ON THE SURVIVAL OF PALEOFORMS

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ABSTRACT. The presence in the contemporary landscape of very old paleoforms, and especially paleosurfaces of low relief, is inconsistent with some of the commonly espoused models of landscape evolution. And although it is not completely at odds with others, the survival of paleoforms nevertheless poses difficulties.

Stabilization and persistence of the land surface are clearly possible in some circumstances. Various factors — structural conditions, positive diastrophism, localization of river erosion and various feedback mechanisms — operating singly or in concert are suggested in explanation of these survivals.

A model of landscape evolution involving increasing relief amplitude is proposed, not to the exclusion of all others, but as one of several possibilities each of which should be considered, and probably modified, in the light of field evidence.

INTRODUCTION

W. D. Thornbury (1954, p. 26) was probably expressing a widely held view when he wrote that "Little of the earth's topography is older than Tertiary, and most of it is no older than Pleistocene". In part this attitude reflects experience and consideration of landscapes profoundly modified either by Quaternary glaciation, or by tectonism, sealevel fluctuations, and climatic changes during that period (see for instance Firman, 1969, p. 206). It mirrors acceptance of W. M. Davis' (1909, p. 266 and following) belief that streamwork in one form or another extends over the entire land surface, and that the latter is subject to slow but continuous and inevitable destruction. It results from a rejection of the whole concept of multicyclic landscape development which is based on the realization that many of the alleged old peneplains described in the literature are little more than "lines in the sky" derived from theory and imagination and not from field evidence (Sauer, 1925; Robinson, 1963; Chorley, 1965).

But having admitted that many of the "dissected peneplains" recognized in many parts of the world are of this intangible quality, it must be asserted also that remnants of some very old paleosurfaces of low relief (paleoplains) and other paleoforms constitute an integral part of many contemporary landscapes. The remnants exist, and they can in many instances be dated within close limits: some studies in denudation chronology are firmly based in stratigraphy (see, for instance, Wooldridge and Linton, 1939; Wopfner and Twidale, 1967). Paleosurfaces constitute only minor elements of the landscape in some areas, but in others such as southern Africa (King, 1940, 1950a, 1960) and central and western Australia various paleoplains form a major part of the modern landscape.

EVIDENCE

Linton (1957, p. 67) has claimed that "All the hill and mountain features we see today belong to Tertiary times unless the present cycle of erosion is exhuming some earlier land surface". And it is true that some elements of the contemporary land surface are paleoforms that

have been resurrected from beneath sediments or volcanic rocks. Thus granite inselbergs of Precambrian age and exhumed type have been reported from the west and southwest of the Canadian Shield (Vogt, 1953a and b). Granite domes occur also in the western Murray Basin in South Australia[1], reexposed by the erosion of Miocene marine strata (Twidale, 1968, p. 121-123), and on western Eyre Peninsula where they have been partially exhumed from beneath late Pleistocene aeolianite (Twidale, Bourne, and Smith, 1976). Resurrected paleoplains of Precambrian age have been identified in northern Greenland (Cowie, 1961), in the Canadian Arctic (Ambrose, 1964), and, in limited exposures, from northeastern Eyre Peninsula and the eastern Gawler Ranges (Twidale, Bourne, and Smith, 1976). An exhumed surface of low relief varying in age from locality to locality between upper Jurassic and Lower Cretaceous is extensively exposed at the western margin of the Great Artesian Basin (Twidale, 1956a; Carter and Öpik, 1961; Wopfner, 1964; Wopfner and Twidale, 1967). It has been identified also on the eastern margin of the Basin (Twidale, 1956a) and elsewhere (Woodard, 1955; Hays, 1967). An unusual landscape exhumed from beneath the late Cretaceous Deccan Traps has been described from the Bari district of central India where step-faulted planation surfaces are being reexposed as a result of the erosional stripping of the volcanics (Choubey, 1972).

These and many other exhumed land surfaces are of considerable interest and in places comprise a significant part of the modern land surface, but they have been preserved as a result of burial and have only recently been reexposed to subaerial attack. Their survival thus poses few problems.

But many paleoplains, which are evidently of considerable antiquity, have survived long periods of exposure to weathering and erosion. The extensive planation surfaces of southern Africa for example are of epigene origin, have never been buried, and yet are of great antiquity (King, 1950a, 1960). The African Surface which in places carries a laterite duricrust is of early-mid Tertiary age, and the higher Gondwana Surface or surfaces preserved above the Drakensberg escarpment developed during the Cretaceous. Moreover King believes there are small remnants of a slightly higher landscape of Jurassic age preserved on the Drakensberg (L. C. King, personal commun.).

