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ON THE ORIGIN OF PEDIMENTS IN DIFFERENT STRUCTURAL SETTINGS

C. R. TWIDALE

Department of Geography, University of Adelaide,
Adelaide, South Australia

ABSTRACT. Pediments are described from regions of folded sediments, flat-lying strata, and crystalline rocks. Most of the pediments are cut in inherently weak or weathered outcrops. Those limited pediments developed on intrinsically fresh, resistant rock are etch features, that is, they are exposed weathering fronts.

Running water in various forms is, however, responsible for shaping other, covered, pediments and for the transport and deposition of their mantles. This is most convincingly demonstrated at the margins of the Flinders Ranges, where boulder mantles of identifiable provenance show that divaricating streams have eroded pediments across weak sedimentary beds and also deposited the protective mantles. Within the uplands similar processes are apparently at work, although the preservation of older pediments is in part due to rock fall deposits. The extraordinary smoothness of pediments is due to surficial deposition and not to the nature of the degradational processes responsible for shaping the bedrock surface.

In granitic areas field observations suggest that the pediments are eroded in weathered rock by rills and wash, but the sedimentological evidence for these processes is inconclusive.

Though scarp retreat has probably occurred in the plateau areas investigated, on obsequent scarps in areas of folded sedimentary sequences, and locally (and ephemerally?) in the fold mountain areas where mantles form a resistant capping to the pediments, general evidence and argument suggest that pediments have evolved as a result of the lowering of the plain surfaces and particularly as a result of the etching out of weathered scarp foot zones. There is no evidence of significant scarp retreat in the areas of crystalline rocks studied.

INTRODUCTION

Arid and semiarid landscapes vary greatly from place to place, but inselbergs and pediments constitute significant landscape elements in such areas. Many workers have explained these landform assemblages in terms of scarp retreat and pedimentation, that is, development of smooth, gently sloping surfaces as a result of mountain front recession. Thus, Cotton (1942, p. 90 and following) accepted the back-wearing of scarps as an integral part of his savannah cycle. King invoked the process in a long series of papers and books (see, especially, King, 1953, 1962). Mabbutt (1955, p. 78) stated that the pediment problem involves mainly "a consideration of extending pediments and retreating mountain faces," and Pugh (1956, p. 26) writing of granite inselbergs in Nigeria suggested that "a mountain mass with a well-developed upper surface will shrink slowly by scarp retreat."

But what does "scarp retreat and pedimentation" mean? What evidence is there of widespread and long-distance scarp retreat as is implied by the extent of many of the plains, and what complex of processes is subsumed in the term "pedimentation"? In practice, it is difficult to find incontrovertible evidence of extensive scarp retreat. Some authors (Howard, 1942; Oberlander, 1972) accept the mechanism almost as an act of faith (which has been defined as an illogical belief in the improbable), while others resort to uncertain assumptions concerning the relationship between climate and slope behavior (Selby, 1977).

As for pedimentation, for some workers sheet flow is implied (Mabbutt, 1955), others invoke stream floods and sheet floods (McGee, 1897; Rahn, 1967), and for yet others "pedimentation" is a word that means anything or nothing according to the whim of the writer. Several processes have been suggested as being responsible for the development of pediments (for reviews, see Tator, 1952-1953; Tuan, 1959), but as commonly used it seems to imply a complex of processes, the details of which are varied or, in some instances, obscure.

In this paper pediments are, following McGee (1897), Bryan (1922) and Tator (1952-1953), defined as gently sloping and virtually undissected surfaces cut in bedrock. Pediments meet adjacent uplands in a sharp break of slope, the piedmont angle (see Lawson, 1915; Johnson, 1932; King, 1949; Twidale, 1967a). Most carry a thin, discontinuous debris mantle which in general, though not in detail, merely simulates the form of the underlying bedrock floor. In this, pediment mantles differ from the fill that underlies alluvial plains, that masks and blankets the essentially flat suballuvial landscape, and that bears no relationship to the bedrock morphology.

