

# SVP First North American Summer Field Conference — Summary

## Hanna and Carbon Basins, South-central Wyoming

BY FIELD CORRESPONDENT

KAREN J. LLOYD

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### Introduction to Field Conference

The first SVP field and topical conference was held in the Hanna and Carbon Basins in south-central Wyoming, USA, and was co-sponsored by the University of Wyoming, Department of Geology and Geophysics. The conference, which was organized by Jay Lilliegraven and Bill Clemens, took place August 5-7 2008 with co-presenters Jay Lilliegraven, Jaelyn Eberle, Pennilyn Higgins and Mark Clementz.

Altogether 35 participants converged on The Virginian Hotel, Medicine Bow, Wyoming: all with the common goal of

learning how the field study of rocks can be applied to the discipline of paleobiology. The trip was very practical and involved us visiting and examining several sites with documented examples of vertebrate fossils in a detailed geologic context.



Group photo, Hanna and Carbon Basins Field Conference. Photo courtesy of R. Anemone, West Michigan University.

The Hanna and Carbon Basins are relatively small compared to other Laramide basins, but despite their size they have long been recognized as having very thick sections of marine and non-marine, Upper Cretaceous and Paleocene strata. Originally, the basins were interpreted as discrete centers of deposition that had separate geological histories. It is now recognized, however, that they represent eastern margins of an originally unified, extremely large Green River Basin, which became subdivided during the Eocene by deep-centered, basement-involved faulting.

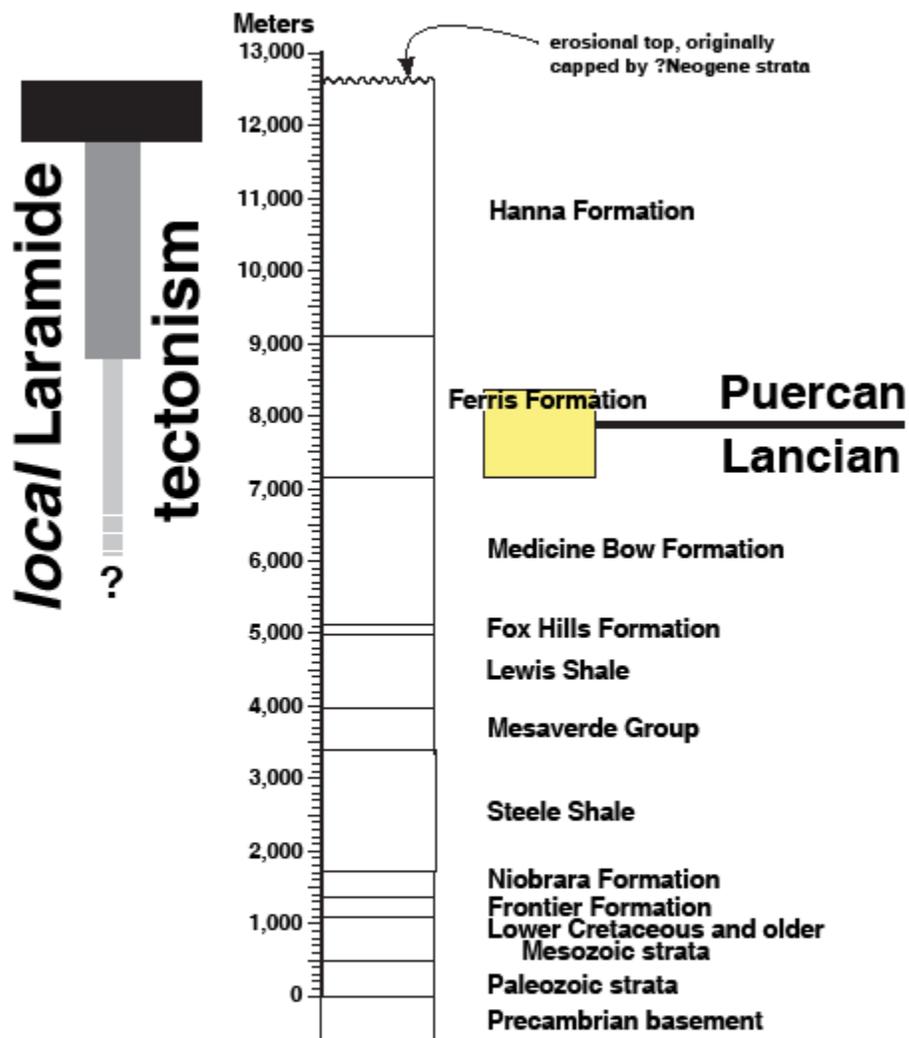
The areas studied on the first two days: The Breaks, in the northeastern corner of the Hanna Basin; and the margins of the Simpson Ridge anticline, which separates the Hanna and Carbon Basins, were both altered by regional tectonism, resulting in

overturned beds and emplacement of younger strata onto older strata. In addition, various unconformities and thin-skinned and thick-skinned faulting also complicate our understanding of the physical stratigraphy.

In both these areas vertebrate fossils have been discovered and studied (Secord, 1998; Higgins, 2003). The fossils date both the Carbon Basin (Secord's study) and the area around The Breaks (Higgins' study) in the Hanna Basin back to the Torrejonian — Tiffanian NALMA transition. Both of these studies have helped in determining maximum and minimum ages for the uplifts and faulting of various structures within and around the basins after the Paleocene, and have further importance in testing and recognizing the taxonomic nature of transitions from one NALMA to the next.

The third day was spent in the west-central Hanna Basin along the uppermost reaches of the Seminole Reservoir. Here the stratigraphy is undeformed and superposed, and the late Cretaceous Lancian — early Paleocene Puercan boundary can be located through the appearance of various fossil mammals. Eberle and Lillegraven (1998a, 1998b) described Late Cretaceous and Puercan mammals from numerous localities around the reservoir, with the Puercan fossil mammals representing the three zones of the Puercan Pu1-Pu3. These zones have been clearly identified based on the first appearance of certain taxa.

For orientation purposes, I have included a stratigraphic column of the area (see Fig. 1: Lillegraven and Eberle, 1999) and also a map (Fig. 2: Lillegraven et al., 2004) showing the areas studied during the field conference.





Lillegraven, Snoke, and McKenna  
 Figure 1

(Unlabeled version of February 16, 2004)

Figure 2. Location Map of Area

## Summary Day 1

**Day 1— Led by Jay Lillegraven and Pennilyn Higgins; location "The Breaks" (northeastern corner of the Hanna Basin)**



Figure 1. First look at The Breaks, Hanna Basin. Photo courtesy of Karen J. Lloyd.

Known as "The Breaks" (fig. 1), this area of badlands within the basin has been altered and sculptured by deposition, erosional unconformities, faulting, and multiple north-directed "out-of-the-basin" thrusts making the basin, structurally, a very complicated issue. As a result of the bending of the North American continent in this area, the surrounding mountains, including the Flat Top and Freezeout Hills, are all anticlinal uplifts that have their axes converging in the Hanna Basin.

