

A humid corridor across the Sahara for the migration of early modern humans out of Africa 120,000 years ago

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It is widely accepted that modern humans originated in sub-Saharan Africa \approx 150–200 thousand years ago (ka), but their route of dispersal across the currently hyperarid Sahara remains controversial. Given that the first modern humans north of the Sahara are found in the Levant \approx 120–90 ka, northward dispersal likely occurred during a humid episode in the Sahara within Marine Isotope Stage (MIS) 5e (130–117 ka). The obvious dispersal route, the Nile, may be ruled out by notable differences between archaeological finds in the Nile Valley and the Levant at the critical time. Further west, space-borne radar images reveal networks of—now buried—fossil river channels that extend across the desert to the Mediterranean coast, which represent alternative dispersal corridors. These corridors would explain scattered findings at desert oases of Middle Stone Age Aterian lithic industries with bifacial and tanged points that can be linked with industries further to the east and as far north as the Mediterranean coast. Here we present geochemical data that demonstrate that water in these fossil systems derived from the south during wet episodes in general, and penetrated all of the way to the Mediterranean during MIS 5e in particular. This proves the existence of an uninterrupted freshwater corridor across a currently hyperarid region of the Sahara at a key time for early modern human migrations to the north and out of Africa.

Middle Stone Age | Eemian | neodymium | paleochannel | sapropel

The Saharan-Arabian desert is currently the largest hyperarid region on the planet, with annual precipitation as low as 1 mm. This region presented the most significant barrier to the migration of anatomically modern humans out of central sub-Saharan Africa during their dispersal into southwest Asia and Europe (1–4). So far, interest has focused on a northward dispersal route through the Sahara via the Nile at \approx 130 thousand years ago (ka). However, new dates on fossils and archaeological sites have revealed a wide distribution of *Homo sapiens* all along the North African coast, north of the Sahara, during this period (5, 6). Moreover, there are considerable inconsistencies between archaeological finds in the Nile Valley and the Levant at the crucial time (4, 7), whereas it has been suggested that conditions in the Nile corridor were inhospitable during a similar Holocene Saharan wet phase (8).

We argue that the Nile should be seen as neither the only nor, perhaps, the most likely potential dispersal route. There is widespread evidence for episodes of significantly more humid conditions over much of the Sahara itself in the past (9–14), driven by orbital insolation-induced African monsoon maxima (15). The most recent of these so-called pluvials occurred during the early Holocene (\approx 10–5 ka), when decorated pottery and other archives attest to a flourishing Neolithic civilization in the heart of what is now desert (16). Our focus here is the even more intense wet phase that occurred during the last interglacial [Marine Isotope Stage (MIS) 5e], coincident with the migration

of early modern humans out of Africa. We show that the radar-imaged fossil river channels (17) bore water during MIS 5e that is sourced in the internal Sahara and that penetrated all of the way to the Mediterranean. Our data represent an indication of an uninterrupted humid corridor stretching across the Sahara to the Mediterranean at a key time for the dispersal out of Africa of early modern humans.

Mediterranean Isotopic Anomalies at 124–119 ka and the Source of Freshwater Discharge to the Mediterranean

We use a combination of two data sets to investigate the existence of a humid corridor across the Libyan Sahara fueled by water that derived from the North African Watershed (\approx 21°N; Fig. 1) and that penetrated all of the way to the Mediterranean. Fig. 2 shows published $\delta^{18}\text{O}$ (18) and new neodymium (Nd) isotope data for surface-dwelling planktic foraminifera in the 135- to 110-ka interval of Ocean Drilling Program (ODP) Hole 971A (Fig. 1) from the western Ionian Sea. Previous work established that the pronounced $\delta^{18}\text{O}$ anomaly seen at \approx 124–119 ka is difficult to explain in terms of any combination of temperature and/or ice-volume changes but, instead, reflects a dramatic change in the freshwater budget of this part of the Mediterranean (18, 19). The $\delta^{18}\text{O}$ anomaly, which is identifiable throughout the eastern Mediterranean, is related to significant surface-water freshening, a shutdown of eastern Mediterranean deep-water ventilation, and anoxia in the deep basin (18, 19). Moreover, the $\delta^{18}\text{O}$ anomaly is much stronger in the western Ionian Sea than elsewhere, which may suggest a freshwater source proximal to the Gulf of Sirte and the Libyan portion of the Sahara (18, 19).

