Quaternary Research 82 (2014) 490–503

Contents lists available at ScienceDirect

Quaternary Research

journal homepage: www.elsevier.com/locate/yqres

A geochronologic framework for the Ziegler Reservoir fossil site, Snowmass Village, Colorado

Shannon A. Mahan [a,*], Harrison J. Gray [a], Jeffrey S. Pigati [b], Jim Wilson [c], Nathaniel A. Lifton [d], James B. Paces [e], Maarten Blaauw [f]

[a] U.S. Geological Survey, Denver Federal Center, Box 25046, MS-974, Denver, CO 80225, USA
[b] U.S. Geological Survey, Denver Federal Center, Box 25046, MS-980, Denver, CO 80225, USA
[c] Aeon Laboratories, LLC, 5835 N Genematas Dr, Tucson, AZ 85704-5919, USA
[d] Department of Earth, Atmospheric, and Planetary Sciences, Purdue University, West Lafayette, IN 47907, USA
[e] U.S. Geological Survey, Denver Federal Center, Box 25046, MS-963, Denver, CO 80225, USA
[f] School of Geography, Archaeology and Palaeoecology, Queen's University Belfast, BT7 1NN Belfast, UK

ARTICLE INFO

Article history:
Received 30 September 2013
Available online 24 April 2014

Keywords:
Luminescence dating
Radiocarbon dating
Surface exposure dating
U-series dating
Ziegler Reservoir

ABSTRACT

The Ziegler Reservoir fossil site near Snowmass Village, Colorado (USA), provides a unique opportunity to reconstruct high-altitude paleoenvironmental conditions in the Rocky Mountains during the Last Interglacial Period. We used four different techniques to establish a chronological framework for the site. Radiocarbon dating of lake organics, bone collagen, and shell carbonate, and *in situ* cosmogenic ^{10}Be and ^{26}Al ages on a boulder on the crest of a moraine that impounded the lake suggest that the ages of the sediments that hosted the fossils are between ~140 ka and >45 ka. Uranium-series ages of vertebrate remains generally fall within these bounds, but extremely low uranium concentrations and evidence of open-system behavior limit their utility. Optically stimulated luminescence (OSL) ages (n = 18) obtained from fine-grained quartz maintain stratigraphic order, were replicable, and provide reliable ages for the lake sediments. Analysis of the equivalent dose (D_E) dispersion of the OSL samples showed that the sediments were fully bleached prior to deposition and low scatter suggests that eolian processes were likely the dominant transport mechanism for fine-grained sediments into the lake. The resulting ages show that the fossil-bearing sediments span the latest part of Marine Oxygen Isotope Stage (MIS) 6, all of MIS 5 and MIS 4, and the earliest part of MIS 3.

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Introduction

The unearthing of several bones of a juvenile Columbian mammoth in October 2010 during the expansion of Ziegler Reservoir, located near Snowmass Village, Colorado (Fig. 1), led to the discovery of one of the most prolific Pleistocene paleontological sites in North America. During the late Pleistocene, the site was occupied by a high-altitude lake that was bounded and underlain by till deposited during the Bull Lake glaciation, which has been dated elsewhere in the Rocky Mountains to ~200 to 130 ka (Blackwelder, 1915; Licciardi, 2000; Pierce, 2003). Lake sediments on top of the till are ~10 m thick, consist primarily of organic-rich silts and clays, and contain thousands of vertebrate and invertebrate fossils, as well as trees, logs, aquatic plants, invertebrates, plant macrofossils and pollen (Fig. 2).

To establish the ages of various sedimentary units at the site, and to date the fossils and environmental markers (directly or indirectly), we used four independent chronometric techniques: radiocarbon (^{14}C), surface exposure dating (*in situ* cosmogenic ^{10}Be and ^{26}Al), uranium-series disequilibrium (U-series), and optically stimulated luminescence (OSL) dating. Radiocarbon dating constrains the age of carbon-bearing materials by measuring the time-dependent concentration of the unstable ^{14}C isotope following plant or animal death (Hedges, 1981). Surface exposure dating using *in situ* cosmogenic radionuclides is used to determine the amount of time that a rock has been exposed at or near the ground surface by measuring rare isotopes that are produced by the interaction of cosmic radiation and target nuclei, mainly Si and O (Gosse and Phillips, 2001). U-series dating determines the age of materials that contain or uptake uranium, such as bone or calcium carbonate, by measuring isotopic concentrations of uranium, thorium, and associated daughter products (Ku, 2000).

In contrast to isotopic methods, OSL dating is not a function of a particular chemical element decay or buildup. Rather, it measures the growth of natural environmental radiation that results in trapped electron charged signals within a mineral grain that are eliminated by exposure to light or intense heat. The primary assumption involved in luminescence dating is that any residual signal from previous burial is removed by exposure to light (or in rare cases to heat) during transport, which would effectively "zero out" the luminescence clock (Aitken,

* Corresponding author.
E-mail address: smahan@usgs.gov (S.A. Mahan).

http://dx.doi.org/10.1016/j.yqres.2014.03.004
0033-5894/Published by Elsevier Inc. on behalf of University of Washington.

