Hidden in the sands of time:
geoarchaeology of sandstone landscapes
in the Keep River region, Northern Territory, Australia

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CHAPTER EIGHT

Conclusions and Suggestions for Further Research

If we define archaeology quite broadly as the application of all current knowledge and techniques to the study of all past knowledge and techniques, then archaeologists are compelled to communicate with their disciplinary neighbours.

- Boddington et al. (1987: 3)

8.1 Introduction

The following discussion summarises the major results of the thesis bearing in mind the initial aims of the thesis (refer 1.5). These aims include a consideration of a geoarchaeological approach to archaeological studies in northern Australia, and the environmental context of the Keep River region; estimations of denudation rates of the sandstone escarpments and accumulation rates of the adjacent sand sheet accumulation using both in situ cosmogenic dating and luminescence dating; an analyses of the rock-shelter, sand-sheet and creek sediments; and finally an evaluation of the chronological and contextual relationship between the landscape and its archaeological record at the site specific and regional level. The chapter themes are further explored in suggestions for further research.

8.2 Summary and Major Conclusions

A range of empirical and observational data generated from within this study and from external sources were used to establish the geomorphic context and provide a geoarchaeological interpretation of archaeological sites in the Keep River region. Specifically this includes describing the landscape context (regional environment and landscape processes), the stratigraphic context (chronostratigraphy), site formation (cultural and natural processes), and the archaeological context (landscape use and modification). The main geomorphic focus is on the sand sheets, which
represent both the landscape on which people lived and the link between the sandstone escarpments and rock shelters.

The Keep River region is a good example of an ancient (Ma) landscape located in a presently semi-arid monsoonal environment, consisting of palimpsest features formed over time under different environmental regimes, upon which are etched the more recent (ka) geomorphic and human landscapes. The regional geological, geomorphological, palaeoclimatic and ecological context of the Keep River region underpin the geochronologic and geoarchaeological interpretations but are somewhat constrained by the limited record for northwest Australia. In particular, the origin of sand sheets is uncertain. In Arnhem Land there is geomorphological evidence for recurring periods of sand sheet accumulation and denudation over the past quarter of a million years, in association with climatic interglacial and glacial cycles (Roberts, 1991). There is also evidence in that region of northern Australia becoming progressively drier over that time (Nanson et al., 1993). Although the climate in the Keep River region has remained essentially semi-arid monsoonal, it too has probably gradually become more arid and the denudation of sand sheets less extensive. In situ cosmogenic dating and luminescence dating indicates that the bulk of the present sand sheets have accumulated in the past 100 ka, but it is likely that, as in Arnhem Land, this is simply the latest episode in a series.

Measurement of in-situ cosmogenic $^{10}$Be and $^{26}$Al in the local eroding plateau surfaces and depth profiles of genetically linked sand sheets provided useful quantitative measures of long term ($10^3 – 10^5$ ka) processes in the Keep River region. Spatially averaged rates of plateau denudation range from 4 - 7 mm.ka$^{-1}$ and are consistent with regional estimates. These denudation rates are used primarily for burial dating. Cosmogenic burial dating of two sediment profiles from the Jinmium sand sheet indicates net vertical accumulation of sediment ranging from 10 to 20 mm.ka$^{-1}$ over the past few hundred thousand years. A high $^{10}$Be concentration at the base of one sediment profile indicates the sand sheets have probably accumulated over a previously exposed pediment.
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Disparity of longer and shorter term dynamics is indicated from the significantly greater accumulation rates measured from luminescence dating (100 – 200 mm.ka\(^{-1}\)) compared to that estimated from burial dating. This partly reflects the chronometric sensitivity of each dating technique to sedimentary processes, in particular mixing, and the timescales over which the measure of these processes are integrated.

The processes of weathering and sedimentation within the sand sheets of the Keep River region have been investigated using evidence from grain size, mineralogy, geochemistry and micro-morphology. Sediment characterisation provides limited information of landscape change because the sandstone source material and depositional and post-depositional processes in the genetically linked sands have remained relatively constant over the past 100 ka. The exploratory analyses indicate that the sediments are locally sourced, with little geochemical differentiation between the bedrock (source) and the sand sheets and rock-shelters (sinks). The sand-sheet sediments represent a mixture of sediment populations derived from local drainage basins. The rock-shelter sediments have higher relative concentrations of calcium (CaO), phosphate (P\(_2\)O\(_5\)) and organic matter (LOI) than the surrounding sand-sheet sediments, reflecting higher levels of charcoal, guano and organic matter. Post-depositional reddening of the sediments, evident both at the macro (cm) and micro (\(\mu\)m) scale reflect the relative position of groundwater rather than depositional age. Ongoing processes of weathering and diagenesis are evident in the form of mixing, and in the development of mottles and concretions. At least one palaeosol horizon dating to 13.9 ± 0.4 ky BP is evident at the Sandy Creek Gorge site, with deep root mottles, pisolites, potassium-enriched sediments, and peculiar indurated silicate deposits all indicating the prior existence of a forest community at this site, which now supports grassland. The facies changes evident in the finer-grained sediments in Sandy Creek Gorge are not evident in the contemporaneous but more unconsolidated sand sheet sediments elsewhere in the Keep River region.

