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ABSTRACT

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Contents

1. Introduction

The possible fate of scientific ideas has been summarized in various ways, but a representative version, that applies for instance to the

Darwinian concept of evolution, suggests that: 'All truth goes through three stages. First, it is ridiculed. Second, it is violently and rudely opposed. Third, it is accepted as being self evident.'

With changing attitudes to interpretation and explanation in mind it is salutary to consider the history of the ancient landscapes concept, which challenges several fundamental aspects of general geomorphological theory but which is widely considered to be based in unreliable evidence and argument and thus beyond belief.

2. Conventional age-range of land surfaces

Commonsense supports the conclusion articulated by James Hutton (1788) and supported by Charles Lyell (1830) that the Earth's landscapes have constantly changed under attack by agencies and processes active at the Earth's surface. They continue to do so, for it is a matter of observation that rivers, glaciers, and the wind carry huge volumes of sediment that are deposited in valley floors, enclosed basins, and the sea. Transport and deposition imply erosion in source areas. Landscapes are in flux.

The theme of constant change was reinforced by Davis (1899) who concluding that rivers are responsible for shaping most of the world's land surfaces, stated that the effects of wash and streams extend to every part of the landscape. Hence the almost universal view that with the exception of exhumed forms, few landscape features predate the later Cenozoic. Brown (1980) suggested that in theory a few forms dating from the earlier Tertiary may persist, but most workers considered that landscapes date from the Miocene or Pliocene at the earliest, and that most are of Quaternary age (*e.g.* Ashley, 1931; Thornbury, 1954).

This conclusion was partly based, and found corroboration, in recently de-glaciated and hence youthful areas of western Europe and northern North America. The midlatitude deserts that so fascinated early explorers and scientists also are of recent derivation. Measured erosion rates and estimates of the time taken to reduce certain areas to baselevel, considered in conjunction with Davis' belief in the ubiquity of erosion by running water, seemingly ensured the elimination of earlier surfaces, and confirmed the essential recency of landscapes (*e.g.* Linton, 1957; Schumm, 1963). The youthful landscapes mindset became embodied in the favored models of landscape development (Davis, 1899; King, 1953; Hack, 1960). That landscapes are both youthful and of epigene origin became a virtually unchallenged and unchallengeable axiom both in the literature and in the minds of many geomorphologists; so much so that the occurrence of landforms of possible pre-Pleistocene age was considered to be worthy of announcement (*e.g.* Bierman and Turner, 1995).

However, there has not been universal accord. Kennedy's (1962) hypothetical model of landscape developments based in the interplay of tectonics, stream dissection and mass wasting suggests that in some circumstances summit surfaces may persist, at least for a time. Also, field evidence has long been cited that points to contemporary landscape elements that evidently predate the later Cenozoic. Some are of exhumed type, that is, they have been shaped, then buried beneath sediments or volcanic materials, and later resurrected; though it is noted that some structural geologists consider 'exhumation' and 'erosion' to be synonymous. In addition, forms and surfaces of etch or two-stage origin that long have been exposed to the elements have been reported from many parts of the world.

3. Nature of paleosurfaces

3.1. Exhumed forms and surfaces

The age of a resurrected surface is bracketed by the age of the youngest rock exposed in the eroded and buried surface and the oldest of the cover material. It usually can be taken as immediately predating the cover. Exhumed forms and surfaces are widely distributed both in space and time. They range in age from Late Archean to Late Pleistocene. Some have been exhumed more than once. The Mesozoic surface that persists on the Armorican Massif of western France is a case in point (Bessin et al., 2015) and the Lake District of northwestern England and Enchanted Rock and associated bornhardts located in the Llano of central Texas offer similar possibilities (Marr, 1906; Barnes, 1981). Their persistence poses no problems unless they were exposed during or prior to the Cenozoic.

Some exhumed surfaces and associated regoliths provide evidence of the environments in which they were shaped. For instance, the mineralogy of the thick (*circa* 200 m) regolith derived from the alteration of a Paleoproterozoic granitic surface and now exhumed in the northern Yilgarn Craton of Western Australia indicates extreme aridity (Lascelles, 2014). Charnwood Forest is an inlier of Precambrian rocks in a Triassic desert terrain (Watts, 1903; but also Bridger, 1981). Barchan dunes are preserved beneath Triassic lavas in the Parana Basin of southern South America (Almeida, 1953) and a field of similar forms was overwhelmed by flood basalts of Early Cretaceous age in Namibia (Jerram et al., 2000). Friable regoliths as well as anomalous sedimentary structures and morphological decorations also are preserved on exhumed bedrock surfaces (*e.g.* Twidale, 1984; Battiau-Queney, 1997).

3.2. Etch surfaces and forms

Etch surfaces evolve in two stages. First a regolith is formed by weathering, and predominantly by water-related alteration, or etching, of the country rock. The junction between the weathered mantle and cohesive country rock is the weathering front or *Tiefenfront* (Büdel, 1957, Mabbutt, 1961). Then, and second, the stripping of the mantle or regolith exposes the weathering front as an etch surface (Fig. 1). Subsurface weathering and formation of a regolith and its subsequent exposure are the most recent and evident processes in the evolution of etch surfaces and justify their being referred to as 'two-stage' features. However, contrasts in the resistance to etching at the weathering front consequent on variations in rock fabric show that many etch forms reflect rock fabric (structural forms *sensu lato*) and are examples of *Gefugerelief* (Sonder, 1948). Thus, they are multistage in character (Gagny and Cottard, 1980; Twidale and Vidal Romani, 1994).

It is not suggested that exposed etch surfaces remain untouched by weathering and erosion after the evacuation of the regolith. Former weathering fronts may be dissected (Fig. 2) and otherwise modified, and also are subject to seismic joggling and dislocation (*e.g.* Twidale and Bourne, 2000a, 2003). Notwithstanding, the essential features shaped in bedrock remain intact, and their nature remains evident. As Hills (1975, p. 300) stated, these old land surfaces 'have naturally suffered some reduction and modification in detail during the long periods of time to which they have been exposed to weathering and erosion but this is relatively minor….'

But whether two- or multi-stage, establishing the age range and accounting for the survival of very old etch forms poses complex problems.

4. Ancient Australian landscapes

4.1. Favorable aspects

The dating of ancient landscapes can be illustrated by reference to specific criteria and by consideration of principles illustrated by reference to Australian examples (Fig. 3). This is not to suggest that very old landscapes are older or more widely developed in Australia than in other parts of the world, but the dating of such surfaces is facilitated by several factors (Twidale, 2007a).

