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Sea level and climate change at the southern Cape coast, South Africa, during the past 4.2 kyr

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ABSTRACT

South African coastal lake sediments provide an excellent opportunity to investigate environmental changes such as sea level and climate variability during the Holocene period. In this study we present a sediment record from the coastal lake Groenvlei located in the southern Cape region which is part of South Africa's year-round rainfall zone. In order to improve the understanding of palaeoenvironmental changes in this region, we provide a high-resolution multi-proxy data set derived from geochemical, mineralogical, isotopic and granulometric analyses. The age-depth model is based on ^{14}C and ^{210}Pb dating and reveals a basal age of 4210 $^{+200}/_{-120}$ cal BP. Differences in the mineralogical composition of deposited carbonates reflect changes in the past lake water chemistry, probably caused by variations in both sea level and climate. Compared to the present, mostly drier conditions and a greater marine influence due to a higher sea level are inferred for the period between 4210 and 2710 cal BP. However, the record also indicates the occurrence of short humid phases during this time, which were probably associated with heavy rainfall events. A transition layer was deposited between 2710 and 1210 cal BP, probably as a result of reworking of sediment. During this time, the lake passed through a major change finally turning into a freshwater system from at least 1210 cal BP until the present. Our data indicate that the marine influence on the lake decreased due to a lower sea level and climate became generally more humid after 1210 cal BP probably resulting in a greater lake-internal and -external bioproductivity. Based on a comparison with other palaeoenvironmental studies from South Africa, our record suggests a prevailing winter rainfall seasonality at the southern Cape coast between 4210 and 2710 cal BP and a stronger influence of summer rainfall from 1210 cal BP onwards.

1. Introduction

Southern Africa occupies a key position in the southern hemisphere regarding the comprehension of past dynamics and interactions of various atmospheric and oceanic circulation systems (Chase and Meadows, 2007). The subcontinent is subjected to three different rainfall zones (Fig. 1a): the summer rainfall zone (SRZ) covering the main part of the interior is affected by migrations of the Intertropical Convergence Zone and hence the tropical easterlies. Circumpolar westerlies are the main source of precipitation within the temperate winter rainfall zone (WRZ) along the west coast. The year-round rainfall zone (YRZ) represents a transition area between the SRZ and WRZ receiving both summer and winter rainfall (Chase and Meadows, 2007; Stager et al., 2013). Moreover, the climate of southern Africa is influenced by surrounding oceans, the Atlantic Ocean in the west with its cold Benguela Current as well as the warm Agulhas Current located in the Indian Ocean south and east of the mainland (Fig. 1a) (Cohen and Tyson, 1995; Scott and Lee-Thorp, 2004). Although these major climatic driving factors are known, their past dynamics and interactions are not yet fully understood (Stager et al., 2013).

In South Africa the occurrence of basins containing Holocene deposits, such as lakes or wetlands, is relatively rare and the quality of existing geoarchives, particularly in terms of their preservation, is often reduced due to the mostly arid and seasonal climate causing desiccation and/or erosion of these deposits (Scott and Lee-Thorp, 2004; Chase and Meadows, 2007). Therefore, Holocene records suitable for palaeoenvironmental reconstructions are scarce and existing records are often of low temporal resolution (Scott and Lee-Thorp, 2004). Several Holocene records from the YRZ either provide only coarse resolution

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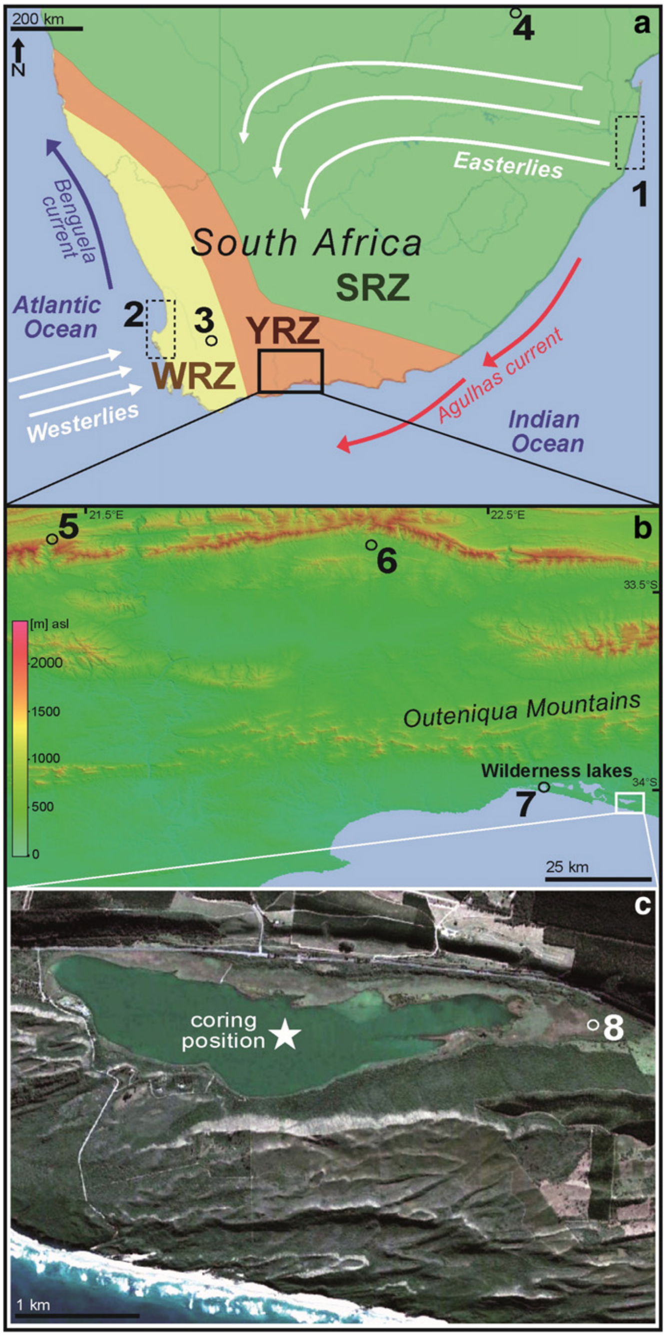