The convergences and the generally north-vergent Dragonfly fault, which runs through the northeastern parts of basin, have caused some spectacular "out-of-the-basin" thrusts, and one in particular is "The Great Tortilla" syncline. Drag faulting, as the result of an out-of-the-basin thrust, has caused the oldest sandstone to be overturned and placed on the footwall of the thrust and the youngest and lighter colored sandstone being placed on the hanging wall.

The many ridges (fig. 2) in this area have made the mapping of the basin very difficult.

Our next stop for the morning was on top of the steeply dipping Upper Cretaceous Almond Formation, which dips to the south-southeast at an angle of  $70^\circ$  (Fig. 3). From this location we could see Kennaday Peak, the most northerly peak of the Medicine Bow Mountains, and Elk Mountain. The former in reality marks the south end of Hanna Basin. Feldspars from the mountain-building episodes around the basin are found in the Hanna Formation. From this stop, the Hanna Formation is seen to depositionally lie on older strata, forming an angular unconformity upon the Cretaceous sequence (left of the trees at the top of Fig. 3). At this point in the discussion Jay pulled out a pack of playing cards to use as an aid to show how the once horizontal beds spread out and gently dipped, before being crunched up by the uplifting of the Flat Top anticline and other mountain-building episodes to form a steeper dip and ultimately the newly defined edge of the basin.



Figure 2. Multiple Ridges in The Breaks. Photo courtesy of Karen J. Lloyd.

A short climb to Tepee Ring Ridge (so called for the rings of stones which once held down the tepees of the local tribes) and looking north above the Medicine Bow River, the Mowry Shale crops out at the far edge, underneath the Freezeout Hills. Structurally, the Mowry Shale and Allen Ridge Formation both have east-west faults throughout.

After a long, steep climb down into the basin, Jim Honey, a fellow participant at the field conference, talked about the crayfish burrows that occur in the layers of siltstone to fine-grained sandstone of the Hanna Formation (Fig. 4). Honey had noticed on previous visits to the basin that the burrows were very similar to those found in the Fort Union Formation in the Piceance Creek Basin in Colorado (Hasiotis and Honey, 2000).

The Hanna Formation in The Breaks is dominated by fine-grained rocks and carbonaceous shale, which grade into lignitic to bituminous coal. The darker facies contain evidence of ancient vegetation, which strongly suggests a well-watered depositional setting, and mollusc-bearing pond deposits, composed of fine-grained sandstone, intersperse the darker, carbonaceous shales (Lillegraven et al., 2004).

The presence and varying depths of the crayfish burrows in the sandstone suggest the water-table within the basin changed as a result of seasonal dryness and periods of flooding. Upper and lower lacustrine units, also present in the formation, provide further evidence of lake systems within the basin.

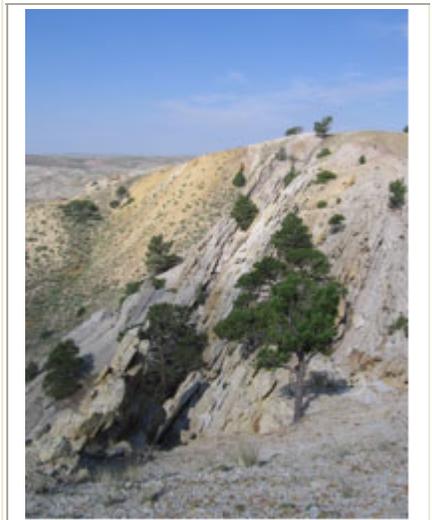


Figure 3. View to west at northeastern extreme of Hanna Basin. Almond Formation. Photo courtesy of Karen J. Lloyd.



Figure 4. Crayfish Burrows in the Hanna Formation, Hanna Basin. Photo courtesy of Karen J. Lloyd.

### Afternoon Session with Pennilyn Higgins

Penny took us to an area of The Breaks where she has been studying the relationship between vertebrate fossils and uranium roll fronts (Fig. 5). Roll front uranium deposits are formed where groundwater in permeable sandstone and conglomerate encounters the interface between reducing (anoxic) water and oxidizing (oxic) water conditions. This interface is known as the redox interface. Roll fronts often form tongue-shaped zones of altered rock with a distinct boundary with unaltered rock; at this boundary a change in color of the deposits may be observed.



Figure 5. Higgins' Research Area, Hanna Basin. Photo courtesy of Karen J. Lloyd.

At one of the sites where the end of a roll front had been observed, Penny pointed out that the altered rock was adjacent to and on the same stratigraphic level as the unaltered rock. The change in color of the deposits was obvious. The altered sandstone and conglomerates were more massive and blocky, bleached in color, and poorly cemented. In addition, sideritic concretions were common. The unaltered sandstone and conglomerate were thin bedded, yellowish in color and cemented with calcite. It was in the unaltered rock that fossils were found. On this particular visit, fossilized turtle fragments were found.

The chemical formula for fossil destruction can be found in the paper by Higgins, 2007, but here I will attempt to give a brief description of what happens when the roll front comes into contact with the chemical and geological components of the rock found in the Hanna Basin at the redox interface. Pyrite and calcite are common in the area, and when the oxidizing groundwater rolls

through, the sulfur in the pyrite is oxidized into sulphate, and the calcite is dissolved. Reduced iron remains to combine with the carbonate liberated from the calcite to form siderite (the purple layers in Fig. 5). Sulfuric acid is also produced during this chemical reaction.

Vertebrate bones and teeth are composed of apatite and when they become fossilized the composition of the bones and teeth become more like francolite, which is common in phosphate rocks used to make plant fertilizer. The presence of vertebrate fossils in unaltered rocks suggests that chemical reactions occurring during progression of the roll front encourage the dissolution of vertebrate fossils and tooth minerals. Further evidence that the chemical reactions in the roll fronts dissolve the vertebrate bone and tooth minerals, is the presence of lichen growing in the area. Phosphate must be released from apatite into a soluble form which is accessible to plants and encourage plant growth (Higgins, 2007).

Our last fossil location for the day was to Tom Buchanan's locality (now president of the University of Wyoming). This site has been very productive in the past, and fortunately the vertebrate fossils found have been useful in helping to determine the age of the formations within The Breaks.

The first day in the Hanna Basin was a very tiring and physically demanding excursion, but it was well worth it! The landscape, which has been sculptured over millions of years by tectonics and weathering, was a sight to behold and was beautiful in its starkness and contrasts. But, in addition to all of this, was the introduction of the importance of the connections between, what Penny termed, the four layers of science: vertebrate paleontology; biostratigraphy; geochemistry; and structural geology. Throughout the coming days, these connections would help us understand fossil vertebrates in their geological contexts and aid in the determination of the timing of post-depositional modification of stratigraphy within the basin.

