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Variability in a Pleistocene Climate Sequence from Bir Tarfawi, Egypt

C.A. Bradbury and C. L. Hill
Department of Anthropology
Boise State University

Primary contact: Cynthia Bradbury
cabradbury@micron.com

Abstract

North Africa contains evidence of environmental change that can be used to examine past climate variability. A sedimentary sequence from the north part of Bir Tarfawi, in southern Egypt, contains a record of variable Pleistocene climate including sediments, gastropods (invertebrate fauna) and stable isotopes. The sequence dates to about 100,000 years ago and appears to document past wet (pluvial) periods in the now hyperarid area. Deposits include both clastics (sand, silt, and clay) and carbonates. Variation in sedimentation can be interpreted as evidence of climate change. Drier climate phases contain more clastics, often with higher amounts of sands. Carbonates and higher amount of muds (silts and clays) can be linked to wet climate phases. A higher resolution climate record is potentially provided by the gastropod *Melanoides tuberculata,* since its shell is secreted in equilibrium with the surrounding waters. *Melanoides* was present and collected in three of the sediment layers likely representing pluvial conditions. Oxygen stable isotope values from both sediment and *Melanoides* are less negative than would be expected from a prevailing westerly Atlantic precipitation. Other potential sources of water include easterly precipitation from the Indian Ocean, alternating precipitation from Atlantic and Indian Oceans, ground water and transport through streams. The stratigraphic and stable isotope record from Bir Tarfawi can be used to examine these potential sources for the variations in hydrologic conditions and can be compared to other sites in northeast Africa.

Introduction

Bir Tarfawi, situated in a basin west of the Nile River and east of the Gilf Kebir highlands in Egypt (Fig. 1), contains evidence of long term climate change. The area currently receives less than 20 mm of rain per year (Sultan 1997) and is characterized by sand sheets. Satellite radar images show prehistoric water channels running from the western highlands through the basin (Ghoneim 2007) and, together with surface limestone formations, suggest significantly more water once existed in the Sahara. The Bir Tarfawi area is also connected with modern humans through the presence of Acheulian and Middle Paleolithic artifacts (Hill 1993, Hill 2001). These artifacts are typically associated with wet phase stratigraphy. Details of the oscillation between savanna (wet phase) and hyperarid desert (dry phase) can provide

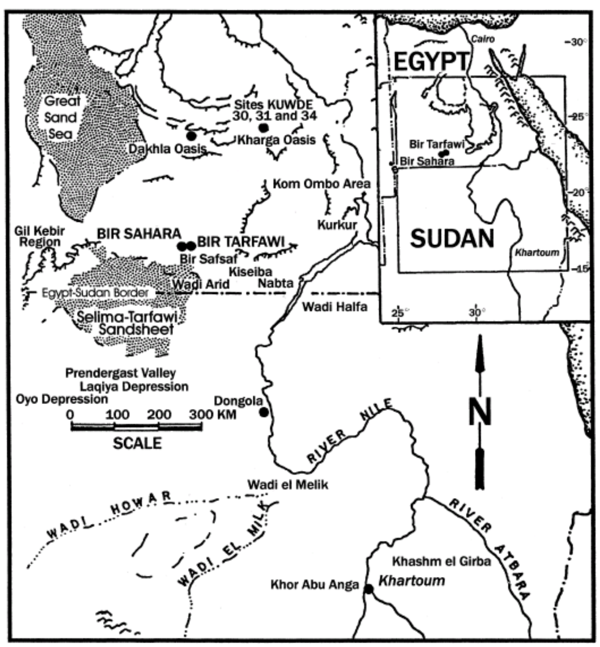

Figure 1. Map showing the position of Bir Tarfawi in southern Egypt and in relation to Kharga and Gil Kebir, Egypt (Hill 2001).

validation of global climate models and may also play a part in human evolution and migration.

Along with the carbonate deposits the stratigraphic sequences at Bir Tarfawi contain clastics (sand, silt and clay) that provide evidence of climate change. Wet phases are linked to carbonates and muds (silts and clays) (Hill 1993). Clastics, including higher concentrations of sand, are associated with drier phases. Carbon and oxygen stable isotope analysis of strata provides supporting information for water volume and depth, water residence time and water source, as well as, organic material type and concentration (Abell 1988, Leng 2004, McKenzie 1993).

