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Geology 2010;38;1135-1138
doi: 10.1130/G31320.1

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Evidence for Pleistocene lakes in the Tushka region, south Egypt

Ted A. Maxwell[1]*, Bahay Issawi[2], and C. Vance Haynes Jr.[3]
[1]Center for Earth and Planetary Studies, National Air and Space Museum, Box 37012, Smithsonian Institution, Washington, D.C. 20013, USA
[2]Consulting Geologist, 16 Misaha Street, Dokki, Cairo, Egypt
[3]Departments of Anthropology and Geosciences, University of Arizona, Tucson, Arizona 85721, USA

ABSTRACT

Space Shuttle Radar Topography Mission (SRTM) data have revealed new details on the extent and geomorphic relations of paleodrainage in southern Egypt. Following a period of late Tertiary drainage from the Red Sea Hills south through Wadi Qena and west across the Tushka region, the Nile River as we now know it established its connections with Central Africa and the Mediterranean in the middle Pleistocene (oxygen isotope stage, OIS 7 to OIS 5). SRTM topography reveals a lake level at ~247 m that is coincident with the elevation of middle Pleistocene fish fossils 400 km west of the Nile, and with the termination of shallow runoff channels in northern Sudan that were active during the middle Pleistocene and Holocene pluvial periods. An additional lake level at ~190 m is based on the current elevation at Wadi Tushka, and is consistent with Paleolithic sites at Bir Kiseiba followed by Neolithic sites at lower topographic levels. Overflow of the Nile through Wadi Tushka during the wetter north African climate of the middle Pleistocene, coupled with limited local rainfall, was the likely source of water for these lakes.

INTRODUCTION

The area west of the Nile between Aswan and the Sudan border is an important key to the evolution of drainage in the northeast Sahara throughout the Cenozoic. However, this region has been partially inundated by five lakes at elevations of 132–144 m since 1998 (Abdelsalam et al., 2008); the surface has started to host irrigation pivots and associated fields, and 100 km west of the Nile, the few scattered oases have begun to be exploited for their near-surface groundwater. Thus it is important to investigate the undisturbed desert surface before it is completely overtaken. Recent hypotheses for Nile evolution suggest major changes in drainage from a pre-Nile southwest direction in the Oligocene–Miocene to late Pliocene (McCauley et al., 1986), to northeastward drainage in the Pleistocene resulting from establishment of the present Nile (Issawi and McCauley, 1992), all of which affected the Kiseiba-Tushka region.

We used Shuttle Radar Topography Mission (SRTM) data at the available 3 arc-second (90 m) spatial resolution (see the GSA Data Repository[1]) to delineate the topography and surficial deposits of the Kiseiba-Tushka depression, bounded by Kiseiba Oasis on the west, Wadi Tushka on the east, the Egyptian western limestone plateau to the north, and the gradual southward rise of the desert surface into Sudan (Fig. 1). The resulting digital elevation model displays evidence for northeast drainage that explains the locations of several oases along the Darb el-Arba'in caravan route and the elevation and extent of paleolakes that eventually disappeared, leaving numerous remnant playas, some of which were key sites for prehistoric humans (Wendorf and Schild, 1998). We present several observations of the topography and key geomorphic features based on the SRTM data, and hypothesize a new series of flood events that may have formed middle Pleistocene lakes.

