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Stable isotopic composition of fossil mammal teeth and environmental change in southwestern South Africa during the Pliocene and Pleistocene

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ABSTRACT

The past 5 million years mark a global change from the warmer, more stable climate of the Pliocene to the initiation of glacial–interglacial cycles during the Pleistocene. Marine core sediment records located off the coast of southwestern Africa indicate aridification and intensified upwelling in the Benguela Current over the Pliocene and Pleistocene. However, few terrestrial records document environmental change in southwestern Africa over this time interval. Here we synthesize new and published carbon and oxygen isotope data of the teeth from large mammals (>6 kg) at Langebaanweg (~5 million years ago, Ma), Elandsfontein (1.0–0.6 Ma), and Hoedjiespunt (0.35–0.20 Ma), to evaluate environmental change in southwestern Africa between the Pliocene and Pleistocene. The majority of browsing and grazing herbivores from these sites yield enamel $\delta^{13}C$ values within the range expected for animals with a pure C_3 diet, however some taxa have enamel $\delta^{13}C$ values that suggest the presence of small amounts C_4 grasses at times during the Pleistocene. Considering that significant amounts of C_4 grasses require a warm growing season, these results indicate that the winter rainfall zone, characteristic of the region today, could have been in place for the past 5 million years. The average $\delta^{18}O$ value of the herbivore teeth increases ~4.4‰ between Langebaanweg and Elandsfontein for all taxa except suids. This increase may solely be a function of a change in hydrology between the fluvial system at Langebaanweg and the spring-fed environments at Elandsfontein, or a combination of factors that include depositional context, regional circulation and global climate. However, an increase in regional aridity or global cooling between the early Pliocene and mid-Pleistocene cannot explain the entire increase in enamel $\delta^{18}O$ values. Spring-fed environments like those at Elandsfontein may have provided critical resources for mammalian fauna in the mid-Pleistocene within an increasingly arid southwestern Africa ecosystem.

1. Introduction

The Pliocene-Pleistocene climatic transition is marked by a global shift from relatively warm and stable climate conditions in the Pliocene to colder and more variable conditions in the Pleistocene (Imbrie et al., 1992; Zachos et al., 2001). Over the course of this transition African landscapes are considered to have become more arid (e.g., deMenocal, 2004; Dupont et al., 2013). In southwestern Africa, intensified upwelling of cold bottom waters in the Benguela Current System has been linked with increased regional aridity and the onset, expansion and speciation of the endemic Cape flora since the Miocene (Marlow et al., 2000; Dupont et al., 2005; Dupont, 2011; Etourneau et al., 2009). While marine-based records indicate major changes in vegetation and climate in southern Africa, terrestrial-based records could provide a more local perspective of the hydrological setting, vegetation and climate of southwestern South Africa since the Pliocene; currently there are few archives of environmental change in this region during the last 5 million years (myr) (Roberts et al., 2011; Eze and Meadows, 2014).

Sedimentary strata from known Pliocene and Pleistocene fossil sites in southwestern South Africa have the potential to provide direct evidence for the local environmental response to climate change (Table 1). Sedimentary records indicate a transition from fluvial to

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Table 1
A summary of the terrestrial records of climate, vegetation and depositional environment from southwestern South Africa.

Age	Locality	Depositional environment	Substrate	Vegetation	Climate	Data sets	References
late Pleistocene (0.35–0.25 Ma)	Hoedjiespunt	Coastal	Sands	Shrubs and widespread grasslands	Glacial	Taxonomy[a] Stable isotopes[a]	Klein, 1983; Stynder, 1997; Hare and Sealy, 2013
mid-Pleistocene (~1.0–0.6 Ma)	Elandsfontein	Spring-fed and eolian	Eolian and marine sands, carbonate-leached sediments,pedogenicaly modified sands	Trees, shrubs, and seasonal grasses	Glacial and/or Interglacial	Taxonomy[a] Stable isotopes[a] Microwear[a] Sedimentology	Butzer, 1973; Klein, 1978; Luyt et al., 2000; Stynder, 2009; Braun et al., 2013
Pliocene (~5 Ma)	Langebaanweg	Fluvial and deltaic	Floodplain, marsh, and river channel deposits	Trees, shrubs, and seasonal grasses	Warm and wet	Taxonomy[a] Stable isotopes[a] Mesowear[a] Microwear[a] Sedimentology	Franz-Odendaal et al., 2002; Roberts et al., 2011; Stynder, 2011

