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The Pangaean inheritance

La herencia de Pangea

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Very old palaeosurfaces have been identified and dated in several parts of the former Gondwana and Laurasia. In Australia the separation from Antarctica was complete by the end of the Eocene so that any surface of earliest Tertiary and certainly of Mesozoic age can be regarded as Gondwanan. Similarly, in the Northern Hemisphere, Laurasia existed from the end of the Carboniferous to the Jurassic so that any landscape elements older than Jurassic can be regarded as Laurasian.The ages of these ancient surfaces have been determined in various ways and with various degrees of confidence, but correlative deposits associated with the widespread Early Cretaceous marine transgression , and the relationship of land surfaces to Cretaceous shorelines and Early Tertiary volcanic extrusions, or regolithic veneers have proved especially useful. Faulting of known age has also been used though it tends to give dates that are too young for the dislocated surfaces.

Many exhumed surfaces have been preserved by burial, but epigene-etch features like those of the Gawler Ranges, Hamersley Ranges and the Arnhemland Massif (Kakadu) have stood as uplands throughout the Cainozoic with little change. The same is true of the remnants of planation surfaces of the Iberian elements of the Hesperian Massif. Epigene-etch surfaces of Mesozoic age are also reported from southern and West Africa, from southern India and from the Guyana Craton of South America. In addition, epigene-etch features, as well as exhumed features of various ages, are, increasingly, being recognised from the Laurasian components of Pangaea, for instance in the Linares-Ubeda region in the south of Iberian Peninsula, so that it is possible to refer to the Pangaean inheritance.

These survival can in some measure be explained in terms of their being uplands, but obviously the conventional models of landscape evolution need to be reconsidered.

Key words: Pangea, Laurasia, landscape elements, Hesperian Massif, paleosurfaces

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INTRODUCTION

Though palaeoforms have survived glacial and nival attack, old planation surfaces and other landforms are manifestly well preserved in regions that escaped the effects of Late Cainozoic glacial and nival activities. In Australia (Fig.1a; Fig.1b shows Pangaea and places mentioned in the text) for example, Late Cainozoic glacial and periglacial effects were restricted to Tasmania and the uplands of the southeastern mainland. Thus, in the remainder of the continent, plains of Early - Middle Cainozoic ages stood virtually undisturbed for several scores of millions of years and in consequence developed duricrusted regoliths, and notably carapaces of laterite, bauxite and silcrete. Dissected duricrusted remnants, for the most part flat-lying and giving rise to plateau forms, but in places folded and forming cuestas and homoclinal ridges, are characteristic of many parts of Australia (Fig.1), as well as of the interior of Brazil and of Africa south of the Sahara. The duricrusts did not necessarily extend over the entire plains with which they were associated - on the contrary - but they are relics of palaeoplains mostly, though not exclusively, of Early Cainozoic age. Today they form cappings on remnants, characteristically of plateau form, and with relief inversion commonplace, for they have been dissected and extensive plains of Late Cainozoic age have formed at their expense. Rolling plains due either to fluvial action or to subsurface weathering and flushing, and dunefields, occupy huge areas of the interior of the continent, and particularly of the basinal regions.

Forms and surfaces which predate the Cainozoic are, however, reported from all of the original Gondwanan elements. Even in Antarctica, where landform analysis is inhibited by the ice cover, there is evidence of very old palaeoforms, preserved in unconformity (e.g. BURGESS et al.,1981) including some buried by Jurassic intrusives (e.g. BRADSHAW, 1981).

Australia may be taken as a starting point in any consideration of the extent, nature and implications of such very old palaeoforms, for not only has there been a long standing interest in ancient palaeosurfaces and their survival (HOSSFELD, 1926; CRAFT, 1932; HILLS, 1934; TWIDALE, 1976; YOUNG, 1983; WYRWOLL, 1988; TWIDALE and CAMPBELL, 1988,1992,1993) but their dating is, by happy chance, more readily and firmly achieved there than elsewhere.

Australia consists of structural units some of which have, throughout Phanerozoic time, been repeatedly uplifted, while others have suffered recurrent subsidence (TWIDALE, 1991; TWIDALE and CAMPBELL, 1992, 1993) On the uplands between the basins and plains are preserved surfaces that predate the Cainozoic and which, as they originated before the final separation of Australia from Antarctica, can be regarded as remnants of Gondwana (TWIDALE and CAMPBELL, 1992). Some of the surfaces are of exhumed type, but others are epigene or etch forms. Many of the epigene features, however, have been stripped of their regoliths, so that they are essentially etch forms, though their morphology closely simulates that of the original surfaces (see HILLS, 1975, p.300). They are referred to here as of epigene-etch type. The dating and correlation of these ancient surfaces has been facilitated first by the Late Palaeozoic (Permian) glaciation which affected huge areas not only of the

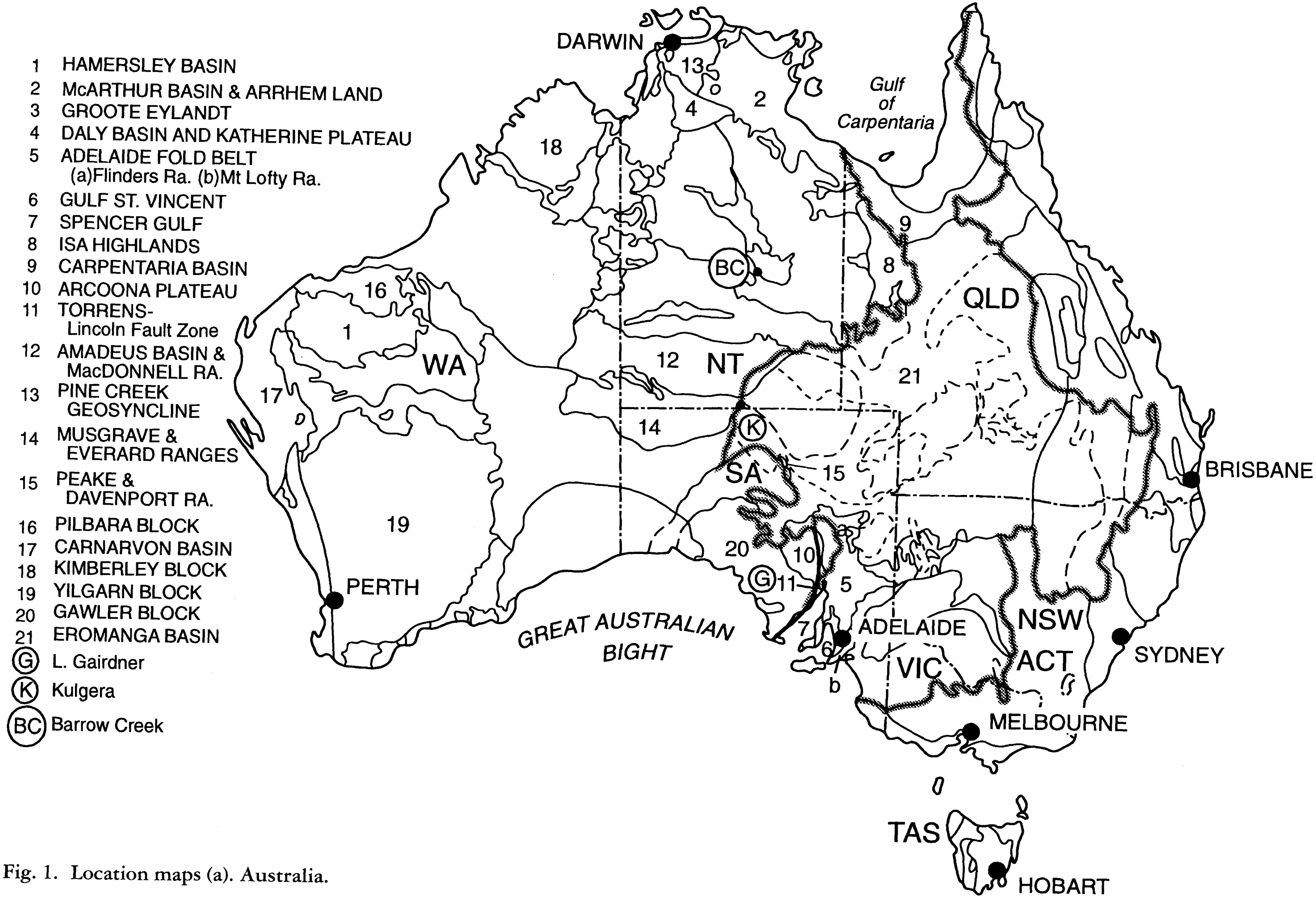

Fig. 1. Location maps (a). Australia.

