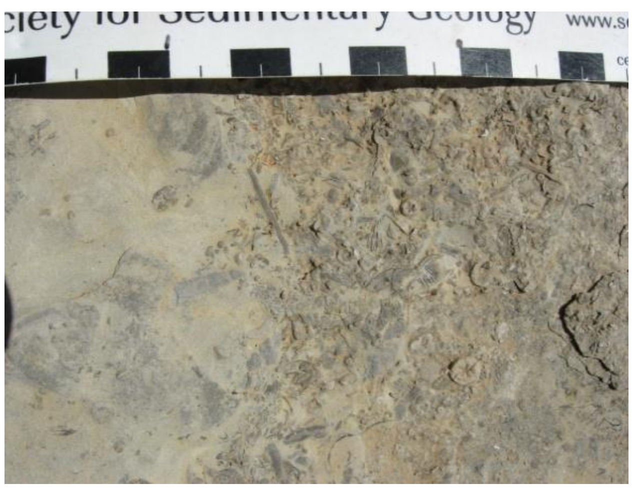


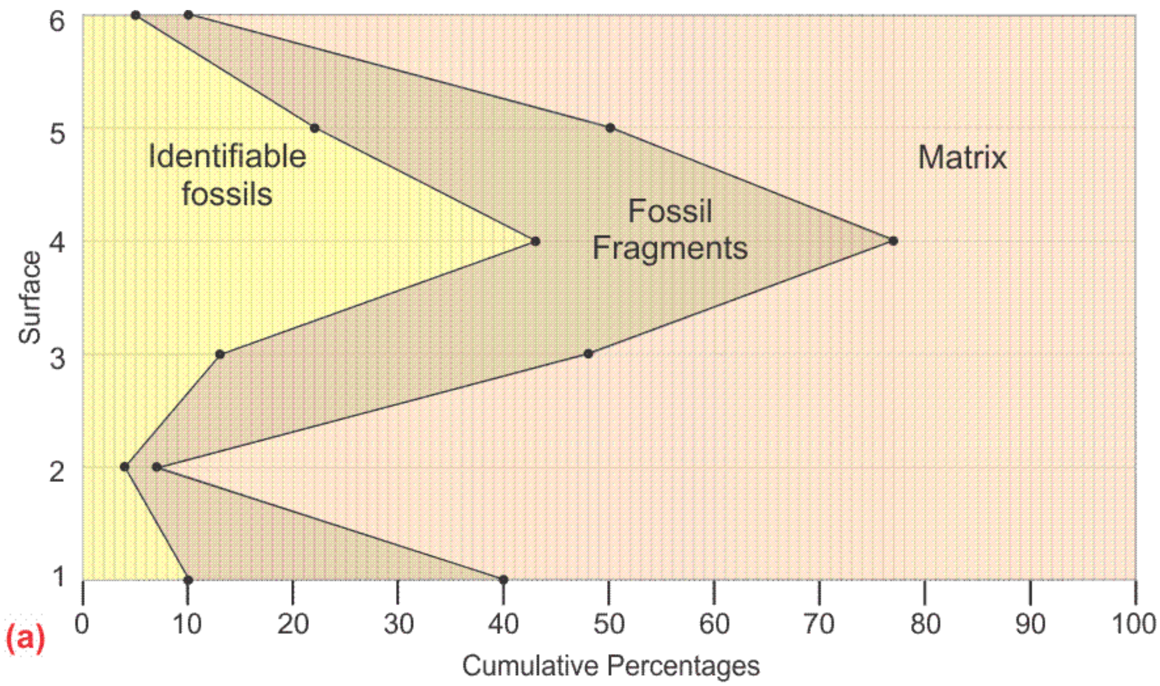
Figure 13. Laterally discontinuous surface. Discreet areas of surface 6 posses Broken Rib Member affinities (dark gray fossiliferous limestone on right) and other, different, discreet areas of the surface with Coffee Pot affinities (light tan unfossiliferous dolostone on left).

Paleontologic Trends

Identifiable fossils, fossil fragments, and matrix occur in differing amounts on the surfaces of limestone units at Monument Lake, and show trends through the section. Identifiable fossils are generally more abundant higher in the section and less abundant near the bottom. Brachiopods, bryozoan zoaria, and pelmatozoan ossicles make up the majority of identifiable fossils while horn corals and gastropods are less common. Brachiopods are more abundant and diverse near the top of the section, and are scarce near the bottom. These trends show that fauna and matrix occur with some pattern throughout the section.

Figure 14a illustrates the cumulative percentages of identifiable fossils, fossil fragments, and matrix documented using the areal estimates method on surfaces 1 through 6. Identifiable fossils are most rare on surface 2 (4%) and most abundant on surface 4 (45%). Fossil fragments are also most rare on surface 2 (3%) and most abundant on surface 4 (33%).

Figure 14b illustrates the cumulative percentages of identifiable fossils, fossil fragments, and matrix recorded using the point count method on surfaces 1 through 6. This technique documents the smallest percentage of identifiable fossils on surface 2 (6%), and the largest percentage on surface 4 (37%). Fossil fragments are most abundant on surface 3 (69%) and least abundant on surface 5 (28%). Table 1 shows the ratio of identifiable fossils to fossil fragments in each surface.