These old land surfaces of southern Africa apparently have their equivalents in other continents, including Australia (King, 1950a, 1950b, 1960). Certainly a lateritized paleoplain of early-mid Tertiary age is widespread in northern Australia (Twidale, 1956a; Hays, 1967; Öpik, Carter, and Randal, 1973), and a siliceous duricrust of similar age-range is extensively preserved in central and southern areas of the continent (Wopfner, 1960; Sprigg, 1963; Stephens, 1964, 1971; Langford-Smith and Dury, 1965; Wopfner and Twidale, 1967; Wopfner, Callen, and Harris, 1974). Surfaces that predate the Cainozoic have been recognized

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[1] For location map showing Australian locations mentioned, see figure 1.
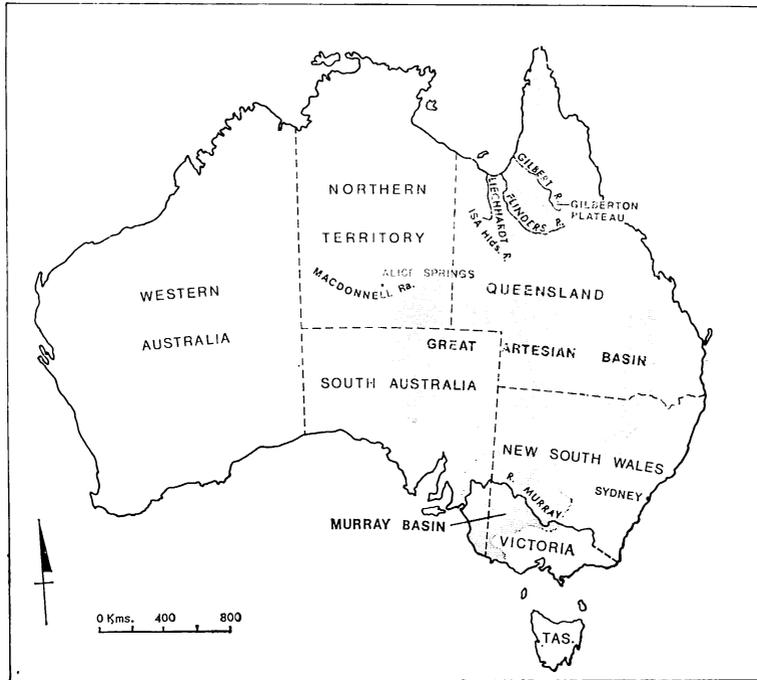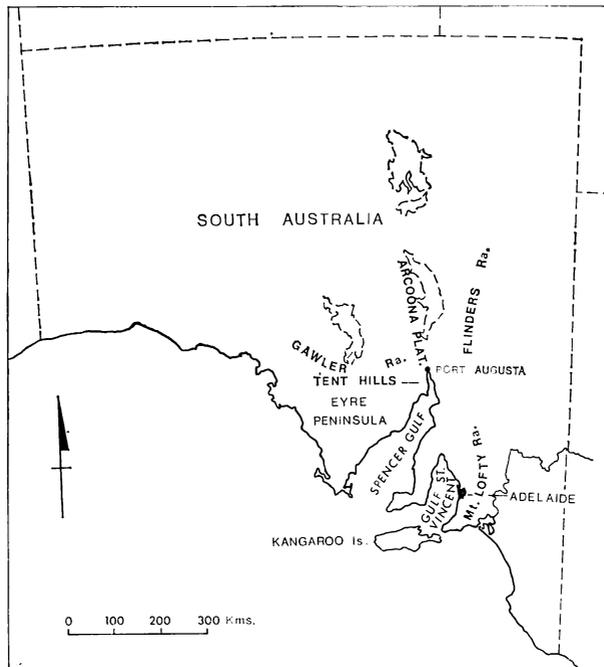
Fig. 1. Maps of (A) Australia and (B) South Australia showing locations mentioned in text.

in central and southern Australia where some of the ranges of the Alice
Springs region are considered to be relicts of a Cretaceous landscape
(Mabbutt, 1965, 1967). The same worker has been quoted as stating
that there are remnants of a surface predating the Cretaceous in the
Macdonnell Ranges (J. A. Mabbutt, cited *in* Brown, Campbell, and
Crook, 1968, p. 304). However, this is not the "only known contemporary
land surface that has persisted unburied since pre-Tertiary times. . ."
(Brown, Campbell, and Crook, 1968, p. 304). For example the lateritized
summit surface of the Mount Lofty Ranges, Kangaroo Island, and
southern Eyre Peninsula is older than the Middle Jurassic and probably
of Triassic age (Daily, Twidale, and Milnes, 1974). Similarly the plateaus
and domed plateaus that form the prominent summit surface of the
Arcoona Plateau and its southerly extension in the Tent Hill region are
of Cretaceous age (Twidale, Shepherd, and Thomson, 1970; Twidale,
Bourne, and Smith, 1976).

