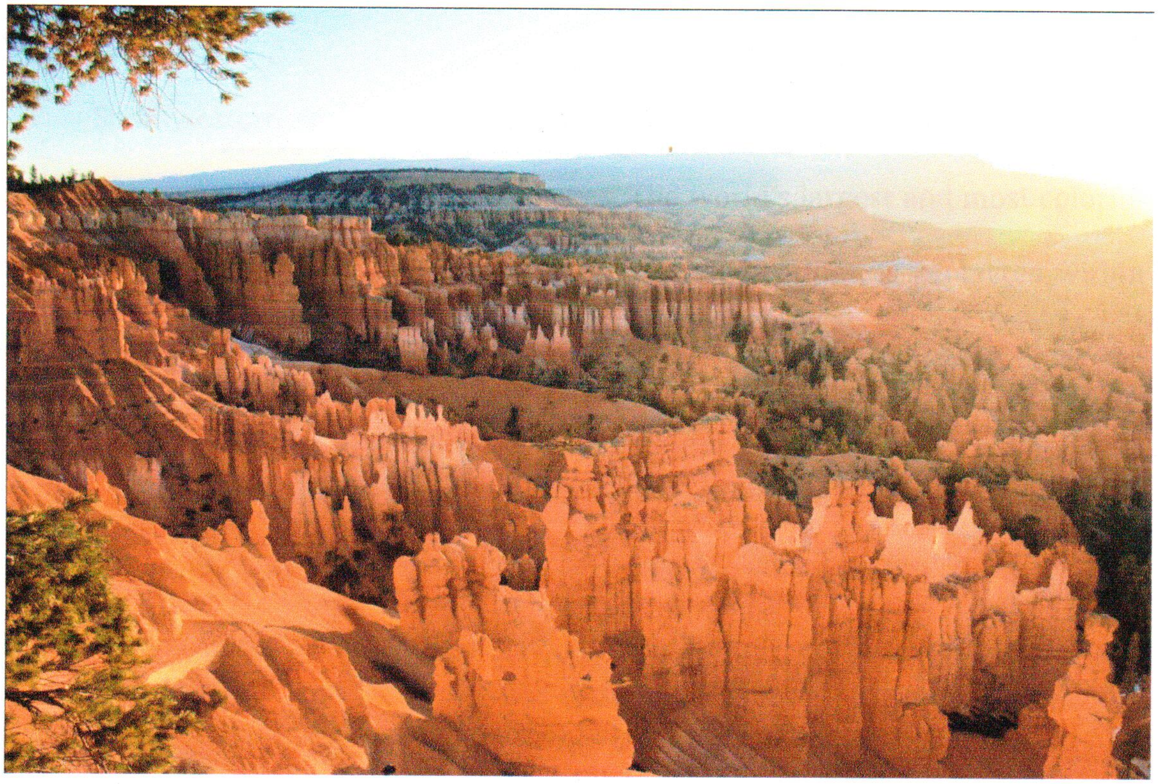


Hidden in the Hoodoos

Interpreting the Chronology and Past Environments of Cedar Breaks National Monument and Bryce Canyon National Park

Caitlin Scully • May 24th, 2012 • CMBC MAS

Committee

Richard Norris (Chair): ______________________

Judith Coats: ______________________

Jericho Burg: ______________________

Introduction

Southwestern Utah is home to the perfect blend of common elements that create uncommonly breathtaking landscapes. The world's largest and most colorful collection of spectacularly shaped rock pinnacles, or hoodoos, is protected within Cedar Breaks National Monument and Bryce Canyon National Park. Little is known about the age of the hoodoo-forming depositional environment. This capstone project uses geochemistry of soil carbonates in the Claron Formation to date the primary geologic features of Cedar Breaks National Monument and Bryce Canyon National Park. The geochemistry of the Claron Formation records evidence of global hyperthermal climate events that have been recognized in both deep sea and terrestrial paleoclimate archives. These hyperthermals were produced by releases of carbon to the atmosphere that are broadly similar to those predicted for the year 2100. The new chronology is part of a manuscript to be submitted for scientific publication. In conjunction, interpretative and educational materials have been created for national park staff and visitors. By providing the National Park Service with an accurate geologic history, visitors will come to understand geology and past super warm climate events, and how both relate to future climate change.

