Climatic significance of Holocene beachrock sites along shorelines of the Red Sea: Discussion

Peter S. Mozley[1] and Stephen J. Burns[2]

The geologic record of climate change is currently a very active area of research. The results of such studies have the potential to greatly improve our understanding of the different factors that influence climate and, consequently, may help to guide policy initiatives regarding global warming. Given the importance of such studies, it is imperative that they be scientifically rigorous and thorough. Friedman (2005) falls short on both counts. In this article, Friedman attempted to use the oxygen isotopic composition of a series of ^{14}C-dated beachrock samples to infer past changes in temperature. On the basis of increasing $\delta^{18}O$ values for beachrock with decreasing age, he concluded that global temperature has decreased dramatically during much of the Holocene. The conclusions of the study regarding changing temperature are not supported by the data presented. Alternative hypotheses, not considered in the study, are far more likely explanations for the observed isotopic trend than decreasing temperature.

The principal problems with the article are that (1) critical assumptions are unsupported, and there is no discussion of alternative hypotheses; (2) there is no description of the petrographic characteristics of the samples; (3) no information on methodology is included; (4) the existing literature on beachrock, much directly relevant to the study, is completely ignored; and (5) the conclusions are contradicted by a large number of paleoclimate studies for the same period. These problems are discussed in detail below.

Friedman makes several important assumptions without adequately justifying them. The first assumption is that cements in the beachrock precipitated from unaltered seawater. He acknowledges that groundwater discharge, mixing with river water, and evaporation effects (particularly significant in the Gulf of Aqaba; Friedman, 1968) can alter the isotopic composition of local seawater, but proceeds to assume, for the purpose of the subsequent interpretation, that all the cements formed from water of 0‰ standard mean ocean water composition (the article says 0°C, but this must be a typographical error). This is a poor assumption. Beachrock forms in intertidal regions, an environment inherently prone to significant meteoric influence. Indeed, numerous studies show evidence for mixed fluid compositions in the zone of beachrock formation (e.g., Moore, 1973; Hanor, 1978). Furthermore, Holail et al. (2004) noted ^{18}O-depleted values for beachrock from the nearby Persian Gulf that are not compatible with an unaltered seawater source. Given the possibility of meteoric influence on water composition for beachrock, it is in some ways the worst sort of carbonate material to analyze in a study where it is necessary to assume a fixed isotopic composition for the water from which it precipitated.

Friedman tacitly assumes that the samples were not diagenetically altered and, thus, only record a pristine seawater isotopic signal. Although the study does not describe the mineralogy of the Gulf of Aqaba beachrock, Holail and Rashed (1992) and Holail et al. (2004) indicate that they are mainly cemented by aragonite and high-Mg calcite. These forms of calcium carbonate are extremely unstable and undergo a variety of alterations (e.g., dissolution, inversion to low-Mg calcite) during early diagenesis. For this reason, workers investigating secular variation in the isotopic composition of seawater traditionally examine only phases that originally precipitated as low-Mg calcite from seawater (e.g., Popp et al., 1986; Banner and Kaufman, 1994). With shoreline progradation or relative sea level drop, beachrock leaves the intertidal environment and can be

[1]Department of Earth and Environmental Sciences, New Mexico Tech, Socorro, New Mexico 87801; mozley@nmt.edu

[2]Department of Geosciences, University of Massachusetts Amhurst, Amhurst, Massachusetts 01003; sburns@geo.umass.edu

Manuscript received July 14, 2005; provisional acceptance August 19, 2005; revised manuscript received August 29, 2005; final acceptance December 13, 2005.
DOI:10.1306/12130505111

subjected to wholly meteoric diagenesis, including direct precipitation of meteoric cements (Beier, 1985; Amieux et al., 1989). Alteration of aragonite or high-Mg calcite in such an environment can occur very rapidly (Harris and Matthews, 1968; Steinen and Matthews, 1973) and would result in a resetting of the oxygen isotopic signature to one compatible with meteoric water. As meteoric water is depleted in ^{18}O relative to seawater, such alterations will result in a decrease in the $\delta^{18}O$ value of the beachrock with increasing alteration. It is particularly telling that the $\delta^{13}C$ values of the carbonate also decrease with increasing age, with $\delta^{13}C$ ranging from about 3.3 for the youngest sample to 1.1 for the oldest. This systematic change in $\delta^{13}C$ cannot be attributed to changing temperature. Using the fractionation relationship for calcite and bicarbonate of Deines et al. (1974), the temperature-induced variation in $\delta^{13}C$ should be 0.1‰, much less than the observed variation of 2.2‰. Thus, the variation in carbon isotopic composition must reflect some other variation, such as initial water chemistry or diagenetic history.

