KAKADU–ARNHEM LAND REGION, NORTHERN TERRITORY

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INTRODUCTION

Alleged variations in the characteristics of weathering profiles have played a significant role in interpreting the evolution of landscape in the north of the Northern Territory. The region, which experiences a monsoonal tropical wet–dry climate, is part of the North Australian Craton (Figure 1) and has a landscape that is much older than previously assumed. This greater age of landscape is indicated by a change from marine Cretaceous sediments on the lowland plain to terrestrial Cretaceous sediments on the upland plateau, and also by the *in situ* (as opposed to 'detrital') nature of deep weathering profiles across the lowland plains. A brief account of the changing views on the age and evolution of the landscape in the north of the Northern Territory is presented below.

PHYSICAL SETTING

The landscape of the north of the Northern Territory (Figure 1) is dominated by plains of low relief and generally flat topped uplands eroded from Proterozoic sandstones. The plains, by contrast, are generally underlain by Proterozoic metasediments and granites. Cretaceous marine sediments, associated with the Neocomian to Albian marine transgression(s), rest unconformably upon the Proterozoic strata in the plains region. The uplands are also underlain, albeit patchily, by Cretaceous strata. Unlike the lowlands, these sediments are commonly of terrestrial origin, even though they too are likely to have accumulated in response to the late Mesozoic sea-level rise(s).

Arnhem Land constitutes the largest region of approximately continuous upland plateau in the Northern Territory. Arnhem Land is a sandstone plateau that varies in elevation from about 100 to 400 m ASL. Along its western edge, the Arnhem Land plateau is separated from the adjacent Kakadu lowlands by a steep escarpment. Elsewhere, such as at Groote Eylandt in the Gulf of Carpentaria and the Tawallah and Yiyinti Ranges to the south of Arnhem Land, the upland plateau occurs as isolated entities. Being largely resistant to the influence of weathering (except for siliceous solution weathering features), these arenaceous sandstones have few deep weathering profiles except where capped by Cretaceous and Quaternary sediments. The lowlands, however, particularly where dominated by Cretaceous marine strata, are extensively weathered with profiles reaching to depths in excess of 10 m (Figure 2). The nature of these weathering profiles, in particular whether or not they developed within the reworked products of pre-existing weathering profiles, has traditionally formed the basis for models of landscape evolution in the region.

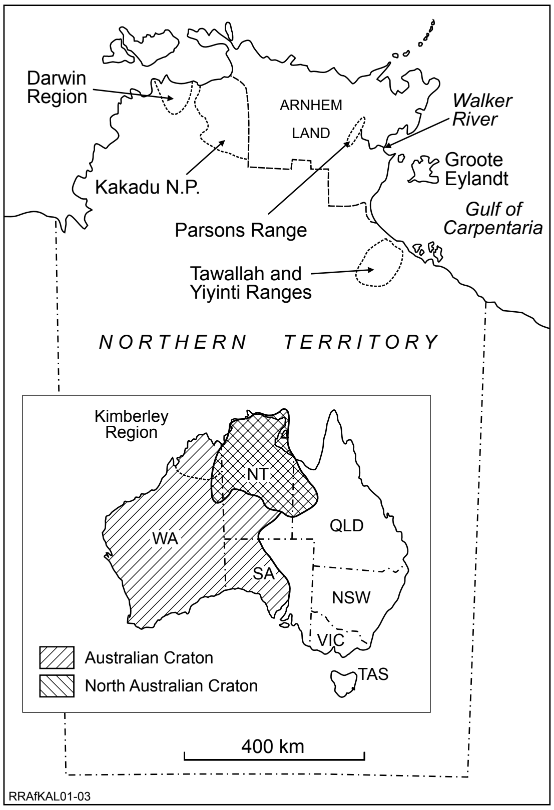

Figure 1. Location of Kakadu–Arnhem Land region in the Northern Territory and of other sites mentioned in text.

PREVIOUS INTERPRETATIONS OF LANDSCAPE EVOLUTION

The prevailing model of landscape evolution, until several years ago, was based upon the assumption that many of the deep weathering profiles in lowland areas throughout the northern part of the Northern Territory contained 'detrital laterite'; that is material, such as pisoliths and fragments of ferricrete, which has been eroded from pre-existing weathering profiles. These detrital weathering profiles were thought to have developed in response to successive waves of erosion through scarp retreat brought about by changes in base-level associated with episodes of tectonic uplift (Hays, 1967, 1968).

