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

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CHAPTER THREE

Regional Setting

The land is my foundation. – Fox (1983: 27).

3.1 Introduction

Situated in the far north western corner of the Northern Territory, the Keep River region is a good example of an ancient landscape in a presently semi-arid monsoonal environment. Superimposed over the ancient landscape features are the more recent (Quaternary) geomorphic features that bear the human-land record. The following discussion outlines the regional geological and environmental setting of the Keep River region, and summarises the modest amount of available palaeoclimatic information for this part of northern Australia. As implied by Fox (1983), the geological, geomorphological, ecological and climatic background provides the foundation for subsequent local geochronologic and geoarchaeological interpretations.

3.2 Geological Setting

3.2.1 Bedrock Geology

The Keep River region is geologically younger than both the Kimberley to the west and the Victoria River District (VRD) to the east (Whitehead and Fahey, 1985) (Fig. 3.1). The geology of the Keep River region is dominated by a basement of sandstone, shale and conglomerate, overlain by alluvial sediments deposited by the Ord and Keep Rivers (Kinhill, 2001). Whilst some consider the Keep River region more typical of the eastern Kimberley than northwestern Victoria River and Arnhem Land (Tacon et al., 1999), others argue that the Keep River region is neither (culturally?) part of East Kimberley, nor is the bedrock as durable as that in the north west Kimberley (Walsh, 2000).
In the study area the geology takes the form of extensively weathered sandstone bluffs and low sandy ridges, separating red earth and black soil (cracking clay) plains (Fig. 3.2). These plains include the Keep River Plain, Weaber Plain and Knox Creek Plain, which are to be developed under ORIA Stage II (Fig. 1.3). Detailed descriptions of the geology of the Ord River area can be found in Traves et al. (1970), Dow and Gemuts (1969), Mory and Beere (1988), and of the Keep River National Park in Whitehead and Fahey (1985).
Please see print copy for Figure 3.2

Figure 3.2  Geology of the Keep River region, combining the Cambridge Gulf (Sheet 5214, BMR 1970) and Auverne (Sheet 5215, BMR 1975) 1: 250 000 mapsheets. Project area and major site locations are marked.
The overall depositional environment of the Keep River region has changed from a continental-fluvial environment in the Palaeozoic to a terrestrial environment in the Quaternary (Whitehead and Fahey, 1985). The basal members, such as the Kelly’s Knob Sandstone Member, comprise conglomerate and pebbly quartz sandstone (Fig. 3.2) formed in a near-shore shallow marine environment during the Devonian. Subsequent deposition of different sediments was determined by varying influxes of terrigenous material, reflecting the continued faulting and uplift of various source areas throughout the Early Carboniferous. Calcareous sediments (dolomite, limestone) were deposited in an environment with significant terrigenous input (shale, sandstone) to make up the Burt Range Formation. Between the Early and Late Carboniferous further uplift of the southeast portion of the Bonaparte Basin supplied coarse terrigenous sediments to river valleys, channels and plains, resulting in the sandstone, conglomerate and siltstone deposits of the Border Creek Formation (Fig. 3.2).

Throughout northern Australia, including the east Kimberley (Young, 1992), Darwin region (Nott, 1994b), and in nearby Arnhem Land (Roberts, 1991), exhumed landforms and palaeosurface remnants are explained in the context of structural controls and subsequent deep-weathering. The major rock outcrops in this study belong to the Border Creek Formation (Jinmium, Weaber Range) and Kelly’s Knob Sandstone Member (Goorurarmum). The general shape and location of these outcrops are considered to be manifestations of spirit figures which crossed the landscape during the ‘dreaming’ (Atchison, 2000). One of the more dominant outcrops is the escarpment (Fig. 3.3) at Wulurungu (eastern Weaber Ranges) which represents Walujapi, a female Black-headed Python (*Aspidites melanocephalus*). The rock shelters situated along the Keep River escarpments are a feature relict of a landscape that has undergone dramatic changes in sea level (Woodroffe, 1993) and climate (Lees, 1992b; Nott and Price, 1994, 1999; Schulmeister, 1992) over tens of thousands of years.
3.2.2 Soils and Sediments

