TWO NEW DINOSAUR BONEBEDS FROM THE LATE JURASSIC MORRISON FORMATION, BIGHORN BASIN, WY: AN ANALYSIS OF THE PALEONTOLOGY AND STRATIGRAPHY

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Abstract

Two new dinosaur bonebeds from the Late Jurassic Morrison Formation, Bighorn Basin, WY: An analysis of the paleontology and stratigraphy

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Vertebrate fossils have been discovered at several locations in the Bighorn Basin (Wyoming). The Virginia Museum of Natural History's (VMNH) digsite is located in the eastern part of the Bighorn Basin, in the Coyote Basin. Many scientists have worked within these basins trying to describe the stratigraphy. One question specifically asked is where the boundary between the Morrison Fm. (Jurassic) and the Cloverly Fm. (Cretaceous) lies. This new study attempted to show if the current method (Kvale, 1986) of determining the boundary is appropriate. The stratigraphy of the area was examined using Kvale, 1986, Ostrom, 1970, and Moberly, 1960's work in order to see which model was more robust. The fossils in the VMNH digsite were used to supplement the stratigraphic data in determining the age of specific beds.

All of Ostrom's units were identified throughout the study area. There is some doubt as to whether the units would be acceptable outside of the Coyote Basin because of laterally discontinuity. Nevertheless, his description of units is satisfactory for the study area, and is more appropriate than other methods. The geologic age of the dinosaurs uncovered in the VMNH quarry is in agreement with the age determined stratigraphically. The VMNH site is below Ostrom's Unit II, which would place it in the Late Jurassic. The determination of the Jurassic/Cretaceous stratigraphic boundary has not been resolved. However, since the Pryor Conglomerate member of the Cloverly Fm. can be identified throughout this area, it is proposed as the Morrison Fm./Cloverly Fm. boundary.

Dedication

This work is dedicated to my grandmother, Kay Brown. You have always believed that I could succeed in whatever I attempted, and this proves you were right. I'm glad that I've had the opportunity to do the things you have always wanted to do, and then come back and tell you about them.

I only wish you could have come along.

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Table of Contents

List of Multimedia Objects

Chapter 1: Introduction

Throughout the world, it has proven to be very difficult to assign a universal definition for the Jurassic-Cretaceous boundary. In Europe, for example, the boundary between the marine Portland Fm. (Jurassic), and the terrestrial to marginal-marine Purbeck Fm. (Cretaceous) has been redefined recently (Ogg *et al.*, 1994). Because of the high degree of provincialism among the marine life in the Portland Fm., global, and even regional correlations are hampered. In China, a study of the vertebrate-bearing beds in Liaoning Province could not conclusively show where a Jurassic/Cretaceous boundary would be (Wang *et al.*, 1998). Biostatigraphic evidence from fossil pterosaurs indicates that the Yixian Fm. may be Late Jurassic in age based on a tentative cladogram grouping of those pterosaurs with others know to be Jurassic (Ji, *et al.*, 1999). But radiometric dates from these beds, along with other evidence, suggest that the Yixian Fm. is Early Cretaceous in age (Swisher *et al.*, 1999).

One of the best-studied Jurassic-aged terrestrial formations is the Morrison Formation that outcrops in western North America. The formation extends over a considerable portion of the United States (Figure 1), covering over 620,000 square miles (Breithaupt, 1998).

Figure 1: The extent of the Morrison Basin in the Western United States [figure1.pdf, 2.29 Mb]

This study aims at a detailed documentation of the stratigraphy of the Morrison Fm. in the Coyote Basin region of the Bighorn Basin (Figure 2) in order to determine the approximate age of the Virginia Museum of Natural History's (VMNH) new digsites in the Bighorn Basin.

Figure 2: A map of the counties in Wyoming [figure2.pdf, 4.51 Mb]

The study area is in north-central Wyoming, near the town of Shell (Figure 3).

Figure 3: Map of Bighorn County, WY. [figure 3.pdf, 5.11 Mb]

The Coyote Basin is a smaller basin within the larger Bighorn Basin (Figure 4).

Figure 4: Approximate extent of the Coyote Basin in Wyoming [figure3.pdf, 13.2 Mb]

Although detailed stratigraphic studies of the entire Bighorn Basin have been done, these stratigraphic theories have problems when examined on a smaller scale. Even with all of the paleontological work that has been done in the Bighorn Basin, there is still no clear-cut Jurassic/Cretaceous boundary used by researchers. The VMNH has two new digsites located in the eastern part of the Bighorn Basin, near the Coyote Basin. The paleontology and stratigraphy of these new digsites need to be studied in order to help unravel the stratigraphic problem in the area.

Chapter 2: Previous Research and Stratigraphic Work

The majority of stratigraphic work that has been done in the Morrison Fm., and the reason it is the most well studied Jurassic-aged formation, revolves around the vertebrate fossils that are found in it. Eldridge originally described the formation in 1896 (Wilmarth 1938), but its stratigraphic range has been expanded since then. In 1909, C. A. Fisher was the first to look at the Morrison in northern Wyoming (Wilmarth 1938). In the late 1800's, the bone wars of Othniel Charles Marsh and Edward Drinker Cope were held on the Morrison battlefield. Cope carried out his first major excavations in Garden Park, near Cañon City, CO. Marsh had one of his digsites near Morrison, CO, the town for which the type section was named. The digsites were near the actual type section for the Morrison Fm., and in Como Bluff in Wyoming. The dinosaur fauna that have been discovered in the Morrison Fm. include *Allosaurus, Ceratosaurus, Camarasaurus, Amphicoelias, Diplodocus, Camptosaurus, Stegosaurus,* and *Apatosaurus* (Colbert 1968, see Appendix A for a complete list). The Como Bluff site is unique because of the number of microvertebrates and mammals that were found there. The first Jurassic-aged mammals in North America were discovered at Como Bluff in the late 1800's. The Carnegie Institute started their digsite in Southeastern Utah, in what was later designated

Dinosaur National Monument in 1909 (McGinnis 1982). Several tons of fossil material have been unearthed since its discovery (See Appendix A for a list of the entire fauna that has been discovered there). The monument is unique for the extreme dip of the beds containing dinosaurs (Chure *et al.*,1989). With a dip of 70°, the bed is a natural display case for the many visitors that come to the monument every year.