Pediments developed on folded sedimentary sequences, flat-lying strata, and crystalline rocks are described, their possible genesis is discussed, and inferences are drawn concerning landscape development in the areas considered.

FLINDERS RANGES

General setting

The Flinders Ranges are semiarid uplands bordered on three sides by desert plains. The Ranges extend from the Lake Eyre Basin as far south as Port Pirie, although structurally the folded and faulted Adelaide Geosyncline sediments extend as far as the Southern Ocean (figs. 1 and 2). The uplands display ridge and valley topography, with some peaks standing well over 1000 m above sea level. This topography is developed on and clearly reflects the patterns of the fold structures of the Precambrian and Cambrian sediments. There are some minor igneous intrusions, particularly in the north around Mt Painter, but various sandstones and quartzites, notably the Pound and the A.B.C., form most of the prominent peaks, ridges, and ranges (see, for example, Twidale, 1971, p. 193, fig. 87). The lowlands and valleys are excavated in shale and siltstone. In the south the Ranges are delimited by resistant strata expressed as prominent ridges, but in the north they are delineated by faults. Faults are not as common and significant in the central and southern Ranges as in the north, but faulting is still active throughout the uplands (Sutton and White, 1968).

Pediments are commonly developed at the margins of basins and valleys within the Ranges, as for example, around the depositional plain that occupies the central axis of the Willochra Plain and Basin. In most valleys there are, in addition to pediments graded to contemporary stream channels, relics of old valley floors (Twidale, 1966, 1967b). However, some of the most extensive and well-developed pediments occur at the margins of the uplands.

Brachina region

In the Brachina region (figs. 1 and 2) the uplands are bounded by a double rampart comprising a higher sawtooth ridge of Pound Sandstone and a lower, but still prominent, ridge underlain by Wilkawillina Limestone of Cambrian age (pl. 1). Both the sandstone and limestone dip to the west at 50° to 60° and are succeeded conformably by the argillaceous Billy Creek Formation, across which the pediments of the Brachina region have been eroded. They form a ramp of gently sloping bedrock plains between the upland and the alluvial flats of the Lake Torrens plains (fig. 3).

The pediment fringe is, however, complex. Not only are there actively developing pediments graded to present stream lines but also remnants of older pediments at several elevations (pl. 1; fig. 4). Of the