The chronostratigraphy of the rock shelters, sand sheets and creek profiles in the Keep River region has been investigated using both thermoluminescence (TL) dating and optically stimulated...
luminescence (OSL) dating. For both the sand sheets and creeks the U- and Th- decay series indicate relative equilibrium. However, the lateritic nature of the sediments indicates past or present changes in the hydrological environment and potential radioactive mobility cannot be disregarded. The mean dose rate determined from thick-source alpha counting (TSAC) is 1.3 ± 0.29 Gy.ky⁻¹ with significantly higher values of 3.0 ± 0.83 Gy.ky⁻¹ for the mottled sediments at Sandy Creek Gorge, reflecting higher concentrations of U, Th and K in these samples. The palaeodose analyses indicate that the sand sheets are generally well-bleached but the rock-shelter and creek sediments show evidence of partial bleaching during deposition. Foreshortened and stepped TL temperature plateaux relating to some sand sheet and creek profiles may be indicative of stochastic depositional events, which may be more widespread but are seldom preserved or deciphered in the relatively uniform sand sheet sediments. Oddly, OSL palaeodose estimates may be up to 20 % greater than the corresponding TL estimate and tests indicate the potential for partial loss of the 325°C TL signal under prolonged yellow light illumination (2 - 3 hrs). Consequently, OSL ages are considered more reliable estimates of depositional age.

The Jinmium, Goorurarmum and Karlinga rock-shelters all comprise sediments and associated cultural sequences that are mid-Holocene in age. Basal OSL ages for the Goorurarmum and Karlinga rock shelter are 0.3 ± 0.07 ky BP and 18.4 ± 5.4 ky BP, although a radiocarbon age of 4080 ± 40 ky BP for the latter is preferred. In contrast, the sand sheets provide cultural sequences from the LGM and non-cultural sequences extending beyond 100 ka. Basal OSL ages for the Goorurarmum and Karlinga sand sheet excavation are 14.3 ± 0.4 ky BP and 18.0 ± 0.6 ka respectively. The cumulative chronological record for the Keep River region indicates temporal continuity between the Pleistocene and Holocene sequences, but within and between sites the sedimentary record is temporally and spatially discontiguous. The intermittent and localised accumulation of sediment results in the formation of time averaged assemblages of material remains. Both individual site records and regionally combined records indicate a progressive increase in the rate of sediment accumulation from ~ 100 mm.ka⁻¹ in the late Pleistocene to over 200 mm.ka⁻¹ in the Holocene. Preservation of organic horizons in a creek site at Karlinga are indicative
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of infilling of a small alluvial swamp around 10 ka. The increase in sedimentation most likely results from enhanced monsoonal activity following the post-glacial marine transgression rather than human activity.

The preceding geoarchaeological results were integrated with the information from radiocarbon analyses, palaeobotanical studies, rock-art studies and regional archaeology. Luminescence dating from this study supports previous chronological estimates for the commencement of seed processing (Atchison, 2000; Atchison et al., in prep.), the introduction of stone points (Fullagar et al., 1996; Boer-Mah, 2002), and an increase in rock art (Watchman et al., 2000; Ouzman et al., 2002) around 3 – 4 ka. Whether these trends reflect ‘intensification’ or preferential preservation of archaeological material is illustrated by showing a correlation between the rates of sedimentation and the rates of stone artefact accumulation in two sand sheet excavations. Stratigraphic and depositional resolution defines the integrity of the sedimentary and archaeological records. Combined radiocarbon and luminescence dating indicates that whilst occupation from the Last Glacial Maximum (LGM) cannot be discounted (at least in the Karlinga area), the majority of occupation records preserved in the Keep River region are Holocene. However, this partly reflects sampling bias as more rock shelter sites (8) have been sampled in this region than open sites (2). Present records indicate a possible connection of the Keep River region with the east Kimberley ‘refuge’, which provided reliable networks of water during the climatic oscillations of the last 40 ka.