The size of the Morrison basin and the nature of terrestrial deposits prevent the stratigraphic correlation of the whole area. Most studies focus on one of the smaller basins within the Morrison basin. The VMNH digsites in the Bighorn Basin in north central Wyoming are close to the famous Howe Quarry located in the eastern part of the basin (Figure 5).

Figure 5: Location of the VMNH digsites are marked on the previous figure [figure5.pdf, 12.5 Mb]

Excavation at the Howe Quarry by Barnum Brown and the American Museum of Natural History began and ended in 1934 (Brown, 1935). In six months of fieldwork, Brown and his crew excavated over 4000 bones (Breithaupt, 1997). Since then, it has been worked by various organizations, and large amounts of bone are still being unearthed there today. Approximately 200 meters to the southwest of the historic Howe Quarry, Köbi Siber, a private collector whose base of operations is in Switzerland, is currently digging (Figure 5). He and his group have uncovered about 1000 bones over the past 10 years, and are continuing to dig today (Siber, personal communication, see Appendix B for the faunal list). In addition, approximately 300 meters to the NE of the Howe Quarry (Figure 5) is the location of the discovery of Big Al, the most complete *Allosaurus* found to date (Laws, 1996). The National Museum of Natural History in Washington has been prospecting for new fossil locations in the Bighorn Basin for many years (Holtz *et al.*, 2001). Members of the museum have several sites in the Bighorn Basin, including one in the town of Shell, WY that has produced a partial juvenile (cf. Barosaurus sp.) in 1993-1994 (Brett-Surman, Michael personal communication). Despite all the paleontological work that has been done at these digsites, none have been placed in a comprehensive stratigraphic context.

All of these digsites, except for the Smithsonian ones, are located in the Coyote Basin, a smaller basin within the Bighorn Basin (Figure 4). The VMNH digsites are located on the western rim of the Coyote Basin, but are technically in the Bighorn Basin (Figure 5). Most of the bonebeds in the study area are in areas mapped as Morrison Fm. (Noggle-Perrin, 1989). The Morrison Fm. was deposited in a seasonal terrestrial setting consisting of lakes, braided and meandering rivers, and floodplains. On a larger scale, the whole interior of the continent had changed from an interior seaway to a terrestrial environment, due to sea-level regression.

People have been investigating the Morrison Fm. for over a hundred years and there is still no consensus as to the upper boundary of the Morrison Fm. The unit that overlies the Morrison Fm. is no less well known for its dinosaurs. The Cloverly Formation is Cretaceous in age. The Sundance Fm. is a Middle Jurassic aged formation, older then the Morrison Fm., and is a marine deposit (Breithaupt *et al.*, 2001). It lies directly below the Morrison Fm. in this area. The contact between the two formations is gradational in the region (Figure 6).

Figure 6: The stratigraphic arrangement of the formations discussed [figure6.pdf, 1.31 Mb]

The new VMNH digsites are 100 yards to the west of the Coyote Basin (Figure 5). The site was found by a group of private collectors, but since the site is on public land under the jurisdiction of the Bureau of Land Management (BLM), it was given over to the VMNH. There have been three full field seasons of work on the new digsites. Three pits are being excavated, with two of them being continuous underground. The continuous pit is named the "Nickopod" Quarry. The smaller site is named the "Little Al" site. The problem that needs to be addressed is the stratigraphic location of the beds containing dinosaur fossils. The fauna will be addressed in a later section.

As with all terrestrial deposits, lateral continuity of beds is poor, making stratigraphic correlation very difficult. With lithostratigraphy, there is always the problem of time transgressive boundaries (Figure 7).

Figure 7: Diagram showing time lines cutting across rock units [figure7.pdf, 8.52 Mb]

"Time lines (which represent depositional surfaces of equal age) cut across the facies boundaries. The rock units or facies (sic) are of different ages in different places; that is, they are time-transgressive" (Prothero 1990). There are many types of deposits that produce time-transgressive facies. A few examples of these are point bars, alluvial fans, and transgressive facies in general (Figure 7). Biostratigraphy is often necessary to have a well-defined margin. The Jurassic/Cretaceous boundary is located at the contact between the Morrison Fm. and the Cloverly Fm., but most of the studies aimed at clarifying the stratigraphy of the Morrison and Cloverly Fms. use very large areas. Although many geologists have included the Coyote Basin in their studies of these two formations, they have come up with various ways to define them, the units within them, and the boundary between them. There are three principle studies reviewed in this paper, Moberly 1960, Ostrom, 1970, and Kvale, 1987, which are discussed separately.