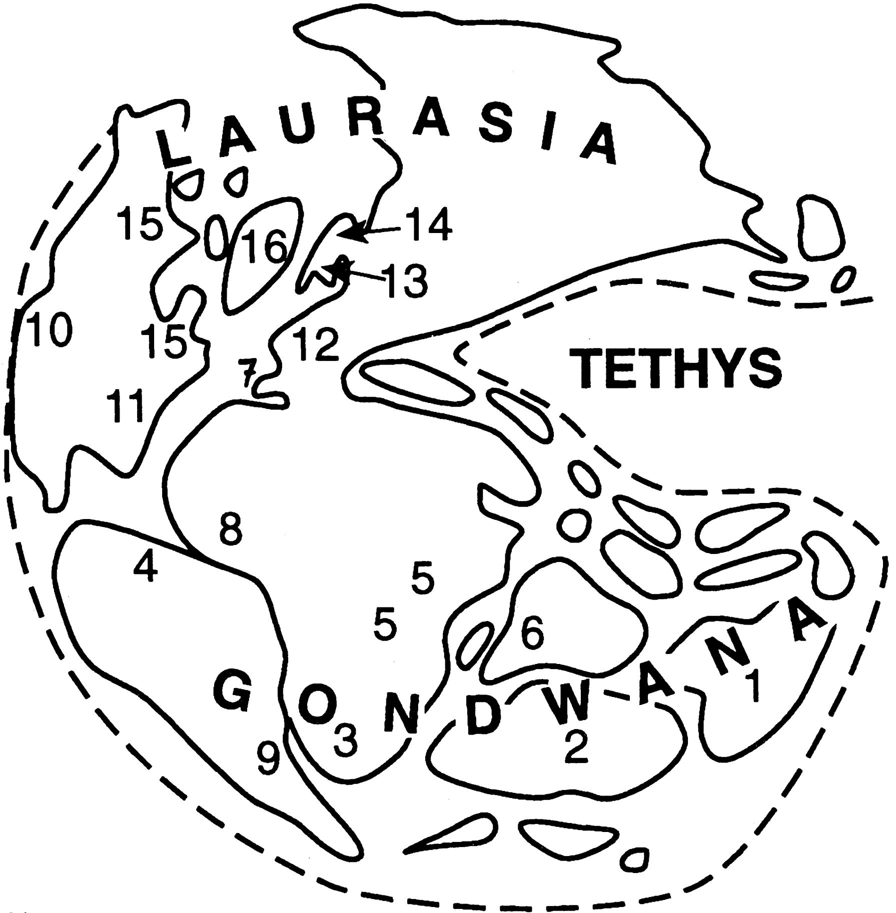

Fig. 1.

(b) Pangaea. (Key: 1 - Australia; 2 - Antarctica; 3 - southern Africa; 4 - Guyana Craton; 5 - Tanzania/East Africa; 6 - peninsular India; 7 - Iberian Peninsula; 8 - West Africa; 9 - Parana Basin; 10 - California; 11 - Appalachians; 12 - Europe: Armorican Massif, England, Scotland, Bohemian Massif, southern Germany; 13 - Skania; 14 - Fennoscandia; 15 - North American Arctic; 16 - Greenland.

present Australia but also of southern Africa and southern South America, and which provides a datum or maximum age for landform development (apart, that is, from some of the exhumed forms); second by the various Cretaceous marine transgressions, but especially the most extensive which is of Early Cretaceous (Neocomian-Aptian) age and in relation to which various exhumed and epigene surfaces can be dated (Fig.2); and third by the widespread Cainozoic volcanicity which permits the dating of surfaces of nonvolcanic origin located adjacent to the extrusives (Fig.3). In the Eastern Uplands the volcanicity is mainly basic, hotspot-related and of Cainozoic age, with Early Tertiary activity widespread. On Kangaroo Island, South Australia, the activity is also basaltic but is related to continental rifting during the middle Jurassic.

Palaeoforms of similar antiquity have been reported from several other components of Gondwana, and notably southern Africa and the Guyana Craton, though in detail the precise age of the «Gondwanan» surfaces varies because the time of final separation varied. Also, though the dating of exhumed surfaces poses only comparatively minor problems, epigene and etch surfaces are everywhere difficult to delimit in a temporal sense. Nevertheless the dating of these surfaces is, on the whole, not as firm in other Gondwanan elements as in Australia, though where there are relevant sedimentary sequences preserved (as in Tanzania) or volcanics (as in peninsular India) close dating of exhumed features is possible. Moreover, the Jurassic Stormberg volcanics of the Drakensberg, southern Africa, provide a back marker for landscape development in the subcontinent, much as the Permian glaciation does in Australia.

Notwithstanding the very real difficulties of dating, it is clear that substantial parts of the former Gondwana are of great antiquity. Indeed, a significant part of the contemporary landscape is of Gondwanan age. What is less frequently recognised is that landforms of great antiquity are also preserved in remnants of the other supercontinental remnant, Laurasia. Though ice can have a protective function (e.g. BOYÉ, 1950; KLEMAN, 1994) preglacial landforms are in some areas difficult to recognise and date because of the destruction or masking of relevant evidence by Late Cainozoic glacial and nival activities. In areas that essentially escaped such activities, as in the Iberian parts of the Hesperian Massif, surfaces have been reduced in area and stripped of regolith as a result of erosion by rivers and streams graded to different sealevels. The existence of these remnants is nevertheless real and the question arises whether it is in order to allude to a Laurasian inheritance with the same confidence that workers in the southern hemisphere can refer to remnants of Gondwana landscapes?.

In this paper we first discuss the difficult problem of dating land surfaces and allude to examples of epigene-etch and exhumed forms reported from Pangaean remnants. Some of their implications are then discussed.

DATING LAND SURFACES OF EPIGENE-ETCH TYPE

The dating of exhumed forms poses few problems but it is difficult to date epigene or etched land surfaces. Cosmogenic nuclides (LAL, 1988) provide orders of magnitude

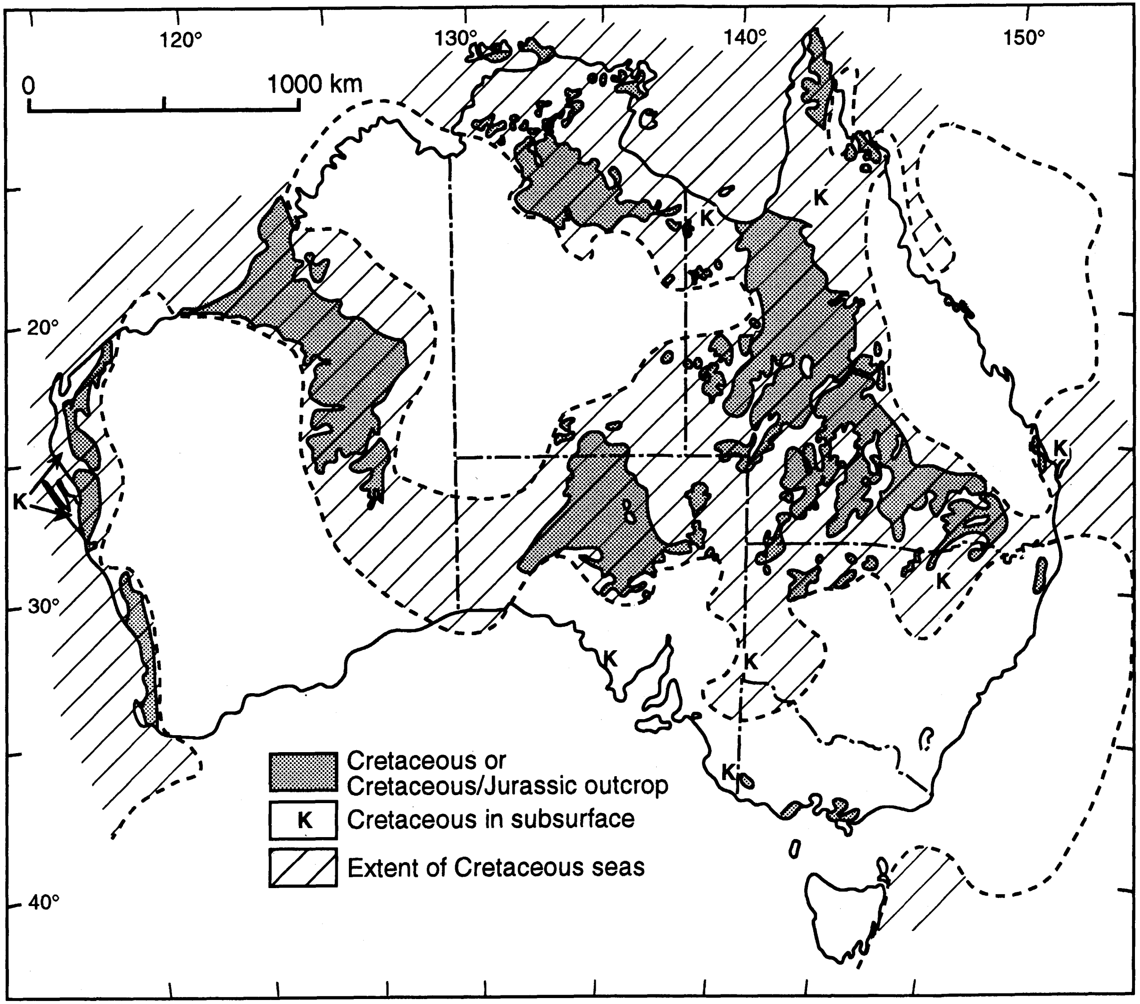

Fig. 2. Extent of the Early Cretaceous transgression in Australia (After Frakes et al., 1988).

