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Miocene–Pliocene vegetation change in south-western Africa (ODP Site 1081, offshore Namibia)

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A B S T R A C T

Aridification is an important component of Late Neogene climate change in south-western Africa probably caused by modifications in the atmospheric circulation in relation to the initiation and intensification of the Benguela Upwelling System due to globally steepening of the meridional pressure gradient. Intensification of the meridional pressure gradient influenced the climate intensively which had then an impact on the vegetation. However, vegetation changes of south-western Africa from the Miocene to Pliocene have not yet been reported and only indirectly investigated by sedimentological data. Here, we present a pollen record of marine ODP Site 1081 retrieved 160 km offshore Namibia covering the time between 9 and 2.7 Ma. Using an endmember unmixing model we distinguished three vegetation phases as follows: a relative wet phase, during the Tortonian, showing higher representations of Cyperaceae, a transition phase during the Messinian, when especially grasses expanded, and a dry one covering the Pliocene with a strong representation of desert and semi-desert plants. The three phases indicate ongoing aridification probably caused by intensified meridional pressure gradients. Additionally, aquatic vegetation indicators appear in our pollen record from around 5 Ma on, which we attribute to a relocation of the lower course of the Cunene River to its modern outlet in the Atlantic Ocean. Redirection of the Cunene River toward the Atlantic would have deprived the palaeolake Cunene of an important source of fresh-water ultimately resulting in desiccation of the lake and the formation of the Etosha Pan.

1. Introduction

The vegetation distribution in south-western Africa is linked to climate, in particular to rainfall, which depends on the atmospheric circulation. Major features of the atmospheric circulation in south-western Africa are the Congo-Air boundary (CAB) (for January/July boundaries see Fig. 1) and the strong south-east trade winds blowing along the coast (Nicholson, 2000; Gasse et al., 2008) that are responsible for the very dry environment of the Namib Desert in combination with the cold sea surface temperatures of the Benguela Upwelling System (Petterson and Stramma, 1991). Initiation of upwelling, implying the increase of the trade winds, is dated in the late Miocene between 10 and 15 Ma (Siesser, 1980; Diester-Haass et al., 1990; Heinrich et al., 2011; Rommerskirchen et al., 2011). Increase of the trade winds is attributed to a steepening of the meridional pressure gradient in association with global cooling during the late Neogene, when the climate shifted from the warm and humid conditions of the mid-Miocene to drier and cooler ones of the Plio/Pleistocene. Driven by the growth of the ice sheets on East Antarctica (Wright et al., 1992; Zachos et al., 2001; Billups and Schrag, 2002), the southern polar front moved northwards strengthening the meridional pressure gradient and the pressure systems on the Southern Hemisphere (Flower and Kennett, 1994; Zachos et al., 2001). In detail, the South Atlantic Anticyclone got stronger and so did the trade winds along the Namibian coast hindering air masses to penetrate into the continent. Additionally the trade winds may have been intensified by the uplift of southern and eastern Africa as indicated by modelling studies (Jung et al., 2014).

The late Neogene aridification started in the Namib region (17–16 Ma) from which it spread over the African continent, reaching the Sahara at 7–6 Ma and East Africa at around 3 Ma (Senut et al., 2009). In spite of the importance of the region, changes of climate and vegetation in south-western Africa are not well known. Van Zinderen Bakker (1984) describes one palynological sample of late Miocene age which might have been originated from a dry, very open vegetation in Namibia coeval with palms growing in the Cape Region (Van Zinderen Bakker, 1984). Most reconstructions of south-western African climate are based on sedimentological data. They are usually limited to the development of the Namib Desert where fossil dunes (aeolianites) including ratite egg shells and other macro and microfaunal fossils were dated between 16 and 17 Ma (Pickford et al., 1995; Senut et al., 1998, 2009). Fossil fauna sites in the Namibian Sperrgebiet (Southwest Namibia) indicate a mid-Miocene vegetation of woodland or open forest in an area that is extremely arid today (Senut et al., 2009). Stable carbon ($\delta^{13}C$) and stable oxygen ($\delta^{18}O$) isotope compositions of fossil ratite eggshells