The article contains no mineralogical or petrographic information about the beachrock or how it was sampled. As noted above, the mineralogy of the samples has important implications for the likelihood of diagenetic alteration. The nature of sampling is also important. Are these isotopic values from whole rock samples, or was the cement phase sampled exclusively? If they are whole rock samples, the isotopic values represent a mixture of the isotopic value of cement and non-cement phases. Thus, some of the observed variation in sample composition could be a function of varying proportions of non-cement phases and have no relationship to water chemistry or temperature. Notably, Friedman (1968) demonstrated that the $\delta^{18}O$ values of carbonate sediments (non-beachrock) in the Gulf of Aqaba vary by more than 4‰, which is approximately the same range observed in the beachrock samples.

The article contains no information on analytical methods. Which acid fractionation factor was used? What are the analytical errors for the stable isotope work? It appears that only four samples were analyzed. How do we know that a single sample is representative of the entire beachrock layer? Could there not be significant isotopic heterogeneity as is frequently seen in carbonate cements (e.g., Bjørkum and Walderhaug, 1993; Klein et al., 1999)? The same questions apply to the ^{14}C dates. What material was dated? Are these whole rock samples, or were biogenic components selected?

In addition to the above problems, the conclusions of Friedman (2005) are at odds with an enormous and varied body of far more detailed studies concerning the Earth's Holocene climate. Records from high and low latitudes, from marine and terrestrial systems, records based on hundreds or even thousands of isotopic analyses, records of borehole temperatures, alkenones in marine sediments, measurements of trace-element contents of foraminifera, and pollen analysis of lacustrine sediments (and many others) amply demonstrate that temperature has not varied by more than about 2°C during the Holocene. To give one specific example near the study area, Arz et al. (2003) presented alkenone Uk'37 and foraminifera $\delta^{18}O$ data from a core in the northern Red Sea that show, at most, a 1°C increase in temperature from the early Holocene to the present, a far cry from the 16°C decrease in temperature Friedman infers. In fact, a 16°C temperature change is almost three times larger than the total temperature change experienced by the tropics and subtropics across the transition from the last glacial maximum to the Holocene (Stute et al., 1995; Stute and Talma, 1998; Weyhenmeyer et al., 2000).

In light of the discrepancy between Friedman's interpretation and the existing literature, alternative hypotheses should be considered to explain the Gulf of Aqaba beachrock data. For example, the data can easily be explained by variable initial water composition and meteoric diagenetic alteration. If the water composition of the intertidal setting changed through time because of variable influx of meteoric water, then the observed increase in $\delta^{18}O$ with decreasing age would suggest that meteoric influx was greater in the past and became less significant with time. One can speculate that such a trend might indicate decreasing rainfall (i.e., a drying trend) during this period of the Holocene. This hypothesis is supported by the work of Moustafa et al. (2000) and Arz et al. (2003), which indicates that early to middle Holocene precipitation and freshwater runoff in the region were much greater than they are today, and is consistent with the fact that the Gulf of Aqaba is currently arid. It also accounts for the variable $\delta^{13}C$ values (more ^{13}C-depleted values are typical of meteoric ground water). Another strong alternative hypothesis is that the trend is the product of diagenetic alteration of chemically unstable beachrock (see above). Subsequent to formation in the intertidal zone, the beachrock may have undergone diagenetic alteration in the presence of meteoric water, resulting in ^{18}O depletion. Older beachrock would experience greater alteration and, thus, have the most ^{18}O-depleted values.

In addition, in a prograding sequence such as this, the most landward (and oldest) beachrock would be most exposed to meteoric water and, again, have the most negative $\delta^{18}O$ values, as observed.

In summary, Friedman (2005) has numerous shortcomings, which render the article's conclusions regarding Holocene climate change highly questionable. Several alternative hypotheses do a considerably better job of explaining the data.

REFERENCES CITED

Amieux, P., P. Bernier, R. Dalongeville, and V. Medwecki, 1989, Cathodoluminescence of carbonate-cemented Holocene beachrock from the Togo coastline (west Africa): An approach to early diagenesis: Sedimentary Geology, v. 65, p. 261–272.

Arz, H. W., F. Lamy, J. Pätzold, P. J. Müller, and M. Prins, 2003, Mediterranean moisture source for an early-Holocene humid period in the northern Red Sea: Science, v. 300, p. 118–121.

