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Oxygen isotope study of Holocene soil carbonates of the Afar Depression and Ethiopian Western Plateau, Ethiopia

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The early Holocene African Humid Period (AHP) has been the major climatic change to affect Africa since the Last Glacial Maximum (18 kya). Defining episodes of the AHP include not only the "greening of the Sahara", but also the dramatic increase in the level of the lakes of the Afar and the Main Ethiopian Rift (MER). Ethiopia in general and the broadly depressed Afar region in particular, are meteorologically sensitive areas likely to preserve a history of such humid periods going back into the Pleistocene and Pliocene. This sensitivity to climate change is because western Ethiopia is where the summer Atlantic Ocean-derived African Monsoon and the Indian Ocean-derived Indian Monsoon converge at the Inter-Ocean Front (IOC). Good proxies for the behavior of this composite Monsoon and the position of the IOC serve as an indicator of how forcing factors affect the summertime Southwest Monsoon, the earth's largest composite monsoon system. Here, we use the oxygen isotope compositions of ^{14}C-dated Holocene carbonate nodules from soil B-horizons of both the Ethiopian Western Plateau (EWP) and the Afar. Ethiopia receives most of its rain during the summer monsoon, with the Plateau receiving about 1200 mm/yr compared to only about 400 mm/yr in the western Afar. There is an extended, highly evaporative winter-time dry season in both regions. Today the western Afar is a hot and dry sub-desert steppe, but the paleo-ecology of the Pliocene Hadar Fm. indicates this was not always so.

The oxygen isotope composition of ^{14}C dated Holocene carbonate nodules from the western Afar shows an average δ^{18}O value of -6.1$\pm$0.4 permil; these nodules have a

^{14}C age of 6.2 to 9.8 ka. In contrast, carbonates from the EWP margin have slightly higher δ^{18}O values; those nodules dated 6.8 to 8.9 ka have an average value of -3.3$\pm$0.8 permil; where as nodules dated as 2.5 to 4.1 ka have an average value of -2.1$\pm$0.4 permil. The δ^{18}O of carbonates from the Afar indicate soil water of about -4.0 permil for the AHP-dated nodules at a mean annual temperature of 25ºC, where as the carbonates from the EWP dated 6.8 to 8.9 ka could have formed from soil water with a δ^{18}O value of -3.5 permil; and those dated 2.5 to 4.1 ka form from soil water having a δ^{18}O of -2.3 permil with the assumption of the soil temperature on the plateau being about 15ºC.

In the early Holocene, ($\sim$10 kya) the Saharan & Tibetan atmospheric Lows were both strengthened due to the Milankovitch cycle, which increased the summer insolation of the northern hemisphere's low latitudes about 8% compared to today. As a result strong atmospheric Lows were developed over the Sahara and the Tibetan Plateau. At the AHP and continuously during pre-Ice Age Pliocene time the Tibetan Plateau was ice free in the summer, allowing full absorption of more solar insolation and strengthening of the Tibetan Low. In contrast to the present, this strengthened Low pulled the Indian and African Monsoons eastward bringing the Inter Oceanic Confluence (IOC) over the western plateau and perhaps the Afar, and causing more of the moist Atlantic-derived air masses to reach the western Afar during the AHP. The enhanced Atlantic-derived Afar rain in the early Holocene brought an increased summertime rainfall and cooler temperatures and less evaporative conditions compared to the hotter, drier Afar of today.

Our study along with those of others indicates that the climate history of the Ethiopian Monsoon has been dramatic, going from the persistently pluvial Pliocene to the briefly pluvial AHP and the mostly arid present. Further documentation of the δ^{18}O of modern waters and soil carbonates throughout Ethiopia in concert with paleosol studies of the many Pleistocene stratigraphic sequences in the Afar will play an important role in illuminating the linkage between the African and Indian Monsoons.