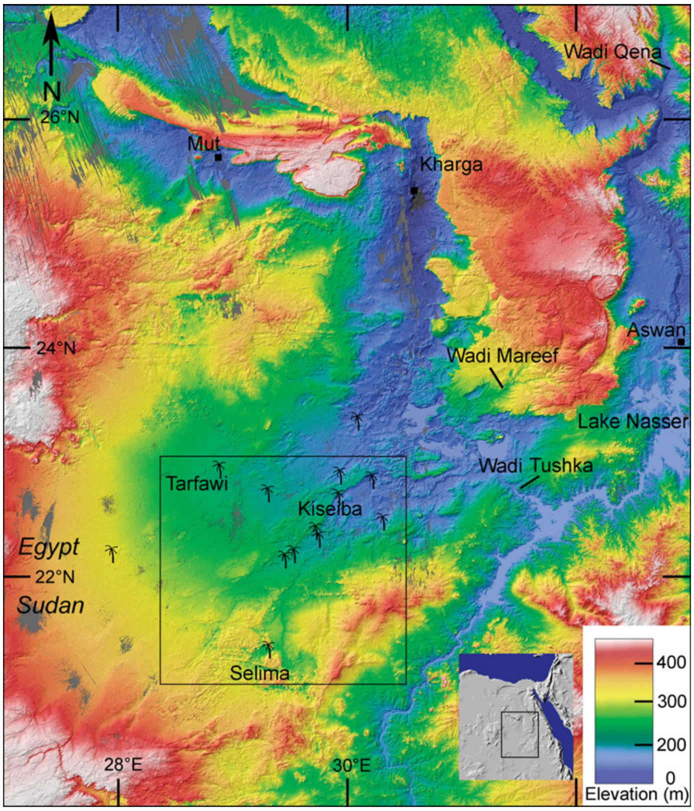

Figure 1. Digital elevation model of southern Egypt and adjacent Sudan derived from National Aeronautics and Space Administration–provided Shuttle Radar Topography Mission 3 arc-sec data. Middle Pleistocene overflow of Nile River to the west through Wadi Tushka is proposed to account for lake remnants, fossil fish, and paleochannel terminations at 247 m and 190 m.

NILE EVOLUTION AND THE WESTERN DESERT

Fluvial activity in the Tushka region was intricately related to the timing and direction of overland drainage across the western limestone plateau before the Oligocene–Miocene rifting of the Red Sea that initiated formation of the Nile valley (Williams and Williams, 1980). Drainage from the Red Sea hills to southwest Egypt (and across Africa) during this period was suggested based on the near east-west orientation and junction angles of the subsurface paleochannels revealed by Space Shuttle Imaging Radar (SIR) (McCauley et al., 1986). Prior to the establishment of the northward-draining Nile, Wadi Qena drained the Red Sea Hills southward through the present Nile valley, and to the west across the Kiseiba-Tushka depression to combine with the northward drainage from the Gilf Kebir plateau, eventually debouching into the Mediterranean (Issawi and Osman, 2008).

Sediments of the Nile valley indicate that the present Nile did not have a connection with Central Africa before the middle Pleistocene, based on the presence of fluvial sand deposits that extend from Wadi

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*E-mail: maxwellt@si.edu.

[1] GSA Data Repository item 2010306, data sources and methods, is available online at www.geosociety.org/pubs/ft2010.htm, or on request from editing@geosociety.org or Documents Secretary, GSA, P.O. Box 9140, Boulder, CO 80301, USA.

Geology, December 2010; v. 38; no. 12; p. 1135–1138; doi: 10.1130/G31320.1; 3 figures; Data Repository item 2010306.

Qena across the present Nile valley and the lack of Ethiopian minerals in sediments older than the middle Pleistocene Dandara silts (Hassan, 1976; Butzer, 1980). The upper part of the Ethiopian mineral-rich Dandara Formation has been dated at 213 ka (oxygen isotope stage, OIS 7; Issawi and McCauley, 1992), although sediments below that horizon contain a mix of Ethiopian and Nubian lithologies.

Current stratigraphic data thus suggest that establishment of the northward-draining Nile and connection with Blue Nile sediments occurred over a time period spanning OIS 7 to OIS 5 (~240–100 k.y.). Williams and Williams (1980) proposed two models for integrating northward drainage: overflow of a lake in northern Sudan, or headward erosion of the Nile through the uplifted rocks of the Nubian swell. In either case, following establishment of northward drainage in the middle Pleistocene, westward transport of Eastern Desert sand and gravel across the Nile valley would have ceased. Construction of the Tushka overflow canal provided access to topographic and stratigraphic data suggesting that Wadi Tushka was once a tributary to the Nile, draining a large middle Pleistocene or earlier lake in the Kiseiba-Tushka depression (Haynes, 1980). Using SRTM topography, we can now constrain the extent of such lakes, compare the boundaries with other geomorphic features, and speculate on the water source.