Quaternary sediments comprise alluvium, including from the Keep River; unconsolidated sediments, which formed in shallow depressions and drainage channels; and black humic soils, which form on poorly drained floodplains (Whitehead & Fahey, 1985). Indications from analogous sand sheets in Arnhem Land are that the development of the sand sheets over the past quarter of a million years has been cyclical with periodic accumulation during periods of high sea level and extensive gullying and denudation during periods of low sea level (Roberts, 1991). At any particular glacial maximum, gullies will erode some sites more than others to leave aprons with a mosaic of sediments of different basal ages (Roberts, 1991: 303). The present sand sheets in the Keep River region are probably representative of the most recent phase of sand accumulation. Uncertainty regarding the geomorphological foundations of the sand sheets is considered in Chapter Four.
The two archaeological site areas of Karlinga (Wulurungu) and Goorurarmum are part of the Cockatoo Land System, and are separated by sediments of the Ivanhoe Land System (Fig. 3.2). The Cockatoo Land System represents former landscape remnants that comprise red-brown earths (Bonaparte) and red-earths (Weaber). The sediments can be described as oxisols (Stace, 1968), with deeply weathered soils having uniform profiles dominated by resistant minerals, particularly quartz, and some deeply weathered mottled horizons (plinthite). Typically these soils are vegetated by eucalypt woodland to open forests but, as in Arnhem Land (Roberts, 1991), most of these sediments have little organic matter due to loss of plant material in the dry season fires and the rapid decay of organics in this tropical climate. The Ivanhoe Land System comprises cracking clays (gilgai) considered to be of Holocene origin (Aldrick and Moody, 1977). The vegetation on these soils is variable; common communities include open grassland (*Themeda australis* and *Sehima nervosum*), and open Acacia shrubland.

Soil distribution is also influenced by the course of present and prior streams, with soils adjacent to freshwater creeks and abandoned channels, such as those alongside Sandy Creek, more typical of quartz-rich spodosols. According to Aldrick and Moody (1977) soil distribution is most apparent in the succession of vegetation with a progression toward treelessness as the soil conditions become less favourable as a result of increasing salinity or aridity. The succession is thought to have occurred under the influence of dynamic changes in soils and fluvial hydrology, and later, to anthropogenic influences associated with fire and overgrazing. Further details of soil studies relevant to ORIA Stage I and II can be found in the draft Environmental Impact Study (EIS) of Kinhill (2001).
3.3 Geomorphological Setting

Modern coastal and offshore geomorphology contains strong elements of Quaternary inheritance, with topography closely resembling that of the adjacent landmass (Van Andel and Veevers, 1967; Woodroffe et al., 1992). Detailed reconstruction of the modern coast and adjacent Joseph Bonaparte Gulf thus provides an important background for geoarchaeological research.

3.3.1 Late Pleistocene

The Keep River region lies within the Ord-Victoria geomorphic region outlined by Paterson (1970). The basement rock underlying the Keep River and Weaber Plain is for the most part undifferentiated Permo-Carboniferous sandstone, over which lie the erosional and alluvial plains (5 - 25 m deep) of the Cambridge Gulf Lowlands (Kinhill, 2001). The ancient course of the Ord River is postulated to have flowed north-east beneath the Weaber Plain and then roughly along the course of the present day Keep River (Kinhill, 2001), although the timing of separation of the two rivers is unknown. It is postulated that some time after the capture of the Ord River, deposition of material from the Keep River and Sandy Creek reduced tidal range in the Keep River region to 3.7 m, compared to 5.2 m in the adjacent Gulf (Aldrick and Moody, 1977).

3.3.1.1 Last Glacial Maximum (25 – 18 ka)

Prior to the Holocene marine transgression, all major rivers of the region drained into the marine lagoon that is now the Bonaparte Depression (Fig. 3.1). The present shoreline lies approximately 100 km south of Joseph Bonaparte Gulf (Fig. 3.4). At the Last Glacial Maximum (LGM), the shoreline would have been a further 600 km offshore at approximately 130 m depth, and marine cores taken to the north and south of the Bonaparte Depression reveal micro-palaeontological indicators of increasingly marine conditions (Yosukame, 2001).
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Figure 3.4 Location of the Keep River (indicated by arrow) in relation to the changing shoreline around the Joseph Bonaparte Gulf at 18 $^{14}$C kyr BP (LGM), 12 $^{14}$C kyr BP, and 6 $^{14}$C ky BP (from Yosukame et al., 2001; their Fig. 5). Bathymetric and topographic contours are indicated by changes in colour scheme, and show the depth increase from 0 m, to 25 m to 50 m depth near the mouth of the Keep River.