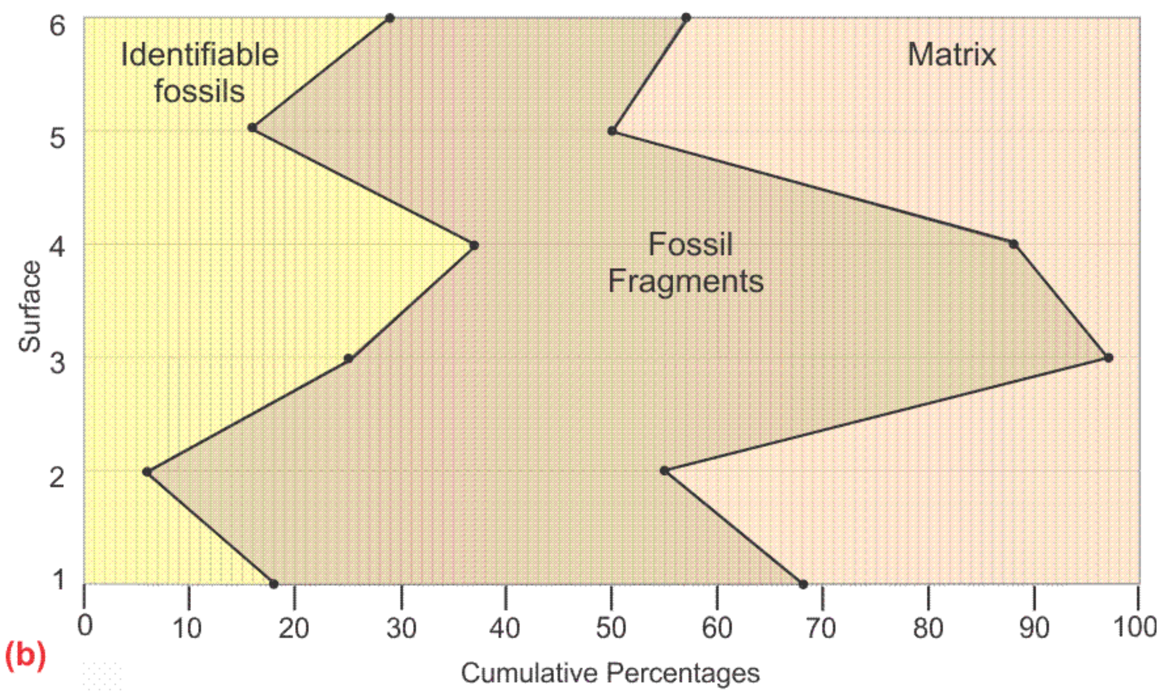


Figure 14. Cumulative percentages of fossils vs. matrix. (a) Cumulative percentages using areal estimates; (a) Cumulative percentages using point counts.

Table 1. Percentages of identifiable fossils and fossil fragments. Normalized percentages of identifiable fossils versus fossil fragments as recorded using point counts and areal estimates on surfaces 1 through 6 at Monument Lake.

	Areal Estimates		Point Counts	
Surface	% Identifiable Fossils	% Fossil Fragments	% Identifiable Fossils	% Fossil Fragments
6	47	53	51	49
5	43	57	32	68
4	57	43	42	58
3	28	72	26	74
2	65	35	10	90
1	25	75	27	73
Mean	44	56	31	69

Point counts record the cumulative percentages of each identifiable fossil, shown in figure 15. Brachiopods occur with the smallest cumulative percentages (6%) on surface 2 and the largest cumulative percentage (49%) on surface 5. Bryozoan zoaria occur with the smallest cumulative percentages (4%) on surface 2 and the largest cumulative percentage (32%) on surface 5. Brachiopods are much less common on the lower surfaces than on the upper surfaces, while the frequency of occurrences of bryozoan zoaria is variable throughout the section. Pelmatozoan ossicles have a cumulative percentage of (85%) on surface 2 and (35%) on surface 5. Gastropod steinkerns have a cumulative percentage of (1%) on surface 1 and (2%) on surface 2. Horn coral fossils make up (2%) of the fauna on surface 2. Table 2 is a complete faunal list.

Brachiopods are the most well preserved and easily identifiable taxa on the surfaces of the limestone units in the study area and at least ten species occur at Monument Lake. Brachiopods were diverse on surface 1, were too fragmented to identify on surface 2, and then continuously increased in diversity through the top of the section, as their cumulative percentages show in figure 16.