Moberly, 1960

Moberly's work (1960) encompassed the entire Bighorn Basin. After completing a literature study, field mapping, and petrography, he divided the area into four formations: the Sundance Fm., Morrison Fm., Cloverly Fm., and the Sykes Mountain Fm. The Sykes Mountain Fm. is a Cretaceous formation overlying the Cloverly Fm., so it will not be reviewed here. Moberly described the Morrison Fm. as being an average of 190-200 feet thick and containing calcareous medium and fine grained sandstone beds that grade to very silty or sandy limestone to pure limestone (Moberly, 1960). He reported the most common rock type in the Morrison Fm. as "calcareous, somewhat sandy mudstone or shale, colored shades of green, gray, olive, and yellow" (Moberly, 1960). Moberly did not break the Morrison Fm. into different units, but looked at it as a whole. However, he broke the Cloverly Fm. into three different units: the basal unit is the Little Sheep Mudstone Member, named after Little Sheep Mountain in northwest Bighorn Basin. This unit is described as bentonitic mudstones with some chert-pebble sandstone lenses. The dominant facies is variegated bentonitic mudstone colored gray and red. The second member Moberly described in the Cloverly Fm. is the Pryor Conglomerate. It is a conglomerate with well-rounded pebbles, granules, and sand grains of black chert, with some angular grains of white chert. Where this conglomerate is present, Moberly said this is the unconformable contact with the Morrison Fm. Where this conglomerate is not present, the contact is conformable with the Little Sheep Mudstone. Above the Pryor Conglomerate, or the Little Sheep Mudstone where the conglomerate is not present, lies the Himes Member. It is a claystone cliff-former with iron oxide, lithic wacke, and quartz arenite veins. The differences between the Little Sheep Mudstone Member and the Himes member are that the Himes Member is finer grained than the Little Sheep Mudstone Member, and that the Himes Member is nonbentonitic, and contains blebs of hematite and limonite.

Ostrom, 1970

In Ostrom's study, he attempted to classify units within the area first, and then to define the Jurassic/Cretaceous boundary. He defined eight units within the Morrison, Cloverly, and Sykes Mountain Fms. He described Unit I, the base of the Morrison Fm., as consisting of "calcareous claystones and siltstones, usually greenish in color". Unit II consists of a heavily cross-bedded, calcite-cemented quartz arenite. He said it is very white, but weathered colors can range from white to yellow, and anywhere between 10-80 feet thick. Unit III is another variegated mudstone, not differing much from Unit I. In fact, Ostrom said that in the absence of Unit II, Units I and III are indistinguishable. Ostrom placed the boundary between the Morrison Fm. and Cloverly Fm. at the base of Unit IV. Units I-III are the complete Morrison Fm. Unit IV is a thick, massive, very resistant, and highly cross-bedded conglomerate and sandstone containing black, dark gray, or brown chert grains. The description of Unit IV has many of the same properties of the Pryor Conglomerate used by Moberly. In his monograph, Ostrom said that Units II and IV are not laterally continuous, as would be expected for a terrestrial setting. There are other units that Ostrom described higher in the section, but those are not a part of this study.

Kvale, 1986

Kvale had a very different idea of how the stratigraphy should be divided. He recognized the Sundance/Morrison Fm. contact in the same way as Ostrom and Moberly do. He also agreed with their description of the lower section of the Morrison Fm. However, there is disagreement in the upper section, Ostrom's Unit III. Kvale placed the Morrison/Cloverly fm. contact well beneath the Pryor Conglomerate, somewhere in the middle of Ostrom's Unit III. He reasoned that where the color changes from red/green to gray/purple there is a change from lacustrine to estuarine conditions (Kvale, 1986). His Morrison Fm. thickness is therefore much less than that of Ostrom and Moberly. He also stated that the conglomerate present in this study area is not the Pryor Conglomerate, but rather a conglomeratic lens (Vondra, personal communication).

All of these workers used a study area that encompassed a vast region. While their study areas did include the Coyote Basin, they also included other basins in Wyoming, and they wound up with a huge area to try to generalize. They came up with a system that would work for the entire area, and then tried to take it even further and correlate between other states, and this naturally has its problems. It maybe more useful to look at smaller geographical areas, to begin with, and see what patterns are easily distinguishable in that area. Then those patterns can be compared to the patterns for other areas. The purpose of this study is to look at a very localized region in detail and see how it matches up with the three different stratigraphic proposals outlined above.

Chapter 3: Current Stratigraphic Research

To assign an age and stratigraphic location for the VMNH digsites, the stratigraphy of the area needed to be clarified. A detailed mapping study was undertaken, and three stratigraphic sections were measured using a Jacob's staff and Brunton compass. Figure 8 is a key for all the stratigraphic columns.

Figure 8: A key to all the stratigraphic columns [figure8.pdf, 4.95 Mb]

VMNH Stratigraphic Section

The first section, Figures 9 and 10, was started on the sandstone cap above the large bonebed (Figure 11).

Figure 9: Lower part of the VMNH stratigraphic section [figure9.pdf, 4.02 Mb]

Figure 10: Upper part of the VMNH stratigraphic section [figure10.pdf, 4.13 Mb]

Figure 11: Picture of the “Nickopod” digsites [figure11.pdf, 32.4 Mb]

The VMNH "Little Al" pit is approximately 6.7 meters (22 feet) above the large bonebed. An important portion of the section to mention is the yellow, calcite-cemented sandstone that begins at 18 meters. This part would correspond to Ostrom’s Unit II. Kvale and Moberly’s theories would also agree with this assessment (Figure 12).

Figure 12: Cross-bedding in Unit II [figure12.pdf, 23.6 Mb]

Above Unit II there are 15.9 meters of variegated claystone. Slickensides are readily visible in this section. This would correspond to Ostrom’s Unit III and is consistent with Moberly's assignments. Near the top of the section, at 40 meters height, there is a medium-grained quartz arenite. Some portions of this unit are calcite-cemented. The portion of the section above this unit is very highly weathered. It is tentatively marked as a claystone, though no unweathered section was visible even after trenching. The section was measured to the bottom of a cliff-forming black-chert bearing conglomerate (Figure 13).

Figure 13: Close-up view of dark chert-bearing conglomerate layer [figure13.pdf, 6.49 Mb]

The unit would correspond to Ostrom’s Unit IV. The red-white boundary was difficult to determine in this area. The boundary is not very distinct, and changes laterally. In some areas, the color change is not present at all. It should be noted that all of the beds in this area were measured using a dip of 24º NE. The dip of the beds shallow near the top of the section.