Background

Cedar Breaks National Monument and Bryce Canyon National Park are symbols of the American West. Bryce Canyon became a national park in 1928 and protects about 36,000 acres, while Cedar Breaks was established in 1933 and encompasses over 6,000 acres (nps.gov). Both are located in southwestern Utah, and are managed by the National Park Service as part of the Department of the

Interior (Figure 1). Charismatic hoodoos, canyons, and amphitheaters bring over one million visitors to Bryce Canyon and several hundred thousand to Cedar Breaks each year (nps.gov). Despite their popularity, there are still many unanswered questions regarding the geology of the parks.

Cedar Breaks and Bryce Canyon are located at the western edge of the Colorado Plateau. The Claron Formation is the primary geologic feature in both parks. It is comprised of red, orange, and white fluvial and lacustrine deposits of Paleogene age (Figure 2). The Claron Formation was deposited as part of a broad freshwater carbonate lake system that stretched from eastern Nevada to western Wyoming (Sprinkel, 2003). The Claron Lake System was about 250 miles long and stretched 75 miles wide, slightly larger than Lake Erie (Chronic, 1990). Although the lake was large, it was also highly dynamic both seasonally and on geologic time scales. Limestone, dolomite, and carbonate rocks preserve subaqueous environments, often extensively modified by soil-forming processes, while sandstone, mudstone and pebble conglomerates reflect both near shore and onshore environments (Morris, 2010). Soil formation, in particular, is responsible for the reddish and yellowish hues of much of the Claron Formation, and hence, the colorful nature of the landscape in both Cedar Breaks and Bryce Canyon.

Today, the chronology of the Claron Formation is poorly known due to the lack of diagnostic fossils, the dynamic erosional environment, and the destruction of sedimentary structures by pedogenic processes (Sprinkel, 2003). Previous studies have used mammal teeth, charyopyte algae and fresh water snails to provide an approximate age for the Claron formation—assigning a Paleocene and Eocene age to rocks in Cedar Breaks and Bryce Canyon. However, the ancient lake system that deposited the Claron Formation is an excellent candidate for carbon isotope analysis. In this project, Cedar Breaks and Bryce Canyon carbon isotope data, based upon geochemical analysis of Claron Formation carbonate rocks, are compared to well-dated benthic foraminiferal $\delta^{13}C$ (Cramer et al., 2009) records from Deep Sea Drilling Project (DSDP) and Ocean Drilling Program (ODP).

Objective

The goal of this project is to accurately date Cedar Breaks National Monument and Bryce Canyon National Park, publish a paper, design an interpretive poster, create a presentation, and write educational materials for national park staff and visitors. By understanding how and when the Claron formation was deposited, the National Park Service will be better equipped to educate the public at some of its most popular parks.

Key questions:

1. When was the Claron Formation deposited?
2. What are the characteristics of the climate and ecosystems of the last superwarm period, as seen in the Claron Formation?
3. What interpretative and educational materials are needed by the National Park Staff?
4. What is the best way to present data to the public?

The Claron Lake System dates to the last super warm greenhouse event called the Early Eocene Climatic Optimum (EECO). During the EECO, primitive primates and horses roamed the American West, conifer and cypress forests covered the Arctic, and there were no glaciers. Today's climate projections infer that by 2100, the Earth's climate will be very similar to the environment that created the Claron Formation at Cedar Breaks and Bryce Canyon.

Methods and Deliverables

Completed Materials:

1. Accurately dated Claron Formation
2. Created interpretative poster for National Park Service
3. Created Prezi presentation to be given by national park staff
4. Wrote a background document to educate national park staff and volunteers

Cedar Breaks sediment samples were collected in September 2006 by Richard Norris, Lisa Tauxe, and members of the SIO Field Paleomagnetism Course. These rock samples were subsequently ground into powder and analyzed in the SIO mass spectrometry facility by Johnny Lyman, then a SIO graduate student of R. D. Norris. Bryce Canyon isotope data were obtained from Amy Ott's 1999 Masters Thesis: *Detailed Stratigraphy and Stable Isotope Analysis of the Claron Formation, Bryce Canyon National Park, Southwestern Utah*. Isotope analysis of Cedar Breaks was completed in Dr. Norris' lab prior to my introduction to the project. I helped analyze this data using Analyseries 2.0 and Cramer's 2009 timescale (Cramer et al., 2009) as part of a Fall Quarter 299 project. I compared the Claron Formation $\delta^{13}C$ record to the deep sea benthic foraminifer $\delta^{13}C$ record of Cramer et al. (2009) in order to use the well-dated deep sea record to provide a firm age scale for the Claron lake record. Dating of the Claron record was done by matching optima and troughs with equivalent features in the deep sea $\delta^{13}C$ record. Through trial and error we achieved the greatest degree of overlap with the minimum of abrupt changes in the sedimentation rate. The Claron and deep sea $\delta^{13}C$ records match almost one-to-one in the lowest ~100 m of the Claron section, but above this, the correlation of the two records becomes more uncertain. Alignment was inhibited by possible unconformities in the middle of the Cedar Breaks record. This analysis suggests that the Claron Formation at Cedar Breaks dates from 54.3 to 40.5 million years ago (Figure 3). Dates for Bryce Canyon are uncertain due to poor data quality.