## Summary Day 2

### Day 2: Morning Session

Day 2 was primarily led by Jay Lillegraven, with the topic of the day being the effects of the Simpson Ridge anticline and other uplifts on the Hanna and Carbon Basins. The Simpson Ridge anticline is situated in the east-central Hanna Basin and follows through to the southeastern part of the basin, while in the Carbon Basin it is situated at the northwestern edge. Essentially the anticline separates the two basins and formed no earlier than late Paleocene (Lillegraven et al., 2004).

On the west side of the Simpson Ridge anticline the faults within the Hanna Basin are contractional rather than extensional faults. The uplift of the Simpson Ridge and other anticline structures altered and deformed the stratigraphic sequences that were present in the area. The newly created Hanna Basin was formed as a consequence of locally late Laramide orogenesis.

Prior to the uplifts, the Hanna Basin was at the eastern part of a much larger ponded Green River Basin, which covered parts of southeastern Wyoming, Utah, and Colorado. Near the end of Paleocene and/or early Eocene time the eastern Green River Basin became subdivided, through basement-involved thrust faults, into the Hanna Basin and Carbon Basin, which are defined in the west by the Rawlins uplift and in the east by the Simpson Ridge anticline (Lillegraven et al., 2004).



Figure 1. Sandstone of the Hanna Formation Hanna Basin. Photo courtesy of Karen J. Lloyd.

Liz Hajek, a PhD candidate at Wyoming studying river avulsion (relocation) behavior in the Ferris Formation in the northern Hanna Basin, spoke about the consolidated sandstone bodies of Hanna Formation that were scattered about the area (Fig. 1). The bodies were a conglomerate of chert pebbles from the Cloverly Formation and clasts of granite from the surrounding the mountains.

Liz interpreted the conglomerates as representative of wide-spread fluvial and rapidly aggrading deposits and river systems prior to basin formation. From her research in the basin, Liz has been able to: determine paleo flow depth; recognize origins of gravels found in the sandstone bodies; and show the lateral extent and end of channels. When asked for a modern analog by Jay, Liz responded that the rapidly aggrading situation throughout the basin was similar to the modern day foreland basin of India and Bangladesh, where sediment is rapidly eroding off the Himalayan Mountains and being delivered into the Ganges river system and surrounding flood plains.

Throughout the morning, we visited areas that showed various faults running through the Hanna Formation and the Simpson Ridge anticline, which resulted in the Hanna Formation dipping steeply to the West.

The other major formation that was studied on Day 2 was the Ferris Formation (Fig. 2), which straddles the Lancia — Puercan North American Land Mammal "Age" (NALMA). The Ferris Formation contains more gravel, chert pebbles, and granites, and is therefore more resistant to weathering. The chert pebbles are from the Cloverly Formation and first

appear within the Ferris Formation, thereby distinguishing it from the underlying Medicine Bow Formation, which does not contain chert.



Figure 2. Ferris Formation in the Hanna Basin. Photo courtesy of Karen J. Lloyd.

The Ferris Formation and Hanna Formation together form a thick layer of Cretaceous and Paleocene sedimentary rock and is one of the thickest sections within the Rocky Mountains, despite the fact that the Hanna Basin is one of its smallest basins. At the eastern boundary of Hanna Basin, which includes Simpson Ridge anticline (Fig. 3), the Hanna Formation is not in depositional contact with the Ferris Formation. Rather, the younger Hanna Formation (late Torrejonian-Tiffanian NALMA) was thrust upon the older strata of the Ferris Formation (late Cretaceous).

In this part of the basin, and still on the Simpson Ridge anticline, the Hanna Formation dips steeply to the west, while the Ferris Formation is fairly vertical. The cause of this uplift has been attributed to a north-south directional out-of-the-basin fault running through the Hanna Formation and the anticline. The Hanna Formation appears to have steeply uplifted and then overturned.

Because the Hanna and Ferris Formations were both disrupted, and the fault shoots through the anticline, the faulting must have occurred after the Hanna Formation was deposited, and probably during formation of the Simpson Ridge anticline by deep-centered, basement involved faulting: so late Paleocene/early Eocene.

Another anomaly in this area is that as you move further away from the axis of the anticline the degree of dip steepens, whereas in a normal situation, the degree of dip generally lessens. Although also probably involved in the uplift of Simpson Ridge anticline, the diversity of dips most probably represent a high degree of variation in the angle of the out-of-the-basin fault planes as they cut through the stratigraphic column.

### Afternoon Session

For the afternoon we spent most of the time studying the Carbon Basin. The Carbon Basin is the smaller of the two basins and is located south-east of the Hanna Basin, being separated by the Simpson Ridge anticline.

The western edge of the Carbon Basin reflects the confluence of four local formations: Lewis Shale (Late Cretaceous); Medicine Bow Formation (Late Cretaceous); Ferris Formation (Lancian — Puercan); and Hanna Formation (Early Paleocene). Using biostratigraphy, tentative age constraints have been placed upon two local phases of deformation within the basin (Secord, 1998).



Figure 3. Simpson Ridge Anticline, Hanna Basin. Photo courtesy of Karen J. Lloyd.

Secord (1998) collected mammalian fossils from two areas in the lower Hanna Formation of Carbon Basin. Two faunas, which were found below an intraformational un-conformity within the lower Hanna Formation, represent either the latest Torrejonian or earliest Tiffanian, or possibly sample both NALMAs. A third and smaller fauna, found above the intraformational unconformity, represents middle or late Tiffanian.

Using the mammalian fossils found in the Carbon Basin, and based upon an unconformity in the Ferris Formation, Secord suggested that the Simpson Ridge anticline was active during deposition of the Ferris Formation. Kraatz (2002) however, disagreed, he countered that an unconformity between the Ferris Formation and the base of the Hanna Formation marked initiation of uplift along the Simpson Ridge, with additional deformation occurring after the deposition of the basal Hanna Formation.

Unfortunately the lack of age-diagnostic mammalian fossils within the area around Simpson Ridge has hindered efforts to accurately date the unconformity and the deformations of Simpson Ridge anticline. But interestingly, the faunas of the Carbon Basin (Secord, 1998) are similar in age to the fauna described by Higgins (2003) in the Hanna Basin near "The Breaks."

## Summary Day 3

### Day 3: The Ferris Formation

Day 3 was spent along the eastern bend of the Seminole Reservoir in the west-central Hanna Basin, Jaelyn Eberle's old PhD stomping grounds. The localities were about a two hour drive from Medicine Bow, and approximately 25 miles northeast of the town of Sinclair, but the drive took us through some beautiful scenery that included following the North Platte River cut through the cliff-forming sandstones of the late Cretaceous Mesaverde Group.