There is no evidence to suggest that these paleoplains and other
paleoforms have been buried. But many are of etch type (Wayland,
1934): the present surface represents either an exposed indurated hori-
zon of the weathering profile, or the weathering front (Mabbutt,
1961a), that is, the base of significant weathering, or the junction be-
tween the regolith and the intrinsically fresh bedrock. Thus to take
a simple example, the so-called "new Plateau" which occupies extensive
areas of interior Western Australia is undoubtedly an etch plain formed
by the stripping of the lateritic mantle, which developed beneath the
higher "old Plateau," and the consequent exposure of the weathering
front (Jutson, 1914, p. 96 and following; Mabbutt, 1961b). The laterite-
capped surfaces, which give rise to plateau, mesa, and butte assemblages
in many parts of southern and northern Australia (see, for example,
Whitehouse, 1940; Twidale, 1956a; Wright, 1963; Hays, 1967; Stephens,
1964; Prider, 1966), are themselves etch surfaces, for the exposure of the
ferruginous zone implies the stripping of the sandy A-horizon charac-
teristic of modern laterite profiles. This A-horizon is commonly several
meters thick, though it varies from place to place (McNeil, 1964; Maig-
nien, 1966), and where present this porous and permeable, though
friable, sand cover forms an absorbent cushion protecting the ferruginous
horizon. So long as the sands remain vegetated they are washed away
only near valleys and escarpments and act as a protective carapace to the
land surface for long periods. In north Queensland, the Gilberton
Plateau (Twidale, 1956a, 1966a) which forms a prominent divide of
Cretaceous sandstone is not greatly dissected. The ferruginized zone of
the mid-Tertiary laterite developed on the sandstone is exposed in
bounding scarps and in the river gorges, but only a few score meters
away the sands, under a eucalypt woodland, still cover the indurated
horizon. Elsewhere in the same general region little or no sand remains
above the pisolitic ironstone on the Normanton and Donors plateaus
which are near the coast and close to the Flinders and Leichhardt rivers.

The silcrete-capped tablelands of central and southern Australia are probably of similar type, though as no modern analogue is known the character of the complete silcrete profile cannot be determined with certainty. A calcrete duricrust has formed on the late Pleistocene Wudinna Surface which occupies much of central and northern Eyre Peninsula (Twidale, Bourne, and Smith, 1976). It has a protective function, and though the A-horizon of calcareous silts remains in situ over wide areas there are also many localities where the calcrete horizon is exposed through the stripping of this cover.

Apart from these paleoplain remnants other landforms seemingly of considerable antiquity and also of etch type survive as integral parts of the contemporary landform assemblage. Thus flared slopes, tafoni, and platforms etched in granite and together indicative of former hill-plain junctions occur at various levels above the present piedmont zone on some of the higher bornhardts of northern Eyre Peninsula (Twidale and Bourne, 1975a). They have been correlated with paleoplain remnants of the adjacent plains and uplands, so that not only are various generations of granite inselberg tentatively identified, but the higher residuals are subdivided into elevational zones the age of which increases with height above the present hill-plain junction. In brief, many granite surfaces and forms date from middle Tertiary times, but some few may be of Mesozoic age. The minor granite landforms mentioned formed at the weathering front beneath the land surface. Hence it can be argued that the former regolithic cover has afforded a measure of protection and that the erosion of the mantle and exposure of the front may have taken a considerable time. But observations of modern erosion suggest that unconsolidated materials such as soil mantles are readily removed by stream action.

Even if it is accepted that estimates of the contemporary rate of degradation of land surfaces are several orders too high (Dole and Stabler, 1909; Judson and Ritter, 1964; see also Gilluly, 1955; Menard, 1961) to provide an accurate yardstick of erosion in the geological past, there has surely been ample time for the very ancient features preserved in the present landscape to have been eradicated several times over. Yet the silcreted land surface of central Australia has survived perhaps 20 m.y. of weathering and erosion under varied climatic conditions, as has the laterite surface of the northern areas of the continent. The laterite surface of the Gulfs region of South Australia is even more remarkable, for it has persisted through some 200 m.y. of epigene attack. The forms preserved on the granite residuals of Eyre Peninsula have likewise withstood long periods of exposure and yet remain recognizably the landforms that developed under weathering attack many millions of years ago.

MODELS OF LANDSCAPE EVOLUTION

The survival of these paleoforms is in some degree an embarrassment to all of the commonly accepted models of landscape development. Perhaps the best-known and most widely favored and applied model of

landscape evolution is that of W. M. Davis (1899, 1909) whose deductive scheme involves stream incision accompanied by the gradual lowering of divides by rillwork, wash, and wasting. The end product of these combined activities is the peneplain. One of the several difficulties inherent in the Davisian cycle as propounded by its author is the inevitable elimination of all vestiges of former peneplains following relative lowering of baselevel, stream incision, and lowering of divides. The identification of remnants of uplifted and dissected paleoplains such as have been described from various parts of the world is a denial of the effectiveness of the agents cited as being at work on divides. Theoretically peneplanation and the lowering of interfluves it implies are inimical to the development of multicyclic landscapes and to the survival of paleoforms.

