# *LEPTOMERYX* DURING THE EOCENE-OLIGOCENE TRANSITION AND THE INTERNET AGE: STUDIES ON ENAMEL MORPHOLOGY CHANGE AND LEARNING VIA SOCIAL MEDIA

By

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To my family

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Scientists historically have had trouble communicating their research to the general public. Incorporating broader impacts projects into graduate research provides invaluable training as both scientists and educators, thus bridging the gap between scientists and the public. The scientific research presented here examines enamel morphology changes to the genus *Leptomeryx* occurring during the same interval as a dramatic climate change. The Eocene-Oligocene transition (~33 Ma) is associated with one of the most pronounced climate changes of the Cenozoic, with continental mean annual temperature dropping ~8ºC. *Leptomeryx* is a small, ruminant artiodactyl that spans the transition, known from the late Eocene (Chadronian North American Land Mammal Age, or NALMA) through the early Oligocene (Orellan NALMA). While it has been suggested that species of early Oligocene *Leptomeryx* have more complex enamel surface area than those found in the late Eocene, this has never been quantified. Occlusal surface enamel (OSE) areas were calculated for specimens of *Leptomeryx* from both the Chadronian NALMA (n=29) and Orellan NALMA (n=35) of

northwestern Nebraska. Areas of the OSE were calculated by isolating the enamel into polygons on digital photographs of each specimen. The mean areas confirm that the OSE significantly ($p=0.0001$) increased by approximately 27% from the Chadronian sample to the Orellan sample.

In an effort to communicate the results of this scientific research as well as related scientific concepts to the general public, a unique weblog (or blog) known as the Badlands Fossil Blogs was created. The popularity of blogs, especially for younger generations, potentially makes them a powerful platform for communicating scientific information. The potential for using science blogs in education as instructional tools is dependent on the reader's ability to learn the scientific information being presented. A two-part survey instrument was designed to test the level of perceived knowledge and interest as well as actual knowledge of nine specific, badlands-related topics within geology and paleontology. This survey was given to two groups of participants (a local fossil club and an undergraduate historical geology course) before and after reading 8 blog posts of The Badlands Fossil Blog over the course of 5 weeks. Significant gains of knowledge were seen for both the perceived knowledge ($p<0.0001$) and actual knowledge ($p<0.0001$). High interest levels in the pre-blog survey correspond to high levels of perceived knowledge in the post-blog survey, suggesting interest is correlated with learning. Perceived and actual knowledge share a similar relationship, suggesting the self-reported perceived data provide a reasonably accurate measure of a participant's actual knowledge. Closer analysis reveals that the blog was most successfully followed by a younger demographic, that the greatest gains in knowledge occurred in those topics about which participants had little to no previous knowledge, and that repetition of topics throughout the blog is an especially effective instructional method.

# CHAPTER 1
# INTRODUCTION: INTEGRATING RESEARCH AND EDUCATION

This thesis represents an alternative approach to a Master of Science program, integrating both traditional scientific research and a public outreach/education component. Many people outside of the current scientific community hold the view of scientists and researchers in the negative stereotype known as the "Ivory Tower," a phrase synonymous with academic elitism and exclusion. This phrase has been used to describe an environment in which intellectuals engage in pursuits that are disconnected from the practical concerns of the average individual's daily life. The inclusion of the Broader Impacts criterion into National Science Foundation grant proposals was introduced in 1997 to encourage researchers to incorporate into their research plans specific projects designed to promote education, outreach, and benefits to society (National Science Foundation, 2009). As a result of this initiative by the National Science Foundation, a number of scientists left their "Ivory Tower," albeit somewhat reluctantly for some. Some scientists today, however, are champions of broader impacts, trying to bridge the gap between researchers and the general public using various methods of education and outreach.

Ideally, a nontraditional thesis would consist of two related research projects. The first project would concentrate in the area of specialization within the graduate student's department, and would satisfy the department's requirements for scientific research. This project would be essentially the same as a "normal" Master's thesis research project, though perhaps of slightly smaller scope. The second component to the nontraditional thesis is the "broader impacts" project. Essentially, in order to complete this nontraditional component, the graduate student takes courses outside of their major department to learn a new skill set, in many cases resulting in the student earning a minor. For example, a student could take courses outside their major to learn how to better communicate and disseminate their scientific research to the public through science education or journalism. A graduate student could minor in museum studies to learn how to communicate through museum exhibits. One could even study in areas as varied as political science or speech and theater, to learn public speaking skills or how the political system operates in an effort to become a science advocate in our government. The inclusion of a broader impacts component to a nontraditional thesis allows for great flexibility, including what outside area the student decides to focus on, and how they structure and design their project. Utilizing this approach, one would preferably not just set up a broader impacts project, but also use this project to answer a second research question, again specifically designed around the subject of interest to the researcher. This nontraditional thesis combines scientific research in the field of paleontology with a science education broader impacts project.

Chapter 2 of this thesis presents paleontological research on changing enamel morphology seen in the genus *Leptomeryx*. The genus *Leptomeryx* is a unique clade, considered by some to be one of only three groups to have speciated around the time of the Eocene-Oligocene Transition (Prothero and Heaton, 1996). This transition towards a cool climate marks the dramatic shift from the “greenhouse” world of the past to the “icehouse” world of the present, and is marked by an approximate 8°C drop in mean annual temperature (Zanazzi et. al, 2007). Ancient soil (paleosol) composition indicates vegetation changes from the moist, warm forests of the Chadron Formation to drier, open grasslands seen in the Brule formation (Retallack, 1990). This change in paleosol composition and vegetation change corresponds temporally to the end of the Chadronian NALMA (North American Land Mammal Age; 37.0-33.8 Ma) and the beginning of the Orellan NALMA (33.8-32.0 Ma; Prothero, 1996). These ages place the changes in soil composition and vegetation as occurring during the Eocene-Oligocene Transition (EOT).

Previous research has shown qualitative differences between *Leptomeryx* from before and after the EOT. *Leptomeryx* from the Chadronian NALMA are characterized by smooth, simple enamel on their molars (Heaton and Emry, 1996; Korth and Diamond, 2002). In contrast, *Leptomeryx* from the Orellan are characterized by more complex enamel, with vertical crenulations and the presence of an extra infolding of enamel known as the *Palaeomeryx* fold, most notably seen on the lower molars (Heaton and Emry, 1996; Korth and Diamond, 2002). Eating plants causes more wear on dentition than does eating meat for a variety of reasons, and a common adaptation seen in animals to deal with the ingestion of abrasive plants is an increase in the functional durability of dentition (Janis and Fortelius, 1998). This increase can be achieved in several ways, such as increasing the hardness, density, or amount of enamel available for wear. The purpose of this research component of this thesis is to determine if the addition of crenulations and the *Palaeomeryx* fold results in a quantifiable increase of enamel on the occlusal surface (wear surface) of *Leptomeryx* lower molars. Area measurements taken from the occlusal surface enamel of both Chadronian and Orellan *Leptomeryx* were compared to determine if there is a statistically significant difference in the amount of enamel is between the two *Leptomeryx* samples.

This shift in complexity in *Leptomeryx* molars occurs during the same interval as the shift from soft, tropical vegetation to more abrasive, arid-adapted plants during the EOT. It is possible that the increasing complexity seen in *Leptomeryx* molars is a response to ingesting the harsher vegetation seen after the EOT. Understanding changes such as this is important, as they potentially link changes in climate and vegetation, and show mammalian responses to these climate and vegetation changes. Studying the changes seen in *Leptomeryx* is especially important because it is an example of one of the less common evolutionary developments for increasing durability of dentition, and because this change occurred during a period of which some have called the most pronounced climate event of the Cenozoic (Janis and Fortelius, 1998; Zanazzi et. al, 2007). Understanding these changes in the past is critical in that it may help us predict responses to the climate changes that the world is experiencing today.

Chapter 3 covers the broader impacts component of this thesis. When determining the form that the project would take, a personal interest in education and the emerging phenomenon of social media led to the creation of a project designed to determine if a science blog could be used as an effective teaching tool to inform the public about specific topics in geology and paleontology. The Badlands Fossil Blog was created in an effort to communicate scientific information related to the paleontological research completed for this nontraditional thesis. This included not only the primary research on the genus *Leptomeryx* and the morphological change to their enamel, but also broader concepts related to the paleontological research, such as badlands geology and fossils, the Eocene-Oligocene Transition, methods used by scientists to determine past temperature and diet of ancient animals, and more controversial topics like speciation, adaptation, and evolution.

The popularity of blogging cannot be denied, with between 346 and 365 million active internet users worldwide reporting to having read blogs in 2008, and with reading blogs being the most reported internet activity in 2006 and 2007 (Universal McCann, 2008). According to a Universal McCann study, approximately 13.6% of active internet users reported reading science blogs, making it the 10th most read blog type (Universal McCann, 2008). Science blogs are those that focus primarily on commenting on scientific issues, though some branch out to also include a wider range of topics and their relationship to science, such as politics and religion (Bonetta, 2007; Wilkins, 2008). With the potential to reach a vast audience, scientific blogging could potentially represent an effective way to convey scientific information and to clarify any misconceptions held by the general public in a new and interesting way. Free choice learning (learning that occurs outside of formal educational environments) is the most dominant form of learning, largely because it is controlled by the learner, choosing when and where to learn based on personal interests (Falk, 2001; Falk and Dierking, 2002). With the popularity of blog reading, learning via science blogs has the potential for being a major source of free choice learning.

As blogs became popular their applications in education were explored, however very little scholarly research exists on the subject. To date, most studies on blog applications in formal, classroom education have focused on the use of teacher and student blogs, and less on using blogs as a source of knowledge or as an instructional tool. Much is written on the success of both teachers and students using blogs as learning logs, or as pages for sharing classroom information (Stiler and Philleo, 2003; Wagner, 2003; Williams, 2004; Duffy and Brund, 2006; Alexander, 2008; Luehmann and Frink, 2009). Using blogs in this fashion has shown many educational benefits, such as the development of critical thinking skills in students, increased communication between both the students and the teacher, and as a way to organize learned material based on a timeline, subject matter, or other defined category (Oravec, 2002; Downes, 2004; Ferdig and Trammell, 2004; Williams, 2004; Brescia and Miller, 2006; Richardson, 2006; Pimpare and Fast, 2008).

The Badlands Fossil Blog project potentially represents a new application of blogs in education, with the blog itself being the instructional tool, much the same way that a teacher might use a textbook or instructional video in the classroom. This study presents statistical data on perceived and actual learning associated with reading the blogs, achieved by comparing the results of a survey given before and after participants read the Badlands Fossil Blog. Because of the sheer number of people who are gaining information from blogs, it is important for bloggers to put out quality information, and it is important to discover if readers are learning the material the bloggers are intending to convey. Using the Badlands Fossil Blog will determine if a science blog can be used effectively for conveying important scientific concepts, and under which circumstances a blog is most successful.

CHAPTER 2

QUANTIFYING *LEPTOMERYX* (MAMMALIA, ARTIODACTYLA) ENAMEL SURFACE AREA ACROSS THE EOCENE-OLIGOCENE TRANSITION IN NEBRASKA

## Introduction

The Eocene-Oligocene Transition (EOT) is associated with a rapid, large-scale climatic event. As early as a century ago, paleontologists began to notice differences between the Eocene and Oligocene. Stehlin (1909) called the differences between Eocene and Oligocene European mammal *la grand coupure*, “the great break.” Osborn (1910) noted a shift from mammal faunas dominated by leaf eaters to those with more specialized teeth for harsher vegetation in the Big Badlands of South Dakota. MacGinitie (1953) first proposed that a major climatic event occurred in the Oligocene based on differences between the Goshen (earliest Oligocene) and Bridge Creek (late early Oligocene) floras from Oregon. Potassium-argon dating of leaf assemblages (Evernden and James, 1964), coupled with a univariate analysis of the percentage of entire-margined dicot species, led Wolfe and Hopkins (1967) to confirm MacGinitie’s hypothesis, determining that the cooling occurred within an interval as short as one million years, and no more than two million. Recent isotopic studies indicate a ~2-3°C drop in the marine record (Zachos et al., 1994; Lear et al., 2000), and a corresponding drop of ~8°C over a span of 400,000 years in the terrestrial record (Zanazzi et al., 2007). These and other studies have provided evidence of the timing of the climate change, the extent of the change, and the effects of the change on the ecosystem.

The dramatic climatic changes occurring at the Eocene-Oligocene boundary resulted in faunal turnover in the marine record (Aubry, 1992; Baldauf, 1992), as well as in the terrestrial record of North America among gastropods, amphibians, and reptiles (Evanoff et al., 1992; Hutchison, 1992). In contrast, relatively little change is seen among most mammal groups, with the possible exception of large brontotheres that went extinct in the latest Chadronian (Prothero and Heaton, 1996). Prothero and Heaton (1996) consider *Leptomeryx* to be one of only three taxa within the White River mammalian fauna observed to have speciated around the time of the EOT (the other groups being *Miniochoerus* and *Palaeolagus*). First appearing in the middle Eocene (late Uintan NALMA, ~41 Ma; Webb, 1998), these small artiodactyls are known most commonly from their recognizable selenodont dentition, the morphology of which changed before their extinction by the early Miocene (early Hemingfordian NALMA, ~18 Ma; Webb 1998).

Heaton and Emry (1996) describe *Leptomeryx* as a cohesive group of approximately seven species, the earliest of which were placed in the genus *Hendromeryx* by some (Black, 1978; Storer, 1981). Along with these early species (*H. defordi*, *H. wilsoni*, *H. esulcatus*), Heaton and Emry (1996) recognize *L. yoderi*, *L. mammifer*, *L. speciosus*, and *L. evansi* as valid members of the genus *Leptomeryx*. *L. evansi* can be distinguished from earlier species based on several characters. Most specimens of *L. evansi* have a well-developed *Palaeomeryx* fold on each of the lower molars (Heaton and Emry, 1996; Zanazzi and Kohn, 2008). The primary ridge behind the P3 protoconid of *L. evansi* is usually more labial than lingual, although considerable variation has been noted in this character (Heaton and Emry, 1996). Strongly developed vertical crenulations around the tooth crowns also distinguish *L. evansi* from other species, though this feature is likewise variable. Heaton and Emry (1996) contend that while several species existed in the Eocene, no variation exists to suggest that more than a single species (*L. evansi*) is present in the Oligocene of the Great Plains.

Korth and Diamond (2002) offer an alternate hypothesis, contending that as many as three distinct species of *Leptomeryx* are present in Oligocene sediments from North America. Analyzing the same characters as Heaton and Emry (1996), these authors agree that the presence of the *Palaeomeryx* fold on the lower molars is fairly consistent among the Orellan specimens, and that the degree of crenulations is generally stronger in the later specimens as well. They also contend that two features of the upper dentition, which were not analyzed by Heaton and Emry (1996), seem to be species diagnostic: (1) the amount of enamel wrinkling (reflective of the crenulations seen in the lower dentition); and (2) the development of a mid-lingual column (protostyle). In addition to *L. evansi*, which they state as being the most common of any of the Orellan species of the genus, Korth and Diamond (2002) assert that *L. exilis* (Cook, 1934) is also found in the Orellan. The smallest species of the genus, *L. exilis* has little to no crenulations and lacks a *Palaeomeryx* fold on the lower molars. The authors also describe a new Orellan *Leptomeryx* species, *L. elissae* (Korth and Diamond, 2002). Like *L. exilis*, this species lacks a *Palaeomeryx* fold and has less crenulated molars than *L. evansi*, but is distinguished by being intermediate in size between *L. evansi and L. exilis*.

Other species have been named from the Whitneyan NALMA, including *L. lenis* (Cook, 1934), *L. minimus* (Frick, 1937), and *L. obliquidens* (Lull, 1922). Korth and Diamond (2002) contend that based on size and morphology, *L. lenis* is possibly a junior synonym of *L. evansi*, *L. minimus* is possibly a junior synonym of *L. exilis*, and *L. obliquidens* exhibits enough variation to potentially be its own valid species. Only two species have been named from isolated and fragmentary specimens from Arikareean sediments. *L. transmontanus* was described by Douglas (1903), but was later assigned by Rasmussen (1977) to the more derived genus of leptomerycid, *Pronodens* (Koerner, 1940), in an unpublished dissertation (Taylor and Webb, 1976; Korth and Diamond 2002). The other Arikareean *Leptomeryx* specimen is *L. agatensis* (Cook, 1934), known only from the holotype (AMNH 81505). Korth and Diamond (2002) argue that this specimen is not distinguishable from *L. evansi* in its size and morphology.

While the number of species included in the genus *Leptomeryx* is certainly of vital importance to the taxonomy of the genus, when looking at morphological variation between the Chadronian and Orellan *Leptomeryx*, it seems reasonable to group the species together based on their age. Generalized morphological characteristics unite the species from the Chadronian and Orellan NALMAs into two broad sample groups. In general, the Chadronian specimens have simple enamel, little to no crenulations, and lack a *Palaeomeryx* fold. In general, the Orellan specimens have more complex enamel, are more strongly crenulated, and most often exhibit the presence of a *Palaeomeryx* fold. The size of the *Leptomeryx* specimens is variable across the Chadronian-Orellan boundary, but with enough overlap to suggest that it is not a factor in comparing species across the boundary. In fact, because there seems to be so much variation within the genus as to make the number of valid species included within it so contentious, comparing the enamel based on the age of the sediments in which they are found provides a simplistic, general trend of the enamel evolution of the genus.

A number of key morphological characters have been demonstrated to have changed between the primitive to the more advanced *Leptomeryx*. The development of the *Palaeomeryx* fold as well as vertical crenulations in the genus *Leptomeryx* has been noted before by several authors (Heaton and Emry, 1996; Korth and Diamond, 2002). Heaton and Emry (1996) made measurements on the development of the *Palaeomeryx* fold in order to determine variations among species. Korth and Diamond (2002) re-examined these measurements to re-evaluate Orellan *Leptomeryx* specimens. Figure 2-1 illustrates characters which distinguish Chadronian and Orellan species of *Leptomeryx*. The Chadronian-aged *Leptomeryx* specimens display a more simple enamel pattern, devoid of crenulations and a *Palaeomeryx* fold. The Orellan-aged *Leptomeryx* specimens demonstrate more complex enamel, with strong vertical crenulations and a well-developed Paleaomeryx fold. The development of more complex enamel has thus been shown qualitatively, but no author has yet quantified this change in enamel. The purpose of this study is to determine if a quantifiable change can be determined between specimens of Chadronian and Orellan *Leptomeryx*. A significant increase in the amount of enamel in the later *Leptomeryx* species is expected.