Fig. 1. Study area: a) The three rainfall zones of southern Africa (WRZ: winter rainfall zone, SRZ: summer rainfall zone, YRZ: year-round rainfall zone) as well as important oceanic and atmospheric circulation systems. b) Location of the Wilderness lakes at the southern Cape coast. c) The coring position of this study within the central part of Groenvlei (map source: Google Earth). Additionally shown are locations of several studies mentioned in the text: sea level reconstructions of 1) Neumann et al. (2010); Ramsay (1995); 2) Carr et al. (2015); Compton (2001); Baxter and Meadows (1999), and Miller et al. (1995); 3) Hyrax midden record from Katbakkies Pass (Chase et al., 2015); 4) Cold Air Cave stalagmite record (Holmgren et al., 2003); 5) Hyrax midden records from Seweweekspoort (Chase et al., 2013); 6) Cango caves stalagmite record (Talma and Vogel, 1992); 7) Eilandvlei lake sediments (Kirsten, 2014; Reinwarth et al., 2013); 8) Coring location of previous studies on the fen east of Groenvlei (Martin, 1959, 1968).

reconstructions (Carr et al., 2006), are intermittent (Cohen and Tyson, 1995), or their age models are based on very few control points (Martin, 1959, 1968; Scholtz, 1986). Further Holocene records for the YRZ are available from the Cape Fold Mountains: A $\delta^{18}O$ and $\delta^{13}C$ stalagmite record from the Cango Caves (Fig. 1b) has been interpreted as evidence for variations in temperature and rainfall seasonality leading to changes in the vegetation composition (Talma and Vogel, 1992); two rock hyrax midden records from Seweweekspoort (Fig. 1b) provide information about Holocene hydroclimatic variability and vegetation change in the area (Chase et al., 2013).

Moreover, several studies on archives from the coastal realm are available which provide insights into sea level variations during the Holocene (Miller et al., 1995; Ramsay, 1995; Baxter and Meadows, 1999; Compton, 2001; Neumann et al., 2010; Carr et al., 2015). However, these sea level reconstructions reveal discrepancies in terms of the exact timing of transgressional and regressional periods. The reconstructed timing of the Holocene sea level highstand (up to 3.5 m above the present sea level) ranges in these studies between ~7000 and 3500 cal BP. After which, all records show oscillations of a few metres above and below the present sea level before reaching modern conditions.

In the present study, we focus on a lacustrine archive from the YRZ represented by the sediments from the coastal lake Groenvlei located in the Wilderness embayment (Fig. 1). Previous studies on sediments from the Wilderness area already indicated that these archives are suitable for reconstructing sea level and climatic variations (Martin, 1959, 1968; Reinwarth et al., 2013; Kirsten, 2014). Several investigations on sediment cores from the fen east of Groenvlei were conducted by Martin (1959, 1968) mainly applying palynological and diatom analyses. The main conclusions of these investigations concerning changes in the marine influence on the lake were that between ~4000 and 2000 BP. Groenvlei was in a lagoon stage and turned into a freshwater lake from ~2000 BP onwards (Martin, 1959, 1968). Regarding palaeoecological changes for the period between ~6870 and 2000 BP, Martin (1968) suggested that the vegetation spread in the area was restricted due to the instability of the dunes and hence sand movement. However, the author proposed two alternative palaeoclimatic interpretations for this period: climate was either dry and hot or wet (Martin, 1968). For the time frame from ~2000 BP onwards, a more effective moisture availability was inferred which was conducive to vegetation spread in the area (Martin, 1968). However, the palaeoenvironmental interpretations of this record are only based on two radiocarbon ages causing uncertainties in the reliability of the chronology.

The aim of this study is to contribute to a better and more comprehensive understanding of palaeoenvironmental change in this area during the Holocene. Therefore, we retrieved a new sediment core from the profundal of Groenvlei and present a more detailed and robust radiocarbon chronology for this geoarchive. A multi-proxy approach including geochemical, mineralogical, stable isotope and granulometric methods was employed. In particular, the investigations on the carbonate mineralogy of our sediment core represent a novel methodological approach for this region. We provide a high-resolution record of environmental change giving new and more detailed insights into the past lake evolution at Groenvlei linked to Holocene sea level and climatic variations in South Africa.

2. Study site

Groenvlei represents the easternmost of several coastal lakes within the Wilderness embayment located at the southern Cape, South Africa (Fig. 1). At the north and south the lake is flanked by up to 200 m a.s.l. high, coast-parallel dune cordons of Pleistocene age (Illenberger, 1996; Bateman et al., 2004, 2011). These dunes evolved into the present aeolianites mainly consisting of well-rounded quartz and bioclastic sand cemented by calcium carbonate. At the top, the aeolianites of the seaward dune cordon south of Groenvlei are covered by unconsolidated Holocene sands of variable thicknesses (Bateman et al., 2011).

Groenvlei probably started to form in times of lower sea levels during the last glacial–interglacial cycles of the Late Pleistocene (Birch et al., 1978; Martin, 1959; Cawthra et al., 2014). During the Holocene sea level rise, the depression between the dune cordons was flooded (Martin, 1959). Thereafter, a possible former surface hydrological connection