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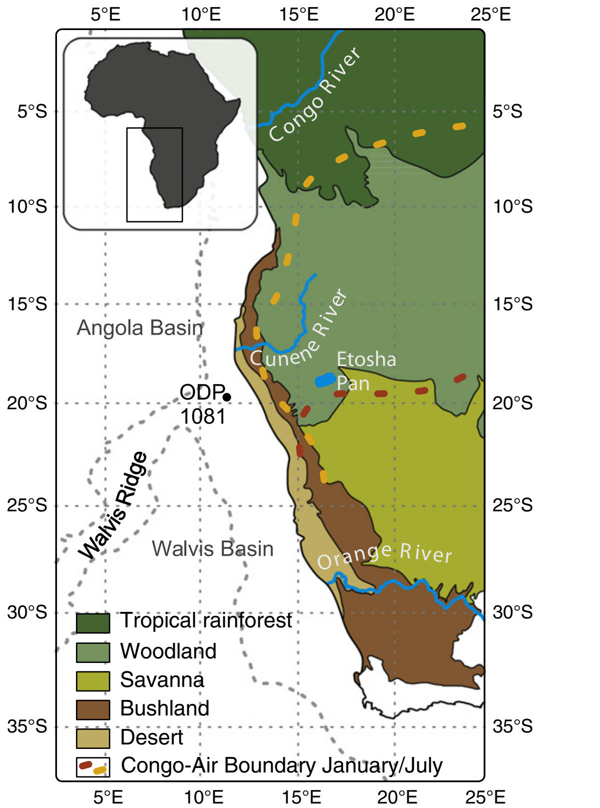

Fig. 1. Map of south-western Africa with simplified phytogeographical units (see also Fig. 2). Average position of the Congo-Air Boundary after Leroux (1983) in January (red dashes) and July (orange dashes). The 4000 m bathymetry is denoted with grey dashes.

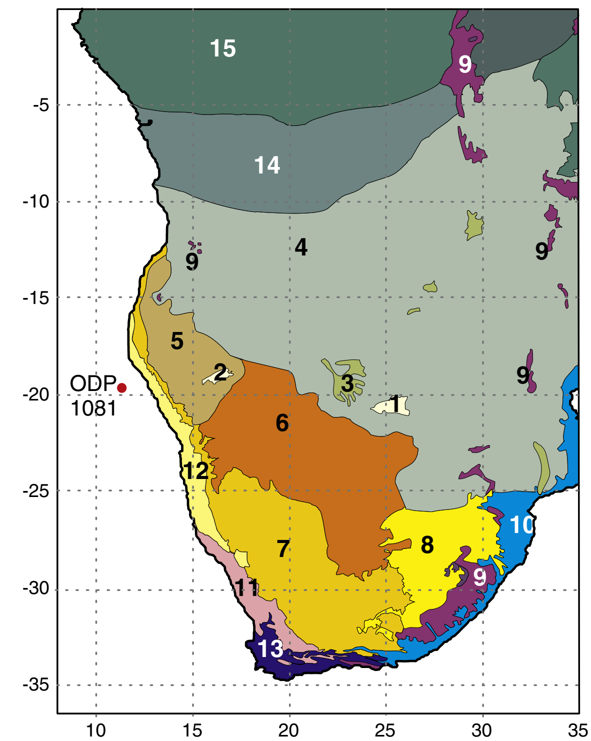

Fig. 2. 1, Makgadikgadi saltpans; 2, Etosha saltpan; 3, Okavango grassland; 4, Zambezian woodland and forest; 5, Mopane-rich Zambezian woodland in northern Namibia and southern Angola; 6, Kalahari savannah; 7, Nama Karoo; 8, Highveld grassland; 9, Afromontane forest; 10, East and Southeast African forests; 11, Succulent Karoo; 12, Namib Desert; 13, Cape Fynbos; 14, Zambezian–Congolian vegetation transition; 15, Congolian rainforest.
Vegetation map of southern Africa adapted after White (1983) and Cowling et al. (1998).