## Materials and Methods

The *Leptomeryx* specimens from the Florida Museum of Natural History (UF) as well as the University of Nebraska State Museum (UNSM) all originate from various fossil localities in classic badlands exposures in Sioux and Dawes counties in the northwestern panhandle of Nebraska (Fig. 2-2). The fossils in the two museum collections represent collection efforts over numerous years. Based on LaGarry’s (1998) and Terry’s (1998) work in revising and correlation of the White River Group, the *Leptomeryx* specimens analyzed were from either the Peanut Peak Member or the Big Cottonwood Creek Member of the Chadron Formation, or from the Orella Member of the Brule Formation.

Specimens were first determined as belonging to either the Chadronian NALMA or the Orellan NALMA. LaGarry's (1998) and Terry's (1998) work was taken into account during this process. The new correlation of the units places the old "Orella A" unit within the Chadronian NALMA, placing the boundary between the Chadronian-Orellan sediments approximately 10 meters above the previous boundary. With this in mind, *Leptomeryx* lower molars with definite stratigraphic information were chosen for analysis. Each population was then further subdivided into 3 wear stages: Juvenile, Adult, and Senior. The wear stages roughly compare to the ontogenetic stages outlined in Clark and Guensburg (1970).

The Juvenile wear stage was selected for analysis for two reasons: (1) this wear stage had the greatest number of specimens; and (2) specimens in this stage of wear showed the best preservation of distinguishable dental characters. Ultimately, 29 specimens from the Chadronian and 35 from the Orellan were included within the analysis. Lower first and second molars (m1s and m2s, respectively) were determined to be similar enough in size, and therefore were both included in the analysis. Isolated lower molars in which the tooth position could not be determined were given the distinction of mx. When both the first and second lower molars were present in the same specimen, the m2 was analyzed to ensure independence of samples. Two-dimensional digital photographs of each specimen in occlusal view were taken using a Nikon D60 SLR camera. The digital images were then uploaded onto a computer and ImageJ™ software was used to draw polygons around the occlusal surface enamel (OSE), excluding any exposed dentine (Fig. 2-3). The areas for each polygon were determined using ImageJ™ calculated in $mm^2$. Length and width measurements for each tooth were also taken using ImageJ™ software. All measurements were stored as a Microsoft Excel file. The average OSE area was calculated for both the Chadronian and the Orellan *Leptomeryx* samples. Using xlstat™ 7.5, a Shapiro-Wilk test was used to determine the distribution of the Chadronian and Orellan samples. A Mann-Whitney U test was then preformed to determine if the null hypothesis, i.e., that the two samples are equal, could be rejected.

## Results

Table 2-1 shows the OSE area for each specimen. Values for the Chadronian sample ranged from 6.02 $mm^2$ to 13.26 $mm^2$, with an average of 8.67 $mm^2$. Values for the Orellan sample ranged from 7.30 $mm^2$ to 16.43 $mm^2$, with an average of 10.98 $mm^2$. These areas were normalized by dividing the area by the length plus the width of the specimen (A/(l+w)) to ensure that tooth size did not factor into the statistical analysis (Chadronian average = 0.827, Orellan = 0.999).

Using xlstat™ 7.5, normality tests were conducted on the data to determine the distribution of the samples. A Shapiro-Wilk test was used to test the null hypothesis (H0), that the samples follow a normal distribution. The two samples (Chadronian and Orellan) were tested individually. For the Chadronian specimens, the Shapiro-Wilk test determined that the null hypothesis should be rejected in favor of the alternate hypothesis (Ha), that the specimens do not follow a normal distribution, with a p-value of 0.017. The risk to reject H0 while it is true is less than 1.74%. However, the Shapiro-Wilk test determined that the Orellan specimens were normally distributed, with a p-value of 0.62 (Table 2-2). Because the comparison of the Chadronian and Orellan OSE would be comparing normal to non-normal data, a non-parametric Mann-Whitney U statistical test was used.

A Mann-Whitney U test was performed to determine if the two samples were significantly different. In this test, the null hypothesis (H0) assumes that the difference between the means is equal to 0. The alternative hypothesis (Ha) is that the difference between the means is different from 0. The computed p-value of 0.0001 is lower than the significance level alpha=0.05, therefore the null hypothesis is rejected in favor of the alternative hypothesis (Table 2-2). The test concludes that the risk to reject the null hypothesis while it is true is lower than 0.01%. The Mann-Whitney U test demonstrates that the Chadronian and Orellan samples are significantly different.

Figure 2-4 shows a Box and Whisker Plot for the mean values of the OSE for both the Chadronian and Orellan samples. A significant difference in the area of OSE is shown between the Chadronian *Leptomeryx* samples and the Orellan *Leptomeryx* samples. The significant difference can be seen by the difference in the median values between the samples. The Chadronian sample has three outliers that fall outside of the 95% confidence range, the implications of which will be further discussed below. The Orellan sample shows a larger range than the Chadronian sample, and is more normally distributed, based on the equal length of the “whiskers.” While Figure 2-4 shows equal length “whiskers” for the Chadronian as well, it is the outliers that cause this sample to be non-normally distributed.

## Discussion

Previous research has shown qualitative changes in the tooth morphology of Chadronian *Leptomeryx* when compared to Orellan *Leptomeryx* (Heaton and Emry, 1996; Korth and Diamond, 2002). The results presented here demonstrate that these changes can be measured quantitatively. A significant increase is seen in the amount of OSE across the Chadronian-Orellan boundary. The mean areas confirm that the OSE increases by approximately 27% from the Chadronian sample to the Orellan sample. This increase results from complex, crenulated enamel, rather than an increase in the size of the tooth, a change in the basic shape of the tooth, or an increase in the crown height. The addition of the *Palaeomeryx* fold also provides a significant source of extra enamel on the occlusal surface of the Orellan *Leptomeryx* population.

While there is a significant increase based on the mean areas of the two *Leptomeryx* samples, considerable overlap is seen in the overall areas between the specimens (Fig. 2-4). This is likely a result of the degree of variability demonstrated in the molars of the genus as a whole. Within both the Chadronian and the Orellan samples, a number of specimens show characteristics markedly different from the majority of other specimens. Four *Leptomeryx* specimens from the Chadronian (UF 201024, UF 207558, UNSM 123974 and UNSM 124099) display unusually large OSE areas compared to the rest of the Chadronian sample (A=11.38, A= 13.256, A=10.19, and A=12.91 $mm^2$, respectively). A few factors might account for these anomalous areas. UF 207558 and UNSM 124099 both demonstrate the presence of a *Palaeomeryx* fold, though neither specimen has particularly strong crenulations. UNSM 123974 appears to have the same extremely weak crenulations, though it lacks a *Palaeomeryx* fold. Stratigraphic information for each rules out the possibility that they are Orellan in age, with little to no possibility that either specimen is displaced from younger sediments. It is possible that these specimens represent an early evolution of the advanced grade of *Leptomeryx* during the Chadronian. UF 201024 has neither crenulations nor a *Palaeomeryx* fold, but appears to be slightly less worn than the other

Chadronian specimens. This unworn enamel likely accounts for the specimen's unusually high OSE area.

The Orellan *Leptomeryx* sample also has a number of specimens that have unusually low areas compared to the rest of the specimens from the same aged sediments. Four specimens (UF 207776, UNSM 65047, UNSM 101835, and UNSM 101840) have areas less than 8 $mm^2$ (A=7.98, A=7.99, A=6.45, and A=7.30 respectively), more than two $mm^2$ less than the mean value for the Orellan sample, and lower even than the mean for the Chadronian *Leptomeryx*. UF 207776 exhibits neither crenulations nor a *Palaeomeryx* fold. The presence of a *Palaeomeryx* fold is also missing in UNSM 65047 and UNSM 101835, though both specimens display weak crenulations. A fully developed *Palaeomeryx* fold and well-developed crenulations are present in only one of these specimens, UNSM 101840. Each of these specimens is identified only to the generic level. Because UNSM 101840 has both crenulations and a *Palaeomeryx* fold, it likely represents *L. evansi*, and it's relatively low OSE area is anomalous. It is possible that UF 207776, UNSM 65047, and UNSM 101835 might represent one of the *Leptomeryx* species (*L. exilis* or *L. elissae*) described by Korth and Diamond (2002) instead of the more common *L. evansi*. The specimens could also be more primitive morphologies from the Chadronian that survived into the Orellan.

The shift seen in the complexity of *Leptomeryx* enamel coincides with a break between two different types of paleosol compositions seen in the Chadron and Brule Formations (Retallack, 1983). A distinct change in paleosol composition occurs between the clayey, pink and green banded Chadron Formation and the silty, nodular, brown to white Brule Formation (Retallack, 1983). The difference in the paleosol composition suggests a decrease in mean annual rainfall by as much as 750 mm (Retallack, 1983). Evidence for a drier climate in the Oligocene is also indicated by a decreased abundance of kaolinite and increased abundance of smectite and illite in paleosols higher in the sequence (Retallack, 1990). The paleosols also contain root traces that provide evidence of changing vegetation. These root traces indicate moist forests of the Eocene giving way to dry forests by approximately 34 Ma, the appearance of dry woodlands by 33 Ma, wooded grassland by 32 Ma, and finally large areas of open grasslands by 30 Ma (Retallack, 1992).

The Peanut Peak and Big Cottonwood Creek members of the Chadron Formation correspond temporally to the upper part of the Chadronian NALMA (37 to 33.8 Ma; Prothero, 1996). The Orella Member of the Brule Formation corresponds temporally to the Orellan NALMA (33.8-32 Ma; Prothero, 1996). This change in lithology of the two units, and the corresponding shift from the Chadronian to the Orellan NALMA, therefore occurs at approximately the time of the Eocene-Oligocene Transition. The shift from the moist forests of the Eocene to open grasslands in the Oligocene (Retallack, 1992) is interpreted to reflect the ~8°C drop in temperature shown in the North American terrestrial record (Zanazzi et al., 2007). The increase in enamel shown by the *Leptomeryx* may be related to the difference in vegetation in the Orellan versus the Chadronian, which in turn corresponds to the dramatic climatic shift during the Eocene-Oligocene Transition.

I interpret the development of the significantly more complex enamel seen in the Orellan *Leptomeryx* as an evolutionary response to the tougher, more arid adapted vegetation. Isotopic work demonstrates a significant difference in $\delta^{13}C$ values between the Chadronian and Orellan *Leptomeryx,* which supports this assumption (Zanazzi and Kohn, 2008). These authors propose two interpretations: (1) although unlikely (Cerling et al., 1997), if C4 grasses were present, *L. evansi* exhibits a stronger preference for C4 plants relative to *L. speciosus*; or (2) in an ecosystem with only C3 plants, a shift in preference among the *Leptomeryx* from woodland to more open environments across the Eocene-Oligocene transition. Either interpretation suggests that *Leptomeryx* could have been ingesting tougher vegetation.

Herbivory causes more wear on dentition than carnivory for a variety of reasons (Janis and Fortelius, 1988). The structure of the plant material itself can be abrasive and tough to masticate, and particles can accumulate upon plants (Janis and Fortelius, 1988). An increase in the functional durability of dentition is a common adaptation to ingesting more abrasive plants. This increase is achieved by either: (1) increasing the wear resistance of the dental tissue; (2) increasing the amount of dental tissue available for wear; or (3) employing both of these methods. The wear resistance of enamel is increased by increasing the hardness, density, or amount of enamel.

As discussed in Janis and Fortelius (1988), greater wear resistance of dental tissue in Orellan *Leptomeryx* was achieved by increasing the amount of enamel available for wear. The development of more complex enamel, chiefly the addition of the *Palaeomeryx* fold and vertical crenulations, increased the area of enamel between the Chadronian and Orellan leptomericids by approximately 27%. The evolution of more complex enamel would have resulted in an artiodactyl better adapted to new environmental conditions, most probably resulting from the dramatic climate change at the Eocene-Oligocene boundary.

Table 2-1. Areas for occlusal surface enamel of Chadronian and Orellan *Leptomeryx* specimens

| Chadronian | | | | Orellan | | | |
|---|---|---|---|---|---|---|---|
| ID Number | Tooth | Area ($mm^2$) | Area/(l+w) | ID Number | Tooth | Area ($mm^2$) | Area/(l+w) |
| UF 191755 | m1 | 7.389 | 0.74727 | UF 191487 | m2 | 9.485 | 0.87042 |
| UF 201024 | m2 | 11.379 | 1.00185 | UF 201905 | m2 | 11.600 | 1.04627 |
| UF 207558 | m2 | 13.257 | 1.16132 | UF 207776 | m1 | 7.980 | 0.79049 |
| UF 209674 | m1 | 6.768 | 0.69501 | UF 207827 | m2 | 11.925 | 0.99791 |
| UF 210212 | mx | 8.924 | 0.81319 | UF 207852 | m1 | 13.397 | 1.16486 |
| UNSM 63230 | m2 | 6.798 | 0.67763 | UF 207872 | m2 | 11.868 | 1.16376 |
| UNSM 63232 | m2 | 8.784 | 0.83993 | UF 216594 | m2 | 9.743 | 0.94611 |
| UNSM 64630 | m2 | 9.521 | 0.87946 | UNSM 60932 | m2 | 14.839 | 1.26046 |
| UNSM 64740 | m1 | 9.606 | 1.00162 | UNSM 63557 | m2 | 10.323 | 0.88831 |
| UNSM 64743 | m2 | 9.323 | 0.95670 | UNSM 65047 | m2 | 7.987 | 0.80852 |
| UNSM 65387 | m2 | 6.355 | 0.68540 | UNSM 101830 | m1 | 9.029 | 0.81851 |
| UNSM 123711 | m2 | 8.018 | 0.68795 | UNSM 101831 | m2 | 10.233 | 0.89033 |
| UNSM 123720 | m1 | 8.493 | 0.85953 | UNSM 101832 | m2 | 12.903 | 1.19109 |
| UNSM 123794 | mx | 7.094 | 0.62065 | UNSM 101833 | m2 | 12.903 | 1.14543 |
| UNSM 123796 | m2 | 9.314 | 0.88418 | UNSM 101834 | mx | 10.968 | 0.92364 |
| UNSM 123869 | m2 | 8.852 | 0.82729 | UNSM 101835 | m2 | 6.452 | 0.80000 |
| UNSM 123887 | m1 | 8.577 | 0.90561 | UNSM 101836 | m2 | 14.194 | 1.29652 |
| UNSM 123889 | m2 | 7.605 | 0.69976 | UNSM 101837 | mx | 9.677 | 0.94074 |
| UNSM 123970 | mx | 8.892 | 0.83626 | UNSM 101838 | mx | 13.548 | 1.18140 |
| UNSM 123971 | mx | 8.804 | 0.84032 | UNSM 101839 | mx | 8.890 | 0.84034 |
| UNSM123974 | mx | 10.190 | 0.93856 | UNSM 101840 | mx | 7.301 | 0.73551 |
| UNSM 123982 | mx | 8.984 | 0.86693 | UNSM 101842 | mx | 10.137 | 0.89915 |
| UNSM 123985 | mx | 6.017 | 0.64602 | UNSM 101843 | mx | 9.773 | 0.97123 |
| UNSM 124047 | m2 | 7.917 | 0.75870 | UNSM 101844 | m2 | 12.425 | 1.07884 |
| UNSM 124048 | m2 | 7.543 | 0.74125 | UNSM 101845 | mx | 9.821 | 0.90246 |
| UNSM 124099 | m2 | 12.911 | 1.21037 | UNSM 101846 | mx | 10.224 | 0.92141 |
| UNSM 124154 | m1 | 7.529 | 0.73026 | UNSM 101847 | mx | 11.33 | 1.02501 |
| UNSM 124156 | m2 | 8.061 | 0.74708 | UNSM 101848 | m1 | 8.978 | 0.88667 |
| UNSM 124453 | m2 | 8.496 | 0.72896 | UNSM 101849 | mx | 9.807 | 0.79258 |
| | | | | UNSM 101851 | mx | 10.092 | 0.91235 |
| | | | | UNSM 101852 | m2 | 8.720 | 0.93033 |
| | | | | UNSM 119664 | m2 | 12.870 | 1.08782 |
| | | | | UNSM 119668 | m2 | 13.624 | 1.18095 |
| | | | | UNSM 119669 | m2 | 14.679 | 1.24567 |
| | | | | UNSM 125159 | m2 | 16.433 | 1.41847 |
| Total | | Average | Average | Total | | Average | Average |
| n=29 | | 8.669 | 0.82721 | n=35 | | 10.976 | 0.99867 |

Table 2-2. Summary of statistical tests

| Shapiro-Wilk test | | Mann-Whitney U test |
|---|---|---|
| Chadronian | Orellan | |
| alpha value: 0.05<br>p-value: 0.017<br>Indicates a non-normal distribution | alpha value: 0.05<br>p-value: 0.620<br>Indicates a normal distribution | alpha value: 0.05<br>p-value: <0.0001<br>Indicates means are not equal |

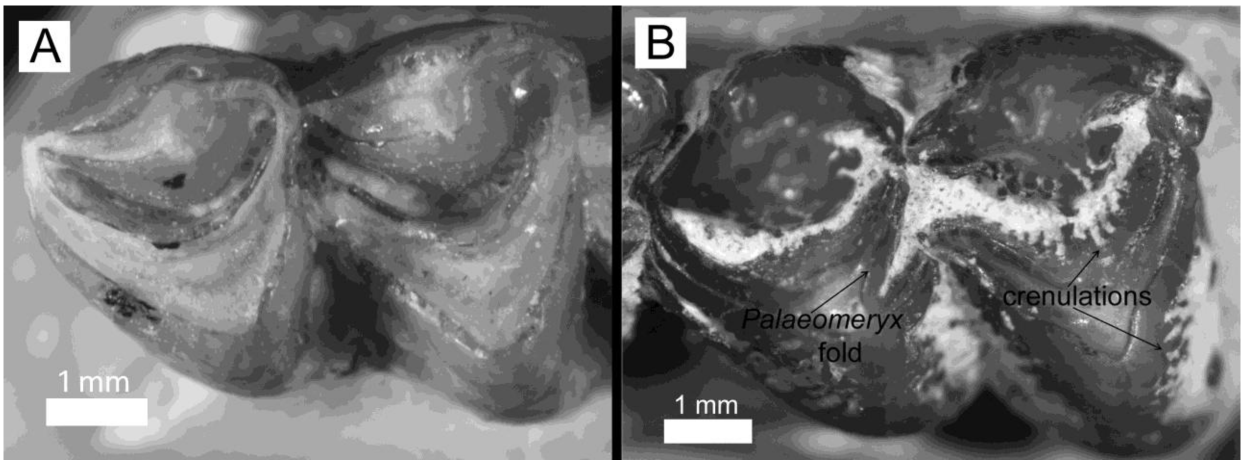


Figure 2-1. Qualitative occlusal surface observations. A)Left first lower molar of Chadronian Leptomeryx (UF 191755) and B) Left first lower molar of Orellan Leptomeryx (UF 207852) showing crenulations and Palaeomeryx fold.