The Australian continent is relatively stable in the sense that there has been no post Paleozoic orogeny though epeirogenic movements and isostatic adjustments continue to this day, even in the relatively stable shield lands (Twidale, 2011a). The lowland character of much of the continent has allowed marine transgressions such as those of the

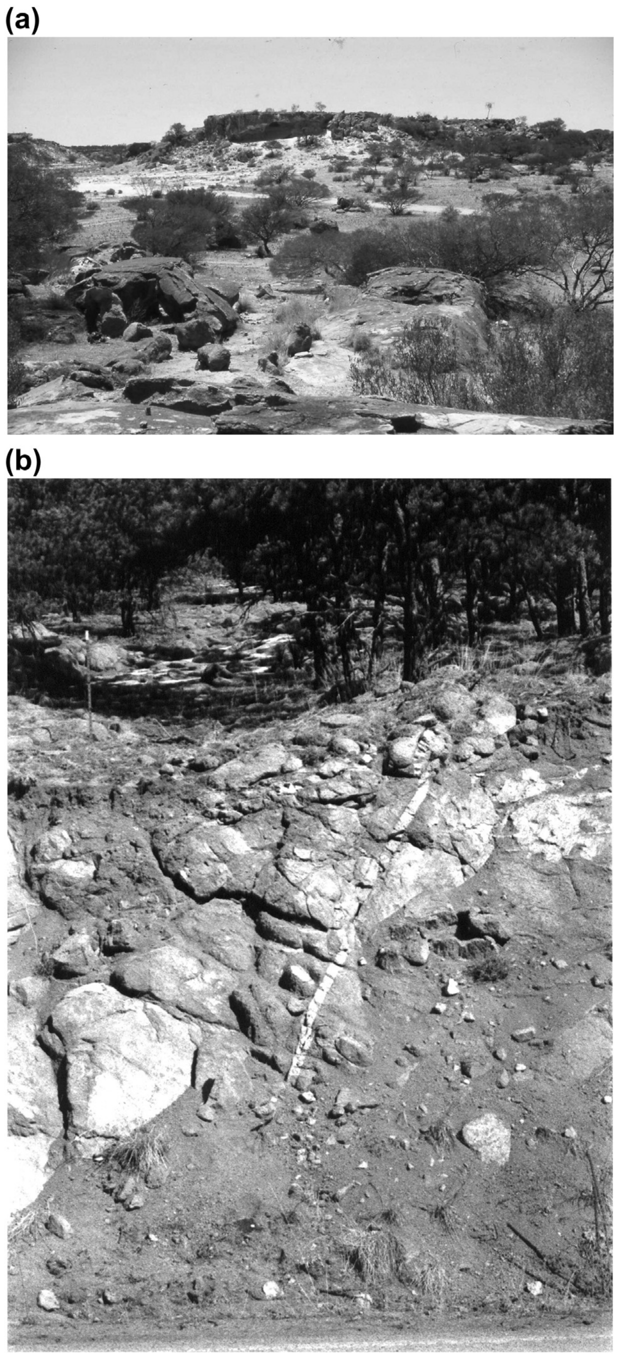

Fig. 1. (a) The laterite-capped plateau that forms part of The Granites, near Mt. Magnet, Yilgarn Craton, Western Australia, has been dissected to the base of the regolith, exposing granitic blocks and boulders in the valley floor at the weathering front. The laterite and the shaping of the weathering front date from the later Mesozoic, but the exposure of the front occurred in the Tertiary, and probably the middle Tertiary. (b) Granitic corestones and intrusive vein exposed in road cutting, Rocky Mountains, Colorado. Note exposed corestone, or boulders, standing on the natural surface.

Cretaceous (Frakes, 1987) to extend widely over the then continent thus facilitating the dating of adjacent and re-exposed surfaces. Widespread Cenozoic hotspot volcanic activity in the Eastern Highlands has assisted dating of topography as have volcanic events associated with the separation of Australia and Antarctica during the Mesozoic. The development and conservation of stratigraphically-dated duricrusts have proved critical in some areas. The compact shape of the continent plus the lack of high mountains and its relatively low latitude also have served to minimize the impacts of Quaternary cold periods and dissection by rejuvenated streams related to low sea levels, thus enhancing the possibility of old land surfaces being preserved. Also, the disappearance of the Permian ice sheets that occupied most of the south and center of the present Australian continent provides a baseline, and an age limit for any remnants of epigene or etch surfaces (*e.g.* Paine, 1990, p. 48).

Fig. 2. Part of the Kuiseb Canyon, central Namibia, showing duricrust-capped mesa and beveled remnants of weathering front preserved on dissected land surface shaped in dipping strata.

No direct (physical or numerical) method of dating pre-Quaternary land surfaces is known at present. Yet for more than two centuries, reasoning from observed data has made it possible to establish the relative age of landforms and later to provide a stratigraphic age. Surfaces and forms can be dated relatively according to their position in the landscape, and geologically by reference to local and regional stratigraphy. In many instances multiple lines of evidence and argument can be adduced in an effort to resolve the age of regional landscapes.

4.2. Topographic and stratigraphic relations

Rütimeyer (1769) and Baulig (1928) long ago deduced that in a tectonically undisturbed landscape older elements stand higher in the relief than the younger. Clearly the highest 'riser' displayed on the stepped northwestern slope of Yarwondutta Rock (Fig. 4), a granite inselberg on northwestern Eyre Peninsula, is older than the lower. A known concavity, already shaped beneath the present piedmont plain and awaiting exposure, is a potential still younger landform. Similarly, superposition demonstrates that the granite hill shown in Fig. 5 predates the late Pliocene or early Pleistocene basalt (age less than 2 Myr: Stephenson et al., 1980) that flowed around and isolated it.

At a regional scale the present scenery of Tasmania has developed through 'the successive inward transgression of landscapes formed at progressively lower levels' (Davies, 1959, p. 20). The value of such relative dating was immeasurably enhanced with the realization that dated valley fills, of whatever kind, provide a minimum stratigraphic age for bevels preserved on the adjacent range. Thus in Tasmania basalts of Early Tertiary age occur in the valleys of several lowland rivers (Owen, 1954; Banks, 1962), showing that their valleys and the central Plateau and high plains into the flanks of which they are incized, are of earlier age. Some low level duricrusts appear to be of Eocene age. Thus, the high central plateau of the island appears to be of earliest Tertiary or Mesozoic age.

