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The Sequence Stratigraphy of the Middle Cambrian Wheeler Formation in the Drum Mountains of West Central Utah

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THE SEQUENCE STRATIGRAPHY OF THE MIDDLE CAMBRIAN WHEELER FORMATION IN THE DRUM MOUNTAINS OF WEST CENTRAL UTAH

by

Loren P. Schneider

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ABSTRACT

The Sequence Stratigraphy of the Middle Cambrian Wheeler Formation

in the Drum Mountains of West Central Utah

by

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The majority of the Middle Cambrian Wheeler Formation in the Drum Mountains was deposited during a single 3rd order sequence. Superimposed onto this sequence are three indistinct 4th order cycles and twenty distinct 5th order cycles. These higher order cycles were likely deposited within short intervals of geologic time (20^4 to 40^5 ky).

The lower sequence boundary zone occurs within the Swasey Formation. The Transgressive Surface is the contact between the Swasey and Wheeler Formations. The Maximum Flooding Surface is located near the top of the lower Wheeler Formation, which also approximates the base of the *Ptychagnostus atavus* range zone. The upper sequence boundary is marked by stromatolites, which occur near the top of the upper member of the Wheeler Formation in the Drum Mountains.

Deposition of the Wheeler Formation in the Drum Mountains was controlled by eustacy and tectonics. Local normal faulting associated with Middle Cambrian post-rifting thermal subsidence may have caused some of the 5th order cycles.

The cycles and surfaces defined in this stratigraphic analysis, and the base of the *Ptychagnostus atavus* and *P. gibbus* range-zones, can be used to correlate strata occurring in other localities in the eastern Great Basin. In addition, this study enables the evaluation of the effect of tectonics (faulting) versus global eustacy on the sedimentary regime occurring within the Middle Cambrian House Range Embayment.

(95 pages)

I dedicate this project to the memory of my mother, Blanche Marie Duvivier.

Life is a bowl of queries.

ACKNOWLEDGMENTS

Above all I would like to thank Dr. Dave Liddell for introducing me to this project and providing friendly guidance, patience, and enthusiasm throughout its development. I am deeply indebted to my second cousin Dawn Anderson and my great aunt Inez Kelly (96 years old) for providing many warm and friendly layovers in Delta, UT at the "old hotel" after weeks of lonely and arduous field work in the nearby mountains. I thank the USU Geology Department for the J. Stewart Williams Graduate Fellowship award. I would also like to thank my committee members, Drs. Peter Kolesar and Jim Evans, for their support and assistance. I thank Tony Williams for assisting me in fieldwork during June of 1999. I owe a big "thank you" to Matt Pachell and Jill Hammond for "being there" during the writing of this thesis.

Loren P. Schneider

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INTRODUCTION

Purpose

The Middle Cambrian Wheeler Formation is world renowned for its well-preserved trilobite fauna (Robison, 1991). As a result, the Wheeler Formation in the Drum Mountains of western Utah has attracted studies of its paleontology and paleoecology (Robison, 1962; White, 1973; McGee, 1978; Vorwald, 1983), sedimentology (Robison and Rees, 1981; Grannis, 1982), and biostratigraphy (Robison 1964, 1976; Rowell et al., 1982). All of these studies, however, were performed before the development, or at least widespread use, of sequence stratigraphy. Sequence stratigraphy provides a unifying framework, within which previous and future studies of the Wheeler Formation can be better understood.

Petroleum geologists first developed sequence stratigraphic concepts in the 1970's (Emery and Meyers, 1996). In seismic data acquired on continental shelves, sets of stratigraphic patterns (system tracts and parasequences) are reported in a vertical sequence (Vail et al., 1977). Collectively, these sets of reoccurring stratigraphic patterns are called sequences (Vail et al., 1977). Sequences are caused by relative sea level oscillations (Vail et al., 1977). They have a predictable internal framework that can be used to correlate sedimentary rock types (facies) over great distances (Emery and Meyers, 1996).

The objective of this project is to present a sequence stratigraphic model that explains the paleontologic, paleoecologic, sedimentologic, and stratigraphic patterns found in the Wheeler Formation in the Drum Mountains. However, before starting the analysis, it was important to address an issue that would affect the sequence stratigraphic interpretations.

The Wheeler Formation in the Drum Mountains is anomalously thick relative to other localities (White, 1973). Further, near the middle of the Wheeler Formation in the Drum Mountains, a structural geologist observed shales having cleavage structures. These two observations, as well as others, led to the hypothesis that the Wheeler Formation in the Drum Mountains was structurally doubled as a result of Late Mesozoic thrust faulting. Therefore, a secondary objective of this project was to test this hypothesis of structural doubling.

This project was significant because it was the first to define high-resolution strata (parasequences) in the Middle Cambrian of west central Utah. These high-resolution strata were likely deposited within short intervals (20^4 to 40^5 ky) of geologic time. The highly resolved framework in the Drum Mountains can be used to correlate Middle Cambrian strata over large areas within the eastern Great Basin. Within this correlated framework, it will now be possible to examine faunal response to eustatic events occurring in different environments.

Previous Work

The Wheeler Formation was first described by Walcott (1908) in the House Range of west central Utah. Robison (1964) described the biostratigraphy of the Wheeler Formation in the House Range and Drum Mountains. White (1973) described the paleontology and depositional environments of the Drum Mountains Wheeler Formation. McGee (1978) described the depositional environments and inarticulate brachiopods of the lower Wheeler Formation in the east central Great Basin, including the Drum Mountains. Dommer (1980) described the general geology of the entire Drum Mountains area. Robison and Rees (1981) described the Wheeler Formation in the Drum Mountains as generally representing a shallowing-upward sequence from deep-water agnostoid-bearing beds to intertidal microbial stromatolites.

Grannis (1982) described the sedimentology of the Wheeler Formation in the Drum Mountains. Rowell et al. (1982) recognized the base of the *Ptychagnostus atavus* Range Zone occurring in the Wheeler Formation as an easily recognizable, time-significant biohorizon, which can be used to correlate rocks in many areas in the world. Vorwald (1984) described the paleontology and paleoecology of the upper Wheeler Formation in the Drum Mountains.

Stratigraphy

Dommer (1980, p. 60) describes the Swasey Formation (limestone) as "appearing much as it does elsewhere in western Utah. The lower 24.1 m form a dark gray, mostly fossil-barren cliff. The upper 31.4 m are also fossil poor, thin bedded, and somewhat argilaceous and form a flaggy backslope above the cliff."

Dommer (1980) mapped three informal members in the Drum Mountains Wheeler Formation. Dommer (1980, p. 61) described the lower member of the Wheeler Formation as consisting of "thin to very-thin-bedded argilaceous limestone, with abundant agnostid trilobites and siliceous hexactinellid sponge spicules. The lower member forms a silver colored flaggy slope."

Dommer (1980, p. 61) described the Middle Member of the Wheeler Formation as consisting of "medium to dark-gray, thin-bedded limestone, the upper portion of which forms prominent ledges in the midst of the Wheeler slopes."

Dommer (1980, p. 61) described the Upper Member of the Wheeler Formation as consisting of "buff-weathering siltstone with limestone interbeds at the base. The limestone interbeds at the base of the upper member are extremely fossiliferous, containing abundant *Elrathia*, *Asaphiscus*, and trace fossils."

The Pierson Cove Formation is dominantly a dark gray lime mudstone mottled with dolomitic mudstone, and fine-crystalline, medium gray limestone (Hintze and Robison, 1975). Dommer (1980) found the contact between the Pierson Cove Formation and underlying upper member of the Wheeler Formation to be gradational. Because it was easier to map, Dommer (1980) placed the contact at the base of the first major cliff above the buff-colored shale of the upper Wheeler Formation. Workers have shifted the upper boundary of the Drum Mountains Wheeler Formation, as well as the lower, over the last 35 years. This boundary evolution is explained in detail on page 41.

Geologic Setting

The Drum Mountains are located in west central Utah, about 45 km northwest of Delta (Fig. 1). The terrain is rugged and rocky with elevations from 1500-2135 m. The dry desert climate and lack of dense vegetation provides for great rock exposures.

The Drum Mountains include nine formations of Lower and Middle Cambrian age (Fig. 2) that have over 5000 m of combined stratigraphic thickness (Hintze, 1988).

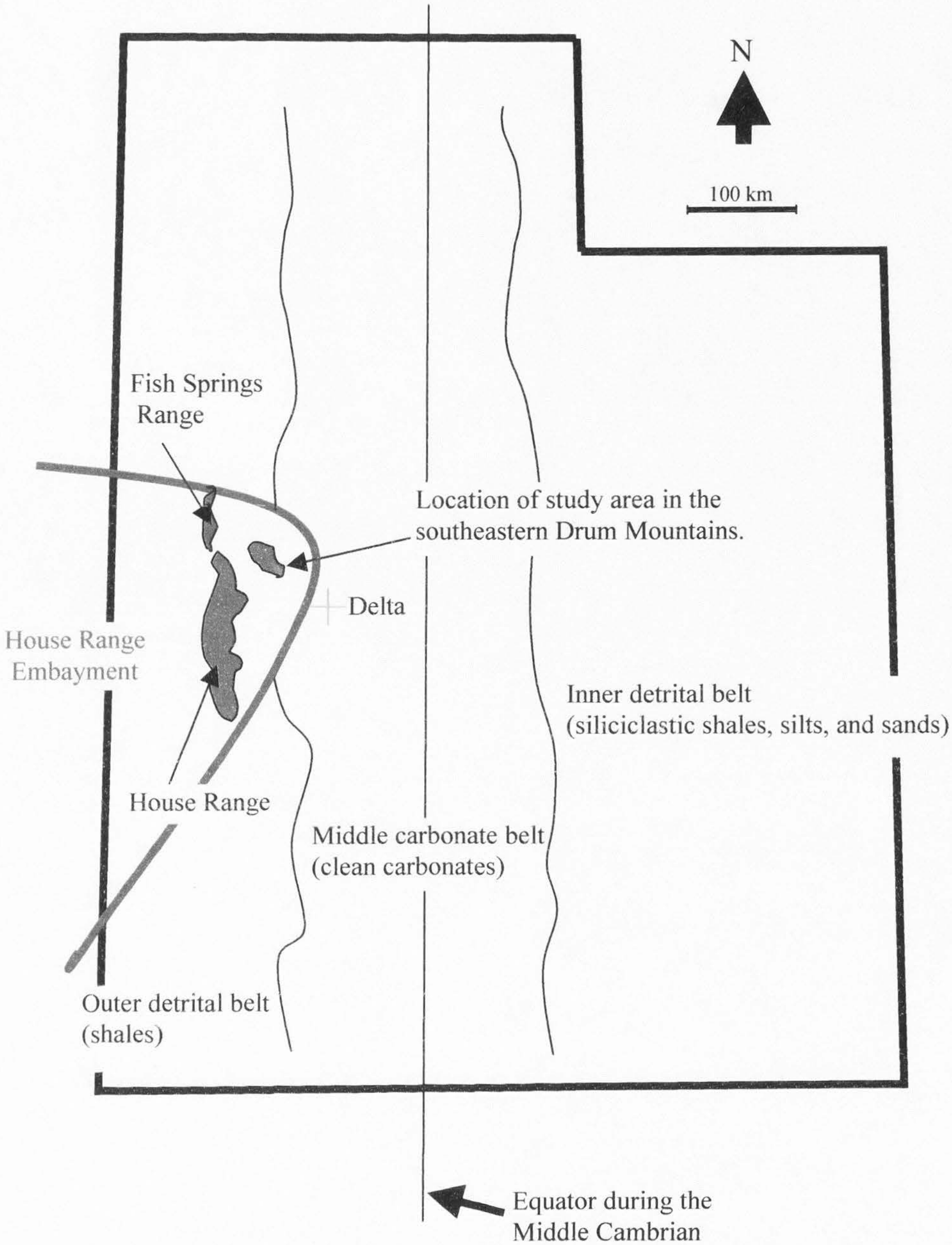


FIGURE 1—Map of Utah with paleogeography during the Middle Cambrian and location of the study area within the Drum Mountains. The outline of the House Range Embayment is adapted from Rees (1986). Note the location of the equator during the Middle Cambrian. Also note the distribution of the three detrital belts (adapted from Hintze and Robison, 1975).

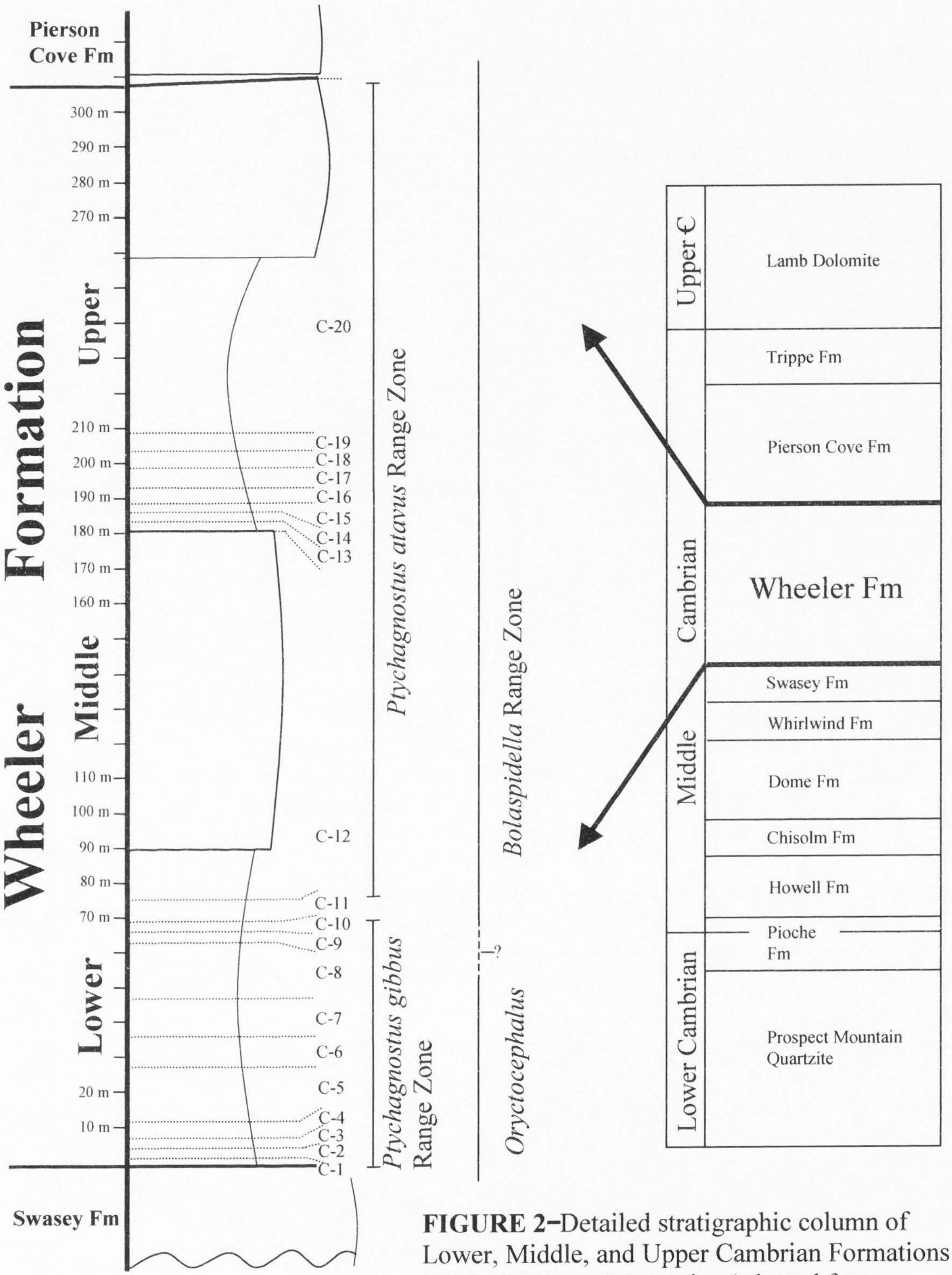


FIGURE 2–Detailed stratigraphic column of Lower, Middle, and Upper Cambrian Formations within the Drum Mountains (adapted from Dommer, 1980). Also shown are cycles 1-20 in the Wheeler Formation and four open-shelf trilobite range zones (Robison, 1976).

The strata dip at approximately 20-30° to the south, southwest, and west (personal observation). Some of these rocks are intruded or covered by Tertiary igneous rocks (Dommer, 1980). Approximately 1.5 km northwest of the field area is the Drum Mine, which exploits disseminated gold from ore bodies in Middle Cambrian carbonate rocks and Eocene to Oligocene igneous rocks (Nutt and Thorman, 1992).

Cambrian Paleogeography

The Cambrian strata were deposited at a time when the North American craton was rotated nearly 90 degrees relative to its modern orientation, and what would eventually become the state of Utah was located at the equator (Scotese, 1997). During the Late Proterozoic and Early Cambrian, rifting occurred in California, Nevada, and Utah (Christie-Blick, 1984). Later, during the Middle Cambrian, the western margin of proto-North America became a passive margin that underwent post-rifting thermal subsidence (Bond et al., 1989). At that time Utah was on the northwestern edge of the craton and the geography consisted of a broad platform that was inundated by a relatively shallow sea (Scotese, 1997). This environment harbored a rapidly evolving and relatively new ecology, including benthic and planktic trilobites, brachiopods, and sponges (Robison, 1991). Also during that time, relative sea level was rising as part of a second order, tectonically driven, cycle (Sloss, 1963). Superimposed on the overall transgression were lower order (3rd- 5th) regressive-transgressive pulses (Vail et al., 1991).

Three general groups of lithofacies in the Cambrian stratigraphy of the eastern Great Basin can be recognized (Palmer, 1971) (Fig.1). Robison (1964, p. 996) states that these lithofacies occur in sinuous, laterally interfingering belts that approximately parallel the ancient cratonic coastline. Rocks of the inner and outer detrital belt are characterized by a high content of argillaceous and arenaceous material, whereas rocks of the middle belt are composed of relatively clean carbonates.