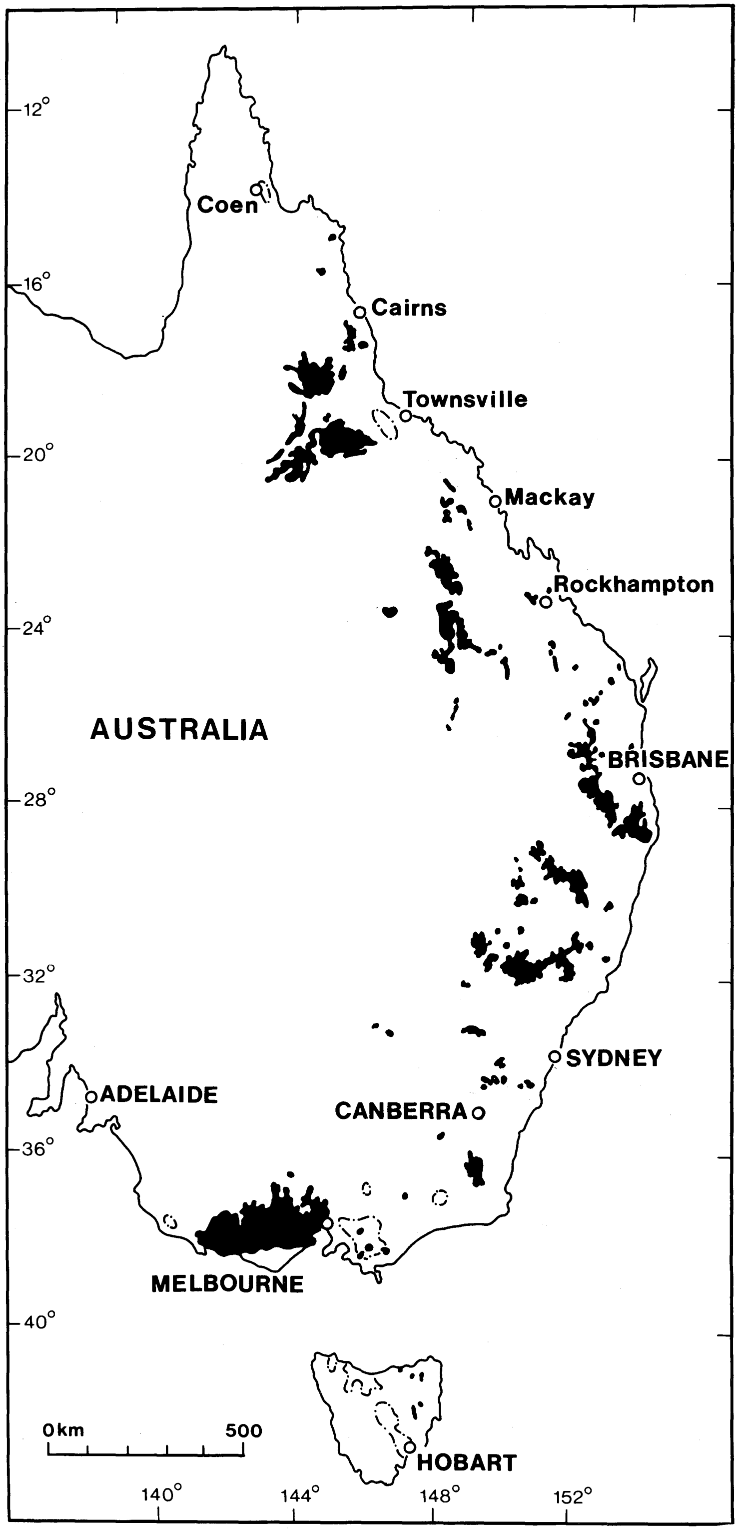

Fig. 3. Distribution of Cainozoic volcanic rocks, eastern Australia.

for comparatively youthful landforms (2 x10^6 years old) though some results obtained by this method are questionable, to say the least (e.g. Phillips et al.,1990). They are, in any case, inapplicable to surfaces of greater antiquity. Several criteria, lines of evidence and argument, based in stratigraphy, geomorphology and commonsense (the first two and the third are not mutually exclusive) have been used over the years, with varying degrees of success.

1. *Correlative deposits*: Correlative deposits undoubtedly provide the most secure means of dating geomorphological events and associated landforms. Thus the Gawler Ranges, in the arid interior of South Australia, is a massif of bornhardts eroded in silicic volcanics (dacite, rhyodacite, rhyolite, collectively known as the Gawler Range Volcanics) of Middle Proterozoic age. Many of the bornhardts are bevelled (Fig.4a) and the prominent summit surface they together form can be traced into unconformity in the Eromanga Basin, to the north and northeast of the upland (CAMPBELL and TWIDALE, 1991; also WOPFNER, 1969 - see Fig.4b). A regolith, with corestones, is preserved in only a few sites in valleys and on hillslopes, though not on the crestal flats; for the most part the summit surface and indeed the bornhardts are shaped in fresh bedrock and are etch forms. It is inconceivable that a regolith of some sort should not have developed on a plain surface, provided it endured sufficiently long, and there are a few pockets of weathered bedrock, with corestones, preserved on some fracture defined valley side slopes. The missing regolith , including cobbles and boulders of Gawler Range Volcanics, is located in the Mt Anna Sandstone, part of the Early Cretaceous sequence preserved in the Eromanga Basin. Thus the regolith was stripped and the present etch surface exposed during the Early Cretaceous. The planation and weathering of the surface must have taken place during the Jurassic or earlier times, though not before the Triassic, for the region was overriden by glaciers during the Permian.

Using slightly different and more tenuous arguments, CLARKE (1994) has postulated surfaces of Permian-Jurassic age from the southern Yilgarn Craton of Western Australia. He argues that the deep regolith of the region was formed prior to the incision of the widely preserved Eocene drainage system (VAN DE GRAAFF et al., 1977) and that there must have been deep erosion of the cratonic rocks during the period stated because it was the source area for sediments deposited in adjacent basins.

The age of the prominent summit surface of the Hamersley Ranges, in the north of Western Australia can also be determined using dated correlative deposits. The Hamersley Ranges is a massif underlain by and shaped in a sequence of only gently disturbed Banded Iron Formations of Proterozoic age (Fig.5a). The rolling summit surface is essentially of etch type, though pockets of a shallow pisolitic regolith remain. Most of the original regolith was transferred to, and reconstituted in, river valleys located marginal to the upland. This stripping took place in Eocene times, for fossiliferous riverine silts are preserved beneath the ferruginous cover, which is known as the Robe River Pisolite. The valley floors were however more resistant than the adjacent divide by virtue of this desiccated ferruginous duricrust, with the result that there has been relief inversion, with the sinuous former

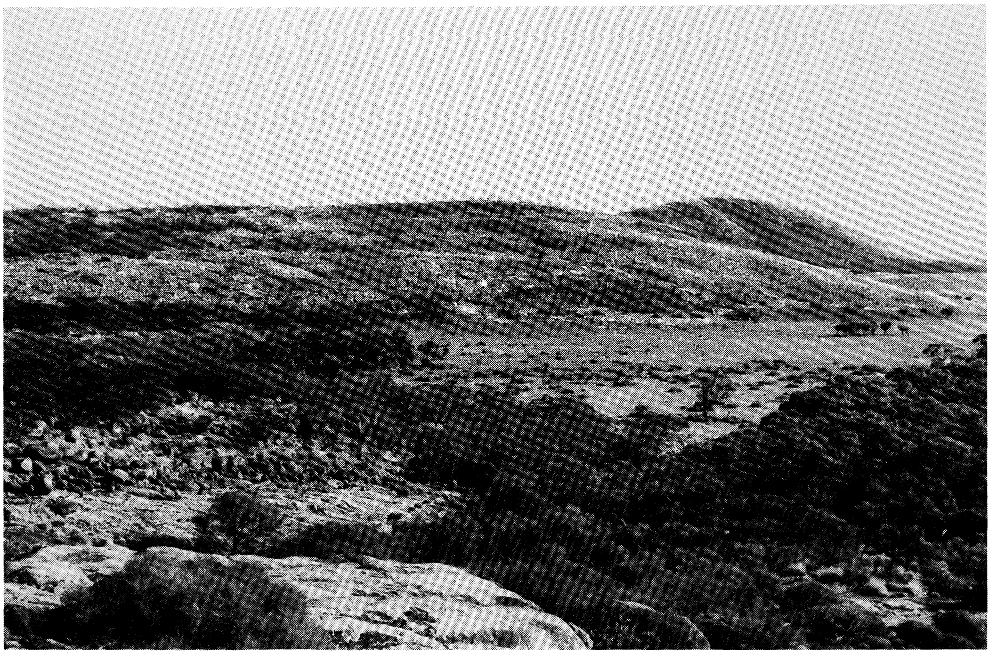

Fig. 4. Gawler Ranges (a).Summit surface cut in Middle Proterozoic silicic volcanic rocks, western Gawler Ranges, South Australia.