4.2.1. Eastern Victoria

Rather earlier, Hills (1934, 1938) observed that many of the beveled crests of ridges eroded in deformed but resistant Paleozoic rocks in the uplands of eastern Victoria are separated by valleys occupied by lavas (Fig. 6). Stratigraphic evidence, later confirmed by physical/numerical analyses, dated the volcanic rocks as of Eocene–Oligocene age. From

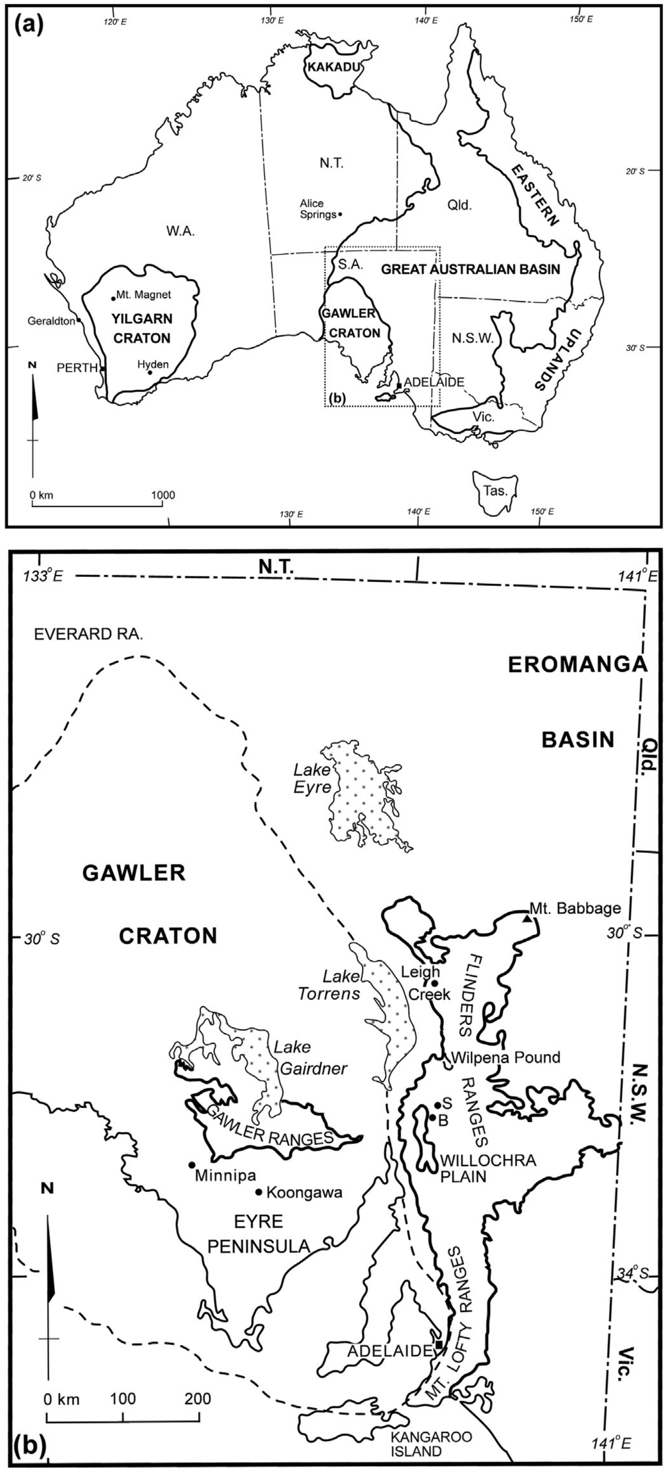

Fig. 3. Location maps of (a) Australia featuring the cratons and basins referred to in text, together with the Eastern Uplands, and the area covered in (b) part of South Australia, with various topographic regions and sites, including three Triassic basins that occur in the vicinity of Leigh Creek, and those named Boolcunda (B) and Springfield (S) further to the SSE.

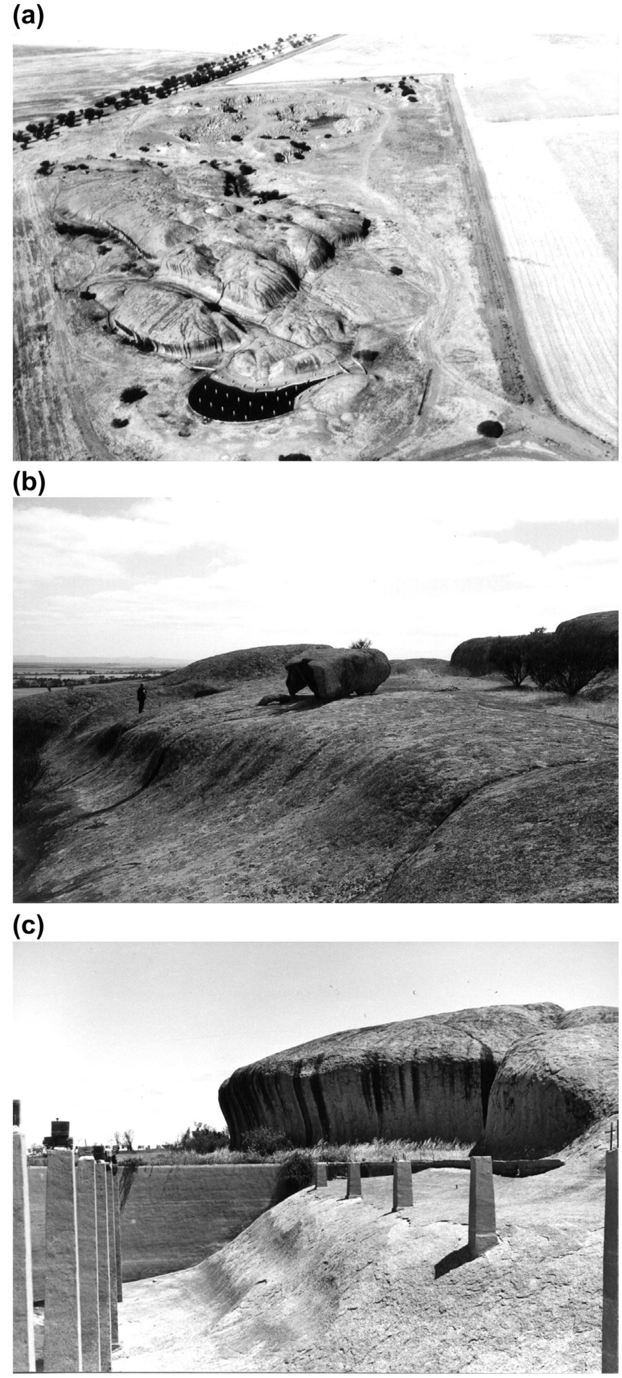

Fig. 4. Yarwondutta Rock is a low granite inselberg located near Minnipa on northwestern Eyre Peninsula, South Australia. (a) Low oblique aerial view from the ENE, showing reservoir, prominent *Kluftkarren* or fracture-controlled clefts and flared marginal slopes, (b) a stepped northwestern slope of the hill with a large residual boulder, and (c) the 'reservoir' in summer without water, exposing a concave subsurface slope that represents an early stage of development of a flared slope, like that seen in the wall beyond.

this Hills deduced that the crestal bevels are remnants of a planation surface of at least Cretaceous age.

