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Introduction to the Snowmastodon Project Special Volume
The Snowmastodon Project

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Introduction

Studies of terrestrial biotic and environmental dynamics of Marine Oxygen Isotope Stage (MIS) 5, also called the Last Interglacial Period, provide insight into the effects of long-term climate change on Pleistocene ecosystems. In North America, however, there are relatively few fossil sites that definitively date to MIS 5. Even fewer contain multiple ecosystem components (vertebrates, invertebrates, plants) that have been studied in detail, and none are located at high elevation. Thus, our view of North American ecosystems during MIS 5 is, at best, an incomplete composite view, and alpine ecosystems are entirely undocumented.

The Ziegler Reservoir fossil site allows us to begin filling these gaps. Discovered on October 14, 2010 by a construction crew while enlarging a small reservoir near Snowmass Village, Colorado (USA), the site is situated high in the Rocky Mountains at an elevation of ~2705 m. Initial excavations exposed a series of stacked fossil ecosystems, including abundant faunal and floral components. Subsequent work revealed an exceptionally diverse biota composed of more than 5000 large bones of late Pleistocene megafauna, including mastodons, mammoths, ground sloths, horses, camels, deer, bison, black bear, coyotes, and big horn sheep. This collection is complemented by more than 200 bones from at least 40 species of small animals including otters, muskrats, minks, rabbits, beavers, frogs, lizards, snakes, fish, and birds, and more than 22,000 salamander bones.

Geomorphic evidence and multiple dating techniques show that the small, ridge-top basin containing the site was formed by a lateral lobe of a valley glacier that filled, and ultimately overtopped, the Snowmass Creek drainage during the Bull Lake glaciation (MIS 6). When the glacier receded, a lake that occupied the basin began to fill slowly with what is hypothesized to be eolian sediment and occasional input from slope failures of the impounding moraine. As sedimentation continued, the lake transformed first into a shallow pond, then a marsh, and later an alpine meadow. In all, the Ziegler Reservoir sedimentary record spans the end of MIS 6, all of MIS 5 and MIS 4, and the earliest part of MIS 3. MIS 5e, which is considered to be the peak warmth of the Last Interglacial Period, is especially well represented.

Preservation of organic material at the Ziegler Reservoir fossil site is exceptional. Even after more than 100,000 years of burial, sedge and willow leaves were still green, mollusks and gastropods showed color, beetle parts remained iridescent, fossil conifer cones were intact, and an entire beach of 20-m-long driftwood logs was preserved. The exquisite preservation allowed for detailed analysis of pollen, plant macrofossils, conifer cones, and fossil wood, as well as insects, chironomids, mollusks, ostracodes, and other invertebrates — all in addition to the spectacular faunal remains.

This special volume of *Quaternary Research* represents a comprehensive scientific report of "The Snowmastodon Project," as the investigations at the Ziegler Reservoir fossil site came to be known. Summarizing the work of scientists from more than 20 institutions, the volume details the environments in which the animals lived, provides insight into how they died, and forms the foundation of our understanding of alpine ecosystem dynamics during the Last Interglacial Period in the Rocky Mountains.

Discovery timeline

In 2010, Gould Construction[2] was contracted by the Snowmass Water and Sanitation District (SWSD) to deepen an existing ~5 ha

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[1] A list of the Snowmastodon Project science team is provided in Appendix A.

[2] Any use of trade, product, or firm names is for descriptive purposes only and does not imply endorsement by the U.S. Government.

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Figure 1. Joe Enzer, Kent Olson, and bulldozer operator Jesse Steele (left to right) hold three mastodon tusks on the morning of October 28, 2010.

lake and create a dammed reservoir on the divide between Snowmass and Brush Creeks just west of Snowmass Village, Colorado. The SWSD had purchased the lake from the Ziegler family, hence the name "Ziegler Reservoir," and began excavating in September 2010. On the afternoon of October 14, 2010, Jesse Steele, a third-generation bulldozer operator working for Gould Construction, unearthed a partial skeleton of a small mammoth.

Steele reported the fossils to Kent Olson, the project foreman, and Joe Enzer, the owner's representative for the SWSD. Olson took the bones home that night and identified them as mammoth using sources he found on the Internet. The next morning, Kit Hamby, the district manager for SWSD, called a contractor for the Colorado Geological Survey who subsequently contacted the Denver Museum of Nature and Science (DMNS). A team from the DMNS Earth Sciences Department visited the site on October 16th, confirmed the find as a mammoth, and SWSD personnel quickly erected a tent over the specimen. Local public interest was already intense by this time and thousands of people thronged to the SWSD offices to see the bones found by Steele.

