DEPOSITIONAL MODELS OF LATE PLEISTOCENE FINE-GRAINED VALLEY-FILL FORMATIONS IN THE FLINDERS RANGES, SA

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Although the general climatic development of Australia during the late Quaternary is well established (Chappell & Grindrod, 1983; Kershaw & Nanson, 1993; Veevers, 2001), detailed regional palaeoenvironmental knowledge remains limited. This is especially the case in present-day semi-arid landscapes located between the continent's arid interior and the humid coastal areas (Harrison, 1993; Hesse *et al.* 2004). Semi-arid environments are very susceptible to hydrologic changes related to variations in precipitation, temperature, vegetation and associated evapotranspiration. They can therefore be considered key regions in reconstructing the environmental impact of global warming and rising sea levels during the last deglacial termination. In the Australian context fundamental questions such as the magnitude of the latitudinal shift of the westerly winds and the expansion or shrinkage of the trade wind-dominated subtropical zone during the glacial interval remain to be quantified (Harrison, 1993; Shulmeister *et al*. 2004). In addition, recent studies dating the onset and southward incursion of the summer monsoon to ~15 ka (Miller *et al.* 1997; Wyrwoll & Miller, 2001), decoupling it from gradual changes in low-latitude summer insolation forcing, need to be supported by independent evidence.

So far, the main obstacle for regional scale Quaternary palaeoenvironmental reconstructions in Australia is the limited availability of continuous sedimentary records from presently semi-arid and arid regions. This is especially evident for the period leading towards the Last Glacial Maximum, during which lakes occupying structural basins acting as internal drainage foci dried out and were deflated (Schmid, 1985; Harrison, 1993; Magee *et al*. 1995). Ensuing dust entrainment led to loess accumulations, i.e. terrestrial deposits of dominantly silt-sized lithogenic wind-blown dust (Pye, 1995), in down-wind desert margins (Smith, *et al.* 2002). Loess sequences are globally recognised as valuable terrestrial proxies for reconstructing palaeoclimatic changes (Liu, 1987). One problem with Australian loess deposits is their generally limited thickness and irregular and discontinuous distribution. In many cases they still need to be identified and dated. Moreover, the nature of their deposition often remains ambiguous and ill-defined (Hesse & McTainsh, 2003).

LATE PLEISTOCENE FINE-GRAINED VALLEY-FILL FORMATIONS IN THE FLINDERS RANGES

The semi-arid Flinders Ranges are seasonally influenced by all the mentioned synoptic atmospheric circulation systems (Gentilli, 1972; Schwerdtfeger & Curran, 1996). The tilted, uplifted and dissected Precambrian and Palaeozoic sedimentary rocks (Preiss, 1987; Drexel & Parker, 1993) of the ranges have a wide distribution of peaks rising up to 1000 m above the surrounding plains. They act as an orographic barrier that can be expected to amplify palaeoenvironmental changes in the precipitation regime. The central Flinders Ranges host one of Australia's best preserved loess-derived sedimentary sequences: the late Pleistocene, fine-grained, valley-fill formations occupying the Brachina and Wilkawillina drainage systems (Callen & Reid, 1994; Cock *et al*. 1999; Williams *et al.* 2001; Chor *et al*. 2003; Williams & Nitschke 2005). Radiocarbon and luminescence dating of the stratigraphic type section 'Slippery Dip' established a continuous depositional record from ~33 to ~15 ka, before renewed incision exhumed the original rock-walled channel. This interval embraces the intensification and peak glacial conditions of the last glacial cycle and extends into the succeeding deglacial termination, which is associated with the most significant and rapid climatic changes in the past 120 ka (Petit *et al.* 1999).