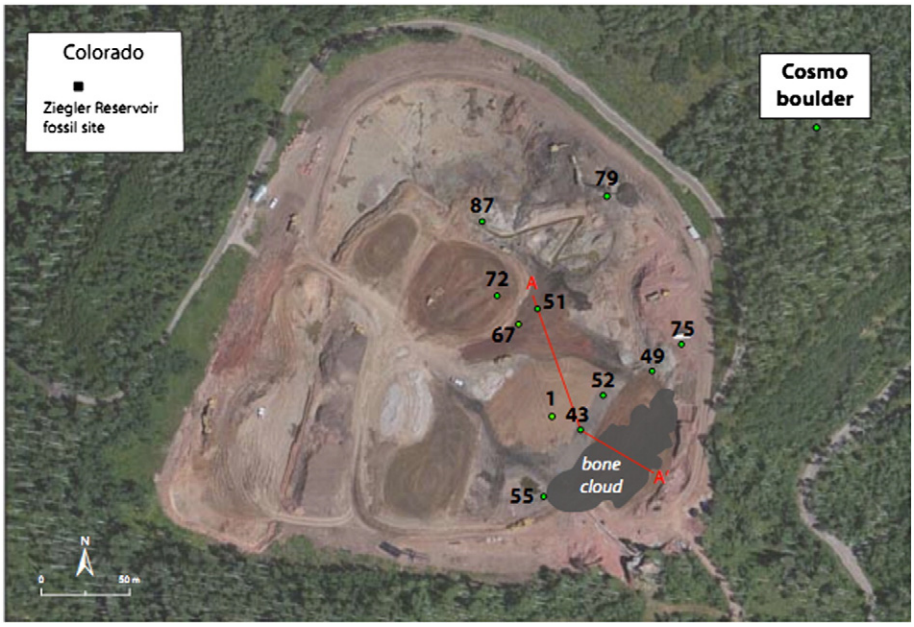

Figure 1. Site map with radiocarbon, cosmogenic ("cosmo"), and OSL sampling localities and "bone cloud" location.

1998; Rhodes, 2011). The potential for heterogeneous or incomplete bleaching is of foremost concern in any optical dating study involving glacial or lacustrine sediments (Fuchs and Owen, 2008). However, if transport pathways and burial conditions can be assessed based on sedimentologic or geomorphologic parameters, then luminescence dating can provide ages in a variety of geologic settings (Simms et al., 2011; Alexanderson and Murray, 2012; Bateman et al., 2012). Moreover, if dose rates are sufficiently low and luminescence signals in the sediments are stable, then the technique can provide reliable ages up to ~200 ka or more (Rhodes et al., 2006; Rhodes, 2011).

Materials and methods

Radiocarbon

We collected three sets of samples at the Ziegler Reservoir fossil site (ZRFS) for radiocarbon dating, including (1) wood, plant macrofossils, sedges, and shell fragments from the main exposures at localities 43, 51, and 52, (2) pieces of bone and tooth enamel from the Clay Mammoth at Locality 67, and (3) wood from near-shore sediments along the eastern margin of the reservoir at Locality 75 (Fig. 1). The analyzed

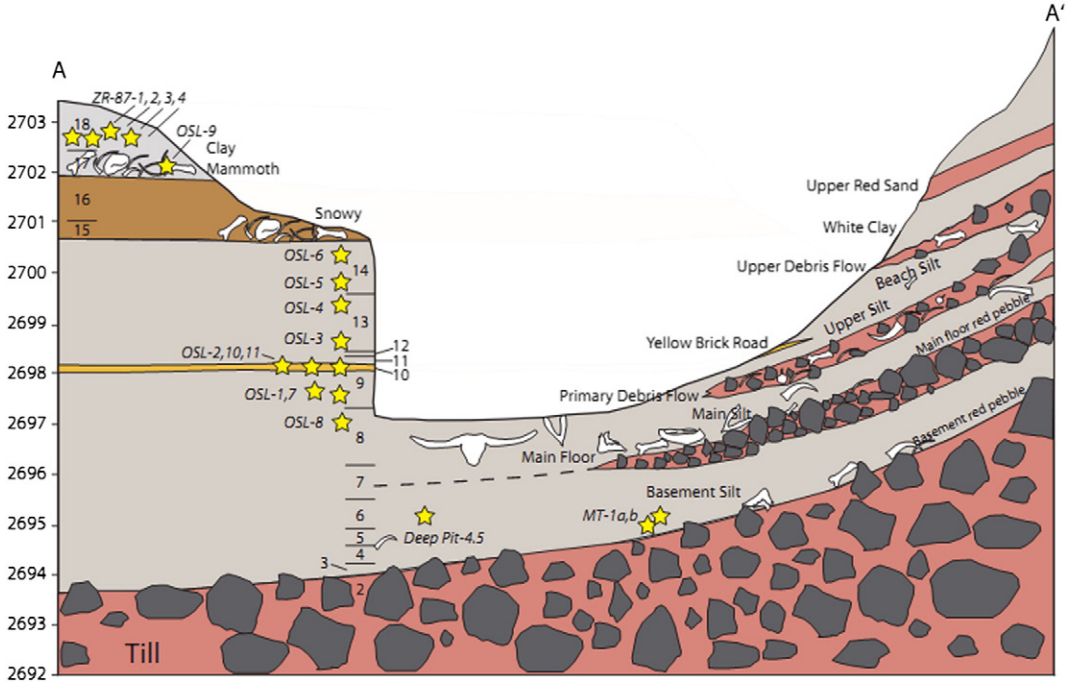

Figure 2. Stratigraphic section with labeled geological units (measured in meters), locations of significant fossil bone finds, and OSL sample locations highlighted as yellow stars.