Most of the Wheeler Formation is interpreted to have been deposited in the outer detrital belt (Palmer, 1971). The Swasey Formation and the Whirlwind Formation are examples of the middle carbonate belt and the inner detrital belt, respectively (Palmer, 1971).

In addition, Palmer (1971) introduced a Middle Cambrian paleogeographic feature called the House Range Embayment (HRE) (Fig. 1, 3). Palmer (1971, p. 68) described the HRE as "a depression in the Eureka-House Range region forming a broad embayment terminating just east of the House Range." More recently, Rees (1986, p. 1054) described this feature as

> an asymmetrical trough that deepened and widened as it extended approximately 400 km westward across the shelf toward the edge of the continent. The trough axis lay near its abrupt southern margin, which was a normal fault separating an area of continuous shallow-water accumulation to the south from deep-water deposition. The northern flank of the embayment was initially a drowned platform that forms a southward-sloping ramp.

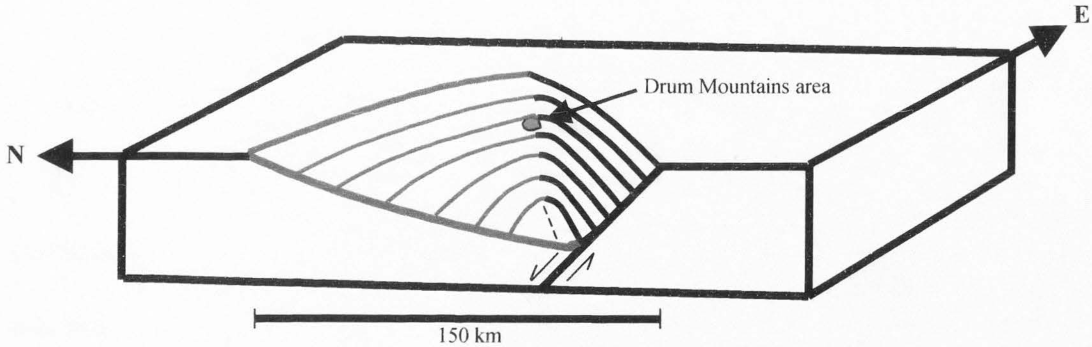


FIGURE 3—Block diagram of the House Range Embayment in west central Utah as described by Rees (1986). Note the normal fault on the southern edge of the embayment. This image is adapted from Grannis (1982).

METHODS

Location of Study Area

The study area is located in the southeastern Drum Mountains. The specific locality of the measured stratigraphic sections can be found in S ½, Sec. 17, T15S, R10W, Drum Mountains Well, UT 7.5' quadrangle, 1971 (Fig. 4). This locality was also studied in detail by Robison (1962), White (1973), McGee (1978), Vorwald (1984), Robison and Rees (1981), and Grannis (1982).

Field Methods

The first field objective was to walk the section and identify meter-scale parasequences. Parasequences were identified, as defined by the University of Georgia Stratigraphy Lab (1999, p. 4), "as a relatively conformable succession of genetically related beds or bedsets bounded by marine flooding surfaces and their correlative surfaces. In addition to these defining characteristics, most parasequences are asymmetrical shallowing-upward sedimentary cycles."

In this project, the word parasequence is used synonymously with the word cycle. The shallowing-upward sedimentary cycles in this study area have a lower carbonate shale unit (deep-water facies) that grades upward into a limestone unit (shallow-water facies). The upper surface of each limestone unit is separated from the shale of the next cycle by a sharp contact (marine-flooding surface).

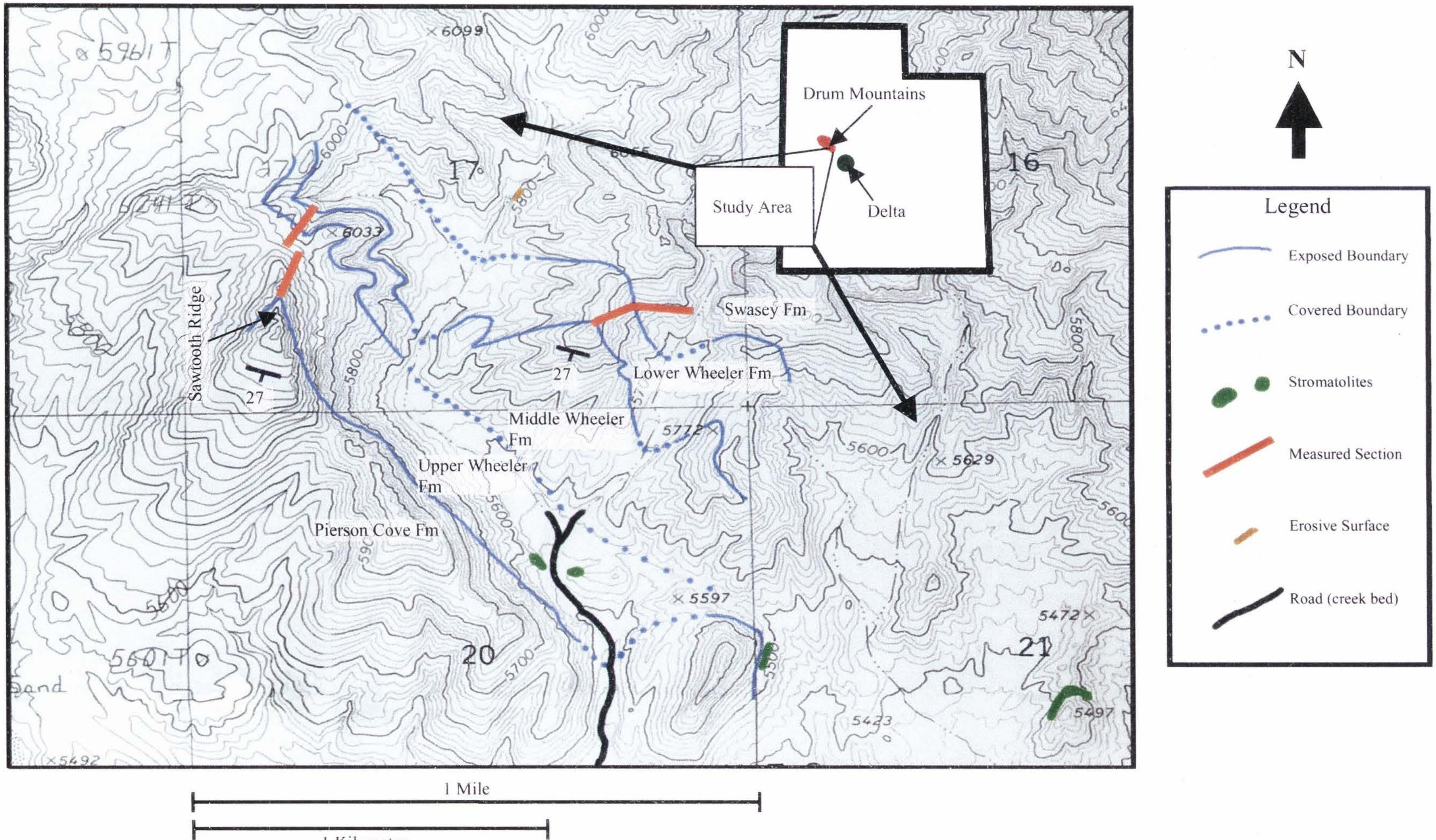


FIGURE 4—Map of study area within the southeastern Drum Mountains of west central Utah.

Rock samples, fossils, and other data were collected from the lower and upper units of each cycle. Many of the lower shale units were less resistant to erosion than the upper carbonate units. As a result, the lower units were often slope-forming and covered by talus. In order to expose fresh outcrop surfaces it was often necessary to dig trenches into the hillslope.

The stratigraphic thickness of each cycle was determined by using a Jacob staff and Brunton compass. Colors of each unit were determined by using the GSA Rock Color Chart. The ichnofabric index of Droser and Bottjer (1988) was used to quantify the extent of bioturbation occurring in the carbonate rocks. Dunham's (1962) classification of carbonate rocks was used to name the limestone lithologies.

Fossil densities were determined by counting the fossils on exposed outcrop surfaces. Because these surfaces had variable areas, I extrapolated each sample density to a standard (fossils/m^2).

Structural observations within the measured section were noted simultaneously with that of the sedimentology and paleoecology. Localities outside of the measured section were also inspected for structural deformation.

Laboratory Methods

Insoluble-Residue Analysis

Thirty-four rock samples were powdered and 50.0 g of each was weighed using a Brainweigh B1500D scale by OHAUS. Each powdered sample was then placed in a preweighed glass jar. Hydrochloric acid (HCl) of 20% concentration was then poured slowly into each of the jars to avoid excessive foaming. This method prevented loss of any portion of the sample. The acid-enriched samples were stirred and then allowed to react for 8 hours. Typically, most of the HCl was consumed within an hour, but it took 8 hours for the mud to settle out of suspension before the supernatant fluid could be removed. After removal of the supernatant fluid, the samples were then subjected to another bath of HCL. If the sample did not react after stirring, it was then set aside from the others and allowed to settle. The other samples that continued to react were put through the process of settling, supernatant fluid removal, and HCl bathing. They were put through these processes for as many repetitions as it took for them to stop reacting.

After each sample stopped reacting and had settled, it was rinsed with distilled water. It then was allowed to settle again, and then rinsed twice more. Samples then were allowed to desiccate until they appeared dry. To complete the drying process they were then placed in a single-wall transit oven at 115° C for 8 hours. Each sample was then removed from the oven and weighed before cooling to minimize any absorption of moisture from the surrounding air. The weight ratio of insoluble material to the original was then calculated using a Microsoft Excel spreadsheet.

Insoluble-Organic-Carbon Analysis

Organic carbon was separated from the total insoluble residue by baking the previously mentioned samples at 550° C for 8 hours in either a Cress Electric Kiln Model C-100-E or a Fisher Isotemp Muffle Furnace Model 184A. Before baking, the samples were weighed using a Fisher Scientific XL-3000 scale to a precision of 0.01 g. After baking, the samples were again weighed before they cooled. The weight ratio of the insoluble organic carbon to the original weight (pre HCl bath) was calculated using a Microsoft Excel spreadsheet.

Quantitative Analysis of Data

A computer program called Multi-Variate Statistical Package (MVSP 3.01) was used to perform a cluster analysis on fossil data. The four general fossil groups observed in the Wheeler Formation (polymeroids, agnostoids, brachiopods, and sponge spicules) were used as variables and the twenty cycles were used as cases. In each of the twenty cycles, the numeral 1 was plotted if a fossil group was present. The numeral 0 was plotted if that fossil group was absent. The clustering was unconstrained. The clustering method was UPGMA. The Jaccard similarity coefficient for binary data was used.

Thin-Sections

Thin-sections were made from rock samples taken from the lower and middle Wheeler Formation. The Geology Department of Utah State University provided the equipment with which the thin-sections were fabricated.

X-Ray Diffraction

The clay mineralogy of four shale samples from four different stratigraphic horizons was determined through the techniques of x-ray diffraction. The samples came from the following stratigraphic horizons: the lower unit of cycle 20 in the upper Wheeler Formation, the lower unit of cycle 1 in the lower Wheeler Formation, the Whirlwind

Formation, and the Chisolm Formation (both of which occur below the Swasey Formation).

To identify the presence of smectite, powdered samples were exposed to ethylene-glycol vapor at 65° C for 1 hour. After cooling, each sample was subjected to the same procedure. To identify the presence of kaolinite, each sample was then heated at 550° C for 1 hour, allowed to cool, and then heated once again.

RESULTS

Stratigraphy, Sedimentology, and Paleoecology

In this study the Wheeler Formation in the Drum Mountains is 309 m thick. The lower boundary is at the sharp transition occurring between light gray, ledge-forming (stair-step) limestone of the Swasey Formation and pale red purple, slope-forming shale (and medium dark gray limestone) of the Wheeler Formation. The upper boundary is at the base of the "southeast-thickening," platey shale, which occurs within the cliffs and ledges of Sawtooth Ridge (Fig. 5).

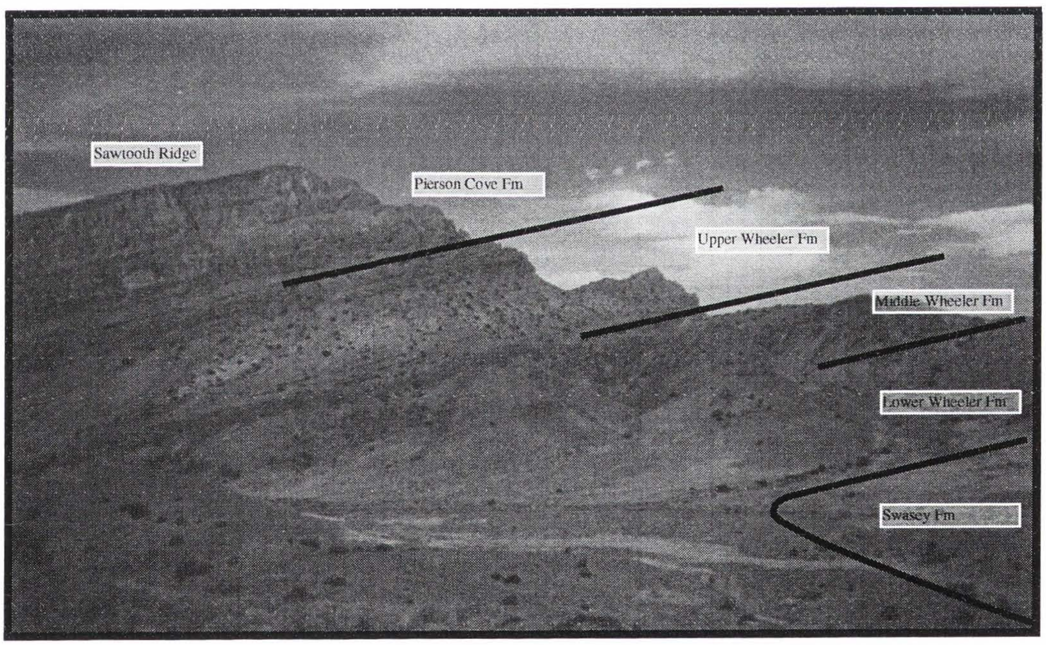


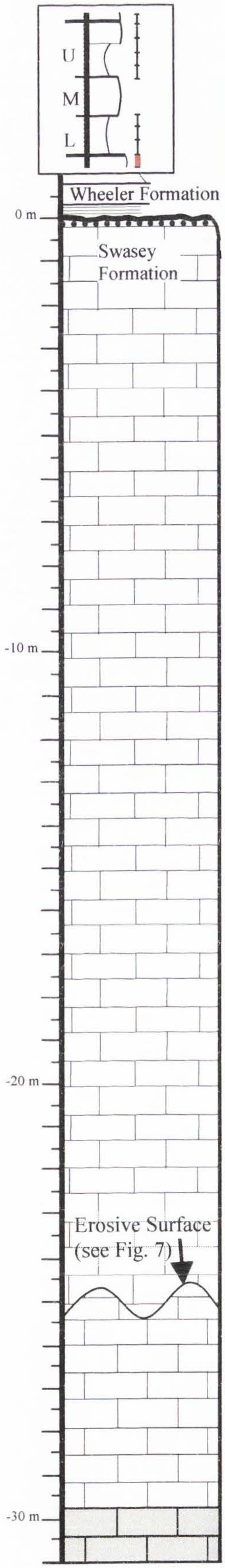
FIGURE 5—Sawtooth Ridge and the approximate boundaries of the Swasey, Wheeler, and Pierson Cove Formations. View is to the west.

Dommer (1980) informally subdivided the Wheeler Formation into lower, middle, and upper members. These members can be identified in the field by their different weathering profiles. The lower member is a slope-former, the middle member is a ledge to cliff-former, and the upper member is a slope and cliff-former. Within these three sections are twenty, well-defined cycles (parasequences), having thicknesses ranging from 0.75-106 m. Each cycle contains a relatively shale-rich, lower unit that grades upsection into a carbonate-rich, upper unit.

Figure 2 contains a stratigraphic column of Lower, Middle, and Upper Cambrian Formations within the Drum Mountains. Also shown is a stratigraphic column of the Wheeler Formation showing the relationship of the three informal members, cycles 1-20, the *P. gibbus* and *P. atavus* agnostoid trilobite range zones, and the *Bolaspidella* and *Oryctocephalus* polymeroid trilobite range zones. Detailed stratigraphic, sedimentologic, and paleoecologic attributes of this generalized column are presented in figures 6, 8-10, and 12-16 (shown later). In these figures, the appearance of the stratigraphic column reflects the relative weathering profile of the sediments occurring in the study area. The color data refer to both the weathered and fresh surface unless otherwise noted. In the upper left corner of each detailed column is a miniature stratigraphic column of the Wheeler Formation, which can be used as reference.

Upper Swasey Formation

The upper 30 m of the Swasey Formation (Fig. 6) is dominantly a ledge-forming, coarse-grained, carbonate pack-grainstone. At 30 m below the Swasey-Wheeler Formation contact, a stratigraphic horizon marks a distinct, bedding-parallel color



Sedimentology			Paleoecology		
Lithology	Structures	Color	Fossils	Taphonomy	Bioturb. Index
sclerite packstone	sclerite condensed zone erosive surface	light gray N6	polymeroid sclerite lenses	disarticulated	1
oncoidal packstone	oncoids ooid lenses sclerite lenses	light gray N6	sclerite lenses	disarticulated	1
oolitic pack-grainstone	ooid ripples	light gray N6	none	———	1
oolitic grainstone	ooid ripples	light gray N6	none	———	1

FIGURE 6-Detailed stratigraphic column of the upper Swasey Formation. (see key in Appendix B).

transition. Below the transition, the rock weathers to medium gray (N5) and above it is light gray (N6). Five meters above this color transition is an undulating erosional horizon that has wavelengths of 1.0 m and amplitudes of 0.5 m (Fig. 7). The lithology immediately above and below this undulating horizon is a rippled oolitic grainstone.

Upsection, oncoidal packstones with ooid and trilobite sclerite lenses occur. The uppermost 10 cm of the Swasey Formation contains a polymeroid sclerite grainstone. The upper surface of the Swasey Formation has irregular relief with wavelengths of 5-10 cm and amplitudes of 1-4 cm.

