Late Quaternary dune development along the western margin of South Africa and its relationship to paleoclimatic changes inferred from the marine record

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Introduction

Lying at the interface of the region's summer and winter rainfall zones, the western margin of South Africa is a transitional area where ca. 400 km of wet winter climates grade northwards to extremely arid conditions with rare summer rains. Throughout glacial–interglacial cycles, hemispheric-scale atmospheric and oceanic circulation variations are likely to have strongly affected environments in this region, with periods of humidity and aridity linked to latitudinal migrations of the westerlies and the frequency and strength of associated frontal systems. Proxies in this belt are, therefore, likely to preserve important information on millennial-scale temperate and subtropical circulation dynamics.

Environmental reconstructions of the west coast of South Africa, however, have been limited by a paucity of terrestrial sedimentary archives. While a series of robust paleoenvironmental records exist for the southern west coast (e.g., Meadows and Baxter, 1999; Parkington et al., 2000), the semi-arid to arid climates of the central and northern regions are not conducive to the preservation of traditional paleoecological proxy data sources (e.g., pollen, charcoal). As a result, such proxy archives are absent from much of the west coast.

The aeolian deposits, which extend along the west coast, have the potential to provide a significant proxy record of paleoenvironmental change in the region (Fig. 1). We sought to explore their potential as indicators of palaeoenvironmental change by applying optically stimulated luminescence (OSL) dating techniques, and identifying phases of aeolian activity and dune development (Chase and Thomas, 2006; 2007).

Aeolian sediment archives

In total, 91 samples from 22 cores were taken from dune deposits along a north–south transect extending up the west coast of South Africa from Elands Bay (32°26'S, 18°14'E) to Kleinsee (29°14'S, 16°59'E) (Fig. 1). OSL ages obtained from these samples allowed for the spatial and temporal dynamics of dune emplacement to be determined.

Recognizing variations in individual dunefield and dune form dynamics, two distinct suites of ages were derived from the OSL data, with accumulating dune forms preserving evidence over different timescales to the region's migrating dune fields. The development of accumulating and migrating dune forms along the west coast is primarily a function of topographic variations in the landscape and the proximity and productivity of potential sediment sources. In sheltered locations, such as the lee of uplands, or in areas of high sediment supply, accumulation is more likely to exceed erosion and allow for the development of thick aeolian deposits, and stacked records of dune development. In more exposed locations, or areas with limited sediment supply, erosion often exceeds accumulation and more migratory dune forms develop. Migratory dunes, identified in this study by their crescentic morphology, are short-lived self-cannibalizing forms that 'roll' across the landscape as sediment is eroded from their windward slopes, transported across the dune, and deposited on the leeward slopes. This constant recycling of the sediment body does not promote the development of long records of aeolian activity, and generally only the termination of the last major phase of activity is preserved.

These variations are illustrated in Figure 2, where ages are rounded to the nearest 1000 years and grouped into 1 kyr intervals, with a five-point moving average calculated for the resulting distribution. The patterning of ages from the accumulating dune forms exhibits five distinct clusters, suggesting phases of activity at 3–5, 16–23.5, 31–33, 43–48.5 and 61–74.5 kyr. Conversely, ages obtained from migrating dune forms exhibit a largely coeval inverse relationship to the ages from the accumulating dunes forms, with periods of activity occurring at 4–8, 11–16 and 21–28 kyr, and single ages at 43.5±2.66 and 82.7±5.88 kyr.

That each major cluster is composed of ages from a range of sites along the coastal transect implies that these phases are not simply episodes of local reworking of sediments, but rather that they are indicative of regional aeolian activity.