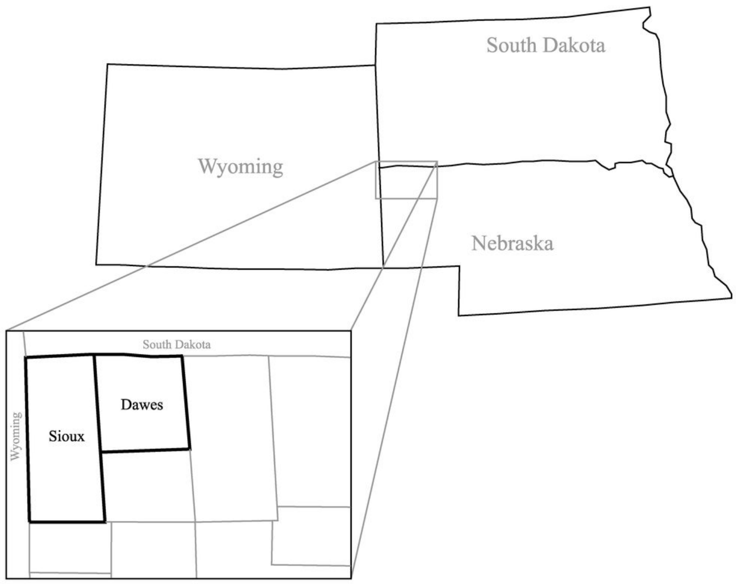


Figure 2-2. Areas where specimens were recovered.

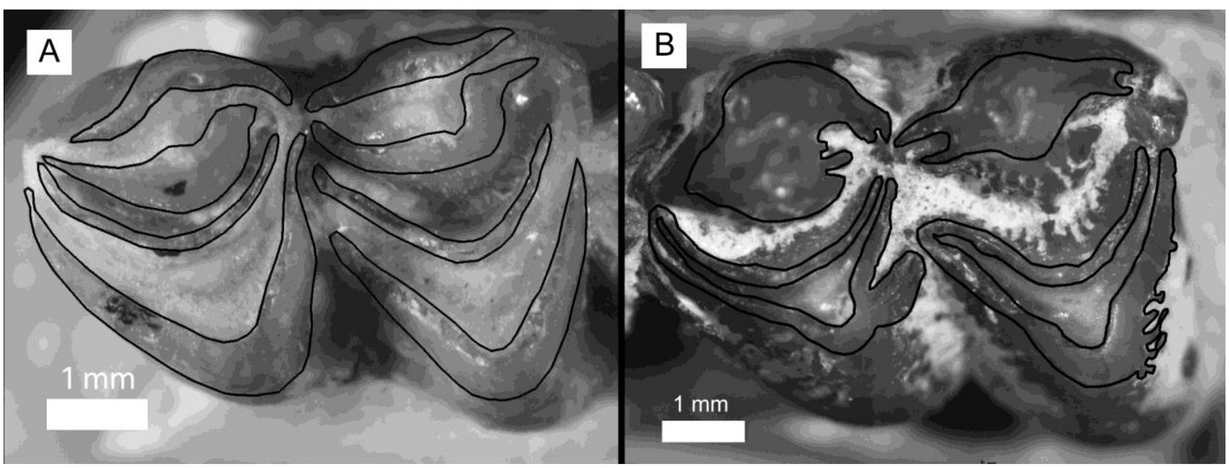


Figure 2-3. Isolated occlusal surface enamel. A) Left first lower molar of Chadronian Leptomeryx (UF 191755) B) Left first lower molar of Orellan Leptomeryx (UF 207852).

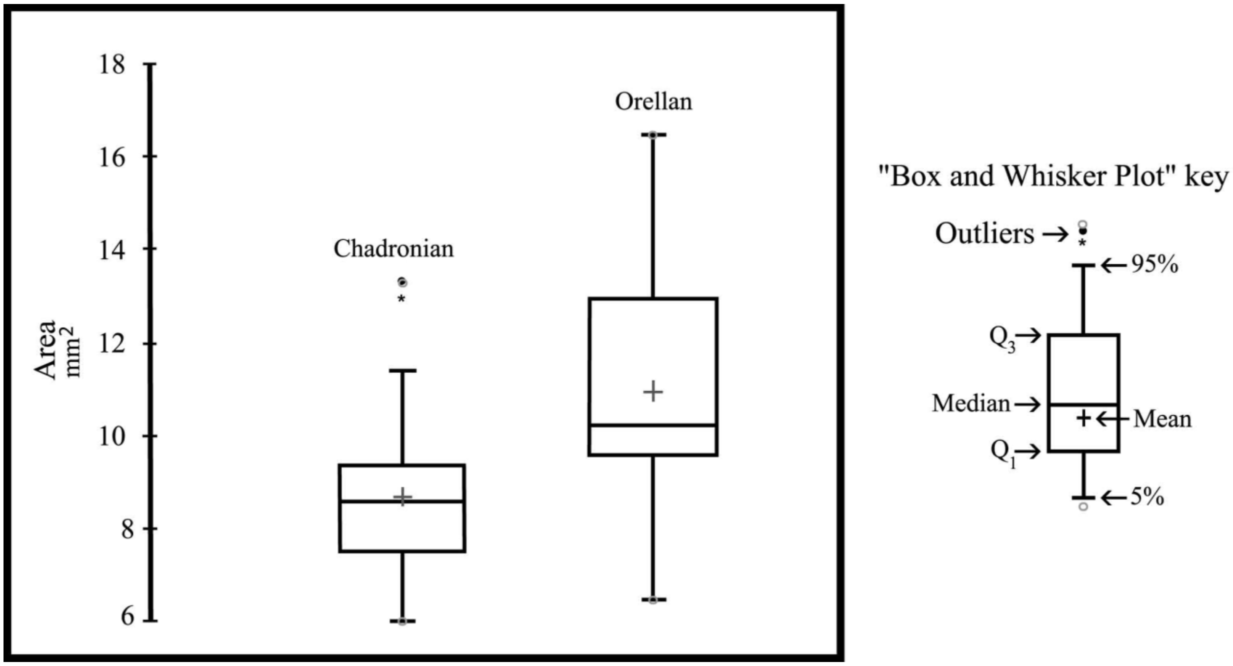


Figure 2-4. Box and Whisker Plot for average occlusal surface enamel. Q1 and Q3 represent the lower and upper quartiles, respectively. Inside the boxes, solid lines indicate median and plus signs indicate mean. Length of the whiskers represents 5th to 95th percentile range. Outliers are indicated with a solid black dot, a gray circle, or a star.

CHAPTER 3

TEACHING VIA SOCIAL MEDIA: THE EFFECTIVENESS OF USING A BLOG AS AN INSTRUCTIONAL TOOL IN SCIENCE EDUCATION

## Introduction

Blogs are quickly becoming a premier source for information on the internet. In 2004, the Pew Internet and American Life Project (an initiative of the Pew Research Center) conducted two nationwide telephone surveys interviewing 1,861 internet users (Rainie, 2005). According to their findings, 6 million Americans received news and information via RSS (real simple syndication) aggregators, which allow users to subscribe to websites or blogs, and inform them when new information is available. Their research shows that 7% of the 120 million U.S. adults who use the internet say they have created a blog. Approximately 32 million people, or 27% of U.S. internet users, reported reading blogs. Interestingly though, this research also shows that in 2004, only 38% of all internet users knew what a blog was, with the rest unsure of what the term meant. In a follow-up study in 2006, 57 million Americans reported reading blogs, a significant increase from 2004 (Lenhart and Fox, 2006). By 2008, the popularity of blogs had grown so much that an estimated 346 to 365 million active internet users worldwide reported reading blogs (Universal McCann, 2008).

The word “blog” is complex, being both a noun and a verb. People who write blogs are known as “bloggers,” the act of posting an article to a blog is called “blogging,” and the collective, interlinking world of blogging has come to be known as the “blogosphere” (Bartlett-Bragg, 2003; Williams, 2004). The question “what is a blog” can be somewhat more difficult to answer. In its simplest form, a blog could be characterized as a website with dated entries, published to the internet in reverse chronological order (Bartlett-Bragg, 2003; Duffy et al., 2006). Pimpare and Fast (2008) define a blog essentially as a website that is frequently updated, built around a theme, and expresses the personal opinions of one or more authors. However, many websites and online journal services could be said to fit the above definitions of a blog, though they are missing an essential characteristic that makes blogs so unique and successful.

The opportunity for readers to give personal responses to the published blog postings by leaving comments is the main feature that most distinguishes blogs from simple websites or online diaries (Williams, 2004; Duffy and Bruns, 2006; Pimpare and Fast, 2008). Williams (2004) speculates that the key to the popularity of blogs is this interactivity. Blogs also allow for hyperlinks to other websites to refer the reader to more information about the subjects being discussed in the blog (Oravec, 2002). The people writing the blog can potentially provide information to a large audience, and the readers can also express their thoughts as comments, or provide information of their own, creating a vast amount of information sharing between individuals.

In 2006, Universal McCann, a global media and communications agency, published the results of their first “Power to the People” survey, known as “Wave 1,” investigating the ways consumers are using the internet (Universal McCann, 2008). The agency has since conducted yearly studies, the most recent known as Wave 4, using the same methodology in each to make comparisons possible. The use of blogs has followed an interesting trend since 2006. “Reading blogs” was the most reported internet activity in the years 2006 and 2007 (Wave 1 and Wave 2), with over 50% of active internet users (defined as individuals using the internet at least every day or every other day) reading blogs in 2006, and over 60% in 2007.

In 2008 “watching video clips online” became the most reported internet activity, followed by reading blogs. Though it was no longer the most popular internet activity, Wave 3 still estimated 77% of active internet users, approximately 346 million people worldwide, read blogs, and 45% of active internet users reported starting a blog. Personal blogs of friends and family were reported as the primary type of blogs read by users, followed by music, TV, film, and news-related blogs. Wave 3 concluded that the blogosphere rivals any mass media in terms of reach, time spent, and cultural, social, and political impact (Universal McCann, 2008). The Wave 4 report focused more on the growing phenomenon of social networking sites, around which users are now focusing their digital life. Wave 4 speculates that blogging has nearly reached saturation, noting that it is not that users are cutting back on blogging, but rather they are increasingly choosing to do so via social network sites, such as Facebook and MySpace (Universal McCann, 2009). In recent years, blogs have moved past the earlier versions of online diaries, and have emerged to focus on specific subjects. Blogs are written specifically to discuss issues such as entertainment, news, politics, and science. With the potential for reaching a vast audience, it is critical that the information being made available be the highest quality possible, especially when it comes to science.

To date, most studies on blog applications in education have focused on the use of teacher and student blogs, and less on using blogs as a source of knowledge or as an instructional tool outside the classroom. The purpose of the present study is to determine if, with such a vast amount of information available online in blogs, science blogs can be used effectively as an instructional tool to inform the public about specific topics within geology and paleontology. Studies have shown that people are reading and getting scientific information from blogs (Bonetta, 2007; Universal McCann, 2009), but the important question is whether or not readers are learning from the science blogs, and whether such blogs foster misconceptions about scientific concepts. According to the Wave 3 study, approximately 13.6% of active internet users reported reading science blogs, making them the 10th most read blog type (Universal McCann, 2008). The main focus or intent of science blogs is distributing and/or commenting upon scientific information (Wilkins, 2008). In 2007, there were 19,881 blogs with a “science” tag, according to the Technorati blog search engine (Bonetta, 2007). Science blogger Bora Zivkovic states that many of these are computer technology, pseudoscience, creationist, or New Age blogs, and estimates the number of actual scientific blogs around 1,000 to 1,200 (Bonetta, 2007).

For the purpose of this study, science blogs are defined as blogs that are written by those with scientific training or schooling, with the intent of distributing, explaining, communicating, and/or commenting on scientific information. Many blogs that distribute and comment upon science are written by those outside of scientific professions, and therefore may or may not contain quality information. Science blogs written by those scientists who have firsthand knowledge of the topics through their research efforts stand the best chance to communicate the highest quality information and to explain and correct any misconceptions about scientific concepts. These science blogs have the potential to be used as instructional tools much the same way as textbooks written by experts in the field, perhaps generating interest and drawing in readers in ways that a textbook might not. Wilkins (2008) lists several benefits for scientific blogging, such as providing better science communication than potentially misleading press releases, as well as demythologizing science and clarifying misconceptions. Furthermore, there are personal benefits to the blogger, such as science bloggers that have gained jobs as a result of their blogging (Wilkins, 2008).

## Background

### History of Weblogs

The origins and history of the blog are somewhat contentious topics, especially in scholarly journals. Not surprisingly, most information on the origin of blogs is found in various online sources, including blogs themselves. The nature of the internet, including the ease with which both correct and incorrect information are readily available, can sometimes make sifting fact from fiction from these sources difficult. Most sources, however, seem to agree at least on how the term “weblog” came into use. According to an article published online by Rebecca Blood (2000), the term “weblog” was first used by Jorn Barger in 1997 on his webpage, which consisted of a daily log of his web activities (Williams, 2004). Various other sources confirm this assessment, including articles published in the Blog Herald (Riley, 2005), *The Economist* (The Economist Newspaper Ltd, 2006), and Wired Magazine (Wortham, 2007). The credit for the shortened word “blog” is generally given to Peter Merholz for his use of the word in his blog in 1999 (Williams, 2004; The Economist Newspaper Ltd, 2006).

The actual first “blog” is a somewhat more debatable subject, as most of the earliest blogs were written before the term was around to describe them. According to Williams (2004) and Pimpare and Fast (2008), the first blog was created in 1992 by CERN (European Organization for Nuclear Research) employee Tim Berners-Lee. Berners-Lee himself described this blog, entitled “What’s New,” as a site developed to share information among scientists and keep track of new websites (Berners-Lee, 2000). Williams (2004) notes that this site, and other early blogs, are not especially close to the current notion of the blog, and cites *Slashdot* (a website owned by Geeknet, Inc) and blogger Dave Winer's *Scripting News*, both established in 1997, as important early precursors of the modern blog.

It was around the end of the century however when blogging as a global phenomenon really took off, when the first free, easily accessible blogging tools were made available online, most notably with the launch of blogger.com (Williams, 2004). Since that time, the blogosphere has grown exponentially, with many different blog platforms available to host blogs, the most popular being LiveJournal, MySpace, Blogger, Xanga, FrontPage, Typepad, Blogspot, Moveable Type and Squarespace, according to a 2006 study by the Pew Internet and American life project (Lenhart and Fox, 2006). Young internet users appear to be the age group most attracted to blogging, with more than half of bloggers under the age of 30 (54%), 30% between the ages of 30 and 50, and 14% between the ages of 50 and 65. Only 2% of bloggers are over the age of 65 (Lenhart and Fox, 2006). Research conducted by the Pew Internet and American Life Project found that the numbers in 2009 remain relatively unchanged, with internet users aged 12-32 being more likely than older users to read others' blogs and create their own (Jones and Fox, 2009). Utilizing the popularity of blogs for education, especially among youth, has the potential to communicate information using a novel and interesting platform.

## Blogs Use in Education

### Benefits

Research on blogs is fairly new, especially investigations into the applications of blogs in education. Even so, many researchers have identified several teaching and learning benefits of blogging. One of the most commonly cited benefits is the potential for reflection and critical analysis by the students as they write in their blogs (Oravec, 2002; Downes 2004; Ferdig and Trammell, 2004; Brescia and Miller, 2006; Richardson, 2006). Using blogs can also help students gain a sense of personal identity, acting as a place for students' voices to emerge where they might not have in the traditional classroom setting (Pimpare and Fast, 2008; Oravec, 2002). Blogs can also foster a sense of community among students, as they post responses and comments on other students' blogs (Williams, 2004; Pimpare and Fast, 2008). Reading blogs over a period of time can give students a better sense of what information is available on the internet, potentially increasing access and exposure to quality information (Oravec, 2002; Duffy and Bruns, 2006).

Drawing from the work of other researchers, Luehmann and Frink (2009) developed five learning opportunities specific to science classroom blogs: (1) long-term engagement with scientific discourse and inquiry; (2) support scientific explanations that bring multiple voices or resources together; (3) extend scientific understanding through engagement with content in a multimodal format, across geography and time; (4) use of peer feedback in developing scientific explanations, supporting the work of a learning community; and (5) engagement with and within the scientific community. Science blogging in particular offers benefits to science students, giving them opportunities to conduct and comment on science in a similar manner to, and with, trained scientists. Though the researchers concentrated on science classroom blogs, it is likely that the learning opportunities listed above could also benefit the general public reading science blogs. Through reading the blog, posting comments, and engaging in conversations with the scientist behind the blog, the reader can potentially gain all of these benefits, thus making the blog an effective instructional tool.

**Previous usage**

Research into the educational usage of blogs is fairly new, though there is a wealth of “non-refereed” commentary available online (Williams, 2004). Because of the variety of types of blogs, the number of different styles, and the potential for personalization by the blogger, every blog will be different from the next. Much of the literature on the educational use of blogs appears to fit into two main categories: teacher driven blogs and student driven blogs. A teacher driven blog is one in which the teacher is the primary author, using the blog for various purposes. One such purpose is the area of teacher training and professional development, during which teachers use blogs much like they have previously used reflective journals as a learning tool (Stiler and Philleo, 2003; Wagner, 2003; Williams, 2004). Duffy and Bruns (2006) list several suggestions for how a blog could be used by teachers, including as a journal to reflect upon their teaching experience, as a place for categorized descriptions of resources for teaching, and as a place to provide tips for colleagues.

Teachers have also used blogs as sources for information, utilizing blogs for their ability to synthesize pertinent information, link to other sources, and as a way to instruct students on how to evaluate the quality of information found in weblogs (Oravec 2002). Blogs provide an online place for teachers to manage their courses by posting resources for students such as a course syllabus, unit-related calendars, reminders of events and assignments, and other materials (Duffy and Bruns, 2006; Alexander, 2008; Luehmann and Frink, 2009). Beldarrain (2006) also comments on the usefulness of teacher-managed blogs to forward updates and information to students, as well as serving as a portal to student created blogs.

Student driven blogs are used just as commonly, if not more so, than teacher driven blogs. Blogs are being used by students in several ways. One of the most frequent uses for student blogs is essentially the same as the way teachers use blogs, i.e., as learning journals (Bartlett-Bragg, 2003; Williams, 2004; Duffy and Bruns, 2006). Bartlett-Bragg (2003) found that incorporating blogs into pedagogical approaches resulted in deeper learning as the students moved through five stages, starting with simple recordings of learning events in the classroom, and ending with reflections on learned knowledge and commenting on peers' blogs. Instructors have also found that reading their students' blogs is a useful way to monitor students understanding of assignments (Pimpare and Fast, 2008). Student-driven blogs offer a platform for students to reflect upon materials discussed in class, critique reading materials related to coursework, develop their own writing style, make students confront their own opinions, reduce plagiarism as students learn to properly cite others' work, and help students organize the content they find online (Oravec, 2002; Williams, 2004; Duffy and Bruns, 2006). "Classroom blogs" are identified by Luehmann and Frink (2009) as blogs that are managed by a teacher for the purpose of having their students post work and exchange ideas, making them a combination between student-driven and teacher-driven blogs.