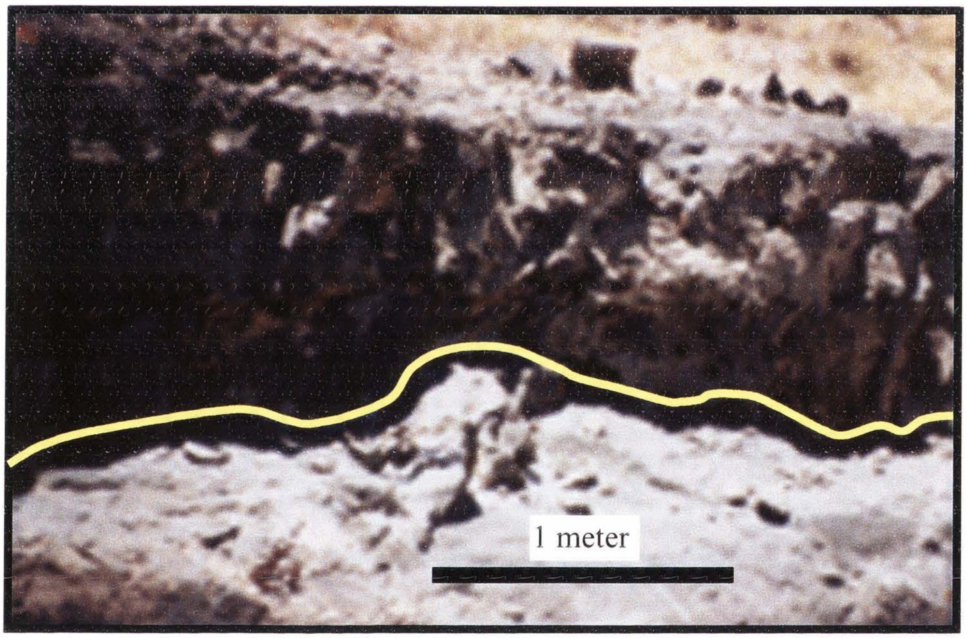


FIGURE 7—Erosional surface in the upper Swasey Formation. The line highlights the undulatory nature of the surface. The lithology above and below the surface is oolitic grainstone.

Cycles 1-6 in the Lower Wheeler Formation

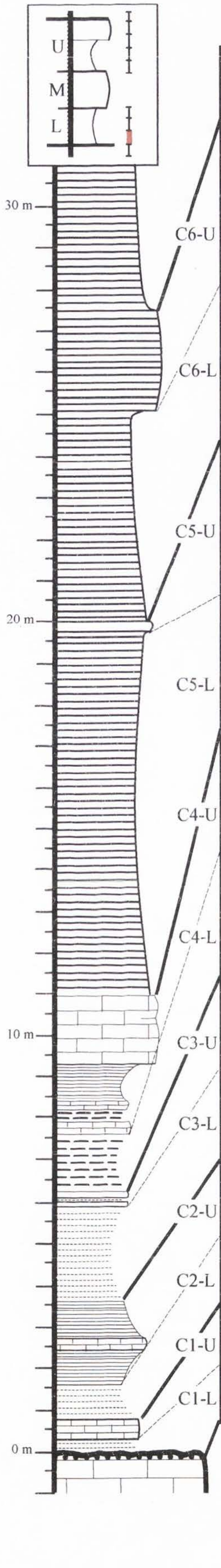
At the Wheeler Formation contact there is an abrupt facies transition. The irregular surfaced, light gray, trilobite sclerite grainstone of the Swasey Formation is covered by a thin (0.2 m), pale-red purple, paper shale. This shale is the lower unit of the first cycle occurring in the Wheeler Formation (Fig. 8).

The first four cycles of the lower Wheeler Formation are characterized by shales that grade upsection into carbonate-rich upper units. The color of all four of these upper units is medium dark gray (N4). This color contrasts noticeably with the medium gray (N5) of the Swasey Formation. Fossils in the first four cycles include sponge spicules and disarticulated agnostoid trilobites. They both occur in low densities (agnostoids 0-2/m^2, spicules 5-50/m^2).

Cycles 5 and 6 differ from the first four. Their lower units are composed of thin-bedded (3 cm) calcisiltite intercalated with very thin (0.3 cm) shale partings. Both the calcisiltite and the shale are laminated. The upper unit of cycle 5 is a thick (25 cm) calcisiltite bed. The upper unit of cycle 6 is ledge forming, intercalated calcisiltite and shale. The shale partings of this upper unit are thinner. Shale is more susceptible to physical weathering processes than limestone, and because the intercalations of this upper unit have less shale, they are therefore more resistant to weathering.

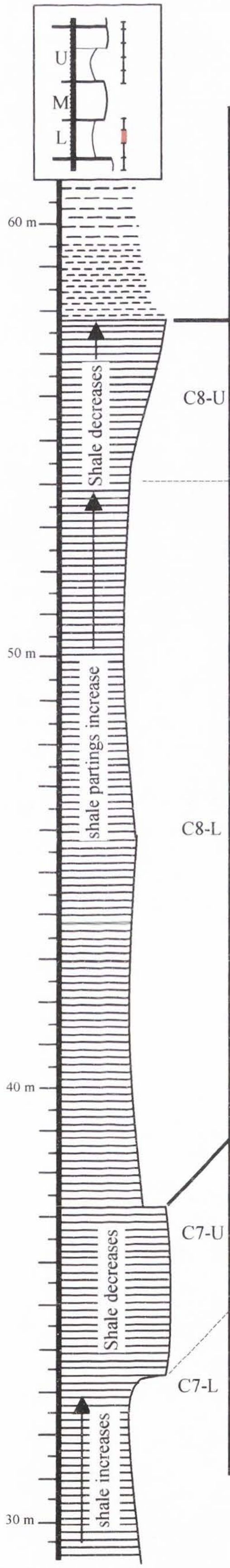
Cycles 7-8 in the Lower Wheeler Formation

Cycles 7-8 (Fig. 9) are also composed of thin-bedded, intercalated calcisiltite and shale. In the lower unit of cycle 7-8, the shale partings thicken upsection. In the ledge-



Sedimentology			Paleoecology		
Lithology	Structures	Color	Fossils	Taphonomy	Bioturb Index
ledge-forming, intercalated, calcisiltite and shale	none	med. dark gray N4	agnostoids 5/m^2 sponge spicules 15/m^2	disarticulated	1
thin-bedded, (3 cm) calcisiltite intercalated with very thin (2mm) shale partings	none	med. dark gray N4	none	———	1
thick (25cm) calcisiltite bed	none	med. dark gray N4	none	———	1
thin-bedded, (3 cm) calcisiltite intercalated with very thin (3mm) shale partings	none	med. dark gray N4	agnostoids 5/m^2	disarticulated	1
massive carbonate mud-siltstone with laminae in thin, isolated, horizons	large (5 x 15cm) yellow dolomitic (?) burrows	med. dark gray N4	none	———	5
thin-bedded, (2-5cm) carbonate mud-siltstone platey shale	none	med. dark gray N4	sponge spicules 10/m^2 agnostoids 1/m^2	disarticulated	1
thin-bedded (5-7cm), carbonate mud-siltstone	laminae	med. dark gray N4	agnostoids 2/m^2 sponge spicules 40/m^2	disarticulate	1
paper shale	none	brownish gray 5YR 4/1 pale red-purple 5RP 6/2	agnostoids 1/m^2 sponge spicules 50/m^2	disarticulated	1
platey carbonate mud-siltstone	laminae hummocks	med. dark gray N4	agnostoids 1/m^2	disarticulated	1
paper shale	none	pale red-purple 5RP 6/2	sponge spicules trace	none	1
carbonate mud-siltstone	laminae 2-3mm thick	med. dark gray N4	none	none	1
paper shale	none	pale red-purple 5RP 6/2	sponge spicules trace	disarticulated	1

FIGURE 8–Detailed stratigraphic column of cycles 1-6 in the lower Wheeler Formation with specific attributes of each cycle.



Sedimentology			Paleoecology		
Lithology	Structures	Color	Fossils	Taphonomy	Bioturb. Index
ledge-forming, intercalated, calcisiltite and shale	agnostoid stringers	med. gray N5 pale red-purple 5RP 6/2	agnostoid 50/m^2 sponge spicules 50/m^2	50% disarticulated	1
intercalated shale and calcisiltite	agnostoid stringers	med. dark gray N4 pale red-purple 5RP 6/2	agnostoid 50/m^2 sponge spicules 15/m^2	50% disarticulated,	1
ledge-forming, intercalated, calcisiltite and shale	agnostoid stringers concretions	med. dark gray N4	agnostoid 15/m^2 sponge spicules 50/m^2	disarticulated	1
intercalated shale and calcisiltite	concretions laminae	med. dark gray N4 pale red 10R 6/2	agnostoid 20/m^2 sponge spicules 100/m^2	disarticulated,	1

FIGURE 9–Detailed stratigraphic column of cycles 7-8 with specific attributes of each cycle.

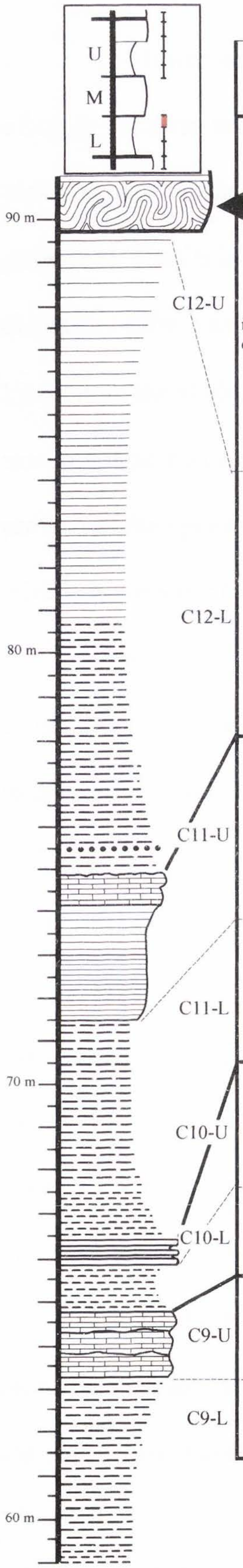
forming upper unit of cycle 7, the shale partings are abruptly reduced in thickness. In the upper unit of cycle 8, the thickness of the shale partings decrease gradually. Agnostoid trilobite and sponge spicule densities (agnostoids 15-50/m^2, spicules 15-100/m^2) increase in these two cycles.

Cycles 9-12 in the Lower and Middle Wheeler Formation

Cycle 9 (Fig. 10) marks an abrupt change in facies from that of cycles 5-8. Its lower unit grades from fissile to platey shale and contains extremely high densities of spicules (1000/m^2), and moderately high densities of disarticulated polymeroid (40/m^2) and agnostoid (40/m^2) trilobites. The upper unit of cycle 9 is a moderately bioturbated (index 3) carbonate mud-siltstone. It contains fossil densities that are greater than that of the lower unit.

Cycle 10 is thin (1.6 m) relative to the other cycles. Its lower unit is fissile shale and it lacks fossils. The upper unit has three thin bedded carbonate mud-siltstone beds that contain disarticulated agnostoid and polymeroid trilobites, and sponge spicules, all of which occur at high densities (75-100/m^2).

The lower unit of cycle 11 grades from fissile to platey shale. Its upper unit is ledge forming with intercalated shale and carbonate mudstone. In this upper unit, the shale thickness decreases upsection while the carbonate mudstone thickness increases. The uppermost surface is a hardground characterized by irregular relief and a grayish purple color (5P 6/2). Both the lower and upper units of cycle 11 have sponge spicules occurring in low densities (25/m^2).



Sedimentology			Paleoecology		
Lithology	Structures	Color	Fossils	Taphonomy	Bioturb. Index
intercalated calcisiltite and shale	contorted beds	med. dark gray N4	trace	———	1
slabby shale platey shale	agnostoid condensed zone	**weathered** very pale orange 10YR 8/2 **fresh** med. dark gray N4	agnostoids 40/m^2 sponge spicules 50/m^2	articulated	1
thin (10cm) carbonate mudstone beds with intercalated shale	hardground	greyish blue 5PB 5/2	sponge spicules 25/m^2	disarticulated	1
platey shale fissile shale	none	greyish blue 5PB 5/2 pale red-purple 5RP 6/2	sponge spicules 25/m^2	disarticulated	1
thin (15cm) carbonate mudstone beds with intercalated shale	none	med. dark gray N4	agnostoids 75/m^2 polymeroids 100/m^2 sponge spicules 150/m^2	disarticulated	1
fissile shale	none	pale red-purple 5RP 6/2	none	none	1
carbonate mudstone	none	med. dark gray N4	agnostoids75/m^2 polymeroids 100/m^2 sponge spicules 1000/m^2	disarticulated	3
platey shale fissile shale	none	pale red-purple 5RP 6/2	agnostoids 40/m^2 polymeroids 40/m^2 sponge spicules 1000/m^2	disarticulated	1

FIGURE 10–Detailed stratigraphic column of cycles 9-12 with specific attributes of each cycle.

The lower unit of cycle 12 contains platey shale. At 0.5 m above the hardground of cycle 11, there is a 2-cm, condensed, agnostoid-sclerite bed. Above the condensed bed, platey shales weather to very pale orange (10YR 8/2) and the fresh rock is medium dark gray (N4). Fossils in this zone include articulated agnostoid trilobites with moderate densities ($40/m^2$) and sponge spicules of moderate to low densities ($50\text{-}20/m^2$). Upsection, the shale increases in thickness until reaching a comformable contact with a medium dark gray (N4) cliff that is approximately 6 m high. This cliff is not only a portion of the upper unit of cycle 12, but it also marks the contact between the lower and middle members of the Wheeler Formation.

The upper unit of cycle 12 (middle Wheeler Formation) is composed of thin calcisiltite (6 cm) beds intercalated with very thin shale partings (0.5 cm) These intercalations have a greater thickness (6.5 cm) than those occurring lower in the section (3.3 cm). The intercalated calcisiltite and shale lithology is maintained throughout the entire thickness (90 m) of this upper unit.

Tightly folded beds distinctly characterize the initial 3 m of the upper unit of cycle 12 (Fig. 11). Folded beds occur at other stratigraphic horizons in different localities within the middle Wheeler Formation, but their intensity of folding is much less than this lower contorted zone. Folded beds that are truncated by non-deformed intercalations mark the top of the contorted zone.

The final 2 m of the upper unit of cycle 12 (bottom of Fig.10) is moderately bioturbated (index of 3-4). At the uppermost surface of the upper unit of cycle 12 there are ooid-filled channels (1 cm deep, 10-15 cm wide).

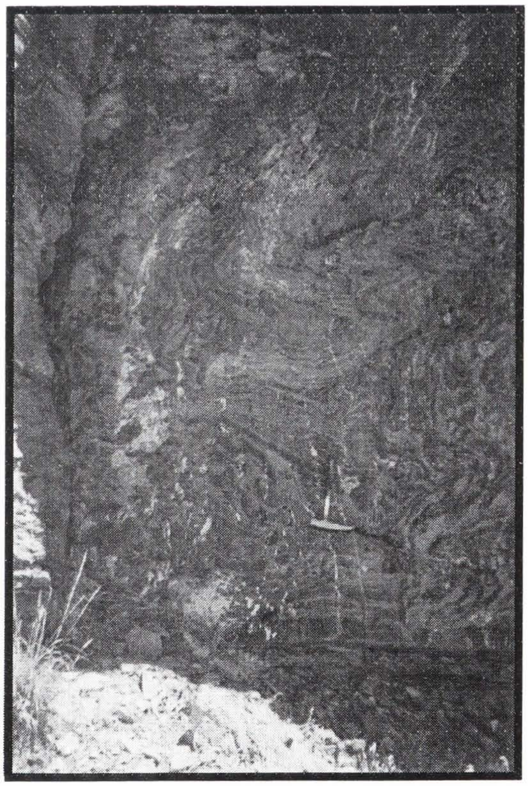


FIGURE 11–Contorted unit at the base of the middle Wheeler Formation. Note the hammer for scale.

Cycles 13-18 in the Upper Wheeler Formation

Cycles 13 and 14 (Fig. 12) continue to maintain the intercalating calcisiltite and shale lithologies found farther below in the section. However, these cycles contain inarticulate brachiopods as well as agnostoid trilobites. The upper units of these two cycles are also slightly bioturbated (index of 1.5-2).

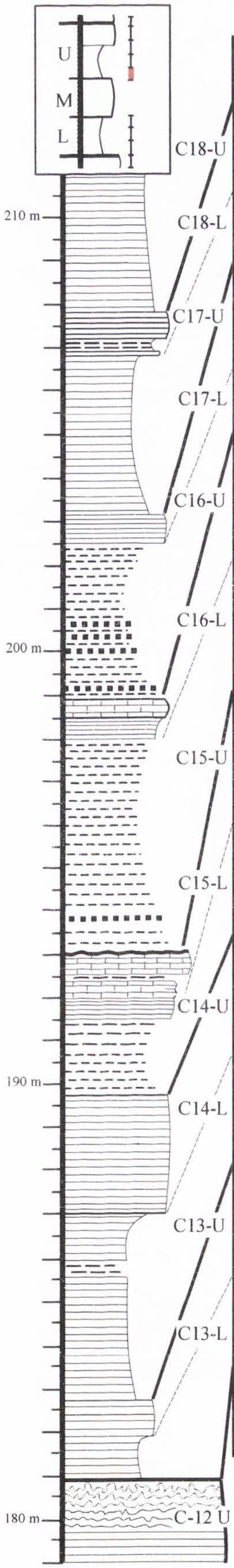
Cycles 15 and 16 have distinct shales in the lower units that coarsen upward into carbonate-rich cycle caps. The upper unit of cycle 15 is moderately bioturbated (index of 3.5) and contains oncoids and ooid cross laminae. The upper surface is a hardground characterized by irregular relief that is grayish purple (5P 4/2). The upper unit of cycle 16 is also moderately bioturbated (index of 3.5) and has oncoids and intraclasts.

The lower units of cycles 16 and 17 have thin beds of gypsum "beef." In the upper unit of cycle 14, polymeroid trilobites become dominant in the upper Wheeler Formation. The lower units of cycles 18 and 19 contain shale-dominated intercalations.