Since 1873, the land on which the localities are found has been owned by the same family of ranchers — the Miller Estate Company. Over the decades, the Millers have allowed many areas of research to be conducted on their land and are strong supporters of wildlife and paleontological research.



Figure 1. Orientation of the Ferris Formation, Hanna Basin. Photo courtesy of Karen J. Lloyd.



Figure 2. Ferris Formation arch, Hanna Basin. Photo courtesy of Karen J. Lloyd.

At our first stop, Jaelyn Eberle gave us an orientation of the area (Fig. 1 and Fig. 2). At this particular location, we were standing on a late Cretaceous (Lancian) outcrop of the Ferris Formation where keen eyes soon spotted fossilized wood and bone fragments.

From the outcrop we could see Elk Mountain to the south-east, with Dana Ridge in the foreground, and the Seminole Reservoir (Fig. 3). The strata are generally undeformed and superposed on each other, with the Ferris Formation dipping approximately 15° east into the basin axis.

The Ferris Formation stretches to the reservoir and beyond. The formation has been interpreted as a dominantly fluvial unit with occasional pond and minor lacustrine additions (Eberle and Lillegraven, 1998a; Lillegraven and Eberle, 1999). The Cretaceous sandstones are poorly sorted, inferring fast-moving braided rivers.

The Ferris Formation preserves the thickest, most continuous stratigraphic section spanning latest Cretaceous (Lancian) and earliest Paleocene (Puercan) time. At some 1,763 ft (537m) thick, the Puercan section zones (Pu1— Pu3) and is important for telling the story of mammalian diversification and evolution in the first million years after the demise of the dinosaurs at the Cretaceous-Tertiary (K-T) boundary.

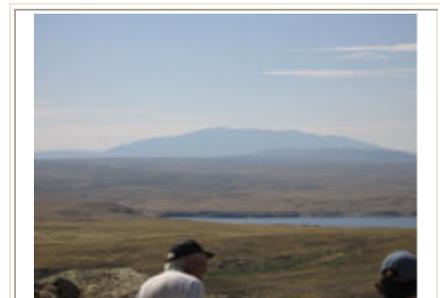


Figure 3. Elk Mountain and Dana Ridge from the Ferris Formation. Photo courtesy of Karen J. Lloyd.

Our next stop was the Ray Palate locality (UWyo locality V-91009), which is the highest stratigraphic assemblage of Lancian vertebrates, and is at the 624 meter level of the section. Fossils of several dinosaurian taxa have been found at this locality (Wroblewski, 1997; Lillegraven and Eberle, 1999) but as yet no mammalian fossils. During our stop at this locality, a few fossils were collected.

The Crashing Ledge locality (UWyo locality V-91010), at the 632 meter level, is the stratigraphically lowest Puercan locality in the Hanna Basin, defined on the basis of the first occurrence of the 'condylarth' *Protungulatum donnae*. Crashing Ledge is separated from the Ray Palate locality by an 8-meter-thick zone of temporal uncertainty, identified as the Lancian-Puercan 'zone' (Lillegraven and Eberle, 1999).

Prior to the field conference, paleomagnetic analyses had not been undertaken in this area. However, Barry Albright (participant from the University of North Florida) offered to carry out some analyses if a suitable mudstone sample could be found. A mudstone sample from Lancian strata at approximately the 605 meter level was taken. Upon analysis the sample indicated reversed polarity (correlated to magnetochron C29R), which is consistent with the magnetic polarity of the K-T boundary sections in the Western Interior. A subsequent field trip in late September located suitable rocks in Puercan strata for paleomagnetic analyses.

Further upsection, the group visited the middle Puercan Turtle Forest Locality (UWyo locality V-91019) and the late Puercan Sherri's Place Locality (UWyo locality V-91022), located near the edge of the Seminoe reservoir (Fig.4). Sherri's place marks the only Hanna Basin occurrence of the multituberculate *Taeniolabis taoensis*, whose first occurrence elsewhere defines the onset of Pu3 (Lofgren et al., 2004). Prospecting both turned up more turtle and crocodile fragments.

Our fifth and final stop was at the top of the stratigraphic section on this side of the reservoir. Fossil mammals from the stratigraphically highest localities in the section suggest a late Puercan or perhaps early Torrejonian age. Looking upsection and across the reservoir, the rocks are most probably Torrejonian in age, and fossil mammals are just waiting to be discovered!



Figure 4. Hunting Fossils at Turtle Forest Locality, Hanna Basin. Photo courtesy of Karen J. Lloyd.

## About the Author

Karen J. Lloyd gained her Master's Degree in Museum and Field Studies, with a concentration in paleontology and geology, from the University of Colorado, Boulder (advisor Dr. Jaelyn Eberle). She is employed in the collections department at The Wildlife Experience museum in Parker, CO, and is also a museum associate at the University of Colorado Museum of Natural History. Her current research is in the latest Eocene (Chadronian) studying the mammalian fauna of intermontane basins of Colorado.

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## **“Recapping The Breaks: Four Layers of Science”**

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### **The four layers are:**

- 1) Structural geology of the Dragonfly Fault System, especially the recognition of out-of-the-basin thrust faults (Jay discussed this at length the first night).
- 2) Roll-front geochemistry and taphonomy of vertebrate fossils.
- 3) Vertebrate paleontology of the Torrejonian-Tiffanian Boundary (the “Tiffejonian”) including looking for new *Fractinus palmorem* material.
- 4) Isotope geochemistry, the Paleocene-Eocene Thermal Maximum (PETM), and climate change at the Paleocene-Eocene Boundary.