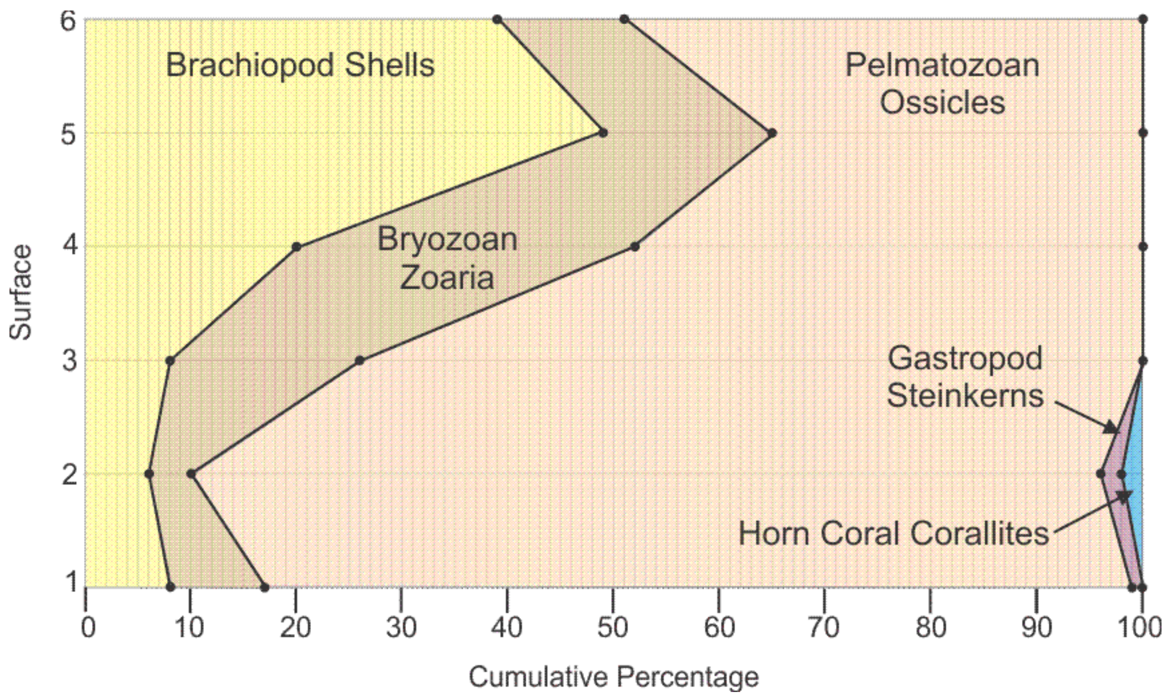


Figure 15. Cumulative percentages of fossil taxa. Brachiopods, bryozoan zoaria, pelmatozoan ossicles, gastropod steinkerns, and horn corals as recorded by point counts.

Table 2. Faunal list. List of taxa found on surfaces 1 through 6 at Monument Lake.

Broken Rib Member of Dyer Formation, Monument Lake area, Colorado	Surface					
	1	2	3	4	5	6
Brachiopoda						
Paurorhyncha endlichi............	X	---	X	X	X	X
Cyrtiopsis kindlei	X	---	X	X	X	X
Cleiothyridina coloradensis	X	---	X	X	X	X
Schizophoria australis............	X	---	X	X	X	X
Strophopleura notabilis	---	---	---	X	X	X
Cyrtiopsis animasensis	---	---	X	X	---	X
Camarotoechia sobrina............	X	---	---	---	X	X
Leioproductus plicatus	X	---	---	X	X	X
Planoproductus depressa	X	---	---	---	X	X
Schellwienella percha	X	---	---	---	X	---
Bryozoa						
Bryozoan zoaria, gen. and sp. undet.	X	X	X	X	X	X
Pelmatozoa						
Pelmatozoan ossicles and calyxes, gen. and sp. undet.	X	X	X	X	X	X
Gastropoda						
Gastropod steinkerns, gen. and sp. undet.	X	X	X	X	X	X
Anthozoa						
Rugosan coral corallites, gen. and sp. undet.	X	---	X	X	X	X
Cephalopoda						
Nautiloid steinkerns, gen. and sp. undet.	---	---	X	---	X	---
Porifera						
Stromatoporoid coenosteums, gen. and sp. undet.	---	---	X	---	---	---
Trace fossils						
Burrows, gen. and sp. undet.	X	X	X	X	X	X

Paurorhyncha endlichi, *Cyrtiopsis kindlei*, and *Schizophoria australis* are commonly occurring at Monument Lake and are the only brachiopods that occur on each of the five surfaces (none are identifiable on surface 2). *Paurorhyncha* *endlichi* increases in abundance until it reaches a maximum on surface 5, then decreases on surface 6. *Cyrtiopsis kindlei* increases in abundance until its maximum on surface 4, then decreases in surfaces 5 and 6. *Schizophoria australis* are less common on the lower surfaces and more common in the upper surfaces. *Cleiothyridina coloradensis* also occurs commonly on all surfaces except surface 5, and this omission may be due to sample size. This species is most abundant on surface 6.