Cycle 19 and Lower Unit of Cycle 20 in the Upper Wheeler Formation

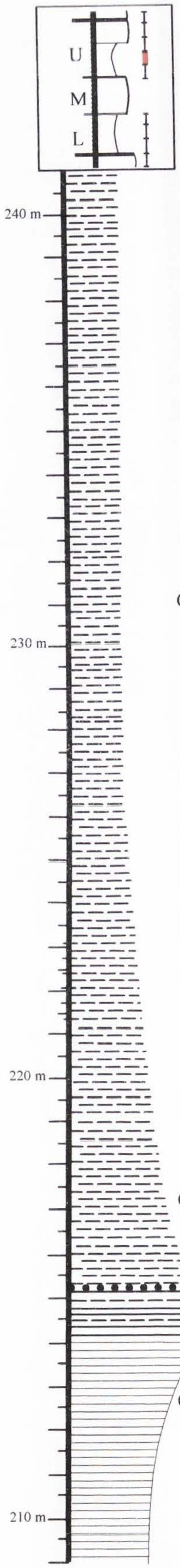
The upper unit of cycle 19 has three thin beds (3-6 cm) having different lithologies (Fig. 13). The first is a carbonate mudstone, the second is an oolitic grainstone, and the third is a sclerite packstone.

The lower unit of cycle 20 is a yellowish gray (5Y 7/2), platey shale. It has well-preserved, articulated, polymeroid and agnostoid trilobites. They both occur in very low densities (1-5/m^2). This lower unit is 51.7 m thick.



Sedimentology			Paleoecology		Bioturb. Index
Lithology	Structures	Color	Fossils	Taphonomy	
ledge-forming, intercalated, mudstone (4 cm) and shale (1 cm)	none	med. dark gray N4	polymeroids 20/m^2 agnostoids 10/m^2 brachiopods 10/m^2	disarticulated	4
intercalated shale (5cm) and mudstone (3 cm)	none	med. gray N5	spicules 10/m^2 polymeroids 5/m^2	disarticulated	4
thin-bedded (3-6 cm), carbonate mudstone with intercalated shale	condensed sclerite troughs	med. dark gray N4	polymeroids 20/m^2 agnostoids 10/m^2	disarticulated	2.5
fissile shale	gypsum "beef"	med. gray N5	polymeroids 15/m^2 agnostoids 15/m^2	disarticulated	1
thin-bedded (5-7cm), carbonate mud-siltstone with thick (35 cm), massive, cycle cap	intraclasts oncoids	med. gray N5	polymeroids 35/m^2 agnostoids 10/m^2	disarticulated	3.5
fissile shale	gypsum "beef"	med. dark gray N4 yellow gray 5Y 7/2 pale red-purple 5RP 6/2	polymeroids 20/m^2 agnostoids 10/m^2 algal residue spicules 10/m^2 brachiopods 5/m^2	disarticulated	1
thin-bedded (5-7cm), carbonate mud-siltstone with thick (40 cm), massive, cycle cap	hardground cross laminae oncoids	med. dark gray N4	polymeroids 30/m^2 agnostoids 10/m^2	disarticulated	3.5
platey shale fissile shale	none	pale red-purple 5RP 6/2	polymeroids 50/m^2 agnostoids 20/m^2 algal residue spicules 10/m^2 brachiopods 5/m^2	disarticulated	1
ledge-forming, intercalated, calcisiltite (7cm) and shale (2cm)	laminae (1 mm), boudins, scoured troughs	med. dark gray N4	polymeroids 30/m^2 brachiopods 25/m^2 agnostoids 10/m^2	disarticulated	1.5
intercalated shale and calcisiltite	laminae (1 mm), ripples, boudins	med. dark gray N4	brachiopods10/m^2 agnostoids 10/m^2	disarticulated	1
ledge-forming, calcisiltite beds (5-8 cm), no shale	laminae (1 mm), yellow burrows (1 x 3 cm, low density)	med. dark gray N4	brachiopods 25/m^2 agnostoids 10/m^2	disarticulated	2
intercalated calcisiltite (5 cm) and shale (2.5 cm)	laminae (1 mm)	med. dark gray N4	brachiopods25/m^2 agnostoids 10/m^2		1
intercalated calcisiltite (6 cm) and shale (5 mm)	ooid lenses	med. dark gray N4	none	———	3-4

FIGURE 12–Detailed stratigraphic column of cycles 13-18 in the upper Wheeler Formation with specific attributes of each cycle.



Cycle	Sedimentology: Lithology	Sedimentology: Structures	Sedimentology: Color	Paleoecology: Fossils	Paleoecology: Taphonomy	Bioturb. Index
C20-L	platey shale	none	yellowish gray 5Y 7/2	polymeroids 5/m^2 agnostoids 1/m^2	articulated	2
C19-U	sclerite packstone 3cm oolitic grainstone 4cm bioturbated carbonate mudstone 6cm	ooids polymeroid condensed zone	—	polymeroid condensed zone	disarticulated	4
C19-L	intercalated shale and mudstone	none	med. gray N5	none	none	1

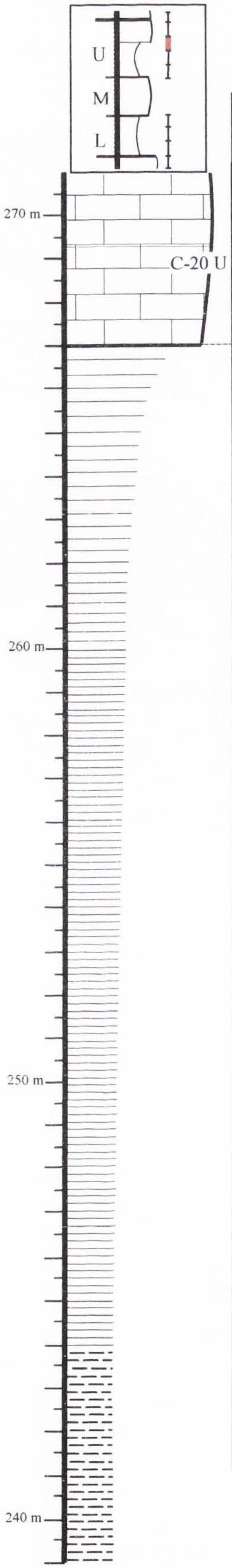
FIGURE 13–Detailed stratigraphic column of cycles 19-20 with specific attributes of each cycle.

Lower and Upper Unit of Cycle 20 in the Upper Wheeler Formation)

About half way up through the lower unit the platey shale turns slabby (Fig. 14). The slabby shale thickens upsection and becomes increasingly bioturbated. The upper unit of cycle 20 is marked by a cliff (~15 m tall). The cliff is a mottled carbonate mudstone.

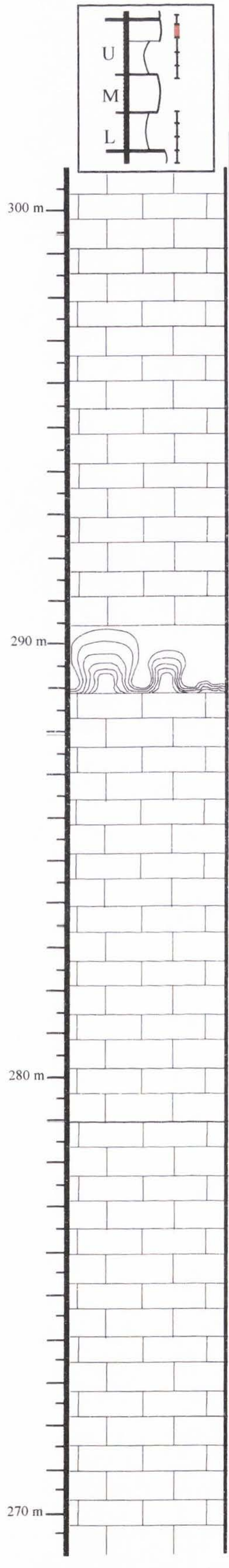
Upper Unit of Cycle 20 in the Upper Wheeler Formation

In the upper unit of cycle 20 there is dramatic variability that occurs laterally within the study area (Figs. 15 and 16). An example of this occurs at approximately 20 m below the contact between the Wheeler and Pierson Cove Formations. At this horizon, on the nose of Sawtooth Ridge (Fig. 5), the lithology is a mottled carbonate mudstone. About 1 km to the southeast, and next to the creek bed (road), there is an outcrop surface exposing a group of relatively small (~ 0.8 x 0.3 m), elongate (in plan view), stromatolites. Farther to the southeast (~ 0.5 km) there is another group of larger (~1.5 x 1.0 m), and less elongate, stromatolites. East of this locality (~ 1 km) there is yet another outcrop of giant (~ 2.0 m diameter) stromatolites having a very hemispherical geometry. In addition, on the nose of Sawtooth Ridge, at the contact between the Wheeler and Pierson Cove Formations, there is a thin (0.7 m) platey shale bed. This bed increases dramatically in thickness (~20 m) to the southeast in just 0.3 km.



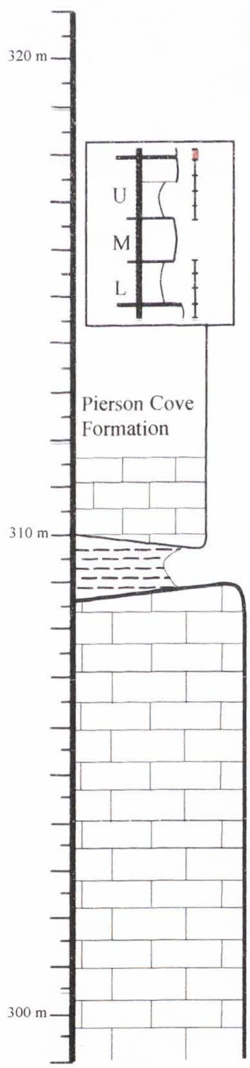
Sedimentology			Paleoecology		Bioturb. Index
Lithology	Structures	Color	Fossils	Taphonomy	
mottled limestone	burrow mottling	?	none	——	4
slabby shale	burrow mottling	yellowish gray 5Y 7/2	none	——	3.5
slabby shale	burrow mottling	yellowish gray 5Y 7/2	polymeroids 2/m^2	articulated	3
platey shale	none	yellowish gray 5Y 7/2	polymeroids 4/m^2 agnostoids 1/m^2	articulated	2

FIGURE 14–Detailed stratigraphic column of the middle of cycle 20 with specific attributes.



Sedimentology			Paleoecology		
Lithology	Structures	Color	Fossils	Taphonomy	Bioturb. Index
carbonate boundstone	stromatolites increase in size to the SE	?	none	———	1
mottled limestone	none	?	none	———	4

FIGURE 15–Detailed stratigraphic column of upper cycle 20 with specific attributes.



Sedimentology			Paleoecology		Bioturb. Index
Lithology	Structures	Color	Fossils	Taphonomy	
platey shale	thickens laterally to the SE	?	polymeroids	articulated	1
mottled limestone	none	?	none	———	4

FIGURE 16–Detailed stratigraphic column of the uppermost Wheeler Formation.

Cluster Analysis of Paleontologic Data

The results of the R-mode cluster analysis are shown in Fig. 17. The R-mode analysis shows the relative frequency of association between each fossil group. For example, spicules and agnostoids occur together more often than any other combination. Similarly, brachiopods and polymeroids occur together more often than any other combination. The cluster containing spicules and agnostoids has a higher coefficient (0.60), and therefore a greater frequency of occurrence, than the cluster containing brachiopods and polymeroids (0.41). The importance of performing this analysis is to identify different faunal communities. Identifying the faunal communities will then support interpretations of the depositional environment.

The Q-mode analysis (Fig. 18) displays the relative similarity of each cycle based on its fossil content. Specifically, the Q-mode analysis identifies the different biofacies occurring within the deposits. There are eight different clusters occurring throughout the Wheeler Formation. Most of the cycles in the lower Wheeler Formation are separated from those occurring in the upper Wheeler Formation, thereby suggesting that the lower Wheeler Formation has a different biofacies than that of the upper.

Insoluble Residue and Organic Carbon Analysis

The results of the insoluble residue and organic carbon analyses are shown in Fig. 19. To minimize graphic complexity, the data for the lower and upper units of each cycle are displayed separately. The data points within the Swasey Formation and middle Wheeler Formation (upper unit of cycle 12) are shown in both the lower and upper unit

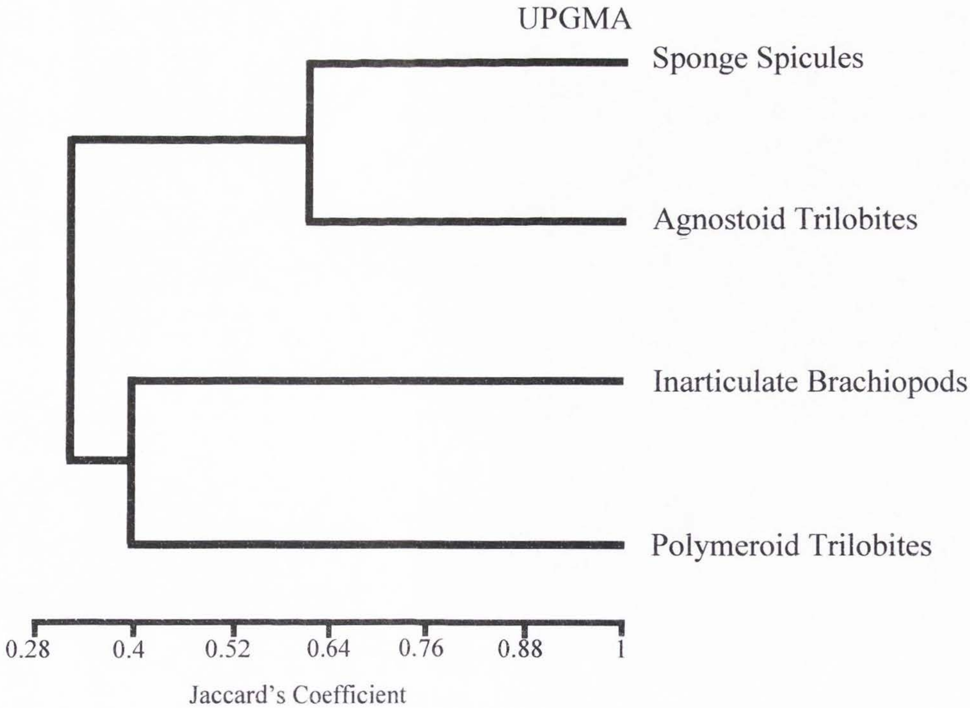


FIGURE 17–R-mode analysis.

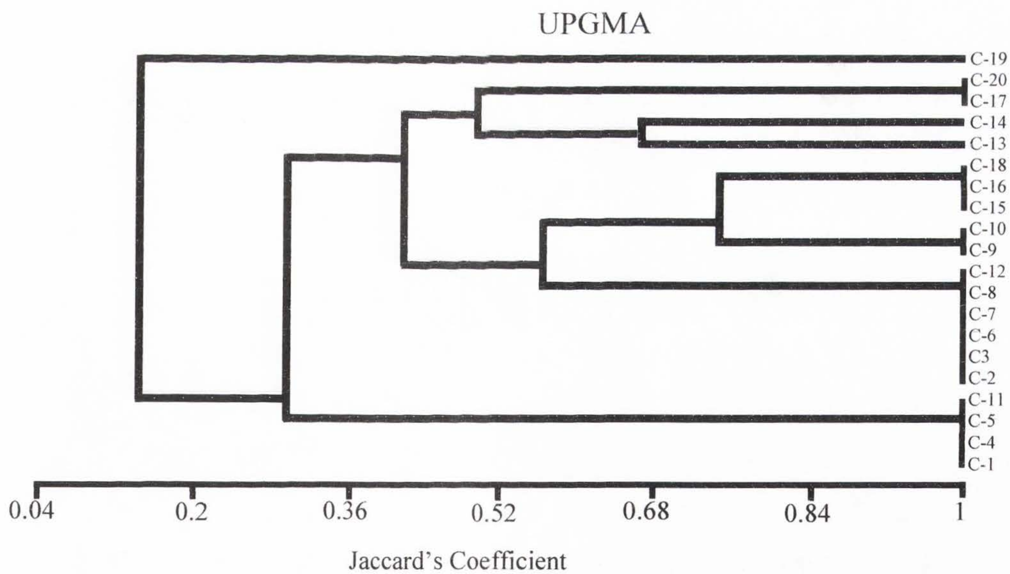


FIGURE 18–Q-mode analysis.