Historic Howe Quarry Stratigraphic Section

A second stratigraphic section was measured in the area of the historic Howe Quarry (Figure 14).

Figure 14: Howe Quarry stratigraphic column [figure14.pdf, 2.21 Mb]

The bottom of the section was started at the base of a yellow calcite-cemented sandstone along the road (Figure 15).

Figure 15: Historic Howe Quarry stratigraphic section [figure15.pdf, 5.85 Mb]

The whole of the measured section was yellow in color. The exact stratigraphic location of Brown's excavations in the 30's is unclear, but it is believed to be in either of the two claystones present, and probably in the upper one. One of these yellow sandstones would correspond to Ostrom's Unit II, probably the one at 3.3 meters. Note this would put the historic Howe Quarry above Ostrom's Unit II, and in the base of his Unit III.

Siber Quarry Stratigraphic Section

The last section that was measured is where Siber is currently digging (Figures 16, 17).

Figure 16: Lower part of the stratigraphic column for the Siber Quarry [figure16.pdf, 2.20 Mb]

Figure 17: Upper part of the stratigraphic column for the Siber Quarry [figure17.pdf, 1.85 Mb]

This section was also started at a calcite-cemented sandstone at the level of the road, but there is some question as to whether or not it is the same sandstone at the base of the

Howe Quarry section. The fossil horizons in this newer quarry are clearly visible. Vertebrate fossils were weathering out at the surface at the time of this study. There were three fossil horizons, all in yellow colored rock units in a section 4 meters thick. It is presumed that either the sandstone unit or siltstone unit would be characterized as Unit II. Above these horizons, the rock is much smaller grained, with a few sandstone lenses. The color is variegated, and it should be noted that surface color is not a reflection of lithologic color. Above the last small sandstone unit, there are 29.2 meters of rock consisting only of variegated claystone. Predominately, the colors are gray and black, but red, pink, green, and white can be found. This section of the rock would be Unit III. At the top of this section there is no conglomerate present. There is, however, a medium-grained quartz arenite with some small chert grains in it, exactly like the one at the top of the VMNH stratigraphic section.

The conglomerate from the top of the VMNH section is a dark-chert bearing, highly cross-bedded conglomerate. It has sandstone lenses in it, and many pieces of weathered fossil. While it's stratigraphic location is only visible in one of the measured stratigraphic columns, there are many places near the VMNH site, in the Bighorn Basin, where this bed is visible at the same stratigraphic level. Because of this, and the consistent stratigraphic location, this bed is determined to be the Pryor Conglomerate. This would correspond to Ostrom's Unit IV.

The stratigraphy beneath the VMNH quarry in this immediate area is much more difficult to unravel. There is a small section of mudstone present, and then a sandstone layer. This lithologic pattern then repeats itself 3-4 times. The sandstones in this area are of note because of the ripple marks that are present in them (Figure 18).

Figure 18: Ripple marks on sandstone layer found in the Coyote Basin [figure18.pdf, 15.7 Mb]

The ripple marks are present beneath the VMNH bonebed and are continuous into the Coyote Basin. There are at least three layers of ripple marks, and the lowest forms the floor of the basin. There is the strong possibility of more layers present beneath the current floor of the basin. In another location approximately 5 miles to the south, there are layers of ripple marks, and also layers of interference ripples (Figure 19).

Figure 19: Interference ripples found in a sandstone to the south of the Coyote Basin
[figure19.pdf, 18.8 Mb]

Near the VMNH site, the dips of the beds steepen with each repetition of ripple marked units until they are vertical (Figure 20).

Figure 20: This picture shows the repeated layers of sandstone in the foreground
[figure20.pdf, 15.4 Mb]

The layers are undulated, and curve around part of the hill to the south of the bonebed. The evidence of the repeated section indicates an imbricate thrust fault. Figure 21 shows how this geometry might have developed.

Figure 21: Schematic diagram showing how an imbricate thrust system might develop
[figure21.pdf, 5.85 Mb]

With force coming from the east, the section formed an anticline when the leading edge of the thrust was pushed against an unmoving barrier. Units III or I would then have broken repeatedly, causing the imbrications. Whether it was Unit I or Unit III that broke is not possible to determine at this time, since the only way to determine this in flat-laying topography is by the presence of Unit II.

Chapter 4: Discussion of Stratigraphy

Because Ostrom's Units II-IV were identifiable in this study, and since all of the VMNH bonebeds are located beneath Ostrom's Unit II, all of the VMNH digsites are in the lower-middle Morrison Fm., in Ostrom's Unit I. A more precise location would hinge on where the Morrison/Cloverly fm. boundary is. Since there is little to no fossil evidence to support an identification of the boundary, it must be a strictly lithologic placement. Between the different authors there are two choices. One is at the base of the Pryor Conglomerate, and the other is at the red/white boundary.

Before a decision can be made about where the boundary is, the facies description of the Pryor Conglomerate needs to be analyzed more closely. Two of the stratigraphic columns reported here show a partially calcite cemented sandstone close to the conglomeratic layer. In other places in the area, this sandstone is in direct contact with the conglomerate, and grades into it. The Pryor Conglomerate largely "consists of coarse sand, pebbly sand and conglomeratic lenses" (Ostrom, 1970). Therefore, the sandstone below the conglomeratic lenses in the area can be classified as part of the Pryor Conglomerate. The conglomeratic portions of this facies are clast-supported, and highly weatherable. It is possible that the conglomeratic sections of this facies are commonly weathered away, leaving only the sandstone. This would explain why in many sections, a sandstone facies is present at the height of the Pryor Conglomerate, but no conglomeratic portions are. It might also explain why the streams in the area all seem to flow at a common stratigraphic height i.e. where the Pryor Conglomerate would be located.

