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Developing a framework of Quaternary dune accumulation in the northern Rub' al-Khali, Arabia

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ABSTRACT

Located at the crossroads between Africa and Eurasia, Arabia occupies a pivotal position for human migration and dispersal during the Late Pleistocene. Deducing the timing of humid and arid phases is critical to understanding when the Rub' al-Khali desert acted as a barrier to human movement and settlement. Recent geological mapping in the northern part of the Rub' al-Khali has enabled the Quaternary history of the region to be put into a regional stratigraphical framework. In addition to the active dunes, two significant palaeodune sequences have been identified. Dating of key sections has enabled a chronology of dune accretion and stabilisation to be determined. In addition, previously published optically stimulated luminescence (OSL) dates have been put in their proper stratigraphical context, from which a record of Late Pleistocene dune activity can be constructed. The results indicate the record of dune activity in the northern Rub' al-Khali is preservation limited and is synchronous with humid events driven by the incursion of the Indian Ocean monsoon.

1. Introduction

Reconstructing environmental change in Arabia is vital for improving our understanding of the context for demographic variability during the Mid-Late Pleistocene (Groucutt and Petraglia, 2012). During much of this time, the presence of the hyper arid Rub' al-Khali desert presented a major environmental barrier for human dispersal. However, fluctuations in the regional climate, driven by the varying latitudinal interface between the south-westerly Indian Ocean Summer Monsoon (IOSM) and the Westerly driven Shamal winds, created occasional humid interludes generating the potential for human migration across this region. Although IOSM rainfall is currently restricted to southern coastal regions of Yemen and Oman, at times it increased in strength and penetrated much further north across Arabia, bringing moist conditions across the now hyper-arid Rub' al-Khali (Fleitmann et al., 2007; Rosenberg et al., 2011; Atkinson et al., 2013). Constraining the timing of these moist incursions is essential for determining when human migration may have occurred (Armitage et al., 2011; Parton et al., 2015a). However, this necessitates having high-quality palaeoclimatic records from the region, combined with good chronological control. One such source of palaeoclimatic information is the Quaternary sediments that occupy the Rub' al-Khali basin. This region (Fig. 1), which extends over 600,000 km^2 and covers one-third of the Arabian subcontinent (White et al., 2001; Edgell, 2006), has an extensive cover of Quaternary deposits. These mostly comprise aeolian dune systems with a suite of alluvial fans along the margins of the Hajar Mountains, and localised palaeolakes and inland sabkhas (Farrant et al., 2012a). The importance of these Quaternary sediments lies in their capacity to document palaeoclimatic changes over the last few hundred thousand years. Most attention has been focused on palaeolake sequences (e.g. Parker, 2010; Rosenberg et al., 2012, 2013; Crassard et al., 2013; Parton et al., 2013) and speleothems from cave systems in adjacent upland areas (Burns et al., 2001; Fleitmann and Matter, 2009). With the notable exception of the north-eastern fringe of the desert and the Liwa oasis the aeolian record from this region has been comparatively underutilised. The application of luminescence