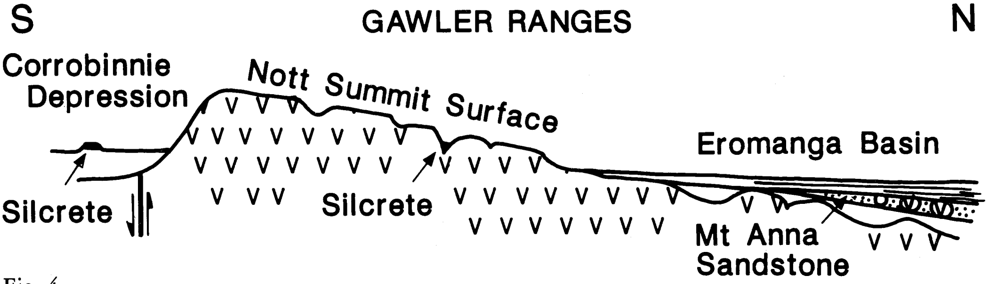

Fig. 4.

(b) North-south section through the Gawler Ranges.

Fig. 5. (a) Hamersley Surface cut across Proterozoic Banded Iron Formation strata.

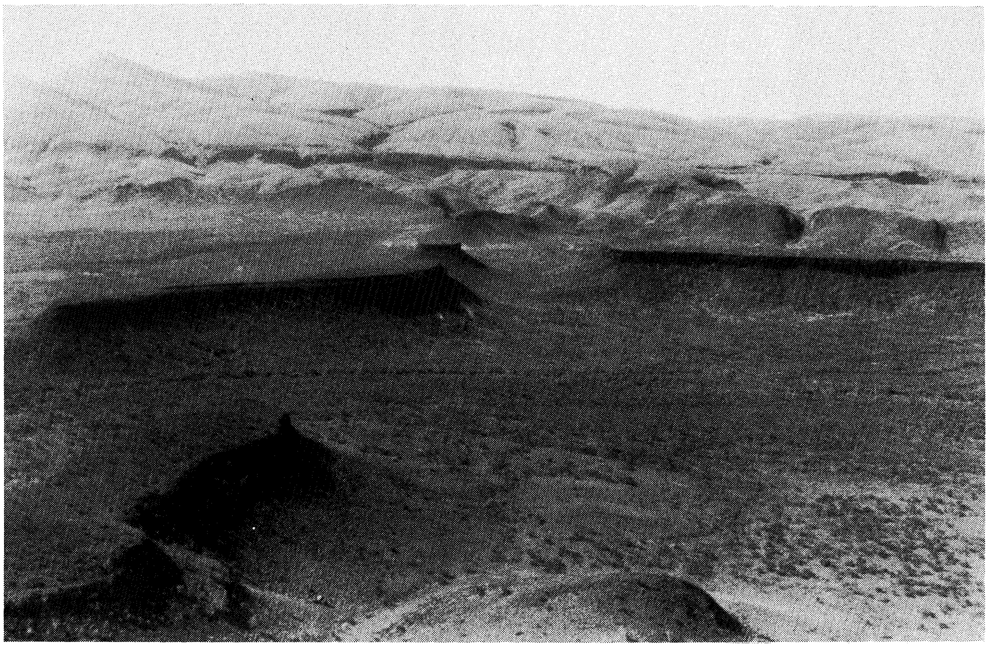

Fig. 5.

(b) Hamersley Surface (horizon), with sinuous plateau capped by Robe River Pisolite - an inverted old valley floor -in the foreground.

valley floors now standing high in the local relief (Fig.5b). As the deposition of the valley floor duricrusts, and hence the stripping of the upland surface, took place in the Eocene, the summit surface must have formed earlier. Regional palaeogeography and stratigraphy suggest a minimum Cretaceous age for the planation and weathering (TWIDALE et al., 1985; HOCKING et al., 1987); and it may be older. Similarly, the bevelled and etched summit surface of Ayers Rock has been dated by reference to fossiliferous valley fill deposits as of probable Late Cretaceous age (TWIDALE, 1978; HARRIS and TWIDALE, 1991).

2. *Topographic relationships with dated materials.* The minimum age of some features can be derived from the topographic relationship between them and dated deposits.Thus, the plains bordering and within the Gawler Ranges massif carry remnants of silcrete which in this region is stratigraphically dated as of Eocene age (FIRMAN, 1983, and Fig.4b). Thus it can be deduced that the massif has stood as an upland at least since the Eocene, the summit surface (see above) having been stripped during the Early Cretaceous. Duricrusts such as silcrete and laterite are useful in this context if stratigraphic dating has been achieved, and provided that extrapolation is restricted to the local and intraregional scales and not interregional or continental. Thus, The Humps (Fig.6), a group of gneissic bornhardts standing on a lateritised plain in the southern Yilgarn of Western Australia, are at least as old as the laterite i.e.Cretaceous-Eocene (VAN DE GRAAFF et al., 1977; FAIRBRIDGE and FINKL, 1978; TWIDALE, 1986).

Similarly, at the northern margin of the continent, the Arnhem Land Plateau (Kakadu) is a massif of Proterozoic sandstones. It stood as an island in the Early Cretaceous seas, for a shoreline of that age has been identified on the western margin (NEEDHAM,1982). To the east, on Groote Eylandt, the highest Cretaceous shoreline stands at only 75 m whereas the upland surface, with its spectacular sandstone towers, stands some 125-175 m higher (FRAKES and BOLTON, 1984). The Katherine Plateau (Fig. 7), also eroded in Proterozoic sandstone, is probably of similar age.

In the Flinders Ranges, in the interior of South Australia, a summit high plain is well and widely preserved, partly as crestal bevels developed on Precambrian rocks of various lithologies - granite, quartzite or sandstone, but also on argillites in the cores of anticlinal structures. In the northernmost parts of the Ranges, Early Cretaceous marine deposits are preserved in Mt Babbage and beneath the adjacent downfaulted or downwarped plains. In Mt Babbage the Precambrian-Cretaceous unconformity is coincident with the level of the high plain, suggesting that the surface is here of exhumed type and Jurassic age (WOODARD,1955;TWIDALE,1980). But the Cretaceous seas did not extend far to the south (Fig.2) so that the physically contiguous surface preserved there, particularly on argillaceous rocks in the core of a regional anticline, is probably an epigene-etch form shaped by rivers graded to the Cretaceous shoreline and hence of that age. This suggestion finds support in the southern Flinders Ranges where Eocene lacustrine beds tongued up valleys between ridges on which are preserved remnants of the summit surface Clearly the present pattern of ridge and valley was already established by the Eocene, so that the (present) high plains surface which was differentially eroded to produce the present

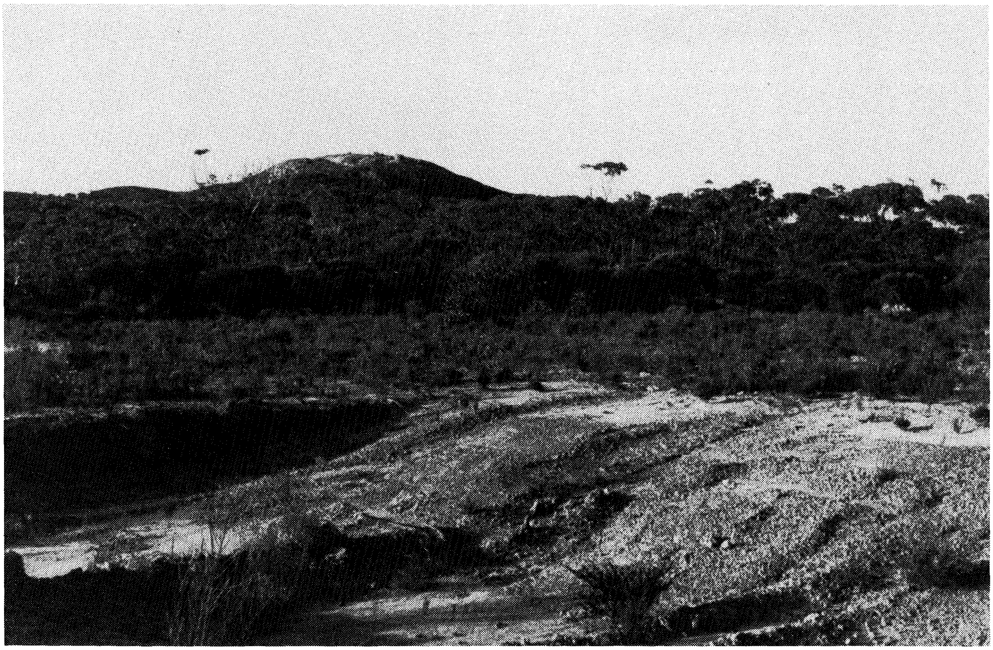

Fig. 6. The Humps, southwestern Yilgarn Block, Western Australia.