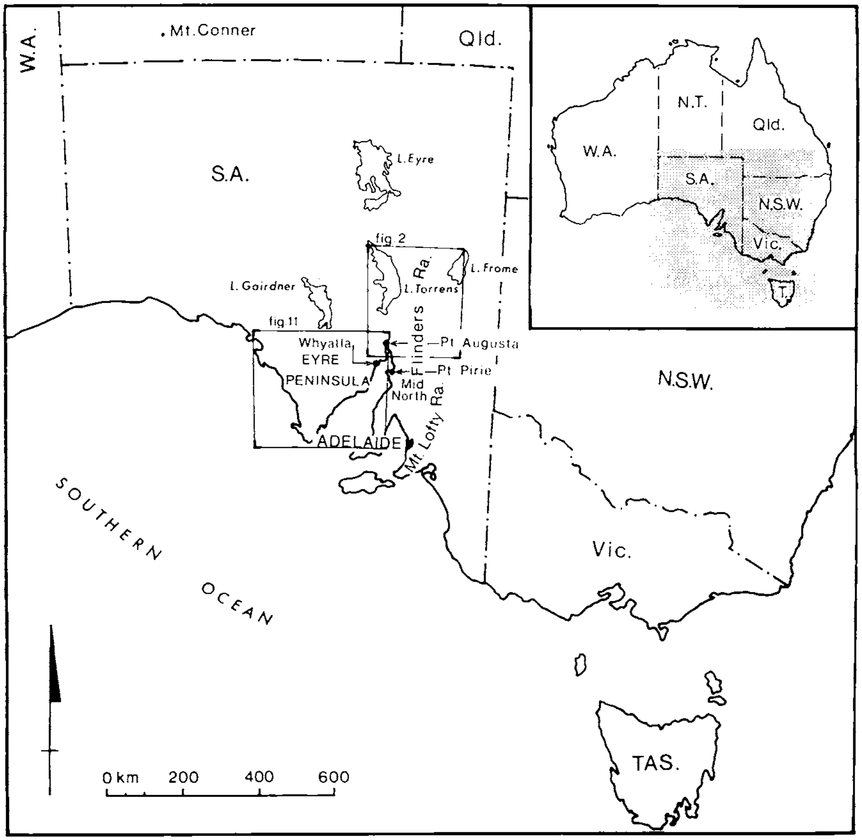


Fig. 1. General location map. The areas detailed in figures 2 and 11 are indicated.

latter, the most extensive comprises a group of low angle cones which stand between 4 and 8 m higher than the contemporary valley floors and slope at angles of 3° to 4°, in contrast to the almost imperceptible half to one and a half degree slope of the present channels and valleys. In addition, pediment remnants, presumably older than the other erosional elements, stand as much as 60 m above the present stream channels and valleys.

A. *Modern pediments.*—The modern pediments are most extensively developed adjacent to Brachina Creek (fig. 4); the major drainage line of the area under consideration.

On leaving its gorge section, Brachina Creek flows in a single braided channel about 100 m wide incised 20 to 40 m into the outcropping siltstone of the piedmont zone. On leaving this sector, it

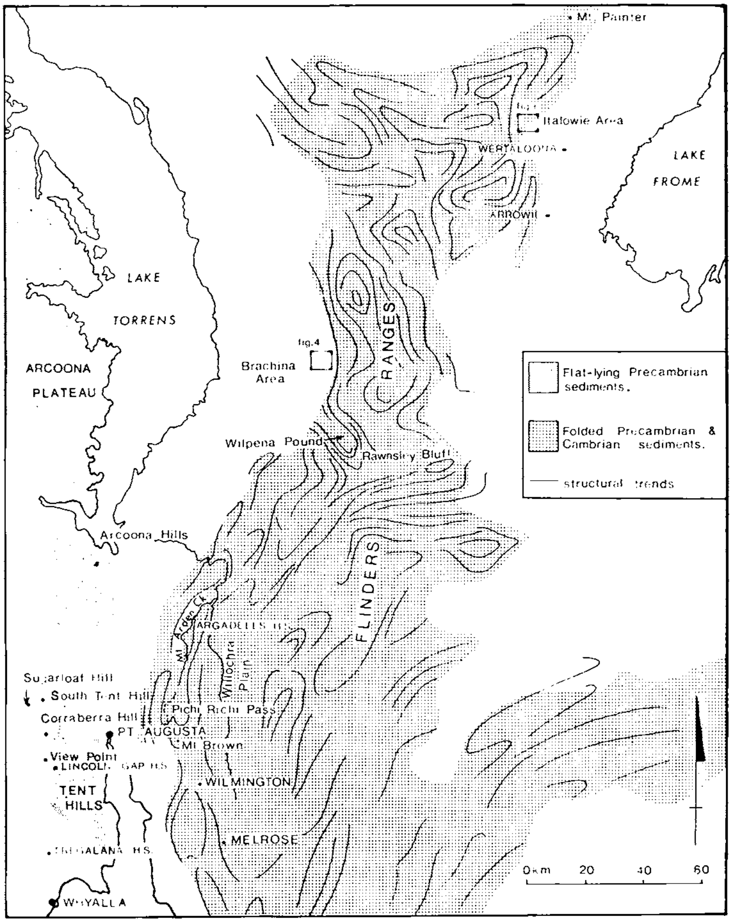


Fig. 2. Location map of the Tent Hill region and the Flinders Ranges, showing geological structure. The areas shown in figures 4 and 6 are indicated.