Later clarification of the regional tectonic setting caused this age-range to be extended (Hills, 1955a, 1955b). The Jurassic strata bordering Bass Strait are down-warped, suggesting that the highlands to the north of any hinge line and on which are preserved Hills' summit bevels, may have been tilted upwards. This was taken to imply that the low relief remnants previously dated as Cretaceous were older than first thought, and were possibly of 'pre-Jurassic, and at least Triassic in age' (Hills, 1955a, p. 32; see also Neilson, 1962; Jenkin, 1988, pp. 408 and 417). Geological mapping of the region led Orth et al. (1995, p. 31) to conclude that the Middle Devonian (Tabberabberan) orogeny 'began a long process of erosion that continued to the late Mesozoic, and which, by the mid Cretaceous, had produced a land surface of low relief over most of southeastern Australia'. These analyses caused a revision of the Pliocene age ascribed to the high plains recognized in the adjacent region (*e.g.* Craft, 1932, 1933).

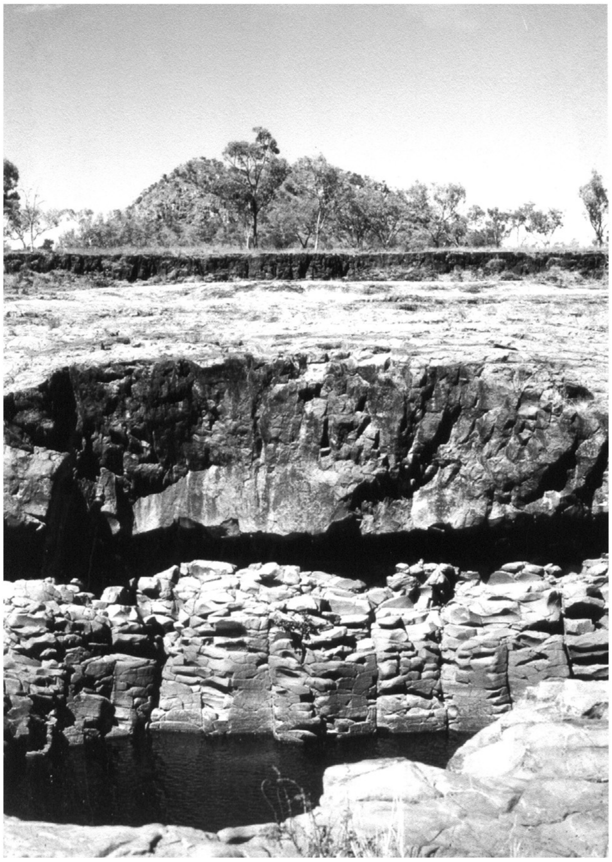

Fig. 5. Granite hill surrounded and partly submerged by Pleistocene basalt flow, Einasleigh, north Queensland.

4.2.2. Flinders Ranges, South Australia

The southern Flinders Ranges is a region of ridge and valley developed on folded Cambrian and Proterozoic strata (Preiss, 1987). Uplift of the western margin of the upland caused the pre-existing westerly drainage to be blocked and a Middle Eocene lake inundated the northern part of the intermontane Willochra Basin (Fig. 3b; Johnson, 1960). It tongued up the valleys, which clearly predate the lacustrine deposits, as do the adjacent ridges. The ridge and valley assemblage was in existence some 60 Mya (Twidale and Bourne, 1996). A pre-Tertiary age for the ridge and valley topography of the northern Flinders Ranges is suggested by the occurrence of silcrete of putative Eocene age (Wopfner et al., 1974) in local and regional piedmonts (*e.g.* Campana et al., 1961; Coates, 1973).

The beveled crests of the quartzite/sandstone ridges are higher and older and probably date from the Cretaceous. They may be relics of a planate surface shaped by rivers graded to the Early Cretaceous marine transgression and shoreline, of which the Mt. Babbage outlier and the sequences preserved beneath adjacent down-faulted lowlands, are a reminder (Woodard, 1955; Sheard, 2001).

In addition to surfaces of definite or putative Cretaceous ages there are hints of possible earlier relics. Several intermontane Triassic basins occur within the upland (Fig. 3b). Considering the regional setting Parkin (1953, p. 16) stated that prior to Triassic down-warping and sedimentation in the Leigh Creek area, the Precambrian and Cambrian rocks of the northern Flinders Ranges had been 'reduced virtually to peneplain level.' This planation must have occurred during the earlier Triassic or later Permian following the end of the earlier Permian glaciation. Kwitco (1995, p. 99) stated that the basins stood in an area of subdued relief and sluggish drainage and that the sediments and contained plant remains indicate deposition in a warm humid climate (also Wopfner, 1969, p. 137).

The regional planation evidently extended to more southerly areas because independent indicators of Triassic planation were reported from the Springfield Basin (Johnson, 1960). In particular, several cores drilled through the sequence indicate an upward fining of sediments. This can be construed as the result of a decrease of relief amplitude through time in the catchment of this particular down-warped depression. However, though the bevels preserved on some of the higher peaks are suggestive, no surfaces or forms that can firmly be linked by field evidence to the Triassic deposits have been located adjacent to these basins.

4.2.3. Other examples

An Early Cretaceous marine incursion that surrounded Kakadu, located adjacent to the north coast of the continent, converted the massif into an island. It follows that the summit high plain of the residual, though complex (Nott, 1994) and transecting various strata, was already in existence prior to the Early Cretaceous (Needham, 1982). Similarly, the Everard Ranges of northern South Australia evidently existed prior to the 'Upper Triassic to Lower Cretaceous' (Wells et al., 1970) when the deltaic De Souza Sandstone, of possible Jurassic age, was deposited in the broad valleys between the beveled granitic bornhardts of the eastern part of the upland.

4.3. Correlative deposits

Whether transported by rivers, glaciers, wind or waves, deposits imply erosion in the source areas. Dating the deposits provides an age-range for the associated destructional surface.

