Holocene Variability in the Indian Ocean Monsoon: A Stalagmite-Based, High-Resolution Oxygen Isotope Record from Southern Oman

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The Indian Ocean monsoon is one of the major weather systems on Earth, affecting the economies, agriculture and fisheries of one of the most densely populated areas of the world. To date, analyses of how and why the monsoon varies through time have mainly been restricted to studies of meteorological records, which extend back perhaps 150 yr, or to investigations of lacustrine and marine sediments, which have a low time-resolution (typically greater than 100 years) and large age uncertainties. However, one sensitive monitor of monsoon variation having considerably finer temporal resolution is the oxygen isotope composition of stalagmites, such as those from Qunf Cave (17°10’ N, 54°18’ E; 650 m a.s.l.) in

**Fig. 1:** a Modern summer circulation pattern over Southern Oman. The red star shows the location of Qunf Cave. The black dashed line shows the position of the temperature inversion and the red dashed line the location of the ITCZ. b Schematic figure of summer circulation pattern at around 7 kyr BP.
Science Highlights

The δ18O profile (Fig. 2) of stalagmite Q5 shows three distinct features. First, a rapid increase in monsoon precipitation between 10.3 and 9.8 kyr BP is indicated by a sharp decrease in δ18O from -0.8‰ to -2‰. Second, an interval of generally high monsoon precipitation lasting from 9.8 to 5.5 kyr BP with δ18O values averaging -2‰. Third, a long-term gradual decrease in monsoon precipitation starting at around 7 kyr BP is indicated by a slow shift in average δ18O from -2.2‰ at 7 kyr BP to ~0.9‰ (slightly more negative than δ18O values of modern stalagmites) at 2.7 kyr BP. Furthermore, the early to mid-Holocene period of generally high monsoon precipitation was apparently interrupted by three distinct intervals of reduced precipitation, occurring at around 9.2-9.1, 8.5-8.1 and 6.3-6.2 kyr BP.

What circulation pattern controlled the amount of monsoon precipitation in southern Oman over the course of the Holocene? The Q5 δ18O record is consistent with the scenario depicted in Figure 1b, showing postulated northward displacement of the ITCZ around 7 kyr BP. Such a shift of the ITCZ into the Arabian Peninsula, as inferred from lake sediments (McClellan, 1976) and stalagmites (Burns et al., 2001; Neff et al., 2001), would lift the height of the temperature inversion, leading to stronger convective cloud development and higher monsoonal rainfall over southern Oman. Moreover, the fine structure in the Q5 δ18O record suggests that characteristic variations also occur at much higher frequencies, afforded the opportunity to gain insight into monsoon circulation dynamics and variability under a range of boundary conditions, and at time-scales relevant to humans.

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