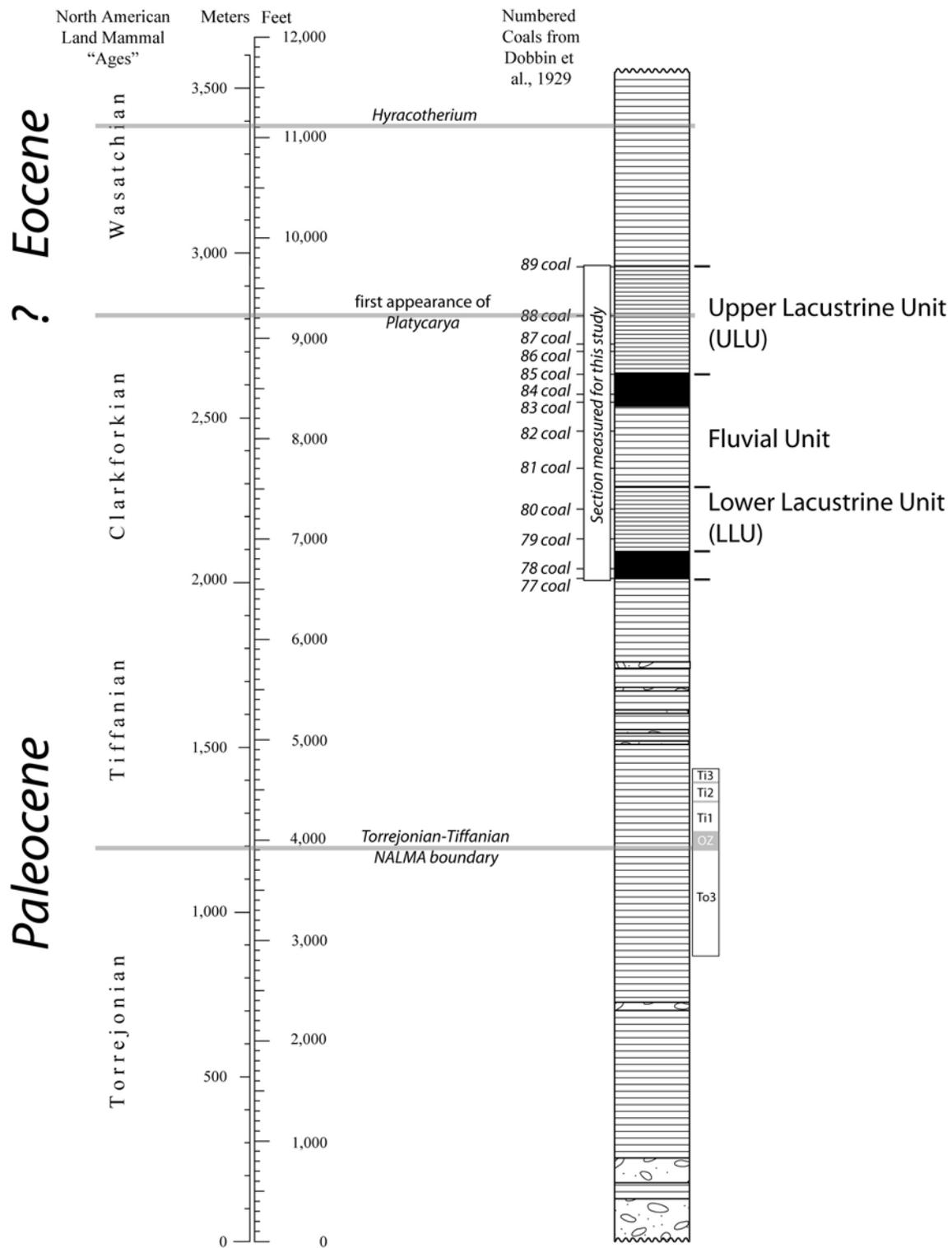


Figure 1. "Composite Section": Measured section for the entirety of the Hanna Formation in The Breaks. Measured by Jay and appended with other information. (Amended from Higgins, 2003; Fig. 2)

Chron	Polarity	EPOCH		Ma	North American Land Mammal "Ages"	Biochron		Characteristic species		
						Archibald et al., 1987	Williamson, 1996			
C24		Eocene	Early	54	Wasatchian					
		Paleocene	Late	55						
56	Clarkforkian									
57	Tiffanian			(Ti6)			<i>Plesiadapis gingerichi</i>			
57				Ti5			<i>Plesiadapis simpsoni</i>			
58				Ti4			<i>Plesiadapis churchilli</i>			
58				Ti3			<i>Plesiadapis rex</i>			
59				(Ti2)			<i>Plesiadapis anceps</i>			
60	Overlap zone			Ti1			<i>Plesiadapis praecursor</i>			
C27				Early	61	Torrejonian	To3	M zone		<i>Mixodectes pungens</i>
							To2	P-M zone		<i>Pantolambda caviroctus</i>
A-P zone		<i>Claenodon ferox</i>								
E-A zone		<i>Ellipsodon grangeri</i>								
62	To1	P-E zone		<i>Protoselene opisthacus</i>						
63	P-P zone		<i>Periplychus carinidens</i>							
C28			64	Puercan	Pu3					
					Pu2					
					Pu1					
C29		Cret.	Maes.	65	Lancian					
				66						

Figure 2. "Paleocene NALMAs" (Higgins, 2003; Fig. 6)

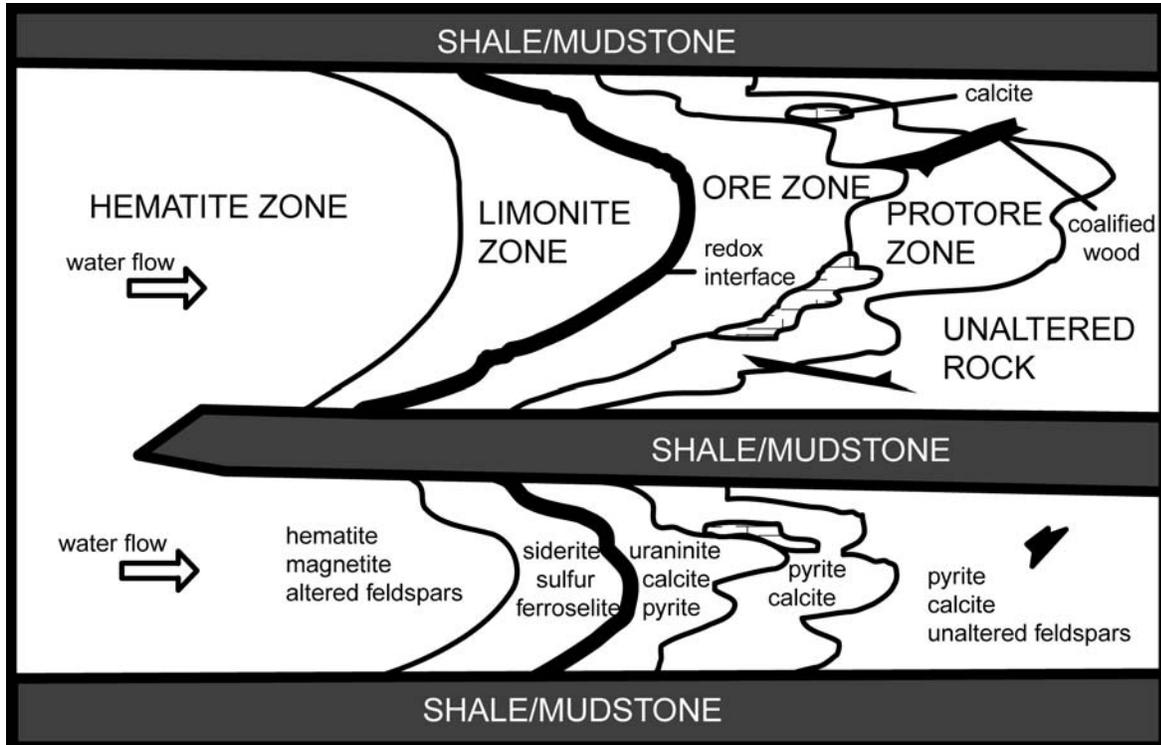


Figure 3. “Roll-Front-Schematic”: Shows various zones and mineralogy of a classic roll-front. (Higgins, 2007; Fig. 2)