4.3.1. Gawler Ranges, South Australia

The bornhardt massif of the Gawler Ranges is developed on a series of Mesoproterozic dacite and rhyolite (Blissett et al., 1993; Allen et al., 2003). It has been attributed to the preferential subsurface weathering of a major orthogonal and rhomboidal fracture system. The corners and edges of the fracture-defined compartments were preferentially weathered to produce an ordered series of rounded or domical bedrock forms, the crests of several of which are beveled (Fig. 7). The present valley floors are underlain by weathered country rock, but only one small regolithic remnant consisting of corestones set in a matrix of weathered dacite has been located on a high plain remnant. Notwithstanding, it can be presumed that a regolith formed on a planation surface that formerly extended over the whole region. Uplift of the southern margin of what is now the Gawler Ranges massif along the Corrobinnie Fault Zone caused rejuvenation of streams flowing north

Fig. 6. The Nunniong Plateau, part of the dissected upland of eastern Victoria. The beveled crests predate the Early Tertiary (mostly Eocene) volcanic flows, which occupy many of the valley floors (Geological Survey Victoria).

Fig. 7. The bornhardt landscape of the Gawler Ranges, South Australia. Note the beveled crests and hence even skyline. Sheet structure developed in dacite can be seen in the foreground.

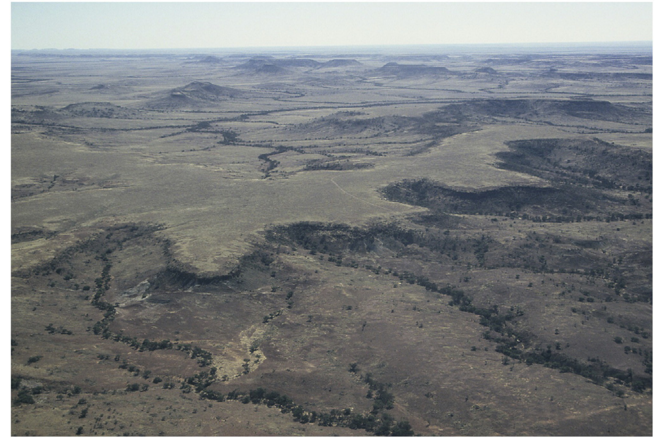

Fig. 8. Dissected plateau capped by Eocene silcrete, southwest Queensland.

to the present Eromanga Basin. Fluvial deposits derived from the upland and including cobbles of Gawler Range Volcanics – construed as corestones derived from the previously developed regolith – were laid down as the Mt. Anna Sandstone (Wopfner et al., 1970). Thickness variations and cross-bedding indicate the southerly provenance for the Sandstone, which was interbedded with fossiliferous marine beds of the Cadna–Owie Formation, showing it to be of Early Cretaceous (Neocomian–Aptian) age.

As deposition implies erosion, this stratigraphic age determination applies also to the source area. The regolith that contributed to the Mt. Anna Sandstone was stripped and the bornhardt landscape exposed during the Early Cretaceous. It also attests a phase of planation and weathering predating the Cretaceous but postdating the Permian glaciation (Campbell and Twidale, 1991). It was during this Triassic–Jurassic interval that the present bornhardt landscape was etched as a topographically differentiated weathering front.

4.3.2. Further examples

Woodward (1914) considered the possible source areas of adjacent basin deposits, and suggested that the bevels that cut across Paleozoic strata in the Geraldton area of Western Australia and the crystalline Archean terranes to the east, in the northern Yilgarn Craton, are of Mesozoic age. Very old landscape events were identified by Jones (1931, p. 58 *et seq.*) who, considering the topography of the Bristol Channel and adjacent regions, stated that in his view probably 'no single episode has contributed so materially to the shaping of the surface of this region as the intense erosion, which succeeded the post-Carboniferous or Armorican earth movements'. He attributed the shaping of the beveled summits of the Welsh massif, later referred to as the 'hill-top surface' (Jones, 1951), and the resultant sedimentary sequences deposited in adjacent basins, to planation during the Triassic. Poag and Sevon (1989) linked flights of planation surfaces recognized in the Appalachians of eastern North America with three post-Triassic depositional phases evidenced in stratigraphic sequences beneath the adjacent continental shelf. Referring to the same areas, Cleaves (1989) suggested an interpretation that included a Late Triassic–Early Jurassic event.

4.4. Duricrusts as morphostratigraphic markers

As well as dated sediments and volcanic lavas, and as mentioned with reference to the Central Plateau of Tasmania, duricrusts frequently have proved invaluable as morpho-stratigraphic markers. Silcretes of stratigraphically determined Eocene age (Fig. 8) are widely preserved as cappings on dissected plateaux in central Australia (Wopfner et al., 1974).

4.4.1. Kangaroo Island and the Gulfs region of South Australia

The broad features of the Gulfs region of South Australia have been determined by recurrent and continuing faulting (Fig. 9). Like the Lincoln Upland of southern Eyre Peninsula and the Fleurieu Peninsula of the southern Mt. Lofty Ranges, Kangaroo Island is dominated by a laterite-capped plateau developed on Proterozoic, Cambrian and Permian strata but the age of which is in dispute.

Sprigg et al. (1954) observed that what was taken to be part of a laterite profile is overlain by, and is therefore older than the volcanic rock that later became known as the Wisanger Basalt (Milnes et al., 1982). At that time the basalt was correlated with the later Quaternary volcanic rocks of the South East district of South Australia and adjacent parts of western Victoria (*e.g.* Sprigg, 1952), suggesting a pre-Quaternary age, possibly Pliocene (Northcote, 1946), for the laterite. Potassium/argon dating (McDougall and Wellman, 1976), however, showed that the Wisanger Basalt is some 174–175 Myr old, *i.e.* of Middle Jurassic age. This extended the time scale of landscape evolution, but the stratigraphic relationships were not. The laterite still appears to be overlain by, and therefore predates, the basalt. It probably indicates weathering under torrid conditions and a putative Triassic age (Daily et al., 1974).

Numerical dating methods applied to different mineral phases have produced contrasting results. Oxygen isotope dating supports an older (pre-Late Mesozoic) age for the Kangaroo Island site under review (Bird and Chivas, 1993), whereas paleomagnetic and K–Ar (potassium–argon) dating indicate Late Tertiary (Miocene) ages (Schmidt et al., 1976; Pillans, 2005).

Though the kaolinized sediment overlain by basalt near Wisanger predates the basalt, no ferruginous pisolitic or other zone of iron concentration occurs in the weathered rock exposed at the critical site. Accordingly it might not be a truncated lateritic weathering profile. On the other hand, a small consanguinous occurrence of basalt west of Penneshaw (Tilley, 1921) appears fresh, despite the site standing lower in the local landscape than the lateritic plateau located a few kilometers to the south. This surely implies that the basalt postdates the period of intense weathering during which the laterite was formed.

