KECK GEOLOGY CONSORTIUM

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

April 2011
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Students: *JESSE DAVENPORT*, College of Wooster, *KRISTINA DOYLE*, Amherst College, *B. PARKER HAYNES*, University of North Carolina - Chapel Hill, *DANIELLE LERNER*, Mount Holyoke College, *CALEB O. LUCY*, Williams College, *ALIANORA WALKER*, Smith College.

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Students: *SHANNON BRADY*, Union College. *LOGAN SCHUMACHER*, Pomona College, *HANNAH ZELLNER*, Trinity University.

KECK SIERRA: MAGMA-WALLROCK INTERACTIONS IN THE SEQUOIA REGION
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EOCENE TECTONIC EVOLUTION OF THE TETONS-ABSAROKA RANGES, WYOMING
Faculty: *JOHN CRADDOCK*, Macalester College, *DAVE MALONE*, Illinois State University
Students: *JESSE GEARY*, Macalester College, *KATHERINE KRAVITZ*, Smith College, *RAY MCGAUGHEY*, Carleton College.

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Keck Geology Consortium: Projects 2010-2011
Short Contributions— Front Range, CO

INTERDISCIPLINARY STUDIES IN THE CRITICAL ZONE, BOULDER CREEK CATCHMENT, FRONT RANGE, COLORADO
Project Faculty: DAVID P. DETHIER: Williams College, WILL OUIMET: University of Connecticut

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USING POLLEN TO UNDERSTAND QUATERNARY PALEOENVIRONMENTS IN BETASSO GULCH, COLORADO
COREY SHIRCLIFF, Beloit College
Research Advisor: Carl Mendelson

STREAM TERRACES IN THE CRITICAL ZONE – LOWER GORDON GULCH, COLORADO
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METEORIC ^{10}BE IN GORDON GULCH SOILS: IMPLICATIONS FOR HILLSLOPE PROCESSES AND DEVELOPMENT
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Research Advisor: Will Ouimet and Peter Crowley

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USING POLLEN TO UNDERSTAND QUATERNARY PALEOENVIRONMENTS IN BETASSO GULCH, COLORADO

COREY SHIRCLIFF, Beloit College
Research Advisor: Carl Mendelson

INTRODUCTION

The mountain ranges of the western United States differ in climate and precipitation, and thus plant life varies as well. During the Pleistocene, oscillating climatic trends created sequences of glacial and interglacial times (Charlesworth, 1957); the Holocene is considered a modern interglacial epoch (Traverse, 2007). By using palynological techniques, it is possible to understand how glacial climates have affected the environment. By documenting the current geographical trends of plant species, and then applying that information to understanding Quaternary pollen samples, it is possible to reconstruct local environments over time.

In the Rocky Mountains, the most recent glaciation is known as the Pinedale. In the Colorado Front Range, it occurred from about 30,000 YBP (years before present) to 15,000 to 12,000 years YBP (Legg and Baker, 1980). As the deglaciation occurred at higher elevations, the flora of the entire Front Range area responded. Certain floral taxa are important in determining the post-glacial environment, as discussed in detail later. One way to understand the paleoclimate of this dynamic time is by using palynological methods to examine the pollen in sediments that are known to be younger than 12,000 years in age.

Betasso Gulch, located in the north-central Front Range of Colorado (Fig. 1), is a good place to collect samples for a palynological analysis due to the development of an organic-rich A soil horizon, which is buried under a modern soil profile. Both radiocarbon and optically stimulated luminescence (OSL) dates are available for the soil horizons exposed in Betasso. A regional laterally continuous buried A horizon corresponds to a time between 9,000 and 6,000 years ago (see Fig. 2). This is an interesting interval to investigate palynologically, because the response of the flora at this time and elevation (~ 2,000 m) is not well known in this area. Samples were taken from this buried A horizon and from modern forest litter to better understand how the climate has changed at Betasso Gulch.