DEPOSITIONAL MODELS AND PALAEOENVIRONMENTAL IMPLICATIONS

The depositional nature of the Pleistocene Brachina valley-fill formation, which unconformably overlies the Neoproterozoic Brachina Formation and effectively levels out the deeply incised palaeorelief, has been repeatedly reinterpreted over the past few years. These interpretations range from Pleistocene lake deposits (Callen & Reid, 1994; Cock *et al*. 1999), wetland deposits (Williams *et al*. 2001), to "floodplain deposits in perennially wet grassy meadows" (Williams & Nitschke 2005, 25). The latest study emphasises the importance of an aeolian contribution as the source of the fine-grained sediments. However, the mode of their deposition and the causes behind the tabular subhorizontal bedding planes and laminations that mirrors both the general gradient of higher rock-cut terraces and the present-day ephemeral stream bed scouring out the pre-existing relief still need to be established. This formation and similar deposits along drainage lines throughout the ranges record important geomorphological events at an exceptionally high temporal resolution and continuity for terrestrial records embracing the last glacial maximum. Yet, they cannot be used for palaeoenvironmental interpretations unless the processes involved in their formation and termination are fully resolved.

Comparable near-vertical fine-grained valley-fill formations have been reported from other parts in the world such as the Sahara (Linstädter & Kröpelin, 2004) and the Sinai Peninsula (Issar & Bruins, 1983). However none display such striking geomorphologic, lithologic and structural similarities as the 'silt terraces' in the drainage systems of the Great Escarpment which delimits the Namib Desert along a near-longitudinal line between 32°S and 14°S. An age range between ~30 and ~8 ka was established by radiometric dating for these "loessic alluvial deposits" (Eitel *et al*. 2001, 57), similar to that of the dated valley-fill succession in the Flinders Ranges (Cock *et al.* 1999; Williams *et al*. 2001). Ephemeral streams under the present arid climatic conditions are eroding the deposits since. Remnants of up to 25 m thickness are preserved in protected localities such as the mouths of tributary valleys (Ward, 1987). Over the past 30 years, studies on the Namib silt terraces established various competitive morphodynamic sedimentation models that can be divided into three groups.

Lake deposits: Initial observers proposed a lacustrine origin caused by dune damming (Goudie, 1972; Scholz 1972; Rust & Wieneke 1974, 1980), similar to the first interpretation of the late Pleistocene Brachina formation (Callen & Reid 1994, Cock *et al.* 1999). Since sub-horizontal gradients of the tabular fine-grained deposits have been established, (Hövermann, 1978 for the Great Escarpment; Williams *et al.* 2001 for the Flinders Ranges) the lacustrine depositional model is not supported.

High-energy flood deposits: Various studies assume that the silt formations were deposited during flash-flood events with rapid sedimentation from heavily laden high-energy floodwaters, partly backflooding tributary side valleys (Ollier, 1977; Heine, 1987; Ward, 1987; Smith *et al.* 1993; Heine & Heine, 2002; Srivastava, 2005). According to Williams & Nitschke (2005), the suspended load consists in large part of eroded dust mantle-derived material. Occurrences of laminated sequences at confluences (e.g. 'Slippery Dip') are interpreted as representing slack-water deposits (Kochel & Barker, 1982; Zawada, 1997).

Low-energy floodout deposits: An alternative explanation is offered by describing the silt formations as low-energy accumulations of river endpoints (Marker, 1977; Marker & Müller, 1978; Vogel, 1982; Eitel & Zöller, 1995; Rust, 1999; Eitel *et al*. 2005). Continuous headward retreat of endoreic streams is described to result in successive upstream deposition of their suspension load. This model accounts for the unchannelled nature of the aggradational surfaces.

Aeolian loess accession: An alternative working hypothesis is presented here. This takes into account the recently established accumulation of loess mantles in the Flinders Ranges from the deflated bed of Lake Torrens (Williams & Nitschke, 2005) and in the Great Escarpment from the western Kalahari (Eitel *et al.* 2001). According to this hypothesis, the silty unchannelled aggradational surfaces are the result of aeolian loess accession. Loess has the capability to absorb precipitation and runoff (Yair, 1987, 1994) and could therefore absorb weak intermittent rainfalls associated with cold fronts embedded in the prevailing westerly winds. A moist surface could sustain grass growth and successfully entrap loess. Net deposition is further believed to be enhanced by diurnal mesoscale wind circulations such as sea- and salt lake breezes, anabatic valley winds and nocturnal katabatic drainage flows (Tapper, 1991; Schwerdtfeger, 1996; Sturman & Tapper, 2006) and the interception by grassy vegetation growing upwards as dust accretion proceeds (Pye, 1995). Laminated successions such as at the 'Slippery Dip' type locality are interpreted as areas of seepage that were able to sustain prolonged growth of cryptogamic crusts (Verrecchia *et al.* 1995).