The Pryor Conglomerate would seem an obvious choice for the Morrison/Cloverly fm. boundary. It is a prominent lithologic marker bed, and is readily identifiable in this area. However, approximately 10 miles to the south of the Coyote Basin, the Pryor Conglomerate is not present. In this region, the Pryor Conglomerate pinches out, as does Unit III (Ostrom, 1970). To the south of Route 14, Unit II is in direct contact with Unit V, in the Cloverly Fm. To the north of this area, between Route 14 and the VMNH digsites, small thicknesses of Units IV and III crop out. The units thicken to the north until they are the thicknesses measured in the stratigraphic sections reported here.

Kvale reports in his paper that the Pryor Conglomerate is not present in this area, and that the conglomerate that is present is a lens (Kvale 1986). To the north of the VMNH sites, no conglomeratic facies was found. However, Units II, III, and V were identified. In between Units III and V, a white, partially calcite cemented sandstone was present. It is quite possible that this sandstone corresponds to the lower part of the Pryor Conglomerate as seen in the area near the VMNH and Howe Quarry digsites. The Pryor Conglomerate does indeed pinch out to the south in this region, but it is present in the area of the VMNH and Howe Quarry digsites, sometimes as only the sandstone portion of the member.

However, the geologic maps (Noggle-Perrin 1989, Manahl, 1985) in the area show the Morrison/Cloverly fm. boundary at a different stratigraphic location than the Pryor Conglomerate. The map was created using Kvale's stratigraphic theory of a red/white boundary. The area to the east of the VMNH bonebed was mapped to see which component, the Pryor Conglomerate or a red/white boundary, is more pervasive. To the east in the basin, over a large rise, the beds are flat lying. The uppermost section of Unit II from near the bonebed was followed out to the basin. Above this unit is a unit of mudstone with small lenses of calcite-cemented sandstone. On the hills that are tall enough, the Pryor Conglomerate is present.

The red/white boundary in the basin is hard to define. In some areas there is a definite break in the color from one to the other. In others, the contact repeats itself. In still other places, the red changes into a gray or yellow. It is impossible to follow one line that would be the contact across any small lateral distance. Because of the pervasiveness of the Pryor Conglomerate throughout the basin, and because the red/white boundary is not present everywhere, the Pryor Conglomerate is proposed as the base of the Cloverly Fm. in the Bighorn Basin.

The evidence for the red/white boundary as being the Jurassic/Cretaceous boundary cannot be dismissed out of hand however. In the Early Cretaceous, there is the beginning of a major transgression. The interior seaway of the North American continent was beginning to come back at this time (Picard, 1993). The change in color from red to white would indicate a more near-marine presence because of oxidation. The red would come from oxidation of the land in a terrestrial setting. The white would indicate the marine influence and less oxidizing environment.

The Pryor Conglomerate was deposited due to a mountain belt that rose in the Early Cretaceous in the Northwest area that is now Wyoming (Picard, 1993). Because of the orogeny, the base level in the area was lowered, and caused incision by streams. The uplifted slope of the beds in the area would be high, and might have made an alluvial fan setting. The tectonic uplift and high slope would cause the streams to cut down into the rock and deposit a sheet of coarse-grained material.

Which event occurred first after the end of the Jurassic, the marine transgression or the lowering of base level? Because of the lack of biostratigraphic information near the boundary, it is very difficult to answer this question. In an area that is geographically closer to the rise in sea level, in the eastern part of the basin, the red/white transition would show up in the rock record before the conglomerate, and should be considered the boundary. In the western section of the Bighorn Basin, the opposite would be true. Both of these markers are time transgressive, and so neither are perfect marker beds. In the area used in this study, the Unit IV marker bed, the Pryor Conglomerate, is again proposed as the base of the Cloverly Fm. for the reasons listed above.

After three seasons of fieldwork, the units that Ostrom described are recognizable. They may, however, be in need of revision. There is a thick, yellow, calcite-cemented sandstone that is much like Ostrom's Unit II except in color, present in all localities in the region. He does not show this in his stratigraphic description from the Coyote Basin (Ostrom, 1970), but it is present in outcrop. There are also many crossbedded and ripple marked sandstones below this yellow layer in the Coyote Basin and in the area of the VMNH digsites. These sandstones are close stratigraphically to Ostrom's Unit II, but would not fall under his description of the unit. All of the many digsites in the region are located in Ostrom's Unit II, or near to it but below a ripple-marked sandstone. The fact that all of these fossil zones are close together in outcrop may lead to a useful marker for the stratigraphy of the area, after further fieldwork. The Unit II described by Ostrom may be expanded to include the ripple marked and cross-bedded sandstones.

All of the VMNH digsites are located beneath a yellow, cross-bedded sandstone that corresponds to Ostrom's Unit II. If Ostrom's units are accepted, then the VMNH digsites are in Unit I. The sandstone bed that the "Nickopod" Quarry is on top of would be a lens in the mudstones of Unit I. If Ostrom's Unit II is revised to include all the rippled marked and cross-bedded sandstones in the Morrison or the region, then the VMNH digsites would be in Unit II. Either stratigraphic system shows that the VMNH sites are definitely not in Unit III.

Chapter 5: Paleontological Chapter

The biostratigraphic data that dates the VMNH bonebeds as Jurassic age is also sound. The vertebrate fossils that have been recovered are all of classically Jurassic-aged dinosaurs. *Stegosaurus*, *Allosaurus*, *Apatosaurus*, *Camarasaurus*, and *Diplodocus* are all strictly Jurassic dinosaurs (except for one questionable identification of *Allosaurus* in the Early Cretaceous, Carroll 1988). In addition to these, there are three bones from the ornithopod, *Camptosaurus*.