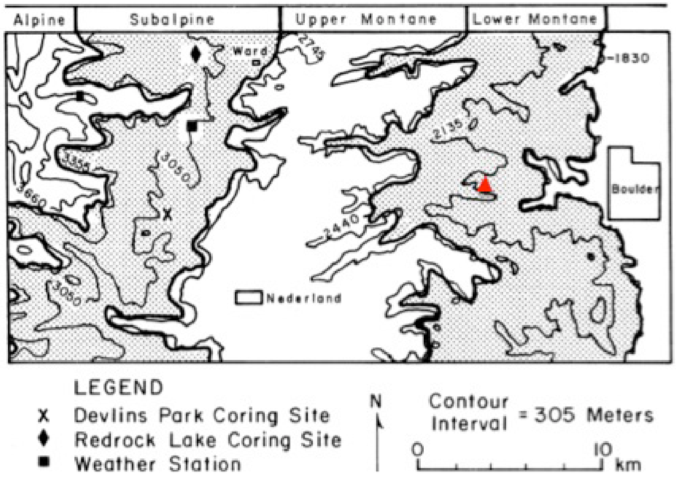

Figure 1. Betasso Gulch sample locality (red triangle). Previously studied sites: Devlins Park (Legg and Baker, 1980) and Redrock Lake (Maher, 1972). Modified from Marr (1961) in Legg and Baker (1980, fig. 1).

Although a wealth of pollen studies have been conducted in the Rocky Mountains and surrounding mountain ranges, two particularly relevant papers focus on pollen data from the Front Range, close to my sample site. Unfortunately, both localities are significantly higher in elevation (Fig. 1), but comparison with Betasso may still yield important information. Legg and Baker (1980) studied Pinedale-age lacustrine sediments from Lake Devlin; the sediments range in age from about 22,000 to 12,000 radiocarbon years before present (RCYBP). The authors found significant pollen contributions from *Artemisia* (sagebrush and relatives) at 42%, Poaceae (grasses) at 13%, and Cyperaceae (sedges) at 4%; *Alnus* (alder) and *Betula* (birch) appeared in small quantities at the top of the section.

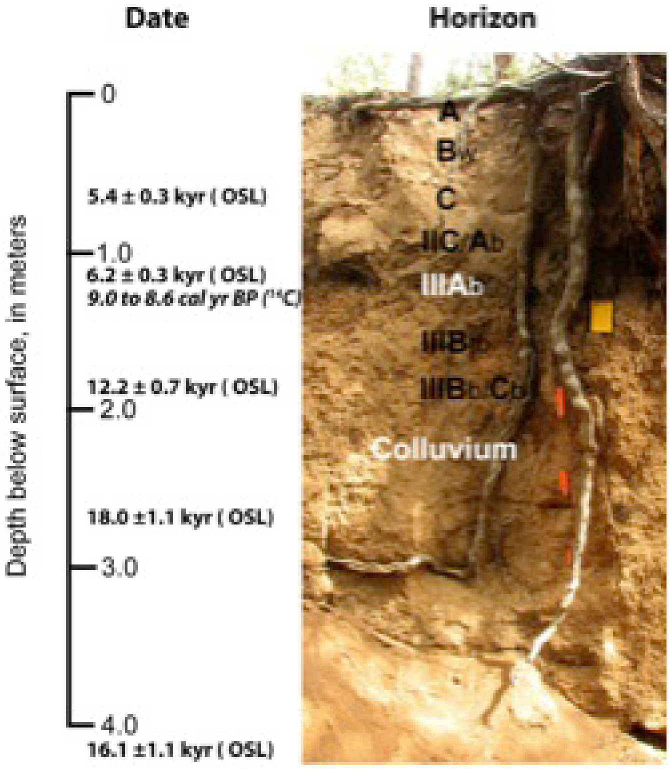

Figure 2. Dated stratigraphic section 50 m downstream from the Betasso Gulch locality. The buried soil A horizon is labeled IIIAb. Radiocarbon dates and image from Dethier (written commun., 2011).

The top of the Lake Devlin section is dated at ~12,000 RCYBP, or about 14,600 calibrated years, which is slightly older than the bottom of the stratigraphic section at Betasso Gulch. The other relevant study is of Redrock Lake, about nine kilometers north of Devlins Park and at a similar elevation (Maher, 1972). Maher investigated the time from 10,000 RCYBP to the modern. He found an increase of *Pinus* (pine) and a decrease of *Picea* (spruce) upsection. Additionally, maxima for deposition of pollen grains occurred from 7,500 to 3,500 RCYBP and *Picea* deposition peaked around 8,500 RCYBP. He concluded that the interval from 6,700 to 7,600 YBP was cooler and/or wetter than earlier post-Pinedale times.

