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A multi-proxy stalagmite record from northwestern Namibia of regional drying with increasing global-scale warmth over the last 47 kyr: The interplay of a globally shifting ITCZ with regional currents, winds, and rainfall

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ABSTRACT

Stalagmite Orum-1 from a cave near Orumana in northwestern Namibia provides a multi-proxy record of regional drying with increasing global-scale warmth over the last 47 kyr, in a region with few long well-dated location-specific paleoclimate records. Data from Stalagmite Orum-1 include carbon and oxygen stable isotope ratios, proportions of aragonite and calcite, pronouncedly differing petrographic fabrics, positions of layer-bounding surfaces, variation in layer-specific width, and changes in layer thickness, all of which combine to support change from wetter to drier conditions. Combined with fourteen U-Th ages, they suggest that climate was wetter in northwestern Namibia during globally cold MIS 3 than it is today, and with more grass than is present today. The climate at Orumana became drier during the deglacial transition after the Last Glacial Maximum, but carbon isotope data indicate that C_4 grasses persisted. In the Holocene, even greater aridity led to a reduction in grass cover and to the present C_3-dominated vegetation. Hiatuses in Stalagmite Orum-1 suggest even drier conditions during the Bølling-Allerød and during the early Holocene thermal maximum.

Wetter conditions at Orumana during glacial times may have resulted from movement of the Intertropical Convergence Zone southward, in a shift that was significant west of longitude 13°E but perhaps less significant east of that line. It may have been accompanied by a lesser southward shift of the Angola-Benguela Front at sea and/or the Inter-Ocean Convergence Zone on land, leading to increased rainfall in northern Namibia (but perhaps not farther south). Extrapolation from the present to warmer conditions in the next century would suggest that further drying in northern Namibia and southern Angola may occur.

1. Introduction

Three factors combine to make studies of past climate in southern Africa important both to human survival and to science. First, the dry climate of the region continually imperils agriculture and animal husbandry, which are critical to human sustenance across the region, and the scarcity of water limits economic development (e.g., Lange, 1997). Secondly, the sharp contrasts in rainfall across the region, both with regard to amount and seasonality, mean that shifts in climatic belts can have great impact on climate at any one location. Consequently, southern Africa is ranked as the region of the world likely to be most impacted by desertification in the next two decades (DARA and the Climate Vulnerability Forum, 2010). Thirdly, past climate change in southern Africa, and especially southwestern Africa, is the subject of explicit disputes about change in the region over the past tens of thousands of years, and most intensely with regard to the Last Glacial Maximum (e.g., Heine et al., 2014, p. 174). Conflicting results from different locations make any synthesis problematical, and there is commonly disagreement between ages generated by radiocarbon dating of organic matter, ages generated by radiocarbon dating of carbonate, and ages from sediments dated using optically-stimulated luminescence (OSL) (Brook et al., 2011; Stone et al., 2010). Furthermore, most interpretations of the region's past climate rely on proxy information from marine sediment cores that receive signals from environmentally diverse landscapes upwind and upstream from the cores themselves

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(e.g., Stuut et al., 2002; Dupont and Wyputta, 2003) (see also Lim et al., 2016, pp. 198 and 203). These factors combine to emphasize the importance of precisely-dated single-point records of past climate from the continent itself.

In light of the above considerations, this paper presents a paleoclimate record from an unusual stalagmite from a cave near Orumana in northwestern Namibia. Stalagmite Orum-1 provides a discontinuous but useful record of climate change over the last 47 kyr, with precise and reliable ages generated by U-Th dating. The stalagmite's characteristics vary greatly in response to what appears to have been considerable change in wetness of climate. Furthermore, the stalagmite's record of drying and aridification from the globally cooler Late Pleistocene environment to warmer Holocene conditions suggests that even drier conditions could develop if climate continues to warm over the next century.

2. Setting

2.1. The landscape and environment of northwestern Namibia

Orumana Cave is near Orumana Mission Station (18° 15.42′ S; 13° 53.68′ E), which is about 25 km SSE from Opuwo or Opuvo, in the northern part of the Kunene Region of northwestern Namibia, at an elevation of about 1450 masl. It is roughly 170 km inland from the Atlantic coast, in the rugged Joubert Mountains that constitute the Kaokoveld Karst terrain (Irish et al., 2001). Orumana is in the upper catchment of the Hoarusib River, which drains toward the Atlantic Ocean and which, although ephemeral, "reaches the sea almost every year" (Srivastava et al., 2005).

Orumana lies in the austral tropical summer rainfall zone (Fig. 1) and has an average annual rainfall of about 300 mm/yr falling mainly from October to April. The quantity of summer rain diminishes progressively toward the south until it transitions into a winter rainfall zone much farther south. Rainfall increases towards the north to where precipitation during the equinoxes dominates at the equator (Transect 1–9 of Fig. 1).

Orumana lies just south of the latitude of the Atlantic Ocean's Angola-Benguela Front (ABF), where the cold Benguela Coastal Current coming from the south meets the warm Angola Current coming from the north (Fig. 2). The 21 °C isotherm of sea-surface temperature, midway between the 15 °C temperature of the Benguela Coastal Current and 27 °C of the Angola Current, moves north and south from 13°S in austral winter to 17°S in austral summer (Fig. 4.1.1 of Veitch, 2002). When the Angola Current breaches the Front and moves farther south, evaporation from its surface causes more rain to fall on the lands to the east (Rouault et al., 2003). The general position of the Front at sea matches that of the northern margin of the Namib Desert on land (Fig. 2).

