KECK GEOLOGY CONSORTIUM

PROCEEDINGS OF THE TWENTY-SECOND ANNUAL KECK RESEARCH SYMPOSIUM IN GEOLOGY

April 2009
Franklin & Marshall College, Lancaster PA.

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2008-2009 PROJECTS

THE BLACK LAKE SHEAR ZONE: A POSSIBLE TERRANE BOUNDARY IN THE ADIRONDACK LOWLANDS (GRENVILLE PROVINCE, NEW YORK)

Faculty: *WILLIAM H. PECK*, *BRUCE W. SELLECK* and *MARTIN S. WONG*: Colgate University
Students*: JOE CATALANO*: Union College; *ISIS FUKAI*: Oberlin College*; STEVEN HOCHMAN*: Pomona College; *JOSHUA T. MAURER*: Mt Union College*; ROBERT NOWAK*: The College of Wooster*; SEAN REGAN*: St. Lawrence University*; ASHLEY RUSSELL*: University of North Dakota; *ANDREW G. STOCKER*: Claremont McKenna College; *CELINA N. WILL*: Mount Holyoke College

PALEOECOLOGY & PALEOENVIRONMENT OF EARLY TERTIARY ALASKAN FORESTS, MATANUSKA VALLEY, AL.

Faculty: *DAVID SUNDERLIN*: Lafayette College, *CHRISTOPHER J. WILLIAMS*: Franklin & Marshall College
Students: *GARRISON LOOPE*: Oberlin College; *DOUGLAS MERKERT*: Union College; *JOHN LINDEN NEFF*: Amherst College; *NANCY PARKER*: Lafayette College; *KYLE TROSTLE*: Franklin & Marshall College; *BEVERLY WALKER*: Colgate University

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Faculty: *LISA A. GILBERT,* Williams College and Williams-Mystic and NEIL R. BANERJEE, U. of Western Ontario
Students: *LAUREN D. ANDERSON*: Lehigh University; *STEFANIE GUGOLZ*: Beloit College; *HENRY E. KERNAN*: Williams College; *ADRIENNE LOVE*: Trinity University; *KAREN TEKVERK*: Haverford College

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Students: *AVERY R. COTA*: Minnesota State University Moorhead; *JANE DIDALEUSKY*: Smith College; *ROWAN HILL*: Colorado College; *ANNA PENDLEY*: Washington and Lee University; *MAIJA SIPOLA*: Carleton College; *STACEY SOSENKO*: Franklin and Marshall College

GEOLOGY OF THE HÖH SERH RANGE, MONGOLIAN ALTAI

Faculty: *NICHOLAS E. BADER and ROBERT J. CARSON*: Whitman College; *A. BAYASGALAN*: Mongolian University of Science and Technology; *KURT L. FRANKEL*: Georgia Institute of Technology; *KARL W. WEGMANN*: North Carolina State University
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BLOCK ISLAND, RI: A MICROCOSM FOR THE STUDY OF ANTHROPOGENIC & NATURAL ENVIRONMENTAL CHANGE

Faculty: *JOHAN C. VAREKAMP*: Wesleyan University and *ELLEN THOMAS*: Yale University & Wesleyan University
Students: *ALANA BARTOLAI*: Macalester College; *EMMA KRAVET and CONOR VEENEMAN*: Wesleyan University; *RACHEL NEURATH*: Smith College; *JESSICA SCHEICK*: Bryn Mawr College; *DAVID JAKIM*: SUNY.