The VMNH had opened three pits as of the 2001 field season. Of these, two of them are in the same bed, which is continuous underground and one is on a totally different stratigraphic horizon. The two that are continuous underground are referred to as one bonebed for the remainder of this work. The main bonebed, the "Nickopod" Quarry, contains all the elements but the *Allosaurus* (aside from a few *Allosaurus* teeth). The bed containing the *Allosaurus* skeleton, here named the "Little Al" quarry, is 6.7 m (22 ft) above the "Nickopod" Quarry stratigraphically. Figure 11 shows the location of two of the pits. Figure 22 shows the location of the "Little Al" pit.

Figure 22: Location of the "Little Al" pit [figure22.pdf, 6.23 Mb]

The elements and number of elements of each group found in the "Nickopod" Quarry as of field season two are in Figure 23.

Figure 23: Skeletal elements found in the "Nickopod" Quarry as of the second field season [figure23.pdf, 331K]

This list does not include the eastern-most section of the "Nickopod" Quarry (on the left of Figure 11). The dominant elements are vertebrae, followed by ribs. When one considers that one *Apatosaur* tail can have up to over 80 vertebrae, it is no wonder that these elements are the most abundant (Carroll 1988). The same theory would explain the high number of ribs. Fewer elements have been found of the *Allosaur* sp., and further excavation may be impossible. The dip of the bed is 24º, and slopes back into a hillside. The whole top of the hill will have to be removed in order to explore the bed more.

One interesting thing about the sites is the deformation of the bones. In the "Nickopod" Quarry, the bones have a definite slant to them, and elements of bones that should be parallel are not. This is probably because of the thrust faulting that has occurred there. Figure 24 shows a comparison between an idealized *Stegosaur* dorsal vertebra and one recovered from the "Nickopod" Quarry.

Figure 24: An idealized stegosaur dorsal vertebra compared with an actual one from the "Nickopod" Quarry [figure24.pdf, 11.7 Mb]

The centrum of a vertebra should be parallel caudio-cranially. The vertebra from the pit is obviously not. Digital images of the vertebra were taken using a high-resolution digital camera (Nikon). The images were then analyzed using Scion to measure the angle of deformation. The two halves of the centrum are deformed by between 10.5º and 11.5º.

All of the bones in the "Nickopod" Quarry are deformed in such a manner. Because of the variation in the orientation of the bones, the deformation is more apparent in some than in others. The reason these data were collected using a vertebra is the lack of anatomical landmarks in dinosaur bones. Anatomical landmarks are points that are Type I landmarks. That is, they are mathematical points that provide the most evidence that they are homologues between samples (Slice *et al*. 1998). An example would be the location of a tear duct on a person's face. These types of landmarks are difficult to assign to fossilized bones since all fossilized bones have undergone some kind of deformation. Which means that there is no "normal" sample from which to compare. If many different fossilized samples were compared together, the results might only show the differences in preservation and deformation. For that reason, pseudo-landmarks were used to analyze the vertebra. Pseudo-landmarks, or Type II landmarks, are supported by geometrical evidence (Slice *et al*., 1998). An example of this is the point of maximum curvature on a theropod tooth.

Pseudo-landmarks were used to anchor the angle. Figure 25 shows the locations of the landmarks and the angle that was measured.

Figure 25: The circles on the figure represent the landmarks used in the analysis [figure25.pdf, 15.6 Mb]

The bones in the "Little Al" pit were not deformed in any fashion noticeable to the eye. There are many reasons for this including: 1) the bed with the pit was on the last imbricated thrust sheet and therefore not under as much pressure as the beds closer to the edge of the thrust, and 2) the bones were deposited at a different time when thrusting had almost ceased.

The orientation of the bones in the "Nickopod" Quarry can lead to information about type of deposit. Using a Brunton compass, the strike of the long axis of all the bones unearthed in the 2000 field season was measured. In order to factor out measurement error, all the strikes were rounded to factors of ten. Figure 26 is the rose diagram showing the strike directions of the bones (Chew 2001).

Figure 26: Rose diagram showing long-bone orientations in the "Nickopod" Quarry [figure26.pdf, 2.68 Mb]

The ten-degree section of the rose diagram with the most bones in it is 70º and 80º. The data are somewhat ambiguous because of a possible second direction of flow in the 30º and 40º. A statistical program that was written by Jerrold Zar and modified by Micha_ Kowalewski was used to determine if the dominant flow direction was actually statistically significant. The program makes use of Rayleigh's test for circular unconformity and the null hypothesis is that the population is uniformly distributed. The reader is referred to Biostatistical Analysis (Zar, 1999) for further explanation of the statistics behind this theory. The program was executed using the SAS software program (Appendix C). The data were analyzed in their entirety, and broken up into sauropods, stegosaurs, and wood. The results of all the analyses show that the distribution around the circle is not uniform, and the dominant flow direction is indeed statistically significant to $p < 0.05$. In this area in the Morrison Fm., the current that was transporting these bones was flowing in a NW/SE direction.

Chapter 6: Conclusion

The new VMNH digsites present an opportunity to look at an area that has been studied for over a hundred years with new, more recent, eyes. This area of the Bighorn Basin has an enormous history of fossil collecting, and these sites will only add to this collection. A Late Jurassic date is assigned to these bonebeds through both stratigraphic methods and paleontological ones. The three VMNH digsites are assigned to Ostrom's Unit I. The current study also presents the idea that the stratigraphic system that is used throughout most of the great basins in Wyoming is perhaps too simplistic, and could use revision. If it is revised as described above, the VMNH sites would be in Unit II.