Shortly thereafter, the DMNS came to an agreement with the SWSD that allowed a museum crew to formally excavate the mammoth skeleton. As a DMNS team toured the site on October 27th, Steele's bulldozer exposed a series of logs and additional proboscidean bones in sediments that were several meters below the original "discovery" mammoth. At that point, it was clear that the site contained bones at multiple depths — and the frenzy began.

The next morning, a team of scientists and directors at the DMNS met to plan for a scaled-up salvage operation to extract the fossils and document as much of the site as possible. During the meeting, construction crews began sending picture messages to the Museum by phone. The photos included an image of a mastodon tooth, which represented only the third known occurrence of the taxon in the State of Colorado, a variety of large limb bones and vertebrae, and what turned out to be one of the more iconic images of the project, Enzer, Olson, and Steele standing in front of a bulldozer holding three mastodon tusks (Fig. 1).

Over the next two weeks, crews from the DMNS, the U.S. Geological Survey, and several academic institutions worked alongside the bulldozers, collecting bones from mastodons, mammoths, giant ground sloths, and extinct deer and bison. The arrival of heavy winter snows forced the closure of the site on November 15th (Fig. 2). In just 19 days, however, the team had salvaged more than 600 large bones, collected hundreds of plant and sediment samples, and began to document the stratigraphy of the site. Interestingly, aside from the original mammoth and a few other scattered finds, nearly all of the large bones recovered in 2010 were from mastodons. Based on tusks alone, at least eight individuals were present at the site, the largest concentration of mastodons ever found in the Rocky Mountains.

The five months of winter closure allowed the DMNS to plan for a large, systematic excavation beginning the following spring. The SWSD needed to finish the dam construction project by the end of the summer of 2011 in order to avoid financial penalties. Thus, the DMNS and SWSD agreed that all excavation work would be finished by July 4, 2011, in order to allow for the on-time completion of the dam project.

Over the course of 7 weeks, between May 15th and July 4th, the DMNS, with the help of the SWSD and a new construction firm (Hudick Excavating), orchestrated a scientific excavation that involved more than 250 volunteers and 40 project scientists. The team removed roughly 8000 m^3 of sediment by hand and collected more than 5000 large bones, at a rate that often exceeded 200 bones per day. At the same time, project scientists described and measured numerous stratigraphic sections and collected hundreds of geochronological, palynological, paleoentomological, and paleobotanical samples.

On July 4, 2011, the scientific excavation of the site ceased and the DMNS handed the site back to the SWSD. All of the lake and marsh sediment under the main footprint of the dam had been excavated down to the surface of the underlying glacial till. The SWSD finished the dam construction project on time and Ziegler Reservoir filled over the winter of 2011/12. Today, the lake has a capacity of ~300,000 m^3 and a maximum depth of ~10 m.

Public outreach

The discovery of the Ziegler Reservoir fossil site led to an extraordinary collaboration among property owners, construction crews, engineers and consultants, local, state, and federal governments, education specialists, and scientific institutions. Although the behind-the-scenes excavation and research collaboration were remarkable, the outreach program was even more so, reaching literally millions of people. Led by the DMNS, these efforts were designed to use the discovery and subsequent scientific work at the site as vehicles to educate students and the general public about climate change, extinctions, and ecosystem dynamics in the Rocky Mountains.

The initial outreach strategy included daily and weekly updates from scientists at the excavation site that were produced by DMNS staff using multimedia elements and posted to the DMNS website

Figure 2. A painting by artist Jan Vriesen of the site as it looked on November 15, 2010 when weather forced workers to abandon the area following the rapid salvage operation of the previous two weeks.

(www.dmns.org) and press room. Media members were invited to the dig site to cover the story as events warranted, and elements gathered for the web updates were sent to media outlets so reporters could cover the story on a daily basis without having to overcommit their own resources. The DMNS also used "e-blasts," social media, and traditional media to disseminate findings.

These efforts generated astonishing results. Between October 2010 and May 2012, more than 630 newspaper, television, and radio stories were reported on the excavation. Project leaders Kirk Johnson and Ian Miller wrote a popular book that was published by the DMNS and People's Press (Johnson and Miller, 2012) and conducted a book tour. And in February 2012, a NOVA-National Geographic special entitled "Ice Age Death Trap" was aired on PBS to 6.3 million people.