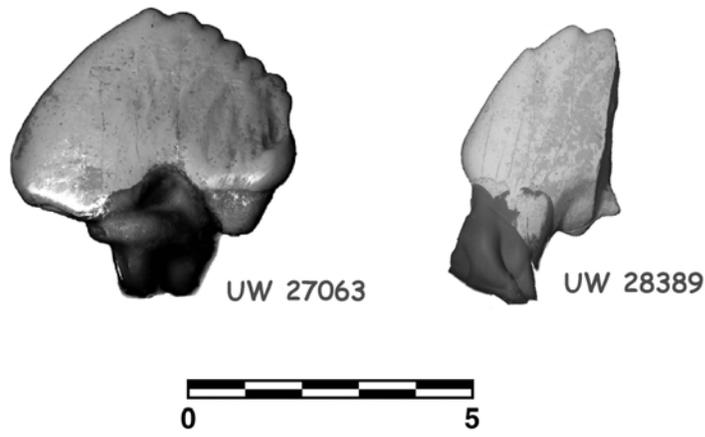
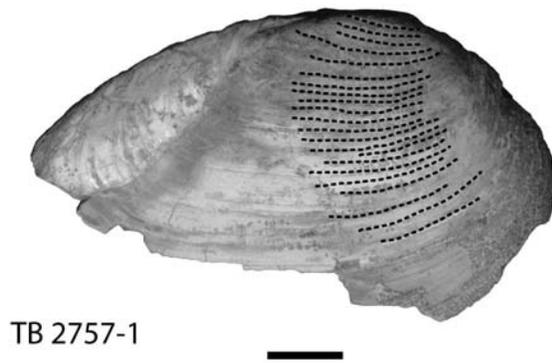
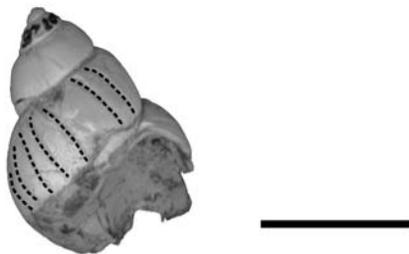


Figure 4. “*Fractinus\_palmorem*”: holotype (UW 27063) and referred specimen (Photo Credit: P. Higgins)



TB 2757-1



TB 2632-2

Figure 5. “Sampling with images”: Shows photos of two mollusks that we sampled for isotopic analysis in our study of PETM paleoclimate. (Photo credit: P. Higgins)

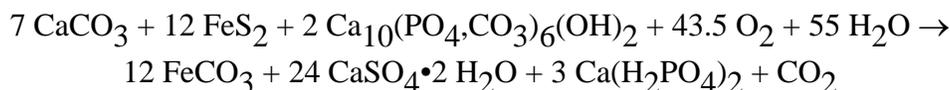
Three of these four layers are my own research foci. The vertebrate paleontological aspects were my Ph.D. research. The roll-front geochemistry was my Master's research. Isotopes are my current focus. The structural geology is all Jay, so I'll leave that to him.

### **Roll-fronts:**

Roll-front alteration (or more basically, oxidation alteration similar to that observed in roll-fronts) is the primary control on the distribution of vertebrate fossils in the lower parts of the Hanna Formation (below the lacustrine units). A roll-front occurs at the interface between oxidizing groundwater and reducing groundwater, where geochemical alteration is actively taking place. In front of the roll-front (where waters are reducing), rocks are unaltered. Behind the roll-front, in the oxidizing environment, rocks are altered. Simply put, oxidation of common sedimentary minerals like pyrite, forms sulfuric acid which dissolves any calcite in the sediment and any vertebrate remains (composed of bioapatite). Reduced iron liberated from the pyrite recombines with the carbonate from calcite to form siderite, which then is further oxidized to make iron oxides like hematite. The dark red color of altered rocks is due to iron oxides.

The dissolution of bioapatite releases soluble phosphate into the groundwater. The soluble phosphate is fertilizer, and in rocks where permeability is low, the phosphate remains in the sediment and helps support a vibrant population of lichens. Rocks in the vertebrate fossil bearing zone (VFBZ) are generally of low permeability, explaining the presence of the vertebrate fossils. Not all rocks of the VFBZ are unaltered, and where there is alteration, there are lovely flushes of lichens, which give the VFBZ a greenish hue when viewed from a distance. Outside of the VFBZ, rocks are all altered, and are also permeable enough that much of the soluble phosphate has also been removed, so lichen populations are generally smaller.

Here's the equation of the total reaction:



### **Vertebrate biostratigraphy:**

The vertebrate fossil bearing zone (VFBZ) brackets the Torrejonian-Tiffanian boundary. Because of rapid rates of sedimentation and the abundance of vertebrate fossils, this boundary could be studied in detail and the presence of an "overlap zone" was noted. I lovingly the period of time represented by the "overlap zone" as the "Tiffejonian," where the Tiffanian has clearly begun (defined by the first occurrence of *Plesiadapis*, but had *Plesiadapis* not been present, I would have called it Torrejonian due to the presence of several characteristically Torrejonian taxa like *Tetraclaenodon*. The "overlap zone" in the Hanna Formation is about 55 meters thick, far too thick to have been the result of reworking. Most obvious channels in the Hanna Formation are far less than three meters deep.

Near the top of the "overlap zone" were the localities that yielded the new species *Fractinus palmorem*. We were scouring those localities in the last two photos I took on day 1. Alas, we did not find any new *Fractinus* material, but we did find some other fun fossils, all of which are now at the University of Wyoming's Collection of Fossil Vertebrates.

### **The Paleocene-Eocene boundary:**

We already knew that the uppermost parts of the Hanna Formation are Eocene based upon a few characteristic mammal fossils and fossil pollen. We know that the lower parts of the Hanna

Formation are Paleocene, since the Torrejonian-Tiffanian boundary is there. In between, therefore, must be the Paleocene-Eocene boundary, which can be recognized geochemically by a rapid negative shift in carbon isotopic values. Carbon isotopic values gradually returned to their original values over a few 10's of thousands of years after this shift, an interval referred to as the Carbon Isotope Excursion (CIE). The CIE is associated with rapid warming at the Paleocene-Eocene boundary called the Paleocene-Eocene Thermal Maximum (PETM).

We found the onset of the CIE at about 2550 meters above the base of the Hanna Formation. By comparing chemostratigraphy from the Hanna Formation with that from Polecat Bench, it appears that whereas the CIE is represented in about 40 meters of rock at Polecat Bench, it may be as much as 400 meters thick in the Hanna Formation.