A similar difficulty attends the schemes involving steady state development or dynamic equilibrium such as that derived by Davis (1922) with his concept of the "old-from-birth" peneplain and the more elaborate developments of Hack (1960) and Chorley (1962, 1965). Steady state implies continuous and equal erosion of the entire land surface, once the system is in adjustment. This is contrary to the field evidence of the widespread survival of old land surfaces. Even if it were argued that such survivals denote temporary maladjustments of the system, it is reasonable to ask how long, in view of the great age of some of the paleoforms, can maladjustment prevail before it is considered the norm?

Models based on the retreat of slopes (Penck, 1924, 1953; King, 1953, 1957, 1960) better explain the survival of paleoplains at least in the short term, for the essence of the concept is that high plain or plateau surfaces are destroyed only as rapidly as the scarps heralding the approach of the new cycle and lower surface recede inland: new plains extend at the expense of the old. But the development of flared slopes at successively lower levels on granite inselbergs (Twidale and Bourne, 1975a) and other evidence of piedmont zones, which have changed location very little in time, argues against significant retreat in some areas. Moreover the great age of some of the paleosurfaces surely implies that scarps retreat only very slowly, and the persistence of very old yet steep slopes surely requires demonstration and, if possible, explanation. Some of the models deduced by Kennedy (1962) explain the survival of paleosurfaces through a dominance of stream incision over wasting of divides, but similar problems arise concerning the ineffectiveness of the processes at work on interfluves.

Thus the Davisian and steady state concepts offer no theoretical possibility for the survival of paleoforms, but the scarp retreat hypothesis and some of Kennedy's models do, provided the relative immunity of interfluves to weathering and erosion can be explained.

SURVIVAL FACTORS AND MECHANISMS

General statement.—The survival of paleoforms must be due either to temporal or spatial variations in the distribution of erosional *energy*, or to the varied susceptibility of the land surface to erosion, or to both

these factors. Estimates of the relative rate of erosion under different climatic conditions have been made (see, for example, Corbel, 1959), but the present is probably not typical of the geological past, and even if it were, difficulties are introduced everywhere by the realities of climatic change. In some regions, it is possible to say that climatic conditions since the formation of a particular form have been conducive to its survival. For instance the arid conditions, which have obtained for much of later Cainozoic time, have no doubt aided the survival of the silcrete surface in central Australia. But the relative significance of arid and humid phases cannot yet be evaluated, partly because the duration of the two is not known, partly because the relative effect of brief downpours and periods of river flow compared to more regular rainfall and flow is difficult to assess in absolute terms. Rather can it be argued that significant erosion takes place largely during periods of climatic change, when the land surface is in geomorphological disequilibrium.

But by and large no generalizations can as yet be made about climatic control of erosional rates in the past.

Various possible factors involving spatial variation are discussed principally in respect to paleosurface remnants that occur in South Australia, though reference is made to other regions. In broad terms these are diastrophism and structure, the nature of river work, and auto-catalytic or reinforcement mechanisms. The significance of some of these was perceived as long ago as 1924 by Eleanora Bliss Knopf who published a paper concerned with erosion surfaces in the eastern Appalachians. In it she wrote (p. 667):

> The effect of (such) repeated uplift is to postpone indefinitely the total degradation of a region by constant addition to the area undergoing reduction and by setting back the progress of the work . . . after each interruption.

This statement is both perceptive and provocative. Perceptive because it is consistent with field evidence in many diastrophically disturbed areas such as the Flinders and Mount Lofty ranges, and provocative because by implication it calls to question the basic tenets of hypotheses of landform development which were as sacrosanct half a century ago as they are now.

Diastrophism and structure.—Linton (1957, p. 67) was aware of the significance of diastrophic rejuvenation. He wrote that "it is unlikely that any mountains can endure as such for more than about twenty million years unless they are raised up anew." Both the Mount Lofty and the Flinders ranges have suffered recurrent uplift, mainly along old-established fracture zones, through the Phanerozoic (Campana, 1958a and b). Both are still seismically active (Sutton and White, 1968). Both uplands are characterized by intense marginal dissection, with complex valley-in-valley forms indicative of repeated phases of rejuvenation. On the western escarpment of the Mount Lofty Ranges perched benches indicate the former piedmont zone now carried high above the present hill-plain junction by faulting. In both uplands there are high plains

or remnants of paleoplains located in core regions: that in the Mount
Lofty Ranges comprises residuals capped by the early Mesozoic laterite
together with its etch-plain equivalent (Twidale, 1968, p. 315-316; Twidale
and Bourne, 1975b); in the northern Flinders Ranges the high plain is
demonstrably an exhumed surface which predates the Lower Cretaceous
(Woodard, 1955; Twidale, 1969), but in the central and southern regions
(Twidale, 1966, 1969) there is no evidence of Cretaceous sedimentation,
and the high plain remnants there, which cut across folded argillaceous
sediments, are more likely to be of epigene type eroded by rivers which
graded to the Lower Cretaceous shoreline.

