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Palynological evidence for Holocene climatic and oceanographic changes off western South Africa

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ABSTRACT

Atmospheric and oceanographic interactions between the Atlantic and Indian Oceans influence upwelling in the southern Benguela upwelling system. In order to obtain a better knowledge of paleoceanographic and paleoenvironmental changes in the southern Benguela region during the Holocene, 12 marine surface sediment samples and one gravity core GeoB8331-4 from the Namaqualand mudbelt off the west coast of South Africa have been studied for organic-walled dinoflagellate cysts in high temporal resolution. The results are compared with pollen and geochemical records from the same samples. Our study emphasizes significantly distinct histories in upwelling intensity as well as the influence of fluvial input during the Holocene. Three main phases were identified for the Holocene. High percentages of cysts produced by autotrophic taxa like *Operculodinium centrocarpum* and *Spiniferites* spp. indicate warmer and stratified conditions during the early Holocene (9900-8400 cal. yr BP), suggesting reduced upwelling likely due to a northward shift of the southern westerlies. In contrast, the middle Holocene (8400-3100 cal. yr BP) is characterized by a strong increase in heterotrophic taxa in particular *Lejeunecysta paratenella* and *Echinidinium* spp. at the expense of autotrophic taxa. This indicates cool and nutrient-rich waters with active upwelling probably caused by a southward shift of the southern westerlies. During the late Holocene (3100 cal. yr BP to modern), *Brigantedinium* spp. and other abundant taxa interpreted to indicate fluvial nutrient input such as cyst of *Protoperidinium americanum* and *Lejeunecysta oliva* imply strong river discharge with high nutrient supply between 3100 and 640 cal. yr BP.

1. Introduction

The Benguela upwelling system along the west coast of southern Africa is one of four major upwelling systems in the world characterized by the transport of cold and nutrient-rich waters to the surface ocean (Nelson and Hutchings, 1983). The oceanography in the southern Benguela region extending along the west coast of South Africa from the Orange River mouth in the north to the south of the Cape of Good Hope is mainly controlled by the interaction of atmospheric and oceanic circulation (upwelling of sub-surface waters, entrainment of cold Antarctic waters, southeast trade winds, southern westerlies, and influences by the Agulhas Current). Water masses of the Benguela upwelling region are mainly from three different sources (Gordon et al., 1992): (1) cold and nutrient-rich South Atlantic central waters; (2) cold waters of the Antarctic Circumpolar Current; (3) warm and saline Indian Ocean waters derived from the Agulhas Current. The Agulhas leakage plays a crucial role in the global oceanic circulation by supplying warm and salty waters from Indian Ocean to the Atlantic Ocean along the southern tip of Africa, which may affect the intensity of the Atlantic meridional overturning circulation (Peeters et al., 2004; Weijer et al., 1999).

Investigations of the paleoceanographic conditions in this region are therefore crucial to provide information on past variability and mechanisms of the climate systems in South Africa. The variability of Agulhas leakage has been studied on different timescales in the Cape Basin and the Agulhas Bank (Caley et al., 2014; Dyez et al., 2014; Esper et al., 2004; Franzese et al., 2006; Petrick et al., 2015; Rau et al., 2002; Winter and Martin, 1990), however, the extent to which the Agulhas leakage did affect the southern

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Benguela region during the Holocene remains unclear. We focus in this study on the Namaqualand mudbelt off the west coast of South Africa which is located in the southern Benguela upwelling system (Fig. 1). Information about the paleoceanographic conditions will allow to better understand the Holocene climate variability in South Africa and to investigate the signature of the Agulhas leakage to the southern Benguela upwelling system during the Holocene.