Common themes are found in the way blogs are being used in education, but the individualistic nature of blogs makes their use by instructors unique in each instance. Luehmann and Frink (2009) investigated nine classroom science blogs, and identified several “activity structures,” often given as “assignments,” intended to engage students with specific science content and processes using the blog. Only four activity structures were present in more than half of the blogs: (1) students write and post documentation and interpretations of daily classroom events; (2) students gather and publish resources focused on curricular topics; (3) students post opinions on a given topic; and (4) structure known as “required response,” in which students were required to respond via writing, though no teacher specifically defined what counted as a “response” (Luehmann and Frink, 2009). For example, one of the classroom blogs analyzed involved a guest scientist who posted descriptions of their field work, and required students to interact with the scientist by asking questions and posting comments, to which the scientist then responded. In addition to the four more common activity structures, seven additional activity structures were used in half or fewer of the classroom blogs, such as using the blog to focus on one specific project, soliciting interactions with people outside of the classroom, publishing results of research, or reflecting on past learning (Luehmann and Frink, 2009).

Most studies to date have shown the uses and benefits of blogs in the classroom, by both teachers and students. Only one example was cited where a science blog written by a scientist was utilized in the classroom as a source of information, to instruct students (Luehmann and Frink, 2009), however its effectiveness in doing so was not examined. In the present study, a unique blog centered on the theme of the Badlands of North America was created to determine if a science blog can be used effectively as an instructional tool to inform the public about certain topics within geology and paleontology. For this study, a science blog is considered effective if learning occurs as a result of reading the blog, therefore knowledge of specific topics needs to be measured before and after reading the blog. If a significant gain in perceived and/or actual knowledge among the participants is demonstrated, this unique blog can be considered an effective instruction tool for communicating scientific information. The use of blogs as an instructional tool potentially represents a new way of using blogs to educate, taking advantage of the popularity of the internet.

## Participant Information

Institutional Review Board (IRB) approval (Appendix A) was granted to conduct the study on two groups, selected based on a presumed pre-interest in paleontology. The first group was a local fossil club that meets monthly to discuss topics of interest. This diverse group was made up of both males and females from a wide age range, though those that participated in the study were estimated to be mostly from an older demographic group (50 years or older). Participants in this group were presumed to be interested in geology and paleontology based on their voluntary participation in monthly meetings and other special events where attendance was not required. The second group was from an undergraduate historical geology course at the University of Florida. This group was made of both male and female students, with the majority of students estimated at being between the ages of ~18 and 25. Though weekly attendance in the students' lab was mandatory, students elected to take this course over other science courses, demonstrating an interest in the geological and paleontological topics taught in this class.

## Methods

This study was designed to test the effectiveness of using a science blog as an instructional tool to inform the public about specific topics in geology and paleontology.

The study consisted of three basic phases. During phase 1, participants completed a two-part survey instrument (Appendix B), designed to assess participants' perceived and actual knowledge of a variety of scientific topics, as well as the participants' interest level in the same topics. Nine topics were chosen to be discussed during phase 2 of the study: (1) Topic 1: Badlands Geology; (2) Topic 2: Badlands Fossils; (3) Topic 3: The Eocene-Oligocene Transition (EOT); (4) Topic 4: *Leptomeryx*; (5) Topic 5: The White River Group; (6) Topic 6: Speciation and Adaptation; (7) Topic 7: Using Teeth to Determine Temperature; (8) Topic 8: Using Teeth to Determine Diet; and (9) Topic 9: Evolution. Perceived knowledge was gauged using a continuous Likert-like scale with respondents asked to rank their current knowledge of nine topics, using a scale with the end-members "not knowledgeable" (value =0) and "extremely knowledgeable" (value =40). Interest level was similarly gauged on the same nine topics, using the end-members "not interested" (value =0) and "extremely interested" (value =40). Actual knowledge was assessed using eleven multiple choice questions, for which the respondents had the option of choosing between 1 correct and 3 incorrect answers. Respondents were also able to choose "I do not currently know." In accordance with IRB rules, participants were also given informed consent documents to sign, so they were aware that their participation was voluntary, and that they would be assigned code numbers so their identities remain anonymous.

During phase 2, participants followed a science blog I created, known as the "Badlands Fossil Blog." New posts were published online twice a week for four weeks, covering the topics listed in the survey. The blog was designed to be a combination of the more traditional reflective journal style blog and a scientific blog. This was done to make the blog more personable and interesting to the reader, but also cover important scientific concepts. In general, most of the posts were scientific in nature, but made personal by including reflections and stories of personal experiences. The topics were incorporated into the blog by different methods. Sometimes a topic was the focus of an entire post, while at other times the discussion of specific topics was spread out through multiple blog entries. Topics were discussed as many times as possible in an effort to encourage retention through repetition. For phase 3, participants were given the same survey instrument to determine if there was a change in their perceived knowledge, actual knowledge, or interest level.

A total of 21 participants from the fossil club completed the survey before reading the Badlands Fossil Blog (hereafter known as the pre-blog survey). A total of 18 participants completed the pre-blog survey from the undergraduate geology course. The fossil club experienced a significant drop in participation (attrition) between the pre- and post-blog surveys, with only 5 participants completing the post-blog survey. Two of these five were not able to be used in statistical tests, due to the participants' failure to include their name on the post-blog survey, making comparisons impossible. The undergraduate geology class only experienced one dropout, with 17 participants completing the post-blog survey. The fossil club and undergraduate geology class combined to a total of n=20 participants used in statistical tests.

Participant perceived knowledge for each topic was represented by a mark from 0 to 40 on a Likert-like scale. Each participant had ten values recorded for perceived knowledge, one for each of the nine topics, and an average of the nine topics, or the "sum of all perceived knowledge." Interest level was similarly recorded for each participant. To determine actual knowledge, percentages of the number of correct responses chosen by the participants out of the total 11 questions were calculated for both the pre- and post-blog surveys. These percentages took into account both the questions the participants attempted to answer, as well as those for which they chose option “E,” or “I do not currently know.” Percentages were then recalculated after removing questions that the participants did not attempt to answer (those for which option E was chosen). For most participants therefore, the adjusted percentages of correct answers on the pre-blog survey rose dramatically, while the percentages on the post-blog survey did not change as much.

The results of the pre-blog and post-blog surveys were then compared using paired t-tests, looking at multiple variables. Pre- and post-blog survey perceived knowledge was compared to determine if the participants believed that they gained knowledge by reading the blog for each of the topics, as well as for the sum of all topics. The participants’ pre- and post-blog survey actual knowledge was then compared, using both the percent correct out of the total number of questions, as well as percent correct out of the number of attempted questions.

## Results

Data from the participants’ perceived knowledge were analyzed using paired t-tests, comparing the sum of knowledge in all nine topics, as well as each topic individually. A statistically significant gain of perceived knowledge from pre-blog survey to post-blog survey was demonstrated for the sum of all nine topics, with a p-value of $<0.0001$ (Table 3-1). The same is true when comparing each of the nine topics individually, all having p-values less than the alpha value of 0.05. For seven of the nine topics, the p-value was $<0.0001$. Topic 6, Speciation and Adaptation, shows significance with a p-value of 0.003, and Topic 9, Evolution, shows significance with a p-value of 0.001. Although both topics still demonstrate significant learning, it is worth noting that these similar topics differ from other topics in the group, which will be further discussed below.

Three different paired t-tests were run on the results of the multiple choice questions to determine if the participants gained actual knowledge. First, a paired t-test was run based on the percentage of total correct responses out of the total 11 questions. A significant gain of actual knowledge for all questions was demonstrated with a p-value of <0.0001 (Table 3-1). A second paired t-test was performed on the recalculated percentages that removed the “I do not currently know” response, therefore testing the gain of actual knowledge for the attempted questions. This analysis yielded no significant difference from pre- to post-blog surveys, with a p-value of 0.141 (Table 3-1).

For many participants, option E had a dramatic effect on their percentages. For the pre-blog survey, option E was chosen at least once by all but one participant, and for one participant as many as nine times. On average, option E was chosen 5 times out of 11 on the pre-blog survey by the 20 participants. Option E was chosen much less frequently on the post-test, with an average of only 0.3 times out of 11. A third paired t-test was conducted to determine how significant this decrease in the number of times participants chose the response “I do not currently know.” This decrease was found to be significant with a p-value of <0.0001 (Table 3-1).

## Discussion

Research has shown that blogging in the classroom has many benefits for both teachers and students (Oravec, 2002; Brescia and Miller, 2006; Richardson, 2006).

Most of the literature focuses on the use of student-driven blogs to develop critical thinking and writing skills, as well as a way to reflect upon their learning over a certain period of time, using blogs as a type of learning journal (Oravec, 2002; Bartlett-Bragg, 2003; Pimpare and Fast, 2008). Science blogs written by graduate students and/or professionals in the field offer an opportunity to present scientific concepts by those who use them firsthand, rather than from secondary sources that might confuse certain issues (Wilkins, 2008).

Communications between the science blogger and the readers can also lead to a deeper understanding of science as the blogger answers readers' questions and clears up any misconceptions the reader has about the subjects (Wilkins, 2008). While investigating nine classroom science blogs, Luehmann and Frink (2009) found one blog that involved a guest scientist posting descriptions of their fieldwork and responding to students' questions left in the comment fields. This seems an ideal use of a science blog in the classroom, with the students getting information directly from the scientist involved in research. There is no way of knowing, however, if the students' benefited from this interaction, as this was not the scope of Luehmann and Frink's (2009) research questions.

The Badlands Fossil Blog was designed to test if a science blog could be used as an effective instructional tool to inform the public about specific topics in geology and paleontology. In order to test the effectiveness of the blog, paired t-tests were performed on multiple variables to determine if learning occurred between the pre- to post-blog survey. The blog was written as a type of reflective journal of my own experiences as a graduate student. This format was chosen to try and blend the more popular journal style of blogging with the concept of a science blog, where I could talk about my personal experiences and the science that I learned along the way. Each post primarily focused on a specific topic, though other topics might be brought up or re-visited. Hypertext links to other websites of interest were included in several blogs. Each post contained numerous images, some of which I produced, while others were from other sites on the internet (for which hypertext links to the source were included). Most posts had a list of suggested reading, including both nonscientific publications and scientific articles.

Interestingly, while a significant gain was seen in actual knowledge when considering all of the multiple choice questions, no significant gain was seen based on percentage correct out of only the attempted questions, i.e., those for which option E ("I do not currently know") was not chosen. This suggests that the prior knowledge the participants brought with them into the study was mostly correct. However, the significant change in the frequency of choosing option E (p=<0.0001; Table 3-1), and the dramatic difference in the average number of times it was chosen pre- to post- blog survey (4.95 versus 0.3 out of 11 questions, respectively), suggests a significant gain in new information and knowledge occurred as a result of reading the Badlands Fossil Blog. A comparison between perceived and actual knowledge for the post-blog survey demonstrates a linear relationship between the two (Fig. 3-1). Higher values for the sum of all perceived knowledge for the participants correspond to higher scores in actual knowledge. Though it is self-reported data, participants' perceived knowledge seems to be a fairly accurate gauge of their actual knowledge of the topics covered in the Badlands Fossil Blog. A similar trend is seen when looking at participants' interest level versus both perceived and actual knowledge. Higher levels of interest reported in the pre-blog survey correspond to an increase in both the perceived and actual knowledge for participants in the post-blog survey, suggesting that higher interest in the topics leads to an increase in learning (Fig. 3-2). A deeper look into each blog post reveals insight into the participants' learning, both perceived and actual, and provides information for the best approach to effectively use a science blog as a teaching tool (summarized in Tables 3-2 and 3-3).

**Post 1: Geology and the Badlands**

The first post to the Badlands Fossil Blog introduced the readers to both the topic of the blog, as well as the blogger. Three of the nine main topics were discussed or briefly introduced in this first posting: Topic 1, Badlands Geology; Topic 3, The Eocene-Oligocene Transition (though not specifically named); and Topic 5, The White River Group. In order to establish a personal connection with the audience, and therefore encourage readership, I described the personal experiences that led me to become a geologist, and what drew me to the Badlands in particular. I described my experiences visiting the Badlands as an undergraduate, as well as describing the fieldwork and related experiences undertaken as part of my master's project. In this first blog post, answers were provided for multiple choice question 1 (the geologic definition of the term badlands) and multiple choice question 6 (the "White River Group").

A significant gain ($p<0.0001$) was seen in the perceived knowledge of both Topic 1 and Topic 5, the topics most discussed in this blog. Multiple choice question 1 asked participants for the geologic definition of the term "badlands." Most participants had a general idea of the definition in the pre-blog survey, with 75% of participants choosing the correct answer, the remaining 25% choosing mostly option E, with only one participant choosing an incorrect definition. In the post-blog survey, 90% of participants chose the correct answer, and only 2 participants chose option E. Multiple choice question 6 asked participants what the “White River Group” referred to. In the pre-blog survey, 35% of participants chose the correct answer, the majority of the remaining participants chose option E. In the post-blog survey, 55% of participants chose the correct answer, while the remaining 45% chose the same incorrect, though closely related answer, believing it to refer to the associated fossils rather than the associated rock formations. While a significant gain is seen in the perceived knowledge for Topic 5, because it was discussed only in this post and the multiple choice question answered only once, participants’ actual knowledge was not especially high. This supports the idea that more repetition of concepts within the blog will lead to higher retention and learning potential.

**Post 2: A Brief Look at Badlands Fossils**

This post primarily focused on Topic 2, Badlands Fossils. It was pointed out early in the post that there is an abundance of material available discussing the fossils of the badlands, more than could be covered in a single blog post. This post therefore concentrated on fossils that I either had personal experience collecting, or found particularly interesting. Highlighted fossil groups discussed include *Stylemys nebrascensis* (land tortoise), *Mesohippus* (ancestral horse), *Brontops* (rhinoceros-like mammal), *Merycoidodon* (oreodont, a primitive hoofed mammal), *Leptomeryx* (deer-like hoofed mammal), *Paleocastor* (ancient beavers), and a few carnivores (the creodonts, canids, and early saber-tooth cats). In this post, the answers to multiple choice question 2 (typical fossils found in the badlands) and multiple choice question 5 (*Leptomeryx*) were given.

Participants' perceived knowledge demonstrated a significant gain ($p < 0.0001$) for Topic 2, Badlands Fossils. Like the multiple choice question associated with Topic 5, the White River Group, the answer to the multiple choice question asking about typical fossils found in the Badlands was only mentioned in this blog post. In the pre-blog survey, the correct answer was not chosen by any participants, with 55% choosing option E, the rest choosing an incorrect answer. In the post-blog survey, the correct answer was chosen by only 10% of the participants, with the majority of the remaining participants choosing the same incorrect answer. A combination of the answer being given only once, and because of my bias for discussing fossils of personal interest, the readers likely overlooked the answer to the question, that the fossils were typically poorly preserved and isolated. This further supports the idea that when writing to inform readers, repetition is important for ensuring retention. The blogger must also remember to be careful to balance the personal information that keeps the reader interested and the scientific information that the blogger is trying to convey to the reader.

**Post 3: The Eocene-Oligocene Transition**

This post focused mainly on Topic 3, the Eocene-Oligocene Transition (EOT). The post began with a disclaimer about the controversial nature of the topic of climate change, and about how the political discussion about climate change should be looked at separately from the scientific discussions and evidence of climate change. I discussed how one of my graduate courses made me realize how complicated the Earth's climate system was, and therefore it was not easy to make black-and-white statements about climate change. The post then discussed Topic 3, first identifying the answer to multiple choice question 3 (timing of the EOT). The climate, vegetation, and fauna of the Eocene were described, followed by a description of the same elements in the Oligocene. Here, readers could find the answer to multiple choice question 4 (degrees Fahrenheit decreased during the EOT). The answer to question 5 (*Leptomeryx*) was also again mentioned, as a reference to one group known to have undergone changes potentially resulting from the EOT.

Participants demonstrated a significant gain ($p<0.0001$) in their perceived knowledge of Topic 3. Two multiple choice questions were associated with this topic, and a definite increase in the actual knowledge is demonstrated when looking at the multiple choice questions pre- to post-blog survey. During the pre-blog survey, for both multiple choice question 3 (timing of the EOT) and question 4 (degrees Fahrenheit decreased during the EOT) only 10% of participants chose the correct answer, with 60% (question 3) and 80% (question 4) responding “I do not currently know.” In the post blog survey, 70% of participants chose the correct answer to question 3 (timing of the EOT), and 60% to question 4 (degrees Fahrenheit decreased during the EOT). Topic 3, the Eocene-Oligocene Transition was brought up in general in multiple blog posts, and the questions answered in other blog posts as well. The repetition of this topic throughout multiple posts resulted in an observable difference from a majority of participants not knowing the answer in the pre-blog survey, to a majority of participants knowing the correct answer in the post-blog survey.

**Post 4: Proxies**

This post, discussing the methods for studying climate change, was one of the most heavily scientific of those included in the Badlands Fossil Blog. The main topic of discussion was Topic 7, Using Teeth to Determine Temperature, though Topic 3 (the EOT) was also referenced. In this post, I attempted not just to state the answer to multiple choice question 9 (isotopes used to determine temperature), but explain as simply as possible why they were used and how the proxy worked. The use of oxygen isotopes to determine temperature was first explained as it applies to the marine record, followed by an explanation of how teeth of terrestrial vertebrates are used. The answers for multiple choice questions 4 (degrees Fahrenheit the climate dropped during the EOT) and 5 (*Leptomeryx*) were also restated in this post.

A significant difference ($p<0.0001$) was seen in the perceived knowledge of Topic 7. Only one participant chose the correct answer to associated multiple choice question 9 (isotopes used to determine temperature) during the pre-blog survey, with 60% responding "I do not currently know." During the post-blog survey, 55% of participants chose the correct answer (oxygen), while the remaining 45% chose the incorrect isotope "carbon." The majority of participants were able to correctly identify the isotope used to determine temperature after reading the Badlands Fossil Blog. It is possible that the remaining participants simply confused the content within the blog, because they chose the same incorrect answer, and because the isotope carbon was discussed as being used to determine diet in a later blog post.