Thus in these regions the field evidence conforms to the theoretical
consequences of repeated uplift. Yet in both the preservation of the
paleoplain remnants involves more than repeated faulting. For example
the central Flinders Ranges is essentially a simple denuded anticline
from which at least 6000 m of sediment has been eroded. Sandstone
and limestone are prominent high in the stratigraphic sequence and
are thus exposed near the margins of the structure where they form
ridges and ranges. It is these outcrops and uplands, not fault zones,
that delimit and delineate the uplands, and being marginally located
they to some extent buttress the weaker sediments exposed between
them by acting as local baselevels of erosion for the streams that drain
radially from the Flinders. Profound erosion of the anticline has ex-
posed the deep core of the structure which was in compression, where
the joints are tight and where the strata are thus resistant to weathering
and erosion. It is not by chance that the high plain surface is best
preserved in the central Flinders Ranges where several structural factors
combine with positive diastrophism to render the land surface less
vulnerable to erosion.

The Mount Lofty Ranges are in many respects similar. The upland
is developed on an anticline the flanks of which are faulted to form a
complex horst. The bulk of the laterite plateau and high plain is
centrally located close to the compressional zone but there are many
remnants in marginal locations, near the fault scarps. In the west these
survivals can partly be explained in terms of their being buttressed by
sandstone and limestone outcrops, but in the east they are preserved
on gneiss and schist which are not notably resistant to weathering and
erosion.

Of course, the ferruginous zone of the laterite, being commonly
pisolitic and vesicular, is permeable and porous and resistant to erosion.
Moreover it retains the protective A-horizon in many places. But the
kaolinized zone beneath the iron rich horizon is readily eroded, causing
undermining and collapse of the whole slope. This indeed is the reason
for the extensive development of the etch plain in the upland, and
particularly in the east.

Localization of river erosion.—In both the Flinders and the Mount
Lofty ranges repeated diastrophism and structural factors are likely to
be responsible for the core survivals in the uplands. In neither area

can the preservation of paleoplains be attributed to interior location, for both are long narrow uplands no part of which is far removed from baselevel.

But in other places remoteness from the sea or from effective stream action is an important factor contributing to the preservation of paleoplains. Thus in southern Africa the land mass is so large that rivers only slowly extend their maximum influence in the interior, and it is significant that the old planation surfaces there are distributed in roughly concentric zones with the older surfaces located in the deepest interior (King, 1960). Again remoteness from river action can be cited in explanation of the survival of the prominent summit surface of etch character and Cretaceous age preserved in the Gawler Ranges (Twidale, Bourne, and Smith, 1976): the area is located inland and is surrounded by plains that are either climatically or lithologically arid (that is, underlain by limestone or other permeable rocks). The high plains of central and western Australia may be preserved for similar reasons.

But distance fom the ocean or from major drainage lines is not the complete explanation for such survivals. Ritter (1968) has pointed out that not only are there considerable variations in the present rate of erosion in the several major catchments of the continental United States but has also indicated that there are major contrasts between different parts of the same catchment. This suggestion is borne out by observations in the Flinders Ranges, for example, where lithological variations largely determine drainage density and hence degree of landscape dissection and paleoplain survival.

Why do some rivers develop long and deep valleys but extend their influence only a short distance from their channels? Knopf (1924, p. 667) was clearly aware of the contradiction between the evidence of some landscapes and the views expressed by the doyen of American geomorphologists and perhaps the most authoritative voice of the day, W. M. Davis. Davis considered that the movement of waste on divides and in rivers are "extreme members of a continuous series" (Davis, 1909, p. 267). He regarded both as moving mixtures of waste and water in variable proportions, and in consequence he saw the "river" as extending "all over its basin and up to its very divides" (Davis, 1909, p. 267). "Ordinarily treated" he wrote "the river is like the veins of a leaf; broadly viewed, it is like the entire leaf." Yet Knopf implied that the various processes at work on the valley side slopes and interfluves are not as effective in lowering the land surface as are trunk streams. And she was not alone in this view, for Crickmay (1932, 1959, 1968, 1969, 1971) has maintained much the same argument.

The reasons for such a contrast between the rate of lowering of stream beds and the intervening divides are surely related to the nature of water flow at the two sites. On the interfluves some precipitation infiltrates into the subsurface and makes its way underground to the stream lines. Part of the surface runoff takes the form of diffuse flow, and any linear flows are of low volume. All these are, however, brought

together in the trunk streams which are thus of much greater capacity than any of the rills and streamlets at work on the divides. Moreover the catchments of the divide streams are very limited, whereas the trunk streams gather runoff from large and probably extending areas upstream.

