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# A high-elevation MIS 5 hydrologic record using mollusks and ostracodes from Snowmass Village, Colorado, USA

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ABSTRACT

Sediments containing terrestrial and aquatic mollusks and ostracodes from the Ziegler Reservoir fossil site (2705 m elevation) near Snowmass Village, Colorado, span ~130–87 ka (MIS 5e through 5b). The southeastern area of the site where taxa were recovered was a relatively fresh, shallow, well-vegetated wetland during MIS 5e through 5c time, approximately 2 m deep, with a total dissolved solids value of ~200–1000 mg $L^{-1}$. The wetland was seasonally or annually variable and groundwater discharged along the margins of the bounding moraine. Groundwater likely contributed solutes to the system and may have contributed $^{18}O$-enriched water. Based on stable isotopes from ostracode calcite ($\delta^{18}O_{OST}$ and $\delta^{13}C_{OST}$), seasonal evaporation occurred and the dissolved inorganic carbon pool was unexpectedly enriched in $^{13}C$. The mollusk and ostracode faunas changed little across the MIS 5e/5d/5c boundaries, whereas a distinct change in the ostracode fauna occurred between the deposition of Unit 11 and Unit 13, which corresponds in time to the MIS 5c/5b boundary, indicating some combination of increased surface and/or groundwater flow, a decrease in water temperature, and a freshening and a possible deepening of the wetland.


## Introduction

Construction began in September 2010, to deepen and enlarge Ziegler Reservoir, located at 39.2075 °N, 106.9648 °W , 2705 m elevation, about 1.5 km west of Snowmass Village, Colorado (Fig. 1). Less than a month later, bulldozer operator Jesse Steele unearthed the bones of a small mammoth. This initial discovery led to the subsequent excavation of more than 5000 large bones and international collaboration among numerous scientists to determine the late Pleistocene environment of this unique site.

Ziegler Reservoir sediments are rich with the remains of large and small vertebrates, insects, mollusks, ostracodes, chironomids, pollen, tree trunks, and plant macrofossils, which are providing robust paleoenvironmental information about this high-elevation site. The mollusk and ostracode taxa discussed herein provide paleohydrologic insights during Marine Oxygen Isotope Stage (MIS) 5. This record is the first hydrologic indicator record that we know of from a high-elevation MIS 5-aged locality in the western U.S.

## Study site

### *Geologic setting and stratigraphy*

The Ziegler Reservoir fossil site (ZRFS) is located in an ~300 m diameter, moraine-impounded basin located on top of a ridge. The ridge divides Snowmass and Brush Creeks in the Elk Mountains near Snowmass Village (Fig. 1). The crest of the impounding moraine is some 25 m above the site and no surface water flows into or out of the basin.

The local geology is composed of a northeastward-younging sequence of late Paleozoic and Mesozoic clastic sedimentary rocks, intruded in its western portion by late Eocene and early Oligocene stocks and dikes (Bryant, 1972). The Snowmass Creek Fault Zone, located just west of the site in Snowmass Creek Valley, produces copper and silver (Bryant, 1972, 1979). The Ziegler Reservoir area is underlain primarily by Cretaceous Mancos shale, which includes thin beds of sandstone and limestone. The Pennsylvanian/Permian Maroon Formation lies above the Mancos shale and is composed of ~300-m-thick interbedded siltstone and fine-grained sandstone (Bryant, 1979).

The Ziegler Reservoir basin formed ~155–130 ka near the end of MIS 6 after a glacier flowed over a low spot on the eastern wall of Snowmass Creek Valley and formed a small lobe a short distance into the Brush Creek drainage. This glacier deposited the Bull Lake age moraine that impounds the ZRFS. After the glacier retreated, the basin, which had no surface outlet, contained water and began filling with fine-grained sheetwash and eolian sediment as well as slump deposits from several mass wasting events. About 55 ka, the basin was breached to the east into the Brush Creek drainage system and subsequently became an alpine meadow (Pigati et al., 2014– in this volume).

A total of 18 stratigraphic units were identified in the ZRFS. Basal Unit 1, the Mancos Shale, is overlain by Unit 2, glacial till consisting primarily of the Maroon Formation. This till consists of unstratified, unsorted matrix- to clast-supported sands, gravels, siltstones, shales,

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and granitic rocks with clasts up to 1 m in diameter. It is Bull Lake in age and as much as 23 m thick toward the southern side of the reservoir with approximately 10 m of clay, silt, and organic-rich mud and silt units deposited above the till (Pigati et al., 2014– in this volume).