showed that the vegetation in Namibia changed and a C_4 grassy vegetation established through the late Miocene to Pliocene underlining aridification (Ségalen et al., 2006; Dupont et al., 2013). In the greater Cape Flora Region (southernmost Namibia and west South Africa) more summer-drought and dry-adapted vegetation types gradually replaced tropical species during the late Miocene (Dupont et al., 2011). Wetter conditions for the late Miocene compared to those of the Pliocene are also suggested by modelling studies (Francois et al., 2006).

So far, a detailed vegetation reconstruction of the Late Miocene during the aridification in south-western Africa is missing. Here, we reconstruct the Miocene to Pliocene vegetation of northern Namibia based on the pollen and spore content of marine sediments from Ocean Drilling Program (ODP) Site 1081 Hole A, retrieved offshore of Namibia. We discuss the vegetation change in south-western Africa during the late Neogene and link these to the global cooling and aridification.

2. Modern regional climate and south-western African vegetation

Modern south-western Africa is climatologically controlled by aridity. There are two major gradients of decreasing annual rainfall, one directed north to south and the other east to west (White, 1983; Gasse et al., 2008). Along the coast precipitation is lowest and seldom reaches 100 mm per year causing the aridity of the Namib Desert. The Namib (Fig. 2) is characterised by extremely sparse and contracted vegetation, which consists of isolated plants. In some areas vegetation is completely absent (White, 1983). Inland parts of south-western Africa receive between 250 and 500 mm rainfall per year. Here, wooded grassland of the Kalahari savanna occurs (Fig. 2). Between the Kalahari and the Namib lies the Karoo shrubland (Nama Karoo) receiving precipitation between 100 and 250 mm. Typically, the landscape in the Nama Karoo is dotted with shrubs or small bushy trees of families such as Compositae (or Asteraceae), Fabaceae and Acanthaceae (White, 1983; Cowling et al., 1998). Most of the precipitation in south-western Africa falls in austral summer, whereas in the South African Cape Region including Fynbos and Succulent Karoo the rain falls mainly during austral winter (Tyson and Preston-Whyte, 2000). The winter rain area in Namibia (northern part of the Succulent Karoo) is very rich in endemic species, many of them belonging to Aizoaceae, Geraniaceae, and other families (Cowling et al., 1998). In northern Namibia the Zambezian woodland (Fig. 2) grows in a climate with very pronounced seasonality and precipitation ranging from 500 to more than 1000 mm per year (White, 1983). The woodland is defined as an open stand of trees forming a canopy of at least 40%. Between these wooded areas the ground is covered by grasses, herbs or shrubs. The vegetation is linked to rainfall which itself is linked to the atmospheric circulation. In the north humidity derives mainly from the Atlantic, whereas further southwards in the summer rain areas of south-western Africa including the Kalahari savanna, air masses derived from the Indian Ocean transported by the Easterlies are the major source of precipitation (Gimeno et al., 2010). Along the coast the strong south easterly trade winds hinder air masses to penetrate over the continent (Gasse et al., 2008). Where Easterlies and Atlantic derived air masses meet the CAB (Fig. 1) is formed which is considered a southern branch of the Inter Tropical Convergence Zone (ITCZ). During austral summers the CAB is located around 20–15°S whereas during the winter it is located at 9–6°S (Leroux, 1983). The position of the CAB is determined by the global thermal gradient and the strength and position of the Hadley cell (Nicholson, 2000). Therefore it is very likely that the position of the CAB changed in the geological past.