Orumana is also located just south of a convergence of air masses, the Inter-Ocean Convergence Zone (IOCZ), which has also been called the "Congo Air Boundary" or "Zaire Air Boundary" (Fig. 2). The IOCZ is the convergence of air masses from the Indian Ocean and tropical Atlantic Ocean (van Heerden and Taljaard, 1998). During summer, and thus during the wet season, the IOCZ runs almost west-east just north of the border between Namibia and Angola, with winds off the nearby tropical Atlantic Ocean on the north (Angolan) side and winds from the distant Indian Ocean on the south (Namibian) side. Offshore, and to the south of the IOCZ, is a nearby semi-permanent coastal high-pressure cell over the cold Benguela upwelling areas along the Namibian coast. The IOCZ coincides with a steep gradient in annual rainfall, with more rainfall to the north associated with tropical Atlantic moisture as opposed to drier air to the south, and this southward migration of the IOCZ brings more rain to northern Namibia (Tyson, 1986; Mattes and Mason, 1998).

Within the austral summer rainfall zone, rainfall increases inland from the coast to Orumana and onward to southeastern Angola (Transect A-C of Fig. 1), leading to climatic zones that change over

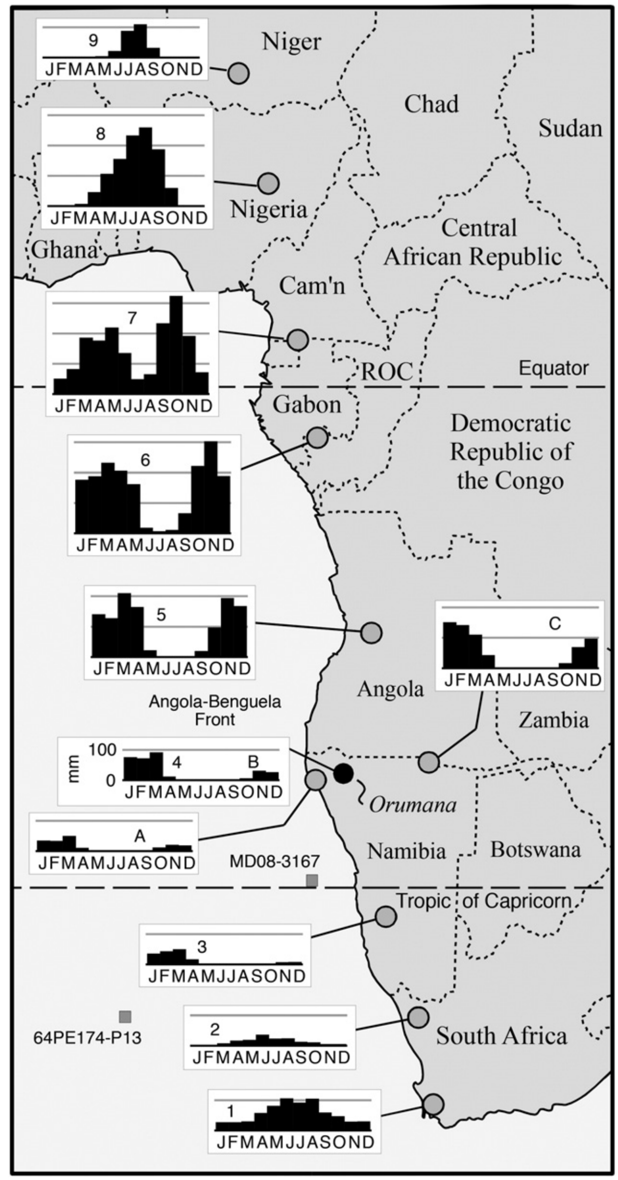

Fig. 1. Map showing the location of Orumana in northwestern Namibia (black-filled circle). Histograms show average monthly rainfall at locations marked with circles; the vertical scale for all is the same as that shown for Orumana. Histograms 1 to 9 provide a south-to-north transect; Histograms A to C provide a transect from the Atlantic coast inland as discussed in Section 2.1. From south to north, climate zones proceed from austral winter rainfall to austral summer rainfall to equatorial equinoctial rainfall to boreal summer rainfall. Histograms of atmospheric precipitation covering the period from 1961 to 1990 are from the gridded data of New et al. (1999) as presented at the World Bank's Climate Change Knowledge Portal at sdwebx.worldbank.org/climateportal/index.cfm?page=global_map. Squares mark locations of marine cores discussed in Sections 5.1 and 5.2.

small distances near Orumana. In the updated Köppen-Geiger climate classification of Kottek et al. (2006), Orumana lies at the boundary of BSk (cold arid steppe, because of the prevailing influence of the coastal high-pressure inversion) and Cwb (warm temperate climate with dry winter and warm summer) (Fig. 3). Only 50 km to the northeast is Cwa (warm temperate climate with dry winter and hot summer) and only about 70 km to the southeast is BSh (hot arid steppe) (Fig. 3). Rainfall increases abruptly to the northeast, doubling from 300 mm annually to 600 mm over a distance of only 210 km (Fig. 2).

This progression of increasing rainfall and wetter climate from west-southwest to east-northeast through Orumana largely accounts for the transition from the hyperarid Namib Desert along the coast to a complex semidesert/savanna mosaic at Orumana as part of the Kaokoveld