After accurately dating the Claron Formation, I was able to begin work on the interpretative materials. This task included: (1) searching for a modern analog to the Claron lake system, designing a poster to present information to the public, and designing both a set of background materials for park staff and an iPad tool for public exploration of scientific information on Claron Formation geology.

Initially, we searched for a modern analogue to the Claron Lake System. This was an unexpectedly difficult task. Some systems, such as the Pantanal or the Okavango River Delta had similar characteristics in being highly seasonal lake systems with distinct wet and dry phases, yet they lacked carbonate sediments. Other systems, including the Narran Lakes and Lake George of Australia, contained carbonate sediments and were subject to cycles of flooding and drying. However, these systems were either too small or saline in nature. Ultimately, a true modern analogue of the Claron Lake System was never found.

A critical asset to all outreach materials was Beverly Serrell's book *Exhibit Labels: An Interpretative Approach*. This guide helped to streamline the outreach message and communicate the data in clear, concise, interesting ways. Serrell defines interpretative labels as those that "serve to explain, guide, question, inform, provoke… and invite participation" (Serell, 1996). The techniques discussed in *Exhibit Labels* were used in all three outreach components of the capstone. Surprisingly, the poster was the most difficult to create. This was due to the volume of information to be included in limited space and the complexity of conveying geochemical information in a manner interpretable by the public. *Exhibit Labels* and coaching from my committee helped to prioritize information and present it in an interpretative way. The poster is titled *Hidden in the Hoodoos* and is broken into three headings: "The Dynamic Ancient Lake System" "Mammals Thrived in Ancient Warmth" and "Fossils and Chemistry Reveal Age" (Figure 4). These headings were chosen to teach the reader the story of the Claron Formation even if he or she does not read the body text of the poster.

The free program Prezi was used for the presentation and iPad program. Prezi is a web-based, user-friendly, combination of Flash and PowerPoint. Similar to the poster, the Prezi presentation is divided into three parts: "Ancient Lakes and New Mammals" "Scientists Search for the Exact Age of the Rocks" and "Past Patterns Hint to Future Change" (http://prezi.com/vutiujat4n02/hidden-in-the-hoodoos/). The Prezi is designed to be flexible. The National Park Service may choose to use part of the presentation for short outreach programs or the entire presentation for full-length ranger programs.

The Educational Document (Appendix 1) is designed to supplement the poster and Prezi and is intended as background material for Park staff rather than for direct public use. The document provides background information about the Eocene (at global and local Southwestern Utah levels), Eocene habitats and biota, challenges associated with dating the Claron Formation, how isotopes were used to date the Claron Formation, and future implications. National Park Rangers and volunteers will use this information to enhance their poster and Prezi discussions.

Partnerships have been a critical component of this capstone project. I worked with the National Park Service to customize the interpretative materials to their needs. Contacts include Daphne Sewing (Chief of Education and Partnerships at Cedar Breaks), Matthew Harrison (Chief Park Ranger at Cedar Breaks), Dave Sharrow (National Park Service Resource Management and Research), and Jan Stock (Bryce Canyon Interpretative Ranger).

EcoFlight is a conservation non-profit organization that takes aerial photos to buttress conservation messages. Ecoflight graciously took beautiful aerial photos of Cedar Breaks National Monument at no cost to us. Unfortunately, heavy snow cover meant that the photographs were not useful for the public presentation. However we did use EcoFlight pictures to trace geologic layers that had been dated during our study throughout Cedar Breaks National Monument.