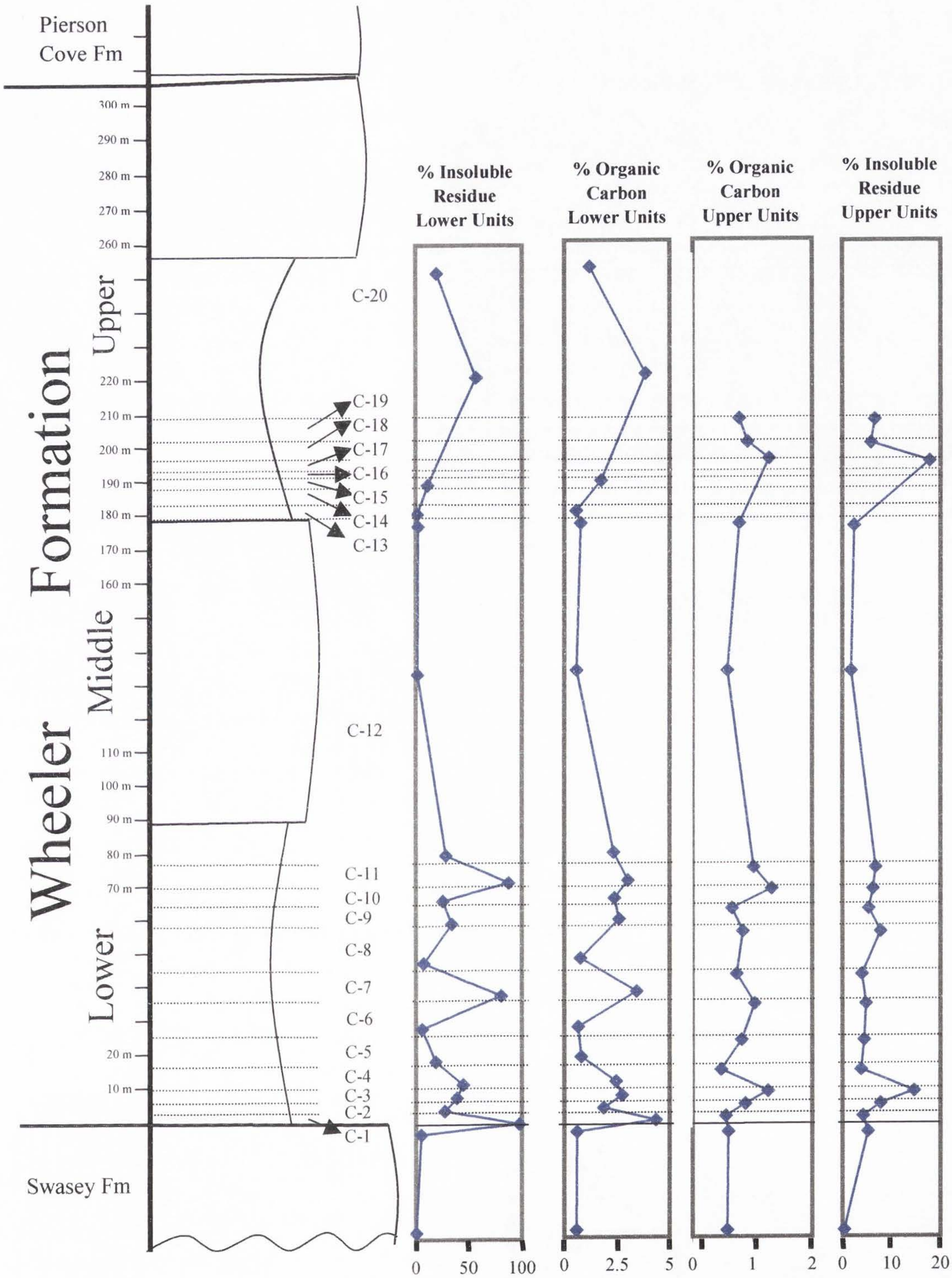


FIGURE 19–Insoluble residue and organic carbon in the Wheeler Formation.

graphs. The patterns formed by the percent insoluble and organic carbon data mimic each other closely.

The lowest percent residue datum (0.4% = highest carbonate content) (Appendix A, Geochemical Data) occurs in the Swasey Formation, 30 m below the Wheeler Formation contact. The highest percent insoluble datum (97.6% = lowest carbonate content) occurs in the lower unit of cycle 1. The lowest percent organic carbon datum (0.48 %) occurs in the upper unit of cycle 4. The highest percent organic carbon datum (4.36 %) occurs in the lower unit of cycle 1. At this horizon, both the insoluble residue and organic carbon data differ dramatically from that occurring in the upper Swasey Formation. Also notable are the two anomalously high insoluble-residue data occurring at the base of cycle 7 and cycle 11.

Thin Sections

Figure 20 shows images of a thin-section made from a sample taken from the middle of the middle Wheeler Formation. Most conspicuously it displays alternating light and dark colored banding. At the bottom there is a relatively coarse lag deposit composed of trilobite sclerites, which lies above a massive, fine-grained (mud) deposit.
From the trilobite lag deposit, the sediments fine upward into pelloids and then into organic-rich, laminated mud.

Figure 21 shows thin-section images of a calcisiltite bed collected from the lower unit of cycle 5. They reveal dark (moderately opaque) laminae containing silt-sized carbonate clasts (calcisiltite). Scattered throughout the thin-section are isolated, light-

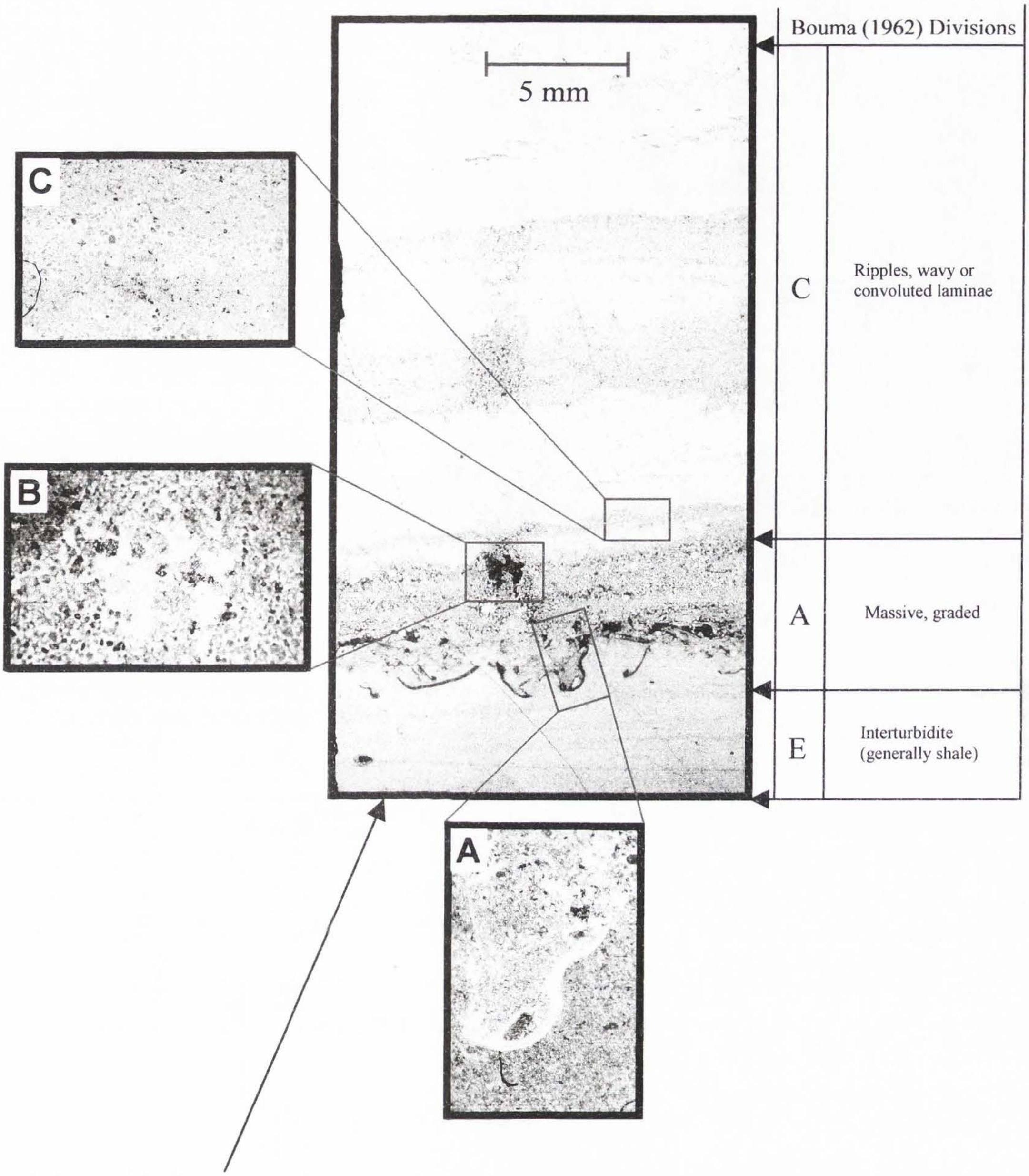


FIGURE 20—Thin-section (negative) of a calciturbidite from the middle Wheeler Formation. Note the upward transition from coarse trilobite lag to pelloids (Bouma A), then to wavy laminae (Bouma C). The trilobite lag deposit lies directly above non-laminated mud (Bouma E). Also note the vertical, narrow and dark pattern just left of the middle of the section. It is probably an escape burrow of an organism after being rapidly transported and buried. (A) Trilobite shepherds crook with sand-sized pelloids above and mud-sized sediment below. (B) Neomorphic calcite surrounded by pelloids. The calcite may have formed in a cavity made by an organism that was rapidly transported and deposited in a turbidity flow. The organism then tried to escape by burrowing vertically. (C) Wavy laminae made of pelloids.

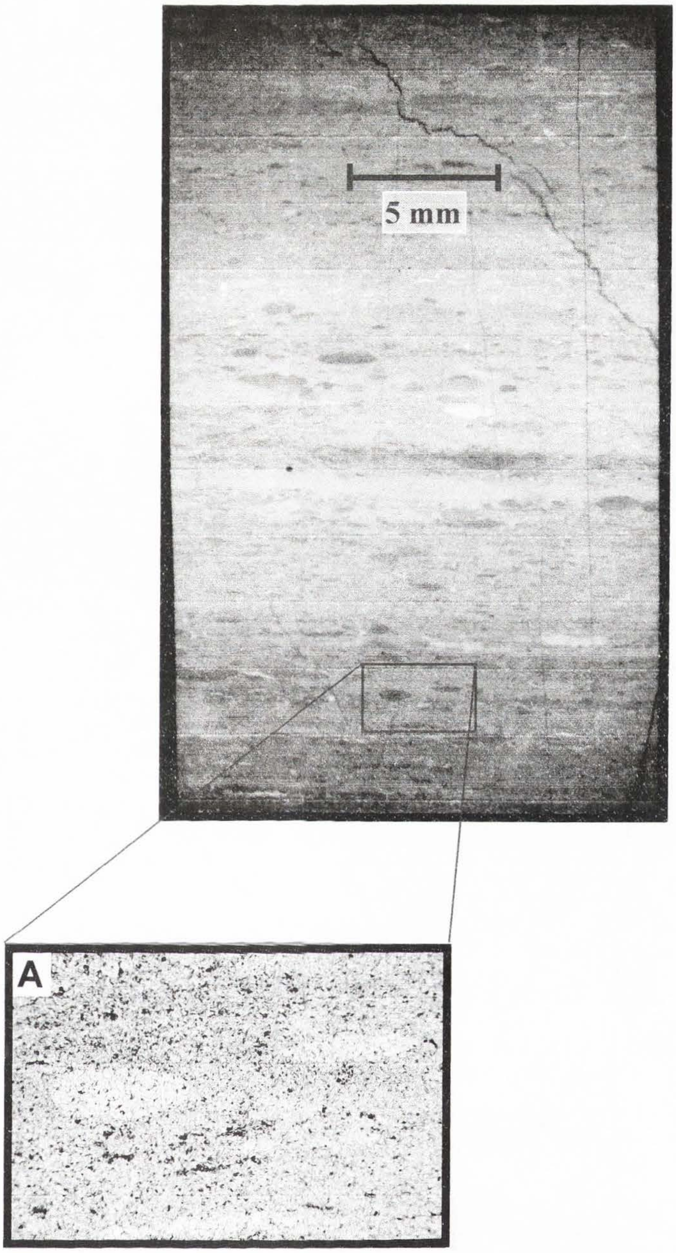
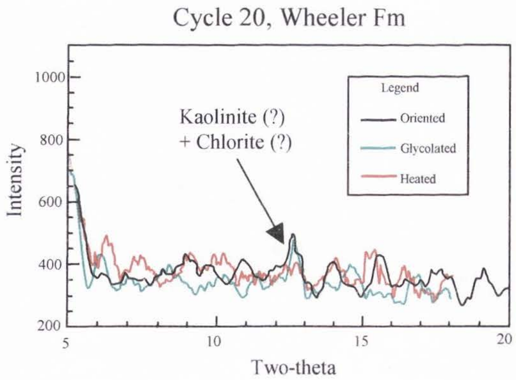


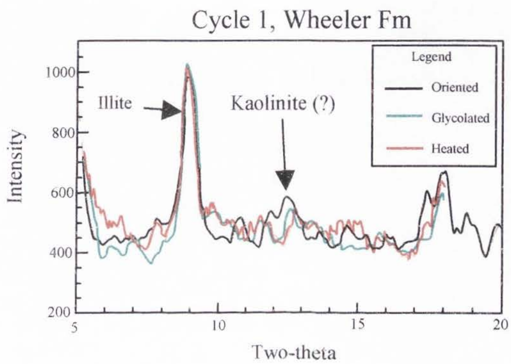
FIGURE 21—Thin-section (negative) from the bottom unit of cycle five in the lower Wheeler Formation. The matrix is carbonate silt. The lens-shaped structures are also made of carbonate silt. They might be rip-up clasts that were abraded during transport in a turbidity current. In comparison to figure 12, this sample is finer-grained and its bedding thickness is thinner. It is interpreted to be a distal calciturbidite. (A) Matrix of carbonate silt and organic material surrounding lens-shaped structures (possibly abraded rip-up clasts).

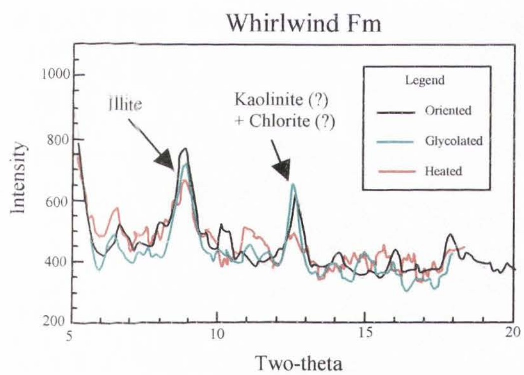
colored, micro-lenses (~1-2 mm in length), which are also made of carbonate silt. Some of these micro-lenses are normally graded (fining upward).

X-Ray Diffraction Analysis

Figure 22 shows the results of the x-ray diffraction analysis. The shale of the Chisolm Formation possibly contains illite. The shale of the Whirlwind Formation contains illite and possibly contains kaolinite and chlorite. Similarly, the shale of cycle 1 in the lower Wheeler Formation contains illite and possibly contains kaolinite. The shale of cycle 20 in the upper Wheeler Formation possibly contains kaolinite and chlorite.







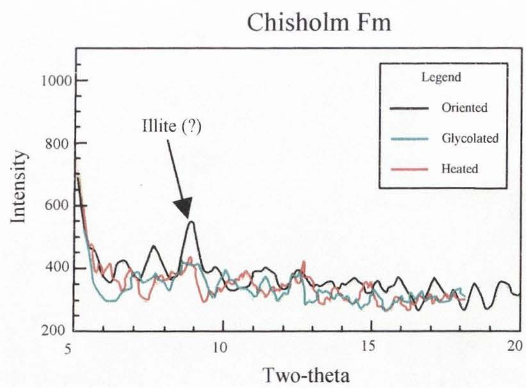


FIGURE 22—X-ray diffraction data from upper and lower Wheeler, Whirlwind, and Chisholm Formations.

DISCUSSION

Wheeler Formation Boundaries in the Drum Mountains

The placement of the upper and lower boundaries of the Wheeler Formation in the Drum Mountains has evolved over the last four decades. Robison (1962) stated that the Wheeler Formation was 94 m thick. Robison's (1962) lower boundary was at the contact between what is now called the middle and upper Wheeler Formation (Dommer, 1980). His upper boundary was at the geomorphic transition from slope to cliff, occurring 94 m above the middle and upper Wheeler Formation contact. This closely corresponds to the cliff of the upper unit of cycle 20, which I measured as 86 m above the middle-upper Wheeler Formation contact.

White (1973) moved the lower boundary of the Wheeler Formation down to the currently recognized contact with the Swasey Formation. This change in the lower boundary was suggested by Robison, who in 1970 found that the Wheeler Formation fauna occurred much farther below than had been previously recognized (White, 1973). White's (1973) upper boundary was also described as a geomorphic change from slope to cliff, and therefore it presumably was the same upper boundary as implied in Robison (1962). White's (1973) total measured thickness of the Wheeler Formation was 302 m.

Dommer (1980) stated that the total thickness of the Wheeler Formation in the Drum Mountains was 237 m. Dommer (1980, p. 61) states:

> The contact of the Pierson Cove Formation with the underlying upper member of the Wheeler Shale is somewhat gradational and is usually covered. The base of the lowest limestone and dolomite cliff of the Pierson Cove was used as the contact since it is much more easily mapped.

Presumably this is the same upper boundary (base of cliff) suggested by Robison (1962) and White (1973).

Vorwald (1984) moved the upper boundary of the Wheeler Formation up into what was previously described by Dommer (1980) as unit 1 of the Pierson Cove Formation. A photograph in Vorwald (1984) shows the amended upper boundary to be located at the top of the "southeast-thickening" platey shale, occurring in the cliffs and ledges of Sawtooth Ridge. This upper boundary was amended because of the presence of Wheeler Formation trilobites occurring in the "southeast-thickening" shales (Vorwald, 1984).

In the present analysis, the Wheeler Formation in the Drum Mountains is considered to be 309 m thick. The lower boundary is at the sharp transition occurring between light gray, ledge-forming (stair-step) limestone of the Swasey Formation, and the pale red purple, slope-forming shale (and medium dark gray limestone) of the Wheeler Formation (Fig. 8). All workers after Robison (1962) have concurred on this boundary.

In this analysis, the upper boundary of the Wheeler Formation is at the base of the "southeast-thickening," platey shale, which occurs within the cliffs and ledges of Sawtooth Ridge. This is different from Vorwald (1984) because it does not include the "southeast-thickening" shale as part of the Wheeler Formation. Like the contact between the Swasey and Wheeler Formations, this is the first abrupt facies transition to occur in the upper Wheeler or lower Pierson Cove Formations. And like the contact between the Swasey and Wheeler Formations (discussed later), this surface likely represents a transgressive surface separating a Lowstand Systems Tract (LST) from a Transgressive

Systems Tract (TST). Therefore, from a sequence stratigraphic perspective, this stratigraphic horizon should be considered the logical contact between the Pierson Cove and Wheeler Formations.

Structural Doubling of the Wheeler Formation

The thickness of the Wheeler Formation in the Drum Mountains (309 m) is more than twice that in the Fish Springs Range (100 m), Wheeler Amphitheater, central House Range (125 m), and Marjum Pass, south-central House Range (140 m) (personal observation). In addition, cycles 1 through 3 in the lower Wheeler Formation in the Drum Mountains have similar colored shales (pale red-purple) as do cycles 15 and 16, which occur in the upper Wheeler Formation. Further, there are horizontal faults that occur near the base of the middle Wheeler Formation. The base of the middle Wheeler Formation coincides with the contorted unit. These phenomena suggested that the strata of the Wheeler Formation in the Drum Mountains might have been structurally doubled.