Three episodes of uplift and erosion are thought to have occurred. Initially, the landscape underwent extensive weathering forming deep ferruginous profiles following recession of the Cretaceous seas. A drop in base level associated with the first phase of uplift initiated erosion, or a phase of pediplanation, where an escarpment migrated inland. The eroded sediments of the initial weathered profile were incorporated into newly developing profiles across a lower topographic level landsurface (Figure 2). The upper surface containing the original *in situ* weathering profiles was named the Tennant Creek surface and the adjacent lower surface

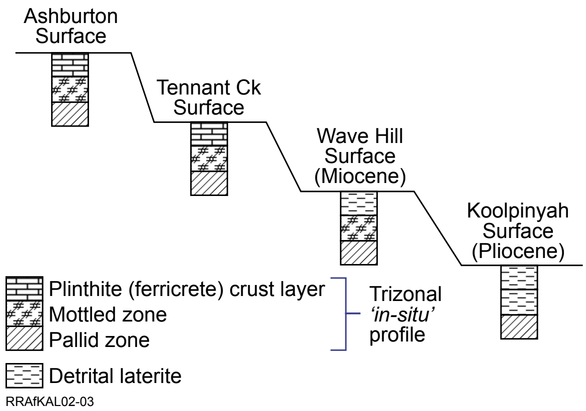

Figure 2. Postulated erosion surfaces in the north of the Northern Territory. Note 'detrital laterite' zones on Wave Hill and Koolpinyah surfaces. The detrital laterite was taken as evidence of regional tectonic uplift and pediplanation.

underlain by the detrital lateritic material was named the Wave Hill surface. Another phase of uplift, erosion and pediplanation ensued resulting in development of the Koolpinyah surface, which contained within its weathering profiles material derived from the Tennant Creek and Wave Hill surfaces (Figure 2). The most elevated topographic surface of all was termed the Ashburton surface. This predated the Tennant Creek surface and had been carved across folded pre-Mesozoic strata (Figure 2).

Two type sections were used as the foundations for this model of landscape evolution. The first was a well on the Wave Hill surface near Wave Hill station, and the second a sea-cliff exposure at Charles Point on the Koolpinyah suface approximately 20 km west of Darwin. Both were argued to display examples of detrital laterite profiles; indeed the Charles Point exposure supposedly contained evidence for two episodes of detrtial laterite formation (Hays, 1967). The well on the Wave Hill surface has been difficult to locate and re-examine. The Charles Point sea-cliff exposure, however, has been revisited and mapped by the Northern Territory Geological Survey as being composed entirely of Cretaceous strata (Peitsch, 1983). This was verified by Nott (1994), who showed that Cretaceous strata with primary depositional structures extend to the landsurface (Figure 3). These observations cast strong doubt upon the Koolpinyah surface being underlain by detrital laterite.

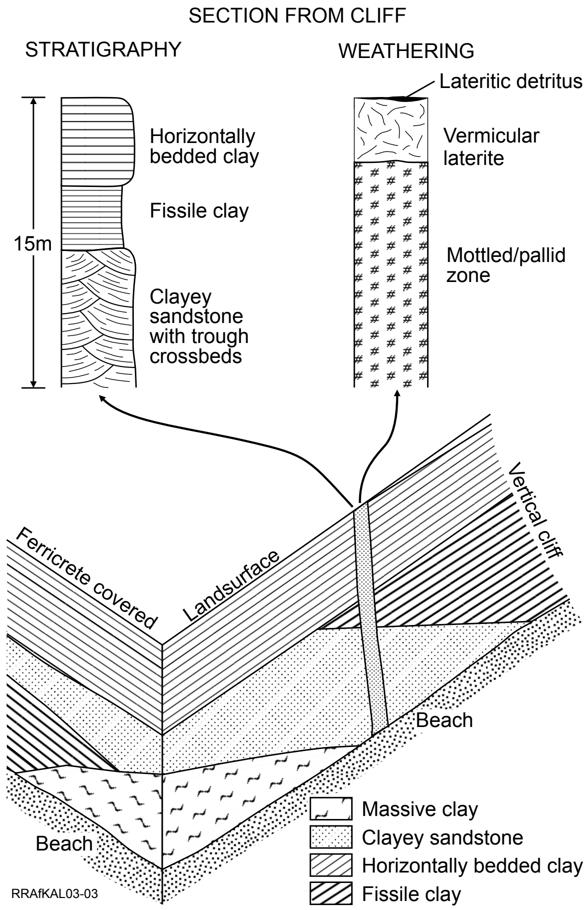

Figure 3. Stratigraphy and weathering of the sea-cliff section at Charles Point, Cox Peninsula to the west of Darwin. This site is the type section for the Koolpinyah Surface where two zones of detrital laterite supposedly exist above the eroded base of the Tennant Creek surface (*in situ* laterite). Detailed mapping shows, however, that the sea cliff section is composed entirely of Cretaceous strata without any detrital laterite.