SIGNIFICANCE

Dating Cedar Breaks National Monument and Bryce Canyon National Park is important for the National Park Service, park patrons, and those interested in climatology. Cedar Breaks and Bryce Canyon provide an excellent opportunity to highlight the importance of Colorado Plateau geology in regard to the climate of the past and to link this ancient record to discussions about future climate. My project provides the first unambiguous evidence that the Claron Formation started to form during the peak of the last "greenhouse' period in Earth history associated with the

Early Eocene Climatic Optimum. The National Park Service, the Bryce Canyon Historical Society, and the Bryce Canyon Natural History Association have all expressed interest in our interpretative materials. They have also invited Richard Norris and I to attend and present at the 2012 Bryce Canyon Geology Festival. I have learned the process of processing data, interpreting complex topics for the public, and look forward to seeing our hard work shared with all those who visit Utah's beautiful national parks.

FIGURES

Figure 1: Utah state map showing location of Bryce Canyon National Park and Cedar Breaks National Monument (USGS).

Figure 2: The Claron Formation is the primary geologic feature of the amphitheaters of Bryce Canyon National Park (top) and Cedar Breaks National Monument (bottom). At Cedar Breaks, our new geochemical record for the Claron Formation comes from the two exposures farthest to the left in the lower photograph.

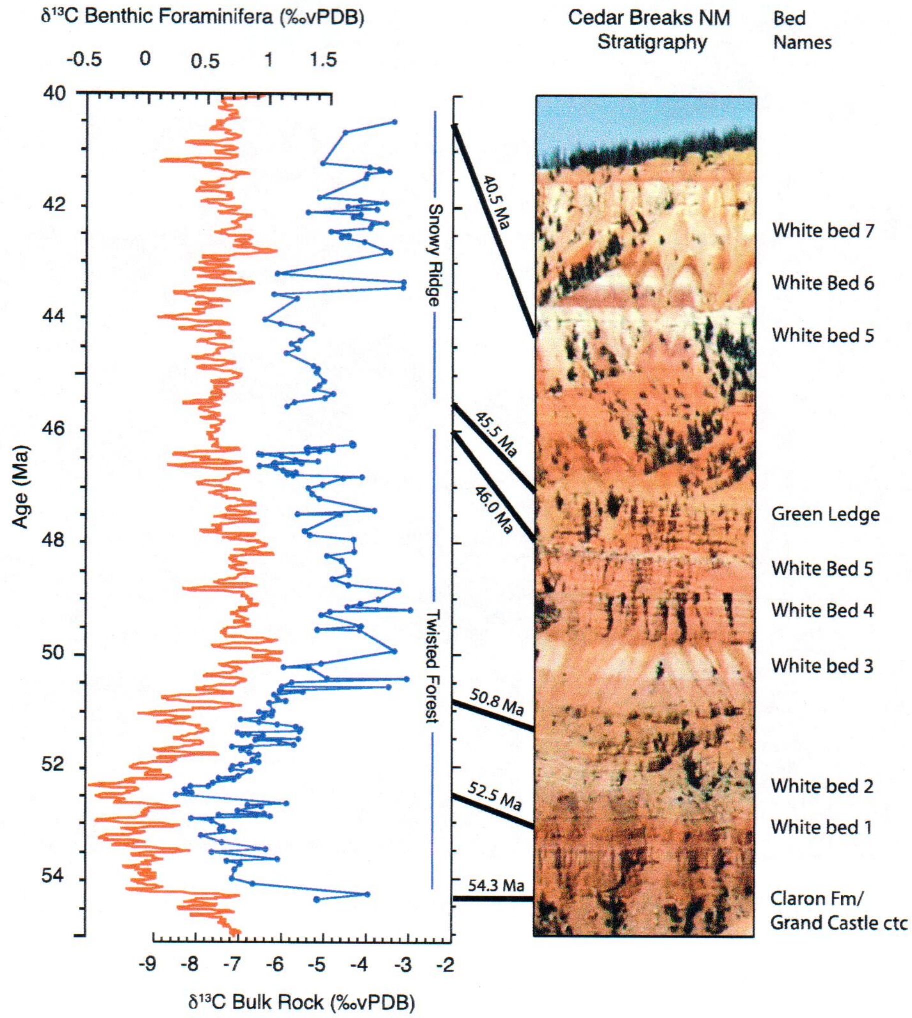


Figure 3: Aligned deep sea benthic foraminifer $\delta^{13}C$ record (from Cramer 2009) and the Claron Formation $\delta^{13}C$ record (new data) showing Cedar Breaks National Monument Stratigraphy and relative age of strata (Ma). "Twisted Forest" and "Snowy Ridge" are Claron Formation rock sequences sampled for their $\delta^{13}C$ geochemistry. Note the generally excellent alignment of the two records between ~54.3 and ~50 Ma, the interval for which our approach yields the best correlation.