Each morphodynamic sedimentation model stipulates different palaeoenvironmental settings. High-energy flood deposits suggest intense precipitation events. The laminated stratigraphies would therefore represent palaeofloods. Low-energy floodout or 'river-end deposits' would indicate the shortening of the river course by decreasing runoff and reflect a successive aridification of the upper catchment. Aeolian loess accession suggests a stable low-energy rainfall regime and draws attention to the influence of wind-blown material on catchment hydrology. In order to infer palaeoclimatic, palaeohydrologic and palaeoenvironmental conclusions from these exceptional late Pleistocene terrestrial records, the processes responsible for their aggradation and subsequent erosion have to be fully resolved.

CHRONOMETRIC APPROACH

So far, all sedimentological studies describing the lithology, sedimentary structures, particle-size distribution, mineral composition, sediment colour, carbonate and microfossil content have failed unambiguously to establish their depositional environment. This may be due to the allochthonous, uniform aeolian source of the sediments (Eitel *et al*. 2001; Williams & Nitschke, 2005) and post-depositional bioturbation (Smith *et al.* 1993). In the absence of sedimentological and lithological evidence, an alternative way to determine the morphodynamic modus operandi responsible for the genesis of the fine-grained valley-fill formations is suggested here. By establishing a chronometric transect along the talweg of these formations, their former aggradation can be traced and quantified over space and time.

The three valid hypothetical morphodynamic sedimentation models can be expected to result in unique temporal-spatial deposition patterns. By combining detailed mapping of lithofacies associations with radiometry and luminescence dating, each model can be distinguished and tested. High-energy flood deposits are characterised by a synchronous deposition of thick sedimentary sequences over great expanses along the main channel and into the mouth of tributaries (Zawada, 1997). Given that the depositional mode is event-driven, ages of discrete sequential tabular bedding planes should produce the same age within their lateral and vertical expanse. Low-energy floodout deposits on the other hand are characterised by a gradual upstream migration of the sedimentation focus. Therefore, ages of specific aggradational surfaces or continuous discrete bedding planes should decrease along the main channel in an upstream direction. Thick sedimentary units are expected to represent a sequence of low-energy, low deposition run-off events. Hence, dates derived from samples of the upper and lower limit of any discrete unit should differ and reflect more continuous sedimentation rates. In contrast, loess deposits blanket the landscape. Their net deposition rate varies according to the local topography, surface properties and the path of dust storm events. But deposition of discrete units can be expected to be gradual and synchronous along the main channel and in adjacent tributaries.

CONCLUSION

Continuous high-resolution terrestrial records covering the culmination and termination of the last glacial cycle from the semi-arid mid-latitudes of Australia are scarce. Recently, loess-derived valley-fill formations in the central Flinders Ranges have been identified and dated to cover the late Pleistocene by a continuous sedimentary sequence. These formations could be linked to similar well-studied silt terrace remnants in Namibia. However, their former morphodynamic depositional environment remains controversial and needs to be firmly established before any further palaeoclimatic and palaeohydrologic conclusions can be inferred.

Because of their uniform allochthonous nature, sedimentological studies alone could not resolve their genesis. By applying a chronometric approach to reconstruct the temporal-spatial deposition patterns along a transect covering the range of fine-grained lithofacies assemblages along the talweg, conclusive evidence for any specific mode of morphodynamic processes can be derived. Current research by the author has the aim to resolve the ongoing international discussion on the formation and termination of these conspicuous late Pleistocene fine-grained valley-fill formations, which are typically being eroded under present day semi-arid to arid climatic conditions. In addition, quantifiable conclusions on the distribution and hydrologic characteristics of mid-latitude synoptic climatic circulation patterns prior to the Last Glacial Maximum and during the dramatic deglacial termination can be expected from the presented approach.

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