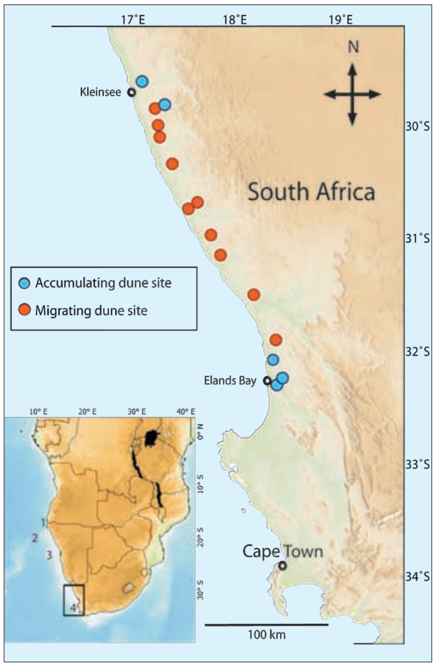

Figure 1: Map of western margin of South Africa indicating dunefield cores sites, sample depths (m) and OSL ages (kyr), with ***inset*** *indicating the study area and sites within the southern African context and the locations of the primary paleoenvironmental sites used for comparison. Sites 1 - 2 indicate the location of the cores displayed in the top 3 panels in Fig 2.*

Interpretations

Most published studies of the timing and cause of aeolian activity during the late Quaternary equate clusters of luminescence ages with periods of increased aridity (e.g. Stokes et al., 1997; Thomas et al., 1998; Munyikwa, 2005). However, a comparison of the OSL ages from the west coast dunefields with the few well-dated paleoenvironmental records from the region suggests that this interpretation cannot be applied to most of the phases of aeolian activity that have occurred during the last glacial–interglacial cycle in SW Africa.

In general, the findings of Stuut et al. (2002) (Fig. 2) corroborate and refine the interpretations of other paleoenvironmental records (e.g., Parkington et al., 2000; Shi et al., 2001), indicating increased humidity and windiness along the west coast of southern Africa during glacial periods, and increased aridity during interglacial periods. These interpretations are consistent with the conceptual models