It was hypothesized that during the Sevier Orogeny a plate containing the Wheeler Formation was thrust in an easterly direction as part of the hanging wall to the Drum Mountains area. The structurally incompetent shales of the Wheeler Formation would have facilitated a detachment surface upon which the hanging wall moved. The end result would have been a dramatic increase in stratigraphic thickness of the Wheeler Formation in the Drum Mountains. Before a proper sequence stratigraphic analysis of the Wheeler Formation in the Drum Mountains could be performed, it was necessary to first address the issue of stratigraphic doubling.

Contorted Unit

The thin calcisiltite and shale intercalations (6.5 cm) composing the contorted unit look as though they were deformed in a plastic state. There is no evidence of brittle deformation within the contorted unit. If thrust-fault shearing occurred in this carbonate-rich horizon, it would be reasonable to expect some brittle deformation.

In addition, non-deformed, intercalated beds of calcisiltite and shale truncate the upper crests of folds in the contorted unit. These truncated folds express a cross cutting relationship that could not have occurred if the beds were deformed by thrust faulting. It is more probable that the beds of the contorted unit were deposited horizontally, and then were only partly lithified when a gravity or seismic induced event deformed them. Subsequent to the deforming event, the upper parts of the folds were eroded flat and younger beds were then deposited.

Grannis (1982) studied the contorted unit in detail at different outcrops within the southeastern Drum Mountains. He not only argued that the contorted unit was created by Cambrian soft-sediment deformation, but also presented data that suggested the direction of paleoslope dip was to the southwest.

Horizontal Faults

The horizontal faults near the base of the middle Wheeler Formation can be found on the west side of the road (creek bed), just east of Sawtooth Ridge. These faults cut the bedding planes at approximately 20-25°. The deformation has both brittle and ductile components. Fault breccia can be seen in small zones.

Nutt and Thorman (1992) studied the Drum Mine, approximately 1.5 km to the northwest of the study area. Nutt and Thorman (1992, p. 1) state that

> …ore deposition was controlled by faults parallel with or at low angles to bedding and their associated ramp structures and by high-angle fractures and faults. The low-angle to bedding-parallel faults are mostly younger-over-older faults that thin units; rarely units are thickened.

Nutt and Thorman (1992) did not observe any thrust faulting within the Drum Mine. The horizontal faults in this study area are likely the same attenuation faults described above. These faults, therefore, could not have caused structural doubling of the Wheeler Formation.

Dommer (1980) studied the geology of the entire Drum Mountain area. Dommer (1980, p. 65) states that "most faults in the Drum Mountains are high angle," and that "neither folds nor thrusts were observed."

Facies Relationships

If structural doubling occurred, then facies in both the lower and upper Wheeler Formation should mimic each other. In this hypothesis, cycles 15-16 in the upper Wheeler Formation would be the third and fourth cycles above the contact of the middle Wheeler. They both have pale red-purple colored shales in their lower units and are 3-6 m thick. The color and thicknesses is similar to that of cycles 1-3 in the lower Wheeler. However, the biofacies in these two groups are very different. Cycles 1-3 contain sponge spicules and agnostoid trilobites, both in very low densities. Cycles 15-16 contain high densities of polymeroid trilobites. Agnostoid trilobites lived a pelagic life in open ocean environments (Robison, 1972). Polymeroid trilobites lived a benthic life within the neritic zone (Robison, 1972). With this major contrast in biofacies, the similar color and thicknesses occurring between these cycles is likely coincidental.

Anomalous Thickness

Approximately 80% of the thickness in the Drum Mountains Wheeler Formation is limestone and the remaining 20% is shale (White, 1973). In contrast, the other three localities referred to above are dominated (60-90%) by shale (personal observation). The thickness of shale found in the field is approximately one quarter of its original thickness (Weller, 1960). In contrast, limestone found in the field is approximately equal to its original thickness (Bathurst, 1975). Therefore, the anomalous thickness of the Drum Mountain Wheeler Formation can be attributed to its abundance of limestone. Further, carbonate sedimentation rates are generally much higher than that of shale (Liddell, 2000, personal comm.). Therefore, the anomalously thick Wheeler Formation in the Drum Mountains could have been deposited in an equivalent amount of time as those localities having decreased thicknesses.

Given the arguments presented above, I conclude that the Wheeler Formation in the Drum Mountains has not been structurally doubled and is therefore stratigraphically conformable.

Sequence Boundary Zone

Sequence boundaries are caused by a relative fall in sea level (U. of Georgia Stratigraphy Lab, 1999). When subaerially exposed, carbonates are prone to dissolution and are often expressed as karst surfaces with solution relief (U. of Georgia Stratigraphy

Lab, 1999). At 25 m below the Wheeler Formation contact, in the Swasey Formation, the lithology is a rippled oolitic grainstone. The rippled ooids reflect a shallow, high-energy depositional environment (Flugal, 1982). The undulating surface at 25 m below the Wheeler Formation contact (Figs. 6-7) might be solution relief that was caused by subaerial exposure. Because the amount of relief on this undulating surface is only 0.5 m, I speculate that the amount of time in which this erosion took place was brief, perhaps on the order of 20-40 ky. This is the interval of time represented by a 5th order parasequence (Vail et al. 1991).

The color change 30 m below the Wheeler Formation contact might reflect a change in ocean water chemistry as a result of shallowing conditions. Both the undulatory surface and the color change are interpreted to represent the lower Sequence Boundary Zone (SBZ).

Lowstand System Tract

In the upper 25 m of the Swasey Formation, above the SBZ, there is a transition of microfacies. The rippled oolitic grainstone in the SBZ is replaced upsection by an oncoidal packstone, which then, at the Wheeler Formation contact, is replaced by a trilobite sclerite grainstone. This transition is interpreted to be the result of a gradual, and then rapid deepening of relative sea level.

I interpret the rippled oolitic grainstone at the SBZ to have been deposited in a shallow-peritidal environment. Flugal (1982, p. 153) states that "marine ooids originate in the tropics and subtropics in high-energy, shallow-water environments influenced by wave action or tidal currents. The majority of ooids originate in depths down to 2 m."

The lack of interstitial mud in the oolitic grainstone indicates that the environment was continually turbulent, at least enough to prohibit the mud-sized particles from settling out of suspension. The ripples indicate sediment transport, presumably in tidal currents.

I interpret the oncoidal packstone to have been deposited in a slightly deeper environment, perhaps shallow subtidal or deeper intertidal. The oncoids reflect an environment that periodically had enough energy to rotate the lobulate form, but in general was low in energy (Flugal, 1982). The interstitial mud also reflects conditions that were low in energy (Flugal, 1982).

The sclerite grainstone, which is the upper most unit of the Swasey Formation, is interpreted to represent a period of time in which sedimentation rates were very low. The characteristics of this narrow horizon are very similar to Kidwell's (1986) R-Sediment Model, Type-2 shell bed. This model states that an upward increase in shell packing density is a result of decreasing sedimentation rates. I interpret the low sedimentation rate to have been caused by a rapid deepening of relative sea level. The deepening of relative sea level was fast enough to prohibit sustainable carbonate production and impound shales at the coastline. This interpretation is supported by the presence of a thin bed of carbonate-poor, paper shale directly above the sclerite grainstone. This shale is the lower unit of cycle 1 within the Wheeler Formation. White (1973) suggests that the contact between the Swasey and Wheeler Formations is a hardground. Rowell et al. (1982) state that the contact between the Swasey and Wheeler Formations likely represents a global eustatic event. This surface coincides with the base of the *Ptychagnostus gibbus* biostratigraphic range zone.

McGee (1978) suggests that the Swasey Formation was deposited in water depths of a few to tens of meters. McGee (1978, p. 69) also states that the "Swasey Limestone and its equivalents in this study appear to exhibit a deepening upward sequence…." This deepening upward sequence, which is located between the SBZ and the Wheeler Formation contact, is interpreted to be the upper part of the lower Lowstand Systems Tract (LST).

Transgressive Surface

The Lowstand Systems Tract is commonly capped by a prominent marine-flooding surface called the Transgressive Surface (TS) (U. of Georgia Stratigraphy Lab, 1999). The TS represents the first major marine-flooding surface to follow the SBZ and is usually distinct from the relatively minor flooding surfaces that occur in the LST (U. of Georgia Stratigraphy Lab, 1999). A marine-flooding surface separates younger strata from older strata, across which there is evidence of an abrupt increase in water depth (Van Wagoner, 1990). The contact between the Swasey and Wheeler Formations marks the first major facies change to occur in the measured section.

At the contact between the Swasey and Wheeler Formations is an irregular surface with wavelengths of 5-10 cm and amplitudes of 1-4 cm. This surface is interpreted to be the Transgressive Surface, which separates the Lowstand Systems Tract from the Transgressive Systems Tract. Above and below this surface are two distinct facies representing very different depositional environments.

Below the contact is a light gray, sclerite grainstone (uppermost Swasey Formation) formed from disarticulated polymeroid trilobites. Robison (1972) states that non-agnostoid trilobites are most common in neritic environments. The insoluble residue of this facies is 5.2% and the total organic carbon is 0.60% (Table 2, Appendix A).

Above the contact is a pale-red purple, 20 cm, paper shale (lowest Wheeler Fm) containing traces of sponge spicules. Four meters above this shale, in cycle 3, there are agnostoid trilobites. Robison (1972) states that agnostoid trilobites are most commonly found in open-oceanic environments. The insoluble residue of this facies is 97.6% and the total organic carbon is 4.36% (Table 2). As shown in Fig. 19, the greatest difference in insoluble residue and total organic carbon occurring between any of the facies in the measured section is located at the Wheeler Formation contact.

Transgressive Systems Tract

Cycles 1-4

Unlike the Swasey Formation, the cycles 1-4 of the lower Wheeler Formation are characterized by a deep-water lower unit (shale) that grades (coarsens upward) into a dark-gray, carbonate mud-wackestone cycle cap.

The fauna of cycles 1-2 (lower units) include only trace amounts of sponge spicules. However, the lower units of cycles 3-4 contain trace amounts of agnostoid trilobites (disarticulated) and increased spicule densities (10-50/m^2). Therefore, from cycles 1-4 there is a slight but noticeable increase in faunal diversity and density.

The increase in sponge spicule density may reflect condensation caused by decreasing sedimentation rates (Kidwell, 1986). The decreased sedimentation rate would have been caused by the rapid increase in relative sea level. A rapid increase in sea level would impound sediments farther up on the shelf in bays and estuaries.

The appearance of agnostoid trilobites might reflect paleoecologic conditions occurring in the ocean water column during the transgression in sea level. Opik (1979) suggests that agnostoid trilobites were planktonic filter feeders. Robison (1972) suggests that agnostoid trilobites avoided neritic environments having excessive runoff. Fine-grained sediment in the water column may have disrupted filter feeding. The lack of abundant agnostoid trilobites in cycles 1-5 may reflect a period of time in which the Middle Cambrian ocean water in the Drum Mountain locality contained enough muddy sediment to prevent their existence.

From cycle 1-6 there is an increase in agnostoid trilobite density. I attribute this increased density to an environmental transition. I hypothesize that as sea level increased, the environment became increasingly favorable for agnostoid trilobites, and therefore their population densities increased. These first six cycles are therefore considered to display a retrogradational-stacking pattern.

Cycles 5-8

A significant change in sedimentology occurs above the cap of cycle 4. The deposits are thin (3-4 cm), intercalated, dark-gray calcisiltite, capped with very thin (0.3 cm), light gray shale. These intercalated deposits occur in a relatively thick stratigraphic interval (47 m) within the lower Wheeler Formation (Figs. 8-9). These fining-upward intercalations of calcisiltite and shale may be the result of turbidite deposition.

A thin-section of a calcisiltite bed (collected from the lower unit of cycle 5) reveals many dark (moderately opaque) laminae containing silt-sized carbonate clasts (calcisiltite). Scattered throughout the thin-section are isolated, light-colored, micro-lenses (~1 mm in length), which are also made of carbonate silt (Fig. 21). Some of these micro-lenses are normally graded (fining upward). It is possible that these micro-lenses are eroded rip-up clasts. The tapered ends may have been formed as a result of abrasive processes that occurred during sediment transport. McGee (1978) described a 4-5 cm thick, Bouma-A division sequence from at least one bed in the lower Wheeler Formation, and he interpreted it as being deposited from a sediment gravity flow, and possibly as a turbidity flow.

Upsection, in the middle Wheeler Formation (upper unit of cycle 12) there are similar intercalations. These intercalations are thicker (avg. 6.5 cm), they are coarser in grainsize, and they contain pelloids, trilobite sclerites, and scoured surfaces. A thin-section from the middle Wheeler Formation reveals what might be Bouma-A, C, and E divisions (Fig. 20). I interpret the intercalations of both the middle Wheeler and those of cycles 5-8 to be calciturbidites.

The thin-bedded and fine-grained intercalations of cycles 5-8 may have been deposited more distally with respect to the southern escarpment of the House Range Embayment. The thicker and coarser grained intercalations of the middle Wheeler may have been deposited more proximal to the southern escarpment of the House Range Embayment. Flugal (1982) developed criteria for the determination of proximal versus distal limestone turbidites (calciturbidites). Of the seventeen criteria shown in Table 1, six of them support the hypothesis that the middle Wheeler Formation is composed of

TABLE 1-Criteria of proximal and distal limestone turbidites (from Flugal, 1982). The bold font indicates that the criteria were observed in thin-section.

	Proximal (middle Wheeler)	Distal (lower Wheeler)
1) Mean bed thickness	**greater**	less, often very **thin**
2) Mean grain size	**larger** (arenite and rudite)	**smaller** (lutite and arenite)
3) Grading	graded, poorly graded or not graded	nearly always graded
4) Inverse grading	common	absent
5) Coarse-tail grading	common	absent
6) Base of the detrital zone	generally sharp	sharp
7) Top of the detrital zone	often sharp	grades into finer sediments
8) Scours, washouts, channels and reworked pebbles at the base	**common**	rare; **no channels**
9) Tool marks	rare	common
10) Geometry of beds	irregular in thickness, lenticular	regular parallel beds
11) Complete Bouma sequence	common	rare
12) Lamination and ripple lamination	less common, restricted to thicker beds	more common
13) Micritic upper parts	thin or absent	well developed and usually well-preserved
14) Arenite/Lutite ratio	**high**	**low**
15) Matrix within the detrital zone	sparry cement	micrite
16) Depositional pattern	**turbidite beds densely spaced, background sedimentation restricted**	**thick "normal" sediments (shales of cycles 9-11)**
17) Lithofacies association	**slumping structures**, fluxoturbidites, conglomerates; cherts rare	**coarse clastics rare**; cherts common

proximal calciturbidites and that the lower Wheeler Formation contains distal calciturbidites.

The thin-section of the lower calciturbidite interval (Fig. 21) displays less varied and generally smaller grainsizes, it has no Bouma divisions, and it has no scours. In contrast, the thin-section (Fig. 20) of the calciturbidite interval in the middle Wheeler Formation displays coarser grainsizes that are graded, it has Bouma A, C, and E divisions, and it has scours. In addition, the upper calciturbidite interval has thicker beds than the lower. Most importantly this upper interval has slumping structures (contorted zone), which indicates deposition on a slope. The calciturbidite beds in the contorted zone may have been deformed during a Middle Cambrian earthquake event. The calciturbidites of the lower interval lack any deformation and therefore were likely deposited on nearly horizontal terrain near the bottom of the House Range Embayment.

Aggradational Cycle Stacking of Cycles 7-10

The fauna within cycles 7-10 includes sponge spicules and agnostoid trilobites. The densities of these two fossil groups generally stabilize in cycles 7-10. I interpret these cycles to represent an aggradational cycle-stacking pattern.

Maximum Flooding Surface

On the upper surface of cycle 11 there is a hardground. Half a meter above the hardground, in the lower unit of cycle 12, there is a 2-cm-thick agnostoid coquina. Both of these horizons suggest that during this time, very low sedimentation rates occurred in the Drum Mountains area. I interpret these two horizons as reflecting a rapid and significant deepening of relative sea level, with consequent sediment slowdown.

Above the agnostoid coquina are medium dark gray (fresh) platey shales. These shales contain moderately high densities (30-40/m^2) of articulated agnostoid trilobites, moderately high densities (20-50/m^2) of sponge spicules, and no bioturbation. The articulated nature of the agnostoid trilobites indicates that they were not allochthonous. The presence of both agnostoid trilobites and dark shales indicates deposition within a basinal environment. Both Grannis (1982) and McGee (1978) interpreted this facies the same way, that is, as the deepest facies that occurs in the Wheeler Formation in the Drum Mountains.

The Stratigraphy Laboratory of the University of Georgia (1999, p. 11) states:

> The maximum flooding surface coincides roughly with the most rapid relative rate of sea level rise, after which sea level rise begins to slow. In outcrop, the maximum flooding surface is also recognized by the deepest water deposits within a sequence.

I interpret the Maximum Flooding Surface (MFS) to occur within the lowest 3 m of the lower unit of cycle 12. From this horizon, up to the contact with the Pierson Cove Formation, the facies indicate a gradual shallowing of relative sea level.

Highstand Systems Tract

Highstand Shedding of the Middle Wheeler Formation

The middle Wheeler unit (upper unit of cycle 12) is a thick section (90 m) composed entirely of calciturbidites. Emery and Meyers (1996, ch. 10) introduced a concept called "highstand shedding," which is the redeposition of carbonate sediment from the platform top to the slope and basin. This redeposition is a result of carbonate production exceeding the space available to accommodate it. Emery and Meyers (1996, p. 214) state, "A carbonate platform will also shed sediment during transgression and sea level fall, but all other factors being equal, a platform will tend to shed most sediment during highstand as the rate of creation of accommodation declines."