TOPOGRAPHIC REMNANTS OF FLUVIAL AND LACUSTRINE FEATURES

SRTM topography reveals several previously unmapped drainage channels that originate in the Selima Oasis region and drain to the northeast (Fig. 2). Selima is an uninhabited oasis that was the site of several Holocene lakes at 265–285 m elevation, and 10 m above the highest Holocene tufas are limestone benches with well-weathered Middle Paleolithic artifacts (Haynes et al., 1989). The lacustrine limestone indicates that a small middle Pleistocene lake occupied the Selima depression, and overflow of that lake to the north explains the source of the paleochannels. Two of the larger channels converge 40 km north of Selima, and eventually become indistinguishable from the surrounding terrain near Dibis Oasis at an elevation of 247 m (Fig. 2).

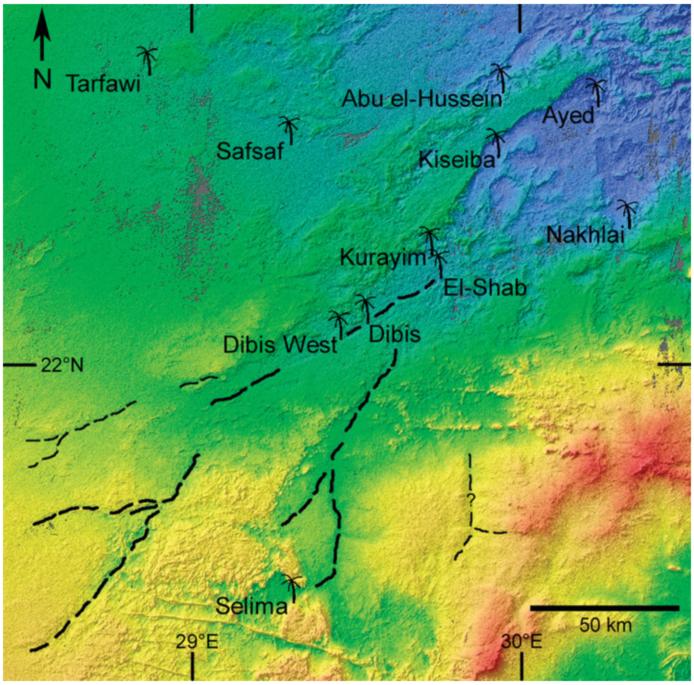

Figure 2. Enlarged portion of digital elevation model along Egypt-Sudan border showing alignment of (unpopulated) oases from Selima to Bir Ayed along paleochannels. Elevated carbonate benches with associated Paleolithic artifacts along northeast margin of Selima Oasis suggest overflowing lake(s) during middle Pleistocene. For elevation legend, see Figure 1.

An even wider valley and set of tributary channels 60 km west of Selima consist of a linear northeast-trending valley joined by a 2-km-wide curvilinear channel. In combination with northeast-trending furrows at 22°N, these channels suggest drainage from the southeastern Selima Sand Sheet to the southernmost edge of the Kiseiba scarp, marked by Dibis and Dibis West Oases (Fig. 2). Prior studies of SRTM topography northwest of this area indicated a dominant northeast trend of drainage, including both paleochannels detected by SIR, as well as predicted channels based on a hydrologic model (Ghoneim and El-Baz, 2007). The channels seen here indicate that this northeast slope, and consequent drainage, is present farther to the east than previously mapped, and the northeast gradation of the channels into the surrounding terrain suggests additional complexity.

We believe that the middle and late Pleistocene drainage was influenced by repeated Nile flooding, following on the working hypothesis of Haynes (1985), who suggested a large Pleistocene lake that drained into the Nile from what he termed the Kiseiba-Dungul depression. Using the elevation of the fossil (Middle Paleolithic) Nilotic fish found at Bir Tarfawi (Van Neer, 1993) as a base level, the SRTM data indicate that a paleolake at that level (247 m) would have flooded the entire Kiseiba-Tushka depression (Fig. 3), and is the same elevation at which the Selima paleochannels and other channel remnants to the west blend into the terrain (Fig. 2). We interpret the combination of topographic coincidence and ages of Middle Paleolithic occupations at Selima and Tarfawi as evidence of at least one lake level at that elevation, forming a local base level, reducing the competence of inflowing streams, and inhibiting channel incision below ~247 m. Such a lake would have covered an area of 68,200 km^2, and would have extended from the Sudan border (22°N) north to the Kharga and Dakhla Oases, until dammed by the limestone plateau at 26°N. Including the relatively minor addition of an estimated 25 km^3 volume for the Tushka lakes as of 2002 (Abdelsalam et al., 2008), the total volume would have been ≤4090 km^3. Obviously there has been both regional denudation as well as differential erosion of this desert throughout the climate variations of the last half of the Pleistocene, so any calculations of volumes should be treated as upper estimates.