**Post 5: My Love, the *Leptomeryx***

My research as a graduate student was the primary focus of this blog, concentrating on Topic 4, *Leptomeryx*. Because this is the area of my paleontological research, this post in particular was able to achieve the blend of personal experience and scientific information. I first discussed how I started my research on the small, deer-like mammals. A more detailed description was given for the genus than the brief mention given to the *Leptomeryx* in previous blog posts. My research investigating changing enamel patterns in *Leptomeryx* lower molars and how this might potentially relate to vegetation change was then described. Answers were provided for multiple choice question 3 (timing of the EOT) and 5 (*Leptomeryx*). Topic 8: Using Teeth to Determine Diet was introduced, and two characteristics of grazers (higher crowned teeth and complex enamel patterns) needed to answer multiple choice question 10 (characteristics of a browsing mammal) were introduced.

Participants perceived knowledge demonstrated a significant gain ($p<0.0001$) for Topic 4. Multiple choice question 5 tested the participants' knowledge of the genus *Leptomeryx*. During the pre-blog survey, two participants correctly identified what the genus *Leptomeryx* referred to, while 75% of participants responded "I do not currently know." In the post-blog survey, 90% of participants chose the correct answer. The repetition of Topic 4 and the restating of the answer to multiple choice question 5 in various posts lead to greater learning for this particular Topic.

**Post 6: Fossil Teeth and Diet**

Topic 8, Using Teeth to Determine Diet, was the main focus of this blog post. The post first explains the way that animals are categorized based on food preference, namely as carnivores or herbivores. The difference between browsing (eating mostly leaves and shrubs) and grazing (eating mostly grasses) herbivores was then discussed. Three characteristics observed on teeth were then discussed: (1) shape/height of teeth; (2) microwear patterns; and (3) carbon isotope signature. The differences between the two types of herbivores were explained for each characteristic. Information from this post provided the answer to multiple choice question 10 (characteristics of a browsing mammal).

A significant difference ($p<0.0001$) in perceived knowledge was demonstrated for pre- to post-blog surveys for Topic 8. During the pre-blog survey, 20% of participants chose the correct answer to the associated multiple choice question 10. The majority of the remaining participants (65%) responded “I do not currently know.” During the post-blog survey, 75% of participants chose the correct answer, with only five participants choosing one of the remaining 3 incorrect answers, and none choosing “I do not currently know.”

**Post 7: What is a Species?**

Like the blog post on proxies, this post contained more difficult content matter, focusing on Topic 6, Speciation and Adaptation. The blog post began with a personal story of my struggles over understanding the simple question of what a species actually was, and about how some concepts in biology were more complex than they first appear. Definitions for both speciation and adaptation were given, along with descriptions of phylogenetics and the biological species concept. Adaptation was then explained, and the process of speciation elaborated upon. The answers to multiple choice questions 7 (adaptation) and 8 (Biological Species Concept) were included within this blog, and Topic 9, Evolution, was introduced.

Two topics, Speciation and Adaptation (Topic 6) and Evolution (Topic 9) stand out from the other topics as having a slightly less significant perceived knowledge gain based on the paired t-tests (though still with p-values lower than the significant alpha value 0.05). Participants perceived knowledge demonstrated a significant gain ($p=0.003$) for Topic 6. Topic 6 had two corresponding multiple choice questions, 7 (adaptation) and 8 (Biological Species Concept). The post-blog survey reveals that every participant could correctly identify how adaptation occurs, but 40% of respondents had trouble identifying the correct definition of species according to the Biological Species Concept. The Biological Species Concept relies on the concept of populations of organisms being reproductively isolated from each other. In the post-blog survey 25%

of the respondents chose the somewhat more familiar definition of species, a group of organisms with similar characteristics. This further supports the assertion made in my blog post that the concept of what defined a species is complex. The fact the correct answer to multiple choice question 8 was chosen by only 60% of participants, and that this question directly relates to Topic 6, might account for its slightly lower levels of perceived knowledge gained.

**Post 8: Evolution**

The eighth and final post discussed probably the most controversial of all topics, Topic 9: Evolution. As this is a fairly heated topic, with a wide array of issues that can be discussed, I chose to concentrate on misconceptions held about evolution. The University of California Museum of Paleontology has an extraordinary website that explains evolution (http://evolution.berkeley.edu/), which I cited and based my list upon, concentrating on a few of the most common misconceptions that I have observed during my time as a graduate student: (1) evolution is a theory about the origin of life; (2) evolution involves the progression of organisms into better, more perfected life forms; and (3) evolution occurs solely as the result of change due to random chance. The textbook definition of evolution, and the answer to multiple choice question 11 (evolution) was then given. I attempted to further explain evolution, using *Leptomeryx* as an example. The post ends with a warning to readers to not take what they are told about this controversial topic at face value, but to research the matter for themselves to gain an understanding of the arguments, to keep an open mind, and decide for themselves their opinion on the matter.

A significant difference (p=0.001) was demonstrated in perceived knowledge for Topic 9. Multiple choice question 11 tested participants' understanding of evolution. The pre-blog survey demonstrated that most participants already had their own idea about the biological theory of evolution, with only two participants choosing option E ("I do not currently know"). However, only 45% of the 20 participants chose the correct definition of evolution out of the three listed misconceptions and option E. The post-blog survey scores showed little change, with only 50% of participant choosing the correct definition for evolution. One participant chose two answers, the correct one and a misconception, while another participant chose option E. There is no pattern to how the percentages stayed relatively similar from the pre- to post-blog surveys for this particular question: four participants changed their answer from a misconception to the correct definition, one from option E to a misconception, and three from the correct answer to a misconception. Six participants chose the same correct answer, 5 participants chose the same misconception, and one participant chose option E in both the pre- and post-blog surveys. More than half of the participants kept their pre-existing views of the theory of evolution after reading the blog, whether their viewpoint was considered accurate or a misconception, but for every participant that chose the more accurate description of evolution, another changed their mind and chose a misconception as the definition of evolution. This suggests: (1) the slightly lower perceived knowledge scores for evolution are reflected in their choices for the actual knowledge scores; and (2) one blog post is not sufficient to explain and clear up misunderstandings on the complicated issue of the theory of evolution.

## Limitations

Even though significant gains were seen in both perceived and actual knowledge, the attrition rate of the participants is a potentially limiting factor for this study. A total of 39 participants completed the pre-blog survey, while only twenty-two participants completed the post-blog survey, a dropout rate of approximately 43%. Two of the 22 post-blog surveys could not be used, resulting in a group of n=20 for statistical tests. Dropout was seen most significantly among the fossil club participants. There are a few factors that might account for this dropout. Blogs and blogging are most popular among internet users under the age of 30 (Jones and Fox, 2009). Because the fossil club was comprised of a mostly older demographic group, the blog format might not have been a preferred or popular manner in which to seek information. The participants who dropped out of the study might represent those who lost interest in following the Badlands Fossil Blog throughout the duration of the study because of the unfamiliar platform. The voluntary nature of the fossil club potentially contributed to the dropout rate. With the undergraduate geology course, the participants were required to attend the class, assuring their presence to take both the pre- and post blog survey. The fossil club offered no such guarantee, and participants who took the pre-blog survey might not have been in attendance when the post-blog survey was given at the next monthly meeting. This researcher found out after the surveys were given that a fossil exhibit and trade show was occurring nearby at the time of their monthly meeting, potentially resulting in a loss of participants to competing interests.

While the dropout rate is discouraging, the highly significant results still provide information on the use of blogs to instruct the public. Though the demographics of those participants' that did not complete the study was not random, one can assume that the knowledge and intelligence of the participants' is random. Assuming that the 19 people who did not complete the full study do not represent a population of people who would have either: (1) gained no knowledge (thus resulting in no significant gain in either perceived or actual knowledge); or (2) came in with more knowledge than other participants (decreasing the difference between the pre- and post-blog survey values), their participation would not have drastically changed the results.

## Conclusions

Together, the eight blog posts provided information for each topic, and answers to each of the multiple choice questions. Some topics were given more discussion than others, which may be reflected in the amount of knowledge gain. The study shows that blogs perhaps have the greatest effectiveness in instructing readers from a younger demographic, capitalizing on the popularity of blogging for internet users under the age of 30 (Jones and Fox, 2009). The greatest differences were seen in those topics for which the participants had no previous knowledge, as reflected in the paired t-test for actual knowledge that considered correct answers out of all eleven questions (including those in which participants chose option E), the decrease in frequency that option E was chosen from the pre- to post-blog survey, and when looking at the percentage of participants who chose the correct answers for each multiple choice question individually. This study demonstrates that for some topics, the participants came into the study with fairly accurate prior knowledge. In other topics the participants had very little previous knowledge, and showed a significant gain in both perceived and actual knowledge after reading the Badlands Fossil Blog. Repetition seems to be a key factor in the retention information and learning. A blend of personal experience and scientific information appears to be an effective way to use blogs to inform the public about geology and paleontology, as long as the blogger's personal bias in choosing topics of personal interest does not overshadow the scientific content.

Table 3-1. Results of statistical analysis

| | Alpha value | p-value |
|---|---|---|
| Perceived Knowledge | | |
| Badlands Geology | 0.005 | <0.0001 |
| Badlands Fossils | 0.005 | <0.0001 |
| The Eocene-Oligocene Transition | 0.005 | <0.0001 |
| *Leptomeryx* | 0.005 | <0.0001 |
| The White River Group | 0.005 | <0.0001 |
| Speciation & Adaptation | 0.005 | 0.003 |
| Using teeth to determine temperature | 0.005 | <0.0001 |
| Using teeth to determine diet | 0.005 | <0.0001 |
| Evolution | 0.005 | 0.001 |
| Sum of all Topics | 0.005 | <0.0001 |
| Actual Knowledge | | |
| Percent correct total | 0.005 | <0.0001 |
| Percent correct attempted | 0.005 | 0.141 |
| Frequency of Option “E” | 0.005 | <0.0001 |

Table 3-2. Summary of blog content

| Topic | Associated multiple choice question | Answer given |
|---|---|---|
| Topic 1: Badlands Geology | # 1 | Post 1 |
| Topic 2: Badlands Fossils | # 2 | Post 2 |
| Topic 3: The Eocene-Oligocene Transition | #3, #4 | Post 3, 4, 5 |
| Topic 4: *Leptomeryx* | # 5 | Posts 2, 3, 4, 5 |
| Topic 5: The White River Group | #6 | Post 1 |
| Topic 6: Speciation and Adaptation | #7, #8 | Post 7 |
| Topic 7: Using Teeth to Determine Temperature | # 9 | Post 4 |
| Topic 8: Using Teeth to Determine Diet | # 10 | Post 5, 6 |
| Topic 9: Evolution | # 11 | Post 8 |

Table 3-3. Percent of participants choosing correct answer to multiple choice questions (MC) pre- and post-blog survey

| | MC 1† geology | MC 2 fossils | MC 3* EOT | MC 4* EOT | MC 5* *Lept*. | MC 6 WRG | MC 7† adaptation | MC 8 speciation | MC 9 teeth/T | MC 10* teeth/diet | MC 11 evolution |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Pre-blog survey % participants correct | 75 | 0 | 10 | 10 | 10 | 35 | 95 | 30 | 5 | 20 | 45 |
| Post-blog survey % participants correct | 90 | 10 | 70 | 60 | 90 | 55 | 100 | 60 | 55 | 75 | 50 |

† Questions for which participants demonstrated a high level of prior knowledge in the pre-blog survey.
* Questions for which answers were given in multiple blog posts.

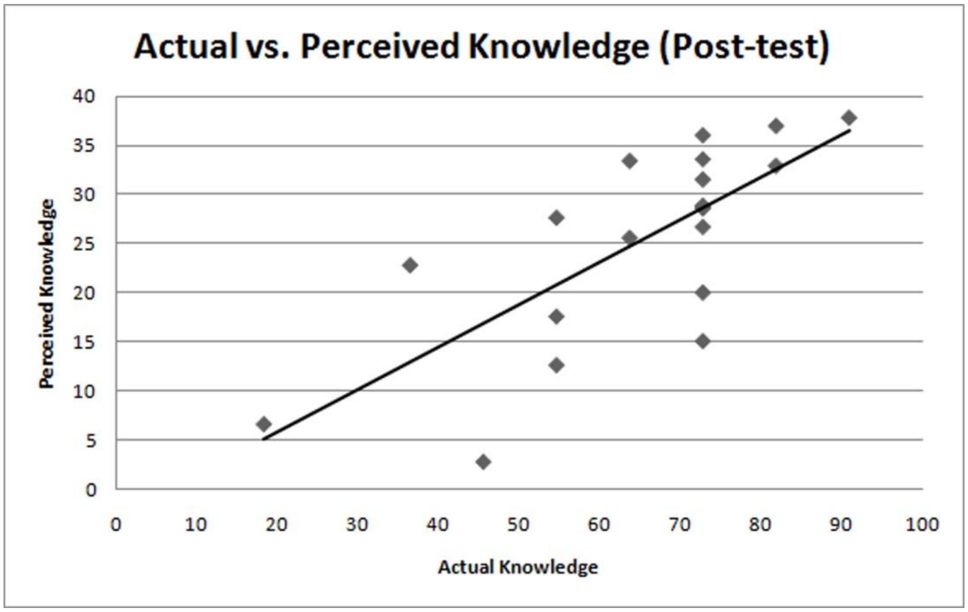


Figure 3-1. Comparison between actual and perceived knowledge in the post-blog survey.

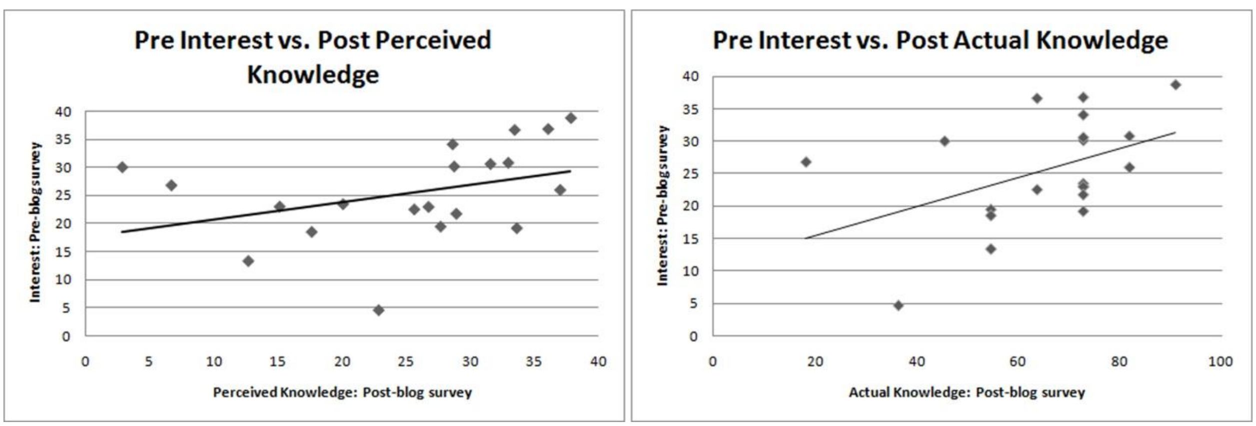


Figure 3-2. Participants interest levels (pre-blog survey) versus perceived and actual knowledge (post-blog survey).

# CHAPTER 4
# SUMMARY OF CONCLUSIONS

This nontraditional thesis investigated two separate questions that together integrate research and education. The first project compared the differing enamel patterns of the genus *Leptomeryx* to determine if a quantifiable change in the amount of occlusal surface enamel is demonstrated between specimens of Chadronian and Orellan *Leptomeryx*. A significant increase was confirmed using a Mann-Whitney U test. Average occlusal surface enamel values demonstrate a 27% increase in the amount of enamel in the Orellan specimens, resulting from the more complex, crenulated enamel and the addition of the *Palaeomeryx* fold rather than an increase in the size of the tooth, a change in the basic shape of the tooth, or an increase in the crown height. The increasing complexity of the Orellan *Leptomeryx* specimens is coincident with a major climate shift during the Eocene-Oligocene Transition, with temperatures dropping an estimated 8°C in North America (Zanazzi et al., 2007). The Eocene-Oligocene Transition is also characterized by a shift from moist forests in the Eocene to open grasslands in the Oligocene (Retallack, 1990). The more arid adapted plants of the open grasslands were harsh, and likely resulted in more wear on mammal teeth than soft, leafy vegetation. The development of more complex enamel and the subsequent increase in the amount of occlusal surface enamel could have been a response to Orellan *Leptomeryx* ingesting this tougher vegetation, providing more enamel for wear.

Four *Leptomeryx* specimens from the Chadronian generated unusually high occlusal surface enamel areas compared to the rest of the Chadronian sample, and have features found more commonly within the Orellan sample, such as crenulations and the *Palaeomeryx* fold. It is possible that these four specimens represent early stages of evolution to the advanced grade of *Leptomeryx* within these individuals during the Chadronian. Four specimens in the Orellan sample also had anomalously low areas compared to the rest of the sample of similar age, lower than even the mean value for the Chadronian sample. Three of these four specimens with comparatively lower occlusal surface enamel areas lack well developed crenulations or a *Palaeomeryx* fold. Contrary to suggestions by earlier researchers (Heaton and Emry, 1996), Korth and Diamond (2002) assert that there are more than one species of *Leptomeryx* present in Orellan sediments. These three *Leptomeryx* specimens potentially provide support for Korth and Diamond's hypothesis, representing the Orellan *Leptomeryx* species with more simple enamel than the dominant species, *L. evansi*. Because the specimens used in this study are only identified to genus level, further work would need to be done to determine if species variation is important in occlusal surface enamel areas. Future work using *Leptomeryx* specimens identified to species level from more discrete intervals within Chadronian and Orellan rock sequences may help to determine if the increase in enamel complexity is a function of time alone, or if the increase results from the change in dental morphology of the species.

With regard to the broader impact component of the thesis, the Badlands Fossil Blog was successful in teaching these research topics and other related topics to participants from a local fossil club and an undergraduate geology course. Eight total blog posts provided information for nine topics and answers to each of the multiple choice questions provided in the survey. The participants' perceived knowledge increased significantly for each of the nine topics with p-values less than the significant alpha value of 0.05. The actual knowledge for the participants increased with a p-value of <0.0001 when all questions were tested with the paired t-test, including those in which the participants chose option E, or “I do not currently know.” No significant difference is demonstrated when testing only those questions that the participants attempted to answer, removing option E. These statistics suggest that for some topics, the participants came into the study with fairly accurate prior knowledge, and the greatest differences were seen in those topics for which the participants had no previous knowledge.