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Keck Geology Consortium: Projects 2008-2009
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Project Faculty: ***DAVID SUNDERLIN***: Lafayette College
Project Faculty: ***CHRISTOPHER J. WILLIAMS***: Franklin & Marshall College

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Research Advisor: Dennis Hubbard

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Research Advisor: David Sunderlin

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BEVERLY WALKER**:** Colgate University
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GARRISON LOOPE: Oberlin College
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INTRODUCTION

As concern for the current climate crisis grows, climatologists look back to times of rapid climate change in Earth's past for clues that could help us understand the present. Of particular interest is the Paleocene-Eocene Thermal Maximum (PETM), a transient 170 ka warming event at about 55 Ma that is reflected in a ~3.5-4.5‰ negative carbon isotope excursion (Röhl et al., 2007). This isotopic shift is believed to be the result of a huge release of methane, but the mechanism is still debated (Tripati et al., 2005; Storey et al., 2007). During the PETM Arctic Ocean sea-surface temperatures rose from 18° to a high of 23° C (Sluijs et al., 2006) while mid-continent terrestrial sites in Wyoming warmed to as high as 26° C mean annual temperature (MAT) (Fricke and Wing 2004). This rapid warming corresponds to a widespread benthic foraminiferal extinction (Thomas, 1998) and a major mammalian migration out of Asia (Bowen et al., 2002).

High-resolution paleontological studies from the intermontane basins of Wyoming have shown that MAT fluctuated dramatically in multiple pulses of warming and cooling over a time scale of a few million years around the Paleocene-Eocene boundary (Wing, 1998; Wilf, 2000). Fricke and Wing (2004) combined leaf-margin and oxygen-isotope data for 16 early Eocene sites across North America to examine the latitudinal temperature gradient. They proposed that the gradient was not as steep as it is today (0.4°C/1° latitude compared to 0.6°C/1° latitude today). This suggests greater warming at the poles, which is indicative of positive feedback processes. The most important polar feedback loop today is the melting of sea ice, but with an ice-free Arctic in the late Paleocene another feedback mechanisms is needed to explain this uneven warming.

Several studies (Fricke and Wing, 2004; Wilf, 2000; Wing, 1998; Wing et al., 2005) have looked for climatic and floral change across the Paleocene-Eocene boundary in North America but were largely restricted to sites in Wyoming and a few sites on the Gulf Coast and the Canadian Arctic. In order to more fully understand the interplay between climate and biological change in the PETM, more data are needed from a wider geographic array of sites.

This study examines one possible site in the Chickaloon Formation of the Matanuska Valley-Talkeetna Mountains forearc basin of south-central Alaska (Sunderlin and Williams, this volume). Paleomagnetic data put the region at a paleolatitude of 48° N ± 11° during the deposition of the Chickaloon (Stamatakos et al., 1989). The goal of this project was to provide a high-resolution picture of the uppermost beds of the Chickaloon with the hope of identifying the PETM within the section dated to the Paleocene-Eocene boundary by Triplehorn et al. (1984). Over 370 fossil-bearing samples from 4 distinct beds were collected during the 2008 Alaska Keck Project at the same Evan Jones Mine sampled by Triplehorn et al. (1984). I use four widely accepted leaf-physiognomy techniques to estimate climatic variables from these beds, and make the case that climatic changes on the order of those envisioned for the PETM are not reflected by the flora examined in the upper Chickaloon Formation at the study site. The data presented in this study do however represent a climatically interesting period that should be more accurately dated and extensively analyzed in future studies.

METHODS

This study was part of the 2008 Keck Alaska Project that sampled rocks near the Paleocene-Eocene boundary in a 900m long, 100m deep pit at the abandoned Evan Jones coal mine on the Wishbone Hill Syncline 3 miles northwest of Sutton, Alaska (61° 44' N, 148° 57' W). Four beds ranging from 15 to 50 cm in thickness were selected (designated G1-G4) (Fig.1). These beds were well indurated due to local carbonate cementation which facilitated the recovery of whole specimens. Samples were collected from each bed until they pinched out or became unreachable. Neff (this volume) shows the sampling locations of each bed.