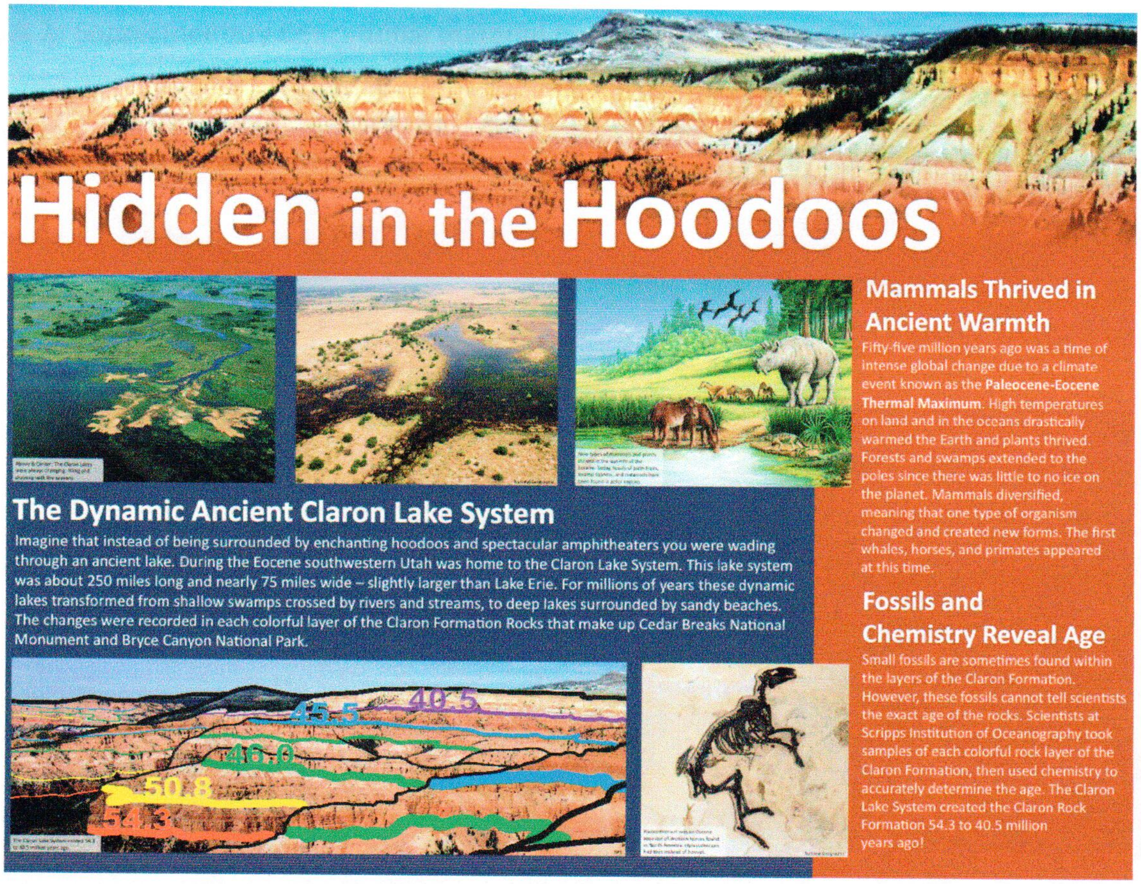


Figure 4: Interpretative poster for the National Park Service staff and patrons.

Appendix 1: Supplementary Educational material for NPS

Hidden in the Hoodoos

The Claron Formation Holds Clues to Past Global Patterns and the Future of Climate Change

Caitlin Scully
Scripps Institution of Oceanography

Why do we care about what is hidden in the hoodoos?

The Claron Formation of southern Utah holds clues to both the past and the future. The ancient Claron Lake System deposited the formation, fossilizing a snapshot of past environments, and preserving a climate record of the warmest period in the last 80 million years. Scientists used oxygen and carbon found within rock samples to date the Claron Formation at Cedar Breaks National Monument to 54.3 to 40.5 million years old. This period of Earth's history is known as the Eocene. The Eocene is characterized by the Paleocene-Eocene Thermal Maximum – a climate event where the Earth naturally released massive amounts of greenhouse gases into the atmosphere. This unusual event caused the entire global climate to change. The importance of the Paleocene-Eocene Thermal Maximum is highlighted by its similarities to global climate trends today. Through the use of fossil fuels and the subsequent release of greenhouse gasses, people are artificially warming the earth. If action is not taken to reduce greenhouse gas emissions, then global climate may be similar to the Eocene by the year 2100.