The elevation of the (pre-canal) Tushka channel at 190 m is an additional base level that relates to Kiseiba-Tushka topography. Project bore hole records indicate that the bedrock beneath the present canal is at 123 m; the local Nile channel bedrock is 5 m below that level (Haynes,

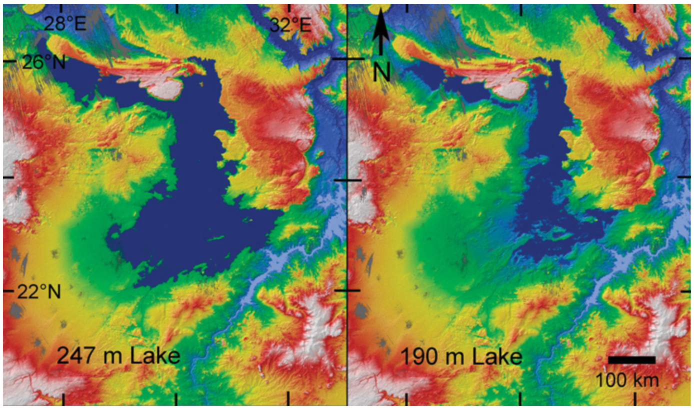

Figure 3. Extent of lake levels at 247 m (68,200 km^2) and 190 m (30,400 km^2) that would have extended 350 km north from Sudan border to Kharga Oasis. Significant middle Pleistocene recharge of Nubian aquifer was likely by-product of these lakes, as well as creating attractive sites for human settlement. For elevation legend, see Figure 1.

1985). However, two Acheulean hand axes were found in the upper 7 m of sediment infill of the Tushka excavations; the specimen from the upper 2–3 m was less abraded than the ax at depth (Haynes, 1980). Such evidence suggests that infilling of Wadi Tushka to near the 190 m level occurred prior to the middle Pleistocene Acheulean occupation. This elevation is remarkably consistent with the elevations and ages of archaeological sites north of Bir Kiseiba, 150 km to the west. There, a 5-km-wide plateau at ~200 m elevation has abundant late Acheulean artifacts weathering out of the topmost 1–2 m (Haynes et al., 2001). The sand sheet surrounding the plateau is at 170–180 m, and is characterized by Neolithic sites (Wendorf et al., 1984), scattered Middle Paleolithic artifacts mixed with the lag, and several generations of paleochannels (Grant et al., 2004). A lake at 190 m would completely enclose the plateau surface (Fig. 3), leaving the two sandy alluvial units that contain the artifacts subaerially exposed, consistent with their sand-abraded appearance. This lake would have covered 30,400 km^2 at an average depth of 47 m, and contained 1450 km^3 of water.

The northeast alignment and location of the Dibis West–Dibis–El-Shab–Kurayim–Kiseiba string of oases can now be considered remnants of Pleistocene drainage. Although each of these oases is in a local topographic low, commonly a few meters below the surrounding sand sheet, the concentration of groundwater is likely aided by subsurface permeable fluvial deposits (as shown for Bir Kiseiba by Grant et al., 2004). The northward topographic gradient likely aided water flow toward the channel thalwegs both during the time of the Selima-Tarfawi lake and during the Holocene pluvial, ca. 10–6 ka.