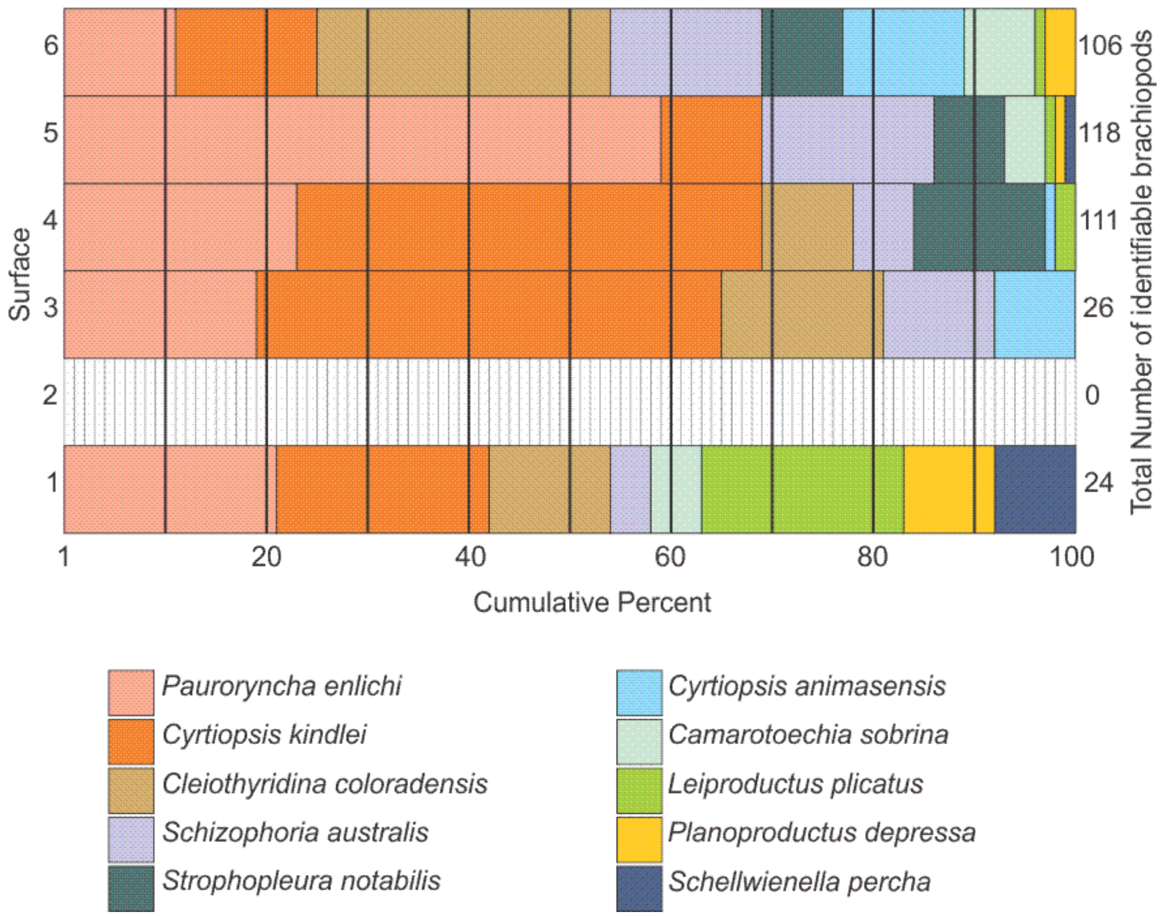


Figure 16. Cumulative percentages of brachiopods. Brachiopod species on surface 1 and on surfaces 3 through 6. The brachiopod shell fragments on surface 2 are too incomplete or poorly preserved to identify.

The remaining identified brachiopods are less common, but also show patterns in their occurrences. *Strophopleura notabilis* is only present on the three uppermost surfaces. *Cyrtiopsis animasensis* occurs most commonly on surface 6. Both *Camarotoechia sobrina* and *Planoproductus depressa* occur in the lowermost surface, and then are not recorded again until surface 5 where they increase in abundance through the top of the section. *Leioproductus plicatus* occurs abundantly on surface 1 and is then not seen again until surface 4 where it maintains its abundance through the top of the section. Finally, *Schellwienella percha* occurs rarely and increases in abundance from the bottom through the top of the section. The number of occurrences of each brachiopod species appears in table 3.

Table 3. Brachiopod species counts. Brachiopod species from limestone surfaces 1 through 6 at Monument Lake.

	Brachiopod Species									
Surface	*Pauroryncha endlichi*	*Cyrtiopsis kindlei*	*Cleiothyridina coloradensis*	*Schizophoria australis*	*Strophopleura notabilis*	*Cyrtiopsis animasensis*	*Camarotoechia sobrina*	*Leioproductus plicatus*	*Planoproductus depressa*	*Schellwienella percha*
6	12	15	30	16	9	12	8	1	3	0
5	70	11	1	20	8	0	5	1	1	1
4	25	52	10	6	15	1	0	2	0	0
3	5	12	4	3	0	2	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0
1	5	5	3	1	0	0	1	5	2	2
Number of brachiopod species	117	95	48	46	32	15	14	9	6	3

CHAPTER V

DISCUSSION

Taphonomy

Fossils found at Monument Lake accumulated on the seafloor that had background sedimentation of carbonate mud. Sedimentation rates were not high enough to dilute the fossil record or to make the water too turbid for brachiopods and other filter feeders to thrive. Conversely, sedimentation rates were high enough to prevent the formation of concentrated shell beds that were not seen in the study area. The presence of burrows on all the weathered limestone surfaces indicates there was some consolidation of mud, intimating that sedimentation rates were moderate allowing for cohesion of the sediment.