Progradation in the Upper Wheeler Formation

Cycles 13-20 exhibit characteristics that indicate a gradual shallowing of relative sea level. These include, ooids, oncoids, intraclasts, moderate to high bioturbation, and densely packed polymeroid trilobites. The parasequence-stacking pattern of these eight cycles is progradational. I suggest the sea level drop was the result, not only of decreasing eustatic sea level, but also of the filling of the HRE.

The uppermost 2 m of the middle Wheeler Formation are moderately bioturbated (index of 3-4) (Fig. 12). On the top surface of the middle Wheeler are u-tube burrows (Diplocriteron), trilobite coquina lenses, and small ooid channels. This evidence suggests that bathymetry was further decreasing.

Cycle 13 in the upper Wheeler Formation is composed of less-resistant calciturbidites. It contains agnostoid trilobites and inarticulate brachiopods. Cycle 14 is similar but it includes disarticulated polymeroid trilobites. The presence of polymeroid trilobites in cycle 14 suggests that bathymetry was decreasing.

Cycle 15 marks the beginning of shale deposition in the upper Wheeler. The lower shale has algal residue and the upper carbonate cap contains relatively high densities of disarticulated polymeroid trilobites. Portions of this cycle cap are moderately bioturbated (index of 3.5). In the uppermost 3 cm of the carbonate cap of cycle 15 is an oncoidal packstone. Cycle 16 is very similar to cycle 15 but the polymeroids become increasingly articulated. On the surface of cycle 16 is an oncoidal/intraclast packstone. This thin horizon may be a storm deposit shed from the platform top. The coarse-grained (rudite) nature of this deposit (and that in the cap of cycle 15) may reflect increasingly shallow depths, and therefore proximity to the platform edge.

Cycles 17-20 continue to display evidence of shallowing. The upper unit of cycle 19 has three thin beds (3-6 cm) having different lithologies. The first is a carbonate mudstone, the second is an oolitic grainstone, and the third is a sclerite packstone. These three beds might be storm deposits shed from the increasingly proximal platform edge.

The lower unit of cycle 20 is a thick accumulation (51 m) of yellowish gray shale. It has well-preserved and articulated polymeroid trilobite body fossils and molts. They occur in very low densities (1-5 /m^2). Kidwell's (1986) R-sediment model suggests that the well-preserved nature of the trilobites and their low density reflect high sedimentation rates. The great thickness of this lower unit supports this interpretation.

About halfway into the lower unit of cycle 20 the shale partings begin to increase in thickness and bioturbation occurs at a moderate intensity (index of 3). As can be seen in Fig. 10, the insoluble residue decreases dramatically from the bottom of cycle 20 to the top of its lower unit. This decrease in insoluble residue reflects an increase in carbonate content. The increased carbonate content and bioturbation likely reflects decreasing bathymetry.

In cycle 20 the mottled nature and thickness of the carbonate beds increases up-section. The slabby slope eventually grades into a highly bioturbated carbonate cliff (upper unit of cycle 20). This thick unit (41 m) of mottled carbonate mudstone is interpreted to be the end of the Highstand System Tract and the beginning of the next Lowstand Systems Tract.

Approximately 20 m above the base of the cliff is a horizon containing stromatolites. Kepper (1974) described an antipathetic relationship between Cambrian trilobites and stromatolites. Kepper (1974, p. 141) states, "Under normal salinity conditions trilobites were abundant and algal stromatolites absent. Along the margins of hypersaline pools within the carbonate bank stromatolites flourished. Salinity conditions there were unfavorable for trilobites and other bottom-dwelling invertebrates."

Vorwald (1984) states that the lithofacies in the upper Wheeler Formation represent deposition in a shallow subtidal lagoon on the lee side of a high-energy shoal. It is possible that a decrease in trilobite density occurring in the upper Wheeler Formation might reflect increasing salinities occurring within the subtidal lagoon. The high salinities may have been caused by poor circulation arising from irregular topography occurring in the Drum Mountain area. The irregular topography would have been a result of differential sedimentation and subsidence rates occurring within the nearly filled House Range Embayment. The normal fault, which facilitated the HRE, might have been a cause of the irregular topography. The normal fault also may have caused the southeast variability in shale-bed thickness and stromatolite size, both of which occur in the upper unit of cycle 20.

As described earlier, there is significant lateral variability in the size and shape of the stromatolites. From the road southeast of Sawtooth Ridge (Fig. 4) towards the southeastern edge of the study area, the size and sphericity of the stromatolites increases dramatically. This change in shape may be a result of changing bathymetries. The larger stromatolites would likely have been deposited in a deep tidal or shallow subtidal environment. The smaller stromatolites to the north would have been deposited at decreased depths. This rapid southeastern bathymetric gradient can easily be explained by the presence of the northeast-southwest trending normal fault that initially formed the House Range Embayment (Rees, 1986).

Upper Sequence Boundary

The stromatolite horizon is interpreted to represent the minimum lowstand of relative sea level and is therefore considered to be the upper Sequence Boundary. This stromatolite horizon marks the end of the sequence occurring in the Wheeler Formation. It also is interpreted to represent the approximate complete filling of the House Range Embayment in the Drum Mountains area.

Above the stromatolite horizon is a sudden lithofacies transition from shallow-water carbonates to deeper-water, fissile shale. This contact is not only interpreted to represent the next Transgressive Surface but also the contact between the Wheeler and the Pierson Cove Formations.

R-Mode Analysis

The R-mode analyses performed on the four fossil groups occurring in the Wheeler Formation support the idea that the lower Wheeler Formation was deposited in a relatively deep environment and that the upper Wheeler Formation was deposited in a relatively shallow environment.

The R-mode analysis (Fig. 17) shows that the polymeroid and brachiopod community occurs separately from the agnostoid and sponge spicule community. Robison (1972) states that non-agnostoid trilobites are most common in neritic environments and agnostoid trilobites are most commonly found in oceanic environments.

Three Different Orders of Cyclisity Within the Wheeler Formation

The twenty cycles previously described are the highest order of cyclisity observed in this study. They can be superimposed onto two different lower orders of cyclisity. The lowest order of cyclisity occurring in the Wheeler Formation is a single cycle that spans from the lower sequence boundary in the upper Swasey Formation to the upper sequence boundary in the upper Wheeler Formation. Between these two cycle orders is a less obvious intermediate cycle order.

Figure 19 shows insoluble residue data in the Wheeler Formation. The left-most graph is data derived from the lower units (shale) of each of the twenty cycles. There are three distinct data spikes in insoluble content occurring in the lower Wheeler. The first is at the Swasey Wheeler contact (97.6%), the second is at the base of cycle 7 (80.4%), and the third is at the base of cycle 11 (87.2%). These insoluble residue spikes approximately coincide with the bases of the retrogradational (cycles 1-6), aggradational (cycles 7-12), and progradational (cycles 13-20) cycle-stacking patterns described earlier. I interpret these three data points to be eustatic signals. Specifically, each of the three spikes is interpreted to represent the deepest facies of a 4^{th} order, eustatically-driven cycle. In contrast, at least some of the 5^{th} order cycles might not have been caused by eustacy.

Possible Cause of the 5^{th} Order Cycles

Beyond its anomalous thickness, the stratigraphy of the Wheeler Formation in the Drum Mountains is different from that in Marjum Pass, Wheeler Amphitheater, and the Fish Springs Range. The well-defined, 5^{th} order, meter-scale cycles in the southeastern Drum Mountains are not found in the other three localities (personal observation). The facies transitions in the other localities are much more gradational. They generally lack the well-defined parasequence structure found in the Drum Mountain locality.

One possible cause of this phenomenon is that each of the Wheeler Formation localities was deposited at a different bathymetric depth within the House Range Embayment. If an environment was deep enough, it is possible that the sediments may not have recorded some eustatic oscillations (i.e. "missed beat"). According to the geometry of the House Range Embayment (Rees, 1986), the Wheeler Formation in the Marjum Pass locality would have been deposited within the trough axis of the HRE and, therefore, at the greatest depth (relative to the other three localities in question). The shales in the Wheeler Formation at Marjum Pass are dark, well laminated, and contain abundant agnostoid trilobites and soft-bodied algae. This evidence supports the hypothesis that the Wheeler Formation at Marjum Pass was deposited at great depth.

The Wheeler Formation at the Wheeler Amphitheater is farther north, and, presumably, farther away from the trough axis of the HRE. This locality contains a great number of well-preserved polymeroid trilobites, which indicates that it was deposited at decreased bathymetries. This locality, however, does not contain the well-defined cycles found in the Drum Mountains locality (personal observation).

The Wheeler Formation in the Fish Springs Range contains dark carbonate rocks in the lower most 1-10 m (depending on which locality in the Fish Springs Range are observed), and then a thick section of yellowish gray shales (very similar to the upper Wheeler Formation in the Drum Mountains). The Fish Springs Range is located the greatest distance from the trough axis (relative to the other three localities), and presumably this facies was deposited at the shallowest depth. Well-defined cycles like those found in the Drum Mountain locality were not observed within the Fish Springs Range.

I propose that each of the meter-scale, well-defined, 5th order cycles within the southeastern Drum Mountains may have been caused by a local, rapid depth increase. The depth increase would have been caused by the rapid down-dropping of a block occurring in the hanging wall of a normal fault. The normal fault would have been that described by Rees (1986). This normal fault facilitated the accommodation space of the House Range Embayment, within which the Wheeler Formation of the Drum Mountains area was deposited (Rees, 1986). According to the nonpalinspastic map of Rees (1986), the fault scarp would have trended approximately northeast and southwest and would have been located southeast of the study area.

During the formation of a normal fault, approximately two thirds of the offset is downdropped and one third is uplifted (Evans, 2000, personal comm.). An uplift of the footwall would have caused an area of the carbonate shelf to be exposed to subaerial processes, including erosion (Fig. 23).

During uplift, a lower slope angle would cause a greater area of the shelf to be exposed. For example, Fig. 24 shows that an uplift of 2 m on a shelf-slope of 0.1 degrees

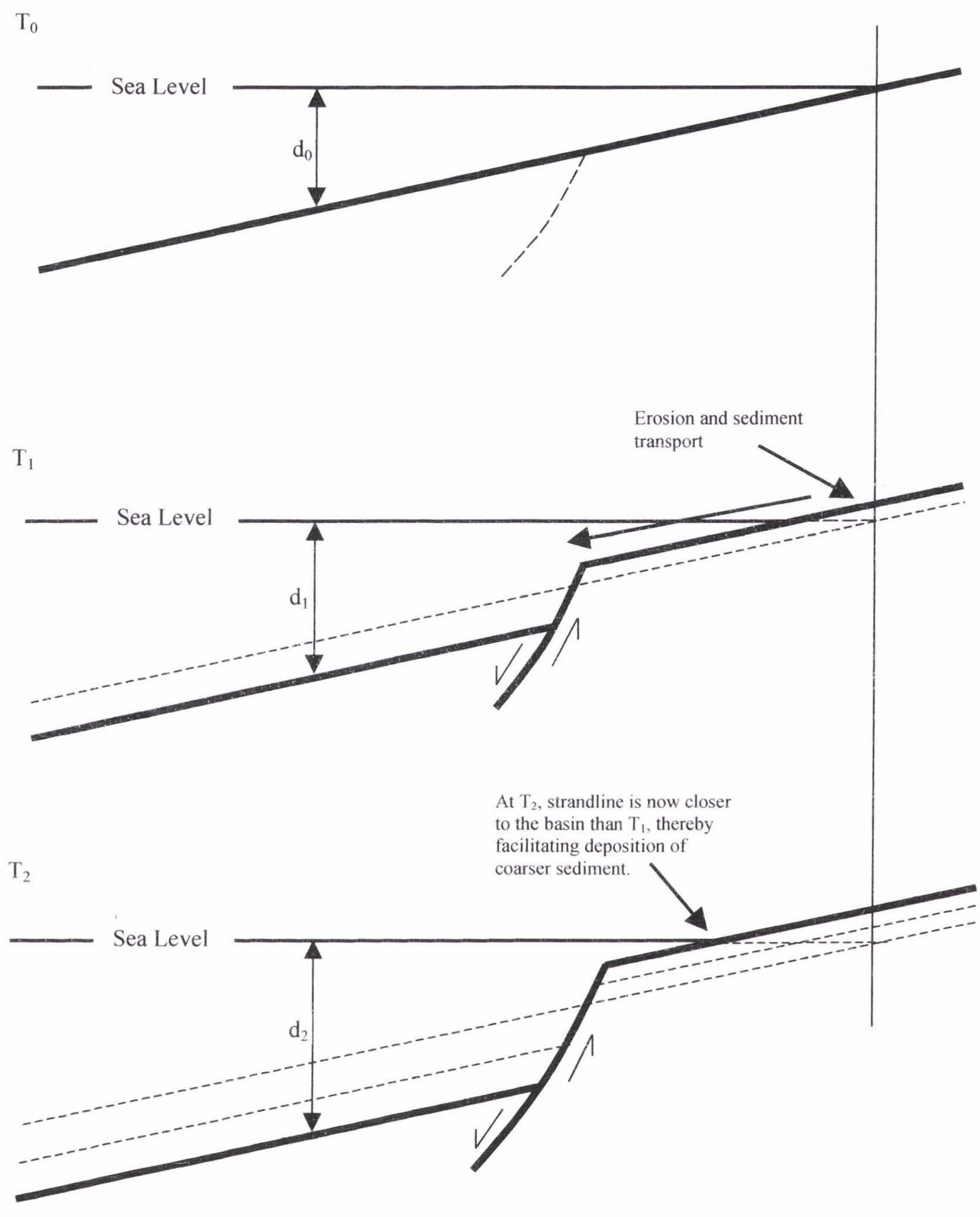


FIGURE 23-Model of how the 5th order cycles in the Drum Mountain's Wheeler Formation might have formed from normal faulting. Note that from $T_0 - T_2$, the strandline becomes more proximal to the basin (T = time interval). Also note that $d_2 > d_1 > d_0$ (d = depth within basin).

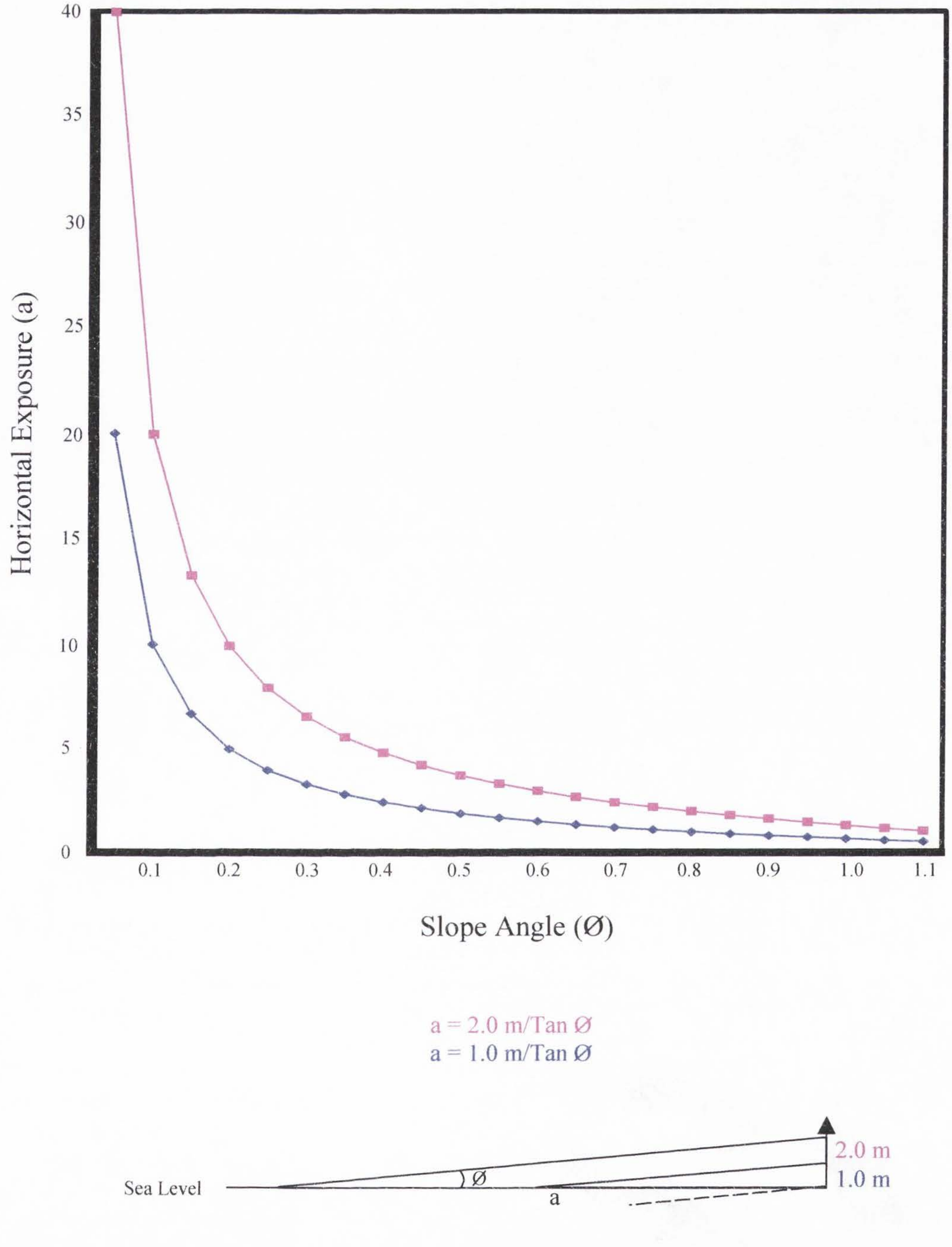


FIGURE 24-Horizontal exposures of a continental shelf with low slope angles (<1.1°) after 1.0 and 2.0 m vertical offsets.

would cause a horizontal distance of 40 m to be exposed. Elevating the shelf would cause the strandline to move closer to the fault escarpment (Fig. 23). It would also drop the relative base level of the ocean. As a result, fluvial systems would incise the shelf and erode the exposed carbonate strata. Sediment would then be transported across the exposed shelf towards the new strandline. Eventually, sediment would be transported across the fault scarp and into the basin. Deposition of the 5th order, shallowing-upward cycles would be controlled by erosion, transport, and other sedimentary processes occurring on the shelf.