During this time, DMNS personnel introduced thousands of local and regional school children to the fossil discoveries through a series of programs designed by professional science educators using specimens from the Museum collections, props, and multimedia presentations. Scientists also shared new discoveries, demonstrated field research techniques, and answered questions at multiple events throughout Colorado to give students a window into various careers in science. In addition to these focused efforts, DMNS educators provided free education programs for students, including information to be used for in-school assemblies, distance learning, and teacher professional development, as well as various early childhood education resources.

Finally, in 2012, the DMNS produced an enhancement to the traveling exhibit "Mammoths and Mastodons: Titans of the Ice Age" that focused on the discovery and highlighted the paleoecology of the Ziegler Reservoir fossil site. The exhibit was seen by more than 200,000 visitors in less than a year. In the future, the Snowmastodon Project will continue to be highlighted at the DMNS through on-the-floor permanent exhibits, student and teacher programs, and popular and scientific talks by project scientists.

Large-scale salvage excavations

Paleontological excavations on the scale and time-sensitive nature of the Snowmastodon Project must direct substantial efforts simultaneously toward the speed of excavation and accurate recording of contextual data. Moreover, much of the subsequent conservation and research must be conducted in the laboratory rather than in the field, requiring suitable facilities and long-term human resources. Relatively few institutions are able to take on such projects because of the large

Figure 3. Ziegler Reservoir as it appeared in the summer 2012 (photo courtesy of Rick Wicker, DMNS).

number of personnel required and the substantial cost of excavating and curating thousands of fossils. Large natural history museums are well suited for such work because it typically aligns with their mission, they often have the required staff expertise, and they possess the ability to raise both human and financial capital on short notice. Even so, it still takes a bit of geologic good fortune, a motivated army of volunteers, and a team of scientists willing to lend their time and expertise to fully realize the scientific and educational potential of a major site. And that is assuming, of course, that the original discoverer – say, a third-generation bulldozer driver, for example – realizes the significance of what he might encounter when pushing his blade through the dirt in the middle of a small, private reservoir high in the Rocky Mountains of Colorado. A little luck never hurts.

A final note

The Ziegler Reservoir fossil site is now home to a beautiful alpine lake (Fig. 3), much as it was for tens of thousands of years. Although this might seem like an odd finale for such a spectacular find, there is a method behind the apparent madness. On their own volition, the SWSD constructed a gravel road to the bottom of the reservoir so that scientific teams may access the site again in future years. The idea is that in a non-drought year, when the local demand for water is relatively low, the reservoir could be temporarily drained, allowing scientists to dig for another season before it fills again during the following fall and winter. In this way, as it has done since the penultimate glaciation, the small lake at the Ziegler Reservoir fossil site continues to act as a time capsule for the remains of Pleistocene animals and the environments in which they lived as they await discovery by generations to come.

Acknowledgments

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The excavation phase of the project would not have been possible without the hard work of hundreds of volunteers and staff members of the Denver Museum of Nature and Science. The outreach aspect of this project was made possible by the imagination, ingenuity, and hard work of the DMNS education, outreach, and programming staff — it was truly a group effort. Finally, we thank History Colorado, the Snowmass Water and Sanitation District, the Town of Snowmass Village, Gould Construction Inc., Hudick Excavating Inc., URS Corporation, and W.W. Wheeler Engineering for their assistance with the excavation. A comprehensive 4-page acknowledgment section is published in the Appendix of Johnson and Miller (2012).

Appendix A

Core Science Team Members: Tom Ager, Scott Anderson, Paul Carrara, Dan Fisher, Russ Graham, Steve Holen, Steven Jackson, Kirk Johnson, Greg McDonald, Ian Miller, Jeff Pigati, Joe Sertich, Beth Shapiro, Richard Stucky.

Project Scientists: Dick Baker, Jordon Bright, Peter Brown, Bruce Bryant, Michael Cherney, Les Cwynar, John Demboski, Scott Elias, Harrison Gray, Elizabeth Hadley, Kirk Hansen, Danielle Haskett, Jeff Honke, Gonzalo Jiménez-Moreno, Doug Kline, Frank Krell, Nat Lifton, Carol Lucking, Shannon Mahan, Dane Miller, Dan Muhs, Steve Nash, Cody Newton, Jim Paces, Hendrik Poinar, David Porinchu, Adam Rountrey, Saxon Sharpe, Sarah Spaulding, Matthias Stiller, Joseph Street, Laura Strickland, Bob Thompson.

Project Students: Nate Fox, Adam Freierman, Brittany Grimm, Tyler Kerr, Gussie MacCracken, Hannah O'Neill, Lesley Petrie, Samantha Richards, Kaitlin Stanley, Corinna Troll.

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