Also, if the Kangaroo Island laterite were of the Miocene or Pliocene age indicated by paleomagnetic analyses and other considerations, earlier sediments ought to be lateritized. They are not. For instance, on southern Eyre Peninsula, the Eocene sedimentary sequences preserved in the Cummins Basin, west of the lateritized Lincoln Uplands, are not themselves lateritized or otherwise intensely altered, though they are discolored white and red as to be expected of sediments derived from an intensely weathered source area (Johns, 1958, p. 65, 1961, pp. 26 and 27; R. K. Johns, pers. comm. 2013).

In addition, the Mt. Lofty horst that forms the eastern flank of the Gulfs region was initiated, and the high plain uplifted, prior to the Middle Eocene for sediments of that and later Tertiary ages that were

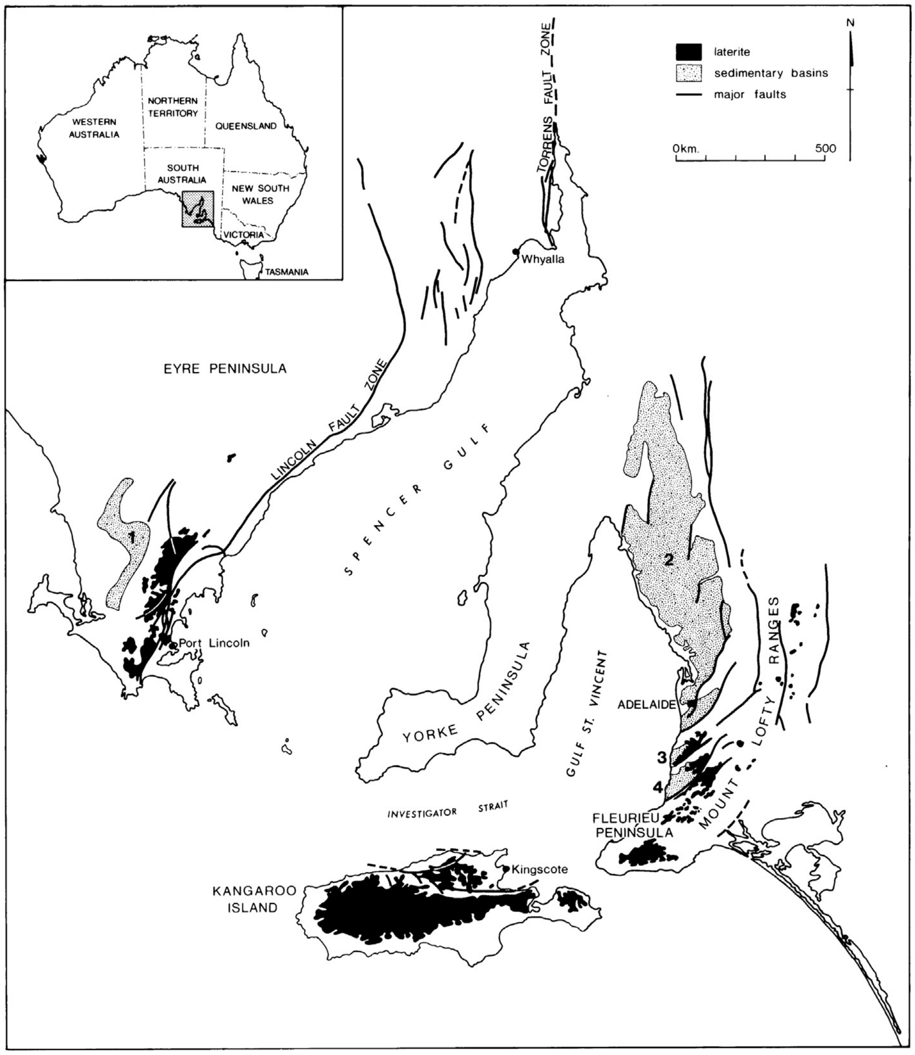

Fig. 9. Lateritic plateau of faulted Gulfs region, South Australia. 1, Cummins Basin; 2, Adelaide Plains sub-basin; 3, Clarendon Basin; and 4, Willunga Basin.

deposited in the fault-angle depressions or half-graben developed at the western margin of the Mt. Lofty Ranges. Lateritic debris occurs in the Tertiary marine sequences (Glaessner and Wade, 1958, p. 117).

In summary, the age of the lateritized plateau of Kangaroo Island remains controversial. The stratigraphic setting is suggestive but some of the evidence is inconclusive or contradictory. As a result most authors oppose the suggestion of great antiquity as unreasonable (*e.g.* Bourman, 1995). It would, perhaps, be preferable to consider the question as 'still open'.

4.4.2. Yilgarn Craton

The landscapes of the Craton proper revealed elements of similar antiquity for Jutson (1914) noted that the so-called New Plateau – really a high plain – is the result of the dissection and partial stripping of the largely lateritic duricrust that forms and underlies the Old Plateau (Fig. 1a). Relative uplift of the lateritized surface of the Old Plateau induced rivers to incise their beds. The valleys so formed merged to become the New Plateau, which continues gradually to extend headwards at the expense of the Old. Near the coast the alluvia (the 'deep leads' of Jutson, 1914) are of Eocene age (Van de Graaff et al., 1977; also, Clarke, 1994), but inland are younger. For instance, the alluvium of the Salt River, south of Kellerberrin, is of Miocene age (Salama, 1997; Twidale et al., 1999). Thus, the New Plateau or high plain is an etch plain of Cenozoic age. The duricrusted Old Plateau clearly predates the Eocene (Twidale and Bourne, 1998).

Possible confirmation for this pre-Eocene age of the duricrusted Old Plateau occurs just north of Perth, where the fluviatile Bullsbrook Beds, of Neocomian or Early Cretaceous age, were deposited in valleys scored in the Darling Fault scarp, below the level of the duricrusted Plateau. They are described as very weathered and partly lateritized (Playford et al., 1976, pp. 174–175), but this can be interpreted as confirming that lateritization postdated the Neocomian, but still predated the Eocene. Alternatively, the reported discoloration of the Bullbrook Beds can be attributed to runoff charged with iron salts washed from a pre-existing lateritized Plateau.

As with Kangaroo Island, paleomagnetic dating has complicated dating of the Yilgarn Plateau with several ferruginous occurrences dated as Cenozoic, but a few as Mesozoic (Pillans, 2005). However, the possible Cretaceous age of the Old Plateau surely cannot be doubted if only because of the many dissected valleys carrying alluvia of Eocene age in the in lower, earlier incised, valley floors and Miocene and younger deposits laid down in the headwater sectors.