Because of complex controls on foraminiferal $\delta^{18}\text{O}$, such data alone cannot conclusively identify the origin of the anomalous freshwater influx. On the basis of a single proxy (oxygen isotopes), and lacking a transect of cores into the Gulf of Sirte to “trace” the inlet, the Rohling *et al.* (18) data set is very suggestive, but other processes involving isotope fractionation or regional oceanographic reorganization cannot be fully excluded. Our Nd isotope analyses of planktic foraminifera from 971A add a key constraint (Fig. 2; see also *Materials and Methods*). The Nd isotopic composition of the oceans is controlled by inputs from the continental crust (see ref. 20 for a review). Old continental crust, with a long history of low Sm/Nd ratios, has a lower $^{143}\text{Nd}/^{144}\text{Nd}$ ratio than material newly extracted from the mantle. $^{143}\text{Nd}/^{144}\text{Nd}$ ratios are expressed in terms of ϵ_{Nd} , or parts per

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large-scale atmospheric circulation, and the basin has not moved from its current position between the temperate westerlies in the North and the subtropical/trades to the South. Hence, the overall vorticity input into the basin remains cyclonic, with a general eastward surface flow in a slightly south-of-central position in the basin known as the Mid-Mediterranean Jet (MMJ) (27). This MMJ flows virtually over the top of ODP site 971A. Westward “return” flow occurs along the northern margins of the Mediterranean. The overall cyclonic nature of the circulation is enforced by significant net buoyancy loss in the easternmost Mediterranean with freshwater additions along the margins. The MMJ is a pervasive feature of the surface circulation that “protects” ODP site 971A from the chemical properties of the westward return flow (which may have been affected by Nile discharge). Hence, one would expect, from dynamical reasons alone, that site 971A is highly unlikely to show an undiluted Nile impact. Instead, one would expect ODP site 971A to show a strong dominance of Atlantic-derived properties, with modifications caused by any nearby (upstream or southwest of the site) discharges. The eastward surface flow over site 971A then puts 967C in a “downstream” position, where it would be likely to record a distal version of the signature seen in 971A.

Nd Isotopic Characterization of the Wet Corridor Through the Sahara

The inferred causal relationship between radiogenic Nd in the southern volcanic mountains and a shift to more radiogenic values in the eastern Mediterranean would require that the freshwater in the fossil river systems carried the radiogenic Nd signal toward the Mediterranean. We test this hypothesis by using the isotopic compositions of freshwater mollusks from assemblages that thrive in shallow lakes or slow-moving rivers (see *Materials and Methods*). These were recovered from Quaternary sediments beneath the modern Saharan sands in Libya, both within the major channels imaged from space, at Wadi Quoquin and Behar Belama, and outside them at Wadi ash Shati (Fig. 1). The data for Wadi Quoquin and Wadi Behar Belama indicate waters that carried unradiogenic Sr and—crucially—radiogenic Nd signatures, with ϵ_{Nd} values reaching as high as -2 (Fig. 3). As with the Mediterranean foraminiferal analyses, such a Nd signature cannot be derived from any proximal source and must, instead, come from the volcanic mountains to the south, in agreement with the layout of the channel network (25). These results contrast sharply with those for the mollusks from Wadi ash Shati, outside the main water courses, the Sr and Nd signatures of which do not require a basaltic source, with ϵ_{Nd} values as low as -12 (Fig. 3).

Our data represent direct evidence for an uninterrupted humid connection between the southern Sahara region and the Mediterranean at ≈ 120 ka. These data supplement previous suggestions that the latitudinal extent of the Sahara desert was much reduced during orbital insolation maxima, especially at 130–120 ka, caused by northward expansion of the African monsoon—the so-called greening of the Sahara. This greening is best documented for the most recent, ^{14}C -datable, Holocene pluvial (see ref. 25 for a review). Palynological studies as well as dated tufas and lacustrine sediments indicate an even more significant extension of wetter conditions during the pluvial of 130–120 ka (9–14). These inferences are consistent with the fact that the orbital insolation forcing of climate was more pronounced during MIS 5e than during the Holocene (15), and Global Climate Models confirm that the resultant northward displacement of the ITCZ (and associated “greening” of the Sahara) would have been more extreme during MIS 5e than during the Holocene (28).