Although the paleochannels north and west of Selima Oasis indicate local runoff from rainfall, the middle Pleistocene timing of Bir Tarfawi fossils and calcareous benches at Selima allow another hypothesis for the origin of the lakes. High discharges in the early Pleistocene coupled with continued sedimentation in the upper Nile valley from the Eastern Desert in the form of the Qena sand and the Kom Ombo gravels virtually ensured that any flooding of an early north-flowing Nile would have been diverted into the Western Desert. However, even after the connection of the present Nile with Central Africa and channel incision due to sea-level lowering in the middle Pleistocene, it is plausible that Nile flooding would have topped the drainage divide at Wadi Tushka, flooding the Western Desert to the levels proposed here. Nile discharge volumes of 300 km^3/yr suggested for the Holocene wet period (Said, 1993) and late Pleistocene terrace levels at 160 m (Butzer, 1980) indicate that older, middle Pleistocene discharge could have easily exceeded the 190 m level at Wadi Tushka. Continued southward flushing of Wadi Qena into the 25 km constriction of the Nile valley in the middle Pleistocene would have aided such a process by inhibiting throughgoing Nile drainage at the Qena bend. Multiple floods to the 247 m (or higher) level at Bir Tarfawi explain the wide range in U-series dates for the various lake phases, and the postdepositional high mobility of uranium (Schwarcz and Morawska, 1993). A historical analogy for this process is the Holocene history of the Faiyum depression into which the Nile overflowed, forming several lakes during Pharonic times (Hassan, 1986).

DISCUSSION

This hypothesis of middle Pleistocene lakes is subject to the assumption that the topography derived from SRTM represents that of the middle Pleistocene. The gross topographic elements of the sand sheet are likely to be retained in this area, as shown by the stability of the sand sheet (Maxwell and Haynes, 2001) and the correlation of SRTM- and SIR-derived drainage >500 k.y. apart in age (Ghoneim and El-Baz, 2007). Additional sources of uncertainty are the absolute ages and longevity of the proposed lakes, and the amount of local precipitation during the middle Pleistocene.

The absolute ages of archaeological assemblages are poorly constrained in southwest Egypt (Schild, 1987), and only scattered uranium-series and optically stimulated luminescence dates in local areas are available to determine the timing of carbonate deposition and associated occupations that are beyond the range of ^{14}C dating (Wendorf et al., 1993; Szabo et al., 1995). Given those caveats, it may still be possible to use the location and elevation of archaeological sites to test these ideas. A brief review of those sites known to us suggests that several Acheulean and Middle Paleolithic artifact locations are found at elevations that straddle the 247 m datum. While such equivocal results do not support a long-standing, monotonically subsiding series of lakes, they are not inconsistent with lakes formed from sporadic flooding.

Past attempts to reconcile a Nile connection for middle Pleistocene fish (Van Neer, 1993) and lacustrine deposits at both Bir Tarfawi (Hill, 2009) and Dakhla Oases (Kieniewicz and Smith, 2009) have relied on a combination of precipitation and groundwater to maintain stable lakes, since estimates of 500 mm/yr precipitation (Wendorf et al., 1993) are insufficient to support a standing body of water. Seasonal (or more frequent) flooding of the Nile, particularly during pluvial conditions, may well have provided the water necessary for the megalakes proposed here.

CONCLUSIONS

Comparison of a SRTM-derived digital elevation model with geomorphic features and scattered archaeological sites and associated sediments suggests the presence of at least two levels of middle Pleistocene paleolakes in the Western Desert. These lakes could have originated from overflow of the Nile through Wadi Tushka, the low point on the west bank of the Nile. An overflow origin is consistent with recent hypotheses on the origin of the Nile and its integration with drainage from Central Africa.

The sedimentary evidence for these old Egyptian lakes is less compelling than that of the newly defined mega–Lake Chad (Leblanc et al., 2006), the Northern Darfur Megalake in northwestern Sudan (Hoelzmann et al., 2001), the White Nile lake in central Sudan (Williams et al., 2010), or Lake Megafazzan in Libya (Drake et al., 2008). Nonetheless, the topographic data add to the growing evidence for numerous early and middle Pleistocene lakes across North Africa that could have supported human migration patterns.

ACKNOWLEDGMENTS

This research is supported by the Smithsonian Institution endowments (Maxwell) and National Geographic Society grant 7567-03 (Haynes). We thank John Grant, Andrew Johnston, Eman Ghoneim, and an anonymous reviewer for their comments on this paper, and Martin Williams for a thought-provoking review.

REFERENCES CITED

Abdelsalam, M.G., Youssef, A.M., Arafat, S.M., and Alfarhan, M., 2008, Rise and demise of the New Lakes of the Sahara: Geosphere, v. 4, p. 375–386, doi: 10.1130/GES00142.1.

