ICE, WIND AND WATER: LATE QUATERNARY VALLEY-FILLS AND AEOLIAN DUST DEPOSITS IN ARID SOUTH AUSTRALIA

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The Australian landscape is a palimpsest of old and new. One of the characteristics of this landscape is the juxtaposition of very ancient and very young landforms. Nowhere is this better displayed than in the more arid parts of the continent. Consider, for example, the Flinders Ranges of South Australia. The eastern and western margins of these rugged ranges are mantled by a relatively thick sequence of Cenozoic lacustrine, aeolian and alluvial deposits (Williams 1973). Within the ranges proper, fine-grained valley-fill deposits of late Quaternary age directly overlie quartzites, argillites and limestones that range in age from Cambrian to Proterozoic, with no rocks of intermediate age. This paper discusses the age, origin and significance of these late Quaternary valley-fill deposits.

Streams within the semi-arid Flinders Ranges are active today only during rare, mostly summer, downpours, when they transport boulders, gravel and coarse sand. They are quintessential desert streams: ephemeral or highly seasonal, with coarse traction loads of sand and gravel. In strong contrast, the late Quaternary valley-fill deposits within the ranges consist primarily of clay, silt and very fine sand, and have been incised by present streams to form terraces and terrace remnants. Such clay-rich deposits are not accumulating today. In and upstream of Brachina Gorge, in the central ranges, these remnant valley-fills are exposed in bank sections up to 18m high.

The valley-fill sediments contain ostracod and gastropod shells and charcoal fragments, and were laid down under very different climatic conditions to the present. Williams *et al.* (2001) dated these sediments using a combination of AMS radiocarbon dating and OSL dating. The sediments are 33,000 years old near the base and 17,000 years old near the summit. They appear to have accumulated as floodplain deposits in perennially wet grassy meadows.

The time interval 33-17 ka was a time of widespread desiccation and regional aridity in Australia. Many of our larger lakes were drying out (Lake Eyre, the Willandra Lakes) and desert dunes were active. The interval spans the Last Glacial Maximum (LGM), here taken to be the 6000-year interval between 18,000 and 24,000 calendar years, equivalent to 15,000-21,000 radiocarbon years BP. The LGM was a time of lower temperatures and enhanced aridity within the sub-tropics in both hemispheres. We therefore need to ask how a perennial wetland could develop and persist for so long in this arid environment, and why the sediments within it were so fine-grained.

PALAEOHYDROLOGY OF THE LATE PLEISTOCENE WETLAND IN THE CENTRAL FLINDERS RANGES

We noted above that fine silt and clay-rich valley-fills accumulated for a period of 15,000 years between 33 ka and 17 ka. The key issue is how a wetland could exist during peak regional activity when the majority of lakes were drying throughout Australia. As a first approximation, we used a simple water balance model based on extrapolation of present day climatic conditions, and ignoring possible seepage gains and losses (Chor 2002). For the wetland to remain saturated, water losses from evaporation and runoff must balance water inputs from runoff and precipitation directly onto the wetland surface. Thus:

$$A_c P_c k + A_w P_w = A_w E \qquad (1)$$

Where A_c is the catchment area, P_c is the mean annual precipitation over the catchment, k is the runoff coefficient, A_w is the surface area of the wetland and E is the mean annual surface evaporation from the wetland.

We first developed a set of regression equations relating present-day mean monthly evaporation to mean monthly temperature for a number of stations in and around the Flinders Ranges.

Secondly, we evaluated the late Pleistocene evaporation in relation to what glacial age temperatures may have been. Regional temperatures during the LGM were thought to be at least 6°C lower than at present (Galloway

1965) and studies by Miller *et al.* (1997) and Barrows *et al.* (2001) suggest temperatures may have been as much as 8°C to 10°C colder. The lower temperatures would imply reduced evaporation.

Thirdly, our analysis involved removal of summer extreme precipitation events and removal of summer precipitation from mean annual precipitation. This modification is designed to mimic a very much weaker summer rainfall regime during the LGM (Williams *et al.*, 2001). Studies on emu eggshell fossils in the Lake Eyre region by Johnson *et al.* (1999) indicated the absence of C_4 grasses from the emu's diet. These grasses are dependent on summer monsoonal rainfall and their absence would imply the absence of summer rainfall. Also, studies on biogenic material in drainage basins in the Kimberley region of northwestern Australia indicated that the onset of an active summer monsoon began about 14,000 years ago following a weak to absent summer monsoon before then (Wyrwoll & Miller 2001).

Fourthly, we adopted the water balance equation used by Bowler (1981, 1986) in his hydrological modelling of lakes, substituting wetland area for lake area. The runoff coefficients we adopted were based on Australian basin data given by Bowler (1986) and studies on runoff characteristics in arid western New South Wales where rainfalls greater than 20 mm produce surface runoff but with runoff rarely exceeding 10% (Pilgrim *et al.* 1979).

Finally, we measured the saturated soil water content of the valley-fill sediments in the laboratory and used data from Marshall *et al.* (1997) to calculate potential water losses from River Red Gums using mapped data on the numbers of present day River Red Gums in part of the former wetland.

The simple hydrological model used in this study was effective in showing that lowered evaporation may have been sufficient to maintain a wetland during peak regional aridity. Refinements in the model are required, such as groundwater inputs and outputs, efficiency of present day runoff, effects of a dust mantle on infiltration, and evapotranspiration of vegetation.