Abundant fossil fragments occur scattered in mud. Fragments are disarticulated, fragmented, and abraded, and indicate transportation within the sedimentary environment (Brett and Baird, 1986). Fossil fragments are sand-sized, rounded to subrounded, and pelmatozoan ossicles and brachiopod shells are the only recognizable fossil fragments that occur in the study area. These skeletal elements are most resistant to destruction in the sedimentary environment (Benton and Harper, 2009). Smaller fossil fragments occur, but are too small to identify. These highly damaged and poorly preserved bioclasts indicate transportation within a few kilometers from their original sedimentary environment by storms (Kidwell and Bosence, 1991).

In contrast, identifiable fossils range from about 2.0 mm to about 7.0 cm in length, have well-preserved, original shell material, and are sometimes articulated. Brachiopod shells commonly retain delicate structures such as spines and brachidia (fig. 17a). Fragile, bryozoan zoaria display fine detail (fig. 17b) and pelmatozoan ossicles occasionally occur in articulated stem segments. The well-preserved state of these fossils indicates they preservation occurred in their original sedimentary environment.

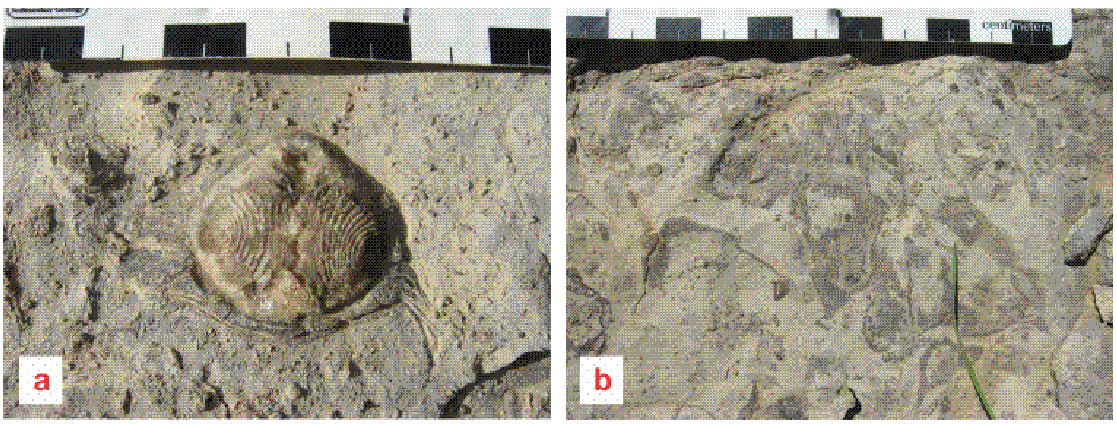


Figure 17. Well-preserved fossils. (a) Brachiopod shell from surface 4 with preserved spines and brachidium; (b) Bryozoan zoarium fragment from surface 4 displays fine detail.

Fossil fragments and identifiable fossils have two different taphonomic histories evidenced by their differing states of preservation; however, they occur together in the fossil assemblages on all surfaces except surface 2. Commonly these two elements are mixed on the surface of the assemblages, but in places, the well-preserved, identifiable fossils occur in thin layers at a slightly higher stratigraphic level, about 1.0 – 3.0 mm, above the sand-sized fossil fragments (fig. 18). This stratigraphic relationship indicates the identifiable fossils formed after the fossil fragments. The fossil fragments likely formed during storms that dislodged the faunal elements of living communities and transported their shells up to a few kilometers (Kidwell and Bosence, 1991). Shells were fragmented and abraded in the higher energy environment before their final deposition. The fossil fragments provided a hard substrate that the larvae of brachiopods, bryozoans, pelmatozoans and other taxa used to grow on and to flourish in a slow shower of lime mud.

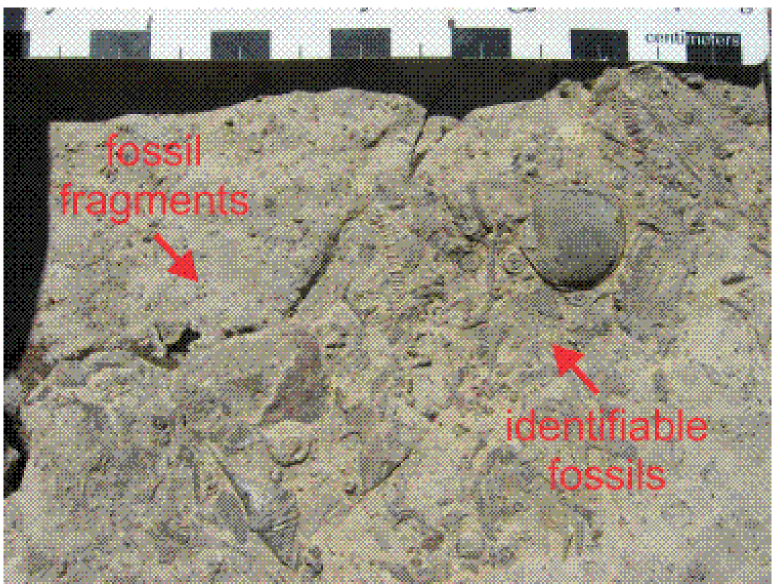


Figure 18. Microstratigraphy of fossil assemblage. Fossil fragments (left) are about 1.0 – 3.0 mm below identifiable fossils (right) in some fossil assemblages at Monument Lake.