Van Andel and Veevers (1967: 38) indicate that the submarine topography of the Joseph Bonaparte Gulf resembles that of the adjacent land (Fig. 3.5). Geomorphological studies on land in the nearby Coburg Peninsula, northeast of the Keep River, also indicate a strong element of Quaternary inheritance that has evolved through the reoccupation of previous intertidal levels (Woodroffe et al., 1992). The Keep Plains now stand several metres above sea level and there is no evidence to indicate that they have formed under marine or estuarine conditions (Aldrick and Moody, 1977). However, the seaward side of the Keep Plain was observed to comprise highly calcareous silty clays typical of marine deposits.
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3.3.2 Holocene (10 ka - present)

Extensive geomorphological studies in northern Australia (Woodroffe et al., 1987; 1989; 1992) have revealed the rapid rise of sea level from about -12 m AHD to its present elevation between 8 and 6 ky BP, with indications from bedded beach deposits that about 5 - 6 ky BP relative sea level was 0 - 1 m above present (Woodroffe, et al., 1992). From 7 to 3.5 $^{14}$C ky BP, much of northern Australia formed part of the “Big Swamp” until subsequent freshwater sedimentation led to the establishment of a more terrestrial environment. The pattern of sea level rise appears to have lagged slightly behind that in eastern Australia, and also indicates that the extreme north of Australia may be undergoing gradual subsidence (Woodroffe et al., 1992). From about 3 ky BP the modern landform with freshwater lagoons and swamps, estuarine and salt-marsh areas, dry land communities on the plains and plateaux were essentially established (Lewis, 1988: 63).
Geomorphological evidence has shown that large macrotidal rivers in northern Australia were diverted or blocked while their coastal plains were prograding as a result of an unusually dry climatic period sometime between 3.5 and 2 ky BP (Chappell, 2000).

3.3.3 Present

The approximate catchment area of the Keep River is 5000 km$^2$, which is approximately equivalent to 8% of the Ord River catchment (Kinhill, 2001). The major rivers draining the uplands and plateaux are the Keep River and Sandy Creek (Fig. 3.2). During the wet season, a number of intermittent water courses discharge from the hills onto the surrounding plains, including Cockatoo Creek, Knox Creek, Border Creek and Oakes Creek (Fig. 3.2). This water spreads out as indistinct sheet flow and only at the extremity of the plains is there defined drainage (Kinhill, 2001, 5-7). Rivers and creeks incise the topography of the plains only locally and to a maximum depth of 5 m (Kinhill, 2001, 4-2), although some minor ephemeral creek systems may generate small delta fans and shallow gullies (Fig. 3.6). Alongside many of the larger creeks, there are small semi-permanent billabongs and sandy strips which are primarily associated with old meanders. Groundwater generally occurs about 20 - 25 m AHD, which is approximately 5 m below ground surface (Kinhill, 2001).

Figure 3.7 shows two cross sections determined for parts of the Ord River Stage II, flanked by the main archaeological sites of Karlinga and Granilpi to the west, and Jinmium and Goorurarmum to the east. The cross sections indicate that the profile observed at Sandy Creek Gorge underlies but is not necessarily contemporaneous with the uppermost sediment horizons. The uppermost silty-clay horizon is also unconformable with older horizons and is laterally discontinuous. The sand sheets are likely to be similarly discontinuous.
Figure 3.6 Photograph of small delta fan in the north-west corner of the Goorurarmum amphitheatre, made obvious by the new growth of Spinifex grass after the 2000 wet season.

