Paleoclimate and Human Evolution Workshop

Over the past two and a half decades, new techniques for studying climate change, applied especially to deep-sea drill core records, have driven the development of environmental forcing hypotheses of human evolution. These hypotheses link specific climate transitions in the Neogene (23 to 2 million years ago) or changes in Neogene climate variability to events in hominin physical and adaptive evolution and species diversification [e.g., *Vrba*, 1988; *Potts*, 1996; *Bobe and Behrensmeyer*, 2004].

Key developments in hominin evolution, and especially in the human genus *Homo* with its unique array of behavioral characteristics, may be tied to specific climate 'events' or to the increase or decrease in climate variability in particular time intervals. The key forcing factors might include the stepwise aridification of Africa during the late Pliocene and early Pleistocene (about 3 to 1.5 million years ago), or changes in the variability of climate (and the food and water resources affected by the new climate regime) driven by changes in the Earth's orbital precession, obliquity, and eccentricity, (Milankovich insolation forcing) or millennial-scale climate fluctuations.

Simultaneously, there has been a tremendous growth in interest in documenting climate change in those regions of the world where major events in human evolution occurred. This interest has been spurred by efforts to complement the paleoanthropological record [e.g., *Cerling*, 1992; *Quade et al.*, 2004] and, more broadly, to understand climate dynamics in the tropics [e.g., *deMenocal*, 1995].

The convergent interests of geologists, paleoanthropologists, archaeologists, and paleoclimatologists, coupled with recent developments in the acquisition of long drill cores from Lakes Malawi and Bosumtwi in tropical Africa, formed the backdrop for a recent workshop on paleoclimates and human evolution. Workshop participants gathered to consider current knowledge of the relationship between human evolution and Neogene climate history and to chart promising directions for future research and interdisciplinary collaborations in this rapidly developing field.

Linking Deep Sea and Lake Cores to Evolutionary History

Workshop participants debated the challenges to understanding the role of climate in human evolution. Although correlation of events cannot demonstrate causation, comparative temporal analyses of paleoclimate versus hominin and other vertebrate fossil records are at least a first step in researching this linkage, and several researchers presented such data.

Workshop participants recognized that fundamental difficulties exist in integrating data derived from very different sources, as these better use environmental history data that are appropriately scaled to the hypotheses being evaluated [e.g. *Behrensmeyer*, 2006].

Drill core records from the deep sea currently provide the most temporally complete record of environmental variability in East Africa during the Neogene; this record shows some striking correlations with major episodes of hominin and other mammalian evolution [*deMenocal*, 2004]. Marine records indicate that African climate has been influenced by a combination of high-latitude teleconnections (~100-kiloyear glacial/interglacial cyles), variability in tropical insolation (driven by the precession cycle), sea surface temperatures [e.g., *Schefuss et al.*, 2003], and monsoon intensity. Drying cycles apparently became larger and longer after 2.8, 1.7, and 1.0 million years ago (Ma), following the predominant orbital beats of global climate variability.

New drill core records from African lakes and the promise of identifying future drill sites provide an exciting opportunity to address this scaling problem by opening up new combinations of spatial/temporal resolution and stratigraphic continuity during key intervals in human evolution, conference participants noted. Potential targets might be situated in existing lakes, in the depocenters of ancient lake basins, or even in the outcrop belts where hominin fossils and artifacts have been recovered. Tropical lakes, with their long-recognized sensitivity to subtle changes in precipitation/evaporation ratios, and their frequent accumulation of annually varved deposits, are ideal for producing such records [e.g., *Johnson et al.*, 2002; *Scholz et al.*, 2005].

Another challenge discussed during the workshop is to link reconstructed changes in paleoclimate to the patterns observed in fossil bones and stone tools. Part of this involves assessing which behaviors and anatomical traits make sense as evolutionary responses to changing climate and habitat.

Conference participants discussed how changes in diet, evidenced from hominin jaw or dental evolution within a species of hominin, might suggest a particular directional shift in vegetation cover and/or climate over the time or in the geographic range of the species in question. Participants also showed that microscopic patterns of wear on fossil teeth related to different types of food consumed could provide evidence that, among early hominins, selective pressures favored generalists capable of falling back on less preferred foods during arid intervals, when preferred food types were scarce.