Banner, J. L., and J. Kaufman, 1994, The isotopic record of ocean chemistry and diagenesis preserved in nonluminescent brachiopods from Mississippian carbonate rocks, Illinois and Missouri: Geological Society of America Bulletin, v. 106, p. 1074–1082.

Beier, J. A., 1985, Diagenesis of Quaternary Bahamian beachrock: Petrographic and isotopic evidence: Journal of Sedimentary Petrology, v. 55, p. 755–761.

Bjørkum, P. A., and O. Walderhaug, 1993, Isotopic composition of a calcite-cemented layer in the Lower Jurassic Bridport Sands, southern England: Implications for formation of laterally extensive calcite-cemented layers: Journal of Sedimentary Petrology, v. 63, p. 678–682.

Deines, P., D. Langmuir, and R. S. Harmon, 1974, Stable carbon isotope ratios and the existence of a gas phase in the evolution of carbonate ground waters: Geochimica et Cosmochimica Acta, v. 38, p. 1147–1164.

Friedman, G. M., 1968, Geology and geochemistry of reefs, carbonate sediments, and waters, Gulf of Aqaba (Elat), Red Sea: Journal of Sedimentary Petrology, v. 38, p. 895–919.

Friedman, G. M., 2005, Climatic significance of Holocene beachrock sites along shorelines of the Red Sea: AAPG Bulletin, v. 89, p. 849–852.

Hanor, J. S., 1978, Precipitation of beachrock cements: Mixing of marine and meteoric waters vs. CO_2-degassing: Journal of Sedimentary Petrology, v. 48, p. 489–501.

Harris, W. H., and R. K. Matthews, 1968, Subaerial diagenesis of carbonate sediments: Efficiency of the solution-reprecipitation process: Science, v. 160, p. 77–79.

Holail, H., and M. Rashed, 1992, Stable isotopic composition of carbonate-cemented Recent beachrock along the Mediterranean and the Red Sea coast of Egypt: Marine Geology, v. 106, p. 141–148.

Holail, H. M., M. N. Shaaban, and A. S. Mansour, 2004, Cementation of Holocene beachrock in the Aqaba and Arabian Gulfs: Comparative study: Carbonates and Evaporites, v. 19, p. 142–150.

Klein, J. S., P. S. Mozley, A. Campbell, and R. Cole, 1999, Spatial distribution of carbon and oxygen isotopes in laterally extensive carbonate-cemented layers: Implications for mode of growth and subsurface identification: Journal of Sedimentary Research, v. 69, p. 184–191.

Moore, C. H., 1973, Intertidal carbonate cementation, Grand Cayman, West Indies: Journal of Sedimentary Petrology, v. 43, p. 591–602.

Moustafa, Y. A., J. Pätzold, Y. Loya, and G. Wefer, 2000, Mid-Holocene stable isotope record of corals from the northern Red Sea: International Journal of Earth Sciences, v. 88, p. 742–751.

Popp, B. N., T. F. Anderson, and P. A. Sandberg, 1986, Brachiopods as indicators of original isotopic compositions in some Paleozoic limestones: Geological Society of America Bulletin, v. 97, p. 1262–1269.

Steinen, R. P., and R. K. Matthews, 1973, Phreatic vs. vadose diagenesis: Stratigraphy and mineralogy of a cored borehole on Barbados, W.I.: Journal of Sedimentary Petrology, v. 43, p. 1012–1020.

Strasser, A., E. Davaud, and Y. Jedoui, 1989, Carbonate cements in Holocene beachrock: Example from Bahiret et Biban, southeastern Tunisia: Sedimentary Geology, v. 62, p. 89–100.

Stute, M., and S. Talma, 1998, Glacial temperatures and moisture transport regimes reconstructed from noble gases and O-18, Stampriet aquifer, Namibia: Isotope Techniques in the Study of Environmental Change, Proceedings of an International Conference in Vienna, Austria, April 14–18, 1999, International Atomic Energy Agency, SM-349/53, p. 307–318.

Stute, M., M. Forster, H. Frischkorn, A. Serejo, J. F. Clark, P. Schlosser, W. S. Broecker, and G. Bonani, 1995, Cooling of tropical Brazil (5°C) during the last glacial maximum: Science, v. 269, p. 379–383.

Weyhenmeyer, C. E., S. J. Burns, H. N. Waber, W. Aeschbach-Hertig, R. Kipfer, R. Beyerle, H. Loosli, and A. Matter, 2000, Cool glacial temperatures recorded by noble gases in a groundwater study from northern Oman: Science, v. 287, p. 842–845.