2012

Examining the Molluscan Biostratigraphy of the Upper Cretaceous Judith River Formation, Montana

Julie Amundsen

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Examining the molluscan biostratigraphy of the Upper Cretaceous Judith River Formation, Montana

By:
Julie Amundsen

Submitted to the University of North Dakota
In Partial Fulfillment of the Requirements for Graduation
Grand Forks, North Dakota
05/10/2012
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ACKNOWLEDGEMENTS

This thesis probably would have not been accomplished if it were not for the help that I have received from many of the people in the geology department. It was their knowledge and support that helped me persevere and see this project through to the end.

I would like to personally acknowledge and thank the advice and guidance of Dr. Joseph H. Hartman, my advisor from the geology department. Dr. Hartman helped me with a thesis topic and has been there every step of the way to answer my endless list of questions. He taught me the basics of paleontology of which I had no experience or knowledge. With providing the documentation from previous geologist who had studied the Judith River Formation, Dr. Hartman helped me formulate questions and hypotheses. Dr. Hartman provided the opportunity for a group of us to be able to travel to the Judith River Formation in Montana and start a collection of fossils for my thesis and for the University of North Dakota. Dr. Hartman took on the responsibility and submitted himself for reading and rereading draft after draft, helping correct the typos, inaccuracies or simply helping me restate ideas. If it were not for his help, his knowledge, and his patience, this thesis probably would not have been accomplished.

Collection of fossils in 2010 would not have been conveniently possible without the kind assistance of Dr. Raymond R. Rogers of Macalester College, Saint Paul, Minnesota. Dr. Rogers facilitated the permit process to the Missouri Breaks National Monument directed the crew to know fossil localities.

I would also like to thank everyone who went on the Montana trip to the Judith River Formation. Without the help of Art Cogan, Angelle van Oploo and Don McCollor, I would not have had a chance to collect as many fossils as I was able too. With their help we were able to put together a fossil collection that I could come to what I feel are accurate conclusions. Also all of them helped me document the trip with photographs, descriptions, and proper documentation. Thank you to Dr. Art Bogan, Angelle van Oploo, and Don McCollor.

I would also like to thank everyone who helped me with the editing and reviewing of my final paper. These people were able to edit my many drafts and help me out in areas that needed fixing. Thank you to Katie Hansen and Cullen Donohue.
ABSTRACT

The "Judith River beds" were discovered by F.V. Hayden in 1855. F.B. Meek helped classified the specimens that Hayden had collected. In the documentations Meek and Hayden, the specimens were collected from the "Judith River Badlands." There was no documentation on where in the Judith River Formation the specimens were collected by Hayden. Subsequently, Stanton and Hatcher (1905) collected specimens from the Judith River Formation and documented where in the formation the specimens were located. Correlating the distribution of the species identified by Stanton and Hatcher could lead to a hypothesis of where in the Judith River Formation Hayden had collected what became type specimens. Examining the published literature on the Judith River Formation was Phase 1 of this project. Phase 2 consisted mainly of field work in the Judith River Formation in north-central Montana. Phase 3 was the examination of fossil specimens brought back to the lab. A new species was discovered on the 2010 expedition. Tables were created based on available data from Stanton and Hatcher (1905) and Russell (1964), Meek (1876) and White (1883) drawings (compiled in Hartman 1987) and photographs of the new specimen were assembled into plates. This study indicates that Meek and Hayden's fauna have a discrete biostratigraphic pattern within the Judith River Formation. There are key species that help establish the biostratigraphic framework.

INTRODUCTION

F. V. Hayden first described the Judith River beds in 1855. The Judith River Formation was formally named in 1869 and published in 1873. At this time, new geologic discoveries were being made all across the western United States. These discoveries were documented by many different scientists. Naturally, the documentation was in different formatting and different styles. Some documents contain information that other documents do not contain. Some geologists provided a substantial amount of information, while other geologists did not provide enough. Failure in documenting everything that could be stated properly could result in poor documentation for further readers. While reviewing Hayden's work, a rather large dilemma started to develop. There was no documentation on the stratigraphic location of the taxa that Hayden had discovered in the Judith River Formation. Publication entries were found on the specimens overall location in the present state of Montana, but very little was stated about where
the taxa were excavated from within the formation itself. The Judith River Formation is on average 160 m in thickness (Russell, 1964).