The onset of the CIE occurs between two lacustrine units (called, creatively, the lower lacustrine unit [llu] and the upper lacustrine unit [ulu]) in the otherwise fluvial Hanna Formation. Freshwater mollusks are abundant within these lacustrine units, as well as between the two units. New research is underway on the stable isotopes of these fossil mollusks to better understand climate change associated with the PETM.

**Talk Title: *Beginning of the Age of Mammals in the Hanna Basin, Wyoming***

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The Ferris Formation in the western Hanna Basin preserves the thickest, most continuous stratigraphic section spanning latest Cretaceous (Lancian) and earliest Paleogene (Puercan) time, and as such provides better understanding of the Lancian–Puercan (~K–T) vertebrate faunal transition and the first few geologic ‘minutes’ of the Paleogene in the Western Interior. In lower parts of the Ferris Formation cropping out northeast of Sinclair, Wyoming, 1,763 ft (537 m) of strata preserve diverse mammalian faunas that uniquely represent all three Puercan interval-zones –Pu1 through Pu3 (early–late Puercan time). The Lancian–Puercan (L–P) boundary zone is a ~8 meter-thick interval of channel sandstone bracketed by the highest occurrence of dinosaurs and the lowermost occurrence of Puercan mammals, specifically the first appearance in the basin of the ‘condylarth’ *Protungulatum*, the index taxon that defines onset of the Puercan (Lofgren et al., 2004; See Fig. 1). The Lancian dinosaurian fauna (Wroblewski, 1997) indicates that several species extend up to the L–P boundary zone and, from a biostratigraphic standpoint, dinosaur extinction seems to have been geologically sudden in the Hanna Basin (Lillegraven and Eberle, 1999; See Fig. 2).

Puercan rocks in the Hanna Basin preserve primarily a story of placental mammals, in particular the ‘condylarths’ or archaic ungulates. Mammals from early Puercan (Pu1) strata are predominantly small-bodied (similar in size to their Lancian counterparts), and they have generalized dentitions. With regard to mammalian evolution and diversification, the real action occurred 200,000 – 400,000 years *after* the L–P boundary, at the onset of the middle Puercan (Pu2) interval zone, wherein taxonomic diversity more than doubled (from 13 species in Pu1 to 27 species in Pu2) and body size increased dramatically. Much of this diversification is amongst ‘condylarths’ (see Fig. 3). Only half the number of specimens has been recovered from Pu2 compared to Pu1 localities in the Hanna Basin and consequently the increased diversity cannot be explained through taphonomy or sampling bias. Similar changes in diversity and body size amongst mammals are known to occur in Pu2/Pu3 correlatives elsewhere, including northeastern Montana (Clemens, 2002). To the south in Colorado’s Denver Basin, however, the mammalian diversification seems to have begun earlier, in late Pu1. In the Littleton Local Fauna (= Alexander and South Table Mountain localities in Littleton and Golden, respectively), at least 21 mammalian species are known and over half of these are ‘condylarths.’ Fossil discoveries to the north in the Washakie Basin (Greater Green River Basin) suggest that the Littleton Local Fauna is not alone in capturing this early onset of mammalian diversification in late Pu1 (Honey, pers. comm. 2008).

In trying to determine origins for middle Puercan mammals in the Hanna Basin, the concepts of ‘residents’ *versus* ‘aliens’ (following Weil and Clemens, 1998; Clemens, 2002) were applied to the Pu2 fauna of the Ferris Formation. Most Pu2 taxa in the Hanna Basin are considered residents in that they can be traced back to Pu1, which differs from the results of Clemens (2002) for the Pu2/Pu3 correlative faunas in NE Montana wherein nearly half of the taxa were considered aliens. However, the earliest Pu2 faunal assemblage in the Hanna Basin appears to be both stratigraphically and evolutionarily

intermediate between interval zones Pu1 and Pu2, and contains some Pu1 ‘holdovers’ (e.g., *Protungulatum*, *Mimatuta*, and *Eoconodon*) that are aliens in Pu1 faunas. Complicating the biogeographic picture is the observation that the Hanna Basin Pu2 fauna is much more similar to southern faunas in Colorado, Utah, and New Mexico than to northern Pu2/Pu3 correlatives in Montana and Saskatchewan. This suggests that by middle Puercan time, just a few hundred thousand years after the L-P (~K-T) boundary, distinct northern and southern mammalian faunal provinces existed, with little (if any) faunal interchange between them. Potential barriers to dispersal during middle Puercan time (that require testing) include: presence of the Cannonball Sea in northern Wyoming, mountain ranges, and climatic barriers. In the Pu2 fauna of the Hanna Basin, the larger ‘condylarths’ including *Ectoconus* and *Periptychus* appear to be aliens, and their distribution ranging from Wyoming to New Mexico and Texas raises the possibility of a southern origin for these mammals.

The Hanna Basin has provided considerable information on the Lancian–Puercan vertebrate faunal transition and subsequent mammalian evolution and diversification at in Wyoming. However, a more regional, multi-basin approach is integral to answering questions regarding the origins and biogeography of mammals at the onset of the Age of Mammals.



Figure 1. Lancian–Puercan boundary zone (~8 meters thick) constrained below by Lancian dinosaurian fauna from Ray Palate Locality (UW V-91009) and above by first occurrence of Puercan index taxon *Protungulatum* at the Crashing Ledge locality (UW V-91010) in the Ferris Formation, western Hanna Basin, WY. (Photo Credit: J. J. Eberle)