Few individual sites can provide a complete record of both palaeoenvironmental and archaeological changes (e.g. Thomas et al., in press). Discrete records were obtained in this study from non-occupational (riverine) and occupational (rock shelters, sand sheets) sites, but the chronostratigraphic coincidence is not always obvious in these unconsolidated sandy sediments. The issues and interpretations outlined above are not unique to the Keep River region, or to northern Australia. The issues and interpretations outlined above are not unique to the Keep River region, or to northern Australia. The human-landscape story is well hidden in the sandstone
landscapes of the Keep River region, at least according to the chronological and sedimentological methods used in this study. Higher resolution analyses may discern landscape changes that are more responsive to human-environmental interactions. This geoarchaeological study in the Keep River region has offered the opportunity to at least begin to relate past and ongoing chronological, palaeobotanical, rock art, stone artefact, ethonographic studies, and explore associations between the changing environment and the archaeological record. The following suggestions for further research are a continuation of these explorations.

8.3 Suggestions for Further Research

8.3.1 Regional Environment

In dry savannas throughout the world, detailed information on Quaternary landscape evolution remains rather incomplete, due to the absence of productive sedimentary archives (Heinrich and Moldenhauer, 2002). Consequently, it becomes difficult to understand the various influences on the stratigraphic and archaeological record, and to consider long-term human-environmental interactions. The stratigraphic and depositional resolution in the Keep River region provides an indication of landscape dynamics over timescales of hundreds to thousands of years. It would be useful to obtain and understanding of landscape processes over timescales of only tens of years, as exemplified in the Selima sand sheets, Egypt (Maxwell and Haynes, 2001).

The period around 4 ka corresponds to the pluvial maximum (Schulmeister, 1999) and is followed by a drier, albeit more variable climate (refer 3.5.3). The period around 4 ka is regarded as one of ‘intensification’. Did the pluvial conditions facilitate a larger cultural network via the drainage basins connecting Arnhem Land and the Kimberley (Lewis, 1988), and an expansion of the classic Bradshaw rock art into the Keep River region? What are the chronostratigraphic connections between these drainage basins? Whilst providing more favourable conditions for occupation, do
pluvial conditions decrease the preservation of these records? Part of the answer may derive from combined proxies of both dry and wet occupation sites (e.g. Thomas et al., in press) and from more detailed research of formation processes in these sandy sediments. The geoarchaeological paradigm is that some archaeological questions can be answered, at least in part, by appropriately framed geological studies (Stein and Farrand, 1985).

8.3.2 *In situ* Cosmogenic Isotope Dating

Future prospects for exposure age dating have been outlined generally by Watchman and Twidale (2002). Although the research for this thesis indicates a relatively consistent plateau denudation rate of 5 – 6 mm.ka⁻¹ for northwest Australia, continued sampling and analyses of sandstone and other rock formations would improve the resolution within and between geomorphic regions. Using plateau denudation rates this study has derived estimates for erosion of the escarpment faces around 50 – 100 mm.ka⁻¹, but it would be more valuable to obtain direct measurements of vertical escarpment retreat rates from *in situ* cosmogenic dating. These estimates may in turn provide a more accurate assessment of the potential rates of erosion of rock art, and allow determination of the relative contributions of source material from the plateaux and escarpment faces to the adjacent sand sheets.

Whilst the theory and application of burial dating is still relatively undeveloped, early research heralds significant potential for geoarchaeological studies. Burial dating of sand sheets in the Keep River region indicates that modelling of accumulation rates can be obtained over depths of less than 10 m and time periods of 100 ka or more. With improved modelling of both the neutron and muon components, better resolution may be obtained from deeper and older sediment profiles, particularly with the inclusion of underlying bedrock, allowing differentiation not only of allochthonous and autochthonous sediment accumulation, but also of periods of erosion and accumulation. With further understanding of shielding factors, similar advances may be made in open rock shelters, and closed cave systems, particularly where combined with higher-resolution luminescence dating.
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Northern Australia is particularly well-suited for such research given the geological antiquity, relatively open landscape, and the purity of the siliceous sands.

8.3.3 Luminescence Dating

The results of luminescence dating of the sand sheets have improved the chronological understanding of each of the archaeological sites studied. TL dating is acceptable for well-bleached sites but OSL dating is preferred for rock shelter and riverine sites. Whilst OSL dating techniques are increasingly preferable for dating because of developments in the use of small aliquot and single-grain OSL analyses and remaining problems with use of yellow illumination in TL, this study illustrates that there remains potential for using the characteristic TL spectra to identify differences in sedimentary provenances and processes, such as events of rapid deposition. In order to distinguish cultural and non-cultural processes, including changes in sedimentation rate, higher resolution dating is needed from occupation and non-occupation deposits. In addition, basal ages from the sand sheets are required to obtain more accurate estimates of volumetric rates of accumulation.