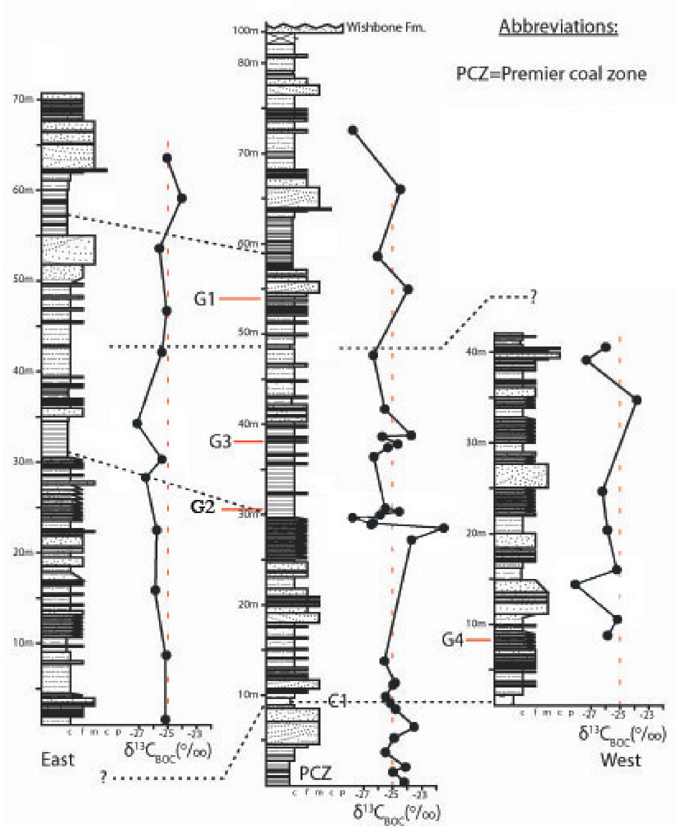

Figure 1. Three correlated composite stratigraphic sections in the Evan Jones mine with associated ∂C12BOC(%) (Bulk organic Carbon) curves. A, B and C are derived from east, central, and west sides of the site respectively. Approximate positions of G1-G4 are shown. PCZ is the zone identified by Triplehorn as containing the Paleocene-Eocene boundary.

Samples were sorted into morphotypes using The Manual of Leaf Architecture (Wing et al., 1999) as a guide. Wolfe and Leopold (1966), Hickey (1977), Brown (1962), and Hollick (1936) were used to help define ranges of variability of morphotypes and to match them with described taxa. Each bed with sufficient morphotypes was analyzed using four widely accepted leaf physiognomic techniques: two univariate MAT analyses both using the percent of morphotypes with entire leaf margins, Leaf Margin Analysis (LMA; Wing and Greenwood 1993; Wilf, 1997), and Provisional Leaf Margin Analysis (PLMA; Kowalski and Dilcher 2003); one multivariate approach, Climate-Leaf Analysis Multivariate Program (CLAMP; Wolfe, 1995); and a univariate mean annual precipitation analysis, Leaf Area Analysis (LAA; Wilf et al., 1998). Each technique is based on a separate algorithm, but all of them use the same primary character to estimate mean annual temperature, proportion of leaves with an entire margin (Fig.2).

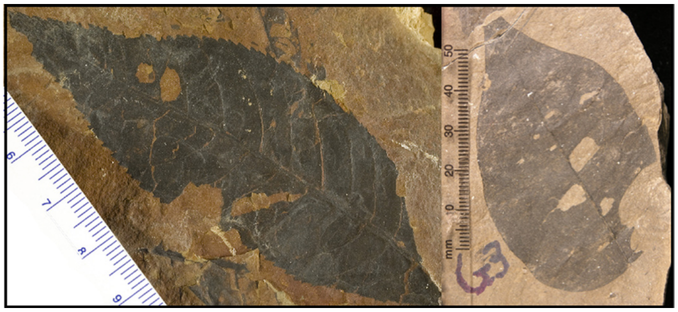

Figure 2. The Aesculus hickeyi leaflet on the left has a serrate margin, while the leaf on the right (Morphotype 3:13) has an entire margin

RESULTS

The 370 samples taken from four beds in the upper Chickaloon Formation yielded a total of 38 discrete dicot leaf morphotypes as well as abundant *Equisetum*, *Haemanthophyllum*, and *Metasequoia* fossils. Beds G3 and G2 contained the highest numbers of morphotypes with 21 and 20 respectively; beds G1 and G4 contained 12 and 11. Table 1 summarizes the distribution of these morphotypes across beds. Only two morphotypes (*Dombeya novi-mundi*, and 2:10) are found in non-adjacent beds without being present in intermediate beds. Each bed had a few morphotypes that dominated the collection and at least a few unique forms not shared with any other bed. These unique occurrences tended to be fairly rare even within a single bed. G3 had the most of these unique forms with 8 out of 21 total types found only within the bed. All beds shared the majority of their morphotypes with other beds and none of the forms that dominated were unique.