Butzer, K.W., 1980, Pleistocene history of the Nile valley in Egypt and lower Nubia, *in* Williams, M.A.J., and Faure, H., eds., The Sahara and the Nile: Rotterdam, Balkema, p. 253–280.

Drake, N.A., El-Hawat, A.S., Turner, P., Armitage, S.J., Salem, M.J., White, K.H., and McLaren, S., 2008, Palaeohydrology of the Fazzan Basin and surrounding regions: The last 7 million years: Palaeogeography, Palaeoclimatology, Palaeoecology, v. 263, p. 131–145, doi: 10.1016/j.palaeo.2008.02.005.

Ghoneim, E., and El-Baz, F., 2007, The application of radar topographic data to mapping of a mega-paleodrainage in the Eastern Sahara: Journal of Arid Environments, v. 69, p. 658–675, doi: 10.1016/j.jaridenv.2006.11.018.

Grant, J.A., Maxwell, T.A., Johnston, A.K., Kilani, A., and Williams, K.K., 2004, Documenting drainage evolution in Bir Kiseiba, southern Egypt: Constraints from ground-penetrating radar and implications for Mars: Journal of Geophysical Research, v. 109, no. E9, E09002, doi: 10.1029/2003JE002232.

Hassan, F.A., 1976, Heavy minerals and the evolution of the modern Nile: Quaternary Research, v. 6, p. 425–444, doi: 10.1016/0033-5894(67)90006-3.

Hassan, F.A., 1986, Holocene lakes and prehistoric settlements of the Western Faiyum, Egypt: Journal of Archaeological Science, v. 13, p. 483–501, doi: 10.1016/0305-4403(86)90018-X.

Haynes, C.V., Jr., 1980, Geochronology of Wadi Tushka: Lost Tributary of the Nile: Science, v. 210, p. 68–71, doi: 10.1126/science.210.4465.68.

Haynes, C.V., Jr., 1985, Quaternary studies, Western Desert, Egypt and Sudan—1979–1983 field seasons: National Geographic Society Research Reports, v. 16, p. 269–341.

Haynes, C.V., Jr., Eyles, C.H., Pavlish, L.A., Ritchie, J.C., and Rybak, M., 1989, Holocene paleoecology of the Eastern Sahara: Selima Oasis: Quaternary Science Reviews, v. 8, p. 109–136.

Haynes, C.V., Jr., Maxwell, T.A., Johnson, D.L., and Kilani, A., 2001, Acheulian Sites near Bir Kiseiba in the Darb el Arba'in Desert, Egypt: New Data: Geoarchaeology, v. 16, p. 143–150, doi: 10.1002/1520-6548(200101)16:1<143:AID-GEA9>3.0.CO;2-6.

Hill, C.L., 2009, Stratigraphy and sedimentology at Bir Sahara, Egypt: Environments, climate change and the Middle Paleolithic: Catena, v. 78, p. 250–259, doi: 10.1016/j.catena.2009.02.003.

Hoelzmann, P., Keding, B., Berke, H., Kropelin, S., and Kruse, H.-J., 2001, Environmental change and archaeology: Lake evolution and human occupation in the eastern Sahara during the Holocene: Palaeogeography, Palaeoclimatology, Palaeoecology, v. 169, p. 193–217, doi: 10.1016/S0031-0182(01)00211-5.

Issawi, B., and McCauley, J.F., 1992, The Cenozoic rivers of Egypt: The Nile problem, *in* Friedman, R., and Adams, B., eds., The followers of Horus: Studies dedicated to Michael Allen Hoffman: Oxbow Monograph 20: Oxford, UK, Oxbow Books, p. 121–138.

Issawi, B., and Osman, R., 2008, Egypt during the Cenozoic: Geological history of the Nile River, *in* Yousef, E.A.A., ed., Bulletin of the Tethys Geological Society, v. 3: Cairo, Cairo University, p. 43–62.

Kieniewicz, J.M., and Smith, J.R., 2009, Paleoenvironmental reconstruction and water balance of a mid-Pleistocene pluvial lake, Dakhleh Oasis, Egypt: Geological Society of America Bulletin, v. 121, p. 1154–1171, doi: 10.1130/B26301.1.