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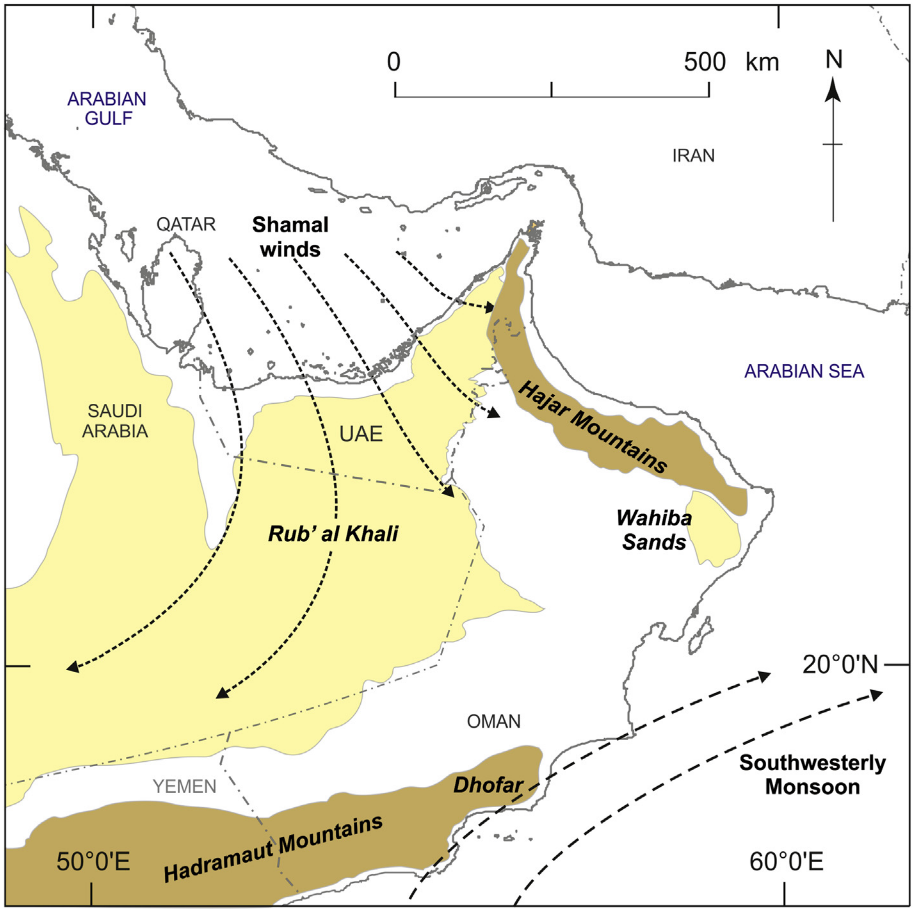

Fig. 1. Location of the Rub' al Khali dunefield and present day wind patterns.

dating techniques to the active and relict dune fields within the Rub' al-Khali basin addresses this, and provides evidence for past climates and environments where dated palaeolake and speleothem records are scarce.

Extracting a palaeoclimatic record from aeolian sequences is not straightforward (Chase, 2009). Many factors influence dune accretion, migration and stabilisation (Thomas and Burrough, 2012; Leighton et al., 2013), notably sediment supply, the transport capacity of the wind and sediment availability (Preusser, 2009). The latter is a function of vegetation, soil moisture, and the position of the water table. Consequently, periods of dune accretion are often used to infer aridity whilst dune stabilisation is usually associated with reduced wind speed or increased vegetation or cementation – both indicators of more humid conditions. Across much of the UAE, generally unimodal north-westerly Shamal wind regimes (Barth, 2001) favour barchan or transverse dune forms. As these dunes migrate, each phase of dune activation may remove evidence of earlier forms, particularly where the sediment supply is limited by high groundwater and sea levels, and the rate of deflation of sand from older deposits is low (Goudie et al., 2000). This can lead to discontinuous sediment records. Higher resolution stacked records are more common towards the eastern and southern borders of the UAE where sand accumulates as star dune or dune ridge complexes along the eastern margin of the dune field. Stacked dune sequences also occur where dunes become rapidly lithified or develop cemented palaeosols. This is common in carbonate-rich dunes such as the Wahiba sands (Preusser et al., 2002; Radies et al., 2004), and calcareous dunes preserved along the Persian Gulf coast (Teller et al., 2000; Farrant et al., 2012a).

Interpreting optically stimulated luminescence (OSL) ages from dune sequences can also be problematic. OSL ages record the last time sand was exposed to daylight (Duller, 2004). During periods of active dune migration, the dune's luminescence clock is constantly reset by sediment recycling and systematic self-cannibalisation. Dates from dormant and stable palaeodunes therefore do not usually reflect periods of aeolian activity and accretion, but rather the timing of dune stabilisation. In addition, there is a lag time between dune deposition and stabilisation, dependant on the sediment turnover rate known as the dune 'reconstitution' time (Allen, 1974; Lancaster, 2008). This is generally greater for large dune forms than smaller, more mobile dunes (Stone and Thomas, 2013). This is important when considering the timing of dune preservation. OSL ages from migrating barchan-type dunes stabilised at the onset of humid conditions can span a few thousand years depending on the rate of sediment turnover and the depth of the OSL sample. For accurately defining periods of dune stabilisation, dunes with short reconstitution times and high preservation potential, such as small carbonate dunes, are the most useful. Equally important are the gaps in the chronological record. These can either mean arid periods with extensive dune recycling or periods of sustained rainfall with minimal dune activity.

To gain a full appreciation of the palaeoclimatic record, a large OSL data set with a broad temporal and spatial coverage is required. Over reliance on a small or local dataset can lead to the