Perhaps the two largest lakes in the Sahara during ancient wet phases were megalakes Chad and Fazzan (14, 29). In neither case has there been any previous suggestion that they drained to the

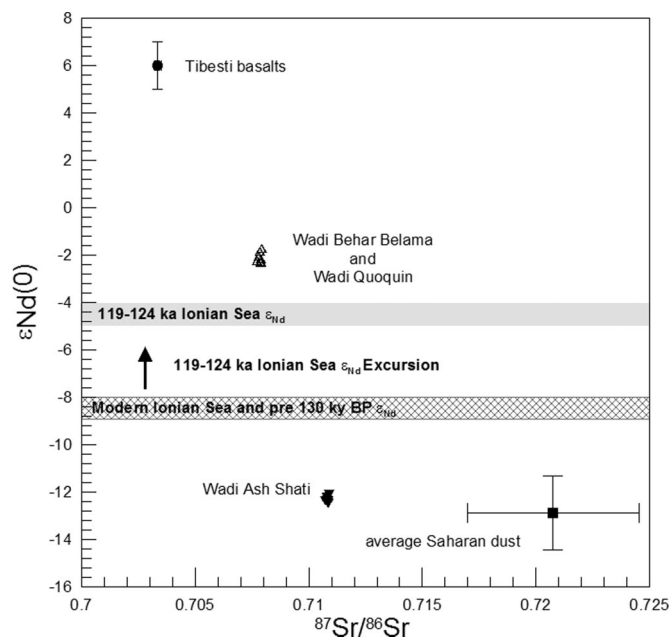


Fig. 3. Nd and Sr isotopic data for mollusks collected from lake sediments recovered from central and eastern Libyan wadis that drain the Tibesti Mountains and the Haruj-Al-Aswad (open triangles, Wadi Behar Belama and Wadi Quoquin) and for mollusks from gravels in a wadi further west (black triangles, Wadi ash Shati) that drains local Phanerozoic sediments and is not linked to the Tibesti Mountains. Uncertainties are about the same size as the symbols (see *Materials and Methods* for analytical details). Also shown is the isotopic composition of average Saharan dust (23) (black square with an error bar denotes 1 SD). The lower cross-hatched bar gives the Nd isotopic composition of both the modern surface Ionian Sea (21) as well as foraminifera from outside the 119- to 124-ka oxygen and Nd isotope excursion (see Fig. 2). The excursion to more radiogenic Nd (arrow and upper horizontal gray bar), accompanied by much lighter oxygen, is explicable in terms of only one local source. That source, and that of the Nd in the wadi mollusks, is the Tibesti Mountains (26) (circle with error bar).

Mediterranean Sea, with Lake Chad probably draining to the south (29) and Lake Fazzan in Libya almost certainly being an internal basin (14). Crucially, and in contrast to previous findings, our data link the Mediterranean and the internal Sahara with a humid corridor.

Conclusions and Outlook

The very widespread distribution of Middle Stone Age (MSA) Aterian assemblages across the Sahara (30) and their precocious appearance in North Africa at the end of MIS 5 or earlier (31) suggest a widespread dispersal of *H. sapiens* at this time. The absence of similar industries from the Nile Valley (32) implies the existence of separate migrations along routes across the Sahara as far north as the Mediterranean coast. The similarity of Aterian assemblages in the Western Desert of Egypt (33) and the Libyan Sahara, extending into coastal areas of Cyrenaica and Tunisia, implies a strong connection between the cultural traditions of these regions. Combining these observations with our evidence for continuous humid corridors through the central Sahara at the critical time, fed by strongly enhanced precipitation over the central Saharan watershed, we infer that northward dispersal from sub-Saharan Africa likely took place through regions that currently rank among the most arid on Earth.

In putting forward our hypothesis, we note that it is eminently testable. Although a significant amount of work has been done on the archaeology of the Mediterranean littoral itself, there is as yet very little evidence to link sites in these areas with finds of MSA material in the Sahara, most of which is undated, found

in low concentration, and comes from surface scatters, often from ill-defined or disturbed contexts. Our hypothesis would suggest that a concerted effort along the edges of the drainage channels would prove fruitful and would yield higher density sites of comparable age to those on the coast.