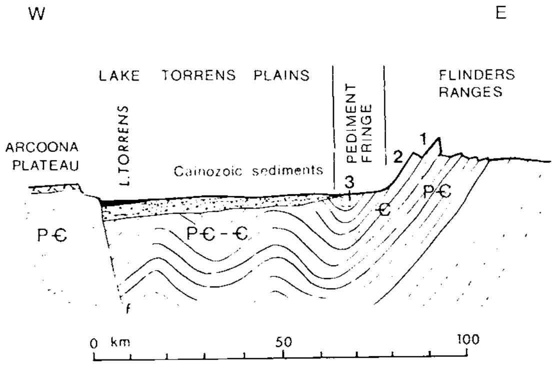


Fig. 3. Diagrammatic cross section through the Lake Torrens Basin and western flank of the Flinders Ranges. (1) Pound Sandstone, typically 900 to 1000 m.a.s.l.; (2) Wilkawillina Limestone; (3) argillaceous Billy Creek Formation standing 200 to 300 m.a.s.l.; the Arcoona Plateau is some 250 m.a.s.l. and the bed of Lake Torrens about 34 m.a.s.l.

develops a large number of distributary channels known locally as "overflows." Some of these channels are 50 to 60 m wide and carry a coarse bed load, but there are, interlaced with these and with each other, many channels 5 to 10 m wide, up to 2 m deep, and floored by silt. Coarse blocks are scattered over the entire distributary zone both in the channel beds and on the interfluves.

Streams tributary to Brachina Creek are eating back into the higher plains or pediments, and the modern pediment extends at the expense of the older; the main relic pediment (M in pl. 1) in particular is being so reduced. The two pediments are separated by low scarps capped by a thick debris mantle. The scarps are being undermined by regressive stream erosion, and they gradually retreat, allowing the extension of the lower surface at the expense of the upper.

Modern pediments are also developing in the valleys of the various minor streams that have cut into the older surfaces. Thus, near the scarp foot, where it is deeply incised, the valley of Windmill Creek (pl. 2-A) is comparatively narrow and deep. The braided stream is actively undermining its banks, cutting sideways, and forming a broad flood plain covered by a veneer of alluvium. The latter is of mixed caliber, but the blocks and boulders, though widespread, are also concentrated in ridges and shoals up to 1 m high and are aligned parallel to the direction of stream flow. The cut bedrock surface is in detail irregular with minor channels and intervening low ridges. The intermittent character of stream flow in this and other arid and semiarid regions entails deposition of all the solid load at the end of each phase of river activity.

These flood plains are incipient pediments formed by lateral corrasion by divaricating streams. Toward the toe of the main pediment where less deeply incised streams have a lesser volume of rock to corrade and transport, and so more readily achieve planation, the Creek has

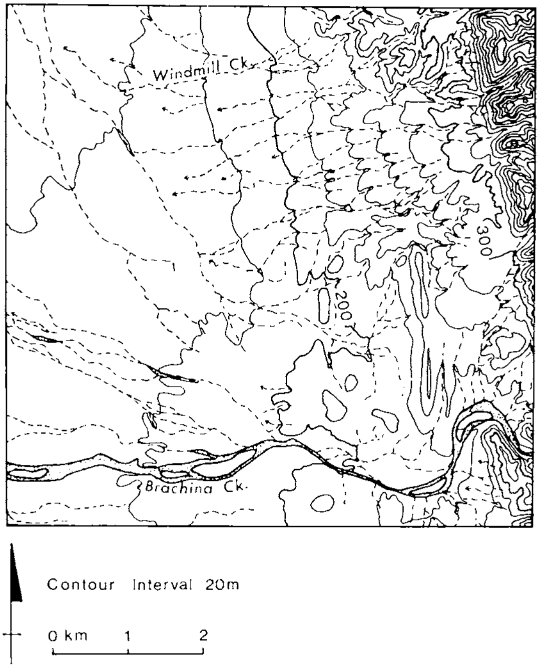


Fig. 4. Topographic map of the Brachina region. (Based on S.A. Lands Dept Topographic Map Series 1:50,000 sheets Edeowie 6535–II, and Oraparinna 6635–III).

developed a markedly distributary habit and forms a broad flood plain cut in siltstone and floored by alluvial deposits. Adjacent streams behave in similar fashion, and their coalescence has caused the formation of a broad distributary plain, in all several kilometers wide.

