Continental Scientific Drilling and the Evolution of the Earth System

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ABSTRACT

Over the past decade, numerous groups within the broad community of sedimentary geology, paleoclimatology, and paleobiology have repeatedly highlighted the need for continental scientific drilling (CSD) to address key science questions in climate and linked Earth systems. Additionally, advances in development of proxy and indicator data for climate parameters such as atmospheric composition, air and water temperatures, effective moisture, atmospheric circulation, and productivity, together with parallel advances in geochronologic resolution and accuracy, in ecosystem reconstruction, and in climate modeling are enabling us to mine sedimentary archives for paleoclimate and other paleoenvironmental information at unprecedented scales and resolution, even for deep-time targets. Application of these advances to pristine, continuous, and well-preserved cores will be a key component to future advances in understanding earth history-- a means to imagine our future by imaging our past (see also ICDP conference on this theme, 11-14 November 2013). This sustained surge of interest and advances forms the motivation for an upcoming workshop to be held May 17-19, 2013 in Norman, OK. This workshop is intended to galvanize researchers to plan proposals for pursuing specific, high-priority drilling targets, to address key science questions related to paleoclimate, paleobiology, and extreme events in Earth's history.

EARTH'S LAB BOOK: IMAGING OUR PAST TO IMAGINE OUR FUTURE

The nearly 4 billion years of history preserved in Earth's sedimentary cover record the results of innumerable experiments in environmental and ecological change. We can harness the results of these past experiments as preserved in the sedimentary record to expand our knowledge of Earth system behavior, particularly of coupling between and among components of the Earth System and coupling of climate processes that operate at a variety of rates. Doing so is particularly critical because major gaps remain in our ability to understand Earth's climate system, contributing to modeling failures and climate-prediction uncertainty. For example, models cannot yet capture abrupt climate change (Valdes, 2011), changes in clouds due to aerosol forcing (e.g., Mahowald et al., 2006; Kump and Pollard, 2008), or simulations of ENSO phenomena (e.g. Philander and Federov, 2003; Guilyardi et al., 2009). The importance of studying Earth's past to clarify its future is well understood by researchers investigating both the "near-time" (e.g. Quaternary) record and the "deep-time" record. Such studies, however, are commonly hampered by lack of access to continuous, pristine, ideally sited sedimentary sections.

Scientific drilling is widely regarded as key in advancing our understanding of critical questions of Earth's past, and indeed several success stories bolster this claim. In the last two decades, several drilling campaigns in sedimentary systems have addressed fundamental questions in the surficial archive of Earth, its biosphere, and the physio-chemical processes that mold the outer veneer of our planet (e.g., Melles et al., 2012; Schulte et al., 2010). These efforts have emanated from two distinct communities: 1) Geoscientists focusing on the recent past (primarily Quaternary) paleoclimates and paleoenvironments (largely the lake science community), and 2) deep-time geoscientists focusing on pre-Quaternary stratigraphy, Earth history, paleobiology, and biogeochemistry. The key science questions posed by both of these communities, however, increasingly overlap, and the time frames of interest are converging. Given that the boundaries that have traditionally separated these communities are both fluid and artificial, it is time to join forces to seek common ground on questions and research targets.

In the past 15 years, multiple initiatives and workshops have occurred involving the sedimentary geology and paleobiology communities, and have resulted in repeated calls for scientific drilling to address key questions. The PAGES report *Continental Drilling for Paleoclimatic Records* (Colman, 1996) was particularly instrumental in galvanizing the lakes community to embrace scientific drilling as an investigatory tool for obtaining long earth historical records. Seventeen years after the publication of that report many of the workshop's goals (i.e. target lakes) have been drilled.

Subsequently, the *GeoSystems* workshops (Soreghan et al., 2003, 2004; Montanez and Soreghan, 2006) brought together representatives from the deep-time community to advocate for systematically expanding Earth history and especially paleoclimate investigations into Earth's pre-Quaternary record. Both this and the PAGES workshop stressed drilling as an essential path toward recovering critical records that had not been compromised by surface weathering or limited by the vagaries of outcrop exposure, and indeed a jointly sponsored 2005 NSF-DOSECC workshop was specifically convened to address issues in drilling for recovery of deep time records. More recently, workshops on "Grand Challenges in Sedimentary Geology" (Montanez, 2010), Earth's "Deep Time Earth Life Observatory Network" (DETELON, Bottjer and Irwin, 2010), and "Transitions" (Parrish, 2012) have further elevated and reiterated the community's collective need for scientific drilling to address fundamental concepts in Earth System history, as did the 2010 and 2011 National Research Council Reports on *"Understanding Climate's Influence on Human Evolution" and "Understanding Earth's Deep Past--Lessons for Our Climate Future"* (NRC, 2011).