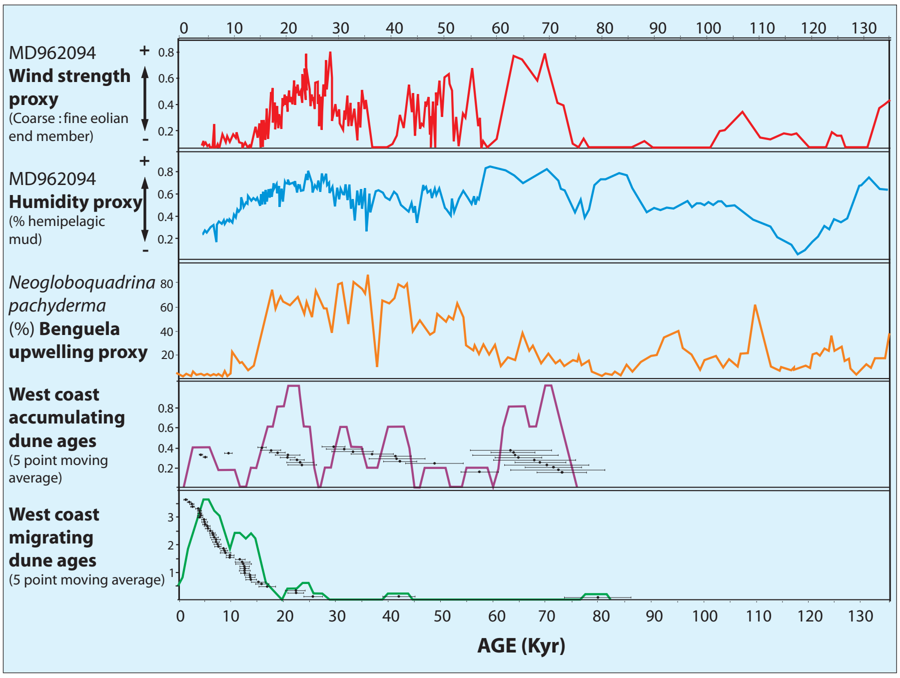

Figure 2: Correlation of Optically Stimulated Luminescence (OSL) age distributions from west coast aeolian sediments with proxies for wind strength and humidity from marine cores off the Namibian coast. Wind strength is indicated by percentages of N. pachyderma *as a proxy for coastal upwelling (Little et al., 1997) and by the ratio of coarse to fine aeolian dust (Stuut et al., 2002), while humidity is inferred from the proportion of aeolian to hemipelagic sediments (Stuut et al., 2002). Dune ages and errors are shown in* ***black***. ***Purple*** *(Chase and Thomas, 2006) and* ***green*** *(Chase and Thomas, 2007) lines indicate five-point moving averages calculated from the ages grouped into 1 kyr bins. The core location for the top three studies can be found in Fig 1 inset.*

that suggest expansions of the Antarctic sea ice would have resulted in an equatorward shift of the westerlies during glacial periods, bringing increased precipitation to SW Africa (e.g., Chase and Meadows, in press; Cockcroft et al., 1987; van Zinderen Bakker, 1976). By exploring correlations between our dune ages and terrestrial and marine records from the region, we have been able to arrive at a more detailed understanding of the dynamics and significance of dune development along the west coast.

Of the phases of aeolian activity preserved in accumulating dune forms, phases from 16–23.5, 31–33, 41–48.5 and 61–74.5 kyr (Fig. 2) are associated with periods of increased windiness and fluvial sediment supply, and correlate with phases of high-latitude cooling, invigorated glacial circulation systems and increased humidity along the west coast (e.g., Little et al., 1997; Parkington et al., 2000; Shi et al., 2001; Stuut et al., 2002). This contrasts sharply with paleoclimatic predictions linking aeolian activity to aridity, and indicates the importance of defining and incorporating the role of wind strength and sediment supply in the interpretation of aeolian proxies.

Rather than indicating phases of increased aeolian activity, ages from migrating dune forms represent a complex history of dune-field development. The oldest ages, between 21–83 kyr, were obtained from the cores of the dunes and, as they were deposited in high wind–high humidity environments, it is likely that they represent localized, fixed aeolian sediments that accumulated around the vegetation that would have been growing in the region. The 11–16 kyr phase of dune development occurred during the still humid, but notably less windy late glacial period (Fig. 2), and aeolian deposits from this phase represent the transition to dormancy of a highly mobile dune field.

The mid-Holocene phase of activity recorded in both accumulating and migrating dune forms occurs during a period of low wind strength and potentially limited sediment supply. It is thus more likely that in this case the widespread reactivation of aeolian deposits occurred as a response to the period of increased aridity that is recorded in the paleoecological proxies from the Elands Bay region (Meadows et al., 1996; Parkington et al., 2000). While human impacts can result in the initiation of aeolian activity through the disturbance of vegetation cover, an occupational hiatus in some of the region's archeological sites from 4–8 kyr (Parkington et al., 1988) does not indicate human agency as a likely driver for this phase of aeolian re-activation.

Conclusions

Compared to other parts of the world where glacial periods were both windier and drier, the increased humidity along the west coast during the last glacial period has allowed for the analysis of the relative importance of wind strength and aridity in the evolution of the region's dune fields. Contrary to the prevailing paradigm of dunes being equated with aridity (e.g., Stokes et al., 1997; Thomas et al., 1998; Munyikwa, 2005), an inverse relationship exists between dune ages and evidence for aridity along the west coast. Instead, phases of dune development correlate most strongly with variations in wind strength; with accumulating dunes recording periods of increased aeolian activity, and ages from migrating dunes marking the threshold in transport capacity below which dunes become dormant.

These results call into question the utility of aeolian sediments as a paleoclimatic proxy. While drier climates can enable aeolian activity, as in the case of the mid-Holocene phase of dune development along the west coast, without evidence of variations in wind and precipitation it is difficult to identify the relative influence of these mechanisms, and thus to clearly attribute phases of dune development to episodes of climatic change.

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