Members of the uranium- and thorium-series differ greatly in their chemical mobility and are subject to post-depositional migration, which potentially affects the accuracy of the geological dose-rate (Roberts, 1996; Roberts and Plater, 1999). Although this study did not find any significant degree of disequilibrium despite the presence of sediment mottling, a more accurate measure of disequilibrium in lateritic sandy sediments of northern Australia is needed. Detailed examination of selected sediment phases, particularly the amorphous- and crystalline-iron and manganese oxides and oxyhydroxides, may help identify and quantify the degree of post-depositional radionuclide migration and in situ chemical weathering. Further examination of the different chemical behaviour of radioisotopes of the uranium- and thorium-series should also provide a more accurate assessment of post-depositional environmental conditions, such as water-table fluctuations and exposure to oxidized and/or reduced waters.
8.3.4 Sediment Characterisation

Preliminary investigations from this study indicate that discriminating cultural and non-cultural processes in sandy sediments of semi-arid monsoonal environments require a more detailed investigation than undertaken in this study. The intensely weathered nature of the sandstone landscape of the Keep River region means that many indicators of weathering (e.g. heavy minerals, carbonate or organic content) is of limited use. Basic sediment characterisation (e.g. grain size, mineralogy, major element chemistry) can provide useful contextual information, and further sediment characterisation might include more details such as minor element chemistry, sediment pH, moisture, magnetic characteristics, compaction and micromorphology.

Whilst this study was able to obtain resin impregnated samples from the sand sheets, comparative micromorphological studies of the rock shelter sediments is necessary. Resin impregnation of samples in the field is preferable, but this research has shown that this may suffer because of the hydrophobic nature of charcoal-enriched sediments, particularly in the rock shelters. Future studies may need to consider use of polyester resins rather than the epoxy resins used in this study. Unlike epoxy resins, polyester resins are not exothermic and can be diluted with acrylic monomers that reduce surface tension and facilitate better the impregnation of loose sediments (Magee, pers. comm., 2003).

The analysis and interpretation of palaeosols at Sandy Creek Gorge indicate that palaeosols may be a prospective source of stratigraphic and palaeoenvironmental information. Palaeosols have been used as a source of stratigraphic and palaeoenvironmental information to archaeology in many parts of the world (Holliday, 1989; Bettis, 1992; Evans, 1995) but remain relatively unexploited in Australian research (Bowman, 1987), despite the recognition of discrete paleosols and relict features (exposed silcrete, ferricrete, etc.) throughout the landscape (Firman, 1994; Young and Young, 1992), and the recognition of silcrete as a component of stone artefact assemblages in some parts of the continent (Hughes et al., 1973; Sullivan and Simmons, 1979).
8.3.5 Archaeological Comparisons

Geoarchaeological investigations provide a means for reconstructing prehistoric and ancient landscapes, depositional environments, and paleoclimatic regimes. Despite arguments that archaeological and geological records preserve and overlap differently over space and time (Dincauze, 2000), studies are showing that environmental and archaeological changes can be explored using multi-proxy data from different environmental contexts.

Many archaeological issues relate specifically to the nature of basic physical, chemical, biological and human properties and processes, to morphological and sedimentological changes on timescales ranging from months to millennia, and at spatial scales ranging from tens of metres to tens of kilometres. Consequently, there remains a great need to quantify all these processes in semi-arid monsoonal sandy terrains in Australia and elsewhere (e.g. Ward and Larcombe, 2003).

Theoretically, according to Lourandos (1997: 194), arid and semi-arid landscapes allow fairly good visibility of archaeological sites, and of the possible historical events that occurred within them. In practice, however, neither archaeological sites nor their formation history are obvious. Indications arising from this study are that semi-arid monsoonal sandy environments comprise a discontiguous palimpsest record of the most durable sedimentary residues (mainly inorganic minerals) and of cultural residues (mainly stone artefacts). The distributions of both these residues have been influenced by diverse natural and cultural formation processes, which remain largely unknown and unquantified. Whilst it is virtually impossible to account for all the various individual processes, and combinations of processes that influence archaeological site formation, it is useful to move towards investigating and quantifying some of the most significant processes (Ward and Larcombe, 2003).