Advances in development of proxy and indicator data for climate parameters such as atmospheric composition, air and water temperatures, effective moisture, atmospheric circulation, and productivity, together with parallel advances in geochronologic resolution and accuracy (even for deep time), in ecosystem reconstruction, and in climate modeling are enabling us to mine sedimentary archives for paleoclimate and other paleoenvironmental information at unprecedented scales and resolution. Application of these advances to pristine, continuous, and well-preserved cores will be a key component to future advances in understanding earth history.

SCIENCE THEMES—A SAMPLING OF KEY ISSUES IN EVOLUTION OF THE EARTH SYSTEM

The *"Future of Continental Scientific Drilling"* workshop (Walton et al., 2009, 2010) identified several needs related to exploring Earth System history: 1) global environmental and ecological change, 2) the history of Earth and its biota through time series studies based optimally on drill cores, 3) lake records containing climate proxies of temperature, winds, precipitation, and watershed biotic evolution, 4) high-resolution records of Earth's magnetic field, 5) deep-time records addressing analogous questions to those of near-time, but including a wider spectrum of boundary conditions, including those potentially relevant to Earth's near-term future return to a pre-Quaternary state (in terms of atmospheric composition). The 2012 *Transitions* report pushed deeper into identifying key science questions answerable in both deep- and near-time archives:

1) What is the full range of potential climate system states and transitions experienced on earth?
2) What are the thresholds, feedbacks and tipping points in the climate system and how do they vary among different climate states?
3) What are the ranges of ecosystem response, modes of vulnerability and resilience to change in different Earth system states?
4) How have climate, the oceans, the Earth's sedimentary crust, carbon sinks and soils and life itself evolved together, through both near- and deep-time, and what does this tell us about the future trajectory of the integrated Earth-life system?

Drilling is essential for recovering high-resolution paleoclimate records to address the above questions. Drilling enables recovery of strata in which the effects of modern weathering are minimized, necessary for many geochemical, biogeochemical and geochronologic studies. Drilling also is essential for obtaining uninterrupted, high-resolution records from thick, basin depocenter sections where stratigraphic completeness is greater than along basin margins. Finally, drill core records enable validation and testing of climate model hindcasts for earth system states that fundamentally differ from the modern; e.g. recent data results from Antarctica are helping to refine problematic climate model predictions (Pross et al., 2012).

THE PATH FORWARD

At this point in time, we must move beyond reiterations of these common goals and actually identify drilling targets as the continental scientific drilling contribution toward meeting these long-standing objectives. Consider the case of the Lakes Drilling Task Force. In 1995, as part of a PAGES effort on drilling for continental paleoclimate records (Colman, 1995), this Task Force identified 62 lakes as "high priority" for drilling. To date, 12