Unlike calcareous or siliceous biological remains which can be affected by dissolution, organic-walled dinoflagellate cysts ("dinocysts" here after) are composed of resistant organic matter and are generally well preserved in most sediments (Dale, 1996). Additionally, dinocyst species have different environmental preferences and their distribution in surface sediments has been shown to correlate well with sea surface conditions such as temperature, salinity, nutrient levels and productivity (e.g., Dale, 1996; Dale et al., 2002; de Vernal et al., 1994; Marret and Zonneveld, 2003; Zonneveld et al., 2013). Dinocysts, therefore, have become a valuable tool to reconstruct paleoenvironmental and paleoceanographic conditions especially in neritic (shallow marine environment on the continental shelf) highly productive environments (e.g., de Vernal et al., 1997; Pospelova et al., 2006, 2015; Verleye and Louwye, 2010). The modern dinocyst distribution off the west coast of South Africa has been studied by several authors (Davey, 1971; Davey and Rogers, 1975; Holzwarth et al., 2007; Wall et al., 1977; Zonneveld et al., 2001a). However, paleostudies of dinocysts in the southern Benguela upwelling region are mostly limited to Miocene, Pliocene and Pleistocene times (Esper et al., 2004; Petrick et al., 2015; Udeze and Oboh-Ikuenobe, 2005) and Holocene dinocyst records are scarce, even in the entire Benguela upwelling region. The early study of Davey and Rogers (1975) involved the dinocyst distribution of two traverses perpendicular to the west coast of southern Africa (the northern Sylvia Hill traverse and southern Orange River traverse). The dinocyst distribution results, in particular those of the latter traverse, are relevant to our study. The dinocyst assemblages of the Orange River traverse are dominated by *Spiniferites ramosus* and *Operculodinium centrocarpum* showing a trend of more *O. centrocarpum* and less *S. ramosus* further offshore. Davey and Rogers concluded in combination with the more detailed study of Davey (1971) that *O. centrocarpum* characterizes sediments beneath warm water associated with the westward-flowing warm water of the Agulhas rings, while *S. ramosus* is dominant in sediments beneath regions of upwelled cold and nutrient-rich waters. Dinocyst assemblages on the coast of western South Africa (Wall et al., 1977) contain high amounts of *Protoperidinium* species (called "*Peridinium*" by Wall et al.) inshore but are dominated by *O. centrocarpum* and *Spiniferites bulloideus* on the outer shelf and slope. Based on the surface sediments off the western coast of southern Africa, Zonneveld et al. (2001a) and Holzwarth et al. (2007) obtained datasets about the spatial distribution of dinocysts and their relationship with the local environmental conditions, which can be used for paleoceanographic reconstructions. At longer time scales, Esper et al. (2004) reconstructed variations in the Late Quaternary Agulhas retroflection on the basis of records of organic-walled and calcareous-walled dinoflagellate cysts, pollen and spores offshore of southwestern South Africa reflecting dynamic environmental changes driven by orbital forcing. Petrick et al. (2015) using a multiproxy approach demonstrated a complex interaction between influences of the Benguela upwelling and the Agulhas leakage. They also showed that there was no period in the late Pleistocene in which Agulhas leakage had been completely cut off.

Paleoceanographic reconstructions using dinocysts are often

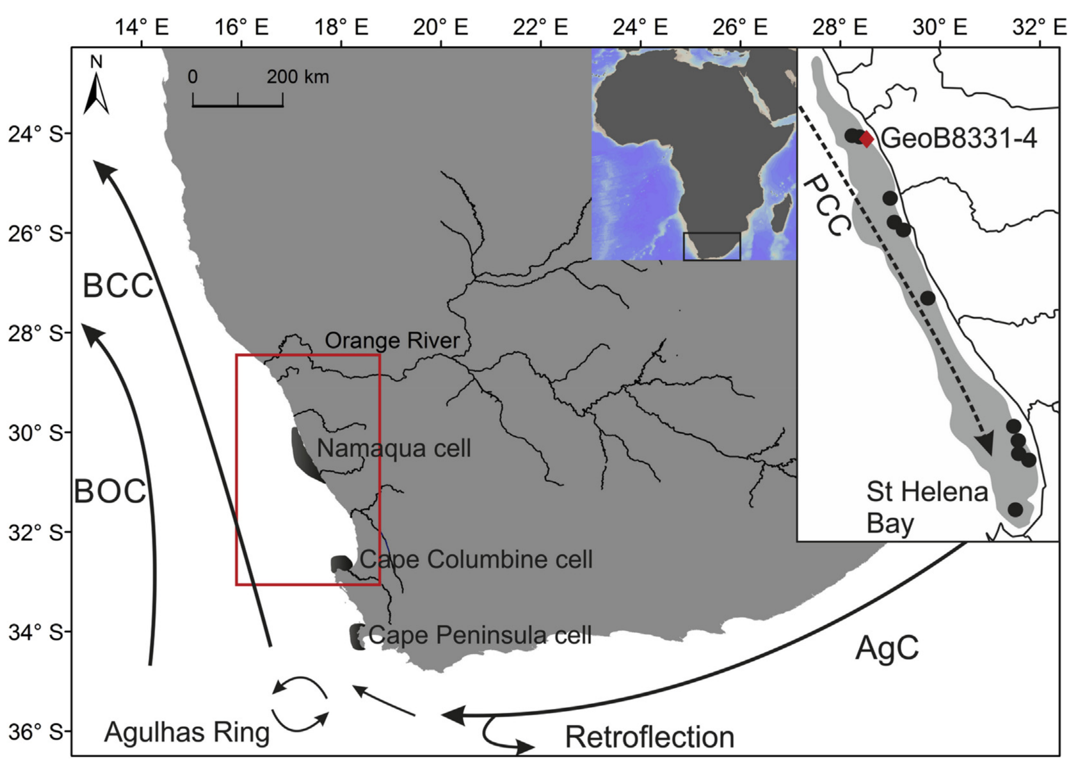

Fig. 1. Map of the research area showing the locations of 12 multicores (black dots) and the gravity core GeoB8331-4 (red diamond) retrieved from the Namaqualand mudbelt (grey shaded area in the upper right corner) off the west coast of South Africa. The arrows indicate the major oceanic surface current systems: BCC (Benguela Coast Current), BOC (Benguela Ocean Current), AgC (Agulhas Current), PCC (poleward countercurrent). The locations of three main upwelling cells in the southern Benguela region are denoted with black shading: Namaqua cell, Cape Columbine cell and Cape Peninsula cell. [1.5-column]. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)