The contrast in the rate of lowering of divides and of stream beds is most pronounced in areas of permeable and pervious rocks. Basalt is resistant to wash by virtue of its well developed jointing which permits water to infiltrate into the subsurface so that interfluves and indeed the major part of the basalt surface are eroded only very slowly. But Waters (1955, p. 676) reports that in the Yakima area of Washington State where there are major linear flows joint blocks are plucked away by the river in spate and it is not uncommon for deep gorges to be eroded in and through basalt formations. Similar deep gorges incised below virtually undissected basalt plateaus occur also in north Queensland (Twidale, 1956b). Some sandstone and limestone areas are resistant by virtue of their ability to swallow water: they are lithological deserts. Thus in the area west of Sydney the high plains and plateaus underlain by flat-lying Mesozoic strata, including massive sandstone formations, are incised by such rivers as the Hawkesbury, Wollondilly, Colo, and Shoalhaven. The upland summit plain is of considerable antiquity, but whatever its precise age the valleys are deep and long but only narrow. Over much of its middle section, for example, the Shoalhaven is only 2 km wide but 500 m deep: a feature that can be termed a gorge, bearing in mind that few valleys are deeper than they are wide (Johnson, 1932).

The River Murray in South Australia is an exotic or allogenic stream which flows in a trench some 25 m deep and 1 km wide and is excavated essentially in flat-lying massively bedded Miocene calcarenites. The widening is due almost wholly to lateral corrasion by the river during post Pliocene times. During the last 12 to 15 m.y. wash, weathering, tributaries, and mass movements on the slopes have achieved little significant retreat of the valley sides (Twidale, 1968, p. 171-175).

Similar situations obtain in different structural settings. Many rivers have carved gorges in resistant members of folded sequences, such as quartzites, as a result of diversion, antecedence, superimposition, or valley impression (Twidale, 1972a). The adjacent ridges remain upstanding and bear testimony to the localized nature of river erosion, for some of the gorges can be correlated with planation surfaces of considerable antiquity (see, for instance, Twidale, 1966b). But even the very recently developed adjustments of drainage illustrate the same point: the famous antecedent drainage channel through the Shaur Anticline in western Iran has cut a minor gorge some 4 m deep in 1200 yrs, but during that same period there has been no significant valley widening (Lees, 1955, p. 224).

Channels eroded in unconsolidated rocks display similar forms. Gullies cut in unconsolidated sediments such as clays and fanglomerates are invariably trough-shaped with precipitous and in places overhanging

sides. This is so whether the gullies are 10 cm or 10 m deep and is independent of the presence of a capping of turf, calcrete, or gibber. In some instances the gullies are eroded in crumbly clays which crack and swell easily and which can offer only minimal resistance to erosion; yet the sidewalls stand in cliffs.

Thus both in cohesive and in unconsolidated rocks, there is strong suggestion that though stream beds are rapidly worn down bank erosion and valley side erosion are less effective.

There is also some evidence that river systems accomplish only slight erosion at the margins of their catchments and that significant back-wearing is restricted to the stream channels that penetrate to the periphery. In many areas, and in various structural situations, there are well-developed zones of scarp-foot weathering which surely argue an essentially stable location of the escarpment and of the scarp-foot for a considerable period of time. Thus in the Lincoln Gap area west of Port Augusta the flat-lying Precambrian strata have been dissected to form plateaus, mesas, and buttes. Three major planation surfaces have been identified in the region (Twidale, Shepherd, and Thomson, 1970). The youngest, of only limited extent, is related to present baselevel. The second, characterized by pediments carrying a discontinuous veneer of silcrete, stands 5 to 10 m above the first, is probably of mid Tertiary age, and is commonly separated from the backing scarp by a scarp-foot valley. The scarps lead up to the third and oldest surface, the prominent summit high plain of the Arcoona Plateau which is of Cretaceous age.

The dissection of the silcrete surface has taken place since the Miocene. The valleys are up to 3 km, but more commonly 1 km, wide so that lateral erosion due to all forces has proceeded at a maximum rate of about 0.15 mm per annum. During this time the backing scarps below the Cretaceous surface have receded by only a few score meters at most, for the scarp-foot valleys and associated weathering zones remain clearly in juxtaposition with the escarpments. There is no doubt that scarps have receded due to slumping, rock falls, and gullying, but it is localized and slow overall. The presence of silcrete in the marginal zones of drainage basins and particularly in scarp-foot situations (Bassett, 1954; Twidale, Shepherd, and Thomson, 1970; Hutton, Twidale, Milnes, and Rosser, 1972) is also indicative of topographic stability, for the evidence suggests that silcrete forms only very slowly and under essentially static conditions (Hutton, Twidale, and Milnes, 1976).

Thus although the case should not be overstated (for catchments have obviously been enlarged and stream piracy has occurred) there is much to suggest that headward stream erosion proceeds at a much faster rate than general scarp retreat.