F. B. Meek did not go out into the field with Hayden to describe the Judith River Formation. Meek examined the fossils that Hayden brought back and Hayden provided assisted in the naming of the taxa. The descriptions that Meek provided on the specimen were thorough. Meek's (1876) publication of these specimen included line drawings and detailed descriptions. A great deal can be learned from Meek's descriptions, but not of the species' stratigraphy.

Hayden was not the only geologist that studied the Judith River Formation. Other geologists, such as Stanton and Hatcher (1905) traveled to north-central Montana and collected specimens from the same area examined by Hayden. Stanton and Hatcher (1905) were more specific about where they fossils were collected. Thus the stratigraphy range of the species they identified could assist in a biostratigraphic framework upon which could be compared to Meek and Hayden's species. These later geologists went back to the Judith River Formation and collected many specimens. In doing so, they were able to provide better documentation, including descriptions of the specimen that were found and where stratigraphically they had excavated them.

PURPOSE OF INVESTIGATION

Fossils were collected by Hayden from the strata that Meek and Hayden referred to as the Judith River Formation. Most of the fossils reported by Meek and Hayden (1856) were documented from the "Judith River Badlands." The exact location of the species is thus unknown. This is true for almost all of the species collected by Hayden in the Judith River Formation. Almost all of the described fossils represent new for species or other important reference specimens.

The stratigraphic horizon from which a specimen was collected is an important part of fossil documentation, and not knowing where a specimen was collected raises questions for the environment that the specimen lived in. Vital information can be obtained the surrounding sediments and faunal association. When the stratigraphic horizon is unknown, there is no way to understand this concept.

Questions that should be asked concerning the fossils collected by Hayden:

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1. Can the geographic location or type area of any of Hayden's species be determined from the existing data from other geologists?

2. Can the stratigraphic position of any of Hayden's species be determined from this existing data?

Comprehensive existing data is represented primarily by Stanton and Hatcher's (1905) study of the Judith River Formation fossils in Montana and Alberta. This project is relevant in that they reported relative position of their fossils within the Judith River Formation.

Thus the questions can be asked: Do Meek and Hayden's Judith River Formation species have variable stratigraphic distribution within the formation? If so, was the collection of fossils made by Stanton and Hayden sufficient to detect this stratigraphic variation?

Paleontologists could argue that if the average continental molluscan species age is about 5 million years, suggesting that recognizing biostratigraphic distribution of species within the Judith River Formation is unlikely. However, if species are found to have discrete biostratigraphic ranges within the Judith River Formation, biostratigraphy within the Judith River Formation could be possible.

THE JUDITH RIVER FORMATION

GEOLOGIC HISTORY

Judith River Formation sediments were deposited in the Upper Cretaceous, specifically during the Upper Campanian, between about 77.05 Ma to 83.5 Ma (GSSP, 2009). Goodwin and Deino (1989) recently dated the Judith River Formation from a site in Hill County, Montana, as 78±0.2 to 79.5±0.2 Ma. During the deposition of Judith River Formation sediments, the middle of the North American continent was inundated by a transgressing and regressing Western Interior Seaway. The deposition of marine and brackish water sediments is directly related to seaway activity and the somewhat lower latitude of the continents at the time. The majority of the mollusks known from continental environments, representing, rivers, lakes, and terrestrial settings, but the lower and upper members of the Judith River Formation contain brackish and
marine fossils. At the end of the deposition of the Judith River Formation, the Western Interior Seaway transgressed one more time, laying down marine sediments of the Bearpaw Formation.

HISTORICAL BACKGROUND

The Judith River Formation crops out in northern Montana, southwestern Saskatchewan, and southeastern Alberta (McLean 1971). The formation was formally named in 1871 by Dr. F.V. Hayden in the “Preliminary report [fourth annual] of the Geological Survey of Wyoming and portions of contiguous territories” for “exposed strata near the mouth of the Judith River.” The Judith River Formation is best known in northern Montana. Essentially equivalent age strata occur in southwestern Saskatchewan and southeastern Alberta, Canada. The strata in this part of Canada are known as the Belly River Group (Dowling 1917). These strata were named by Dawson (1883; “Belly River series”) for the exposed bed that were located along the Belly River, now known as the Oldman River in southern Alberta. Dawson failed to recognize the Claggett Shale, now known as the Pakowki Shale, that underlies the group. This created stratigraphic confusion across the region. After Dawson’s introduction of the Belly River series, many geologists followed suit and correlated these beds across Canada.