Please see print copy for Figure 3.7

Figure 3.7 Cross-sections across the planned Ord River Irrigation Area, showing a stratigraphic section from the Keep River to Sandy Creek (T - T’), and from Border Creek to the Keep River (S – S’) (from Kinhill, 2001). Although oversimplified, these depictions indicate that the average thickness of the upper sediment horizons are less than 5 m thick, and are laterally discontinuous.
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3.4 Vegetation

The Keep River region occurs in the general biogeographic province known as the Tropical (Torresian) Zone, which encompasses the humid tropical and subtropical regions of northern Australia (Hope, 1984). The variety of vegetation types found in this region range from remnant tropical-subtropical rainforests in northeastern Australia, to dry sclerophyll and grassland in northern Australia, with mangrove forest established along much of the coastline. The appearance of modern environmental patterns and vegetation communities (and fire regime) probably had its origins in the early Pleistocene and developed during the Pleistocene – Holocene transition (Hope, 1984), as a result of positive feedback between fire, vegetation, soil, nutrient status and water balance (Kershaw et al., 1997).

In a history of fire in Australia, Kershaw et al. (2002) continue to debate whether climate rather than human activity has exerted the major control over both fire activity and vegetation change. Anthropological evidence does indicate that fire was an essential part of the Aboriginal way of life, but the impact of people was predominantly in the disruption of previous vegetation-environmental relationships, possibly such as the transition from rainforest to more open savannah-type woodland at about 120 ky BP (Kemp, 1981; Kershaw et al., 2000). Discussions by Head (1989; 1996) argue that anthropogenic influence on preservation or demise of wet and dry rainforest in northern Australia is intimately associated with the seasonality of its climate during the Holocene, and possibly also during the Pleistocene, but continuous palaeoecological records from central and northern Australia are required to fully evaluate the magnitude of human impact.

More specifically the Keep River region is situated within the Victoria-Bonaparte biogeographic region (Whitehead and Fahey, 1985), with a range of vegetation types from open savannah to tall grassland. Open woodlands (Eucalyptus spp.) occur on the plains and rocky areas, and low woodland on sandy soils (Tristania, Grevillea, Banksia spp.). Pandanus is dominant along waterholes and dry annual creeks beds, while freshwater mangroves and tall perennial grasses
dominate along more permanent streams (Whitehead & Fahey, 1985). Detailed vegetation and flora surveys conducted for ORIA (Kinhill, 2001) indicate the most numerous families in the area are Poaceae (grasses), Myrtaceae (eucalypts and paperbarks), Cyperaceae (sedges and rushes), Mimosaceae (wattles), Asteraceae (daisies), Papilionaceae (peas) and Combretaceae (Terminalia spp.). Aquatic plants include mixed rushes and grasses, waterlilies (Nymphaea spp.), bladderwort (Utricularia australis) and algae. Head et al. (2002) document the past and present use of many of these plants by Aborigines, including the burning of Cypress Pine (Callitris intratropica) to keep away mosquitoes, the collection of seeds of Cathormium umbellatum for making necklaces, and the harvesting of various other edible and non-edible fruits, seeds and roots including species of figs (Ficus spp.), yams (Dioscorea spp.) and water lily (Nymphaea spp.).

3.5 Palaeoclimate

Large glacial-interglacial oscillations of global climate have, with periods of 40 – 100 ka have occurred for several millennia. The last glacial cycle, which began 125 kya, was not significantly different from its predecessors of the last 800 ka and differed only moderately from those of the preceding 2 million years. The changes of climate over the last 100 ka lie within the last of a long series of climatically comparable cycles. A general outline of palaeoclimatic trends for Australia from 100 ky BP to the present is depicted in Fig. 3.8 and discussed below.

Figure 3.9 shows the existing palaeoclimatic data, synthesised from CLIMANZ archives (http://rses.anu.edu.au/enproc/AQUADATA/archive.html), prior to and following the Pleistocene-Holocene transition in northern Australia and New Guinea. Climatic differences between the northeast and northwest regions relate to the presence of the coastal escarpment (The Great Dividing Range) and highlands of New Guinea, which influence both orographic rainfall and exposure to westerly winds. In the northwest, the absence of many physical or thermal barriers means that the main stress has been changing aridity (Hope, 1994), which has partly been a result of changes in sea level, and resultant continental (low sea-level) or maritime (high sea-level)
conditions depending on distance from the coast (Ross et al., 1992). The other major influencing factor is the relative strength and shifting of the Australian monsoon, which in turn is affected by the El Nino/Southern Oscillation (ENSO) (Schulmeister, 1999). A broader discussion of Australia’s monsoonal palaeoclimates has been summarised by Van der Kaars (1991) and Johnson et al., (1999).