Materials and Methods

Samples. For the foraminiferal Nd analyses, mixed samples of *Globigerinoides ruber* and *Orbulina universa* were picked from the 250- to 355- μm fraction of ODP Hole 971A (24°41'N, 33°43'E; water depth = 2,026 m) and cleaned by using methods described elsewhere (22). Mixed samples were used on the basis of previous work, which obtained identical results for each species (23). The freshwater mollusk samples from within the Libyan wadis were recovered from the top 1 m of limnic sediments, now buried beneath ≈ 0.5 m of desert sands, during fieldwork in December 2006. The Wadi Behar Belama (27°27.627' N, 21°15.603' E) and Wadi Quoquin, (25°44.888' N, 19°09.863' E) shells were all gastropods, and the species assemblage (*Biomphalaria pfeifferi*, *Bulinus truncatus*, *Gyraulus ?ehrenbergi*, and *Lymnaea peregra*) indicates that the areas were once shallow freshwater lakes or slow-moving rivers that may have become seasonally dry. Mollusk samples from outside the major channel network, from Wadi ash Shati (27°30.703' N, 14°02.736' E), were collected from coquina-type deposits in a 2.6-m-high outcrop, location XV discussed by Petit-Maire *et al.* (9) and the same location as samples FZ11 and FZ12 discussed by Armitage *et al.* (14). The assemblage (*Melanoides tuberculata* and *Cerastoderma ?glaucum*) and previous work (9) indicate that this is a "beach-rock" type of deposit from the shores of a brackish to saline lake. All mollusk samples were cleaned and analyzed by using the same methods as for the planktonic foraminifera with the exception of the reductive cleaning step, which was omitted.

Isotopic Analysis. Nd and Sr were separated from all carbonate samples by using chemical procedures described elsewhere [see Vance *et al.* (22) and references therein]. Nd isotopic analysis was performed on a Neptune multi-collector inductively coupled plasma mass spectrometer (MC-ICPMS) at the Bristol Isotope Group by using the procedure described in detail by Vance and Thirlwall (34). Between 7 and 9 La Jolla standards were analyzed per analytical session, and the measured $^{143}\text{Nd}/^{144}\text{Nd}$ varied from 0.511843 ± 0.000004 (2 SDs) to 0.511854 ± 0.000008 (2 SDs) for a single analytical session. All isotopic analyses were normalized to a La Jolla value of 0.511857. Sr isotopic analysis of the mollusk samples was also analyzed on the Bristol Neptune MC-ICPMS and normalized to an $^{86}\text{Sr}/^{88}\text{Sr}$ of 0.1194. Between 8 and 10 analyses of the National Institute of Standards and Technology Standard Reference Material 987 Sr standard were performed per session, and the measured $^{87}\text{Sr}/^{86}\text{Sr}$ varied from 0.710254 ± 0.000012 (2 SDs) to 0.710257 ± 0.000012 (2 SDs). For the mollusk analyses, individuals from each of the species collected were analyzed and, for samples from the same location, there were no significant differences in the measured isotopic compositions of Sr and Nd.