Mean annual temperature

Based on the three analyses, mean annual temperature varied between 7.5º and 13.8°C across all sites (Fig. 3). G2, G3, and the composite run (using all 38 morphotypes) are similar for each of the analyses with LMA estimating the lowest temperatures (11.2-11.8º), PLMA estimating the highest (13.9-14.6º), and CLAMP falling in between (13-13.7º). G1 and G4 have lower MAT estimates from LMA and PLMA than G2 and G3 but they also have larger standard deviations and are too small to run CLAMP.

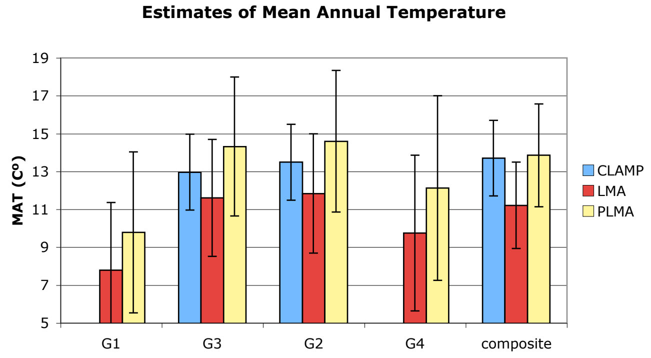

Figure 3. A comparison between the three methods of finding mean annual temperature used in this study; CLAMP, LMA, and PLMA. Error bars show one standard deviation.

Precipitation

The two beds (G2, G3) with enough species to run leaf area analysis had similar mean annual precipitation values (160.3 and 158.9 cm/yr; Table 1). These are close to the value derived in a composite run (154.6 cm/yr). CLAMP predicts mean growing season precipitation of about 118 cm for all beds. This value is based on an estimated 7.5 month growing season so is difficult to compare to data from LAA. CLAMP also shows that the area did not experience a severe dry season because three driest months had an estimated 39 cm precipitation.

Table 1	**Morphotype Distribution**			
Morphotype	**G4**	**G2**	**G3**	**G1**
1:01				X
1:02				X
1:03				X
Acer sp.		X		
Dombeya novi-mundi		**X**		X
2:07		X		
Chaetoptelea microphylla	X	**X**	X	
2:09		X		
2:10	X	X		X
Sinowilsonia sp.		X		
Hakea alaskana	X	X		
2:13		X		
2:14		X		
Ampelopsis acerfolia		X		
Dicotylophyllum alaskana		X	**X**	
3:02			X	
Grewiopsis auriculaecordatus		**X**	**X**	X
Hamamelites inaequalis			X	**X**
Aesculus hickeyi	X	X	X	**X**
Carya antiquorum			X	
Pterospermites dentata			X	
3:11			X	
Joffrea sp.	X	X	X	
3:13			X	
3:14		X	X	
Averrhoites affinis		**X**	**X**	
Magnolia magnifolia		X	X	X
3:19			X	X
3:21			X	
3:22			X	
3:24	X	X	X	X
Dicotylophyllum richardsoni		X	X	
Cocculus flabella	**X**	X	**X**	**X**
Trapa angulata			X	
Meliosma longifolia	**X**	X		
4:03	X			
4:04	X			
4:05	X			

Table 1. Beds are ordered stratigraphically from lowest on left to highest on right. "X" represents presence of morphotype while "X" signifies a dominant morphotype