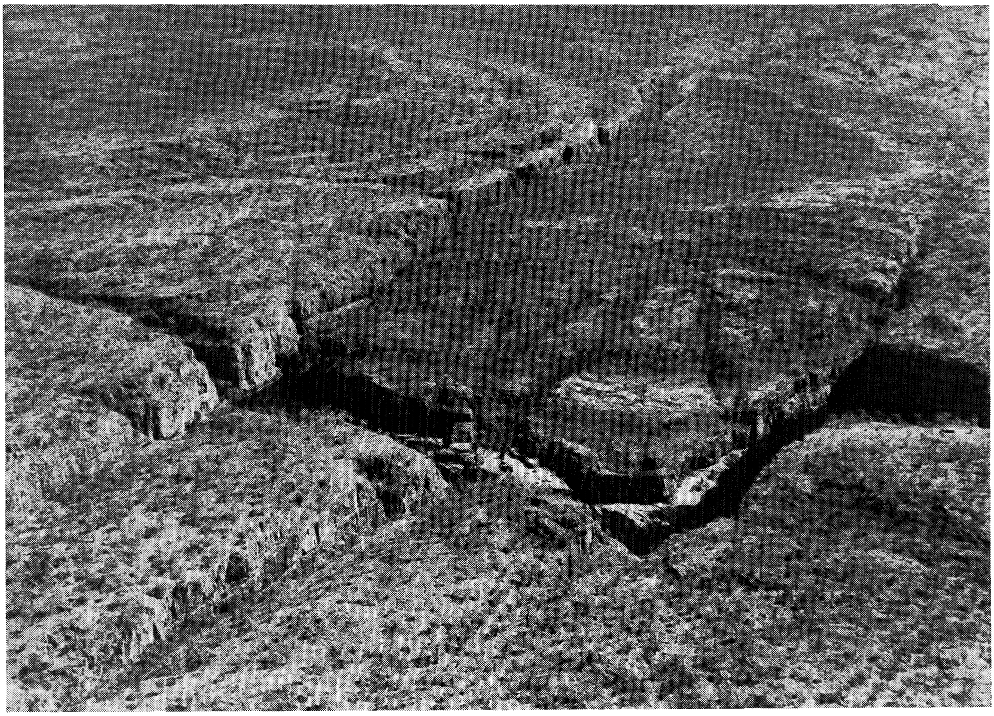

Fig. 7. Katherine Plateau, Northern Territory.

ridge and valley assemblage, must predate the Eocene (TWIDALE, 1980).

Volcanic rocks are readily dated using radiometric methods, and they provide minimum dates for adjacent nonvolcanic surfaces. In the Eastern Uplands, prominent summit surfaces (Fig.8) are present throughout. However, though it is likely that remnants of several planation surfaces are present, rather than of a single feature (for common experience suggests that the old landscape is multicyclic or at least polycyclic - see BAULIG, 1935), it is not yet possible to differentiate consistently and with certainty between different surfaces and for the present they are discussed as a single entity.

As deduced by HILLS (1934, 1975), the summit high plain of predates the Early Tertiary Older Volcanics of eastern Victoria (Fig.3), for the lavas flowed in valleys incised below the level of the high plains (see also Craft,1932,1933). It is also of etch type though the gentle slopes are everywhere consistent with regional gradients. These perceptive findings have been confirmed by later radiometric datings of the lavas and associated stratigraphic work (e.g. RUXTON and TAYLOR, 1982; YOUNG and MCDOUGALL, 1985; TAYLOR et al., 1985). The summit high plain in many places closely dated by means of volcanic extrusions is well developed and preserved in New England, in northeastern New South Wales (OLLIER, 1982), and in north Queensland (e.g. KEYSER, 1964). Subvolcanic surfaces are also being exhumed, as for instance in New England (e.g. FRIED and SMITH, 1992). In north Queensland the summit surface of the western slopes of the upland merges with an exhumed preCretaceous surface before passing into unconformity beneath the Carpentaria Plains and re-emerging in the Isa Highlands (TWIDALE, 1956).

Volcanic extrusions also provide a means of dating duricrusted high plains in the Gulfs region of South Australia. The surface is widely lateritised and the duricrust is developed on rocks of Proterozoic, Cambrian and Permian ages. On northern Kangaroo Island a basalt, dated as of Middle Jurassic age, overlies the laterite. Thus the duricrust and the surface on which it is developed is of Permian-Middle Jurassic age (DAILY et al.,1974).

3. *Relationship to faulting* : Where a surface is disrupted by faulting the age of faulting provides a minimum age for the surface.This is theoretically sound, but in practice it can be misleading. for the method appears to give a too-young age though reactivated faults can suggest ages that are too great. Thus in the region just referred to, the Gulfs region of South Australia, the Mt Lofty Ranges is a complex horst with a summit surface carrying remnants of laterite. Marine deposits, including lateritic blocks, laid down in fault angle depressions or half grabens marginal to the horst are of Eocene and younger ages, suggesting that the faulting occurred prior to the Eocene, and that the disrupted surface is also older than Eocene (MILES, 1952; GLAESSNER, 1953; CAMPANA 1958; see also HOSSFELD, 1926). On this basis the surface could reasonably be dated as Cretaceous, though the date derived from the stratigraphic position of the dated volcanics is much greater.

Another example is provided by the prominent summit surface of the Arcoona Plateau. On its western side the plateau is disrupted by the Torrens Fault Zone. On the downfaulted block, freshwater strata

Fig. 8. Summit plains in the Eastern Uplands (a) in the Snowy Mountains, near the New South Wales-Victoria border, with The Pilot as a residual remnant.

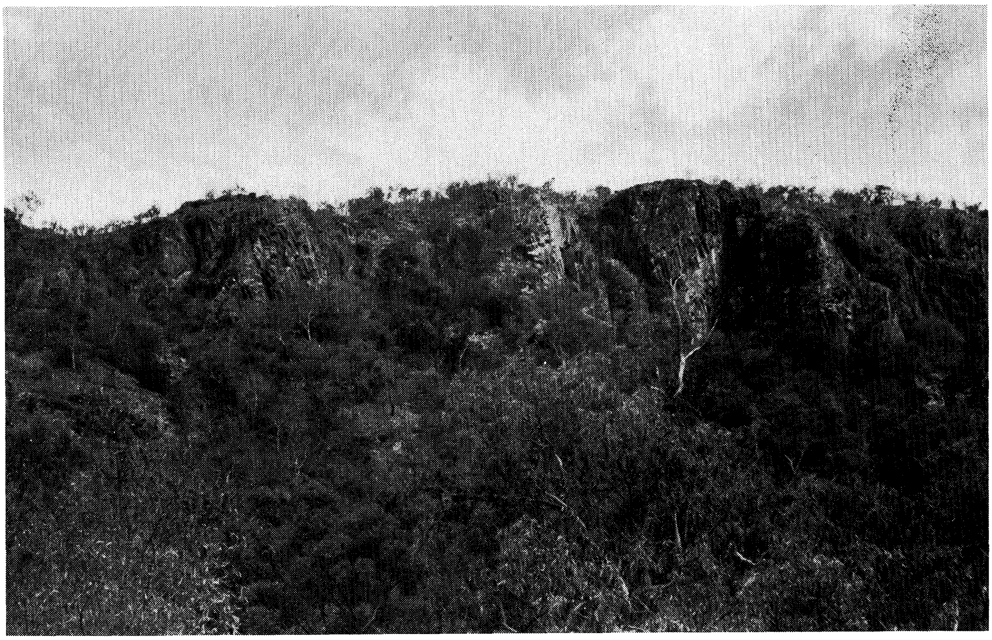

Fig. 8.

(b) Cut across Late Palaeozoic silicic volcanics, Newcastle Range, north Queensland.

Fig. 8.

(c) In the Atherton Tableland, north Queensland (After Keyser, 1964).

including some of Eocene age, are deposited, suggesting a minimum Eocene age for the faulting and the dislocated surface. In fact, the surface is at least of Jurassic age because at the northwestern margin of the Plateau the Early Cretaceous seas (Fig.2) extended up valleys already incised below the summit high plain (JOHNS, 1968a, 1968b; TWIDALE et al., 1970).

On the other hand, many of the Hercynian (Late Palaeozoic) faults of the Hesperian Massif (Iberian Peninsula) have been reactivated during the Mesozoic and Cainozoic, and the relative age of any rift sediments, faulting and surfaces preserved on adjacent horsts is not everywhere apparent. To interpret sediments as necessarily postdating a particular phase of dislocation may produce an incorrect too old age.

4. *Relationship to shorelines.* The use of shorelines in the dating of land surfaces has been illustrated by the dating the summit surface of the central and southern Flinders Ranges from its possible relationship to Cretaceous shorelines. The Yilgarn Block of the southwest of Western Australia provides another example.The high plain preserved on the Yilgarn Block is a complex feature, with duricrusted remnants (the Old Plateau of JUTSON, 1914), and extensive etched plains (the New Plateau; see also MABBUTT 1961; Finkl and Churchward, 1973).The possible age of the surface, though whether of the Old or the New plateau is not clear, is indicated by the presence of marine Cretaceous beds, with lateritic material, in valleys incised in the western margin of the Block (PLAYFORD et al.,1976). They surely suggest a minumum Cretaceous age for the feature.

Remnants of a summit high plain are preserved on quartzite ridges in the folded MacDonnell Ranges of central Australia. They are regarded by MABBUTT (1966) as having been shaped by rivers graded to the Cretaceous shorelines and they certainly stand higher in the landscape and are, therefore, presumably older than both old valley floor remnants which are duricrusted and are of Miocene age (see e.g. WOODBURNE, 1967) and lake basins of the same Miocemne age preserved as cappings in the Ooraminna Ranges, south east of the MacDonnell Ranges (e.g. MCMICHAEL, 1968; WELLS et al., 1970; TWIDALE and MILNES ,1983).