3.5.1 Late Pleistocene (100 - 10 ka)

There is very little palaeoclimatic or palaeoenvironmental information for northwestern Australia in the early Pleistocene, with the first direct evidence of regional trends being provided from pollen records off the north Australian coast (van der Kaars, 1991; van der Kaars et al., 2000; Wang et al., 1999). These records indicate a decrease in temperatures and rainfall from the early part of isotope Stage 5, followed by a cooler and drier climate during Stage 4, becoming wetter during Stage 3 (van der Kaars et al., 2000), when it is argued that the Australian monsoon was at full strength (Johnson et al., 1999).

A similar story emerges from geomorphological and palaehydrological studies in the east Kimberley Plateau (Wende et al., 1997), Lakes Woods and Lake Gregory in northwestern Australia (Miller et al., 1999; Bowler, et al., 2001), and other regions of monsoonal Australia (Nanson et al., 1992) including the Magela Creek catchment in Northern Arnhem Land (Nanson et al., 1993). These studies spanning the last 300 ka, indicate a trend of increased aridity towards the late Pleistocene, with pluvial events broadly corresponding to interglacial phases (Stages 1, 3, 5 and 7), and intervening dry periods (including the LGM) characterised by dune expansion (Fig. 3.8). Thus across northern Australia and Papua New Guinea there evidence of oscillating wet and dry conditions corresponding with glacial and interglacial cycles prior to 25 ky BP.
Please see print copy for Figure 3.8
From about 40 ky BP, the palaeoclimatic and palaeoenvironmental record is geographically and temporally more contradictory. CLIMANZ records indicate wetter conditions in the northwest and cooler, drier conditions in the northeast of Australia and New Guinea around this period (Fig. 3.8). Higher terrace levels surrounding plunge pools in Kakadu National Park have been interpreted to indicate wetter conditions as a result of a strengthening of the northwest monsoon in this part of northern Australia around 25 to 18 ky BP (Nott and Price, 1994). This evidence contrasts with the general consensus that this was a very dry period. In other parts of northern Australia, perhaps due to the coincident period of occupation, climatic (Miller et al., 1999) and environmental changes (van der Kaars et al., 2000; Wallis, 2001) have questionably attributed to human impact. It has not yet been demonstrated that human impacts have had a more significant effect on the climate of northern Australia than the regional changes in sea-level and concomitant ocean circulation off the north coast. Rather because the northern region was so arid, small climatic changes may have had large impacts locally, indicating the need for more temporally and spatially constrained paleaeoenvironmental studies in this region.

3.5.1.1 Last Glacial Maximum (25 – 18 ka)

During the LGM, the Australian monsoon was virtually non-existent (Johnson et al., 1999), although the seasonal wet/dry regime was operating (Allen and Barton, 1989). Mountain and coastal areas of PNG were at least 6 °C cooler (Hope, 1989; Aharon, 1983), while slightly cooler (-1.5 °C) and possibly warmer sea-surface temperatures have been indicated for northern Australia at this time (Schulmeister, 1999). From a retrodiction of climates across Australia at 18 ky BP, Hubbard (1995) indicated that only the extreme north of the Kimberley and the Northern Territory would have received monsoonal precipitation. Even in these areas summer rainfall is likely to have been diminished due to the increased landmass and closure of the Torres Strait that blocked the easterly warm current (Bowler, et al., 1976; Hubbard, 1995; Schulmeister, 1999).
Figure 3.9  Palaeoclimatic data for the period prior to and following the Pleistocene-Holocene transition in northern Australia and New Guinea, modified from CLIMANZ (http://rres.anu.edu.au/enproc/AQUADATA/archive.html).
Although moisture in the form of precipitation and streams had decreased, sufficient moisture was apparently available to support perennial grasses and shrubs in parts of the southern Kimberley (McConnell and O’Connor, 1997; Wallis, 2001). The low effective precipitation and sparse vegetation cover facilitated a major phase of dune building in the north (Lees et al., 1990; Wende et al., 1997; Bowler et al., 2001) and in other parts of Australia (Chen et al., 1995; DeDeckker, 1986) (Fig. 3.8). In the archaeological record there is a decline in site occupation at this time (Shulmeister, 1992), except along the arid shoreline where it is evident that humans utilised both coastal and hinterland resources during the Pleistocene (Veth, 1999). Site use increases toward the terminal Pleistocene as climate ameliorated (Schulmeister, 1992; Veth, 1999), with definitive evidence for re-establishment of the monsoon regime in northern Australia from about 14 ky BP (Wyrwoll and Miller, 2001).