While the methods used in previous studies may work in a general sense for a large area, on closer inspection there are many discrepancies between the stratigraphic system and the rocks. The new system proposed for the Coyote Basin in this study may not be exact enough for a basin adjacent to it. However, looking at as much area as possible in close detail may be necessary in order to see a complete and competent overall picture.

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Appendix A

Historic Faunal Lists

Como Bluff Quarries, WY (Ostrom and McIntosh, 1966)

Class: Reptilia

Order: Saurischia

Suborder: Sauropoda

Apatosaurus sp.

Apatosaurus excelsus (Brontosaurus)

Apatosaurus amplus (Brontosaurus)

Barosaurus sp.

Camarasaurus grandis

Camarasaurus sp.

Camarasaurus lentus

Pleurocoelus montanus

Diplodocus sp.

Suborder: Theropoda

Antrodemus atrox (Allosaurus)

Antrodemus sp. *(Allosaurus)*

Antrodemus valens (Allosaurus)

Antrodemus lucaris (Allosaurus)

Antrodemus ferox (Allosaurus)

Coelurus fragilis

Coelurus agilis

Coelurus sp.

Order: Ornithischia

Suborder: Ornithopoda

Camptosaurus amplus (Camptonotus)

Camptosaurus dispar (Camptonotus)

Camptosaurus medius (Camptonotus)

Camptosaurus nanus (Camptonotus)

Camptosaurus browni (Camptonotus)

Camptosaurus depressus

Laosaurus sp.

Laosaurus consors

Laosaurus gracilis

Laosaurus celer

Camptosaurus sp.

Suborder: Stegosauria

Stegosaurus sp.

Stegosaurus ungulatus

Stegosaurus affinis

Stegosaurus sulcatus

Stegosaurus stenops

Stegosaurus laticeps (Diracodon)

Order: Pterosauria

Dermodactylus montanus

Order: Crocodilia

Suborder: Mesosuchia

Goniopholis sp.

Order: Crocodilia or Eosuchia:

Suborder: Mesosuchia or Choristodera?

Macellognathus vagans

Order: Chelonia

Species indeterminate

Suborder: Amphichelydia

Glyptops ornatus

Glyptops plicatulus

Order: Rhynchocephalia

Opisthias rarus

Theretairus antiquus

Order: Squamata

Suborder: Lacertilia

Cteniogenys antiquus

Class: Osteichthyes

Subclass: Choanichthyes

Order: Dipnoi

Ceratodus guntheri

Class: Amphibia

Order: Anura

Suborder: Aglossa?

Eobatrachus agilis

Suborder: Neobatrachia

Comobatrachus aenigmatis

Order: Urodela

Comonecturoides marshi

Class: Aves?

Laopterys priscus

Class: Mammalia

Order: Multituberculata

Ctenacodon serratus

Ctenacodon scindens

Ctenacodon laticeps (Allodon)

Psalodon potens (Ctenacodon)

Psalodon fortis (Allodon)

Psalodon marshi

Order Triconodonta

Phascolodon gidleyi

Aploconodon comoënsis

Trioracodon bisulcus (Triconodon)

Priacodon ferox (Tinodon)

Priacodon robustus (Tinodon)

Priacodon lulli

Priacodon grandaevus

Order: Symmetrodonta

Tinodon bellus

Tinodon lepidus

Amphidon superstes

Eurylambda aequicrurius

Order: Pantotheria

Paurodon valens

Archaeotrigon brevimaxillus

Archaeotrigon distagmus

Tathiodon agilis

Dryolestes priscus

Laolests eminens

Laolestes vorax (Dryolestes)

Laolestes segnis (Asthenodon)

Amblotherium gracilis (Sttylacodon)

Amblotherium debilis

Herpetairus arcuatus (Dryolestes)

Herpetairus humilis

Herpetairus obtusus (Dryolestes)

Melanodon oweni

Melanodon goodrichi

Euthlastus cordiformis

Miccyclotyrans minimus

Malthacolestes osborni

Pelicopsis dubius

Order: Docodonta

Docodon victor (Diplocynodon)

Docodon striatus

Docodon crassus (Enneodon)

Docodon affinis (Enneodon)

Docodon superus

Morrison CO Quarries (Ostrom and McIntosh, 1966)

Class: Reptilia

Order: Saurischia

Suborder: Sauropoda

Diplodocus lacustris

Atlantosaurus montanus

Apatosaurus ajax

Apatosaurus laticollis

Atlantosaurus immanis

Suborder: Theropoda

Antrodemus sp. *(Allosaurus)*

Order: Ornithischia

Suborder: Stegosauria

Stegosaurus armatus

Order: Crocodilia

Suborder: Mesosuchia

Goniopholis felise (Diplosaurus)

Order: Chelonia

Species indeterminate

Garden Park Quarries, CO (Ostrom and McIntosh, 1966)

Class: Osteichthyes

Subclass: Choanichthyes

Order: Dipnoi

Ceratodus guntheri

Class: Reptilia

Order: Saurischia

Suborder: Sauropoda

Camarasaurus (?) sp.

Haplocanthosaurus priscus

Haplocanthosaurus utterbackii

Brachiosaurus sp.

"Morosaurus" agilis

Apatosaurus sp.

Diplodocus longus

Suborder: Theropoda

Antrodemus fragilis (Allosaurus)

Labrosaurus ferox (Allosaurus)

Ceratosaurus nasicornis

Coelurus agilis

Antrodemus sp. *(Allosaurus)*

Order: Ornithischia

Suborder: Ornithopoda

Laosaurus gracilis

Camptosaurus medius

Suborder: Stegosauria

Stegosaurus stenops

Stegosaurus armatus (?)

Order: Crocodilia

Suborder: Mesosuchia

Goniopholis sp.