The first excavation of fossils from this formation occurred in 1855 by Hayden. Specimens were subsequently also collected from the type Judith River Formation by E. D. Cope in 1876, and White (1877) named molluscan species from Cope’s collection. Meek and Hayden’s and White’s new species make up the core molluscan fauna from the type area of the Judith River Formation.

Other geologist collected fossils from the fossil-rich layers of the Judith River Formation. After Cope and White, Stanton and Hatcher (1905) provided the stratigraphic horizons on which the specimens they collected were located. Again, in 1940 and 1964, Russell published on the equivalent age fossils in Alberta and Saskatchewan and provided stratigraphic horizons from which the species where known.

OVERVIEW OF PREVIOUS STUDIES

There were quite a few paleontologists that studied the Judith River Formation. The first and most famous of these geologists were F.V. Hayden and F.B. Meek. In 1855, as stated before, Hayden went on an excavation to central Montana and started a collection of the continental and
brackish mollusks. These mollusks were collected near Judith River, presumably on Dog Creek and other tributaries of the Missouri River to the east (Eberth 2005). A few years later, Cope, a vertebrate paleontologist from Philadelphia and illustrated the stratigraphy and his collecting areas in the Dog Creek area. Cope’s collections were analyzed by Charles A. White, who provided names for new taxa not classified by Meek.

White (1883) preferred to use the Belly River Series instead of the Judith River Formation. From 1903 to 1905, Stanton and Hatcher had a closer look at the relationship between the Judith River and Belly River strata in Montana and Canada. Stanton and Hatcher (1905) correlated Dawson’s “Belly River Series” by establishing the stratigraphic succession (youngest to oldest): the Bearpaw Formation, Judith River Formation, Claggett Formation and the Eagle Formation (Stanton and Hatcher 1905). All formations crop out by the Milk River in Montana (Stanton and Hatcher 1905). The correlation proved that the Judith River Formation was the first and correct name for the strata in the Montana sequence.

LITHOLOGY, SEDIMENTOLOGY, STRATIGRAPHY

The Judith River Formation is overlain by the Bearpaw Formation, a marine shale formation that was deposited at the end of the Cretaceous (Eberth 2005). The underlying formations differ in Montana and the provinces of Saskatchewan and Alberta. In Montana, the Judith River is underlain by the Claggett Shale. In Alberta, the Belly River Group, consisting of the Oldman and Foremost Formations, is underlain by the Pakowki Shale (Eberth 2005). Throughout this region there are inconsistencies of the stratigraphic names. Geologists went out into the north central part of the country and named the formations without seeing if the formation had been named before. There were also correlation issues as well. What one geologist thought was a new formation was a portion of another formation that had already been named.

Stanton and Hatcher (1905) recognized the difference between the Belly River Group and the Judith River Formation. The latter consists of: sandstone beds, with interbedded darker shale and clay beds. There are frequent lignite beds, consisting of brown coal. The lignite in this formation reaches a thickness of several feet. The upper part of the formation includes brackish shell banks, anywhere from a foot to three feet thick (Stanton and Hatcher 1905; 2010 observations). Stanton and Hatcher (1905) observed that the brackish beds that are similar to the freshwater sedimentary
deposits that contain freshwater mollusks. The contact between the Judith River Formation and overlying Bearpaw is quite distinct, as shown at the 2010 field study area (Hartman and others, 2010, unpublished).

The Belly River Group

PRESENT FIELD WORK AND MOLLUSCAN STUDIES

ANALYSIS OF COLLECTIONS

Dr. Joseph Hartman had earlier collected and borrowed continental mollusks from the Judith River Formation from northern, Montana, in the vicinity of Havre. The fossils were borrowed by long-term studies on vertebrates by University of California—Berkeley. In 2010, a Hartman crew from the University of North Dakota, in cooperation with Dr. Ray Rogers of Macalester College, also excavated fossils from the Judith River Formation in Fergus County, Montana.