These examples illustrate methods of dating old land surfaces. Their application and the use of other, less secure methods (though in many regions they are all that are available!). They also serve to indicate the extent of very old palaeoforms of epigene-etch type in the Australian context. Though they constitute significant landscape elements, such old palaeoforms are not as widely recognised in other continents as in Australia. This may reflect difficulties of dating as much as reality. Nonetheless, surfaces of similar type and antiquity are reported from several other parts of Gondwana. Thus, DIXEY (1946), KING and others (see KING, 1962 for references) long ago suggested a Mesozoic age for the high summit plains of eastern and southern Africa (Fig.9). The Mesozoic age of the Drakensberg high plain has been questioned (e.g. PARTRIDGE and MAUD, 1987) but if its etch character is taken into account some of the problems posed by suggestions of antiquity are resolved (TWIDALE, 1990). Stratigraphically dated lateritised surfaces of Mesozoic age are recorded from West Africa (MICHEL, 1978) and southern India

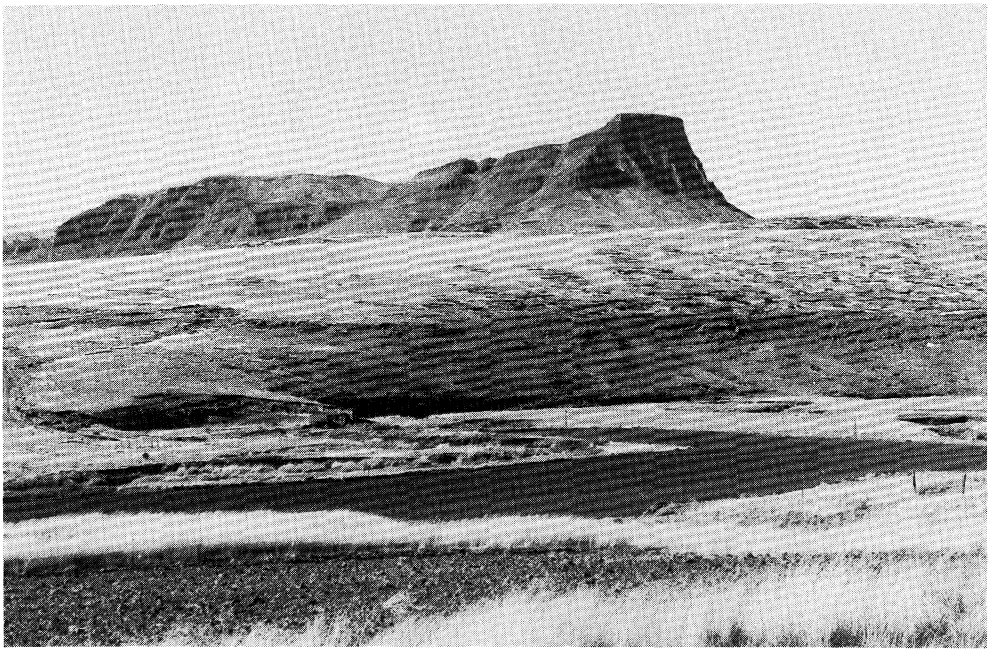

Fig. 9. Remnant of summit surface cut in Jurassic basalt, overlying sandstone, southern Drakensberg, South Africa.

Fig. 10. (a) Remnants of summit bevels preserved on quartzite ridges, near Mt Isa, Isa Highlands, northwest Queensland.

(DEMANGEOT, 1978). The upper surface of the Roraima Surface, developed and preserved on a sequence of massive Proterozoic quartzites on the Guyana Craton is evidently of Cretaceous age (BRICEÑO and SCHUBERT, 1990).

OLD EXHUMED FORMS

Some of the ancient remnants that constitute part of the contemporary landscape have been buried and later exhumed. In Australia they range in age from Archaean to Pleistocene though many Australian examples are associated with periods of extensive marine transgression and date from the Neoproterozoic, the Early Cambrian and, and especially, the Late Jurassic and earliest Cretaceous. The latter occur at the margins of sedimentary basins occupied by the Early Cretaceous seas which inundated almost half of the Australian continent and reduced it to an archipelago consisting of several very large islands (see e.g. FRAKES et al.,1988, and Fig.2).

The precise age range of such exhumed forms cannot be determined. All that can safely be stated is that they predate the cover material and are younger than the youngest materials across which they are eroded. In practice it is reasonable to assume that they existed immediately prior to the event during which they were buried (whether a marine transgression, a lava flow or ash deposit, or transgressive dunes) and to allocate them this age.

Deposition in marine, lacustrine, fluvial or glacial environments usually implies stripping of any pre-existing regolith, for such unconformities are essentially clean, whereas a volcanic cover, whether lava or ash, better preserves the earlier formed regolith and even, in some instances quite delicate landforms, as for example in the Parana Basin of South America where barchans are visible beneath a basaltic cover (ALMEIDA, 1953). Similarly regoliths are preserved beneath dunes, as for instance on the west coast of Eyre Peninsula, in South Australia, where a regolith up to 10m thick developed on granite and gneiss remains beneath a cover of Middle-Late Pleistocene calcarenite accumulated in coastal foredunes.

Such exhumed preCretaceous surfaces are prominent along the eastern margin of the Australian Craton, for instance, in the Isa Highlands of northwest Queensland (Fig. 10) where the subCretaceous unconformity occurs both high in the relief and at plain level near the margins of the upland (TWIDALE, 1956). In the northern part of the Northern Territory the Pine Creek area is underlain by Proterozoic granite, the Tindal region, south of Katherine, by Cambrian limestones, but both were buried by sandstone deposited in the Early Cretaceous epicontinental seas (STUART-SMITH et al., 1987). Stripping of the Cretaceous beds has re-exposed the surface over which the seas advanced: a granite plain with occasional low whalebacks and clusters of residual boulders south of Pine Creek, and, around Tindal, a karst plain with groups of pinnacles and low flat-crested hills. The extraordinary feature of the karst region is that even minor forms like solution hollows, flutings and bedding planes widened by solution predate the Cretaceous transgression, for they contain or are coated by Cretaceous sediments (TWIDALE, 1984).

PreCretaceous surfaces of low relief are represented south and southwest of the Eromanga Basin (JACK, 1931; WOPFNER, 1964) and the Peake and Davenport Ranges (Wopfner, 1968). The

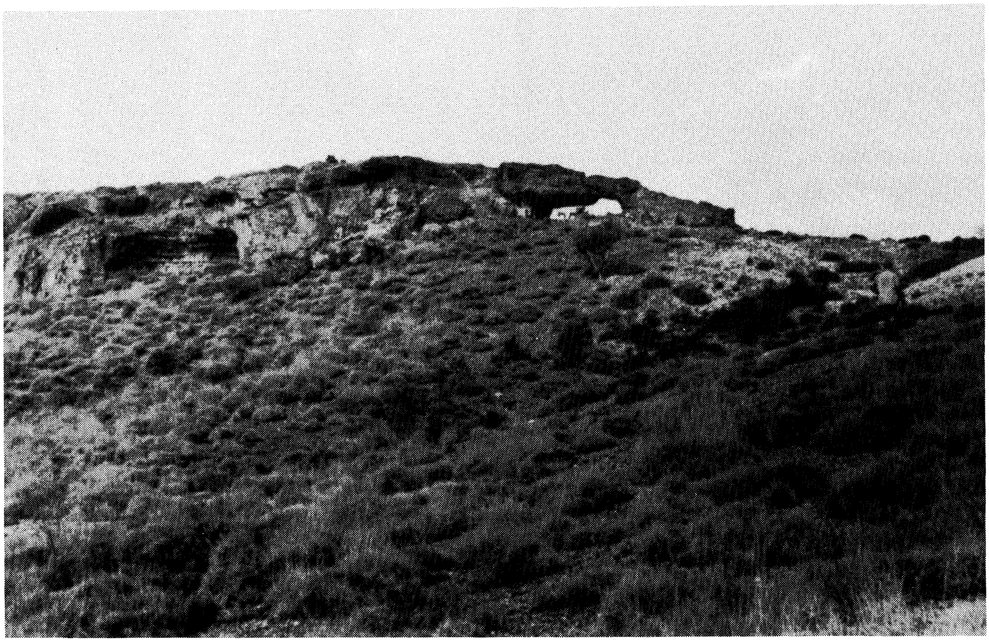

Fig. 10.

(b) The summit surface is an exhumed pre Cretaceous surface, for it is coincident with the unconformity, seen here in the southern Isa Highlands, between lateritised Cretaceous strata above and Proterozoic granite below.