Core message for the public:

- The Claron Formation holds clues to the past that provide insight to future global climate patterns.

Communication Goals:

1. Describe the global Eocene setting in which the rocks were deposited.
2. Understand Utah's Eocene Claron Lake System and how scientists determined the age.
3. What can rocks of the Clarion Formation tell us about future climate change?

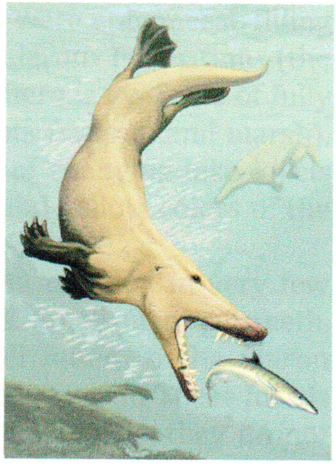
What was the planet like during the Eocene?

Ancient Lakes and New Mammals:

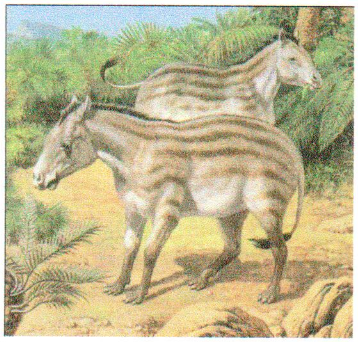
The Eocene Epoch (65 to 23 million years ago) was a time of global warmth that occurred after the extinction of the dinosaurs. The warming trend began after the Paleocene-Eocene Thermal Maximum, a time 55 million years ago when massive amounts of greenhouse gases were naturally released into the atmosphere warming the entire planet. High temperatures and warm oceans created a "hothouse earth" that lasted through much of the Eocene. The planet got so hot, so quickly, that life on Earth was profoundly changed. Plants thrived in the warm humid environment. Forests and swamps extended to the poles since there was little to no ice on the planet. Today, fossils of palm trees, swamp cypress, and redwoods have been found in Polar Regions. There is even evidence of tropical rainforests growing as far north as Europe and North America!

Some of the earliest known fossils of modern mammal types are from the Eocene. Mammals diversified, meaning that one type of organism changed and created new forms. The first whales, horses, and primates appeared at this time. Most of the land mammals of the Eocene were very small in size, which may have helped them manage the heat. Here are a few examples of Eocene Mammals:

Ambulocetus <u>(am-bue-low-see-tus) A Walking Whale</u>: Ambulocetus was an early whale transitioning from life on the land to life in the water. It looked like a nine-foot long cross between a crocodile and an otter! Ambulocetus used its four legs and large, likely webbed, feet to move through both salt and fresh water. It was not very agile and probably ambushed its prey (similarly to a crocodile). Like modern whales, Ambulocetus did not have external ears. Instead of listening, it may have used its massive jaw to feel vibrations of moving prey. Today, most Ambulocetus fossils are found in Pakistan.



Hyracotherium <u>(hi-rack-o-theory-um) The Dawn Horse</u>: Hyracotherium was an ancestor to horses, tapirs, and rhinos. It was small in stature, only about two feet tall, but was heavy for it's size (maybe up to 50 pounds). Hyracotherium was an herbivore and lived in sheltered woodlands. This horse relative had yet to develop hooves, instead it had paws similar to a dog. They had four toes in the front, and three in the back! Fossil Hyracotherium are found in the Northern Hemisphere.



Darwinius <u>(darwin-ee-us) First "Modern" Primate</u>: This Eocene primate has a skeleton very similar to modern day lemurs with additional primate-like characteristics. It is believed to have lived close to when lemurs and modern primate's branched apart in the primate family tree. Darwinius had grasping hands, opposable thumbs, and digits with nails instead of claws. A fossil found in Germany still had remains of its last meal in its stomach– fruit, seeds, and leaves.

Now that we understand the global environment during the Eocene, let's focus on what it was like in southwestern Utah.