The Berkeley mollusks were sorted into different general morph trays; one for the elliptical-shaped bivalves, one tray for the triangular shaped bivalves, and one tray for the gastropods. Once observing the different shapes and patterns for each shell group, the fossils were further sorted by shape and size. The gastropods were sorted by the whorl direction, dextral vs. sinistral. Classification of the Berkeley mollusk species followed. Dr. Hartman provided a document, Preliminary Guide to the Mollusca of the Judith River Formations (1987), of the various bivalves and gastropods found in the Judith River Formation and its equivalents. The classification occurred through examining the specimen and comparing them to Dr. Hartman’s guide to reach a respectable conclusion to the species name.

After the Berkeley collection was organized and classified, I went to Macalester College in Minneapolis, Minnesota, to discuss the mollusks with Dr. Roy Rogers, a stratigrapher, sedimentologist, and vertebrate taphonomist. His studies had given him the opportunity to collect a wide variety of vertebrate and invertebrate specimen. He let me examine a few of the specimen that he found, as well as package them up to take back from the University of North Dakota to expand the UND collection. Many of these specimens that Rogers had collected were very small and delicate mollusks. The specimen had to be sifted out of the sediments very carefully and
very slowly. Once the specimens were sifted out of the sediments, I was able to take a closer
look at them and gather them into containers to bring back safely to North Dakota.

**ANALYSIS OF ORIGINAL MANUSCRIPTS**

Examining specimens from the Judith River Formation was only a part of the research that
needed to be done. Looking at the original papers allowed me to put together a part of the puzzle
about the stratigraphy of Hayden’s species already noted. Just looking at fossils does not provide
the depositional environment or any of the history associated with that section of land. Only a
certain kinds of ecological information can be learned from fossils. The in situ environments also
provide important information, which can be accomplished to some extent from previous studies
and field work. Hayden, Meek, Cope, White, and Dawson provided limited context specific to
fossil taxon.

**MONTANA FIELD WORK**

In August, 2010, a small group of students, including me, and professors travelled to north­
central Montana to study the Judith River Formation species. The camp site was located about
thirty miles east northeast of Winifred, Montana, at N47° 42.8047’, W109° 23.269’, in the
Missouri River Breaks National Monument. There were several different sites that needed to be
examined. As indicated, the Judith River Formation in the study area is divided into three parts, a
lower marine—brackish unit known as the Parkman Member, the main body continental facies,
and the overlying unnamed brackish member. The first site, L6916-L6923, investigated was
from the upper brackish member. The site is located some distance off the Stanford Ferry Road.
The 9-ft thick shell bank is a coarse breccias and well- compacted. We collected specimens from
six sites along the outcrop. This unit is the local top of the section.

Collecting specimens was a new experience for me and, at times, a very long process. A few of
the specimen were collected in blocks to be brought back to the lab. Because the rock was so
well compacted, retrieving fossils was difficult at times. Rock hammers were used to loosen the
rocks and that gave us the ability to look more closely at the specimen. A surface survey was
done at the beginning of the excavation. This provided the opportunity for everyone to examine
areas in which they would start to dig.
Along an exposure of a specific horizon, students worked specific pits, each under individual numbers, to look for differences in depositional composition. Specimens were collected in place and from the loose sediment disturbed. Every retained specimen was wrapped and put into plastic bags while out in the field. The specimen and bags were labeled with premade Write-in-Rain labels that included waypoint number, location number, location, date, stratum, collectors, and other basic data. In field books, longitude and latitude were recorded, along with the stratigraphy and photographic information about horizon excavated.

Other sites collected from were accessed from the Power Plant Road in the Heller School area. Some recent local name changes make the quadrangle names no longer valid. A fifteen minute hike or so will reach the first location; an additional ten minutes will gain the second and third locations in this area.

The first location in the Heller School area, L6924, is where the majority of the large elliptical clams were collected and was visited multiple times. The sediment here are much less carbonate rich than the oyster bank and thus notably easier to work through the rock. It was still well compacted and require considerable effort to retrieve large blocks to get nearly complete large bivalves. The fossils were more brittle (subject to exfoliation) and easily fell apart. Glue had to be used to keep the fossils intact. Large rock picks were used to extract boulders with the fossils enclosed in them. The boulders were chipped down to smaller blocks of rock. Some of the rocks were wrapped in tin foil and brought back to camp as blocks, and other blocks were picked apart to retrieve the fossils. Using various chisels and rock hammers the fossils were removed from the sediment. Half a day was spent at this location before moving on to the next.