Higher values for the sum of all perceived knowledge for the participants correspond to higher scores in actual knowledge, suggesting that the self-reported data known as perceived knowledge are a fairly accurate gauge of the participants’ knowledge in each of the nine topics. Likewise, higher levels of interest reported in the pre-blog survey correspond to an increase in both the perceived and actual knowledge for participants in the post-blog survey, suggesting that increased interest in the topics leads to an increase in learning. The Eocene-Oligocene Transition and *Leptomeryx* were among two of the most frequently mentioned topics in the Badlands Fossil Blog. The high values of learning for these topics demonstrate that repetition is an important factor in the retention of information and learning. A blend of personal experience and scientific information appears to be an effective way to use blogs to inform the public about geology and paleontology.

This study also revealed important information regarding the use of science blogs as instructional tools among different demographic groups. The Badlands Fossil Blog was followed by two groups. The first was a local fossil club that met voluntarily monthly to discuss topics of interest. The second was an undergraduate historical geology lab required to meet weekly. While a total of 39 participants took the pre-blog survey, only 22 participants followed the blog from start to finish. A significant drop in participation was seen among the local fossil club, with only five of the original twenty-one participants completing the post-blog survey. Two of those five could not be used because no name was provided, making comparison pre- to post-blog survey impossible. The undergraduate geology lab experienced only one participant drop out, with seventeen participants taking the post-blog survey. This likely indicates that the use of science blogs as an instructional tool will have the greatest success in instructing readers from a younger demographic group, perhaps due to the popularity of blogging for internet users under the age of 30 (Jones and Fox, 2009). While the attrition rate potentially represents a limiting factor for the study, the results are strong enough to represent new and valuable information on the use of blogs in education, if one assumes randomness in the amount of knowledge these participants had. Because of the high values of significance demonstrated in the sample size of 20, the participants who failed to follow the Badlands Fossil Blog would only have affected the statistics if they had higher levels of incoming knowledge (thus not learning new material), or were all incapable of learning by reading the Badlands Fossil Blog. Future studies employing these methods could decrease this dropout effect by offering incentives to complete the study.

The unique style of a Master's thesis presented here demonstrates an approach designed to train Master's students in science fields as both scientists and science educators. A nontraditional thesis provides an opportunity for the future generation of scientists to be well prepared for designing broader impacts projects, for either personal satisfaction or to fulfill such requirements from granting agencies such as the National Science Foundation. This research represents a blend of paleontological research on the genus *Leptomeryx*, and a project to teach about this paleontological research and related topics using a novel approach to science communication. Both studies contribute new knowledge to their respective fields, and offer possibilities for future work.

APPENDIX A
IRB APPROVAL

**UF | Institutional Review Board**
**UNIVERSITY *of* FLORIDA**

PO Box 112250
Gainesville, FL 32611-2250
352-392-0433 (Phone)
352-392-9234 (Fax)
irb2@ufl.edu

DATE: August 24, 2009

TO: Julie Mathis
PO Box 112710
Campus

FROM: Ira S. Fischler, PhD; Chair ISF/dl
University of Florida
Institutional Review Board 02

SUBJECT: **Approval of Protocol #2009-U-851**
Formative Assessment of Knowledge of Badland Paleontology

SPONSOR: None

I am pleased to advise you that the University of Florida Institutional Review Board has recommended approval of this protocol. Based on its review, the UFIRB determined that this research presents no more than minimal risk to participants. Your protocol was approved as an expedited study under category 7: *Research on individual or group characteristics or behavior (including, but not limited to, research on perception, cognition, motivation, identity, language, communication, cultural beliefs or practices, and social behavior) or research employing survey, interview, oral history, focus group, program evaluation, human factors evaluation, or quality assurance methodologies.*

Given this status, it is essential that you obtain signed documentation of informed consent from each participant. Enclosed is the dated, IRB-approved informed consent to be used when recruiting participants for the research. If you wish to make any changes to this protocol, *including the need to increase the number of participants authorized,* you must disclose your plans before you implement them so that the Board can assess their impact on your protocol. In addition, you must report to the Board any unexpected complications that affect your participants.

It is essential that each of your participants sign a copy of your approved informed consent that bears the IRB approval stamp and expiration date.

Your approval is valid through **August 19, 2010**. If you have not completed the protocol by this date, please telephone our office (392-0433), and we will discuss the renewal process with you. It is important that you keep your Department Chair informed about the status of this research protocol.

ISF:dl

An Equal Opportunity Institution

APPENDIX B
SURVEY INSTRUMENT AND INFORMED CONSENT DOCUMENTS

## Badlands Fossil Blog

The “Badlands Fossil Blog” will be a twice a week web log discussing the paleontology and geology of the Badlands of North America. Topics will be as varied as scientific posts regarding specific fossil groups or the stratigraphy of the rock units, to general discussions about interesting fossil sites to visit or the particulars of fossil collecting.

As part of my nontraditional Masters thesis at the University of Florida, I will be assessing if a blog can be used as an effective teaching tool to inform the public about geology and paleontology, using the Badlands as my setting.

Are you interested in participating in a study to determine if a blog can be used to effectively teach scientific concepts?

Yes No

**The following are potential topics that could be covered in the Badlands Blog. Please rank your current knowledge of the following topics by placing a mark on the line ( for example, if you knew a little about a topic, the line might look something like this:** I---X-----------------I **):**

| | not knowledgeable extremely knowledgeable |
|---|---|
| 1. Badlands Geology | I---------------------------------------I |
| 2. Badlands Fossils | I---------------------------------------I |
| 3. The Eocene-Oligocene Transition | I---------------------------------------I |
| 4. *Leptomeryx* | I---------------------------------------I |
| 5. The White River Group | I---------------------------------------I |
| 6. Speciation and Adaptation | I---------------------------------------I |
| 7. Using teeth to determine temperature | I---------------------------------------I |
| 8. Using teeth to determine diet | I---------------------------------------I |
| 9. Evolution | I---------------------------------------I |

**Please rank you level of interest in learning more about each of the potential topics**

| | not interested extremely interested |
|---|---|
| 1. Badlands Geology | I---------------------------------------I |
| 2. Badlands Fossils | I---------------------------------------I |

3. The Eocene-Oligocene Transition I---------------------------------------I
4. *Leptomeryx* I---------------------------------------I
5. The White River Group I---------------------------------------I
6. Speciation and Adaptation I---------------------------------------I
7. Using fossil teeth to determine temperature I---------------------------------------I
8. Using fossil teeth to determine diet I---------------------------------------I
9. Evolution I---------------------------------------I

**Please indicate the 3 topics listed above you are most interested in learning about:**

1.

2.

3.

**Please circle the correct answer to the following questions.**

1. In geology, the term badlands refers to:
   a. an area that is generally unsuitable for the preservation of fossils
   b. an extensive region characterized by little vegetation and deeply eroded ridges and rocks
   c. an area characterized by heavy deformation due to tectonic processes
   d. an area generally considered geologically uninformative
   e. I do not currently know

2. Typical fossils found in the Badlands include:
   a. Poorly preserved, isolated skeleton fragments
   b. Mostly well-preserved marine organisms
   c. Dominantly reptiles, with some mammals
   d. Dominantly mammals, with some reptiles
   e. I do not currently know

3. When did the Eocene-Oligocene Transition occur?
   a. approximately 10 million years ago
   b. approximately 30 million years ago
   c. approximately 50 million years ago
   d. approximately 70million years ago
   e. I do not currently know

4. During the Eocene-Oligocene Transition, the average annual temperature dropped by how many degrees Fahrenheit?
    a. approximately 5
    b. approximately 10
    c. approximately 15
    d. approximately 20
    e. I do not currently know

5. The genus *Leptomeryx* refers to:
    a. a group of small, deer-like mammals whose fossils are found commonly in the Badlands
    b. an extinct group of very rare rodents whose fossils are sometimes found in the Badlands
    c. a diverse group of large carnivores whose fossils are found occasionally in the Badlands
    d. large reptiles distantly related to crocodiles whose fossils are found in Badlands
    e. I do not currently know

6. The “White River Group” refers to
    a. The Native American People for which the White River is named
    b. The unofficial name for the states in which the White River Badlands are found
    c. The associated fauna or fossils of the White River Badlands
    d. The association of the different rock formations of the White River Badlands
    e. I do not currently know

7. Adaptation occurs as a result of
    a. an organism deciding to change its appearance to better fit in its environment
    b. an organism becoming better suited to its environment
    c. an organism evolving into a different species
    d. an organism moving to a new environment better suited to its current features
    e. I do not currently know

8. According to the Biological Species Concept, a species is defined as
    a. a group of organisms exhibiting similar characteristics
    b. population of organisms that share similar diets and behaviors
    c. a natural population that is reproductively isolated from other such groups
    d. a group of organisms originating from the same habitat
    e. I do not currently know

9. What isotope found in teeth and bones is used to determine the temperature of ancient environments?
   a. oxygen
   b. carbon
   c. potassium
   d. strontium
   e. I do not currently know

10. A browsing animal, as opposed to a grazing or mixed feeder, generally has teeth characterized by:
    a. More positive Carbon isotope values
    b. Lower crowned teeth
    c. More heavily scratched microwear features
    d. Complex enamel patterns
    e. I do not currently know

11. Biological evolution:
    a. is a theory about the origin of life.
    b. occurs solely as the result of change due to random chance.
    c. is descent with modification through heritable natural selection
    d. involves the progression of organisms into better, more perfected life forms
    e. I do not currently know

Last name________________________________________

(if more than one member of your family is participating, please provide the first letter of your first name as well as your last name)

**Informed Consent**
**Protocol Title:** The Badlands Fossil Blog

**Please read this consent document carefully before you decide to participate in this study.**

**Purpose of the research study:**

The purpose of this study is to determine if a weblog can effectively be used to convey scientific information to the general public.

**What you will be asked to do in the study:**

You will be asked to fill out a brief survey determining your level of knowledge and interest in several important Badlands topics. After completing the survey, you will be asked to follow an online blog that will post twice a week for approximately 5 weeks. After the topics have been covered in the blog, you will be asked to complete a survey to determine what you learned about the Badlands/Fossils from the Badlands. You will be asked to put your last name on both the before and after survey, as well as to fill our demographic information. Personal information will not be used in any reports.

**Time required:**

15 minutes for first survey, approximately 30 minutes to an hour twice a week for 5 weeks (this is entirely dependent on the reader), and 15 minutes for the final survey.

**Risks and Benefits:**

No more than minimal risk is involved. Potential benefits include a greater understanding of various topics pertaining to the Badlands, as well as determining the teaching potential of online sources.

**Compensation:**

No compensation will be provided for participating in this study

**Confidentiality:**

Your identity will be kept confidential to the extent provided by law. Your information will be assigned a code number. The list connecting your name to this number will be kept in a locked file in my faculty supervisor's office. When the study is completed and the data have been analyzed, the list will be destroyed. Your name will not be used in any report.

**Voluntary participation:**

Your participation in this study is completely voluntary. There is no penalty for not participating.

**Right to withdraw from the study:**

You have the right to withdraw from the study at anytime without consequence.

**Whom to contact if you have questions about the study:**

Julie Mathis, Graduate Student, Florida Museum of Natural History PO Box 112710 UF Campus, 352-273-1936

Bruce J. MacFadden, PhD, Florida Museum of Natural History PO Box 112710 UF Campus, 352-273-1937

**Whom to contact about your rights as a research participant in the study:**

IRB02 Office, Box 112250, University of Florida, Gainesville, FL 32611-2250; phone 392-0433.

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**Agreement:**

I have read the procedure described above. I voluntarily agree to participate in the procedure and I have received a copy of this description.

Participant: ___________________________________________ Date: _________________

Principal Investigator: ___________________________________ Date: _________________

**Parental Consent Form**

Dear Parent/Guardian,

I am a graduate student in the Department of Geological Sciences at the University of Florida, conducting research on the effectiveness of blogs on teaching scientific concepts under the supervision of Dr. Bruce MacFadden. The purpose of this study is to determine if a online web-log can be used to convey difficult scientific information to the general public in an effective, easy to use format. The results of the study may help scientists of all disciplines be able to better convey their work to the public in an easily understandable manner. With your permission, I would like to ask your child to volunteer for this research.

Your child will be asked to complete a brief survey assessing their knowledge in various topics pertaining to the Badlands. Then, over a course of approximately 5 weeks, your child will read an online web-log, each addressing a specific topic. At the end of the study, your child will be asked to complete a second assessment to determine if the blog effectively taught scientific concepts. On each survey, I will ask for certain demographic information as well as his/her last name. Each name will be assigned a code number. The list connecting your name to this number will be kept in a locked file in my faculty supervisor's office. When the study is completed and the data have been analyzed, the list will be destroyed. Your child's name will not be used in any report, and personal demographic information will not be associated with your child's name.

You and your child have the right to withdraw consent for your child's participation at any time without consequence. There are no known risks or immediate benefits to the participants. No compensation is offered for participation. If you have any questions about this research protocol, please contact me at 352-273-1936 or my faculty supervisor, Dr. Bruce MacFadden, at 352-273-1937. Questions or concerns about your child's rights as research participant may be directed to the IRB02 office, University of Florida, Box 112250, Gainesville, FL 32611, (352) 392-0433.

Julie Mathis

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I have read the procedure described above. I voluntarily give my consent for my child, _________________, to participate in Julie Mathis's study of the effectiveness of a web log as a teaching tool. I have received a copy of this description.

____________________________ ___________
Parent / Guardian Date

____________________________ ___________
2nd Parent / Witness Date

APPENDIX C
BADLANDS FOSSIL BLOG ENTRIES

(Text only. Text and images available online at http://badlandsfossilblog.blogspot.com/)

TUESDAY, SEPTEMBER 15, 2009

## Geology and the Badlands

I remember the exact moment when I wanted to become a geologist. I was a sophomore at the University of Tennessee, sitting in my undergraduate Earth, Life, and Time class. My professor, whom I would later do my undergraduate research and thesis with, picked up a container that was left behind in the classroom, and started examining its contents with a magnifying lens. “Pure gold,” he says. “About 10 dollars worth.” WOW. How cool, I remember thinking, to be able to know something like that, to be able to look at something and determine what it is based on its physical characteristics. It seems like such a minor thing, but something about having the ability to possess that kind of knowledge became my ultimate goal. The next day, he came in with a small lizard skeleton. BAM. I wanted to be a paleontologist.

I graduated with a degree in Geology in the Fall of 2006. The summer before that, I went to Geology field camp, required by some departments to teach their students about working out in the field. I should also say that this was another reason being a geologist or paleontologist was so attractive to me. You mean I get to work outside? Hike around as a job? SOLD! During field camp, we traveled all over northern North America. We studied glacial deposits which looked like fields dotted with rocks, some bigger than houses. It’s a testimony to the power of nature that these rocks were carried so far from their places of origin, only to be dropped off as the glaciers melted and receded back into the mountains. We spent the night at Devils Tower National Monument in Wyoming. I was amazed looking up at this giant volcanic rock, which is almost 900 feet from its base to the summit. If you’re ever nearby, I highly suggest you stop by.

But by far, my FAVORITE place we went to was Badlands National Park, South Dakota. All you could see for miles were hauntingly beautiful rock formations, heavily eroded into buttes, pinnacles, and spires. The vegetation was very sparse, so the colors and shapes of the rocks take center stage and command your attention. From the moment we arrived, I was in love. Because of my interest in paleontology, I was very excited to get to see the “Big Pig Dig” they were running at the time, where scientists and volunteers have excavated numerous fossil mammals. The site was to be opening the day after we left. Needless to say, I was upset.

I began graduate school at the University of Florida and started discussing potential projects with my advisor. He mentioned the possibility of working in the badlands of Nebraska, and I jumped at the opportunity. The badlands are renowned for their rich fossil collecting history, where fossils are both numerous and in many cases almost perfectly preserved. I began working on a project centered around a deer-like mammal known as *Leptomeryx* (don't worry, you'll hear more about this wily guy later!). After a year of working with the fossils in the collections at the Florida Museum of Natural History, it was decided that I would spend the summer in Crawford, Nebraska, to experience the geology and collect the fossils firsthand.

I lived at Fort Robertson State Park, where my day job was working at the Trailside Museum of Natural History. Again, if you're ever in the area and want to see one of the most spectacular fossils ever found, go check out the dueling mammoths they have on display there. Two nearly complete
Columbian Mammoths were found with their tusks locked around each other, and their bones have been arranged to recreate the original excavation. It's spectacular.

On my days off, I collected fossils near Toadstool Geologic Park and surrounding government lands. I did this under a permit issued to my advisor, as fossil collection is prohibited within the park areas. Collecting on private ranches nearby is solely up to the owners-some let you collect, some don't. I was very fortunate to have the man that redefined Badlands geology, Dr. Hannan LaGarry, working nearby. One day, I met him at Toadstool Park and he walked me through Badlands Geology. He told me the story of how the original scientists that worked there defined the differences between the rock formations, collectively known as the White River Group, using different colored layers known as "purple-white layers." They are neither purple nor white, but were named so, according to legend, because of the color they appeared due to the sunglasses the men were wearing. Funny how things like that make a difference.

Dr. LaGarry and his colleagues have since defined the units based on their lithology, or basic, collective physical characteristics. The rocks in the area I would work in basically can be placed into one of two formations: the Chadron Formation, roughly Eocene in age (approximately 59 to 33 million years ago), and the Brule Formation, roughly Oligocene in age (approximately 33 to 23 million years ago). Rocks of the Chadron Formation are bluish green mudstones with a popcorn-like texture to them. At the contact between the two formations, the rocks change to more tan and brown siltstones and sandstones, with the occasional sandstone channel running through. The boundary between the Eocene and the Oligocene was once considered to be at the uppermost purple white layer, or UPW, but is now thought the be coincident with this change in lithology. Each formation has its own distinct fossil content within, and tells the story of two vastly different environments…but more on that later!

FRIDAY, SEPTEMBER 18, 2009

## A brief look at Badlands Fossils

I say "brief" because it almost has to be. The fossil content of the badlands is so rich that you could write a book on the subject. In fact, many people have. The White River Badlands in particular is well known for its spectacular fossil finds. Dr. Cleophas C. O'Harra, in his 1920 book The White River Badlands, described it as "the most important badland area of the world." The White River Badlands derives its name from the river that provides most of its drainage, and are considered to lie primarily in southwestern South Dakota as well as in northwestern Nebraska and eastern Wyoming.

Within the rocks of the White River Badlands, fossils have been found representing many different environments, from marine, to tropical forest, to woodland forests, to grasslands. Turtles and crocodiles, rodents and insectivores (small mammals like hedgehogs and shrews), horses, camels and rhinos, all have been found. The vast majority of fossils found are poorly preserved, isolated skeletal fragments. In my experience collecting in northwest Nebraska, fossils were most often seen eroding out of the ground, exposed to the elements that quickly broke and wore them down, sometimes making identification almost impossible.