The many inselbergs, such as Hyden Rock, that project above the level of the New Plateau were initiated by differential weathering beneath the Old. Some however stand as uplands on the lateritic Old Plateau. Residuals like The Humps, which stands over 420 m above sea level and about 80 m above the adjacent lateritized plain (Fig. 10), are clearly part of the former (?) Cretaceous landscape (Twidale and Bourne, 2004). But the residual is stepped (*cf.* Twidale and Bourne, 1975) and displays an upper dome about 10 m high. It is flanked by

(a)

(b)

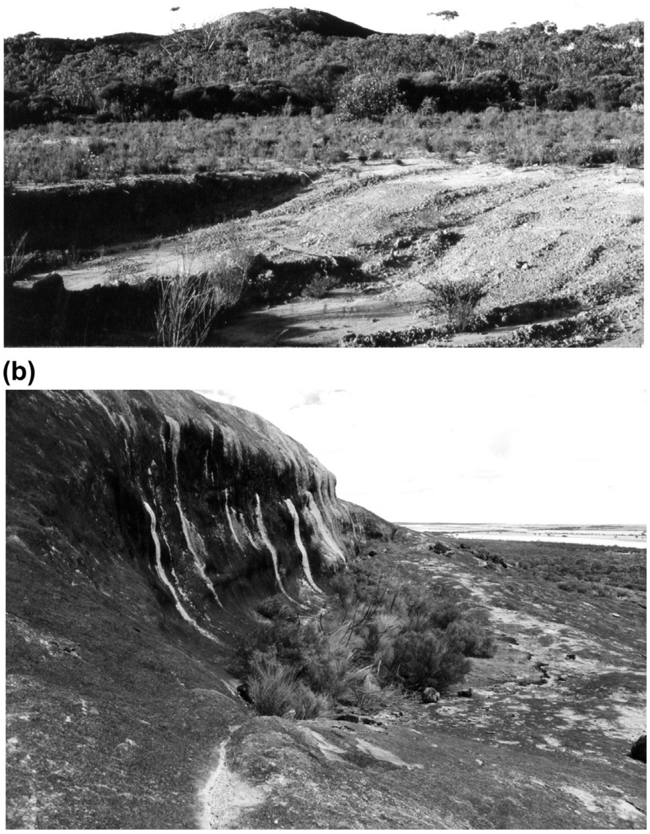

Fig. 10. (a) The Humps, a stepped, dome-on-dome inselberg located some 12 km north of Hyden, Western Australia, and standing on a lateritized surface of putative Cretaceous age with laterite exposed in a shallow borrow pit in the foreground, and (b) the flared wall of an upper dome construed as a former piedmont.

flared sidewalls that identify a former piedmont (*e.g.* Twidale 1962) and possibly a higher and hence older plain level. Several other bornhardts, such as McDermid Rock (Bourne and Twidale 2002), located on the southeastern Yilgarn Craton, display a similar 'dome-on-dome' morphology.

4.4.3. Further examples

Working beyond the southern margin of the Yilgarn Craton, Fairbridge and Finkl (1978) recognized old valley systems dating from the Permian – presumably later, postglacial, Permian – and from the later Jurassic to early Cretaceous. They occupy upland divides and imply local relief inversion.

The Macdonnell Ranges of central Australia consists of ridges and valleys developed on folded and faulted strata of Precambrian and Paleozoic ages. The assemblage was already in existence by the Eocene because the bevels preserved on the summits of the low ridges can be correlated with adjacent low hilltop bevels cut across steeply dipping strata and with low level beveled quartzite ridges and silcrete-capped piedmont and valley mesas. Older relics of a summit bevel shaped by streams graded to Cretaceous seas occupying adjacent basins also have been recognized (J. A. Mabbutt, *in* Brown et al., 1968, p. 304). The crests of Uluru (Ayers Rock) and Kata Tjuta (The Olgas) massifs of central Australia may be of similar antiquity for they rise from and stand above plains in which are preserved relics of the Eocene silcreted surface (Fig. 10; Mabbutt, 1965; Wopfner, 1997; Twidale, 2010). Silcreted surfaces dated as of Eocene age are also recognized in United States as well as southern Africa (Partridge and Maud, 1987; Gassaway, 1988; Partridge, 1998).

5. Conservative factors

Very old paleoforms are a global phenomenon, and distinguished and experienced geologists of earlier times apparently had no difficulty in accepting the implications of their field evidence and concluding that considerable tracts of their study areas are of great antiquity. How very old landforms had withstood the elements over the ages was of less concern than the self-evident argument that if a thing exists it must be possible.

Nevertheless, several conservative factors can be invoked (*e.g.* Twidale, 1976, 2007b). First, the structure, for most of the old land surfaces is of etch type in which coherent rock is exposed. Most old surfaces are preserved on tough resistant rocks of which the Gawler Range Volcanics can be cited as an example. Many of the granites on which the Yilgarn Craton bornhardts are shaped are buttressed by sills and dikes. Some Brazilian *morros* (bornhardts) are shaped in resistant compartments based in deep compressed antiforms (*e.g.* Lamego, 1938), and the summit surface of the Roraima Plateau of northern South America is shaped in massive quartzite (Briceño and Schubert, 1990; Schubert and Huber, 1990).

Second, location is significant because some older remnants persist on drainage divides. Interior position also is especially significant. For example, the interior Mesozoic and Early Cenozoic plains and inselberg landscapes of southern Africa are buttressed against erosion by the great size and compact shape of the subcontinent. Recurrent uplift has caused repeated phases of exoreic stream rejuvenation and landscape revival with nick points and valley side facets working inland from the coast, and younger plains extending at the expense of the old (*e.g.* Lister, 1987).

Third, though widely active in shaping the land surface, rivers *per se* are not as effective as has been supposed (*e.g.* Baker, 1988). Potholes, flutings and concave scoops are scoured and gouged in fresh granite exposed in the channel of major rivers, especially during floods. The capacity of minor streams, rivulets and wash, however, is questionable. Soils and regolith are readily stripped by rivulets and wash but incision virtually ceases where coherent rocks are encountered (*e.g.* Jutson, 1934; Noldhart and Wyatt, 1962). As E. S. Hills (pers. comm. 1962) stated, when rivers cut into a soil-covered terrain developed on cohesive bedrock, "…there is first of all a period of rapid skimming off of the soil and rotten rock, followed by a sudden decrease in removal of detritus when fresh rock is exposed to the eroding agents." Like some glaciers (Boyé, 1950; Bird, 1967; Lidmar-Bergström, 1997), minor streams and diffuse wash act as bulldozers rather than excavators.