Strata with significant carbonate (marl) deposition contain *Melanoides tuberculata*, a mollusk, with a life span of at least 2 years. This gastropod is ubiquitous in Africa and Asia (Abell & Williams 1989, Leng 2004). While intolerant of high concentrations of dissolved salt and temperatures below 10°C, the *Melanoides* grows in equilibrium with its environment (Abell 1985, Abell & Nyamweru 1988, Leng 2004). Growth is controlled by pH, calcium and other nutrient availability, and temperature (Abell & Nyanweru 1988). Nutrients are supplied by dissolved carbonate in the water and decaying flora such as aquatic plants, algae, epiphytic organisms and adhering detritus (Leng 2004). Using modern gastropods and zonal shell analysis, Abell (1995) showed temperature increases over the lifespan resulted in lower oxygen stable isotope ratios. Conversely, with decreased rainfall and increased evaporation, the gastropod shell stable oxygen isotope ratio was increased.

Sediment composition and stable isotope analysis of sediment and *Melanoides* are used in this paper to develop a hypothesis on the source of water contributing to the wet phases in Bir Tarfawi about 100,000 years ago. McKenzie (1993), Sultan (1997), and Smith (2004) propose Pleistocene and Holocene pluvial events in the Western Desert of Egypt were the result of precipitation from westerly systems. The movement of these western systems over northern Africa would produce the negative oxygen isotope values measured in the Western Desert.

Methods

Field studies were conducted by Hill as part of the Combined Prehistoric Expedition directed by F. Wendorf and R. Schild (Hill 1992). Samples of sediments were taken from each stratigraphic layer of Trench 3/86 which is adjacent to several important Middle Paleolithic localities at north Bir Tarfawi. *Melanoides* was sampled from strata 3 through 5. Compositional studies (treatment with HCl, particle size analyses, loss-on-ignition), used to determine the proportion of carbonate and clastics, were conducted at the University of Minnesota Archaeometry Laboratory (Hill 1993). Gastropod whole shell carbonate oxygen and carbon stable isotope analysis was performed by Hill in 1986 at the Southern Methodist University Stable Isotope Laboratory. Uranium series measurements on carbonates from strata 4 and 5 provided ages of 82 ± 10 ka and 101 ± 12 ka corresponding to Marine Isotope Stage (MIS) 5 (Wendorf 1994).

Graphs and analysis were conducted by Bradbury using Excel™ to evaluate strata in Bir Tarfawi Trench 3/86 sediment composition and stable isotope data. The results of the analysis can be used to interpret the landscape present during deposition and the potential source or sources of moisture that led to the presence of wet phase strata. Oxygen stable isotope data from Bir Tarfawi Trench 3/86 was also compared with data from Kharga, Egypt and adjacent areas in Sudan for a regional evaluation of water sources.