Leblanc, M., Leduc, C., Stagnitti, F., van Oevelen, P.J., Jones, C., Mofor, L.A., Razack, M., and Favreau, G., 2006, Reconstruction of Megalake Chad using Shuttle Radar Topographic Mission data: Palaeogeography, Palaeoclimatology, Palaeoecology, v. 239, p. 16–27, doi: 10.1016/j.palaeo.2006.01.003.

Maxwell, T.A., and Haynes, C.V., Jr., 2001, Sand sheet dynamics and Quaternary landscape evolution of the Selima Sand Sheet, southern Egypt: Quaternary Science Reviews, v. 20, p. 1623–1647, doi: 10.1016/S0277-3791(01)00009-9.

McCauley, J.F., Breed, C.S., Schaber, G.G., McHugh, W.P., Haynes, C.V., Grolier, M.J., and El-Kilani, A., 1986, Paleodrainages of the eastern Sahara, the radar rivers revisited (SIR-A/B implications for a mid-Tertiary trans-Africa drainage system): IEEE Transactions on Geoscience and Remote Sensing, v. GE-24, p. 624–648, doi: 10.1109/TGRS.1986.289678.

Said, R., 1993, The River Nile: Geology, hydrology and utilization: New York, Pergamon, 320 p.

Schild, R., 1987, Unchanging contrast? The late Pleistocene Nile and eastern Sahara, *in* Close, A.E., ed., Prehistory of arid North Africa—Essays in honor of Fred Wendorf: Dallas, Texas, Southern Methodist University Press, p. 13–27.

Schwarcz, H.P., and Morawska, L., 1993, Uranium-series dating of carbonates from Bir Tarfawi and Bir Sahara East, *in* Wendorf, F., et al., eds., Egypt during the Last Interglacial: The Middle Paleolithic of Bir Tarfawi and Bir Sahara East: New York, Plenum, p. 205–217.

Szabo, B.J., Haynes, C.V., Jr., and Maxwell, T.A., 1995, Ages of Quaternary pluvial episodes determined by uranium-series and radiocarbon dating of lacustrine deposits of Eastern Sahara: Palaeogeography, Palaeoclimatology, Palaeoecology, v. 113, p. 227–242, doi: 10.1016/0031-0182(95)00052-N.

Van Neer, W., 1993, Fish remains from the last interglacial at Bir Tarfawi (Eastern Sahara, Egypt, *in* Wendorf, F., et al., eds., Egypt during the Last Interglacial: The Middle Paleolithic of Bir Tarfawi and Bir Sahara East: New York, Plenum, p. 144–154.

Wendorf, F., and Schild, R., 1998, Nabta Playa and its role in northeastern African prehistory: Journal of Anthropological Archaeology, v. 17, p. 97–123, doi: 10.1006/jaar.1998.0319.

Wendorf, F., Schild, R., and Close, A.E., eds., 1984, Cattle keepers of the Eastern Sahara: The Neolithic of Bir Kiseiba: Dallas, Texas, Southern Methodist University Press, 452 p.

Wendorf, F., Schild, R., and Close, A.E., 1993, Summary and conclusions, *in* Wendorf, F., et al., eds., Egypt during the Last Interglacial: The Middle Paleolithic of Bir Tarfawi and Bir Sahara East: New York, Plenum, p. 552–573.

Williams, M.A.J., and Williams, F.M., 1980, Evolution of the Nile basin, *in* Williams, M.A.J., and Faure, H., eds., The Sahara and the Nile: Rotterdam, Balkema, p. 207–224.

Williams, M.A.J., Williams, F.M., Duller, G.A.T., Munro, R.N., El Tom, O.A.M., Barrows, T.T., Macklin, M., Woodward, J., Talbot, M.R., Haberlah, D., and Fluin, J., 2010, Late Quaternary floods and droughts in the Nile Valley, Sudan: New evidence from optically stimulated luminescence and AMS radiocarbon dating: Quaternary Science Reviews, v. 29, p. 1116–1137, doi: 10.1016/j.quascirev.2010.02.018.

Manuscript received 21 April 2010
Revised manuscript received 16 July 2010
Manuscript accepted 23 July 2010

Printed in USA