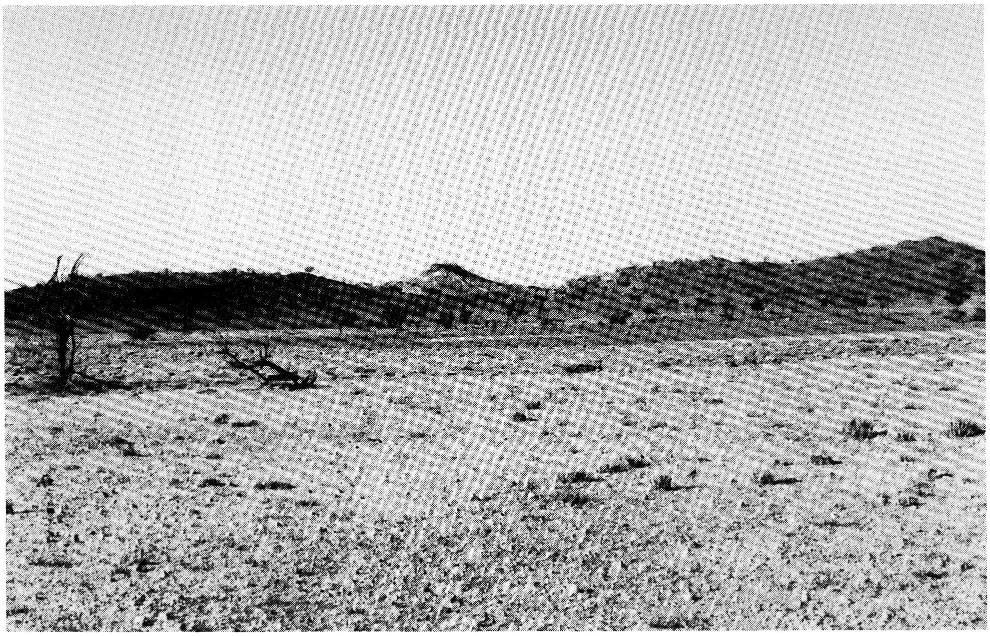

Fig. 11. The exhumed character and pre Late Jurassic age of granitic bornhardts around Kulgera, southern Northern Territory, is demonstrated by exposures like this with Jurassic sediments preserved between and standing higher than the granitic basement.

inselberg landscapes of the Kulgera area, astride the Northern Territory-South Australia border, are clearly exhumed and of Jurassic age, for remnants of (?) Jurassic sediments form widely scattered mesas standing on plains eroded in granite and interspersed with the granitic domes (Fig.11). The granitic Everard and the gneissic Musgrave Ranges, located west of Kulgera, are also old, though how ancient is a matter of speculation The known extent of Mesozoic strata make it likely that both uplands, stood as uplands bordering the later Mesozoic shorelines. The Musgrave Ranges display a prominent rocky summit bevel, and if, as seems probable, the bornhardts of the Everard Ranges developed by differential weathering beneath a surface of low relief, the latter could be represented by the Musgrave Ranges bevel. In that case the bevel predates the Later Jurassic.

On the western side of the Craton, preCretaceous forms are reported from the northern Pilbara (TWIDALE, 1986; TWIDALE and CAMPBELL, 1988) and from the Carnarvon Basin (HOCKING et al., 1987), where, in addition to exhumed plains, the Murchison Gorge, incised in the Victoria Plateau, demonstrably predates the Cretaceous for sediments of this age are preserved within the upper part of the narrow valley (Fig.12).

Exhumed forms of preCretaceous age reported from other Gondwanan regions include the classical inselberg landscapes described from the present Tanzania by BORNHARDT (1900), for as pointed out by WILLIS (1936) and others, the granitic

Fig. 12. Part of the Murchison Gorge, near Carnarvon, Western Australia, which was incised into the sandstone plateau in pre Cretaceous times (Courtesy R.M.Hocking).

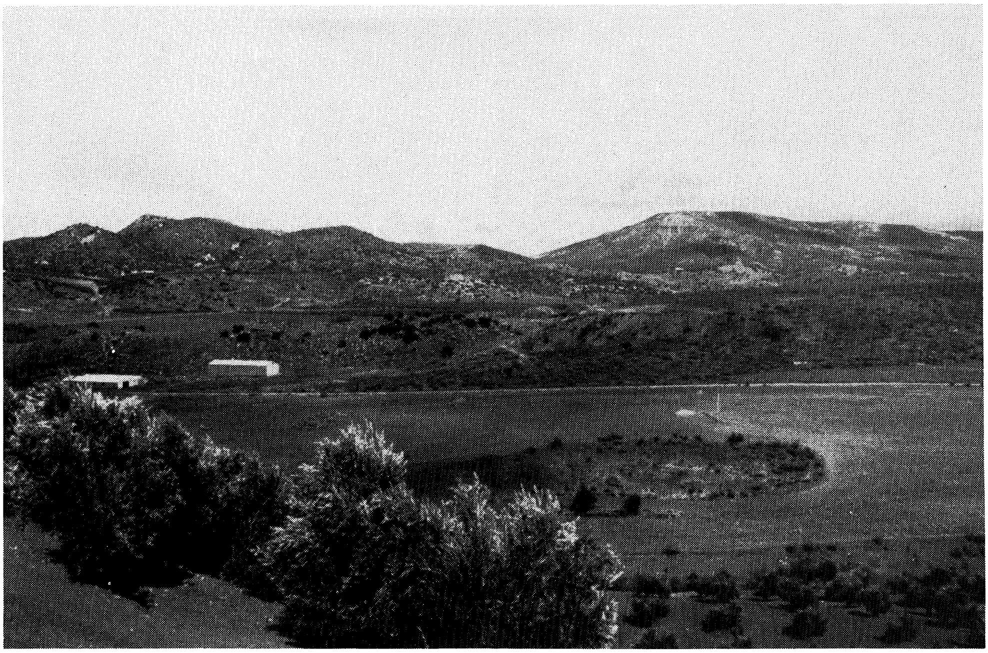

Fig. 13. (a) Photo and.

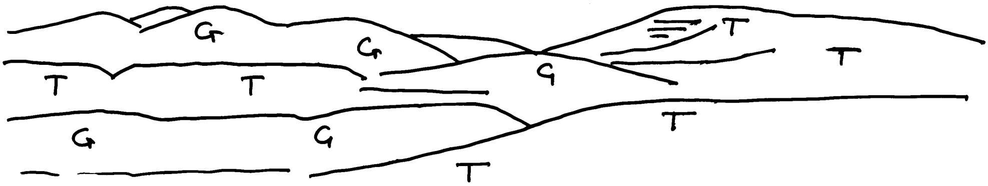

Fig. 13

(b) explanatory sketch of region near Linares, southern Spain, showing partially exhumed preTriassic landscape. G - granite, T - Triassic sediments.

landform assemblage has been exposed as a result of the erosion of a thick sequence of Cretaceous sandstone which manifestly once covered the entire region. In India, Choubey and others (e.g. CHOUBEY, 1969) have described landscapes re-exposed by the erosional stripping of the Deccan lavas of (?) Cretaceous age.

The Gondwana landscape is, and possibly was, complex for older elements were already in place either exhumed or ready for re-exposure. Thus, ÖPIK (1961) has identified pedimented plains of pre Middle Cambrian age from the southern part of the Isa Highlands, in northwest Queensland, and resurrected Proterozoic plains occur at several sites in Australia including the Barrow Creek area of the Northern Territory, and the region east of Lake Gairdner, in the arid interior of South Australia (TWIDALE et al., 1976). Parts of the Kimberley Plateau may be of similar age, though some regard it, in part at least, as an epigene glaciated surface (OLLIER et al., 1988). Granitic inselbergs of Archaean age are being exhumed from beneath a sequence of mixed sediments and volcanics in the central Pilbara, in the north of Western Australia (TWIDALE, 1986), and exhumed glaciated surfaces of Late Palaeozoic age are widely reported from Gondwana elements (e.g. WOPFNER and KREUSNER, 1986). Also, in Antarctica the exhumed Kukri Erosion Surface, of post Ordocvician-pre Devonian age, has been mapped in some detail (e.g. BRADSHAW 1981) and a subJurassic surface is also well known (e.g. BURGESS et al.,1981).

LAURASIAN ELEMENTS

Ancient palaeoforms of a range of preCainozoic ages are evidently preserved also in parts of Laurasia. In California, the prominent summit surface of the Sierra Nevada , which is of epigene-etch type, is putatively dated as Cretaceous (CURTIS et al., 1958), and high level planation surfaces have long been recognised in the Appalachians (e.g. BASCOM, 1921; JOHNSON, 1931) though until recently no convincing evidence of their antiquity had been found (for summaries see FAIRBRIDGE, 1968; THORNBURY, 1968). Correlation of sediments preserved in offshore basins, however, suggests phases of weathering and erosion during the Early-Middle Jurassic, early - Middle Cretaceous, and the late Cainozoic (POAG and SEVON, 1989) so that the higher surfaces of the Appalachians are of great antiquity.