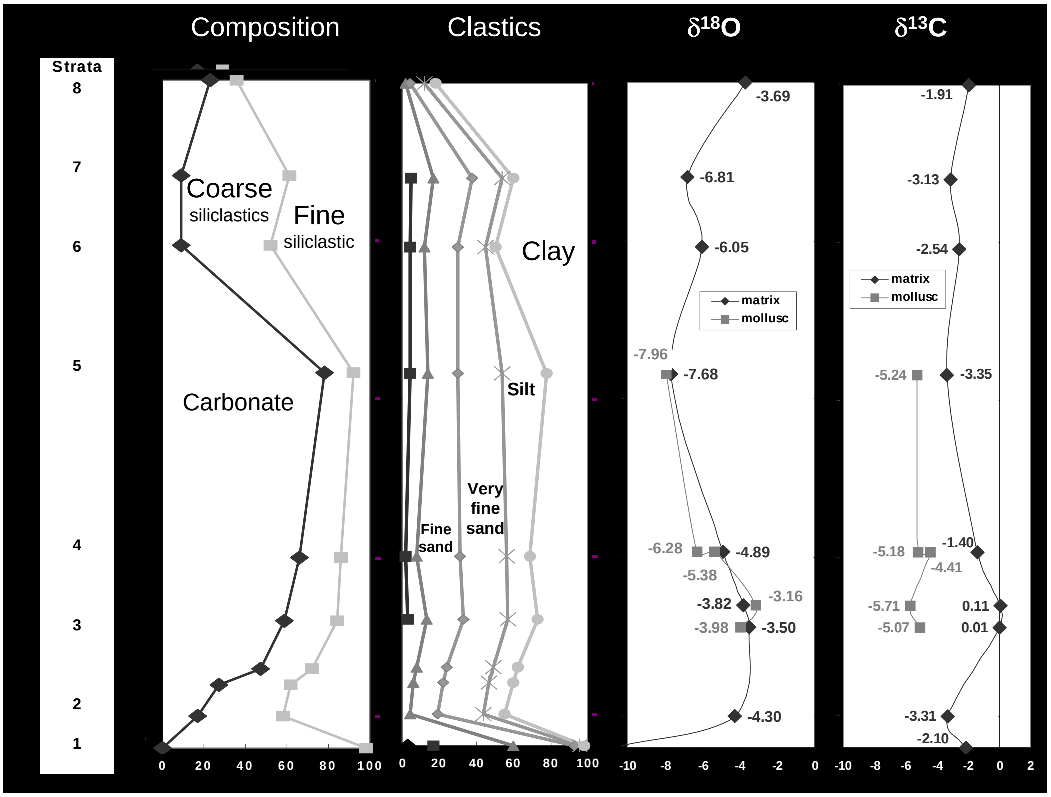

Figure 2. Sediment composition and oxygen and carbon stable isotopes Trench 3/86 Bir Tarfawi, Egypt. Stable isotope data are referenced to PDB (Hill 1993).

Results

Figure 2 shows sediment composition and stable isotope results for chemically precipitated carbonate sediment and gastropod shell. Carbonate contents ranged from 60% to 80% in strata 3 through 5. In the remainder of the sequence, carbonates were a minor component in comparison to siliclastics which constituted up to 90% of strata 6 and 7. There are higher amounts of clay in strata 2, 6, and 8. The proportion of clastics is relatively stable until stratum 8 where there is a significant decrease.

The $\delta^{18}O$ values are negative for both sediments and gastropod shells. Stratum 1 is the most negative at -10.7‰. In strata 3 through 5 there is a decrease in the $\delta^{18}O$ from -3.5‰ to -7.7‰ for sediments and a similar decrease for *Melanoides* shell values. Strata 6 and 7 values are in the -6‰ to -7‰ range, while stratum 8 has a value similar to stratum 3.

Sediment $\delta^{13}C$ values (Fig. 2) are negative with the exception of two values in stratum 3. Note that the gastropod values are more negative than sediment values with very little variation (from -4.4‰ to -5.7‰). A comparison of the $\delta^{13}C$ and $\delta^{18}O$ shows covariance with a correlation coefficient of 0.5 (Fig. 2).

Interpretation and Discussion

A model sedimentary sequence reflecting a wet-dry pluvial cycle at Bir Tarfawi would consist of a series of different lithofacies. These would include strata composed of alluvium (redeposited aeolian sands), high organics indicative of swamps and bogs, marls and fine-grained clastics from ponds and lakes, and sandy aeolian deposits (Hill 1993). Trenched areas sometimes contain evidence for more than one of these pluvial cycles and this is the case with Trench 3/86 at Bir Tarfawi. Strata 1, 6 and 8 contain increased clay concentrations and low carbonate that may indicate swamp/bog conditions. Pluvial or wet phase sections have higher amounts of carbonate along with low concentrations of clastics, as present in strata 3, 4 and 5. The fine grained clastics imply some impediment may have restricted the movement of clastic material, such as vegetative ground cover (McKenzie 1993). The lack of coarse clastics can also be the result of higher ground water levels, leading to a transgressive lake phase and the filling of the hydrologic basin. *Melanoides* were found exclusively in strata 3 through 5 corresponding to the pluvial/wet phase. Strata 1 though 5 constitute a single full pluvial phase while the remaining strata 6 and 8 are less extensive wet phases as reflected by the lower amounts of carbonates. The wet phases of strata 6 and 8 are separated by aeolian clastics in strata 7 indicative of drier conditions.

Oxygen stable isotopes of precipitation are useful as climate proxies since precipitation temperature and distance between precipitation source and deposition result in measurable ratio differences at the point of deposition (Dansgaard, 1964). Data from ocean and ice cores show that the ^{18}O of Earth's hydrologic cycle increases during glacial periods because ^{16}O is preferentially sequestered in glacial ice (Shackleton 2000). Conversely, during interglacial periods the ^{18}O of Earth's hydrologic cycle decreases as ^{16}O-enriched ice melts. The $\delta^{18}O$ in precipitation (such as rainfall over continents) is also sensitive to the distance from its (marine) source. Thus the farther from the initial source, the more enriched in ^{16}O the precipitation (Dansgaard, 1964). For Bir Tarfawi, this means precipitation originating in the Atlantic would be very isotopically light resulting in a strongly negative $\delta^{18}O$ value of around -10.9‰ (Smith 2004). In contrast, Indian Ocean sourced precipitation has much less distance to travel and has an estimated value of -2.0‰ (Smith 2004). Also deep aquifer ground water was measured with a value of -8.4‰ (McKenzie 1993), which might suggest a mixing from at least two isotopically distinct sources.

