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Miocene climate and vegetation changes in the Cape Peninsula, South Africa: Evidence from biogeochemistry and palynology

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Organic material from the Noordhoek area on the western margin of the Cape Peninsula, South Africa, was obtained from a ~50 m-long drill-core dominated by fluvio-lacustrine siliciclastic sediments. The aim of this study is to constrain fluctuations in climate and the decline of tropical vegetation elements along the southwestern coast and the Cape Peninsula of South Africa, during the Late Cenozoic phase, when the Benguela upwelling system was established. The approach was to combine palynological, biogeochemical (tetraether lipids) and stable isotope (C, N) studies of the organic-bearing record from the Noordhoek area on the western margin of the Cape Peninsula. Bulk C and N isotope data of sediment organic matter, point to a predominantly C_3 higher plant source vegetation. Mean annual air temperature (MAT) from the analyses of tetraether lipids (MBT′–CBT index) was compared with palynomorphs from partly unpublished data of a previously drilled core adjacent to the study site. The palynomorphs are of subtropical affinities, and suggest that an open riparian forest would have existed in the early to middle Miocene of the southwestern coast of South Africa. Together these data sources allow vegetation and climate reconstructions of subtropical conditions during the early to middle Miocene, which comprised fluctuating open riparian forest and swamp vegetation. Temperatures rose in the middle Miocene and were higher than those of the present day.

1. Introduction

Globally, the Late Palaeogene and Neogene included periods of generally increased but fluctuating temperatures and precipitation (Spicer, 1993; Tong et al., 2009). Historically, the Late Cenozoic of southern Africa is characterised by aridification and cooling with the loss of tropical-affinity vegetation along the south-western coastal area (Tankard and Rogers, 1978; Coetzee, 1986). Late Cenozoic organic carbon-rich sedimentary deposits are a scarcity in the terrestrial realm in southern Africa. This is generally attributed to poor preservation as a result of aerobic carbon degradation (Killops and Killops, 2005; Carr et al., 2010b), largely due to aridity created by the establishment of the Benguela Current from the late Oligocene.

In contrast with the mentioned scarcity of Late Cenozoic organic carbon-rich deposits in South Africa, the Cape Peninsula of South Africa contains a notable exception. Located in Noordhoek, a c. 50 m-thick deposit of fluvio-lacustrine siliciclastic sediments containing discrete organic-rich layers (peats) of Late Cenozoic age is located stratigraphically below present day sea-level. In 2009, a borehole (NH1) was drilled within a few metre proximity to a previously obtained drill-core (S20) of which Coetzee (1978a, 1978b, 1980) studied the palynology. On the basis of pollen zones (Zones M–Li) from S20, she gave the first evidence of a transition in the Western Cape from sub-tropical woodland to fynbos vegetation during the Late Cenozoic. Her reconstruction was based on fluctuations of a selection of key pollen taxa, which were correlated with late Palaeogene and Neogene marine isotope data (Shackleton and Kennett 1975; Coetzee, 1980). Since Coetzee (1978a, 1978b) did not provide details about the microfloral assemblages, the depths of the zones or their geological associations, we contribute new information for the reconstruction climatic conditions and the vegetation under which the Noordhoek deposits were formed, by combining biogeochemical and palynological data of NH1 and comparing them to Coetzee's (1978a, 1978b) S20 pollen sequence.

Clues about the origin, climatic fluctuations and evolution of the modern environment in the southern and south-western coastal

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regions of Africa are revealed in a patchy record of poorly dated organic deposits that contain fossil pollen. This record starts somewhere near the Cretaceous–Tertiary boundary, with the crater lake deposits of the Arnot pipe (Scholtz, 1985), and is followed by coastal swamp deposits at Koingnaas (de Villiers and Cadman, 1997). Younger organic deposits from the later Palaeogene and Neogene are represented by several sequences from the Knysna and south-western Cape areas (e.g. Theirgart et al., 1963; Coetzee, 1978a, 1978b, 1980; Coetzee and Rogers, 1982; Thwaites and Jacobs, 1989; Scott, 1995; Carr et al., 2010a, 2010b, 2010c; Sciscio et al., 2013, and others). These records show climate change and associated vegetation development from forests, indicating more tropical conditions, through a series of steps associated with global late Cenozoic climatic evolution to the Quaternary pattern (Schalke, 1973; Neumann et al., 2011), which is currently represented by the Fynbos, Forest, Karoo and Nama Karoo Biomes of the region (Mucina and Rutherford 2006). Details of this environmental history are discussed in a recent review by Neumann and Bamford (2015) outlining vegetation evolution in the context of global climatic change and the geological evolution of the region.

The present study continues this line of research on deposits from Noordhoek, a site which was first reported by the late J. A. Coetzee (1978a, b; 1980, etc.), and which is one of the key areas where late Cenozoic environmental evolution of the region can be traced. Since Coetzee's palynological work dealt mainly with the biogeographic aspects of selected extinct elements in the vegetation and has never been completed, several questions remain, e.g. in connection with dating and the local and regional vegetation and climatic evolution. Some of these questions were addressed in a recent study by Roberts et al. (2013) and the present study is the next step in on-going research on the environmental history in the region. We investigate the potentially highly informative deposits at Noordhoek by comparing Coetzee's palynological data from core S20 and biogeochemical records from the adjacent NH1 core. Palynomorphs were also recorded by the first author from core NH1 but the detailed results are not reported here. Based on the proximity of the cores, and the stratigraphic development of the Elandsfontyn Formation, correlation according to depth between the NH1 biogeochemical data and Coetzee's unpublished pollen counts was possible. The current data aids in linking results of the biogeochemical study with the previous meticulously detailed work of Coetzee (1978a, 1978b).