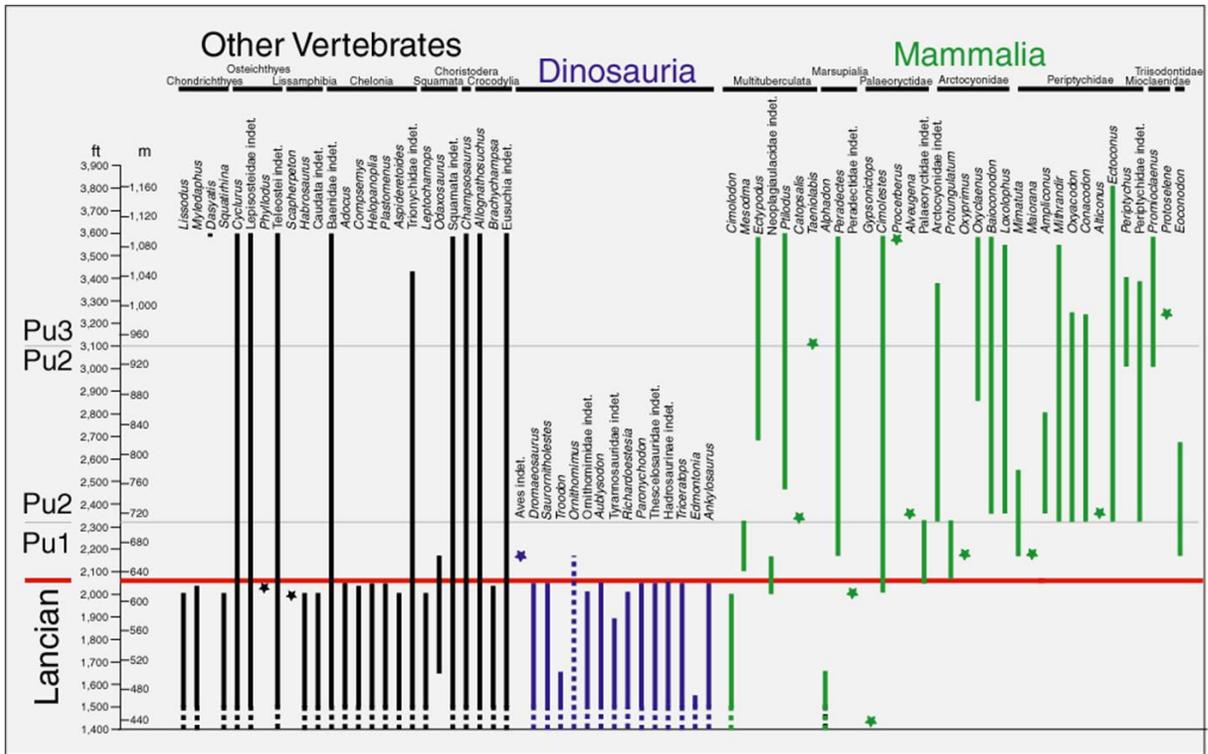


Figure 2. Ranges of fossil vertebrates known from strata of late Lancian through Puercan age in the Ferris Formation, plotted against true stratigraphic scale, from Lillegraven and Eberle (1999).

# Hanna and Carbon Basins Conference Application

Hanna and Carbon Basins, South-central Wyoming

Cosponsored by The University of Wyoming, Department of Geology and Geophysics

August 5-7, 2008

General theme — "The Importance of Field-based Geological Documentation to Paleobiological Research"

Co-organizers: Jay Lillegraven, Jaelyn Eberle, Pennilyn Higgins, and Mark Clementz

**Applications for the Field Conference are due April 30, 2008.**

## PRINCIPAL SCIENTIFIC GOALS FOR THE CONFERENCE:

This conference centers on special opportunities, as gained uniquely through the field study of rocks, to the discipline of paleobiology. The trip will be practical, emphasizing on-site examination of documented examples involving fossil vertebrates in detailed geological context. How did regional tectonism (expressed through changing sedimentary sources, appearance of well-defined basins, development of various nonconformities, and influences of superficial versus deep-centered faulting) affect our stratigraphic interpretations? In turn, how did post-depositional modification of physical stratigraphy affect our interpretations of organic evolution and biogeographic change through geologic time? How did basin evolution influence ancient geochemical environments, and how did that complex interaction affect the bias, or even the very existence, of a fossil record? In what new ways can stratigraphic sampling for isotopic geochemistry be used in concert with traditional biostratigraphy to help accept or reject claims of temporal correlation within and among basins? Looking broadly, how reliable are existing stratigraphic studies upon which so much of our interpretation of North American vertebrate evolution depends? Is field-based research still necessary in the 21st century, or has enough already been done on this continent and elsewhere? Do theoretically oriented specialists in paleobiology really need sophisticated knowledge about the strengths and limitations of procedures in field geology?

## GENERAL BACKGROUND:

The field conference will involve three day-trips (conducted from the town of Medicine Bow) to parts of the Hanna and Carbon Basins. These relatively tiny, Laramide basins in south-central parts of Wyoming have long been recognized for their astonishingly thick sections of marine and nonmarine, Upper Cretaceous and Paleocene strata. Originally, the Hanna and Carbon Basins were interpreted as discrete centers of deposition that had separate geological histories. We now recognize, however, that they represent eastern depositional components of an originally unified, enormous Green River Basin that secondarily became subdivided during the Eocene by deep-centered, basement-involved faulting. Because of regional contractional relationships, the eastern Hanna Basin exhibits the most complex structural history of any basin in the Rocky Mountain region. Recently mapped, out-of-the-basin thrusting is ubiquitous and magnificently expressed along the margins of adjacent uplifts. Such faulting greatly affects interpretations of local stratigraphy. Incontrovertibly superpositional assemblages of fossil vertebrates have become increasingly important in dating parts of local Paleocene sections, in testing the reliability of North American Land Mammal 'Ages,' and in recognizing the taxonomic nature of transitions from one NALMA to the next. Geological essentials related to paleogeographic interpretations (paleobiological and geological) of basin subdivision will constitute an important introduction to detailed features to be observed in the field.

## PRINCIPAL LOCALITIES TO BE VISITED AND TOPICS OF DISCUSSION:

Day 1 — 'The Breaks' (northeastern corner of Hanna Basin). Big-picture geologic setting; how to tell an erosional unconformity from a fault; what out-of-the-basin thrust faults look like; problems in documenting such thrusts; nature of local fossil-bearing section; Torrejonian-Tiffanian NALMA transition; geochemical concepts of uranium roll-fronts; taphonomic importance of roll-fronts; recognizing the Paleocene-Eocene boundary globally; and relevance of all this detail to paleobiology.

Day 2 — Margins of Simpson Ridge anticline (east-central Hanna Basin, northwestern Carbon Basin, southeastern Hanna Basin). Big-picture geologic setting; recognition of out-of-the-basin thrusting at multiple scales; significance of stratigraphic curtailment caused by down-section thrust vergence; appreciating blessings of marker beds; recognition of thrusting-related stratigraphic curtailment within largely unexposed sections; interpreting meanings of sudden changes in stratigraphic dip; recognition of overturned strata; coping with geopotential surprises during mapping; judging just where to measure a representative section; view toward eastern edge of Dana klippe and consideration of its paleogeographic significance; and relevance of all this detail to paleobiology.

Day 3 — Along uppermost reaches of Seminole Reservoir (west-central Hanna Basin). Big-picture geologic setting; viewing a gloriously undeformed and unequivocally superposed, fossil-rich section; Lancian-Puercan boundary and its

global implications; validity of subdivisions of Puercan NALMA; regional and more distant paleogeography of Puercan NALMA (faunal alliances with Denver Basin, Williston Basin, San Juan Basin, Chinese equivalents, etc.); value of such sections to other disciplines within paleobiology (especially invertebrates, palynology, macrofloras); view to western edge of Dana klippe and consideration of its paleogeographic significance; and relevance of all this detail to paleobiology.

#### NUMBER OF PARTICIPANTS

Because of the need to keep the group together within a complex terrain, the number of participants must be limited to approximately 35.

#### COST PER PARTICIPANT

Cost per participant, which will include transportation in the field, three nights lodging at The Virginian Hotel in Medicine Bow, breakfast and packed lunches (dinner not included), and field guides will be \$400. A limited number of scholarships for student members will be available.