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Invited Review

Reconstructing palaeoenvironments on desert margins: New perspectives from Eurasian loess and Australian dry lake shorelines

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ABSTRACT

Desert margins preserve evidence of more extensive arid conditions in the past and represent global hot spots with respect to climate change. The balance of scientific evidence now suggests that dryland landscape reactivation did not correspond simply to ice age aridity peaks as previously assumed. This paper provides a new perspective on, and more nuanced understanding of, desert marginal landscapes as palaeoenvironmental archives.

The two case studies represent ends of a sediment availability spectrum. Both environments experience substantial spatial and temporal variability in deposition, with implications for reconstructing past environments at individual sites. Recently generated chronostratigraphic data from the dry subhumid Dobrogea loess, Romania, are synthesised to provide quantitative insights into the spatial and temporal organisation of loess plateaux. Loess accumulation peaks during the LGM and MIS4, but not at all sites. Accumulation rates vary substantially between sites. Comparison of geographical context yields no clear driving mechanism for this variability. Secondly, two transverse lunette dunes in semi-arid Willandra Lakes, Australia, yield comparable chronostratigraphies and distribution of stratigraphic units. A first attempt is made to identify changes in wind regime through time on the Australian desert margins, and suggests that high latitude climate forcing may have acted upon semi-arid Australia over millennial scales.

The novel perspectives generated from the new datasets provide unprecedented insights into past climate circulation and land surface processes along desert margins. These new perspectives, coupled with the new geochronological and quantitative palaeoclimate proxy tools now available, represent the next frontier for palaeoenvironmental research on desert margins.

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1. Introduction

The desert margin regions of the world are at greatest risk of dryland expansion under accelerated climate change (Huang et al., 2016). Drylands, and in particular the desert margins most vulnerable to desertification and drought, have overseen substantial climatic and environmental changes associated with the Quaternary. Climatic evolution over the last few million years has resulted in the expansion of arid and semi-arid zones to represent almost one-third of all present-day land surfaces (UN, 1989; Williams, 2014). Many of these marginal areas preserve typical arid landforms, which represent the legacy of phases of drier Quaternary climates than prevail presently (e.g. Goudie, 2002; Hesse et al., 2003; Wasson, 1976; Williams, 2014). Since the drylands of the world host at least one fifth of the world's population (IPCC, 2007; Williams, 2014), it is increasingly important to understand the geomorphic and anthropogenic processes responsible for change in these regions, as well as the thresholds and trajectory for change. This understanding is fundamentally underpinned by the palaeoenvironmental information preserved within these landscapes.

Until recently, our models for dryland change broadly assumed a pattern of arid zone expansion during cold ice ages, and contraction and stability during interglacial phases, as popularised by Sarnthein (1978). Prior to reliable dating control – and even now in regions where researchers do not as yet have ready access to geochronological methods – volumes of literature have been published

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assuming ice age peaks in aridity and coeval aeolian activity (examples from Australia include, but are not limited to, Bowler, 1976, 1982; Bowler et al., 1998; Hesse et al., 2004; Magee and Miller, 1998; Nanson et al., 1992; Sprigg, 1982; Wasson, 1983, 1986, 1990; Williams, 2014). The best gauge of these changes is preserved in the fossil desert landforms and sediment deposits of the dryland margins. Despite the extent of the world's desert marginal regions, however, astonishingly little is known about the nature and timing of dryland environmental change in the past (Atkinson et al., 2011; Bateman et al., 2003; Chase, 2009; Fitzsimmons et al., 2013b; Stone and Thomas, 2008; Telfer and Hesse, 2013).

The advent of widespread luminescence dating has facilitated more robust correlations for the timing of deposition in drylands (Lancaster et al., 2016; Singhvi and Porat, 2008). The widespread applicability of this technique – which quickly overtook radiocarbon in dryland regions with minimal organic preservation - resulted in the accumulation of a critical mass of evidence suggesting that aeolian accumulation did not so simply correspond to ice age aridity peaks as previously thought (e.g. Fitzsimmons et al., 2007a, 2007b; Haberlah et al., 2010; Lomax et al., 2003, 2011; Roskin et al., 2011a, 2011b; Stone and Thomas, 2008; Telfer et al., 2009; Thomas and Burrough, 2016; Xu et al., 2015; Yang et al., 2006). Nor did records of palaeohydrology (Bowler et al., 2001, 2012; Burrough and Thomas, 2008; Burrough et al., 2009a; Fitzsimmons and Barrows, 2010; Fitzsimmons et al., 2012b; Maroulis et al., 2007).

Over the same period, the development of new palaeoproxy techniques applicable to dryland sediments has vastly expanded our potential for extracting quantitative palaeoenvironmental information (e.g. Burrough et al., 2012a; Caves et al., 2014; Eagle et al., 2013; Long et al., 2014; Miller et al., 1997, 2007, 2016b; Stone and Edmunds, 2016; Stone et al., 2010; Witt et al., 2017; Zamanian et al., 2016). The new datasets have prompted a shift in our approach to interpreting geomorphic data, requiring a revision of process- and climate-based explanations for depositional events and the activation (and reactivation) of landforms in dryland regions (Burrough et al., 2009b, 2012b; Cohen et al., 2010, 2011, 2012; Duller, 2016; Fitzsimmons et al., 2013b, in press; Halfen et al., 2016; Hesse, 2011, 2016; Lomax et al., 2011; Roskin et al., 2012; Telfer et al., 2010; Thomas and Burrough, 2012, 2016; Yang, X. et al., 2012a, 2012b, 2015, 2016; Yang and Williams, 2015).