DISCUSSION

The beds described in this study were deposited in a fluvial system at low elevation close to the Pacific Ocean (Trop et al. 2003). The climate appears to have been moist year-round with a mean annual precipitation close to 150 cm. The different analyses yielded a large amount of variation in estimates of MAT ranging from 7.8º for LMA in G1 to 14.6º for PLMA in G3. The large standard deviations associated with these estimates make it difficult to discern whether this variation is real or the result

Bed	LAA		CLAMP		
	Mean Annual Precip (cm)	Std. Error (cm)	Growing Season Precip. (cm)	Growing Season Length (months)	3Month Dry (cm)
G2	160.3	112-230	114.3	7.6	39.9
G3	158.9	111-228	122.9	7.4	39.3
Composite	154.6	108-221	118.0	7.7	36.6
CLAMP Stdev			33.6	0.7	9.3

Table 2. Precipitation estimates for beds with >20 morphotypes. All CLAMP categories have a single reported standard deviation shown at bottom of table

of factors not addressed by the methods or insufficient sampling. Beds G1 and G4 have by far the coolest estimated MAT but have scarcely half as many morphotypes as G2 and G3. The low number of morphotypes makes it impossible to run CLAMP and casts some doubt on the beds with cooler temperatures.

The data from the two most statistically robust beds, G2 and G3, both suggest a MAT between 11.5° and 14.5° C. All beds contain abundant *Equisetum*, and *Haemanthophyllum*, both of which are known to have been common riparian and wetland taxa. PLMA is designed to work best for riparian and wetland sites while LMA does not acknowledge the dominance of these environments in the fossil record. This suggests that for this study PLMA may be more appropriate so temperatures are more likely to range from 13° to 14.5° C. Although this is considerably warmer than today (~1.5° C at Sutton, AK), it is lower than expected for rocks of this age in Alaska, and well below any reasonable estimate for PETM.

Wolfe and Leopold (1966) reports that the entire flora of the Chickaloon represented subtropical conditions due to the presence of fan palms and tropical genera such as Macaranga and Dennstaedtia. He also found that nearly 50% of species in the formation had entire margins suggesting temperatures upward of 18° C. Wolfe (1977) describes the early Ravenian (middle Eocene) of southern Alaska as paratropical with MAT ranging from 20-25° C with 65% of species having entire margins. The beds described in this study lack the tropical taxa found by Wolfe and Leopold (1966) and my analyses indicate considerably cooler temperatures. However, Wolfe describes the climate based on an amalgam of the entire Chickaloon which masks transient episodes of climate change such as the PETM. It is unlikely that any of the beds in this study represent the PETM because of the absence of a strong negative carbon-isotope excursion (Neff, this volume) and the relatively low MAT estimates reported here. Studies from Wyoming show that the PETM was associated with a 5° increase in MAT over baseline temperatures and a radical shift in floral composition (Wing et al., 2005). The composition of the ecosystems preserved in beds G1-G4 does seem to be shifting, but not in a radical way. Most common morphotypes are shared between beds, and a change in flora between beds is most likely a result of chance preservation and laterally migrating vegetation zones that adjust to stream course.

High-resolution studies such as this can provide important information about the nature of rapid climate change, but by their nature they are unable to cover large swaths of geologic time. Although this study is unable to identify the PETM in the Chickaloon, I believe that beds G1-G4 lie just tens of meters above the PETM based on the work of Triplehorn et al. (1984). It appears that the beds described by Triplehorn are now buried under a mine reclamation project, so future studies will need to examine the numerous other pits in the area to find corresponding strata. Wing et al. (1998) found that about 500 ky after the end of the PETM temperatures dropped from over 18°C MAT to around 11°C in the upper Haplomylus-Ectocion Zone (UHEZ) before rising again. If Triplehorn et al. (1984) were correct in their date, the unexpectedly low temperatures reported in this study may correspond to the low temperatures of the UHEZ reported by Wing (1998). As of now this is little more than pure speculation, and more work on the precise chronology of the upper Chickaloon needs to be done to provide any concrete evidence for this supposition.

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