[a] Datasets that apply to teeth.

spring-fed and eolian deposition in southwestern South Africa (Roberts et al., 2011; Eze and Meadows, 2014). Data from pre-Holocene mammalian fossils suggest the presence of significant amounts of surface water and a vegetated landscape composed of a fynbos shrubland and grassland mosaic, interspersed with trees and broad-leafed bush, which contrasts the dry, eolian landscapes that are prevalent in southwestern South Africa today (e.g., Luyt et al., 2000; Franz-Odendaal et al., 2002; Stynder, 2009, 2011; Braun et al., 2013).

Here we use the carbon and oxygen isotopic composition of fossil herbivore tooth enamel obtained from paleontological and archeological sites in southwestern South Africa to investigate trends in regional climate and hydrology, vegetation and animal diet between the Pliocene and Pleistocene. Together with marine archives off the coast of southern Africa that record broader, regional-scale climate and vegetation, we use these terrestrial-based data to improve upon the understanding of how environments in southwestern South Africa responded to global climatic changes during the Pliocene and Pleistocene.

2. Background

2.1. South African climate and vegetation

South Africa is predominantly semiarid with three distinct rainfall zones and corresponding vegetation zones (Fig. 1; Cowling and Lombard, 2002). The winter rainfall zone of western South Africa encompasses an area of ~200-km^2 where ~65% of mean annual precipitation (MAP) occurs between April and September. The summer rainfall zone is affected by the warm Agulhas Current that flows along the eastern coast of South Africa. At the intersection of these two major meteorological zones, situated along the South Coast of South Africa, there is a region that receives rainfall during both the summer and winter. This annual rainfall zone spans from the southern coast of the Eastern Cape Province of South Africa into the Western Cape Province (e.g., Chase and Meadows, 2007).

Rainfall zones in South Africa partition zones of vegetation, which can be seen through the spatial distribution of the frequency of the

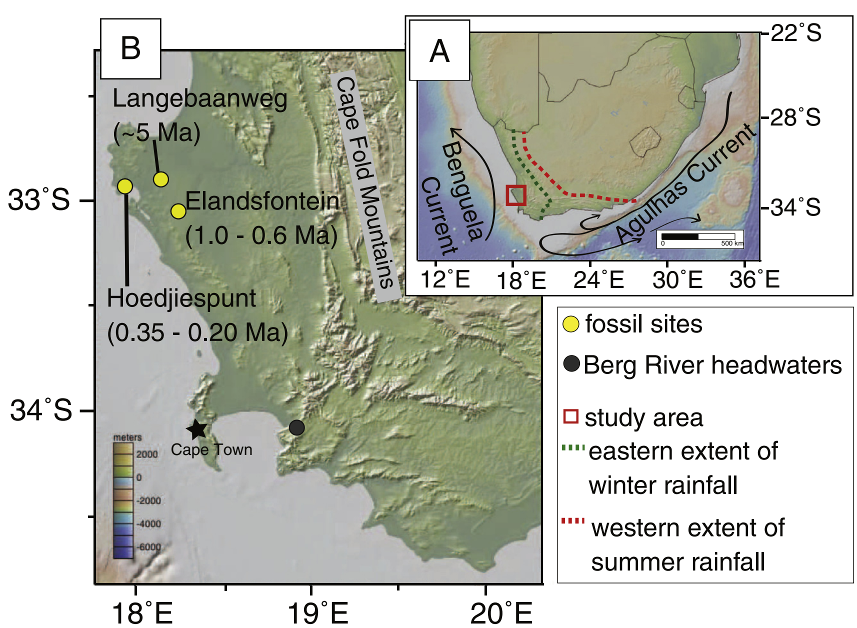

Fig. 1. Marine currents, climate zones and southwestern South African fossil sites discussed in text. A) A map of southern Africa indicating the location of the study area with a schematic of the present-day extent of the winter and summer rainfall zones, the Benguela and Agulhas Currents and present-day political boundaries (Chase and Meadows, 2007). B) A map of the study area denoting the fossil localities discussed in text (yellow circles), Cape Town, the Cape Fold Mountains and the headwaters of the Berg River. The color base maps indicating topography were generated using Global Multi-Resolution Topography from http://www.geomapapp.org (Ryan et al., 2009).

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