The second site contained a few sights, L6926b, L6926c, and L6927a-d, we excavated in this area was about a two hundred meters east of the bivalve locality (L6924). The sediment changed drastically from the previous site to this site. This site had very loose sediment with virtually no cement that made excavating much simpler. We used shovels to move past the weathered fossils and top soil. The overall taxa found at this site changed drastically as well. Before they were very sizable clams ranging from about four centimeters to about fifteen centimeters. The species found here were more snails and small clams and they were minuscule compared to our previous
finds. The third site associated with the Heller School area, L6926a, was located a few meters away from the second group of sites.

The fourth site, L6928, in the Heller School area was about 100 m east of the second sites. This is where most of the time was spent collecting specimen. At this site Dr. Hartman found a very large viviparid snail. This species had not been discovered and was an exciting find. Several specimens of this large snail were found by the crew, some in good condition and some in poor condition. Many snails and sphaerids were recovered from this location from a number of pits.

There is one more main quarry that was worked in this area. Not very many specimen collected from the previous areas were small clams. In order to see the overall picture of what was happening at this time in the Cretaceous, a wide spectrum of fossils needed to be collected. A small clam bed was found meters away from the large snail site. The smaller the clams were, the harder it to successfully retrieve them from the rock. Much glue was needed to protect the findings and be able to transport the specimen back to the lab in Grand Forks, North Dakota. Prospecting occurred while the small clams were excavated. Interesting float specimens of “Anodonta” and “Viviparus” were found. The producing sites, however, could not be located. Bags of loose sediment were also packed up and brought back.

LAB PROCESSES

After the Montana trip, all of the specimens were brought back to Leonard Hall at the University of North Dakota, Grand Forks. The specimens were unpacked and sorted. Bags of sediment were set aside for sifting through and specimens that needed cleaning were also set aside. Different colored paper labels were made with the waypoint, locality numbers, and collectors, and placed with every specimen to help with organization. Once organized and sorted, the blocks of fossils were unpacked to be processed. The blocks contained many specimens. Extracting specimens without damaging them was a difficult process. The specimen had to be glued and then the rock had to be cut apart. Most of the specimens that were gathered from the blocks were the very small finger nail clams.

The bags of sediments that were brought back had to be sifted through to be able to collect any of the fossils that were in the sediments. In order to do this, different sized sifters were placed
one on top of the other. The larger screen dimensions were located at the top of the stack and the smallest screen opening at the bottom. This allowed for different sized specimen to be sorted out from the smaller ones and the very fine-grained sediments to be sifted through all of the screens. The stack of screens was placed in a bucket of water so the loose sediment could filter through to the bottom. When the sifting was done, the screens were removed from the water and each screen was individually placed on paper towels within plastic trays upside down. This allowed the contents of what were caught to dry out. Once the entire tray was dry, sorting had to occur. Among the debris of broken shells were very small snails. Because small clams are so delicate and usually broken upon excavation, no small clams were collected from the loose sediment. After sorting out the snails from the shell fragments, some were examined under a microscope to better understand their morphology.

Well preserved specimens were photographed. If the specimen was larger, a normal camera was used to take a variety of views. The first picture was of the colored paper label that provided the information of where the specimen was found. Subsequent photos were of the specimen in different orientations with mm bar scale. For each specimen picture, the exposure of the lens was changed. Different lighting gives the viewer the opportunity to see different characteristics of the shell. Some characteristics can only be seen in low exposure while other characteristics in a higher exposure. Other than different exposures, the specimens were photographed in different positions. This also provides more information about the specimen than being able to see one view. With clams, mussels and oysters, photographs of the outside of the shells were taken as well as photographs of the ventral and dorsal views if obtainable. The outside of the shell shows the growth pattern of the shells. One of the more important views of a clam that is rather difficult to provide is the inside of the shell. The interior shell structure gives the viewer a chance to see the hinge and the teeth of the clam. Different species have different hinges and different tooth patterns. Photographing snails is a little simpler. Photographs of snails are usually of the apex, the lateral view, and of the aperture. Sometimes, if it can be seen, the umbilicus is photographed as well.

For the smaller species, a microscope camera is used to compile many layers of photographs together to provide on composition of the specimen. Each photograph that is taken has a different

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level of focus. When all the pictures are compiled together, the result is one clear photograph of the specimen.