IDENTIFICATION AND SIGNIFICANCE OF AEOLIAN DUST MANTLES IN THE FLINDERS RANGES

Williams *et al.* (2001) noted the presence of discontinuous layers 5-30 cm thick of red-brown fine sandy clay and silty clay on the summits of almost every quartzite and argillite ridge examined. Irrespective of underlying lithology, these red-brown clays occur sporadically across hillslope and footslope. From their uniform colour, lithology, field texture and ubiquitous distribution, they inferred that these red-brown clays were the remnants of formerly continuous aeolian dust mantles blown in from the west during times of greater dust flux.

In an attempt to test this hypothesis quantitatively, we collected a series of samples from a variety of localities for analysis. Samples came from *in situ* bedrock argillites, from the valley-fill sediments, from the red-brown clays on the summits of quartzite, limestone and argillite hills and from the uppermost beds in the Lake Torrens playa system to the west of the ranges (Nitschke 2002). These latter samples came from Lake Torrens Bore No. 3, Moonta Drill Core Library, Primary Industries and Resources, Adelaide, South Australia.

Particle size analysis revealed that the ridge-top samples are well-sorted silty clays to fine sandy clays, with a significant particle population in the 2-23 μm size range, irrespective of underlying bedrock lithology. Kaolinite and illite dominate the clay mineral suite in the ridge-top samples. The trace elements Zr, Ti, Th, La, Ce, Y, Cr and Nd are enriched in the ridge-top samples compared to the underlying bedrock. $^{143}Nd/^{144}Nd$ ratios of the ridge-top, valley-fill and Lake Torrens samples show clear correlation with the argillite Bunyeroo and Brachina Formations. $^{87}Sr/^{86}Sr$ residue ratios show a similar pattern, with ridge-top, valley-fill and Lake Torrens samples similar to the Bunyeroo and Brachina Formations. $^{87}Sr/^{86}Sr$ leachate ratios are notably lower, ranging from 0.710 to 0.715, reflecting the influence of the limestone rock units in the Flinders Ranges as well as calcareous aeolian dust of marine origin. Except for one sample, the Lake Torrens samples have the same clay mineral suite, similar major and trace element geochemistry patterns and similar $^{87}Sr/^{86}Sr$ and $^{143}Nd/^{144}Nd$ ratios as the ridge-top and valley-fill samples along with the Bunyeroo and Brachina Formations.

The particle size, geochemical and isotopic data all imply a significant recycling of sediment between the Flinders Ranges and Lake Torrens. We suggest that during regionally drier intervals fine sediment is blown eastwards from the Lake Torrens playa to form the ridge-top and hillslope aeolian dust mantles, later reworked by slope wash and incorporated into the fine-grained valley-fill deposits. During more humid phases fine sediment is ferried westwards in streams flowing out from the western ranges and laid down in the Lake Torrens depocentre. We therefore conclude that the fine-grained late Pleistocene valley-fill in the central ranges contains some material derived from the weathered argillites within the catchment and some material blown in from the west as aeolian dust.

One further point deserves mention. Aeolian dust or parna mantles are widespread in southeastern Australia but seldom attain more than a metre or two in thickness (Butler & Hutton 1956, Butler 1982). More commonly, the dust component is incorporated into the regolith (Chartres *et al.* 1988, Greene *et al.* 2001, Gatehouse *et al.* 2001). Even the well-known Coonawarra Terra Rossa soils, once thought to have formed by weathering of the underlying limestones *in situ*, are in fact dominated by local aeolian dust (Mee *et al.* in press).

Prompted by the experimental observations of Yaïr (1994) on loess-mantled in the northern Negev Desert of Israel, we are led to ask what impact these aeolian dust mantles may have had upon local runoff in the Flinders Ranges. In particular, did aeolian dust mantles alter the hydrological responses of desert hillslopes to precipitation events during the late Quaternary? We know that during the late Quaternary and earlier, extensive wind-blown dust mantles accumulated on desert hillslopes in every continent, especially Africa, Asia and Australia. The most recent phase of Aeolian dust accretion spans the LGM at 18 ka and may have lasted from about 30 ka to 15 ka. We consider that these aeolian mantles may have altered hillslope runoff sufficiently to mask the direct influence of late Quaternary climatic fluctuations upon the landscape. The putative sequence of events is as follows:
1. Bare impermeable rock surfaces become covered by permeable aeolian silts;
2. Hillslope infiltration is increased and runoff reduced;
3. Increased base flow and fewer flash floods;
4. Change from bedload to suspension load transport; increase in fine-grained sediment supply; and,
5. Widespread alluviation in valley bottoms and progressive accumulation of fine-grained valley-fills.

The end result of these processes is a change from deposition of coarse sand and gravel bed-loads by ephemeral or highly seasonal late Quaternary desert rivers to a depositional regime characterised by fine-grained and widespread alluviation in the valley bottoms. If this hypothesis is correct, we should expect to find fine-grained late Quaternary valley-fills well beyond the confines of the central Flinders Ranges. Limited evidence suggests that this may indeed be so in western New South Wales (Williams *et al.* 1991, Fanning 2002, Keating 2002).

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