Stratum 1, the beginning of the wet phase, has carbonate $\delta^{18}O$ of -10.7‰ (Fig. 2) which is consistent with direct Atlantic rainfall (McKenzie 1993, Sultan 1997, Smith 2004). Higher in the sequence, strata 3 through 5 have significant carbonate deposition and $\delta^{18}O$ values range from -3.5‰ to -8.0‰. The $\delta^{18}O$ from mollusks in these strata are slightly more negative than the carbonate matrix . The differences between matrix and gastropod values may be the result of metabolic fractionation or differences in hydrologic conditions within the basin. For instance, mollusk growth in a hydrologic setting of slightly more negative $\delta^{18}O$ water than the overall conditions producing the chemically precipitated carbonate or seasonal differences in the deposition of sedimentary carbonate and mollusk growth may account for the different values. Areas of more negative $\delta^{18}O$ could also indicate the incursion of ground or spring water within limited regions of the main water body since a mixture of spring water at -8.4‰ would reduce the local water $\delta^{18}O$ compared to the rest of the lake. One mollusk sample from stratum 3 exhibits a more positive value than surrounding matrix, perhaps indicating a shallow pool or other area of higher evaporation existed during the lifespan of the gastropod. Since these mollusk values were from whole shell analysis they cannot be used to determine if spring versus evaporation or shallow conditions may have been seasonal. Zonal analysis along the gastropod shells may provide this type of information (Abell 1996, Smith 2004).

With the exception of stratum 1 and the final stratum 5, where $\delta^{18}O$ values are consistent with direct precipitation from a westerly source and aquifer water respectively, all other oxygen stable isotope values in this sequence are inconsistent with ground water and either easterly or westerly direct precipitation. Mid-range values between easterly and westerly precipitation may be the result of: seasonal precipitation from different regional sources; seasonal precipitation alternating with evaporation; or, evaporation from a larger body of water. Additional multipoint shell analysis could help to distinguish this type of alternating sourced precipitation/evaporation. Another possible hydrologic source for mid-range $\delta^{18}O$ values would be streams. Satellite radar images

(Ghoneim 2007) indicate significant stream drainage into the Bir Tarfawi region from the Gilf Kebir highlands (Fig. 1). An explanation for the $\delta^{18}O$ values at Trench 3/86 might be deposition of precipitation of water in these highlands to the west and subsequent fluvial drainage into the Bir Tarfawi area. This surface drainage flow model would account for the decrease in negativity of the sedimentary matrix and gastropod shell since evaporation during fluvial transport could be expected to result in the preferential loss of ^{16}O.

Carbon stable isotope data (Fig. 2) provides information about residence time of water and resulting organic productivity (negative values) and exchange with atmospheric CO_2 (positive values) (Leng 2004). All values at Trench 3/86 were negative, although mollusk shell samples were more negative than the matrix perhaps due to the ingestion of decaying organic material. Carbon and oxygen stable isotope covariance is an indicator of duration of water residence (Leng 2004 & McKenzie 1993) providing time for carbonate precipitation and biologic activity including organic material decay.

Figure 3 shows the most negative $\delta^{18}O$ data from significant wet phases at Kharga (Smith 2004), Trench 3/87 at Bir Tarfawi (McKenzie 1993) and BS-16 at Bir Sahara (McKenzie 1993), in Egypt, and other deposits in northern and central Sudan (Abell 1996). Sequences from each site have different dates: Kharga at 126,000 years ago (Smith 2004), northern and central Sudan at 9,000 years ago and 5,000 years ago (Abell 1996). Figure 3 also provides a comparison of $\delta^{18}O$ values for sediment and deep aquifer water from Egyptian locations (Smith 2004, McKenzie 1993). Values from

Kharga interpreted as indicating precipitation derived from the Atlantic and Indian Oceans can be used as a basis for comparison (Smith 2004).