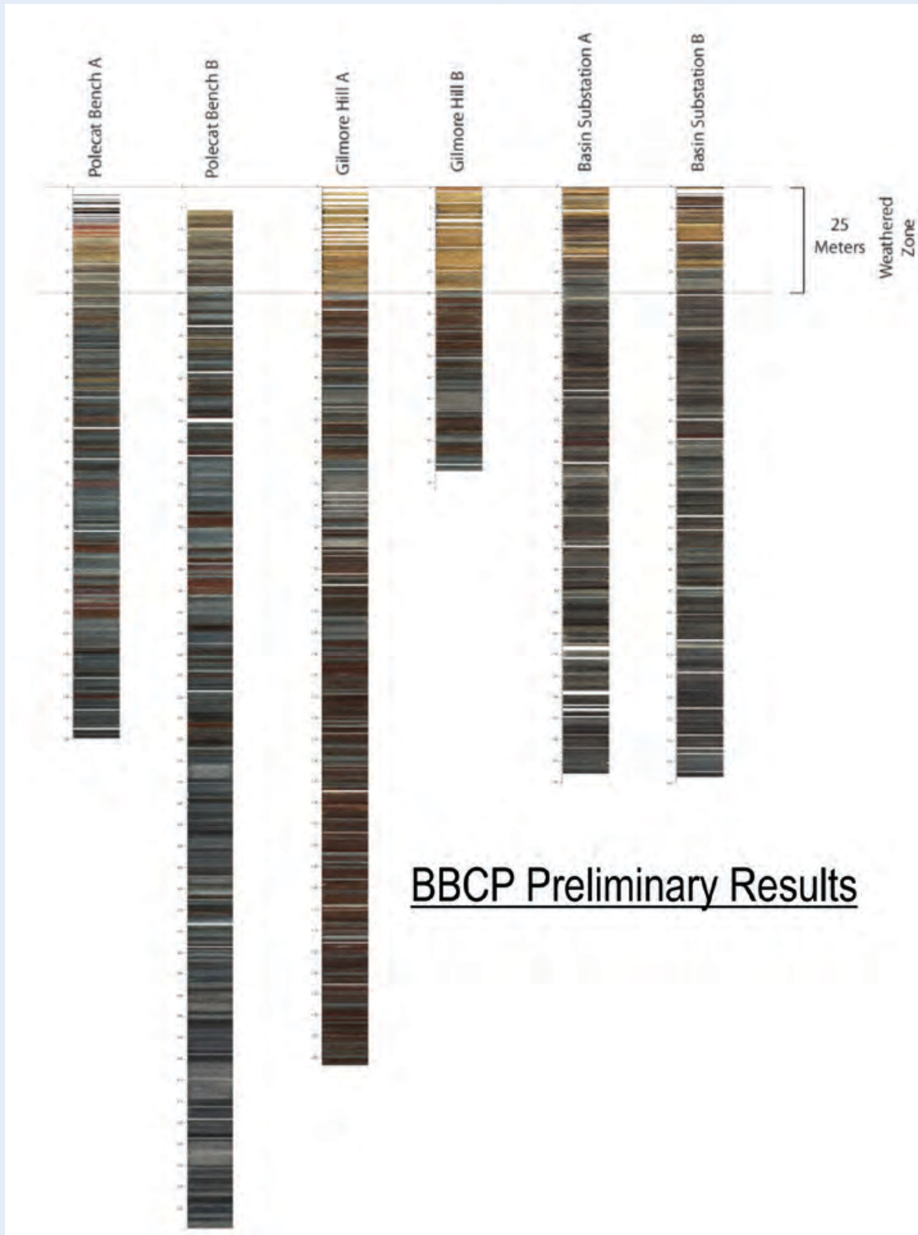

Figure 1: Core image scans from the Bighorn Basin, Wyoming, illustrating subsurface stratigraphy at a key location for understanding continental climate history through the early Paleogene hyperthermal events. A strong weathering profile is evident from the core color changes below ~25m, providing a clear rationale for why obtaining unweathered drill core is critical for a variety of geochemical and paleoecological indicators of environmental history. Figure courtesy of the Bighorn Basin Coring Project.

have been drilled, and four are in an advanced stage of planning. In addition, 8 others not on the original list have either been drilled or are in a planning stage. Given the technical and financial hurdles attendant with any drilling program, especially for lake drilling, this is a very positive result. This success occurred because the PAGES workshop moved beyond stating generalities of the need to acquire core, to actually identifying targets for specific sites to answer critical science questions.

We are following this model in convening a workshop on scientific drilling and the evolution of the earth system. Any interested participant may apply to attend the workshop by submitting a brief (2-3 page) pre-proposal identifying a potential drilling target. We will also consider drilling project proposals submitted by scientists who for whatever reason are unable to attend the workshop. Our primary goal is to 1) help galvanize a community of scientists with related interests in seeing CSD applications to Earth and life history move forward, and 2) to provide information and feedback for scientists who may or may not have prior experience with continental drilling, to help them understand what makes for a competitive proposal in CSD. This NSF-supported workshop will occur May 17-19, 2013, on the University of Oklahoma campus in Norman, Oklahoma. NSF personnel will be there to discuss funding options for research involving drilling. Details of the application process appear below. Please join and be part of a major transformation of how we collect and interpret records of Earth history.

Call for Pre-Proposals: Scientific Drilling and the Evolution of the Earth System--NSF Workshop

May 17-19, 2013 in Norman, OK

Objectives: 1) galvanize researchers interested in using scientific drilling to develop proposals for pursuing specific, high-priority targets to address key questions of Earth System evolution, and 2) offer these researchers strategies for developing competitive and compelling continental drilling proposals.

To secure participation, submit a brief (3 pages, excluding references) pre-proposal identifying a viable continental scientific drilling target that addresses fundamental problems of scientific importance in areas of paleoclimate, earth history, stratigraphy, palececology and/or paleobiology from any interval of Earth History. Criteria to address:

Science

- *Location and age of target deposits*
- *Compelling science issue(s)/hypotheses to be addressed by drilling, focusing on topics in paleoclimate, paleoenvironments, paleobiology, and/or extreme events*
- *Stratigraphic completeness, continuity and resolution*
- *Existence of baseline stratigraphic, and paleontologic data*
- *Existence of, or potential to collect, supporting data from correlative outcrops, geophysics or prior drilling*
- *Existence of, or potential to collect, a robust age model through the target interval*

Logistics

- *Challenges to drilling and obtaining subsurface information (e.g., suitable terrain for site-survey geophysics)*
- *Access for drilling equipment and Permitting issues*
- *Complexity of operations, local impact/cooperation (community and environmental)*

Pre-proposals may be submitted by teams, and we will strive to accommodate as many members of a team as funds allow while enabling as many teams to be represented as possible. *Pre-proposals are due by* **Friday April 12, 2013**. *Submit as .pdf files to* Dr. Lynn Soreghan (lsoreg@ou.edu) or Dr. Andrew Cohen (cohen@email.arizona.edu)

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