As yet, however, this shift in scientific perspective remains in a state of transition while researchers 1) make sense of the new datasets; 2) come to terms with new methodological developments and proxies; and 3) realise the caveats and limitations of sedimentary records from desert margins, and which often compare unfavourably with the high resolution marine and ice core records.

This paper addresses this shift in scientific approach by presenting examples of how the new datasets can provide us with a fresh perspective on, and more nuanced understanding of, desert marginal landscapes as palaeoenvironmental archives. The two case studies discussed represent two ends of a spectrum with respect to sediment availability. Thick loess archives from the dry subhumid steppe of the Dobrogea Plateau, southeastern Romania, provide a case study for desert margins in areas with plentiful sediment supply. Transverse source-bordering dunes marginal to two adjacent ephemeral lake basins in semi-arid southeastern Australia provide a case study for investigating dryland margin areas characterised by low sediment availability and poor preservation potential. In the first case study, recently generated chronostratigraphic data from the Dobrogea loess are synthesised to provide quantitative insights into the spatial and temporal organisation of loess plateaux, with implications for understanding loess depositional processes and palaeoclimatic interpretations at individual sites. In the second case study, the transverse source-bordering dunes are investigated for their potential to reconstruct past wind regimes based on data on spatial and temporal variability of stratigraphic units. The perspectives presented by the new datasets provide unprecedented insights into past climate circulation and land surface processes.

2. Regional settings

2.1. Dobrogea Plateau loess: high resolution records from sediment-rich environments in the dry subhumid steppe

The substantial loess deposits of the Eurasian mid-latitudes represent the thickest and most comprehensive palaeoenvironmental records on the continent (Dodonov and Baiguzina, 1995; Fitzsimmons et al., 2012a; Guo et al., 2002; Haase et al., 2007; Liu and Chang, 1964; Marković et al., 2015; Sun et al., 2006). They are overwhelmingly distributed across the dry subhumid to semi-arid climate zones of the temperate latitudes (Fig. 1). Eurasia's widespread, thick blanket of loess has accreted almost continuously over the last million years or more, depending on location (Buggle et al., 2013; Guo et al., 2002; Marković et al., 2011). Stacked sequences of primary loess and buried soils (paleosols) generally reflect responses of the landscape to alternating cooler glacial and milder interglacial climates, respectively (e.g. Marković et al., 2015). Correlations based on paleosols as marker horizons have been attempted between Eastern Europe and China (Fitzsimmons et al., 2012a; Marković et al., 2015).

The investigation of loess as an archive for European past environments has had a long history, extending back to the Austro-Hungarian empire (Marsigli, 1726) and continuing to the active research of the present day (Marković et al., 2016). The last decade has overseen a particularly fruitful period of loess research in the Danube region, coincident with major methodological developments for understanding both the timing (e.g. Anechitei-Deacu et al., 2014; Antoine et al., 2009; Constantin et al., 2014, 2015; Fitzsimmons and Hambach, 2014; Marković et al., 2014; Novothny et al., 2009, 2010; Schmidt et al., 2010; Stevens et al., 2011; Sümegi et al., 2016; Timar et al., 2010; Újvári et al., 2014; Vasiliniuc et al., 2011) and past conditions of loess deposition (e.g. Basarin et al., 2011; Bokhorst et al., 2009; Buggle et al., 2008, 2009, 2011; Marković et al., 2000, 2005, 2006a,b, 2009, 2011; Schatz et al., 2011; Sümegi et al., 2012; Zech et al., 2009). By and large this work focussed on the north Serbian Vojvodina and Hungarian Carpathian basin, due to the geographically concentrated constellation of workers, collaboration partners and facilities. Recent work in the Dobrogea region south of the Danube delta, by comparison, had a slower start (Balescu et al., 2003; Jordanova et al., 2007, 2008; Jordanova and Petersen, 1999). Work accelerated after 2010 with the coeval establishment of a luminescence dating laboratory and loess research cluster in Cluj, Romania (Timar et al., 2010), and a number of large projects focussing on human-environmental interactions in the area (Anghelinu et al., 2012; Fitzsimmons et al., 2013a; Iovita et al., 2012, 2014; Sitlivy et al., 2014). By early 2012, a critical mass of state-of-the-art palaeoenvironmental data had been generated from the lower Danube basin. This facilitated the publication of the first review linking loess archives from Hungary downstream to Romania and Bulgaria (Fitzsimmons et al., 2012a), and the generation of a unified basin-wide stratigraphic model pinned to a synthetic type section (Marković et al., 2015), comparable with the synthesised stack developed for the Chinese Loess Plateau (Sun et al., 2006). Environmental conditions in the lower Danube basin over at least the latter half of the Quaternary have resulted in relatively continuous loess deposits uninterrupted by glaciation or tundra settings (Fitzsimmons et al., 2012a).

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