The lithology and fossils on surface 2 are the exception to the taphonomic scenario described above. This surface is mostly micrite with few fossil fragments and rare identifiable fossils, and likely formed during higher rates of sedimentation. Surface 2 is located on top of the thickest, structureless unit 12.

Bioturbation is extensive on surface 2, indicating at least some consolidation of sediments, but the thick accumulation of mud was too soft to be suitable for the development of the major taxa seen on the other ledges. Surface 2 probably formed below storm wave base, during the largest transgressive event to occur during deposition of the Broken Rib.

Paleoecology

Fossil assemblages at Monument Lake consist most commonly of well-preserved brachiopods, bryozoans, and pelmatozoans that float in a sand-sized fossil fragment and micrite matrix. Horn corals, gastropod, and nautiloids occur with less frequency and are scattered in a sand-sized fossil fragment and micrite matrix. Rare stromatoporoid coenosteums occur on surface 3. In addition, each surface includes burrows.

The taxa of the fossil assemblages represent different marine lifestyles. Brachiopods, bryozoans, pelmatozoans, horn corals, and stromatoporoids represent the sessile, epifaunal benthos (Benton and Harper, 2009). All are suspension feeders except the horn coral that is carnivorous (Dodd and Stanton, 1981). Gastropods are part of the mobile epifaunal benthos and the burrowing organisms may be, too (Benton and Harper, 2009). Most Paleozoic gastropods were likely detritus feeders or herbivores and the feeding habits of the unnamed burrowers are unknown (Benton and Harper, 2009). The carnivorous nautiloids may be nektonic or demersal and therefore, part of the mobile nektobenthos

(Benton and Harper, 2009). No taxa from other environments occur in the fossil assemblages indicating that these organisms lived together in associations. The absence of any terrestrial taxa suggests the assemblages formed far from land and no deep sea or strictly pelagic taxa occur in the assemblages.

The overlapping environmental requirements of each taxon indicate they represent associations. All modern brachiopods require well-oxygenated, clear water of normal marine salinity, and by environmental analogy, Paleozoic brachiopods did as well (Rudwick, 1970). Modern brachiopods live at all depths and the depth tolerances of most Paleozoic brachiopods is unknown (Rudwick, 1970). However, fossil brachiopods often occur in micritic limestones indicating they were adapted to live with slow accumulation rates of lime mud (Ager, 1963).

Many of the environmental requirements of bryozoans are similar to those of brachiopods. Modern bryozoans live in a variety of environments from fresh to hypersaline water, but are most diverse in a marine environment of normal salinity. They are most abundant and diverse between depths of about 20 to 80 m, on the continental shelf, where they often attach to a hard substrate. Bryozoans cannot tolerate high rates of sedimentation, but many are adapted to turbulent conditions (Dodd and Stanton, 1981).

Pelmatozoans, like brachiopods, require marine water of normal salinity. Dodd and Stanton (1981) assert they are most abundant in shallow to moderate water depths while Harper and Benton (2009) claim they occur with the most diversity in deeper water. Pelmatozoans live attached to a hard substrate or rooted in soft sediments and while the holdfast structures indicates the preference of the species, none were found at Monument Lake (Dodd and Stanton, 1981; Harper and Benton, 2009).

The environmental requirements of the major taxa are not outside the range of environmental tolerances of the minor taxa, and in fact, some minor taxa may provide depth controls. When interpreted to be hermatypic, horn corals occur in water less than about 150 m where light can penetrate to the sea floor, thereby adding a maximum depth control to the association. Additionally, stromatoporoid fossils are associated with shallow water carbonate sediments, indicating they lived in shallow water (Stanton and Dodd, 1981; Harper and Benton, 2009).

Interpretation

The presence of brachiopods, bryozoans, and pelmatozoan fragments indicates the assemblages at Monument Lake formed in a sublittoral, marine environment with well-oxygenated water of normal salinity, where the slow accumulation of lime mud formed a muddy bottom. These taxa associations formed on bits of hard substrate. Intermittent storms dislodged the associations and transported them with enough energy to abrade and fragment their shells. These fragments came to rest on the sea floor where they provided an ideal hard substrate for the larvae of another generation of marine organisms to develop. Eventually, mud buried the brachiopods, bryozoans, pelmatozoans and other minor taxa. Burrowers then mixed the fossil fragments and identifiable fossils in the sediments. This cycle repeated through the entire deposition of the Broken Rib Member with the exception of surface 2. Surface 2 probably represents a deeper water environment where a higher rate of sedimentation of lime mud resulted in a substrate too soft for the colonization of the taxa seen on the surfaces above and below it. Deposition of surface 2 probably took place during the maximum transgression of the sea in the area.

CHAPTER VI

CONCLUSIONS

Deposition of the Chaffee Group took place during a series of eustatic events that characterize the Famennian stage of the Late Devonian Period (Sandberg and Ziegler, 1996). The Broken Rib Member of the Dyer Formation formed between the underlying, sandstone, near-shore Parting Formation and the overlying, dolostone, tidal flat Coffee Pot Member of the Dyer Formation. The fossiliferous limestone beds of the Broken Rib Member at Monument Lake reveal trends from the bottom to the top of the section and reflect fluctuating conditions associated with these eustatic events.