MODERN VEGETATION AND CLIMATE

It is possible to classify vegetation zones on the eastern slope of the Front Range (Legg and Baker, 1980; see Fig. 1). Beginning on the eastern plains is the grassland zone, which is below 1,800 meters in elevation. Moving westward, on the lower slopes of the mountains, is the montane zone, which ranges from 1,800 to 2,800 meters; Betasso Gulch is located in this zone at an elevation of about 2000 m. Higher yet are the subalpine (2,800 to 3,350 m) and alpine (above 3,350 m) zones. The montane zone is characterized by an open forest populated by *Pinus ponderosa* (Ponderosa Pine), *Pinus contorta* (Lodgepole Pine), and *Pseudotsuga menziesii* (Douglas Fir), along with many shrubs, grasses, and herbs (Legg and Baker, 1980). This description is reflected in the modern sample I collected (see Results).

METHODS

Field Methods

Samples were collected at Gordon Gulch and Betasso Gulch. The Gordon Gulch samples, while rich in pollen, were not included in this paper due to time constraints in pollen identification and the fact that Gordon Gulch occurs at a higher elevation, and thus may have been more affected by recent glaciation. Samples at Betasso Gulch were collected at five-cm intervals from the base (1.2 m) to the top (1.05 m) of the buried A horizon (Fig. 2, level IIIAb). The succeeding meter of sediment was not sampled due to bioturbation by roots, resulting in a mix of pollen grains from different levels. The sampled horizon was located in a channel, which had been eroded by a flood from pipes for a nearby water-treatment facility. A modern sample was taken at the surface, in an area at least two meters from any tree, and without significant undergrowth. Several handfuls of surface sediment were collected in an area of about one square meter, to help rid the sample of a bias toward grasses and shrubs growing on the surface. Therefore, five total samples were collected: four from the buried A horizon and one modern sample. All of these samples were composed of dry sediment and organic debris.

Laboratory Methods

Pollen was extracted from the sediment and concentrated using a variety of chemical methods (see Traverse, 2007). After washing about 2 ml of sample in 5% KOH, the residue was filtered using a 250-µm screen to exclude rock fragments and large organic debris. The sample was then washed in HCl to dissolve carbonates, and washed again in hydrofluoric acid to dissolve silicates. After rinsing in acetic acid, residues were acetolyzed (nine parts acetic anhydride to one part sulfuric acid) in order to dissolve the part of the exine of the pollen grain that does not consist of the highly resistant sporopollenin. After diluting thoroughly in water, residues were washed through a 10-µm screen. Remaining residues were successively dewatered with 95% ethanol and tert-butyl alcohol (TBA). Storage in TBA prevented the pollen grains from deflating or degrading. Slides were made using silicon oil as a mounting medium, and cover glasses were sealed with colored nail polish.

Identification Methods

It is necessary to identify 300 pollen grains from each sample in order to reach the 95% confidence interval for this kind of pollen analysis (Traverse, 2007). Pollen grains were identified using a Zeiss compound microscope under 40x and 100x (with oil) objectives. Identification was confirmed by referring to Kapp (1990) and to reference slides of modern pollen grains (courtesy of Robert Nelson, Colby College). Some grains were impossible to identify due to folding and exine degradation.