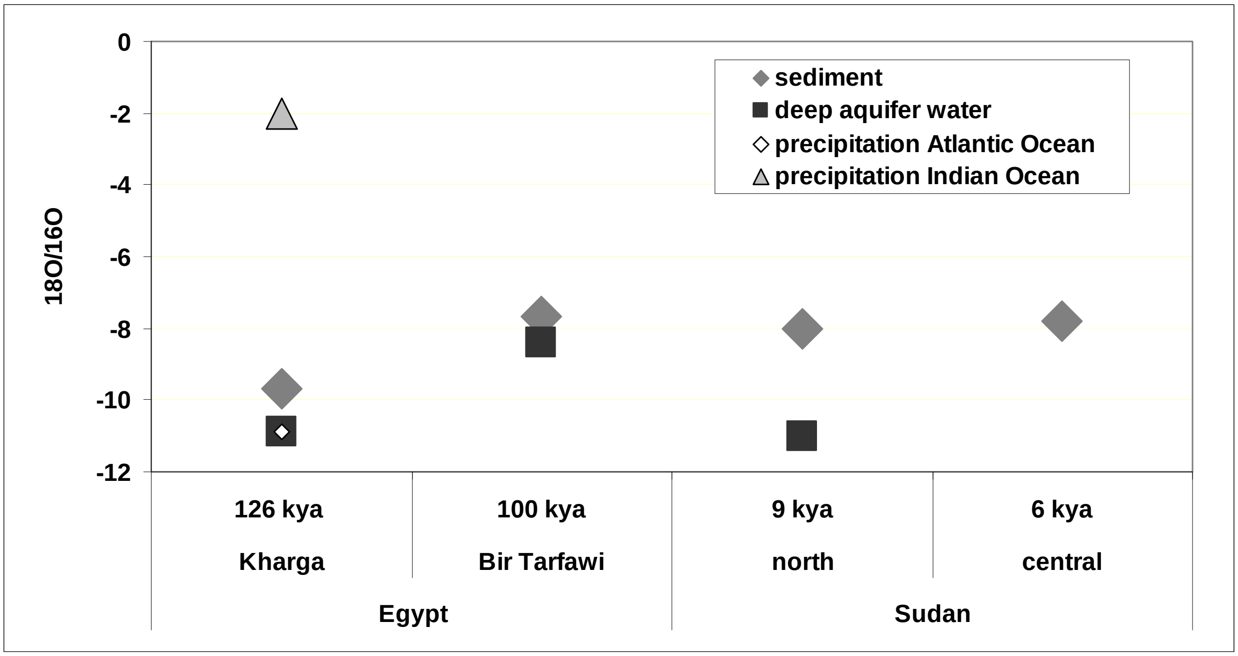

Figure 3. Average sediment (McKenzie 1993, Smith 2004, Abell 1996), deep aquifer (McKenzie 1993, Smith 2004) and modern Atlantic and Indian Ocean source precipitation (Smith 2004) values for stable oxygen isotope ratios.

Kharga, Bir Sahara, Bir Tarfawi, and the Sudan sites (Fig.1) are located at about the same longitude resulting in similar distances from both main precipitation sources, the Atlantic and the Indian Oceans. Since the $\delta^{18}O$ values for these localities have similar negative values (Fig. 3), we argue that the precipitation sources were the same in each case. The highly negative value for $\delta^{18}O$ indicates that precipitation derived from the Altantic Ocean played a role in these regions either as direct rainfall, runoff from highlands to the west or as a recharge source for groundwater.

Conclusions

Sediment sequences in Trench 3/86 at Bir Tarfawi indicate the presence of significant water in the now hyperarid desert of western Egypt. Stable isotope analysis of the sediments and gastropod, *Melanoides tuberculata*, provide an indicator of the source of the water. The values for all materials are less negative than expected for direct westerly precipitation except for the initial inundation sequence. The main pluvial event is likely the result of alternating westerly and easterly precipitation sources, or surface transport of westerly sourced precipitation from the highlands to the west of the Bir Tarfawi basin or recharge of ground water. Additional analysis of *Melanoides* shells would provide more information concerning seasonal variation.

When the sequences at Bir Tarfawi are compared with earlier, more northern samples from Kharga, and later, more southerly samples from northern and central Sudan, there appears to be a strong case for precipitation from the Atlantic either as direct precipitation, runoff or as ground water recharge. The discrete nature of these humid events, the proposed westerly precipitation source and multiple distribution methods constitute a simple model which is consistent with the arid-savanna model. Details of past climate change can be used to examine the range of natural variation and the response of the environment to changes, as well as, the biological and behavioral evolution of humans.

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