Probably by far the most common fossils I encountered while doing my field work were blown out turtles. This occurs when a turtle shell is exposed at the surface, only to break apart into the many smaller bone fragments that make up its carapace (upper, curved shell) or plastron (lower, flat shell). These scattered pieces often littered the ground I was walking upon.

Though most fossils found exposed at the surface are often fragmentary, there are plenty of fossils that can be correctly identified and used for scientific studies. Various mammal jaws, though often isolated, are quite common in the White River Badlands as well. And there's always the chance of coming upon some spectacular finds, such as the dueling mammoths previously discussed, or the fossil trackways that Toadstool Geologic Park is known for.

In order to keep this brief, I'll concentrate on discussing some of the most common fossils found in the White River Badlands.

My experience with the extraordinary number of turtle shell fragments is an indication to the great abundance of fossil turtles found in the badlands. Specimens can be found ranging from a few inches to a few feet. The most common species is the land tortoise *Stylemys nebrascensis*. I never found a complete tortoise myself, but I did take this picture while touring Reptile Gardens, South Dakota. It's a very poor picture, but much better quality ones can be found using any online search engine. Fossil crocodiles have also been described from the White River Badlands, but as far as I know, their record is relatively poor. Dr. O'Harra refers to only two species, *Crocodilus prenasalis* and *Caimanoidea visheri*.

Obviously, I'm biased. I study fossil mammals, so that is the group I know the most about. Luckily, this is the group of animals that have probably the most abundant fossil record in the White River Badlands. Again, I do not wish to bore you with long, textbook like descriptions of all the different mammals that can be found. So I will just highlight some of the most common fossils of the badlands that I have either personally found during my field work, or that are favorites of mine I have learned about through my studies.

Ungulates, or hoofed mammals, are by far the most abundant fossil mammals I encountered while collecting in badlands. Ungulates can be divided into two groups: those with an odd number of toes (perissodactyls) such as horses and rhinoceroses, and those with an even number of toes (artiodactyls) such as pigs, deer, sheep, and cattle, to name a few.

Among the perissodactyls, the *Mesohippus* and *Brontops* are my favorites. *Mesohippus* was an ancestral horse about 60 cm tall. It first appeared about 40 million years ago, and went extinct by 28 million years ago. Unlike modern horses, these animals had lower crowned teeth and three toes. Most reconstructions of their environment show these animals having come from forests near flowing water, or occasionally in swamp areas. I was very fortunate to find what potentially might be a skull of such an animal, but more work will have to be done in the lab before I can positively identify the fossil.

The elephant-sized *Brontops* belong to an informal group known as the brontotheres, or “thunder beasts.” These mammals are known from their prominent hornlike features on the front of their skull. The *Brontops* have low-crowned, crescent-shaped teeth used for eating soft vegetation. The brontotheres are interesting because, unlike other mammals, this group went completely extinct by the end of the Eocene (approximately 33 million years ago). This time period, at the transition from the Eocene to the Oligocene age, was marked by many changes in climate and environment, so the impact it had upon the mammals is of particular interest to me.

Among the artiodactyls, or even-toed ungulates, *Merycoidodon* is the most common fossil found in the White River Group. These animals belong to a group commonly known as oreodonts, thought to be related to ancestral camels. Their size has been estimated to be around 100 lbs, and they have been suggested to have inhabited environments as varied as evergreen forests to savanna grasslands. While in the field, my most spectacular fossil find has been identified as potentially belonging to this group. It was late in the day, my field helper and I were tired and hot, and we were headed out. My friend spotted something in a ravine below, and thought it might be a jaw. It turned out to be a skull, which was later identified as possibly being an oreodont (again, I need more time studying it in the lab to be sure!). We stayed an extra 2 hours or so to make sure there wasn’t any extra material, and to carefully get it out of the ground. This is my reminder to myself that you always have to keep your eyes peeled, even when it’s quitting time!

My favorite group of all, the *Leptomeryx*, is the second most common fossil artiodactyl in the White River Group. This is the group that two years ago I began studying, and have come to love almost as much as I love my puppy. I guess I would love them just as much if I had one in real life, and it proved to be as cuddly. But, though they are just bones and therefore not so cuddly, I still hold a special place in my heart for these small, deer-like animals. They were about the size of a rabbit, though one species was a bit larger than this, maybe closer to a medium sized dog. They first appeared about 40 million years ago, and went extinct approximately 18 million years ago. Because this is the group I conduct my research on, I have a great deal to say about them. So I think I’ll wait until later to talk more about these fascinating animals and what they can tell us about the earth in the past!

As for other common mammal groups, rodents are among the other most common jaws that I personally found. Though most material I found were very small rabbit jaw fragments, ancestral squirrels, beavers, and rats are also known from the White River Badlands. *Paleocastor* was an ancient beaver known for digging its characteristic burrow, the *Daemonelix* or “Devil's Corkscrew.” While I was in Nebraska, I saw many, many of these astonishing structures along the road. The Trailside Museum has a great example of one such structure, with the animal preserved inside.

Carnivores have a strong fossil representation in the White River Badlands. Sadly, I never personally found any while I did my own collecting. But I do love the fierce beasts, so will mention a few of the more common groups found fossilized in the badlands.

Primitive carnivores known as Creodonts are known from only one family here, the *Hyaenodons*. Though this group is not found abundantly, enough is known to indicate that these animals would have been wolf-like in appearance, and approached the size of a modern black.

More than 20 species of canids are known from the White River Badlands, a group which today includes wolves, coyotes, foxes, jackals, and the domestic dog. Though a great number of species are described, only a few are known from complete skeletons. The most abundant of these was *Cynodictis gregarious*, smaller than a common red fox. The group *Daphoenus* is a member of a larger group known as the “bear dogs,” has been proposed to represent the ancestral stage of the present day wolf.

The cat family, or felidae, is also well represented in the fossil record of the badlands, though less so than the canids. The most well known are from one of two groups, *Hoplophoneus* and *Dinictis*, early forms of the saber-tooth cats or tigers. Not as large as later great cats, these groups are still characterized by powerful canine teeth, strong bodies, and strong claws. They doubtless made life much more interesting for the numerous herbivorous mammals of the time!
http://2.bp.blogspot.com/_gbSCRvRcziw/SrQmBTyu1aI/AAAAAAAAAEg/NHhBZXZwm90/s1600-h/hyaenodon.jpg
Recommended reading:

My knowledge is far from complete, and I urge anyone who is interested to look into the various books and papers on the matter. All information in this blog comes from the following three sources, as well as my own personal experiences.

O'Harra, C. C, 1920. The White River Badlands, South Dakota School of Mines Bulletin No. 13, Rapid City, South Dakota.

Zanazzi A, and Kohn MJ (2008) Ecology and physiology of White River mammals based on stable isotope ratios of teeth. Palaeogeography, Palaeoclimatology, Palaeoecology 257:22--37.

The Paleontology Database: an EXCELLENT source on all things ancient and modern: http://paleodb.org/cgi-bin/bridge.pl?user=Guest&action=displayHomePage

TUESDAY, SEPTEMBER 22, 2009

## The Eocene-Oligocene Transition

Climate change is a hot topic right now (no pun intended). Everyone is talking about global warming, the effects of climate change on the environment, “going green,” etc. You can’t turn on the TV without hearing about it from someone. It is a very heated topic, having broad implications. Growing up, one of the sayings I remember various people saying was “don’t discuss religion or politics at your dinner party,” because those were the things that ended up as debates, as not so fun dinner conversations. I almost feel like climate change has reached that status.

But then, climate change is somewhat political now. I don’t confess to understand all of the political implications of the debate, but I do understand some of the science behind climate change. One of my favorite classes I have taken as a graduate student was “Global Climate Change.” In the class, we started in the past and worked our way forward, looking at all the major climate changes the Earth has experienced in the past hundreds of millions of years. We looked at different hypotheses for what might have caused each of these changes, and how these changes affected the ecosystems on Earth. If anything, the class served to prove just how complicated a system the Earth’s climate really is, and that it’s not easy to make black-and-white statements about climate change.

BUT:

We can talk about the evidence. We can make logical suggestions based on what the evidence shows us. As a student of paleontology, I began working on a project studying small, deer-like mammals known as *Leptomeryx*. What makes *Leptomeryx* so interesting is that they survived and adapted to changing environmental conditions that are correlated with a major climate change, known as the Eocene-Oligocene Transition.

Today, I would like to talk about some of the characteristics of the Eocene-Oligocene Transition, which occurred approximately 33 million years ago, and how the Earth changed as a result. In my next blog entry, I’ll talk more about the methods scientists use to reach these conclusions.

The Eocene-Oligocene Transition isn’t one of those major events in Earth’s history that gets a lot of attention. It’s not like the mass extinction at the end of the Cretaceous period (approximately 65 million years ago) that wiped out all the non-avian dinosaurs, as well as numerous other creatures. Or, the mass extinction at the Permian-Triassic boundary (approximately 250 million years ago) with estimates of up to 95% of marine and 70% of terrestrial vertebrate (animals with a backbone) species becoming extinct.

During the Eocene (approximately 59 to 33 million years ago), the world was much different than today. Fossil plants from areas as far north as Washington, Oregon and North Dakota demonstrate that these regions once were more similar in appearance to the rain forests of Central America than what they are today. Average annual temperatures in these areas have been estimated by several different methods to be approximately 65-75° Fahrenheit during the early Eocene. Today, the average annual temperature of North Dakota is about 41° Fahrenheit. Visualize the badlands then, being covered by a dense tropical rainforest, teeming with wildlife as varied as crocodiles and turtles, large carnivores such as the creodonts, small ancestors to our modern horse, primitive primates distantly related to living lemurs, as well as my favorite, the *Leptomeryx*, just to name a few.

Oh, and there was the “terror crane,” the Diatryma. You can call me crazy if you’d like, but I think seeing one of these guys around today would be AWESOME!

By the end of the Oligocene (approximately 33 to 23 million years ago) the world had changed dramatically. The tropical forests of the Pacific Northwest were replaced by plants such as oaks, ash, sycamores, elms, braken ferns and horsetails, similar to modern redwood forests. The average annual temperature of the Oligocene has been estimated to have dropped by as much as 10-15° Fahrenheit compared to the Eocene. Along with the change in the types of trees making up the forests, shrub and grasslands began to spread. There is evidence of a steady drying trend, as once moist tolerant plants and animals were replaced by animals and plants more adapted to arid, dry conditions. These changing environmental conditions were particularly hard on the reptiles, amphibians, and some invertebrates such as land snails, but very little change was seen among most mammal groups. Some more primitive creatures, such as the relatives to camels and the large brontotheres, died out. Most mammals however were able to adapt to their new surroundings. I will discuss some of these adaptations later.

So, though the climatic event known as the Eocene-Oligocene Transition does not have a major, mass extinction associated with it, it is special because of its magnitude. In a study using fossil tooth enamel, Alessandro Zanazzi and colleagues found evidence of a decrease in average global temperatures of approximately 15° Fahrenheit. This 15° drop in temperature is estimated to have occurred in as short a time scale as 400 thousand years: this seems like a long time to us humans, but in geologic terms, its like the blink of an eye! This dramatic shift has been demonstrated to be one of the most pronounced climate events of the Cenozoic Era, that is, the geologic era we now currently live in, starting 65 million years ago. The Eocene-Oligocene Transition marks the time when the Earth shifted from a “greenhouse” to an “icehouse” world, with rapid ice growth occurring on the Antarctic, only to be followed millions of years later by growth on the arctic pole.

The Eocene-Oligocene Transition set the stage for the world that we live in today.

Recommended reading:
Once again, I do not claim to be an expert on these subjects. The following are some fantastic sources that have taught me a lot of what I know, and what I have shared with you today!

Prothero, D.R., 1994. The Eocene Oligocene Transition: Paradise Lost. Columbia University Press, New York.

Zanazzi, A., Kohn, M.J., MacFadden, B.J., Terry, D.O., 2007. Large temperature drop across the Eocene-Oligocene transition in central North America. Nature 445, 639-642.

SATURDAY, SEPTEMBER 26, 2009

## **Proxies**

In my last blog I talked about climate change, and used one instant in history (the Eocene-Oligocene Transition) to illustrate some of the dramatic effects climate change can have on our planet. Today, I wanted talk about some of the evidence for that particular climate change and how scientists look at certain things, referred to as proxies, to help study and understand climate change.

So, proxies... In climate research, proxies are measurable attributes used to infer the value of another attribute of interest. A non-climate related example would be using tree-rings to infer the age of a tree. The tree rings are not in-and-of themselves the age, but by counting them, you can come up with a very good approximation of the age of the tree. The rings therefore, are a proxy for age.

In climate studies, ocean drill core proxies are usually the most direct way of making inferences into past climate. A core sample is obtained by drilling into rock or sediment with a hollow steel tube. Thousands of cores have been drilled from all of Earth's oceans, as well as many bodies of water on land. The core is removed from the tube in the laboratory, and inspected and analyzed by different techniques and equipment depending on what question is being asked. In a core, one can see changes in the rock or sediment composition, evidence of plants or pollen, ash layers from volcanic eruptions, or different species of very small micro-organisms. In my opinion, one of the most important proxies for temperature reconstructions is the ratio of oxygen isotopes found in drill cores.

So what exactly are isotopes, and why are they used as a proxy for temperature? All of Earth is made up of atoms of different elements (oxygen, carbon, nitrogen, etc.). Every atoms are made up of three sub-particles: protons, electrons, and neutrons. Isotopes are different atoms of the same element, each having a different number of neutrons. The difference in the number of neutrons will slightly alter the weight of each isotope relative to each other. For example…..

Most elements exist primarily in one state: 99.8% of all the oxygen on Earth is found in the form of O-16. This means that this isotope has 8 protons and 8 neutrons. However, a very small percentage of Oxygen exists as O-18, with 2 extra neutrons. These extra neutrons make the O-18 isotope heavier relative to O-16 atom. This becomes important when looking at temperature.

The way to use oxygen as a proxy for temperature is simply by examining and slightly expanding on the concept of the water cycle. Water is in the ocean (or a lake or stream), it evaporates and forms clouds, and eventually it rains down to rejoin bodies of water. Sometimes the precipitation falls as snow, to accumulate as glaciers or ice sheets. It is easier to evaporate lighter isotopes, so the oxygen in water vapor is mostly O-16. This leaves the water in the ocean with a higher concentration of O-18 compared to O-16. When the Earth is particularly cold, the lighter oxygen (O-16) gets locked in ice sheets, leaving the ocean even more enriched in O-18 relative to O-16.

The shells of tiny animals and corals are typically made of calcium carbonate ($CaCO_3$). They use the oxygen in the water to form their shells. When they die, their shells fall to the bottom of the ocean, and can be recovered from drill cores. Because these organisms record the relative abundance of oxygen isotopes in their shells, the isotopic signature can be used as a proxy for temperature.

Oxygen isotope curves show the abundance of O-18 relative to O-16 (designated δ18O). So, whenever the earth is colder (an icehouse earth), an abundance of O-16 will be locked in ice sheets, and the ocean will have a higher ratio of O-18 to O-16. The organisms' shells, and therefore the isotope record, will have higher δ18O values. Conversely, when it is warmer (a greenhouse world), the organisms' shells and isotope record will have lower δ18O values. This is because the lighter isotopes are not frozen and return to the oceans.

Make sense? Yeah, it confuses me a lot too. But, the simple answer is this: Increase the temperature, decrease δ18O values. Decrease the temperature, increase δ18O values.

The isotope record presented by James Zachos and his colleagues (pictured above) shows the dramatic climate shift over the past 65 million years brilliantly. This figure from their 2001 paper may seem a little complex, but on the left you can see how the record shifts from lower values (around 0 or 1) to higher values (around 4 or 5). I've circled the Eocene-Oligocene transition to demonstrate just how dramatic of a change it really was. On the right, in the red circle I've pointed out some of the effects this change had on the organisms alive at the time, as I talked about in the last blog entry. As you can see, the climate is constantly shifting, and organisms are either forced to adapt or face extinction.

So what about fossils from land? While alive, animals drink water. Their teeth record the isotopic signature of their drinking water much in the same way that the tiny organisms in the ocean record the ocean's oxygen isotope ratio in their shells. This isotopic signature can be used to determine temperature as well. Alessandro Zanazzi and his colleagues collected hundreds of teeth from four of the most abundant White River mammals from Nebraska, South Dakota, and Wyoming: *Mesohippus* (an ancestral horse), *Merycoidodon* (a sheep-sized artiodactyl related to ancestral camels), *Leptomeryx* (a small deer-like artiodactyl) and *Subhyracodon* (an ancestral rhino). Using these fossil teeth, the scientists looked at their oxygen isotope composition to come up with an oxygen isotope curve. What is special about this curve is that it addresses the changes occurring on land, versus the ocean. They were able to determine that the temperature dropped approximately 15°F in central North America during the Eocene-Oligocene Transition.

Isotopes aren't the only evidence we rely on when making these paleoclimate reconstruction. Fossil plants also play a big role, since the relationship between temperature and plant life is fairly well understood. Even looking at the proportions of reptile and amphibian species can give us clues, as the regions these animal live in is temperature dependent as well.

I know this post has been quite heavy, but I wanted to explain why (and how) scientists are able to make statements about climate change in the past, or the present. If you have questions, please ask! I certainly did while writing this, and consulted with friends who work with isotopes on a day to day basis, unlike myself. If I can't answer your question, I'm sure they can!

And I promise next post I will talk about something fun and easier to explain!

Scientific Articles:

Zanazzi A, and Kohn MJ (2008) Ecology and physiology of White River mammals based on stable isotope ratios of teeth. Palaeogeography, Palaeoclimatology, Palaeoecology 257:22--37.

Zachos J, Pagani M, Sloan L, Thomas E, Billups K (2001) Trends, rhythms, and abberations in global climate 65 Ma to present. Science 292:686--693.

TUESDAY, SEPTEMBER 29, 2009

## **My love, the Leptomeryx**

When I started graduate school, I felt pretty intimidated. Why? Well, I was a geologist. I knew rocks. I knew a bit about crinoids, commonly known as "sea lilies," since that was the organism I did my senior research project in. I knew I wanted to be a vertebrate paleontologist, and study animals with bones (nothing at all against invertebrate paleontologists! I just like the fuzzy, cute variety of animals!). But I didn't really know anything about vertebrates.

One of the first paleontology classes I took, thankfully, was simply titled "Vertebrate Paleontology." For a class project, we were given the freedom to pick an area of interest and investigate a question related to a particular animal group, or subject, pretty much whatever we wanted. As mentioned in a previous post, I discussed with my advisor potential projects, and started work on a project involving the genus *Leptomeryx*. The project didn't quite work out by the end of the semester, but showed a lot of potential to answer some interesting questions about climate change, mammalian evolution, and the relationships between animal diet and tooth morphology, or shape. I decided to keep working on it, and eventually the *Leptomeryx* project evolved into my Master's thesis.

