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The palaeoclimate potential of continental scientific drilling

Climate change is stressing societies by altering temperatures and the water cycle[1]. Future climate trajectories lie outside the range known from the instrumental record[2] and may be irreversible, making historic data insufficient to anticipate future climate hazards. While climate modelling can inform our understanding of these future climates, reconstructions of past environmental conditions derived from geological records provide a critical avenue for constraining Earth system behaviour when CO_2 was higher, temperatures were warmer, and precipitation highs and lows were more extreme. In particular, an expanded and strategically distributed network of climate reconstructions is needed to better understand past conditions and the response of continental ecosystems and landscapes to climatic change, an objective achievable through continental drilling.

The level at which Earth is instrumented, observed, and modelled has radically advanced our knowledge of recent and ongoing climate change, but this knowledge lends a false sense of sophistication to our understanding of Earth system behaviour. The geological record has revealed repeated examples of seemingly unimaginable climate scenarios — times when Earth's climate evolved in surprising ways (for example, complete ice sheet coverage, no ice sheet coverage, equable climate in polar and equatorial regions). The data tell us that extreme states occurred — but fundamental questions about the forcings, feedbacks, and tipping points that led to these alternative Earth-system states remain unresolved.

Earth's continental sedimentary archives can be used to develop proxy records to test hypotheses and further elucidate past climate states at local to global scales. Scientific drilling, which provides more pristine and continuous sediment records than surface sampling, enables investigation of alternative Earth-system states. This includes past warm periods, spanning the relatively warm interglacial intervals between glaciations over the last few hundred thousand years to the extreme greenhouse climate of the Palaeocene–Eocene Thermal Maximum (around 55.7 million years ago). Additionally, continental records capture times when plate configurations were quite different from those of today, including the Eocene–Oligocene transition (around 33.4 million years ago), when a reconfiguration of ocean gateways led to the growth of Antarctic ice, and earlier in the Mesozoic and Palaeozoic, when the assembly and disintegration of Pangea had drastic impacts on continental climate.

Continental scientific drilling and coring in Unaweep Canyon, Colorado, USA.

Both theory and models predict that continued climate warming will intensify the water cycle by increasing extremes and variability on a global scale[3]. The scant hydroclimate records that exist for past intervals characterized by high-CO_2 hothouse conditions suggest that precipitation changes also include conversion of dry regions into wet regions, and vice versa. Documenting the cause(s) of these changes and how quickly they occurred is critical for making realistic future projections[4]. In addition, the observed variability in regional hydroclimate responses to changes in major forcings makes robust inferences about spatiotemporal teleconnections between forcing factors, such as ocean temperatures, and hydroclimate extremes difficult.

The temporally-long, highly-resolved, and well-dated records needed to answer outstanding palaeoclimate questions can be obtained with continental coring, including drilling deeper and at more challenging sites than before. Drilling efforts targeting continental sites sensitive to hydroclimate changes enable examination of both past conditions and their drivers, providing a basis for deciphering hydroclimate variation and associated biological and carbon cycle feedbacks. Continental climate records are complex, with temporal gaps and diagenetic alterations that can complicate proxy reconstructions. However, they commonly have high temporal resolution with the potential to capture societally-relevant short-lived climate processes (for example, the El Niño/Southern Oscillation) and abrupt events not recorded by most open ocean sites, while continuously extending deeper in time than ice cores. Targeted drilling can also provide opportunities to integrate continental proxy records with coastal or marine successions to better understand processes that operate across the land to sea continuum.

Probing deeper into the Earth comes with challenges. Drilling in remote locations often requires substantial logistical support, increasing the complexity and expense of operations. Subsurface heterogeneities also pose drilling and coring challenges, especially for the collection of high-quality samples across variable lithologies. Extracting these records of past climate change necessitates substantial investment and increased capabilities in continental scientific drilling, as well as resources to develop the scientific and operational workforce to conduct these activities. Despite these obstacles, continental scientific drilling provides unique opportunities to explore past Earth system behaviour and is an important component of assessing future climate change and its potential impacts on society.

Correspondence

Jonathan Obrist-Farner [1] ✉, **Lesleigh Anderson** [2], **Paul Baker** [3], **Melissa A. Berke** [4], **Emily J. Beverly** [5], **Julie Brigham-Grette** [6], **Erik Brown** [7], **Isla S. Castañeda** [6], **Alan L. Deino** [8], **Sherilyn C. Fritz** [9], **Steven L. Goldstein** [10], **Natalie M. Kehrwald** [2], **Matthew Kirby** [11], **Kenneth G. Miller** [12], **Paul Olsen** [10], **Lisa Park Boush** [13], **Marci M. Robinson** [14], **James Russell** [15] & **Gerilyn S. Soreghan** [16]

[1]Department of Earth Sciences and Engineering, Missouri University of Science and Technology, Rolla, MO, USA. [2]US Geological Survey, Geosciences and Environmental Change Science Center, Denver, CO, USA. [3]Nicholas School of the Environment, Duke University, Durham, NC, USA. [4]Civil and Environmental Engineering and Earth Sciences, University of Notre Dame, Notre Dame, IN, USA. [5]Earth and Environmental Sciences, University of Minnesota, Minneapolis, MN, USA. [6]Department of Earth, Geographic, and Climate Sciences, University of Massachusetts Amherst, Amherst, MA, USA. [7]Large Lakes Observatory, University of Minnesota Duluth, Duluth, MN, USA. [8]Berkeley Geochronology Center, Berkeley, CA, USA. [9]Earth and Atmospheric Sciences, University of Nebraska–Lincoln, Lincoln, NE, USA. [10]Lamont–Doherty Earth Observatory, Columbia University, Palisades, NY, USA. [11]Geological Sciences, California State University Fullerton, Fullerton, CA, USA. [12]Department of Earth and Planetary Sciences, Rutgers University, Piscataway, NJ, USA. [13]Department of Earth Sciences, University of Connecticut, Storrs, CT, USA. [14]US Geological Survey, Florence Bascom Geoscience Center, Reston, VA, USA. [15]Department of Earth, Environmental and Planetary Sciences, Brown University, Providence, RI, USA. [16]School of Geosciences, University of Oklahoma, Norman, OK, USA.

✉e-mail: obristj@mst.edu

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Competing interests

The authors declare no competing interests.