3.5.2 Holocene (10 ka - present)

As can be seen from CLIMANZ maps (Fig. 3.9), only a small number of Holocene palaeoclimatic studies have been undertaken in northern Australia (Lees, 1992a; Wende et al., 1997; Wyrwoll et al., 1986, 1992; Nott and Price, 1999; Nott et al., 1999; Schulmeister, 1999; Bowler et al., 2001). Early evidence was thought to indicate that the climate of the Ord and Keep River region has remained broadly similar for the last 8 ka (Aldrick and Moody, 1977), but evidence outlined below is slowly emerging of a less stable climate with locally significant effects. A comparative palaeoenvironmental record for the Holocene from interior and southeastern Australia is provided by Holdaway et al. (2002), which show regionally similar trends to the northwest but with some exceptions, as outlined below.

The early Holocene climate history of Northern Australia is dominated by the effects of the marine post-glacial transgression that flooded the extensive continental shelf around 7 ky BP and a gradual return of the summer monsoon (Shulmeister, 1999). In parts of northwestern Australia, the establishment and use of archaeological sites continued to increase in accordance with climatic
amelioration (Schulmeister, 1992), although up to 10 m of land per year was being lost in the Pleistocene-Holocene transition (Woodroffe, 1993). The available evidence from pollen (Schulmeister, 1992; Kershaw, 1986) and palaeohydrological records (Nanson et al., 1993; Nott and Price, 1994; 1999; Bowler et al., 2001) all point toward significantly wetter conditions in the early/middle Holocene (~ 10 - 5 ky BP) than in the late Holocene. Nott et al. (1999) question whether the increase in precipitation to the pluvial maximum was gradual, or whether it was interrupted by short, intense phases of aridity or cooling around 8 - 6 ky BP, as evidenced from activation of dune fields in tropical northern Australia.

The pluvial maximum occurred around 4 ky BP (Schulmeister, 1999), at least 1000 years later than in southern and northeast Australia (e.g. Holdaway et al., 2002). This hypsothermal is thought to be a result of increased ENSO activity that generated a stronger but more latitudinally confined summer monsoon (Moss and Kershaw, 2000; Schulmeister, 1999). A drier phase followed the wet phase from 2.8 ky BP (Ross et al., 1992; Bowler et al., 2001), with coastal dune sequences indicating reduced wet season precipitation from 2.7 – 1.8 ka (Lees et al., 1990; 1992). A rise of rainfall from 1.4 ky BP in northeast Australia is not recorded in the northwest (Ross et al., 1992), perhaps because of lack of indicative sites. Although such evidence points to increased climatic variability during the Holocene, under what Johnson et al. (1999) argue was a moderately effective monsoon, climatic variability may have been as great or greater under the stronger monsoonal climate of the Pleistocene.
3.5.3 Present

The present regional climate of the Keep River region is semi-arid, with a distinct monsoon season during which much of the annual rain (ca. 900 mm) falls (Fig. 3.10). The atmospheric circulation in this area is dominated by the monsoon and trade winds, with a southeast circulation dominating during the winter and northwest monsoon and southwest trades dominating during the summer. Average maximum temperatures exceed 30 °C, and mean annual evaporation (ca. 2000 mm) is lowest in June and during the summer monsoon (Bureau Meteorology, 1996). The rivers of northwestern Australia flow seasonally, leading to constant changes in the local importance of erosion, transport, and deposition.

Please see print copy for Figure 3.10

Figure 3.10 Average rainfall and temperature for Kununurra (sourced from http://www.bom.gov.au/climate/averages/, 2001).
3.6 Topographic Setting and Study Area

3.6.1 Local Topography

The project area of Keep River region (inset of Fig. 3.11) occupies the northwest corner of the Auvergne and Legune mapsheets. The area consists of dissected plateaux that rise over 200 m above the surrounding low lying alluvial plains. The elevation of the Keep River Plain varies from 20 m AHD in the south-west to 10 m AHD in the north-west (Kinhill, 2001). Details are given below.

