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Out of Africa and into an ice age: on the role of global climate change in the late Pleistocene migration of early modern humans out of Africa

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ABSTRACT

The results from two climate model simulations are used to explore the relationship between North Atlantic sea surface temperatures and the development of African aridity around 100,000 years ago. Through the use of illustrative simulations with an Earth System Climate Model, it is shown that freshwater fluxes associated with ice sheet surges into the North Atlantic, known as Heinrich events, lead to the southward shift of the intertropical convergence zone over Africa. This, combined with the overall increased aridity in the cooler mean climate, leads to substantial changes in simulated African vegetation cover, particularly in the Sahel. We suggest that Heinrich events, which occurred episodically throughout the last glacial cycle, led to abrupt changes in climate that may have rendered large parts of North, East, and West Africa unsuitable for hominin occupation, thus compelling early *Homo sapiens* to migrate out of Africa.

Introduction

According to the ‘Out-of-Africa 2’ hypothesis, all humans living today descend from a population of anatomically modern *Homo sapiens* that evolved in Africa approximately 200,000 years ago, but did not migrate out of Africa and spread into the rest of the World until 100,000 years or so later (Stringer and Andrews, 1988). As a result, interest has developed in establishing a comprehensive understanding of the factors that motivated these early *H. sapiens* to venture out of Africa at this time (see for example Derricourt, 2005; Stringer and Andrews, 2005; Mellars, 2006).

The earliest fossil remains attributed to *H. sapiens* have been found in Ethiopia in the Omo Kibish formation, dating back to 195 ka (195,000 years ago; McDougall et al., 2005), and at the site of Herto, dating to between 160 and 154 ka (White et al., 2003), suggesting that East Africa was the likely region of the origin of our species. Around 125 ka, early *H. sapiens* began to expand their geographical range throughout Africa (Finlayson, 2005). The oldest, securely-dated fossil remains of modern humans found outside of Africa come from Skhul and Qafzeh in the Middle East and date to between 119 and 85 ka (Bar-Yosef, 1995; Valladas et al., 1998). The oldest fossil of modern *H. sapiens* in China comes from the Liujiang Cave site and dated to 67 ka (Yuan et al., 1986) and, more recently, to perhaps even more than 111 ka (Shen et al., 2002). The earliest *Homo sapiens* fossils in Australia date between 50 and 42 ka (Thorne et al., 1999; Bowler et al., 2003; O’Connell and Allen, 2004). The oldest *H. sapiens* fossil remains in Europe date to around 35 ka (Trinkaus et al., 2003) and in the Americas to about 13.4 ka (Dixon, 1999). Based on these fossil dates, most scientists conclude that anatomically modern humans had evolved in Africa at around 200 ka and subsequently began migrating to diverse parts of the world in several waves, the first of which began between 110 and 90 ka (Stringer, 2000; Walter et al., 2000).

The traditional view has been that *H. sapiens* colonized the world through an inland route, moving out of Africa northwards through the Levantine corridor and into the Middle East, subsequently spreading to Europe and across the middle of Asia into India and the Far East (Stringer, 2000). Once there, they adapted to coastal life and developed boats necessary for migration to Australia (Stringer, 2000). An alternate view that has gathered recent support is that early *H. sapiens* may have taken a southern coastal route out of Africa along the coast of the Red Sea, migrating into the Levant across a land bridge exposed by a drop in sea level (Stringer, 2000; Walter et al., 2000; see also Field and Lahr, 2005). It is postulated that by continuing along the narrow shorelines of southern Asia they progressed all the way to Indonesia (Stringer, 2000).

Support for the idea of a climate-driven migration and a southern coastal migration has been derived from the discovery of a number of coastal sites along the eastern and southern coasts of Africa that suggest a novel transition to coastal living began around 125 ka, although recent evidence extends this date back to about

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164 ka (Marean et al., 2007). These include the archaeological localities dating to the last interglacial recently discovered near Abdur, on the Red Sea coast of Eritrea (Walter et al., 2000). Embedded within this raised fossil reef, Walter et al. found broken fragments of oysters, giant clams, and crustaceans, as well as fossils of terrestrial mammals and stone tools. While they did not recover any human fossil remains, early modern *Homo sapiens* fossils have been found at contemporaneous sites in the East African interior such as Lake Eyasi (~130 ka), Mumba Rockshelter (~109–130 ka), and the Ngaloba beds (~120 ka), as well as the aforementioned older sites of Omo Kibish and Herto. The fossil evidence at these sites suggests that early *H. sapiens* were present throughout East Africa by the time the reef sites were formed, and they were its likely occupants (Walter et al., 2000). Evidence of coastal adaptation by humans at this time is also supported by the sudden appearance of a number of South African coastal sites between 125 and 75 ka (see Trinkaus, 2005 for a review). These sites include the system of caves found at Die Kelders Cave 1 (70 ka; Feathers and Bush, 2000), Blombos Cave (70 ka; Henshilwood et al., 2001), Border Cave (75 ka; Grün and Beaumont, 2001), and Klasies River Mouth (120 – 115 ka; Singer and Wymer, 1982). The Eritrea site and the Klasies River Mouth site also provide the earliest evidence of an early human adaptation to seashore living (Walter et al., 2000), potentially implying that a major change in human adaptive capacities may have occurred at this time, perhaps associated with the onset of glaciation and the beginning of the last glacial cycle also around 115 ka. Paleoclimate data sets from the African continent further suggest a shift towards a drier and cooler climate state with the onset of glaciation (Adams et al., 1997). Guided by this archaeological and paleoclimate evidence, we examine the hypothesis that movement along the coasts may have been in response to an episodic and abrupt switch to hyper-arid conditions and dwindling water resources.

