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Dune ages in the sand deserts of the southern Sahara and Sahel

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ABSTRACT

In this paper we aim to document the history of aeolian processes within the southern Sahara as part of the INQUA Dune Atlas. We review available luminescence ages for sand dunes across the southern Sahara to develop an improved understanding of the dune chronology on a regional basis and attempt to correlate periods of sand accumulation. This was achieved by analysing dune age by country, as well as by latitude and longitude. The results show a very patchy spatial distribution of dune ages with large gaps that encompass some of the largest sand seas. Despite these gaps, some related patterns in dune morphology and stratigraphy appear to be consistent between northern Nigeria and southern Mali where older linear dunes are distinct from younger Late Holocene transverse and barchanoid dunes. Elsewhere in Mauretania linear dunes with different orientations appear to have accumulated at different times, most likely in response to changes in atmospheric circulation. Regional climatic changes are identified where dunes are transgressed by lake deposits within endorehic basins. We identify four locations where dune accumulation is terminated by lacustrine transgressions, two of which, in Lake Chad and the Bodélé Depression, occur shortly after the last glacial maximum (LGM). The third example at Gobiero in Niger occurred later, in the early Holocene, around 8.4 ka and a fourth marks a later transgression of Palaeolake MegaChad after 4.7 ka. Larger-scale latitudinal and longitudinal distributions in dune ages across the southern Sahara do not show any consistent patterns, though this may be due to the small sample size relative to the study area. In addition, local variations in external controls such as wind regime, rainfall, vegetation and sand supply need to be considered, sometimes on a site by site basis. Limiting the analysis to dune ages determined using the single-aliquot regenerative-dose (SAR) protocol indicates a lack of dune preservation during the LGM and the Younger Dryas, times associated with increased dust input to the oceans which is assumed to indicate increased aeolian activity. The SAR dune dates suggest that preservation of dunes at the onset of succeeding humid intervals is an important component of the dune record. The most striking examples of this phenomenon occur where dunes are preserved within endorehic basins by lacustrine transgressions.

1. Introduction

In their 1968 paper on “Quaternary landforms and climate on the south side of the Sahara” Grove and Warren note that the limits of the desert have shifted long distances north and south in the later stages of the Quaternary. They review the relative chronology of coastal, fluvial, lacustrine and dune landforms across the African continent from Mauritania in the west to Sudan in the east and establish alternating wetter and drier intervals marked by the appearance of different generations of sand dunes and their relationships to fluvial and lacustrine sediments. Grove and Warren (1968) established the now widely accepted chronology for late Quaternary climate change in North Africa, whereby the late Pleistocene was characterised by a drier climate with more extensive dune systems, followed by a wetter climate in the early Holocene, and a return to more arid conditions from the middle Holocene to the present day. They suggested that vegetated dunefields south of the Sahara indicate that the 500 mm isohyet lay some 500 km south of its present position (Grove and Warren, 1968). The expansion of the Sahara during the last glacial maximum (LGM) was supported by Sarnthein (1978) who asserted that active sand dunes were most extensive 18,000 years ago and that sand dunes were generally dormant 6000 years ago. The cause of the latitudinal shift in the desert is linked with the strength of

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the West African monsoon and the latitude of the intertropical convergence zone (ITCZ). Tracing the low salinity zone associated with the marine ITCZ, Arbuszewski et al. (2013) estimate that the ITCZ moved latitudinally over the ocean and shifted at least 7° south during the LGM to a latitude of 2° South. During the early Holocene there was a northward shift in the ITCZ and the monsoon rain-belt towards 10° or 12° North, from which it has subsequently shifted south to around 5° North at the present day (Haug et al., 2001).

While there is general consensus that the Sahara changed from a humid "green" to an arid "brown" since the mid Holocene, there is some debate over the timing of the change and whether it was gradual or abrupt. Talbot (1981) suggested that the onset of the drier windier conditions occurred around 4500 years ago with desert expansion between 4500 and 3800 years ago. Subsequent research on lake sediments across the southern Sahara has supported and refined this chronology e.g. (Gasse, 2000). In 2000, deMenocal et al. suggested that the change occurred a little earlier, around 5.5 ka and asserted that the change was abrupt. Subsequent papers have questioned the abrupt change (Eggermont et al., 2008; Kröpelin et al., 2008), although the case for an abrupt change was reiterated by McGee et al. (2013) who refine the onset and end of the AHP as 11.8 ± 0.2 and 4.9 ± 0.2 ka respectively based upon a review of the marine record. In addition, there is potential for different proxies to respond in different ways and in their review of palynological and palaeohydrological data across the Sahara and Sahel Lézine et al. (2011) point out that there will be a lag within wetland response due to groundwater recharge which is likely to have influenced the record of endorehic lake basins as well as ground water fed systems such as Lake Yoa, the source of the gradual change hypothesis. Most recently, Shanahan et al. (2015), suggest that the termination of the African humid period was locally abrupt, but occurred progressively later at lower latitudes accompanied by both declining rainfall intensity and gradual southward migration of the tropical rainbelt.