During the Late Precambrian and Early Cambrian, rifting occurred in the western margin of North America (Christie-Blick, 1984). During the Middle Cambrian this region was undergoing post-rifting thermal subsidence (Christie-Blick, 1984). This thermal subsidence and faulting is the proposed mechanism that drove the 5th order relative sea-level oscillations.

Sea Level Model

Figure 25 is a sea level model that displays the relationship of the three orders of cyclisity occurring in the Wheeler Formation. The relative water depths to which the facies are assigned came from Bond et al. (1989). Grannis (1982) evaluated the deposits of the Wheeler Formation in the Drum Mountains and suggested that the maximum local depth of the House Range Embayment was 200 m.

Figure 26 is the same sea level curve found in Fig. 25, but it is turned on its side and correlated with a lower-order sea-level curve encompassing the entire Middle Cambrian. This lower-order curve is from Bond et al. (1989). The data for this lower-

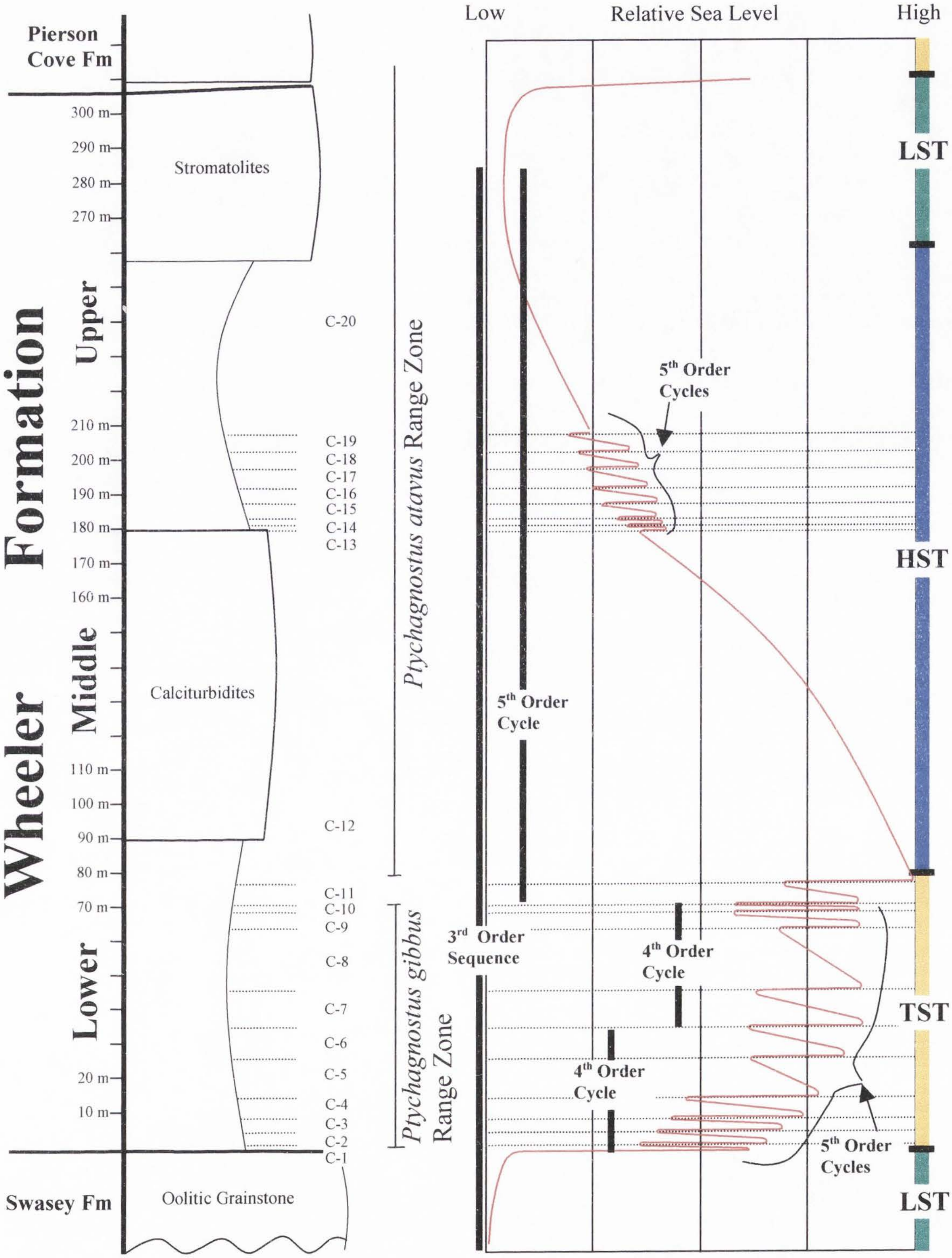


FIGURE 25–Sea level model of the Wheeler Formation in the Drum Mountains. Note the distribution of the system tracts and three orders of cyclisity.

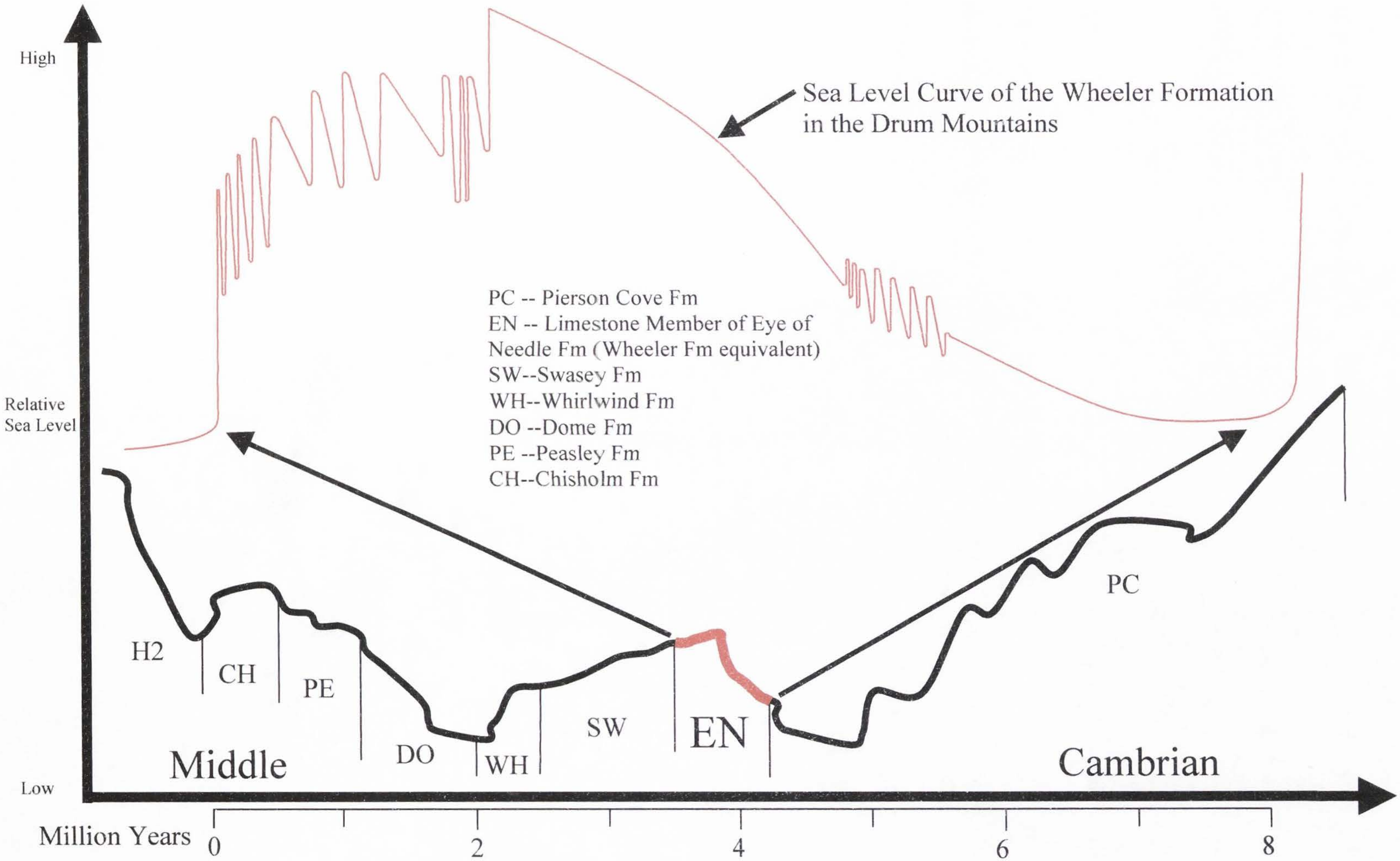


FIGURE 26–Sea level curve of the Drum Mountains Wheeler Formation correlated with the Middle Cambrian sea level curve of Bond et al. (1989).

order curve were derived from the Wah Wah Range, which is approximately 100 km southwest of the Drum Mountains. At this locality the equivalent of the Wheeler Formation is called the Eye of the Needle Formation. This unit is dominantly a clean carbonate that lies conformably between the Swasey and Pierson Cove Formations.

According to the time scale of Bond et al. (1989), shown at the bottom of Fig. 26, deposition of the Eye of the Needle Formation, and therefore the Wheeler Formation, is shown to have occurred during a million-year interval. Vail et al. (1991) suggest that 3rd order depositional sequences occur during a 0.5-5 million-year interval. Therefore, the time interval represented by the Wheeler Formation is within the limits of a 3rd order depositional sequence. I interpret the Wheeler Formation in the Drum Mountains to have been deposited during a 3rd order sequence, and therefore the higher order cycles are 4th and 5th order.

In contrast, the Middle Cambrian sea-level curve of Bond et al. (1989) (Fig. 26), shows a 3rd order sequence starting from the base of the Whirlwind Formation and ending near the base of the Pierson Cove Formation. As a consequence, the Eye of the Needle Formation, and therefore the Wheeler Formation, is shown to only represent a component of that 3rd order sequence. However, in this analysis a sequence boundary, transgressive surface, and maximum flooding surface were identified within the Wheeler Formation in the Drum Mountains. These three surfaces separate systems tracts, which are the major subdivisions of a 3rd order depositional sequence (Vail et al., 1991). It is possible that the analysis of Bond et al. (1989) may have been too coarse to identify sequence boundaries and other sequence stratigraphic surfaces occurring in the Eye of the Needle Formation.

Trilobite Range Zones in the Wheeler Formation

Figure 2 shows four trilobite range zones occurring in the Wheeler Formation. The transition between the *Bolaspidella* and *Oryctocephalus* open-shelf, polymeroid-trilobite range zones occurs in the lower Wheeler Formation (Robison, 1976). The transition between the *Ptychagnostus gibbus* and *P. atavus* open-shelf agnostoid trilobite range zones also occurs in the lower Wheeler Formation (Robison, 1976).

Two important chronohorizons that can be used to correlate strata in the eastern Great Basin (and worldwide) are the base of the *Ptychagnostus gibbus* and *P. atavus* range zones (Rowell et al., 1982). Rowell et al. (1982, p. 161) state that "the base of the *P. atavus* Zone is a superior biohorizon for chronocorrelation because it is typically present in monofacial strata, whereas the *P. gibbus* Zone commonly occurs above an unconformity or an abrupt lithofacies change."

The base of the *P. gibbus* range-zone occurs at the contact between the Swasey and Wheeler Formations (Rowell et al., 1982). According to Rowell et al. (1982), in the Drum Mountains, the base of the *P. atavus* range-zone occurs at 71 m above the base of the Wheeler Formation. In this analysis, the base of the *P. atavus* range-zone occurs at the agnostoid-condensed zone (cm-thick coquina bed of Rowell et al., 1982) in the lower unit of cycle 12 (Fig. 10), which is 76 m above the base of the Wheeler Formation.

The base of the *P. atavus* range-zone in the Wheeler Amphitheater, just southeast of the U-dig trilobite quarry, was found to occur very low in the section, approximately 20 m (Fig. 28, Appendix B) above the base of the Wheeler Formation at the first fossiliferous, tan shale ledge.

The base of the *P. atavus* range-zone at Marjum Pass was also found very low in the section, approximately 15-20 m above the base of the Wheeler Formation in gray, platey shales, occurring below the concretion horizon. According to Rowell et al. (1982), the base of the *P. atavus* range-zone at Marjum Pass occurs at 27 m above the base of the Wheeler Formation. The base of the *P. atavus* range-zone in the Fish Springs Range was not identified.

SUMMARY AND CONCLUSIONS

(1) The stratigraphy of the Wheeler Formation in the southeastern Drum Mountains has not been structurally doubled. The seemingly "anomalous" thickness can be attributed to sedimentation and not to tectonics.

(2) The facies of the three informal members in the Wheeler Formation in the Drum Mountains indicate a conformable eustatic sequence. During the deposition of the lower member there was rapid and then gradual deepening of relative sea level. The calciturbidites of the middle member were shed from the carbonate platform during maximum highstand. The shallowing facies of the upper member were deposited during the end of the highstand and beginning of the next lowstand of relative sea level.

(3) In this sequence stratigraphic analysis there are twenty distinct 5th order cycles, which are superimposed unequally within three, indistinct 4th order cycles. These three 4th order cycles are superimposed on to a single 3rd order depositional sequence.

(4) At least some of the 5th order cycles may have been caused by local normal-fault-induced, down-dropping events. These events were likely related to the evolution of the House Range Embayment. This study enables the evaluation of the effect of tectonics (faulting) versus global eustacy on the sedimentary regime occurring within the Middle Cambrian House Range Embayment

(5) The cycles and surfaces defined in this sequence stratigraphic analysis were likely deposited within short intervals (20^4 to 40^5 ky) of geologic time. These sequence stratigraphic surfaces, and the base of the *Ptychagnostus atavus* and *P. gibbus* range-

zones, can be used to correlate strata occurring in other localities in the eastern Great Basin.

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APPENDIXES

Appendix A

Geochemical Data

TABLE 2–Geochemical data in lower units of cycles 1-20 in the Wheeler Formation.

CYCLE #	% ORGANIC CARBON	% INSOLUBLE RESIDUE
upper unit, cycle 20	1.20	20.0
20	3.86	57.0
15	1.74	11.4
13	0.56	1.6
upper middle Wheeler Fm	0.78	2.4
middle middle Wheeler Fm	0.58	1.8
12	2.34	28.4
11	3.02	87.2
10	2.38	25.6
9	2.60	34.2
8	0.76	7.4
7	3.44	80.4
6	0.66	6.0
5	0.80	19.0
4	2.46	45.2
3	2.74	39.0
2	1.86	27.4
1	4.36	97.6
top of Swasey Fm	0.60	5.2
sequence boundary	0.58	0.4

TABLE 3-Geochemical data in upper units of cycles 1-20 in the Wheeler Formation.

CYCLE #	% ORGANIC CARBON	% INSOLUBLE RESIDUE
20	0.78	6.6
19	0.92	5.8
18	1.28	17.8
upper middle Wheeler Fm	0.78	2.4
middle middle Wheeler Fm	0.58	1.8
11	1.02	6.8
10	1.32	6.2
9	0.66	5.4
8	0.84	7.8
7	0.74	4.0
6	1.04	4.8
5	0.82	4.4
4	0.48	3.8
3	1.26	14.6
2	0.88	7.8
1	0.56	4.2
top of Swasey Fm	0.6	5.2
sequence boundary	0.58	0.4

Appendix B

Stratigraphy

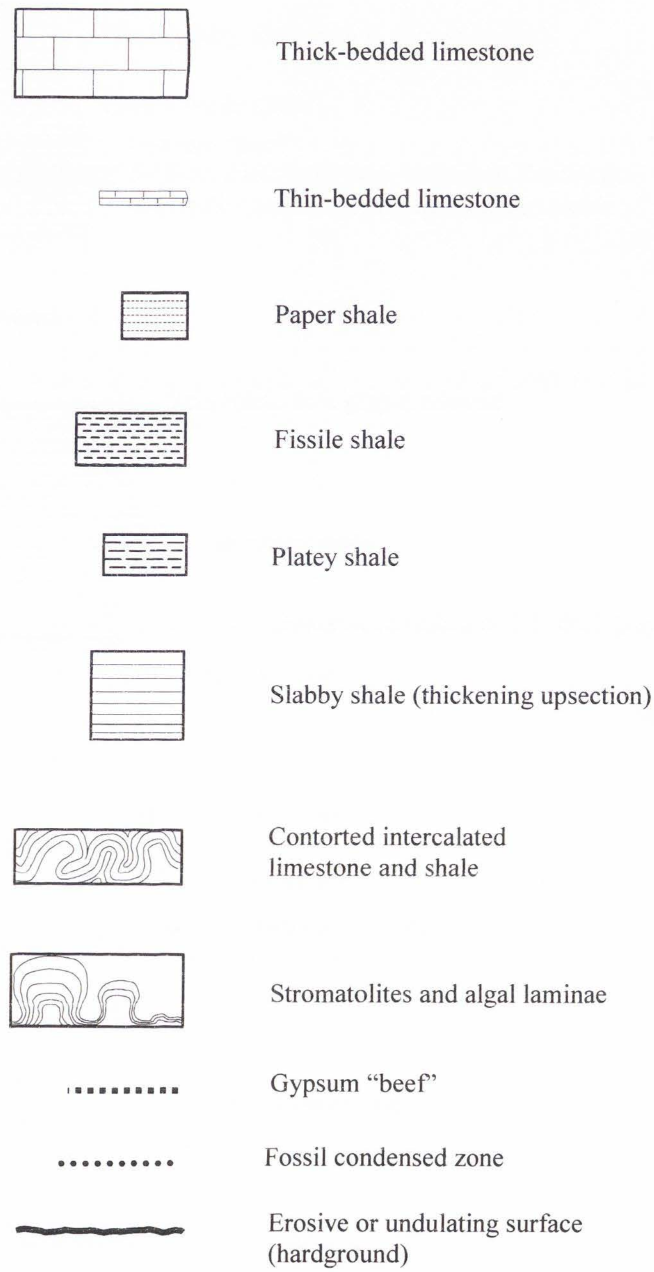

FIGURE 27-Key for stratigraphic symbols.