RESULTS

The 2010 Montana field trip resulted in a better understanding of the Judith River Formation continental and brackish molluscan fauna. Many species were collected over a wide geographic area of the Judith River Formation. A number of different species were collected. The variety of species represents the biodiversity of the paleolandscape at that specific moment in time. The surrounding sediment helps represent the paleoenvironment. The specimens show the species distribution as well as species populations and which species tended to be more successful in that environment.

The Judith River Formation consists of fluvial and lacustrine sediments, with the majority of the mollusks being excavated from quiet waters. The sediments are very fine-grained which, represents low energy conditions. The fragile shell structure of the mollusks also reflects the low energy of the water. The shells are well preserved, but highly fractured and easily broken.

One of the more common clam species found in Heller School localities is *Sphaerium praecoxum* (Plate 1). These fossils are abundant and extremely delicate and easily broken. The more abundant mussel species seen in the Heller School area was *Lampsilis consueta* (Plate 2). Russell (1964) documented this species from the Oldman Formation, from the upper part of the Belly River Group.

A couple of the most common gastropod species found at the Heller School sites were *Lioplacodes gracilenta* and *Lioplacodes invenusta* (Plate 3). Stanton and Hatcher (1905) and Russell (1964) indicated that these two gastropods occurred in the middle to upper parts of the Judith River Formation.

A new species of viviparid was discovered in the Hell School area. It is similar in structure to *Viviparus nidaga* and *Viviparus conradi*. Stanton and Hatcher (1905) and Russell (1964) documented that *Viviparus nidaga* was present throughout the entirety of the Judith River Formation. *Viviparus conradi* is only known from the upper part of the Judith River Formation. The new species is larger than the more common gastropod species found during the Campanian.
On average, \textit{V. conradi} and \textit{V. nidaga} have 3 to 5 whorls for the same shell size, while the new species ranges from 6 to 8 whorls. \textit{Viviparus nidaga} is about 18–23mm in diameter, while the new species is about 25–30mm in diameter.

**DISCUSSION**

The excavation of the specimens in Montana in 2010 occurred in the upper part of the Judith River Formation. Knowing this stratigraphic horizon of this study and the stratigraphic horizons of Stanton and Hatcher’s fossils and Russell’s fossils, the specimens can be compared to each other. The specimens that occurred in the upper part of the Judith River Formation for Stanton and Hatcher and Russell should appear in the Montana study of 2010.

Tables 1 and 2 in Appendix B were constructed as a result of Stanton and Hatcher’s (1905) study. Table 3 is based on Russell’s (1964) compilation of mostly Canadian data. A study of the table data shows there are similar species seen in same parts of the Judith River Formation from all three studies. This pattern is further supported by the occurrence if the same species that were found on the Montana trip in 2010, as well as not seeing some of the species that have a tendency to appear in the lower part of the formation. If the same species appear in individual sections of the formation, but not in others, that species can be used in proving that biostratigraphy is possible within the Judith River Formation. If all of the species occurred throughout the entirety of the formation, there would not be a difference in speciation from the lower part of the Judith to the upper part of the Judith.

The species that appear to prove most biostratigraphically useful in the Judith River Formation are \textit{Lampsilis consueta} (Plate 2), \textit{Lioplacodes judithensis} (Plate 2), \textit{Lioplacodes gracilenta} (Plate 2), \textit{Anodonta propatoris}, and \textit{Corbula confinisensis} (Plate 3). These species are found in the upper part of the Judith River Formation as determined from Stanton and Hatcher (1905) Russell (1964) and Hartman (2010, unpublished). These species, according the Stanton and Hatcher (1905) and Russell (1964) do not appear in any other portion of the Judith River Formation.

Less useful species are \textit{Ostrea subtrigonalis} (Plate 3), \textit{Rhabdotophorus senectus}, and \textit{Physa copei} (Plate 2). These species occur throughout the entire thickness of the Judith River Formation (Stanton and Hatcher, 1905; Russell, 1964; Hartman, 2010, unpublished).
CONCLUSION

The average continental molluscan species duration is estimated to be about 5 million years. This species’ life expectancy suggests that recognizing biostratigraphic distribution of species within the Judith River Formation is unlikely. However, a biostratigraphic organization of species ranges can be seen through the analysis of observations made by Stanton and Hatcher (1905), Russell (1964), and Hartman and crew (2010) observations and collections.