Feedback mechanisms.—Slope retreat is the dominant mode of slope modification in many areas. Particularly is this so where slope behavior is controlled by the presence of a caprock (Tricart, 1957; Twidale, 1960). In these conditions the rate of scarp retreat is largely determined by the activity of self-regulatory mechanisms. Though scarp-foot weathering

induces slope instability, collapse, and hence recession (Twidale, 1960, 1967a and b), it is gullying that is in large measure responsible for the regrading of scarps. Coarse debris from the bluff accumulates in gullies, the beds of which are thus protected against further erosion. The low divides between gullies are however unprotected and are eroded; they in turn are lowered and become receptacles for coarse debris from the bluff above. This process of gully gravure (Bryan, 1940) involving the alternation of the locus of intense erosion through the protective effects of coarse debris derived from the bluff effectively slows the rate of overall retreat of the scarp.

Thus the stripping of the laterite capping of the southern Mount Lofty Ranges can be shown to have taken place at a maximum of 1 cm in 200 yrs or 0.05 mm per annum, if it is assumed that the laterite originally extended to the margins of the fault blocks, as the present distribution of remnants suggests, and if in order to maximize the rate of recession it is assumed that the drainage was established de novo on the laterite plateau. This is more comparable with rates of slope erosion derived from observations in hot arid regions than with those derived from the humid tropics. Scarps bordering the Grand Canyon have retreated at a rate of only 0.06 cm per annum (Schumm and Chorley, 1966), and sandstone cliffs in Colorado appear to recede as a result of rainwash at a rate of 0.005 mm a year (Schumm, 1964). These contrast strongly with contemporary rates of erosion in the humid tropics: almost 8 cm per annum on 40° to 50° slopes in Oahu (Wentworth, 1943); 1 cm in 7 to 10 yrs in one area and in 44 yrs in another in New Guinea (Simonett, 1967); and 0.1 to 10 cm (variable) per century over an entire catchment in central Japan (Yoshikawa, 1974).

This contrast may in part be explained by the self regulatory mechanism described above in the context of gully gravure. For in the humid tropics weathering is so efficient that little or no coarse debris survives to afford the ephemeral but significant protection.

A different type of feedback mechanism involving reinforcement or autocatalytic effects has also been invoked to explain the preservation of paleoplains on sandstone and other resistant massifs within fold mountain belts, in areas of horizontal strata (Twidale, Bourne, and Smith, 1974), and of paleoforms on granite and other inselbergs such as those described from northwestern Eyre Peninsula (Twidale and Bourne, 1975a).

The ridges and ranges of fold mountain belts are built mainly of intrinsically resistant rocks, but once they are in relief they shed water to the adjacent valleys or plains. The latter are eroded in weaker rocks anyway, but they receive a disproportionately high run-off and are thus more and more vulnerable to weathering and erosion. Thus there is a tendency not only for relief amplitude to increase, as has been suggested for the Flinders Ranges through the Cainozoic (Twidale, 1966b), but for remnants of paleoplains developed on sandstone for instance to be long preserved. Such residuals of the late Mesozoic exhumed surface also

survive on quartzites of the fold sequence involving Precambrian rocks in the Isa Highlands (Twidale, 1956a). Plateaus capped by sandstone also shed water to the plains and themselves are little affected by it, though there is some sapping of the caprock and consequent collapse and recession of the bluffs. Granite residuals of various shapes and sizes owe their development fundamentally to their effectively massive structure and to their propensity for shedding water to the adjacent plains, but the nature of granite and its reaction to moisture must also be borne in mind. It has long been known that granite is susceptible to attack by moisture, but that it is virtually inert when dry (Barton, 1916; Bain, 1923; Griggs, 1936, Wahrhaftig, 1965). This compounds the tendency to the preservation of inselbergs and similar forms and the weathering and lowering of plains on compartments of more densely jointed granite.

SUMMARY

The gravamen of this discussion has been that several factors, including lithology, structure, diastrophism, the unequal activity of rivers within their catchments, and self regulatory and autocatalytic mechanisms all contribute to the survival of paleoforms. Where several occur in conjunction, as they do on the western side of the Mount Lofty Ranges where there are massive sandstones, a lateritic carapace, recurrent positive diastrophism, protective alluvial aprons, and unequal stream activity, landforms, and land surfaces can survive long periods of weathering and erosion. Many of the paleosurfaces, which have not been exhumed, are admittedly of etch type, but their survival through long periods of geological time is nevertheless remarkable.

AN ALTERNATIVE MODEL

Models of landscape evolution either take insufficient or no account of the mechanisms and survivals outlined in this paper. The occurrence in the contemporary land surface of considerable areas of paleoplain assemblages is quite alien to some of these concepts, and though more conducive to survival than other models scarp retreat alone does not explain the continued presence of very old paleosurfaces in the landscape.