REVISED VIEW OF LANDSCAPE EVOLUTION

An alternative hypothesis of landscape evolution for the region was proposed by Nott (1994, 1995). There is no need to invoke cycles of uplift and erosion to explain the topography and weathering characteristics of the region. The Koolpinyah surface in the Darwin region appears to be structurally controlled. A bioturbated bed in the Darwin Member of the Cretaceous Bathurst Island Formation has limited the depth of weathering and commonly also of erosion in the vicinity of Darwin to the level of the Koolpinyah surface. Likewise, a silicified horizon in the deeply weathered Cretaceous strata has controlled the level of the Koolpinyah and Wave Hill surfaces in the Daly River region south of Darwin.

In Kakadu National Park and western Arnhem Land, the Wave Hill surface corresponds to the upland plateau surface eroded from sandstones of the Proterozoic Kombolgie Formation. The same situation applies south of Darwin near Litchfield National Park, where the Proterozoic Tolmer Sandstone forms upland surfaces corresponding to the Wave Hill surface, and also south of the Arnhem Land Plateau adjacent to the Gulf of Carpentaria where the plateaux of the Tawallah and Yiyinti Ranges correspond to the Wave Hill surface. Hays (1967, 1968) argued that the Wave Hill surface at these locations developed during the Miocene and that the lower elevation Koolpinyah surface developed during the Pliocene. However, Cretaceous strata locally underlie these upland surfaces (Figure 4). Furthermore, valleys eroded into the Yiyinti Range have subsequently filled with Cretaceous strata, with terrestrial facies at the base grading upwards to fossiliferous marine strata, which in turn grade back to terrestrial facies near the top of the valley fill (Nott, 1995). Palaeovalleys carved into the upland surface of Groote Eylandt are likewise filled with Cretaceous strata (Nott, 1996).

It appears that a stepped landscape was already in existence

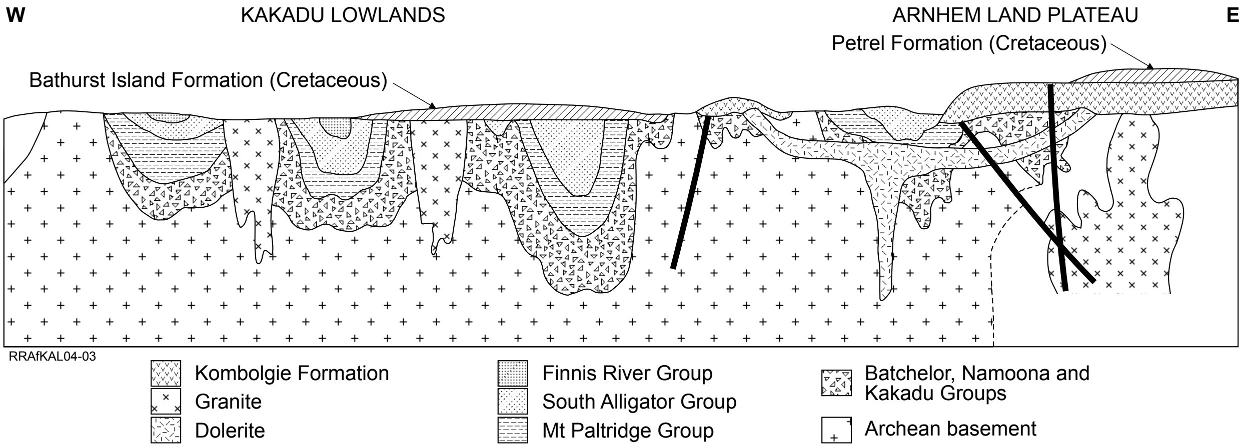

Figure 4. Stratigraphic cross-section of Arnhem Land plateau and Kakadu lowlands showing Cretaceous marine and terrestrial sediments on lowlands and plateau, respectively. Note also the close correspondence in elevation between angular unconformity at base of Proterozoic Kombolgie Formation and lowland plain, indicating that the Koolpinyah surface is probably an exhumed Proterozoic landsurface. (Adapted from Needham, 1988)

throughout the north of the Northern Territory at the close of the Jurassic. In Kakadu National Park, the unconformity between the Proterozoic Kombolgie Formation and the underlying metasediments coincides closely with the level of the lowland plain or Koolpinyah surface (Figure 4). Hence it is likely that the Koolpinyah surface in this region is an exhumed early Proterozoic landsurface which was subsequently inundated by the Neocomian and Aptian seas leaving a relatively thin succession of marine Cretaceous strata. The Cretaceous strata that in places cap the 200–300 m high adjacent upland surface stretching eastwards to Arnhem Land are of terrestrial origin, suggesting that this surface (Wave Hill) may have been graded to the Cretaceous seas (Nott, 1995). The Cretaceous strata capping the Tawallah and Yiyinti Ranges are also mainly terrestrial, whereas those on the surrounding lowland plains are of marine origin. The area to the south of Arnhem Land likewise shows evidence of a landscape of much greater antiquity than envisaged in Hays' scheme.