Recognizing a biostratigraphic organization of molluscan species is possible in the Judith River Formation. Specific species are only seen in parts of the formation. Certain species prove to be useful in biostratigraphy because they only occur in a certain section of the formation. Species such as are Lamapsilis consueta, Lioplacodes judithensis, Lioplacodes gracilenta, Anodonta propatoris, and Corbula confinisies are seen in only the upper part of the Judith River Formation. Other species prove to be less helpful in biostratigraphy because they occur throughout the formation. The species that prove to be less useful are Ostrea subtrigonalis, Rhabdotophorus senectus, and Physa copei.

With having concluded that biostratigraphy is possible, further studies must be done on this subject to determine where on the stratigraphic horizon Hayden collected his fossils by addition fossil collections. Knowing the stratigraphic horizons of type specimens will stabilize species concepts and help interpret the age relations associated with the deposition of the Judith River Formation.

Different studies on the Judith River Formation fauna over the last century have produced only generalized results. By combining study results, Judith River species can be biostratigraphically organized. Species appear to occur in different parts of the Judith River Formation and Belly River Group indicating further biostratigraphic studies would be worthwhile.
REFERENCES


Appendix A:

Maps
Map 1: Camp location 2010 field trip with Dr. Hartman and crew on Montana base map (Google Earth base map).

Map 2: Stanton and Hatcher (1905) and Russell (1964) localities relative to 2010 Hartman camp site (Google Earth base map).
Map 3: 2010 fossil localities relative to Hartman camp site and Winifred, Montana (Google Earth base map).
Appendix B:

Tables
### Judith River Formation: Gastropods

**Stanton and Hatcher (1905) – Montana molluscan stratigraphic distribution in the Judith River Formation.**

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Table 1. Gastropods found in the Judith River Formation by Stanton and Hatcher's (1905). All information acquired through literary research and analysis. Taxa are arranged on the basis of first and last stratigraphic appearance. Somewhat current taxonomic names are used. Taxa with no stratigraphic assignment have been documented in the north-central Montana area, but not seen in this collection of specimens or within the Judith River Formation.
Judith River Formation: Bivalves

Stanton and Hatcher (1905) – Montana molluscan stratigraphic distribution in the Judith River Formation.

Table 2. Bivalves found in the Judith River Formation by Stanton and Hatcher's (1905) field study. All information was acquired through literary research and analysis. Taxa are arranged on the basis of first and last stratigraphic appearance. Somewhat updated taxonomic names are used. Taxa with no stratigraphic assignment have been documented in the north-central Montana area, but not seen in this collection of specimens or within the Judith River Formation.
Judith River Formation Taxa Stratigraphically

Russell (1964) – Alberta molluscan distribution in the Judith River Formation

<table>
<thead>
<tr>
<th>Mollusk taxa, continued</th>
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<tr>
<td>Oldman</td>
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### Table 3. Stratigraphic position of taxa found throughout the Judith River Formation and split up into Foremost Formation and Oldman Formation based on Russell (1964). Tables consist of both bivalves and gastropods and have been rearranged by the occurrences stratigraphically. Some species are without stratigraphic data.
Appendix C:

Plates
Plate I: Continental Bivalves

Line drawing provided by original author type specimen, assembled in Preliminary Guide to the Mollusca of the Judith River Formation by Dr. Joseph H. Hartman (1987) (from White, 1883).

Photographs provided by Paleontology program: Randy Ronsberg, Don McCollor, and Julie Amundsen. Scales are 3mm.

*Sphaerium praecoquum*
Plate 2: Continental Gastropods

Line drawing provided by original author type specimen, assembled in *Preliminary Guide to the Mollusca of the Judith River Formation* by Dr. Joseph H. Hartman (1987) (Meek, 1876).

Photographs provided by Paleontology program: Randy Ronsberg, Don McCollor, and Julie Amundsen. Scales are 1 mm and 2 mm.

*Lioplacodes gracilenta*

*Lioplacodes subtortuosa*

*Lioplacodes subconica*

Excavated during Montana 2010 trip from upper part of Judith River Formation, but not documented stratigraphically by Stanton and Hatcher (1905) or Russell (1964).
Plate 3: Elliptical Bivalves


Photographs provided by Paleontology Department: Randy Ronsberg, Don McCollor, and Julie Amundsen.

*Lampsilis consueta*

*Plesielliptio danae*