Climate change during the last glacial cycle

In the Northern Hemisphere, the termination of the last glacial cycle was characterized by the melting of high-latitude ice sheets at the end of Marine Isotope Stage 6 (MIS 6) around 130 ka. Deglaciation was followed by a brief interglacial during MIS 5e (128–120 ka) that ended around 117 to 115 ka, when glacial inception during MIS substage 5d initiated the formation of large ice sheets over Europe and North America—sea level was low and ice volume was high (Kukla, 2000). MIS 5d culminated at 111 ka, when after the brief interstadial MIS 5c that lasted until 106 ka, a gradual climatic deterioration during MIS 4 (72– 62 ka) resulted in the establishment of full glacial conditions (Imbrie et al., 1984). A variable but progressive drop in global relative sea levels ocurred throughout the last glacial cycle starting with a maximum height of just a few meters above present levels during MIS 5e (Lambeck et al., 2002), and reaching between 118 and 135 m below present during the last glacial maximum (LGM; Clark and Mix, 2000).

Marine records of pollen and dust flux off the west coast of Africa indicate that between around 125 and 120 ka rainforest occupied a far greater area than at present in West Africa, and rainfall was generally higher over North Africa (Frenzel, 1992; van Andel and Tzedakis, 1996). This respite of warmth lasted until about 115 ka (MIS 5d), when it appears that the north-western African environment gradually entered a phase of extreme aridity (van Andel and Tzedakis, 1996). Subsequent cooling and drying of the climate led to a cold maximum at about 75 ka (van Andel and Tzedakis, 1996). Detailed marine sediment records from Cap Blanc in northwestern Africa have revealed that over the last 160,000 years (beginning in MIS 6), the pollen content and flux were lower during glacial periods and higher during the wet interglacial periods (Zhao et al., 2003). The lower pollen flux is mainly caused by the concomitant sparse vegetation cover on the northwest coast of the African continent (Zhao et al., 2003). The Sahara also changed dramatically during this period. During the last glaciation the desert was even more extensive than it is today (Grove and Warren, 1968; Swezey, 2001). A record of charcoal (containing charred particles of African vegetation) deposition in marine sediments of the tropical Atlantic analysed by Verardo and Ruddiman (1996) revealed that maximum charcoal concentrations occurred during glacials (MIS 2, 3, 4, 6, and substages 5b and 5d), and lower concentrations occurred during interglacial stages (MIS 1, and substages 5a, 5c, and 5e). These results are interpreted as either an indication that glacial winds in this region were stronger than interglacial winds or that there was a southern shift in glacial wind directions near the equator that allowed eolian charcoal (and dust) to be carried farther south in much greater abundance than today. The enhanced variability in African climate during 145– 75 ka has been documented in several studies of marine records for the Atlantic (Jahns, 1996; Dupont et al., 2000; deMenocal, 2004) and the Indian Ocean (Bard et al., 1997).

In West Africa, rainforest was strongly reduced after 115 ka, especially during MIS 5d (115– 105 ka) and 5b (93– 85 ka) when montane forest, dominated by spruce, fir, and pine tree species indicative of cool environments, expanded in its place (Dupont and Hooghiemstra, 1989). According to marine sediment cores retrieved off the Ivory Coast (Frédoux, 1994), the Niger Delta (Lutze et al., 1988), and off the coast of Gabon (Lutze et al., 1988), the area covered by forests of *Podocarpus* (a genus belonging to a family of yellowwood, brown and black pine trees that are moderately drought-resistant, frost-hardy, and grow best in moist mountainous areas) widely expanded during the cold stadials of the last glacial cycle in marine isotope sub-stages 5d and 5b (Dupont et al., 2000). A strong rise in the percentages of *Podocarpus* pollen suggests that the climate in West Africa became cooler but remained humid (Dupont and Agwu, 1992).

Records of East African paleoclimate are derived from palynological records of the vegetation of northeast Africa and the Arabian Peninsula, which are based on the marine pollen record from the Arabian Sea. During the glacial periods, the frequency of pollen from the Mediterranean steppe increases while that of the humid tropical taxa decreases, indicating a shift of the main pollen source area from East Africa to the Arabian Peninsula (van Campo et al., 1982). Dust transport into the Arabian Sea reconstructed by Leuschner et al. (2004) and Reichart et al. (1998) has revealed that during the relatively warm MIS 5c (105 –93 ka) and 5a (85 – 75 ka), dust deposition from the Arabian Peninsula was greatly reduced, which implies more humid conditions there. In contrast, during the cold MIS 5d (115 – 105 ka), 5b (93– 85 ka), and 4 (75 –60 ka), and during the LGM, large quantities of dust were deposited in this area. Similarly, lake level records from Lake Malawi (Johnson et al., 2002) and Lake Tanganyika (Felton et al., 2007) have suggested that the cold LGM climate was characterized by arid conditions in East Africa.

The Ficken et al. (2002) paleovegetation reconstruction on Mount Kenya for the last glacial revealed that during this period terrestrial productivity was lower than today, and C_4 mesic grasses and sedges (arid-adapted) out-competed C_3 plants (moisture-adapted) due to lower CO_2 and precipitation. In fact, Huang et al. (2001) suggest that changes in $p\text{CO}_2$ by itself are insufficient to explain glacial-interglacial changes in the abundance of C_3 and C_4 plants. Rather they suggest that such changes must also occur in conjunction with appropriate changes in temperature and water availability. Records from Lake Malawi (East Africa) show periods of severe aridity with concomitant increase in desertification between 135 and 75 ka, when the lake's water volume was reduced by at least 95% (Cohen et al., 2007; Scholz et al., 2007). From these cores and from records from Lakes Tanganyika (East Africa) and