Swezey (2001) reviewed the Late Quaternary aeolian stratigraphy in the Sahara even though, at that time (2001), few aeolian sediments in the Sahara had been dated directly. As a consequence there were, and still are, numerous uncertainties regarding the timing of aeolian sediment mobilisation and stabilisation (Swezey, 2001). Despite these limitations, Swezey concluded that "although the data are relatively sparse, when viewed as a whole, they reveal a general pattern of widespread eolian sediment mobilisation during the Late Pleistocene, eolian sediment stabilisation during the early Holocene, and a return to widespread eolian sediment mobilisation in the later Holocene" (Swezey, 2001, p.128). At the same time, Swezey predicted that "further use of luminescence dating and more precise mapping of stratigraphic relationships should make it possible to resolve Quaternary eolian chronologies with greater resolution and to create more precise models of eolian sediment response to climate change" (Swezey, 2001, p.127).

Amongst the most outstanding debates on North African climate in recent years is that concerning the rate at which change has occurred and the degree of synchronicity across the continent. In his classic 1978 paper on sand deserts during the LGM, Sarnthein (1978) commented that "climatic changes from desert to vegetated land and vice versa are very rapid, spanning no more than a few hundred years" (Sarnthein, 1978, p.46). Further evidence for abrupt change is found in the dust record of offshore cores (deMenocal et al., 2000; McGee et al., 2013). The main aim of this paper is to review the progress that has been made during the past decade, concentrating on the record that we now have from optical dating of dune sands in the southern Sahara, to try to elucidate the aeolian record of dune activity and response to climate change.

1.1. The Sahara

The Sahara is the largest warm desert on Earth. It covers an area of approximately 9 million km^2, similar to that of the USA and spans latitudes 15° to 34°N in North Africa. In this paper we are considering only the southern half of the Sahara which is divided from the north by elevated plateaus and mountains that straddle the Sahara including the Adrar des Iforas, Hoggar, Ajjer, Tibesti and Eneddi. However, there is interaction between the north and south because hydrological connections have operated during the Holocene (Drake et al., 2011) and northeasterly winds transport sand through these highland areas (Wilson, 1971; Mainguet, 1978) into basins on the southern side of the highlands. Along the way, upland areas divert and deflect the northeasterly trade winds and sandflow is diverted around and between the upland areas locally converging and diverging (Mainguet, 1978). In his review of ergs Wilson (1973) mapped the distribution of 56 ergs larger than 12,000 km^2. Around a half of these, 27 are located in Africa north of the Equator, of which 16 are located within the southern and western Sahara area covered by this review.

1.2. The database

In this paper we review the existing luminescence age data for dunes in the southern Sahara which have been entered into a global digital database and atlas of Quaternary dune fields and sand seas; see http://inquaduneatlas.dri.edu for further details of the INQUA dune atlas. Within the database each sample has a unique identification number e.g. (AFNL000n) which is reported in this paper in parentheses. Initially the dune ages are considered regionally, country by country from Sudan in the East to Mauretania in the West. This is followed by an overview investigating latitudinal and longitudinal dune age distributions across the southern Sahara; firstly using all available luminescence ages, and secondly considering only those luminescence ages produced using the SAR method which is considered to produce more reliable age estimates.

2. Available data sets

Luminescence ages from 13 papers are incorporated into this review (Armitage et al., 2015; Berking and Schütt, 2011; Bubenzer et al., 2007; Bushbeck and Thiemeyer, 1994; Felix-Henningsen et al., 2009; Gumnior and Preuser, 2007; Holmes et al., 1999; Lancaster et al., 2002; Mauz and Felix-Henningsen, 2005; Rendell et al., 2003; Sereno et al., 2008; Stokes and Horrocks, 1998; Stokes et al., 2004; Theimeyer, 1995), with sample locations shown in Fig. 1. These papers use a variety of different methods for calculating the equivalent dose, reflecting the development of luminescence dating methods over the past twenty years. The earliest results come from Buschbeck and Thiemeyer (1994) using thermoluminescence (TL) to date dunes in northeastern Nigeria. Their results indicate ages in the range from 1.1 ± 0.85 ka to 12.6 ± 5.6 ka, with very large uncertainties, and the authors themselves describe the dose rate as "not very reliable". In addition, TL is no longer considered an appropriate method for dating young sedimentary samples and Thiemeyer (1995) questions the validity of the calculated TL ages for the Lantewa and Gudumbali dune fields, concluding that he is "not able to relate the TL ages of NE- Nigerian dunes to certain phases of dune formation" (Thiemeyer, 1995, p.105). Furthermore, the papers by Buschbeck and Thiemeyer (1994) and Thiemeyer (1995) do not provide coordinates for their sample locations, making it difficult to incorporate their data into the atlas format. Consequently, the TL ages from Buschbeck and

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