Order: Chelonia

Suborder: Amphichelydia

Probaena sculpta

Glyptops plicatulus

Class: Mammalia

Order: Pantotheria

Kepolestes coloradensis

Order: Docodonta

Docodon sp.

Carnegie Quarries, Dinosaur National Monument, UT (Chure *et al.*, 1998)

Class: Mollusca

Unionidae

Class Amphibia:

Anura gen. et sp. indet.

Class: Reptilia

Order: Chelonia

Dinochelys plicatulus

Glyptopos plicatulua

Order: Spenodonta

Opisthias rarus

Order: Crocodilia

?*Goniopholis* sp.

Order: Saurischia

Suborder: Theropoda:

Allosaurus fragilis

Ceratosaurus nasicornus

Torvosaurus tanneri

Suborder: Sauropoda

Apatosaurus louisae

Barosaurus lentus

Camarasaurus supremus

Camarasaurus lentus

Order: Ornithischia

Suborder: Ornithopoda

Camptosaurus medius

Dryosaurus altus

Suborder: Stegosauria

Stegosaurus stenops

Stegosaurus ungulatus

Historic Howe Quarry Fauna, WY (Michelis, 2001)

Class: Reptilia

Order: Saurischia

Suborder: Sauropoda

Camarasaurus sp.

Apatosaurus sp.

Barosaurus sp.

Camptosaurus sp.

Order: Saurischia

Suborder: Theropoda:

Theropoda indet.

Appendix B

Siber Quarry Faunal List

Siber Quarry, WY

Class: Reptilia
- Order: Saurischia
  - Suborder: Sauropoda
    - *Diplodocus* sp.
    - *Camarasaurus* sp.
    - *Brachiosaurus* (?) sp.
    - *Barosaurus* (?) sp.
    - *Apatosaurus* sp.

  - Suborder: Theropoda
    - *Allosaurus* sp.

- Order: Ornithischia
  - Suborder: Stegosauria
    - *Stegosaurus* sp.

  - Suborder: Ornithopoda
    - *Hypsilophodontid* sp.

Appendix C

SAS Program

```
*******************************************************************;
/*

A SAS-IML code for computing a sample angular mean.

WRITTEN BY

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References:

Zar, J.H. 1999. Biostatistical analysis. Prentice Hall, 4th ed., 663
pp.

*/
********************************************************************;

%let pi=3.1415926535;

DATA azym;
        infile cards;
        input azym;
cards;
303
303
353
355
348
355
353
```

270
336
298
284
279
290
318
45
336
305
60
330
288
304
356
308
280
285
307
3
348
350
36
85
322
346
25
50
290
314
54
85
50
50
330
342
285
288

```
288
57
74
346
52
310
342
57
320
288
50
5
283
18
323
73
290
330
295
340
322
;
RUN;

PROC IML;
USE azym;
READ all var{azym} into X1;

START AZYMUTH(D1,ang);
        n=nrow(D1);
        Y1=D1/(180/&pi);
        C1=sum(COS(Y1))/nrow(Y1);
        S1=sum(SIN(Y1))/nrow(Y1);
        R1=sqrt(C1**2+S1**2)*nrow(Y1);
        a1=arcos(C1/(R1/nrow(Y1)))*(180/&pi);
        ang=round(a1,.001);
            z=R1**2/n;
            print 'r' R1;
```

```
            print 'z' z;
            print 'sample size' n;
        print 'angular mean' ang;
FINISH AZYMUTH;

RUN AZYMUTH(X1,ang);
RUN;
QUIT;
```

Modified by Brooke Wilborn

CURRICULUM VITAE

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Research Interests

Vertebrate paleontology, paleobotony, bio- and lithostratigraphy, paleoecology of terrestrial ecosystems

Study of teaching styles in undergraduate intro-geology classes: the importance of first impressions

Grants Awarded

Department of Geology and Geophysics Travel Grant, University of Oklahoma, 2001 ($300)
Matching funds from Sam Noble Oklahoma Museum of Natural History, 2001 ($300)
Department of Geological Sciences Travel Grant, Virginia Tech, 2000 ($322), 1999 ($380)
Virginia Museum of Natural History Travel Grant, 2000, 1999

Teaching Experience

Physical Geology Lab, Historical Geology Lab

Field Experience

My field experience includes three years of paleontological, geological, and geophysical field work with the Virginia Museum of Natural History and Virginia Tech in Wyoming. It also includes one field season attending geology field camp with Oklahoma State University in Colorado.

Professional Activities

I was the on the committee for the Geological Sciences Student Research Symposium (GSSRS) at Virginia Tech for the 2001 event. The day-of activities were my responsibility, including informing students of the media available to them, organizing the transfer of all the presentations to the meeting venue, and running the presentations on the two days. I also gave a presentation at the event in 2001, and in 2000.

At the 2000 annual meeting of the Society of Vertebrate Paleontology, I presented a poster that I co-authored.

Professional Affiliations

Attended the Society of Vertebrate Paleontology meetings in 1999, 2000, and 2001.
Member, Society of Vertebrate Paleontology, 10/00 – present.

Graduate Courses

Paleoecology, Virginia Tech	B+
Morphometrics, Virginia Tech	A
Current Research in Geobiology (4)	P
GTA Training Workshop	P
Comparative Vertebrate Osteology	P
Terrigenous Depositional Systems	B
Quantitative Paleobiology	A
Environmental Paleontology	P
Global Plate Tectonics	A-
Clastic Depositional Facies (current)	
History of Geology (current)	

Publications

Breithaupt, B. H., M. Fox, N. Fraser, N. Matthews, and B. Wilborn. 2000. A New Dinosaur Bonebed in the Morrison Formation of Bighorn County, Wyoming (poster presentation). *In* Journal of Vertebrate Paleontology, v. 20, (supplement to number 3): 31A.