GJESSING (1967) has postulated the preservation of remnants of a Mesozoic surface and associated regolith in Norway, and Permo-Triassic and Jurassic-Cretaceous surfaces, some marine but others epigene, have been identified on the stepped borders of Armorican massifs of western France, southern Germany, southwestern England and Bohemia (e.g. DESIRE-MARCHAND and KLEIN, 1987; KLEIN, 1990) A preTriassic surface preserved beneath the Bunter Sandstone is reported from the Eifel region of Germany, and palaeosurfaces and associated regoliths of Cretaceous- Eocene age are reported from Schwäbische Alb of southern Germany (BORGER, 1992)

Many of the uplands of the Iberian Peninsula are bevelled and many are stepped, i.e. there are prominent planation surfaces at various levels. Evidence from faulted Early Miocene basins and from the putative ages of alluvial sediments in valley floors suggest that those standing a few scores of metres above sea level near the Galician coast, for example, are of Later Cainozoic age, (NONN, 1966; PANNEKOEK, 1966, 1967), but the prominent surfaces standing at 1500m and more above sea level, and above the level of several valley side facets, in, for example, the valley of the Rio Valcarce, are Paleocene or older (HERAIL, 1984; MARTIN-SERRANO, 1994). These planation surfaces stand higher in the relief than others preserved on horst blocks separating the rias of the type area on the western coast of Galicia (RICHTHOFEN, 1886). In fact the rias occur in a tectonic landscape related to the tensional rifting and opening of the Atlantic basin that began during the later Mesozoic (VANNEY et al., 1979) A postglacial marine transgression inundated the lower parts of the tectonic coast, producing the ria coastline with remnants of older Cainozoic surfaces preserved on the intervening horst blocks. There is no direct evidence of the age of the upland surfaces but on the sea floor off the coast of northwestern Spain, the occurrence of horsts covered by Triassic evaporites (BOILLOT et al., 1979; VANNEY et al., 1979) on the seafloor suggests that some, at least, of the palaeosurfaces of the western Iberian Peninsula are of this age. Such evidence illustrates that correlative deposits offshore and in the Valle Inclan depression (BOILLOT et al., 1979), and the Douro and Ebro basins may help resolve the question of the age or ages of the high planate remnants preserved in adjacent uplands.

Thus there is evidence of ancient survivals in various parts of the former Laurasia. But are they truly Laurasian, that is do they predate rifting and separation? Some clearly do not. For instance Laurasia remained intact from the Carboniferous through the Jurassic. Yet the evidence for the antiquity of some of the Appalachian surfaces derives from basins formed in the rifted ocean basin that is the Atlantic (POAG and SEVON, 1989). Here is a problem of terminology that has not been resolved. Ought surfaces that predate the final separation of all Pangaean elements be considered as Pangaean or ought a more regional or local chronology be observed?

Exhumed forms have been reported from several parts of Laurasia. Lidmar-Bergström and others have demonstrated the presence of preCretaceous forms, including an exhumed river gorge (cf. the Murchison Gorge noted above) in Skania, southern Sweden (LIDMAR-BERGSTRÖM, 1989; LIDMAR-BERGSTRÖM and AKESSON, 1987) and the same author has summarised the evidence for exhumed surfaces of sub-Cambrian and Permo-Triassic, as well as sub Cretaceous, ages in Fennoscandia (LIDMAR-BERGSTRÖM, 1992, and earlier workers cited there, e.g. RUDBERG, 1970).

A preTriassic granite landscape is in process of exhumation in the region north of Ubeda and Linares, in Andalucia, southern Spain (Fig.13). The many bouldery hills were completely buried by the Triassic sediments (equivalent to the Muschelkalk - see AZCÁRATE, 1972) are exposed now in the flanks of plateaux as high as such granite peaks as Cerro de las Monjas (690 m above sea level). The Triassic has been eroded in phases for prominent plateaux are preserved at 420 m above sea level, and some 40 m above river level in the wide basin drained by the Rio de Escuderos, and many granite nubbins are bevelled at this same level. The higher granite residuals are notched at this level, though whether this is due to scarp foot weathering or to littoral erosion is not clear, though the occurrence of exotic cobbles suggests drift and wave action. The Triassic

Fig. 14. (a) Photo and.

Fig. 14.

(b) Explanatory sketch of Lewisian landscape, northwest Scotland, showing gneissic hills partly exposed from beneath Proterozoic Torridonian Sandstone. L - Lewisian, T - Torridonian. (Courtesy G.E.Williams).

Fig. 15. Summit bevels in granite gneiss, southern Greenland (Courtesy Oen Ing Soen).

landscape of the Ubeda-Linares region is comparable in age to those reported from the English Midlands (WATTS, 1903, 1947) and from the Parana Basin of South America (ALMEIDA, 1953).

Older exhumed forms are present in Laurasian remnants as they are in Gondwanan. To take just a few examples amongst many, and in addition to the examples cited earlier from Fennoscandia, WILLIAMS (1969) has described a subTorridonian inselberg landscape eroded in Lewisian gneiss from northwestern Scotland (Fig.14), ROSE (1955) has indicated the presence of exhumed elements of Early Palaeozoic age in parts of Labrador and exhumed plains of Proterozoic age are widely distributed in the North American Arctic, including Greenland (COWIE, 1960; AMBROSE, 1964). Whether the bevels illustrated by SOEN (1965) from south Greenland (Fig.15) are epigene-etch or exhumed is not known.

Thus though glaciation, frost action and other agencies have destroyed or masked evidence of older paleoforms in many parts of the former Laurasia, some survives and more may be found if sought. Experience in the former Gondwana, and particularly in Australia, suggest that correlative deposits, and relationships with chronostratigraphic markers of known ages (volcanic extrusions, duricrusts) offer the best possibilities for dating old land surfaces, though faulting and topographic relationships are also useful. But taken together the various relics of old Gondwanan and Laurasian landscapes suggests that in the near future it will not be unrealistic to speak or write of a Pangaean inheritance on the global scale.

DISCUSSION

The dating of exhumed landforms is a simple matter, but for epigene-etch forms it is difficult. Marine transgressions stratigraphically dated duricrusts and volcanic extrusions are helpful, but various methods can be used, and though the data necessary for their application are not everywhere available, a reasonable «guesstimate» is usually possible. Nevertheless it is likely that in some areas very old surfaces are present but cannot be identified as separate entities. For instance in the southern and central Flinders Ranges basin deposits of Triassic age are derived from a surface of low relief. Such surfaces occur nearby but they cannot be identified as Triassic; rather, or so it seems, are they more reasonably attributed to fluvial action during the Cretaceous.

The Australian landscape is especially rich in very old palaeoforms. This is partly because if the essential stability of the continent: though the surface is and has been constantly disrupted by folding and faulting, probably related joggling induced by the northward migration of the continent, these effects are minor, and over wide areas of the continent flat lying, essentially undisturbed sedimentary sequences of Proterozoic age attest a long term tectonic stability. Substantial areas of the continent have been repeatedly reduced to low relief. Marine incursions like those of the Late Proterozoic, the Cambrian, the Cretaceous and to a lesser degree the Miocene, had profound effects on landscape development, not only providing new baselevels, but also inducing isostatic responses to erosion and deposition (TWIDALE and CAMPBELL, 1992). They were crucial to the preservation of palaeoforms not only in unconformity but high in the relief. Contrary to suggestions of basin inversion, the development of the Australian landscape suggests a consistency and continuity of tectonic behaviour, with some structural units repeatedly uplifted, so that palaeosurfaces are preserved on these multicyclic uplands, whereas in the intervening basins, which have suffered repeated subsidence, corresponding surfaces are preserved in unconformity. Southern Africa has behaved in similar fashion. KING (1962) attributed the prominent major planation surfaces to repeated uplifts induced by isostatic response to erosional offloading, but they may be related to epeirogenesis and river rejuvenation consequent on hotspot activities beneath the subcontinent. Similar old landscape elements, some exhumed, but others apparently of epigene-etch origin have been recognised in Laurasian components and more will come to light as correlations are made between surfaces and basin and offshore sediments. The day when we can seriously write and speak of the Pangaean inheritance is surely not far away.

The very old palaeoforms preserved in the Pangaean elements pose serious problems for conventional models of landscape development. Exhumed surfaces are preserved in unconformity, though the absence of significant modification by weathering, for instance in the karst plain resurrected around Tindal, is difficult to understand. Epigene-etch forms ought not survive so long (TWIDALE, 1976; see also YOUNG, 1983; WYRWOLL, 1988). That they have done so reflects the operation of several factors and mechanisms. The bedrock in which most of them are preserved is resistant, or there are resistant rocks buttressing or protecting the surface against dissection. Water is the great destroyer and upland sites especially if underlain by permeable or pervious rocks, remain virtually untouched (TWIDALE, 1991; TWIDALE and CAMPBELL, 1992). It cannot be assumed that because a multicyclic land mass is near the coast, past or present, any palaeosurfaces will have been eliminated. Rejuvenated rivers have not everywhere extended headwards far inland as might be expected. In addition to clarifying the age of the various summit high plains in the Eastern Uplands of Australia, radiometric dating of lava flows has allowed estimates of the rate at which steep gradient rivers flowing to the Pacific have extended headwards. The rate of regression is surprisingly slow, being as little as 100km in 60 ma (TAYLOR et al., 1985; YOUNG and MCDOUGALL, 1993). Also, the work of rivers and run off does not everywhere extend over the entire land surface, for as suggested by KNOPF (1924), CRICKMAY (e.g. 1932, 1976) and HORTON (1945), in some circumstances rivers have eroded powerfully in and near major channels but the intervening divides remain essentially untouched. Reinforcement or positive feedback effects are implicit in several of the factors mentioned above, particularly with respect to uplands shedding or draining water, and rivers maintaining their courses (little wonder that so called transverse streams or drainage anomalies exist and are explained in terms of antecedence and persistence - see e.g. OBERLANDER, 1965, TWIDALE, 1966, 1972!).

Thus the possibility of long term survivals, even of Pangaean provenance, cannot be ruled out of court. Nevertheless it is not surprising that many still doubt the feasibility of such long term survivals. If, however, such very old surfaces exist they must be possible. Moreover «Not everything which is incredible is untrue».

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