Unfortunately, it's hard to talk about exactly what a *Leptomeryx* is. The group has been described as "deer-like," but they are not actually related to deer at all. Some scientists believe that they are part of a larger group that includes the modern day "mouse deer", making these very small mammals' cousins to *Leptomeryx*. The hornless mouse deer are also not true deer, the males of which grow and shed new antlers each year.

In my mind, whenever I think about *Leptomeryx*, I envision Bambi. Only, Bambi grew up, and got bigger. The *Leptomeryx* never got past "Bambi size." Most species averaged about 17 pounds, though one species, aptly named *Leptomeryx mammifer*, might have been around 50 pounds. In relation to animals we are familiar with today, *Leptomeryx* were probably somewhere between the size of a rabbit and a medium-sized dog.

*Leptomeryx* first appeared in the middle Eocene, around 41 million years ago, and became extinct in the early Miocene, around 18 million years ago. This means that this group existed both before and after the Eocene-Oligocene Transition that occurred about 30 million years ago. Researchers have shown that the climate change actually had little effect on most of the mammal groups at the time. The *Leptomeryx* were one of the three groups that did show significant changes over the boundary. That makes these little guys special.

What the *Leptomeryx* did that is so different than other mammals is gradually change the morphology, or shape, of their teeth. As one of my old professors once said, being a vegetarian is tough to do. There are many specializations an animal must be equipped with to deal with eating plants, which are tougher on their teeth than meat would be. For instance, grass actually contains strands of silica, or glass. This wears down the teeth of plant-eaters over the course of their life. Plant-eaters, or herbivores, have come up with some interesting ways of dealing with this. Horses, for example, evolved higher crowned teeth. These longer teeth are better suited to eating grasses. Because grasslands were starting to spread, horses with these types of teeth were better adapted to their environment, and these were the horses that survived to give rise to our modern horses.

*Leptomeryx* did something a little different than the horses. Around the same time as the Eocene-Oligocene Transition, the enamel of *Leptomeryx* molars started to become increasingly complex. Early, primitive species of *Leptomeryx* had very smooth enamel, while in the later, more advanced species, the enamel became more wrinkled. An extra fold of enamel, known as the *Palaeomeryx* fold, is also present on later species.

Like the changes in the teeth of horses, these changes in *Leptomeryx* are also correlated with a change in environment. In the areas where *Leptomeryx* fossils are found, a change in the ecosystem is seen in the plant fossils. Areas that were once moist forests gave way to dry woodlands and finally open grasslands. These more complex patterns seen on the later *Leptomeryx* were perhaps a response to eating the tougher vegetation that resulted from the climate change.

There has been a great deal of research on the links between diet and tooth morphology, between what animals eat and what their teeth look like. By studying these relationships in the present, paleontologists are able to make hypotheses about the ecosystems of the past. This is one of my favorite aspects of paleontology, and one you'll probably hear more about later!

FRIDAY, OCTOBER 2, 2009

## Fossil Teeth and Diet

Have you ever wondered how paleontologists are able to say what animals in the past were eating? Well, there are many different methods they use. Sometimes they observe the plant fossils that are found in association with the animals (or, what other animals were around to be prey for the meat-eating folks), and make assumptions based on the availability of food sources. Other times, they make inferences based on the teeth of the animals. “The present is the key to the past.” That is one of the first things I was taught in geology. Observing the feeding behaviors in modern mammals and comparing them to tooth morphology, or shape, is one of the best ways to determine the relationship between teeth and diet.

Animals are often categorized based on food preference. For instance, carnivores eat meat, while herbivores eat plants. Herbivorous mammals can be often classified based on which type of plants they prefer to eat. Plants are variable in their shape and chemical composition, leading to different adaptations in the anatomy and behavior of herbivores. Herbivorous mammals are generally lumped into one of two categories: those that eat primarily grasses (Grazers), and those that eat primarily leaves, shrubs, and flowering plants (Browsers). Each plant type has its own positive and negative aspects as a food source, and the herbivores that eat these sources are marked with distinguishing characteristics as a result.

A grazer’s diet consists of as much as 90% grasses. Grasses tend to have thick cell walls, which are tough and require a large amount of energy to break down. These cell walls contain plant fibers known as cellulose, which digest slowly. Grasses also have chemicals that act as a defense for the plant. They have a high concentration of silica, or glass, which increases the wear on herbivores’ teeth. Grasses are a relatively consistent food source, with the leave, stem, and fruit of the plant being indistinguishable to the grazing animal.
http://2.bp.blogspot.com/_gbSCRvRcziw/SsYjPS3cz2I/AAAAAAAAAKk/cBghTPgGYnY/s1600-h/cow.jpg

A browser's diet is primarily made of leaves, succulent plants, and fruits, collectively known as browses. Browses have thin cell walls which contain the indigestible fiber known as lignin. But within the cells are compounds like sugars and proteins that are completely digestible. Browses, like grasses, have defensive chemicals. These chemicals reduce protein and dry matter digestibility. Unlike grasses, browses have a variety of parts that are easy for the browser to distinguish. These different plant parts (young buds, mature leaves, stems, and fruits) each have different nutritional values.

Modern grazers and browsers have been studied in detail, especially the hoofed mammals, or ungulates. Key traits have been identified that can be used to determine which of the food sources make up the animals primary diet. These observable characteristics from modern mammals can then be examined on fossils to try and determine diet. These types of studies are great for determining past ecosystems and the relationships between animals and plants in our Earth's history.

Shape/Height of teeth

One of the most recognizable differences between grazers and browsers is in the structure of their molars. Grazers tend to have higher crowned teeth (more tooth above the gum, with a short root), allowing for longer wear. This adaptation allows them to eat the extremely abrasive grass throughout their lives. A grazers tooth will often be modified with complex ridges designed for grinding down grasses. Browser teeth in contrast generally have less complex, short crowned teeth (less of the tooth above the gum with a longer root). This is because the leaves and shrubs are softer, easier to break down, and do not cause as much wear on their teeth.

Microwear patterns

Microwear analysis is used to identify wear features on enamel surfaces by the way they reflect light when viewed under high powered microscopes. These microscopic wear features will be different depending on what types of plants the herbivore eats. Wear features are commonly classified as scratches, pits, or gouges. In general, grazers are characterized with a higher concentration of scratches, caused by the highly abrasive grasses they are eating. Browsers, on the other hand, have fewer scratches but might have more pits and gouges from eating seeds and stems.

Carbon isotope signature

The element carbon, like oxygen, has different isotopes (C-12 and C-13). Different carbon isotopes are taken in by plants during photosynthesis, the process by which plants convert carbon dioxide into a food source. Browses use a different type of photosynthesis than grasses, leading to a difference in the carbon isotope signature between the two types of plants. Trees and shrubs generally have a lower carbon isotope signature than grasses. When an herbivore eats these plants, the carbon isotope composition is recorded in their teeth. Therefore, fossil teeth of a browser eating trees and shrubs will have a lower carbon isotope value (around negative13) than a grazer eating grasses (around positive 1).

For example:

During the course of their evolution, the teeth of horses increased in crown height. Early horses were small, with simple, short-crowned teeth, indicative of browsing. Modern horses have much higher-crowned teeth, and are known to be grazers. Recent isotopic work by Bruce MacFadden has shown this change in diet. The earliest horses have carbon isotope values indicating browsing feeding behaviors. Fossil teeth from later horses have intermediate carbon isotope values, suggesting that they were mixed feeders, eating both grasses and browses. The more advanced horses, including the modern species, have carbon isotope values reflecting their almost exclusive diet of grasses. Microwear analysis also reflects these changes.

People have been collecting fossils for thousands of years. They've been used by ancient cultures as jewelry and adornment, tools, and possibly even as a form of currency. Kids of all ages enjoy looking at their collections and imagining what the animal would have looked like when it was alive, how it might have acted. I was one such kid! One thing that graduate school has made me realize is that fossils are most exciting when they can be used to learn something about ancient environments and ecosystems. These methods are just the tip of the iceberg of what paleontologists can do!

Scientific Articles:

MacFadden, B.J. 2005. Fossil Horses-Evidence for Evolution. Science 307, p. 1728-1730.

Solounias, N. and Semprebon, G.M., 2002. Advances in the reconstruction of ungulate ecomorphology with application to early fossil equids. *American Museum Novitates* 3366, p. 1–49.

TUESDAY, OCTOBER 6, 2009

## What is a Species?

Speciation and adaptation are two concepts in evolutionary biology that are often confused and misunderstood. One, speciation, explains the how new species arise. The other, adaptation, refers to the acquisition of new structural, functional, and behavioral traits that allow the organisms to be more reproductively successful. They are related and work together, but are two different concepts. Understanding these concepts can help us to understand the changes our planet and the life on it has seen these past years.

Last year I took a class that might have been the hardest one I have taken in graduate school to date. It was called "Systematics in the Fossil Record." The entire purpose of the class was to discuss, in a nutshell, how paleontologists classify and group organisms based on their evolutionary relationship to other organisms. Broadly speaking, this is known to paleontologists and biologists as "phylogenetics." Phylogenetic systematics studies the diversification of life, both past and present, and the relationships among living things through time. These relationships are then shown on evolutionary or phylogenetic trees.

One day in class we had a discussion about species. Interestingly, this topic was one of the most difficult to grasp, the one that made me realize something. When asked what a species was, I gave the answer I had always heard growing up. Species are groups of organisms that share similar features and produce viable offspring. Well, turns out it's a lot more complicated than that. There are several different concepts of what defines a species. Some are based exclusively on physical appearance. Others are based on reproduction. With all of these different concepts, how do you answer the question: What is a species?

For most purposes, the "Biological Species Concept" is used to define the word. According to the biological species concept, species are groups of interbreeding natural populations that are reproductively isolated from other such groups. It's this isolation that is the key to this concept. Today, certain hybrids between animals exist, such as the "Liger"-a hybrid between a tiger and a lion. These animals only exist in captivity because in nature, these animals are from different regions. Under natural circumstances, these animals do not breed. So, according to the biological species concept, lions and tigers are two different species. Ligers themselves do not have a scientific species name because they are considered to have human assisted ancestry, and ligers are generally infertile.

Isolation can be either geographic in nature, such as mountain or an ocean, or could be simply because the animals develop different mating habits, or are not anatomically compatible, and therefore do not mate and reproduce offspring with similar groups. Either way, the populations' hereditable traits, or genes, are isolated from similar groups.

Each group will experience different environments, and will adapt to them in their own, unique ways. Adaptations are features that are common in a population because it provides some improved function. Because adaptations improve the quality of living, the organisms with these adaptations have a better chance of surviving. For instance, at some point in their evolution, horses with higher crowned teeth were better suited for their environment, and therefore survived to pass on their genes. High-crowned teeth are an adaptation that allowed horses to eat grasses. The Leptomeryx that I study have crenulations and extra enamel that I believe are an adaptation to eating tougher plants.

Given enough time and enough variation of adaptations among the groups, new species may arise. This process is known as speciation.

Speciation is the biological process by which new species arise. These speciation events require specific THINGS to happen:

• First, you have a single species, a population of naturally interbreeding organisms.

• Next, some genetic mutation must occur and spread through part of the species, with the bearers of this mutation only breeding with bearers of the same mutation; the two gene pools are isolated from one another.

• The initial population is now split into two separate, though related species. The two new, isolated interbreeding populations experience different conditions and different random events, and evolve different adaptations as a result.

• Given enough time, the gene pool of each becomes distinct from its ancestor, and the two populations would not be able to reproduce with each other even if they were reintroduced.

It's sometimes hard as a paleontologist to rely on the Biological Species Concept, because you can't really know if species are interbreeding or not. This is when phylogenetic systematics, or cladistics as it is sometimes called, comes into play. Cladistics is a method of hypothesizing relationships among organisms by constructing evolutionary trees.

To do this, a paleontologist will base their hypothesis on a set of traits or characters possessed by the organisms. These characters could be anatomical and physiological characteristics, behaviors, or genetic sequences. In cladistics, the more characters two organisms share, the more closely they are related. The result of a cladistic analysis is a tree, which represents a supported hypothesis about the relationships among the organisms.

For example, in the picture below, 7 groups are analyzed based on 6 traits. The tree shows that amphibians are equally related to both primates and dinosaurs. The tree also shows that primates and dinosaurs share a more recent common ancestor than either does to amphibians. The tree shows both the relatedness and splitting of lineages of the organisms involved.

In the class I mentioned above, I preformed a cladistic analysis on 7 known Leptomeryx species. In general, cladistic analysis involves examining hundreds, if not thousands of teeth to identify what species they belong to and what traits they have. Character lists can be extremely long, especially if you are looking at numerous species. My analysis was a very simple experiment, using characters other researchers had identified. And it still took days, weeks, months.

Understanding speciation events and the adaptations that new species evolve can make the study of diversity and the relationship of organisms an easier task. The methods scientists use are very thorough, and well supported by fossil evidence. Discussing evolution is a tricky topic, but I think it's important to know some of the key concepts behind it in order to make educated opinions on the matter.

FRIDAY, OCTOBER 9, 2009

## **Evolution**

If there is any topic that can beat climate change as a controversial dinner topic, it's evolution. I've spent 8 years of my life, in one way or another, devoted to the study of evolutionary biology. It was in my undergraduate geology classes that I had my first real discussions about evolution. I didn't realize then what a huge topic it was. I wonder if that's because it wasn't such a hot topic then, or if it just wasn't talked about in my high school in TN. But it seems that it is discussed everywhere now, and some of the people talking are giving bad information.

Evolution is a huge topic. So huge that there is no way to cover its many dimensions without writing a book. So I want to talk about why I accept the scientific theory of evolution. I want to explain what evolution is, but perhaps more importantly, what it isn't. There are several misconceptions about evolution, so it is important to recognize and understand why they are wrong. I've heard them numerous times from numerous sources.

The best online resource that I have seen explaining evolution is the "Understanding Evolution" website created by the University of California Museum of Paleontology. I can't stress enough what a wonderful website this is! One of its many resources is a list of the most common misconceptions about the theory of evolution and the way it works. My list below is inspired by the most common misconceptions from their list that I have encountered in my years of study and defending the theory of evolution.

**Misconception: Evolution is a theory about the origin of life**
The theory of evolution involves the study of how life has changed after its origin, not an explanation of the origin of life itself. Other areas of science do make attempts to explain the origin of the universe or of life (Big Bang theory, experiments creating proteins from inorganic compounds, etc.), but these are not addressed by the theory of evolution. Evolution studies not the origin, but the branching off of life after its start.

**Misconception: Evolution involves the progression of organisms into better, more perfected life forms**
This misconception springs from a misunderstanding of the role natural selection plays in evolution. During the process of natural selection, some individuals have genetic traits that improve their chances to survive and reproduce, during which these genes are also passed down to their offspring. As these traits continue to be passed down among offspring, they become more common, weeding out the less advantageous traits.

But no organism is perfect. Various organisms (some fungi, mosses, crayfish, and sharks) have remained relatively the same over a very long period of time. They are not marching up a ladder of progress, as they are fit enough to survive and reproduce without further adaptations. Other organisms have changed and diversified a great deal, but this still doesn't necessarily make them better. Organisms are adapted to the environment that they live in, but if the environment changes these adaptations may not prove to be as useful as they once were.

**Misconception: Evolution occurs solely as the result of change due to random chance**

Random mutation is the primary source of genetic variation, so there is some truth in saying that life changed “by chance.” But, it’s only a very small part of the evolution story. Natural selection drives evolution, and that process is not random. Natural selection is the result of the complex interplay of living organisms trying to survive in the environment they have been born into. For example, the different beak shapes of the Galapagos Finches often are used to illustrate differences in species, and how the beaks relate to the finches’ environments and food sources. Chance mutations give them the traits or skills, and then it’s up to the organism to survive. If they are well adapted to their environment, they will pass on their traits. If not, they face extinction.

**So what is evolution?**

The short answer: biological evolution is descent with modification. Evolution is sometimes described as change over time, which is in part true. But lots of things change that are not examples of biological evolution. The distinction must be made that evolution is change caused by the inheritance of genetic traits. Natural selection then determines which traits are fit for the environment at the time. The central idea to biological evolution is that the diversity of life on earth has changed over time and that different species share common ancestors. The relationships between organisms can be shown on evolutionary trees. These trees are used to classify and understand the organisms.

To explain the lines of evidence for evolution is out of the scope of this post. I accept the theory of evolution because I have read the scientific articles, been in the field to understand geology, rock sequences, and collect fossils. And everything makes logical sense to me. I understand the dating techniques that give the earth an age of 4.6 billion yeas old. If changes in genetic variation can be seen in as short as a few hundred years, think of what can happen in millions of years, with the changes in climate and environment that the earth is known have undergone.

The group that I work on, the *Leptomeryx*, can offer a great example of this. Their lineage can be traced through time, with the primitive species changing the morphology and size of both their teeth and bodies, potentially in response to a changing environment. Researchers Timothy Heaton and Robert Emry proposed an evolutionary history where the species *Leptomeryx yoderi* probably gave rise to all later species. A speciation event gave rise to *Leptomeryx speciosus* and *Leptomeryx mammifer*. *Leptomeryx speciosus* then appears to have undergone gradual changes resulting from mutations such that the ancestor population went extinct, with a new species, *Leptomeryx evansi*, taking its place. This hypothesis is consistent with the fossils found in a specific sequence in the rocks, as well as looking at the different patterns on the teeth. Though no cladistic analysis has been done for the *Leptomeryx*, their evolutionary tree might look something like the image I have drawn, shown below.

Numerous other examples exist, some with support from many different scientific methods, be it paleontology, genetics, geology, or chemistry. The most important thing to remember when discussing evolution, in my opinion, is to not take what you are told at face value (even what I say!). Research the material yourself to gain an understanding of the arguments, keep an open mind, and decide for yourself what your opinion will be.

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## BIOGRAPHICAL SKETCH

Julie Elizabeth Mathis was born in 1983 in Nashville, Tennessee. She grew up with her mother, father, and two sisters in Mt. Juliet, Tennessee, graduating from Mt. Juliet High School in 2002. From there, she spent her first year of college at Middle Tennessee State University, before transferring to the University of Tennessee. Here, she earned her B.S. in geology in December 2006. Julie began graduate school in August 2007 at the University of Florida in Gainesville, Florida. While working on her master's project, she was also actively involved in education and outreach, presenting talks at various fossil clubs, talking about paleontology at special events, and volunteering in the education division at the Florida Museum of Natural History. Julie Mathis was among one of the first geology graduate students to complete a "non-traditional thesis," incorporating broader impacts into her thesis along with her scientific research, gaining a minor in science education in the process. Upon completion of her M.S. in geology, Julie will attempt to continue educating the public about science, working in an informal setting such as a museum or science center.