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- Stringer C (2000) Coasting out of Africa. *Nature* 405:24–26.
- McBrearty S, Brooks AS (2000) The revolution that wasn't: A new interpretation of the origin of modern human behavior. *J Hum Evol* 39:453–563.
- McDougall I, Brown FH, Fleagle JG (2005) Stratigraphic placement and age of modern humans from Kibish, Ethiopia. *Nature* 433:733–736.
- Vermeersch PM (2001) "Out of Africa" from an Egyptian point of view. *Quat Int* 75:103–112.
- Smith TM, *et al.* (2007) Earliest evidence of modern human life history in North African early *Homo sapiens*. *Proc Natl Acad Sci USA* 104:6128–6133.
- Bouzouggar A, *et al.* (2007) 82,000-year-old shell beads from North Africa and implications for the origins of modern human behavior. *Proc Natl Acad Sci USA* 104:9964–9969.
- Van Peer P (1998) The Nile corridor and the out-of-Africa model. *Curr Anthropol* 39:5115–5139.
- Kuper R, Kröppel S (2006) Climate-controlled Holocene occupation in the Sahara: Motor of Africa's evolution. *Science* 313:803–807.
- Petit-Maire N, Casta L, Delibrias G, Gaven C, Testud A-M (1980) in *Geology of Libya*, eds Salem MJ, Busrewil MT (Academic, London), Vol III, pp 797–813.
- Gaven C, Hillaire-Marcel C, Petit-Maire N (1981) A Pleistocene lacustrine episode in southeastern Libya. *Nature* 290:131–133.
- Szabo BJ, Haynes CV Jr, Maxwell TA (1995) Ages of quaternary pluvial episodes determined by uranium-series and radiocarbon dating of lacustrine deposits of eastern Sahara. *Palaeogeogr Palaeoclimatol Palaeoecol* 113:227–242.
- Hoelzmann P, *et al.* (2004) in *Past Climate Variability Through Europe and Africa*, eds Battarbee RW, Gasse F, Stickley CE (Springer, Dordrecht, The Netherlands), pp 219–256.
- Kieniewicz JM, Smith JR (2007) Hydrologic and climatic implications of stable isotope and minor element analyses of authigenic calcite silts and gastropod shells from a mid-Pleistocene pluvial lake, Western Desert, Egypt. *Quat Res* 68:431–444.
- Armitage SJ, *et al.* (2007) Multiple phases of North African humidity recorded in lacustrine sediments from the Fazzan Basin, Libyan Sahara. *Quat Geochron* 2:181–186.
- de Noblet N, Bracannot P, Joussaume S, Masson V (1996) Sensitivity of simulated Asian and African summer monsoons to orbitally induced variations in insolation 126, 115 and 6 kBP. *Clim Dyn* 12:589–603.
- Roset JP (1995) in *Environments, Societies and Archaeology*, ed Marliac A (Orstrom-Karthala, Paris), pp 161–196 (in French).
- Jet Propulsion Laboratory Imaging Radar (1995) Wadi Kufra radar image (Image P-45719). Available at <http://southport.jpl.nasa.gov/cdrom/sirced03/cdrom/DATA/LOCATION/AFRICA/WADIKUFRA/WADIKUFRA.HTM>. Accessed November 1, 2007.
- Rohling EJ, *et al.* (2004) African monsoon variability during the previous interglacial maximum. *Earth Planet Sci Lett* 202:61–75.
- Rohling EJ, *et al.* (2004) Reconstructing past planktic foraminiferal habitats using stable isotope data: A case history for Mediterranean sapropel 5S. *Mar Micropaleontol* 50:89–123.
- Frank M (2002) Radiogenic isotopes: Tracers of past ocean circulation and erosional input. *Rev Geophys*, 10.1029/2000RG000094.
- Tachikawa K, *et al.* (2004) Neodymium isotopes in the Mediterranean Sea: Comparison between seawater and sediment signals. *Geochim Cosmochim Acta* 68:3095–3106.
- Vance D, *et al.* (April 27, 2004) The use of foraminifera as a record of the past neodymium isotope composition of seawater. *Paleoceanography*, 10.1029/2003PA000957.
- Scrivner AE, Vance D, Rohling EJ (2004) New neodymium isotopic data quantifies Nile involvement in Mediterranean anoxic episodes. *Geology* 32:565–568.
- Grousset FE, *et al.* (1998) Saharan wind regimes traced by the Sr-Nd isotopic composition of subtropical Atlantic sediments: Last glacial maximum versus today. *Quat Sci Rev* 17:395–409.
- Pachur H-J, Altmann N (2006) *Die Ostsahara im Spätquartär* (Springer, Berlin-Heidelberg).
- Allegre CJ, Dupré B, Lambert B, Richard P (1981) The subcontinental versus suboceanic debate. I. Lead-neodymium-strontium isotopes in primary alkali basalts from a shield area, the Ahaggar volcanic suite. *Earth Planet Sci Lett* 52:85–92.
- Pinardi N, Masetti E (2000) Variability of the large scale general circulation of the Mediterranean Sea from observations and modelling: A review. *Palaeogeogr Palaeoclimatol Palaeoecol* 158:153–173.
- Brovin V, *et al.* (2002) Carbon cycle, vegetation and climate dynamics in the Holocene: Experiments with the CLIMBER-2 model. *Global Biogeochem Cycles* 16:1139, 10.1029/2001GB001662.
- Schuster M, *et al.* (2005) Holocene Lake Mega-Chad palaeoshorelines from space. *Quat Sci Rev* 24:1821–1827.
- Garcea EAA (2004) Crossing deserts and avoiding seas: Aterian North African-European relations. *J Anthropol Res* 60:27–53.
- Stringer CB, Barton RNE (2008) Putting North Africa on the map of modern human origins. *Evol Anthropol* 17:5–7.
- Klein RG (1999) *The Human Career* (Chicago Univ Press, Chicago).
- Caton-Thompson G (1946) The Aterian industry: Its place and significance in the Palaeolithic world. *J R Inst Great Britain Ireland* 76:87–130.
- Vance D, Thirlwall MF (2002) An assessment of mass discrimination in MC-ICPMS. *Chem Geol* 185:227–240.