Erosional surfaces clearly do exist across the Northern Territory, but they do not appear to have been initiated during the Tertiary. Furthermore, it has been widely assumed that the highest surface in a stepped sequence must be older than the lowest. The Koolpinyah surface, however, poses the possibility that it may have originally developed during the Proterozoic and has since been buried and exhumed. In Kakadu National Park the adjacent higher level Arnhem Land plateau (Wave Hill surface) appears to be younger than the Koolpinyah surface because it probably developed, or was at least modified, during the Cretaceous. The summit of the Tawallah Range was also graded to the Cretaceous seas, as shown by the transition from marine to terrestrial sediments near the summit, and was possibly also formed during the Cretaceous (Nott, 1995). The valleys incised into the Tawallah Range and nearby Yiyinti Range must be older than the modified summit surface for they are filled with Cretaceous sediments and graded to the lowland plain. A similar situation also exists on Groote Eylandt (Nott, 1996). Hence the lowland plains in this region (Groote Eylandt and south of Arnhem Land) possibly

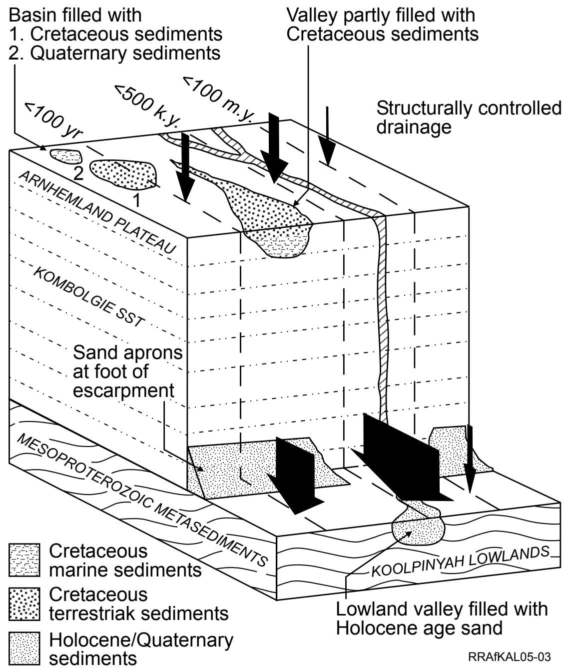

Figure 5. Variable rates of erosion on the Arnhem Land plateau and Kakadu lowlands. (from Nott and Roberts, 1996)

predate the upland plateaux although it is uncertain whether the Koolpinyah surface here is exhumed such as in the Kakadu region.

Erosion has been the dominant force shaping the landscape following regression of the Cretaceous seas. The rates of denudation, however, do not appear to have been constant since this time (Figure 5). Denudation rates were analysed at a number of timescales over the past 100 m.y. in the Kakadu region using cosmogenic ^{26}Al and ^{10}Be, thermoluminescence, ^{14}C and ^{210}Pb methods, time-lapse bathymetric and air photo surveys, and field measuremenets of sand, washload and terrigenous solute yields in modern streams (Nott and Roberts, 1996). The results showed that denudation rates have increased in this region by at least an order of magnitude in the late Quaternary compared to the previous 100 million years (from <1mm k.y.$^{-1}$ to 3–5mm k.y.$^{-1}$ on the Arnhem Land Plateau and 2–3mm k.y.$^{-1}$ to 23–40mm k.y.$^{-1}$ on the Koolpinyah surface). At all time scales the relative difference between denudation rates on the plateau and lowland probably has remained the same; the lowlands appear to have lowered at a considerably higher rate, however, than the plateau (Figure 5). This difference in denudation rate reflects the contrasting susceptibility to erosion of the two surfaces. The plateau is composed of competent, variably cemented and case hardened sandstone, whereas the metasedimentary strata underlying the Koolpinyah surface, and the remains of the Cretaceous marine sediments that once covered it, are deeply weathered and highly erodible. This also appears to be the case elsewhere throughout the north of the Northern Territory where the uplands are composed of resistant sandstones and quartzites, and the lowlands made of more erodible strata.

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