The Claron Lake System

The Claron Lake System of southwestern Utah was about 250 miles long and nearly 75 miles wide – slightly larger than Lake Erie. The lake basins were located on a floodplain crossed with streams and rivers. The streams and rivers flowed into the basins and brought sediment from the ancestral Rocky Mountains into the lakes. Geologic processes, such as uplifting from the Laramide Orogeny and faulting, changed the basins over time. The Claron Lakes themselves were ephemeral, filling and draining with the changing seasons. Within the Claron Formation (the sedimentary rocks left behind by the Claron Lake System) there is evidence of fully aquatic environments (deep water), near shore environments (swamp and marsh), and onshore environments (beaches). Thousands of years of changing lake levels and environments is what creates the beautiful red, white, and yellow colors of the Claron Formation.

The dynamic environment of the Claron Lake System resulted in very few fossils that can be used to find the exact age of the Lakes. Small mammal teeth, freshwater snail shells, fossil tree roots, and algae are all found in the Claron Formation. Trace fossils, like bee nests and ant nests, are also present. These fossils tell scientists about the environment surrounding the lakes, however they do not tell the exact age.

A team of geologists, magnetostratigraphers, and climatologists visited the Claron formation at Cedar Breaks National Monument to figure out the exact age of the rocks. They took nearly 100 samples carefully marking the position of each sample within each colorful layer of the Claron Formation. The samples were brought back to the lab at Scripps Institution of Oceanography to study the amount of oxygen and carbon within each sample. Oxygen and carbon are used to understand past climate records. The rock samples were ground up to a fine powder then dissolved with acid. The oxygen and carbon gas was released as the powdered rock dissolved in the acid. A machine called a mass spectrometer was used to measure the released carbon and oxygen gases. Each sample had a specific amount of carbon and oxygen within. When placed together, the samples created a unique pattern that could be compared to the known past climate patterns recorded in oxygen and carbon. Scientists knew the Claron Formation was deposited during the Eocene; it was just a matter of discovering exactly when. By comparing the Claron Formation climate pattern to the known global climate pattern, scientists discovered that the Claron Lake System existed from 54.3 to 40.5 million years ago!

What can rocks of the Clarion Formation tell us about future climate change?

Future Implications:

People speculate about what will happen to the Earth if global temperatures continue to rise due to the influence of humans. Many of the answers can be found in studying the Eocene rocks of the Claron Formation. The Paleocene-Eocene Thermal Maximum was a global climate event that caused worldwide temperature to rise to the highest levels in the last 80 million years! During the Paleocene-Eocene Thermal Maximum, the Earth "burped" and a massive amount of greenhouse gasses was released. This event is similar to a catastrophic earthquake, astroid collisoion, or super volcanic eruption – it was an unusual and unprecedented, and nothing like it has had such massive impact on the Earth's climate since.

Today, the amount of carbon being unnaturally released into the atmosphere is on track to rival the Paleocene-Eocene Thermal Maximum. We already understand that releasing greenhouse gasses, such as carbon dioxide, is causing the global climate to warm at an increased rate. If action is not taken to curb the release of carbon dioxide, then our current climate system may be similar to the Eocene by the year 2100. Remember, during the Eocene there was no ice on Earth and there were forests and swamps with crocodiles at the poles. It took nearly 200,000 years for the earth to return to "normal" temperatures after the Paleocene-Eocene Thermal Maximum climate event. We will not see a reappearance of hyracotherium and ambulocetus; rather, Earth will take on the characteristics of Eocene habitats. If people do not take steps to reduce the amount of carbon emissions, then we may be living in a world very similar to the Eocene by 2100.

For more information

American Museum of Natural History – Science Bulletin

Long Ago in a Climate Not Far Away...
http://www.amnh.org/sciencebulletins/content/e.f.PETM.20081126/resources/601/

BBC Nature – Eocene

Great description of plants and animals of the time
http://www.bbc.co.uk/nature/history_of_the_earth/Eocene

National Geographic Magazine – Hothouse Earth Article

Discusses the Paleocene-Eocene Thermal Maximum and future implications
http://ngm.nationalgeographic.com/2011/10/hothouse-earth/kunzig-text/1

References:

"BBC Nature Paleocene Life." *BBC News*. BBC. Web. 14 Apr. 2012. <http://www.bbc.co.uk/nature/history_of_the_earth/Eocene>.

Davis, Stephen J., Andreas Mulch, and Alan R. Carrol. "Geological Society of America Bulletin." *Paleogene Landscape Evolution of the Central North American Cordillera: Developing Topography and Hydrology in the Laramide Foreland*. Web. 14 Apr. 2012. <http://bulletin.geoscienceworld.org/content/121/1-2/100.abstract>.