The availability of organic material, including pollen, in the Noordhoek sequence may be accounted for, not only by climatic conditions conducive to preservation, but also by deposition during times of lowered sea-level (Du Toit, 1933; Partridge and Maud, 1987; Roberts et al., 2008; Moore et al., 2009). Along the south-west coast of South Africa this is augmented by the fact that the coastline, on which the Noordhoek (NH1) site lies, is a stable, passive intraplate margin which has not been influenced by volcanic activity during the Cenozoic (Roberts et al., 2008; Carr et al., 2010c). However, there is debate on the role of Neogene uplift in this region (Partridge and Maud, 1987, 2000; Burke and Gunnell, 2008; Neumann and Bamford, 2015). Furthermore, low rates of denudation (estimated at less than 2 m/Ma) and uplift have also been established over this period during which peat accumulation is likely to have occurred (Roberts et al., 2011).

Several studies have used molecular biomarkers to reconstruct the continental mean annual temperatures (MATs) and pH of Miocene sites from the Northern Hemisphere (Donders et al., 2009; Peterse et al., 2009a; Peterse et al., 2010). The application of molecular-level methods on organic-rich sediments from a South African site, in conjunction with palynological and stable isotope studies, is a multi-proxy approach which has hitherto been vary scarcely implemented in southern Africa and has great potential to constrain local and regional evolution of palaeoclimate (Sciscio et al., 2013). Our results are compared with those from other Southern Hemisphere continents to trace Gondwanan links and to broaden and integrate palaeoclimate trends. Comparisons with case studies from the Northern Hemisphere are made in order to elucidate the dynamic nature of late Tertiary climate globally. Knowledge of the Southern African and Southern Hemisphere Miocene climate, in which the configuration of the continents and the flora and fauna were similar to modern times, may assist in making informed opinions and models as to present climate change.

Furthermore, palaeoecological and palaeoclimate studies in Southern Africa for the Tertiary are often fragmentary and disconnected due to the geographical and temporal separated sites (Chase and Meadows, 2007). More recent studies (Carr et al., 2006a, 2010a, 2010b, 2010c) have focused on sites along the south-Eastern Cape coast near Still Bay (Rietvlei) and within the Knysna area (e.g. the Makhulu lignite). Regional comparisons are greatly hindered by the lack of precise dating methods for geographically separated sites that have relied heavily on biostratigraphic age estimates between sites separated by long distances (Coetzee et al., 1983). OSL dating has been attempted on the Knysna Formation coversands (Carr et al., 2010a) in order to compliment palynological estimates. The Knysna Formation lignites and their palynofloras show several similarities within the Elandsfontyn Formation of the Western Cape (Carr et al., 2010a). It is likely that these two Formations represent two geographical separated but diachronous units.

2. Setting

2.1. Present climate regime

Currently, the south-western tip of South Africa is characterised by a Mediterranean climate with dry summers and wet winters, which was established by the late-Miocene (Goldblatt and Manning, 2002; Cowling et al., 2009). The convergence of the cold Benguela and warm Agulhas currents – of the Atlantic and Indian Oceans respectively – near the Cape Peninsula, exert a powerful influence on climate (Fig.1; Camberlin et al., 2001; Chase and Meadows, 2007). The circumpolar westerly system (westerlies) generate cold fronts from which much of the West Coast's rainfall stems (Carr et al., 2006a; Carr et al., 2006b; Cowling et al., 2009). The boundaries of the regional temperate and sub-tropical atmospheric circulation system positions are marked by the winter rainfall zone (WRZ) of the Western Cape coast (Carr et al., 2006a). These systems respond to climatic perturbations on variable timescales, and are thought to be driven largely by orbital forcing (Carr et al., 2006a). Annual rainfall in the Western Cape varies between 300 and 2000 mm p.a. (c. 851 mm at Noordhoek), with the waning effects of the polar frontal systems decreasing northward (Cowling et al., 2009). The monthly range of temperature is 15–24 °C in summer and winter temperatures ranging between 9 °C and 21 °C, with mean annual temperatures of ~17 °C for Cape Town (Adelana et al., 2010; Hanekom et al., 2009).

2.2. Regional geology

The study site lies on the south-western coast of South Africa (Fig. 1) within the Noordhoek Basin. This basin extends parallel to the coastline over a distance of 3.6 km and inland for up to 3.1 km, with the deepest portion in the south reaching ~60 m below sea level (Fig. 2). It is likely that the basin is fault-controlled and a well-developed shear zone is indicated in the north with a down-throw to the south (Rogers, 1980; Theron et al., 1992). Neoproterozoic granites of the Cape Granite Suite underlie the basin, and are thought to have been eroded by riverine activity during the Oligocene drawdown in sea level (Rogers, 1980; Roberts et al., 2013). The basin is surrounded by highlands comprising folded Palaeozoic quartzose sediments of the Table Mountain Group.

Sediments of the Noordhoek Basin fall within the Sandveld Group stratigraphy. The Sandveld group consists of the fluvial (terrestrial) Elandsfontyn Formation, marine/estuarine Varswater Formation and the aeolian Prospect Hill, Langebaan, Springfontein, and Witzand Formations (Roberts, 2006a,b,c,d and e). Focus is placed on the