Fourth, erosion is differential and not evenly distributed as had been supposed by Hutton, Davis and others (Behrmann, 1919; Bliss Knopf, 1924; Crickmay, 1976; King, 1970; Twidale et al., 1974; Brunsden, 1993). Accordingly, once in positive relief resistant masses shed water and become relatively dry sites. Rocks like granite disintegrate in contact with moisture but they are relatively stable and resistant when and where dry sites tend to persist (Logan, 1851, p. 326; Alexander, 1959; Eggler et al., 1969).

Episodic periods of uplift, whether epeirogenic or isostatic, have induced alternations of weathering and erosion, leading to the development of stepped topography and an increase in relief amplitude through time (Twidale and Bourne, 1975; Bourne and Twidale, 2000). In this way, there were formed local or regional uplands not immune to destructive processes but subject only to slow change. Thus, concatenation, involving structurally initiated unequal weathering and erosion plus positive feedback or reinforcement, has contributed significantly to the enhancement and persistence of the forms (Twidale, 2007b).

Furthermore, though scarp retreat is a real and critical factor in landscape evolution (but see also, Moss, 1980), its effectiveness is reduced in time. Gully gravure (Bryan, 1940; Twidale and Bourne, 2000, 2003) delays recession. Diminution in the area of headward catchments induces a decreased rate of recession (Twidale, 1978) such that late in a phase of recession virtual standstill of the backing scarp has allowed weathering to shape a well known suite of piedmont forms around the bases of surviving upland remnants or inselbergs (Thorbecke, 1927; Clayton, 1956; Pugh, 1956; Twidale and Bourne, 1998).

6. Significance

Major dating factors are emphasized in these regional accounts but in most instances multiple lines of evidence and argument are germane to the problem. Cretaceous surfaces are well represented and though putatively identified in only a few areas, the possibility of still older Triassic landscapes is implied by the field evidence in the Gawler and Flinders ranges of South Australia, in southeastern Australia, notably eastern Victoria, and on the Yilgarn Craton of Western Australia. That surfaces of great antiquity are preserved in other continents is confirmed by reference to various authors additional to those already cited (*e.g.* Curtis et al., 1958; King, 1962; Briceño and Schubert, 1990; Birkenhauer, 1991; Demoulin et al., 2005).

In addition to influencing the way scenery is viewed, the possibility of there being very old remnants in the contemporary landscape of very old land surfaces ought also to enhance stratigraphic interpretation by relating deposits to source areas. With some notable exceptions geological reports provide accounts of bedrock occurrences but neglect the erosional side of the depositional coin.

Very old landscapes are of interest to paleobotanists, and to pedologists. For instance, very old eucalypt species survive in favorable niches on the slopes of bornhardts of putative Early Cretaceous age on the Yilgarn Craton of Western Australia (Hopper et al., 1996; Twidale and Bourne, 2004). As is well known, some elements and minerals are concentrated in old regoliths.

But above all paleosurfaces pose problems that are challenging and stimulate the curiosity. In particular, plausible evidence of the survival of very old – earliest or pre-Tertiary landforms – serves as a reminder of the implications for a general theory of surfaces that have persisted despite eons of exposure to the elements.

7. Discussion

The possibility of Triassic landforms having survived to become elements of the contemporary landscape has been canvassed previously (Twidale, 2000b). However, the re-evaluation and testing of older evidence, and in particular the implications of the regional stratigraphic settings of key areas, justifies this further consideration of possible very old paleoforms, and indeed it appears that considerable areas of the continents, and especially the cratons and older orogenic belts that constituted Gondwana are occupied by very old surfaces and features, either exhumed or etched.

The great age of some resurrected forms is accepted by all, but the postulated great age of some etch features is not only questioned and challenged – which would be proper and welcome – but denied without consideration of the evidence. Even if in due course some of the evidence and arguments presented in justification of the postulated antiquity of these forms are found to be flawed, other examples remain validated on the basis of topographic and stratigraphic sequences, correlative deposits, and regional stratigraphy. They are enough to call into question various aspects of conventional geomorphological theory. Also the evidence pointing to antiquity, like that referred to here, also will still call for an explanation.

The degree of antiquity that is considered incredible varies. Cenozoic landscape elements have endured for 50–60 Myr and are accepted without demur (Fig. 8), but claims that Mesozoic landforms and landscapes persist are peremptorily dismissed. Those who condemn the ancient landscape concept have neither stated their reasons, nor have they offered alternative explanations for the evidence and argument of the kind presented here.

Even when a full account has been taken of the various conservative factors cited above, and bearing in mind Hills' comments on the nature of such old surfaces, they still pose problems and call for investigation and explanation. However, if the evidence of their great age proves to be sound – and it has not so far been refuted or explained in alternative terms but rather condemned (Twidale and Bourne, 1998; Twidale, 2011b) – then surely it is more rational to accept that if surfaces of great antiquity exist they must, somehow, be possible, and proceed to test the evidence and argument on that basis, rather than assert that they are not real because of a disbelief founded in convention.

8. Conclusions

If some landscape elements are as old as is suggested – and though some of the evidence and arguments are debatable, some are compelling and difficult to deny – they change the way we view our scenery. Their age is such that they have been subject to significant climatic changes and to the cumulative effects of tectonic stress as well as adjustments to changing lithostatic pressures. They are palimpsest surfaces that surely must find a place in the stratigraphic record if only as the source areas for sedimentary sequences. These old forms and surfaces have persisted in part as a result of differential erosion, which necessitates adjustments to previous estimates of rates of exogenous geomorphological processes. They stand in denial of general landscape lowering over time for they imply enduring local and region increases in relief amplitude.

If they are as old as suggested paleosurfaces like those discussed here are anomalous and as such pose problems for the conventional models of landscape evolution. Scientific research begins with the identification of anomalies, and the definition of problems. It has been claimed that science is merely applied and organized common sense (which may have been true a century ago), and certainly the simple dating methods outlined above were conceived and used by early geological investigators interested to explain not only the rocks and structures but also the landscapes of the particular areas with which they were concerned.

Though the evolution of the ancient landscapes hypothesis can realistically be considered at the second of the stages cited in the introduction to this essay – it is rudely and violently opposed – it is encouraging for those who see merit in the ancient landscapes hypothesis to recall Einstein's suggestion that: 'If at first an idea is not absurd, then there is no hope for it.'

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