In an earlier discussion of the development of the Flinders Ranges (Twidale, 1966b, p. 26) the term "persistence of relief" was used to describe the longevity of the basic pattern of relief through the Cainozoic in the southern uplands despite profound erosion. It is not suggested that the ridges have suffered no lowering, but that they have been degraded so slowly that old land surfaces survive on them, and that relief amplitude has increased. Nor is it argued that the planimetric location of ridges and valleys has gone unchanged, for deep erosion of folds has brought about the migration of ridges and valleys (Twidale, 1972a) and even the advance of escarpments (Twidale, 1927b). But the basic pattern of relief has remained for some 70 m.y.

In similar fashion reinforcement mechanisms have been invoked in explanation of the survival of the various inselbergs of northwestern Eyre Peninsula through at least the Cainozoic and in some instances possibly through the last 200 m.y. of earth history (Twidale and Bourne, 1975a).

Such survivals of landforms are embraced in a model characterized by persistent and increasing relief, a model in which initial structural contrasts are accentuated by weathering and erosion of weaker zones (fig. 2). Continued exploitation of weaker zones is made possible by recurrent uplift, by restricted effectiveness of river systems, and by reinforcement effects. This model is offered not as one of universal application but as one of the several, outlined earlier, which should be considered in the light of the field evidence.

It may for instance be necessary to differentiate between landscape evolution in humid lands, where erosion of slopes is relatively active and where divides are seemingly being consumed at a measurably rapid rate (Wentworth, 1943; Simonett, 1967), and arid or semiarid environ-
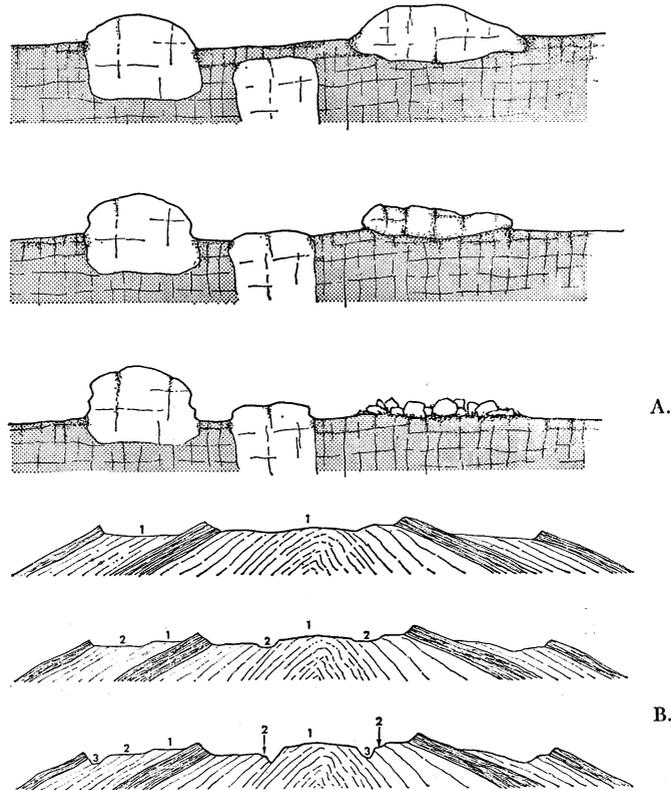
A.

B.

Fig. 2. Suggested models of landscape development: (A) granite—stippled areas represent weathered granite; (B) fold mountain range—1. oldest paleoplain, 2. second paleoplain, 3. present surface of low relief.

ments (either climatic or lithological) where under comparable conditions of anthropogenically induced disequilibrium, slopes are being eroded only very slowly (see Schumm, 1964; Schumm and Chorley, 1966). In humid regions, paleoforms do not long survive; in arid zones, they may. Thus it is that the tropical and subtropical deserts are characterized by extensive survivals of paleoforms, while they persist in the humid lands only where structural conditions are favorable, as for instance on the chalk uplands of southeastern Britain (Wooldridge and Linton, 1939) and in regions, such as the Labrador Peninsula where coastal indentations are few, where recent dissection is marginal, and where the high plain which occupies much of the Peninsula is an etch surface representing a preglacial weathering front stripped of its regolithic cover by glacial erosion during the Pleistocene.

It has been said that "The essence of geomorphology is the discrimination of the ancient from the modern" (Bryan, 1950, p. 198). It may be that Bryan did not appreciate how ancient are some facets of the modern land surface, but certain it is that studies of denudation chronology at their best furnish a perspective on the evolution of the contemporary landscape without which our comprehension and appreciation would be sadly diminished. Whether such investigations are viewed as historical geology, as Bryan averred, and whether or not they are regarded as geomorphological, is, *pace* Chorley (1965), irrelevant. Even if the conclusions reached by many workers over the years are only partly correct, it is clear that remnants of paleoforms are an integral part of the modern land surface, particularly in tropical arid and semiarid regions. Their persistence provides valuable insights into the character of erosional processes. The hills are not everlasting as Jacob implied (*Genesis*, 49, 26), but they persist for much longer periods than has been generally conceded.

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