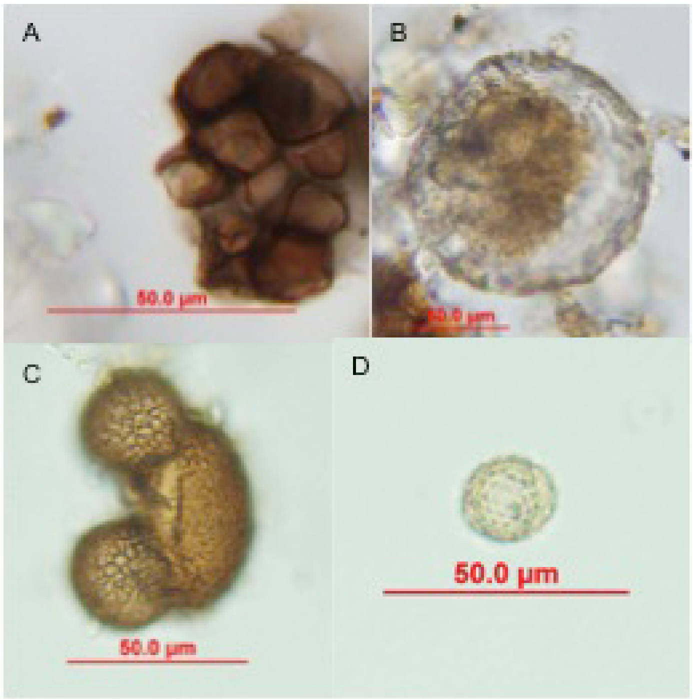

Figure 3. Light-microscope images of Betasso spores and pollen grains. A) unidentified spore found throughout the buried A horizon. B) degraded Pseudotsuga menziesii (Douglas Fir) pollen grain. C) Pinus ponderosa pollen grain. D) Ambrosia artemesiifolia (common ragweed) pollen grain. (Ambrosia is a composite, and thus a member of the Asteraceae.)

RESULTS

Modern

Figure 3 shows selected pollen grains. High amounts of *Pinus* grains were identifiable; they represented at least 67% of the Betasso sample. Almost all of the unidentified pollen from the modern sample (9%) is arboreal; much of it probably belongs to *Pinus*, so 67% is a minimum. *Pseudotsuga menziesii* is also an important arboreal component, at 3% of the modern sample. *Juniperus* (juniper) and *Artemisia* (sagebrush) together represent the majority of the shrubs found in the Front Range area, and constitute 21% of the Betasso modern sample. Grasses (Poaceae) are at a fairly average level (5%).

Early Holocene

Pinus, Artemisia, Poaceae, and Asteraceae (composites) contributed the most pollen grains to the early Holocene samples (Fig. 4). Progressing upward at Betasso, there is a slight increase of Pinus; in the modern sample, *Pinus* is most common by far (67%).

Artemisia (sagebrush and wormwood) pollen also represented a significant percent, but in the modern sample it dwindled to 18%. It was rarely possible to identify *Artemisia* grains to the species level. Poaceae and Asteraceae both showed decreasing trends (Fig. 4).

Pseudotsuga menziesii (Douglas Fir) represented less than 1%, and in some cases 0%, in the buried A samples, but had a 3% representation in the modern sample. Because *P. menziesii* rarely rises above a 5% pollen representation in modern-day forests where it is known to grow in large quantities (Whitlock, 1993), I consider this result to be important.

In the samples from the buried A horizon, many grains, particularly those of arboreal pollen types, were folded in a way that made identification impossible. They were counted, and a percent of unidentifiable grains was found. The most unidentified grains were in the middle of the buried A section, rising to almost 20% in one sample.

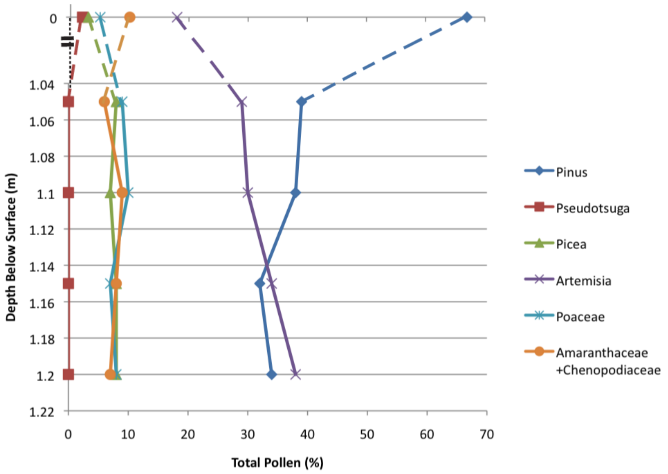

Figure 4. Pollen percentage diagram (includes identified pollen only). Note the scale break between 0 and 1.05 m. Dashed lines represent unsampled interval and are an estimate only of the trend of the pollen percents. The modern sample is plotted at 0 m. The percents of total pollen grains that could not be identified were as follows: 1.20 m (13%); 1.15 m (19%); 1.10 m (17%); 1.05 m (15%); 0 m (9%).