The measured section (plate 1) reveals lithologic variation throughout the Broken Rib Member. Limestone units occur in four distinct lithologic packages and include knobby wackestones, structureless wackestones, and structureless mudstones that recur throughout the section. One interbedded wackestone and dolostone unit occurs only at the top. More mudstone units occur at the bottom and indicate they were deposited below storm wave base. Surface 2 forms the top of these mudstone beds and is interpreted to represent the maximum transgression of the sea during the deposition of the Broken Rib

Member. Wackestone units are more common at the top of the section and indicate reworking by waves while the sea was once more regressing.

The tops of the limestone units at Monument Lake are exposed as a series of six, step-like, laterally continuous surfaces. Detailed observation of the assemblages using areal estimates, point counts, and brachiopod species identifications, reveals the highly fragmented and rounded fossil fragments have a different taphonomic history than the well-preserved identifiable fossil fragments. Fossil fragments are the remains of shelly fauna that storms dislodged, transported, and then deposited. Identifiable fossils are well-preserved and commonly found in life positions in thin layers at a slightly higher stratigraphic level than the fossil fragments. The fossil fragments provided a hard substrate that the successive marine fauna colonized.

The observed fossil taxa at Monument Lake occur in associations of marine organisms that required similar environmental conditions. The assemblage taxa primarily include brachiopods, bryozoans, and pelmatozoans that indicate a sublittoral, marine environment with well-oxygenated water of normal salinity, where the slow accumulation of lime mud formed a muddy bottom. Minor taxa, such as horn corals, gastropods, nautiloids, and stromatoporoids, have environmental tolerances that overlap the major taxa. Abundant burrows left by unknown organisms indicate well-oxygenated substrates.

While fossil fragments occur in all assemblages, identifiable fossils are rare on the lower two surfaces and common to abundant on the remaining upper surfaces. Assemblages on the lower surfaces are comprised mostly of fossil fragments with only rare identifiable fossils. In fact, identifiable fossils are the least common on surface 2 and indicates that the environment was unsuitable, probably too muddy, for the colonization of the fossil taxa observed higher in the section. On the remaining four upper surfaces, fossils occur commonly, indicating mud was accumulating at a slower rate, or was reworked by waves and fossil fragment hardgrounds provided substrates on which communities of sessile, suspension feeders could attach.

Brachiopods are generally well-preserved and were identified from all the surfaces except surface 2 at the study area. A decrease in diversity is demonstrated between surface 1 where eight identifiable species occur and surface 2 where no identifiable species occur. An increase in diversity follows, represented by five identifiable species of brachiopods on surface 3, seven on surface 4, eight on surface 5, and nine or surface 6.

The above-described patterns indicate environmental conditions were less favorable for shelly, benthic, marine fauna to develop at the beginning of deposition of the Broken Rib Member represented by the lower beds. During this time, the sea was transgressing and lime mud was abundant. The maximum transgression of the sea during the deposition of the Broken Rib Member is represented at Monument Lake by surface 2, the most muddy and least fossiliferous surface. The remaining upper units are less muddy, with a more abundant and diverse fossil taxa. These trends indicate conditions clarified as the sea regressed and resulted in a diverse benthic, marine fauna.

Future Potential Studies

Questions remain regarding the fauna and lithologies of the Broken Rib Member at Monument Lake and in the greater Flat Tops area of the White River National Forest. Three ideas for future studies include:

1) Identify all the fauna found at Monument Lake to determine patterns in their diversity. Marine fauna suffered heavy losses following the Frasnian-Famennian mass extinction (McGhee, 1996). The Broken Rib member fauna represents the greatly reduced surviving taxa. Bryozoans, pelmatozoans, gastropods, nautiloids, and stromatoporoids should be identified to at least genus. Of special note, stromatoporoids are rarely found in rocks of confirmed Famennian age in the Western United States (C.W. Stock, oral and written communs., 2012; Morrow and others, 2011). Accordingly, their presence at Monument Lake should be documented.

2) Correlate findings with other exposures of the Broken Rib Member throughout the White River National Forest. The findings of this study are admittedly limited due to the rarity of a complete section of the Broken Rib Member with well-exposed surfaces. However, even partial exposures in the Flat Tops area may allow the correlation of features such as the large burrows on surface 3 that might represent marker beds. These marker beds could then correlate changes seen in the section to a broader area.

3) Determine the distribution in space and time of the species of brachiopods that occur at Monument Lake. The Rhynchonellida, Spiriferida,

Orthida, and Strophomenida brachiopod orders that occur at Monument Lake may have unique paleoenvironmental implications that would allow a more precise reconstruction of the conditions during deposition of the Broken Rib Member.

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APPENDIX A

Areal Estimate Data

Table 4. Percentages of identifiable fossils. Numbers recorded using areal estimate technique on each limestone surface.