"Evolution of Earliest Horses Driven by Climate Change." *Nsf.gov*. Web. 14 Apr. 2012. <http://www.nsf.gov/news/news_summ.jsp?org=NSF>.

"The Evolution of Whales." *Understanding Evolution*. Web. 14 Apr. 2012. <http://evolution.berkeley.edu/evolibrary/article/evograms_03>.

"Long Ago, in a Climate Not Far Away..." *American Museum of Natural History*. Web. 14 Apr. 2012.

<http://www.amnh.org/sciencebulletins/content/e.f.PETM.20081126/resources/601/>.

""MISSING LINK" FOUND: New Fossil Links Humans, Lemurs?" *National Geographic.* National Geographic Society. Web. 14 Apr. 2012. <http://news.nationalgeographic.com/news/2009/05/090519-missing-link-found.html>.

Patrick, Goldstrand M. "Tertiary (1) Sedimentary Rocks in Southwestern Utah." *(UTT1;8)*. Web. 14 Apr. 2012. <http://tin.er.usgs.gov/geology/state/sgmc-unit.php?unit=UTT1;8>.

Jeffrey, Pietras T. "Lake Basin Response to Tectonic Drainage Diversion: Eocene Green River Formation, Wyoming." Journal of Paleoclimatology, 11 Dec. 2002. Web.

Kunzig, Robert. "Hothouse Earth." *National Geographic*. Oct. 2011. Web. 14 Apr. 2012. <http://ngm.nationalgeographic.com/2011/10/hothouse-earth/kunzig-text>.

Smith, Elliot M. "Synoptic Reconstruction of a Major Ancient Lake System: Eocene Green River Formation, Western United States." Geological Society of America. Web.

References

"Cedar Breaks National Monument (U.S. National Park Service)." U.S. National Park Service - Experience Your America. Web. 12 Jan. 2012. <http://www.nps.gov/cebr/index.htm>.

Cramer, B. S., J. R. Toggweiler, J. D. Wright, M. E. Katz, and K. G. Miller. "Ocean Overturning since the Late Cretaceous: Inferences from a New Benthic Foraminiferal Isotope Compilation." PALEOCEANOGRAPHY, 24 (2009). Web.

Chronic, Halka. Roadside Geology of Utah. Missoula, MT: Mountain Pub., 1990. Print.

Goldstrand, P. M. Tectonic development of Upper Cretaceous to Eocene strata of Southwestern Utah. Geological Society Of America Bulletin 106, 145-154, doi:10.1130/0016-7606(1994)106<0145:tdouct>2.3.co;2 (1994).

Goldstrand, P. M., and Mullett, D.J., . in Geologic studies in the Basin and Range-Colorado Plateau transition in southeastern Nevada, southwestern Utah and northwestern Arizona Vol. 2153 U.S. Geological Survey Bulletin (ed F. Maldonado, Nealey, L.D.,) 59-78 (1997).

Goldstrand, P. M. Tectonic development of Upper Cretceous to Eocene strata of southwestern Utah. *Geological Society of America Bulletin* **106**, 145-154 (1994).

Morris, Thomas H., Scott M. Ritter, and Dallin P. Laycock. Geology Unfolded: An Illustrated Guide to the Geology of Utah's National Parks. Provo, UT: Brigham Young UP, 2010. Print.

Ott, A. L. Detailed stratigraphy and stable isotope analysis of the Claron Formation, Bryce Canyon National Park, Southwestern Utah MS thesis, Washington State University, (1999).

Serrell, Beverly. Exhibit Labels: An Interpretive Approach. Walnut Creek: Alta Mira, 1996. Print.

Smith, M. E., Carroll, A. R. & Singer, B. S. Synoptic reconstruction of a major ancient lake system: Eocene Green River Formation, western United States. *Geological Society Of America Bulletin* **120**, 54-84, doi:10.1130/1326073.1 (2008).

Sprinkel, Douglas A., Thomas C. Chidsey, and Paul B. Anderson. Geology of Utah's Parks and Monuments. Salt Lake City, UT: Utah Geological Association, 2003. Print.

"Utah; National Park Units Where USGS Vegetation Characterization Program Products Exist." Utah; National Park Units Where USGS Vegetation Characterization Program Products Exist. Web. 19 May 2012. <http://biology.usgs.gov/npsveg/states/ut.html>.