*Chronology*

Four independent chronometric techniques were utilized to determine the ages of sediments at the ZRFS: $^{14}C$, surface exposure dating, U-series, and luminescence (Mahan et al., 2014– in this volume). Optically stimulated luminescence (OSL) of quartz provided reliable ages, based on accepted criteria, for the bulk of the stratigraphic sequence. Overall, these dates maintained stratigraphic order and they were within the bounds established by $^{14}C$ and cosmogenic surface exposure ages. A Bacon age–depth model produced reasonable accumulation rates for most of the record using the OSL ages. Ages in a ~2.5 m interval centered on units 13 and 14 were tuned using three of the transitions in the ZRFS pollen record because the OSL ages did not change with depth during this interval (Mahan et al., 2014–in this volume; Anderson et al., 2014–in this volume). The 18 OSL ages for the ZRFS sediments range from 57 $\pm$ 4 to 122 $\pm$ 12 ka with individual age errors to 2 sigma spanning 4 to 15 ka; they span the latest part of MIS 6, all of MIS 5 and 4, and the early part of MIS 3.

## Methods

Sediment samples were collected by each author at pre-determined localities at the ZRFS: Locality 71 (middle section, units 8 and 10; Unit 9 was not deposited at this location), Locality 43 (middle section, units 8–14), Locality 49 (Twisty Trench, units 9–16), and Locality 51 (upper section, units 15–18) (Fig. 2). Additional samples were provided by the Denver Museum of Nature and Science (DMNS). Systematic, stratigraphic sampling for both mollusks and ostracodes was time-limited because of reservoir construction and efforts that focused on extracting the vertebrate fossils.

*Mollusks*

Eighty-four sediment samples from 19 localities were obtained from units 6–18 for analysis of mollusks. Forty bulk sediment samples were collected from stratigraphic section localities; individual mollusks from 29 samples were bagged on-site by DMNS volunteers during excavation; 10 bulk sediment samples were screened (0.46 or 1.0 mm mesh) and picked by DMNS volunteers; and five sediment samples were collected in 2010 during initial reconnaissance.

The five sediment samples collected in 2010 were placed in 250 mL deionized water with 45 mL sodium hexametaphosphate (commercial Calgon®) for 6 to 24 h until clays were dispersed. For the remaining samples, the volume for each sample was noted (~2200–4400 $cm^3$) and sediment was gently broken apart with a spatula. Baking soda (15–45 $cm^3$) was placed on top of the sample (volume varied with sample size and percentage clay) and boiling water was slowly poured over the sediment. The sediment was stirred and left to cool until the clays disaggregated. Sediments were rinsed, sieved with deionized water through nested screens (smallest 250 μm), and air-dried. Mollusks were picked from the dry sediment matrix using a Nikon microscope at 10× or greater magnification and identified. Bagged samples from DMNS were free of sediment and contained only mollusks.

Identifications were made using the author's (Sharpe) reference collection, Pilsbry (1939, 1946, 1948), Burch (1975, 1989), Clarke (1981), and Burch and Pierce (1990). Some identifications were verified using the mollusk reference collection at the Utah Museum of Natural History, Salt Lake City, Utah. Taxonomy used here follows USDA Integrated Taxonomic Information System (http://www.itis.gov, accessed 11/20/2013).

*Ostracodes*

Fifty-two blocks of sediment (~250 $cm^3$) were collected at 10–20 cm intervals (depending on unit thickness) from stratigraphic section localities. Additionally, five samples were collected in 2010. Ten samples (>250 μm residue) from Locality 71, Unit 8, and one vial of hand-picked ostracodes from Locality 9, Unit 8, were analyzed.

Bulk sediment was disaggregated following a modified version of Forester (1988). Sediments were disaggregated by soaking in a weak (approximately 5 g $L^{-1}$) sodium bicarbonate (rather than Calgon®) and distilled water solution for about one week. Samples were frozen and thawed daily. Sediment slurries were washed over a 250 μm sieve using distilled water. Whole adult ostracode valves in the >250-μm residues were counted and identified to species level when possible.

Ostracode identifications were made using Sars (1926), Delorme (1970a,b, 1971), Danielopol and McKenzie (1977), Meisch (2000), Curry and Yansa (2004), and Smith and Delorme (2010). Ostracode ecological parameters used in this paper are based primarily on data housed in the North American Non-Marine Ostracode Database (NANODe, www.kent.edu/nanode, accessed June 10, 2012; Forester et al., 2005a). NANODe contains ostracode species, water chemistry, and physical variables (e.g., elevation, temperature) for 605 sites in the United States, plus a small number of sites in Canada and Mexico. Additional information is provided by published literature (Forester, 1986, 1991; Smith, 1993; Curry, 1999; Curry et al., 2012) and unpublished data (Forester, R.M., personal communication, 2013).


**Figure 1.** Site location maps (A-B) of the Ziegler Reservoir fossil site, Colorado and other localities discussed in text. C. Highland Peak, CO, U.S. Geological Survey 1:24,000 Topographic Map.