In addition, conference attendees showed that skeletal differences between humans living under different climatic regimes are evident even between modern populations of *Homo sapiens*. Similar climate response arguments may help in the understanding of major transitions between *Austalopithecus* and *Homo*, between species of *Homo*, or even within cies diversity of hominins today (n = 1), models linking skeletal or size differences both within and between species and sexes to climate or vegetation differences in other types of modern mammals, especially primates can also be developed.

Defining Time Intervals for Study and Subjects for Interdisciplinary Research

There was a consensus among workshop participants that improved climate reconstructions for Africa and the hominin expansion corridors in Eurasia are an immediate, pressing goal. With continuous African continental drill core records, researchers now can test ideas linking cultural innovation and human dispersal with the timing of specific climate events (e.g., wetter periods or periods of greater or lesser climate variability). In Eurasia, where regional climate reconstructions for the middle to late Pleistocene transition are more broadly available, this approach has already paid off in a better understanding of the differences in habitat and climate range between modern *H. sapiens* and Neanderthals.

There was also a consensus concerning the need for interdisciplinary research on key time intervals. These are intervals when there are both data supporting extremely important evolutionary events and the potential to obtain much more highly resolved climate records than we have at present. Three intervals stood out as noteworthy for future intensive, integrative study:

- 3.0–2.4 Ma: Onset of 41-kiloyear glacial cycles in Arabian Sea dust records, origin of stone tools and the genus *Homo*, evidence of faunal change in East Africa
- 2.0–1.5 Ma: Evolution of *H. erectus*, expansion of *Homo* out of Africa, evidence for expansion of grassland habitats
- 0.4–0.05 Ma: Diversification of *Homo*, origin of anatomically modern humans, beginning of Middle Stone Age and major transition in stone tool and other technological innovations, dispersal of modern humans out of Africa.

In taking a time-slice approach, the challenge for the paleoclimate/human evolution community will be to better integrate outcrop, marine, and lake core data and modeling results, in order to reconcile their very different temporal and spatial scales and resolutions. Conference participants agreed that a research consortium of like-minded scientists could provide an umbrella of symposia, databases, and Web sites or publications to promote such an effort. It would also sharpen the focus on where improved climate records might be obtained on the continents, specifically through scientific drilling technology. Such records might come from a range of possible targets, from drilling existing fossil/artifact outcrop sites in order to sample unweathered strata, to drilling depocenters near such sites for more complete records, to drilling extremely long continental records in areas such as Lake Tanganyika in central Africa, where a continuous record of the span of human evolution might be obtained.

Regardless of the approach, the workshop made clear that this is only the beginning of what promises to be an exciting time for collaborative efforts to understand the climatic context in which our species and our close relatives evolved.

Paleoclimates and Human Evolution: A Workshop on Integrating Continental Drilling Research with Paleoanthropology and Other Geological Records, held 17-20 November 2005 at the Smithsonian's Conservation and Research Center in Front Royal, Va., was sponsored by the U.S National Science Foundation; the Smithsonian Institution's National Museum of Natural History's Human Origins Program; and the Drilling, Observation and Sampling of the Earth's Continental Crust (DOSECC) Inc. Additional workshop information can be found at http://www.geo.arizona.edu/web/HumanEvolutionWorkshop/

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—ANDREW S. COHEN, Department of Geosciences, University of Arizona, Tucson; E-mail: acohen@geo.arizona.edu; GAIL M. ASHLEY, Department of Geological Sciences, Rutgers University, Piscataway, N. J.; RICHARD POTTS, Human Origins Program, National Museum of Natural History, Washington, D. C.; ANNA K. BEHRENSMEYER, Department of Paleobiology, National Museum of Natural History; CRAIG FEIBEL, Departments of Geological Sciences and Anthropology, Rutgers University; JAY QUADE, Department of Geosciences, University of Arizona.