Surface	Average percent of specimens by phylum			Average percent of identifiable fossils	Average percent of fossil fragments	Average percent of matrix	Total percent per surface
	Pelmatozoan Ossicles	Bryozoan Zoaria	Brachiopod Shells				
6	4	0	0	4	5	87	96
5	13	3	5	21	28	50	99
4	20	17	5	42	33	23	98
3	10	0	3	13	35	52	100
2	4	0	0	4	2	93	99
1	8	0	2	10	30	60	100

APPENDIX B

Point Count Data

Table 5. Number of identifiable fossils, fossil fragments, and matrix. Numbers recorded using point count technique on each limestone surface.

Number of Specimens by Phylum				
Surface	Number of identifiable fossils	Number of Fossil fragments	Number of Matrix particles	Total number of points counted
6	214	208	314	736
5	137	290	431	858
4	314	428	99	841
3	202	564	54	820
2	48	425	382	855
1	155	428	278	861

Table 6. Number of taxa by phylum. Numbers recorded using point count technique on each limestone surface.

Number of Specimens by Phylum						
Surface	Brachiopod Shells	Bryozoan Zoaria	Pelmatozoan Ossicles	Gastropod Steinkerns	Horn Coral Corallites	Total Number of Identifiable Fossils
6	84	25	105	0	0	214
5	67	22	48	0	0	137
4	64	98	151	1	0	314
3	17	36	149	0	0	202
2	3	2	41	1	1	48
1	12	15	127	1	0	155

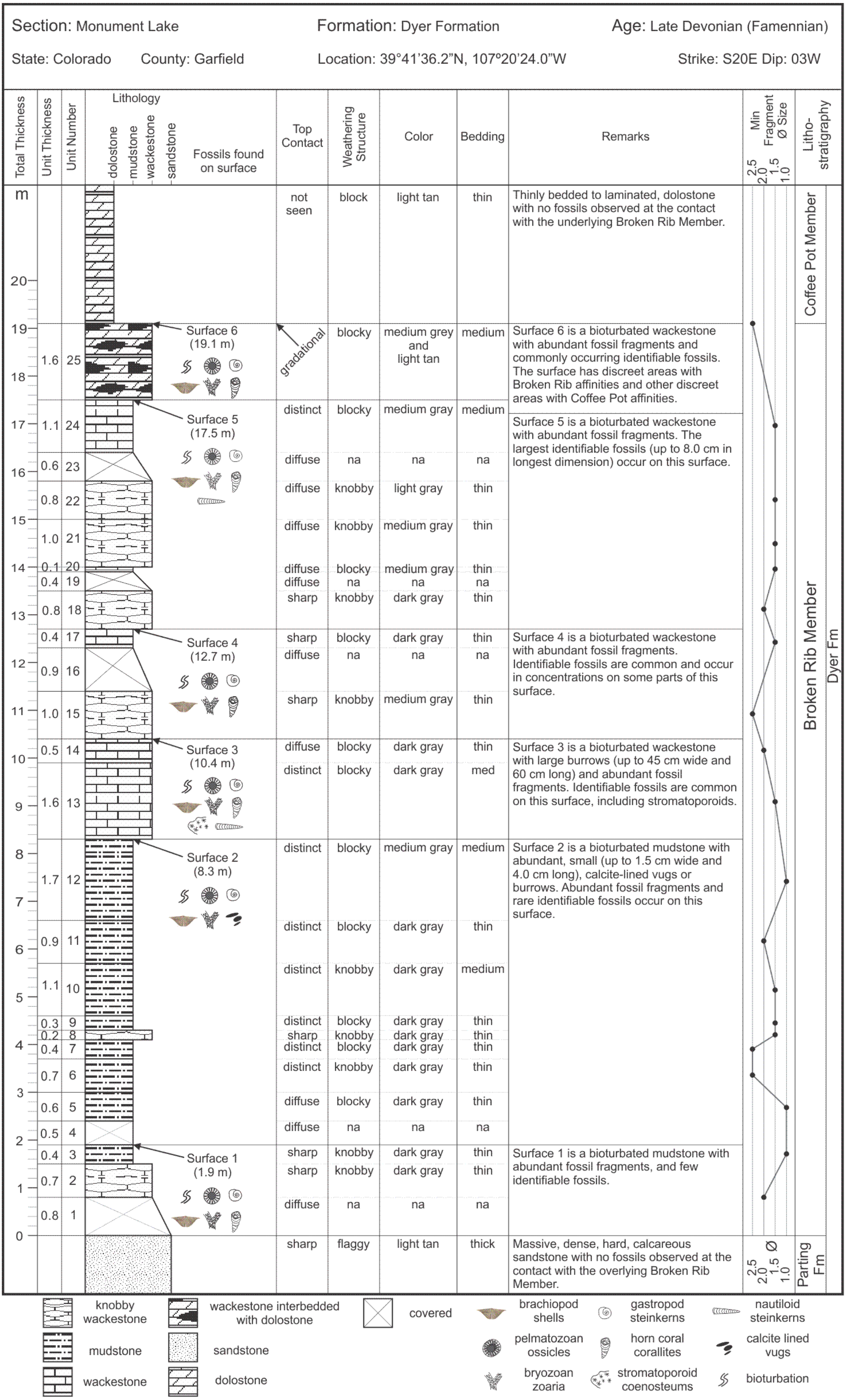

Plate 1. Graphic log of the Broken Rib Member of the Dyer Formation near Monument Lake.