DISCUSSION

Pollen percentages are typically used to indicate changes in climate (Table 1). In modern-day forests, pine trees grow in relatively dry areas. Where precipitation increases, other arboreal species tend to win out in the battle for forest dominance. Pines in particular flourish in dry conditions, as seen in current-day Betasso Gulch, which hosts a pine-enriched forest; significant species include *Pinus ponderosa* and *P. contorta*. Because the percentages of *P. ponderosa* were lower in the buried A horizon, I infer that the climate at 9 ka was probably wetter and/or cooler than today's climate. Today in the Front Range, P. ponderosa does not grow above the montane zone due to its inability to thrive in the cold temperatures experienced in the subalpine and alpine zones (Weber, 1976). Therefore, because the P. ponderosa percent increases from the buried A section to the modern, the environment may have become more favorable for Ponderosa Pines. Hence, it was becoming warmer and drier from the buried A to present. The pollen percent of total *Pinus* species almost doubles in the modern sample; this substantial leap suggests that the climate has become considerably warmer and drier than the time represented at the top of the buried A section (1.05 m below the surface), that is, since the early Holocene.

Taxon	**Common Name**	**Climate Implications (If pollen levels increase)**
Picea	Spruce	Moister
Pseudotsuga menziesii	Douglas Fir	Drier
Poaceae	Grasses	Drier
Chenopodiaceae	Herbs and Subshrubs	Drier
Pinus	Pine	Drier and warmer
Artemisia	Sagebrush	Drier and warmer

Table 1. Climate trends associated with increases of certain taxa in pollen samples.

Whitlock (1993) concluded that a decrease in *Artemisia* indicated a wetter, cooler climate. She also argued that an increase in *Picea* suggested a wetter, cooler climate. In the surface sample, *Picea* decreases from 10% to 2% (indicating warming) and *Artemisia* levels decrease by 11% (indicating cooling). Although the decrease in *Artemisia* indicates a wetter and cooler environment, the decrease in *Picea* and significant increase in *Pinus* suggest a warmer environment. Moreover, although the Amaranthaceae + Chenopodiaceae pollen group stays fairly constant in the buried A horizon, its percentage rises by 5% in the modern sample. Bright (1966) and Davis et al. (1986) inferred a drier climate when Amaranthaceae + Chenopodiaceae levels increased. Lastly, an increase in *Pseudotsuga menziesii* (Douglas Fir) has been shown to indicate warming (Whitlock, 1993). The increase from 0% to 3% from the buried A to modern gives further evidence for warming, keeping in mind that 5% is the maximum percent *P. menziesii* reaches in any forest (Whitlock, 1993).

I conclude that the environment at Betasso Gulch changed from a wetter, cooler climate (soil horizon A) to the current warmer and more arid conditions. Maher (1972) argued that the time from about 6,700 to 7,600 YBP was cool and wet, compared to the preceding ~3,000 years. Although evidence for cooling within the buried A horizon is weak, there is a possibility that this section fits in slightly before 7,600 YBP, or between then and 6,700 YBP, and may thus be consistent with the findings of Maher (1972). Further studies of this buried soil horizon should be undertaken before such a conclusion can be confirmed.

My tentative conclusions are not statistically robust. For example, the percents reported for the buried A horizon are at best estimates because 15-20% of the pollen grains could not be identified due to folding and degradation. In the modern sample, most unidentified pollen grains are bisaccate, so are probably *Pinus* species. Most significantly, the samples from the buried A horizon might not yield reliable information regarding trends in pollen percents—this horizon, like the succeeding meter of sediment, may have been bioturbated, resulting in homogenization of the microflora. For a more accurate understanding of climate change in this area, more samples should be taken from the buried A horizon, and additional surface samples need to be collected to confirm the pollen percents representative of the current climate. It would also be beneficial to collect older samples in the section. Finally, the discrepancy between the radiocarbon and OSL ages (Fig. 2) needs to be resolved.

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