Figure 3.11 Topographic map of Keep River region indicating the project area and major site locations. Enlargement of the Karlinga and of the Jinmium-Sandy Creek catchment area is given in Figure 3.12.
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Figure 3.12 Topographic map of project area showing major site locations of Karlinga, Jinmium, Goorurarmum and Sandy Creek Gorge.

3.6.2 Aerial Photography

Aerial photos show the protrusion of the isolated sandstone escarpments above the surrounding sandy plains, such as those around Goorurarmum (Fig. 3.13a), which themselves are dissected by the ephemeral Sandy Creek and its tributaries. Little or no change in the rivers or surrounding plains is evident between aerial photos taken in 1992 and in 1999, indicating the geomorphic processes over this time period are relatively stable. Goorurarmum and Sandy Creek Gorge are situated less than 2 km apart but their topographic relationship has yet to be determined from surveys.
Figure 3.13a  Aerial photo of the area around the archaeological site of Goorurarmum, and the non-archaeological sites of Sandy Creek, and Sandy Creek Gorge.
The majority of site locations in this study occur below 100 m AHD. The bedrock escarpment between Goorurarumum and Sandy Creek peaks at a little over 85 m (Fig. 3.12), and dips about 20° southeast to the base of the sand sheets. At the base of the escarpments, there is an abrupt change of slope to the subdued relief of the sand sheets. The sand sheets abut the escarpment directly where the dip of the bedrock is upward, and are interposed by a scree slope on the downward dip. The sites of Jinmium and Goorurarmum are situated approximately 1 km apart at the same relative level of ca. 50 m AHD. About 18 m lower than these two topographic highs in the landscape, is a dry swamp. North of the main Jinmium site, the landscape drops around 20 m over a distance of 1.5 km to another swampland.

Aerial photos of the Weaber Ranges (Fig. 3.13b) reveal the heavily dissected plateaux, which form the maze of beehive-like formations evident at ground level. The escarpment range represented by Walajupi is one of the highest points in the landscape around Karlinga at around 180 m AHD (Fig. 3.12). The bedrock escarpment between the two main excavation sites (Karl-1 and Karl-3) peaks at a little over 75 m, and the bedding dips more gently about 10° to the south. The surrounding sand plains form a series of terraces, which dip gently about 2 - 5° towards the Keep River. Field surveys indicate a relative drop in elevation of about 5 m between the main Karlinga escarpment to the rock outcrop at Karlinga North, and a further drop of 2.5 m less than 200 m further south into swamp sediments. In the south-west, the site of KR99 is clearly seen in the river-course draining from the upper plateaux to the well forested sand plains below (Fig. 3.13b).
3.7 Sampling Strategy

From the physical layout of the Keep River region, a conceptual layout of the site sampling strategy (Table 3.1) is proposed with the aim of linking the major archaeological and landscape contexts of the sandstone escarpments and adjacent sand sheets. Representative sampling is focused towards a geological continuum from supposed source (escarpment bedrock) to sink (rock-shelter, sand sheet, creek profiles), and a cultural continuum from occupied, intermediate to non-occupied sites.
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Source

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<th>SANDSTONE ESCARPMENTS</th>
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<td>Karlinga, Jinmium, Goorurarmum</td>
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Sediment pathways

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Environmental Inputs/Modifications

| Karlinga, Jinmium, Karlinga, Sandy Creek |
| Goorurarmum |
| (2 excavation sites) |
| (2 sections) |
| (20 auger core sites) |

Anthropogenic Inputs/Modifications

| OCCUPATION SITES |
| Karlinga, Goorurarmum |
| (2 rock shelter sites) |

Table 3.1 Summary of field sampling strategy, which provides a continuum from human occupation sites to those where there is no indication of human activity.

3.8 Conclusion

Although the palaeoclimate and palaeoenvironment record for northwest Australia is scant, there is emerging evidence of a changing landscape over long term millennial scales and during short periods of rapid alteration. The question of continuity and change in the Keep River region can be addressed from a geoarchaeological perspective (Chapter 2), using chronology (Chapters 4 and 6), sediment stratigraphy (Chapter 5), and archaeology (Chapter 7). The regional and local environmental and climatic background outlined above provides important contextual information for each of the following geoarchaeological studies.