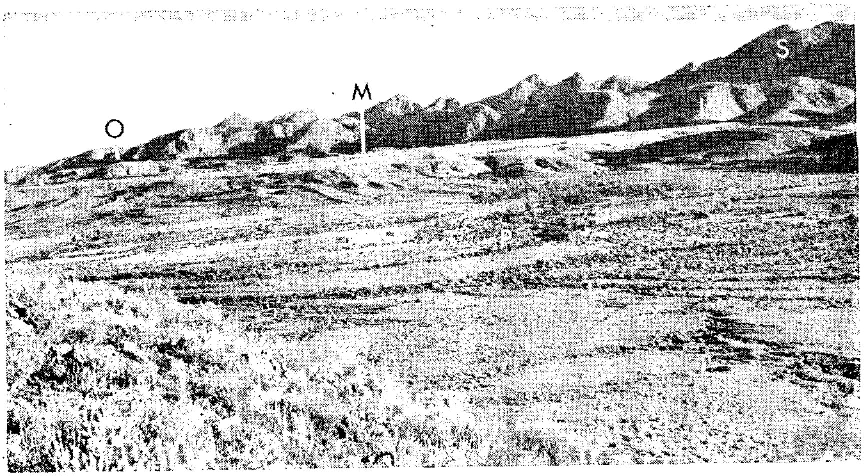
Thus the modern pediments consist of flats underlain by silt and sand separated and surmounted in places by linear ridges of boulders. The flood plain is incised by narrow gullies up to 2 m deep (pl. 2-B). Near the head or apex of the distributary plains large slabs of the local siltstone are incorporated in the boulder bed. Windmill Creek and Brachina Creek, like other major streams, have eroded their bed and banks and simultaneously deposited a thick mantle of debris.

These contemporary streams, though they flow only intermittently, are, nevertheless, forming pediments, and the whole assemblage recalls Blackwelder's (1931, p. 137-138) view that "pediments are graded plains due . . . to the active sideways cutting of desert torrents," and is also evocative of the stream floods described by Rahn (1967).

B. *Main relic pediment.*—The main Brachina pediment (M in pl. 1) consists of a series of coalesced and interlocking low angle cones incised by narrow steep sided gullies eroded by streams debouching from the uplands to the east (pl. 1). The cones are cut across the dipping Billy Creek siltstones and slope gently from the base of the limestone escarp-

PLATE 1

A.



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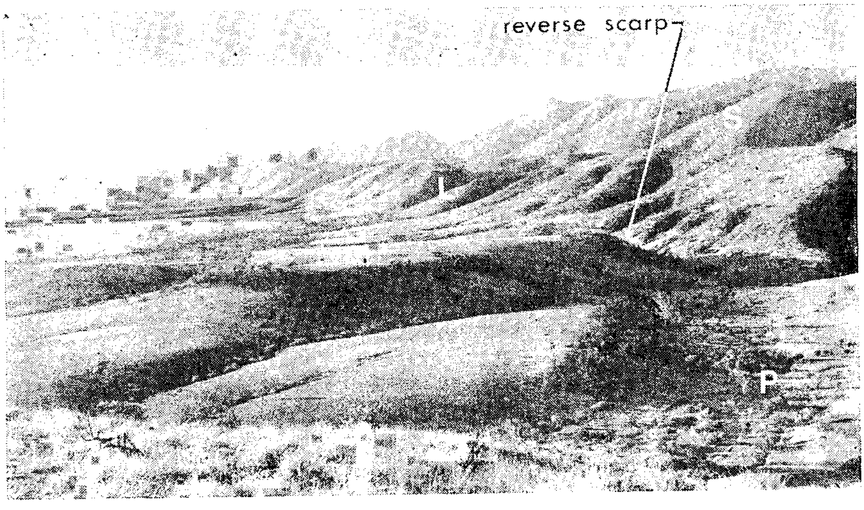


C.

PLATE 2

A.

B.

PLATE 2

A. South bank of Windmill Creek showing the mantle of the main pediment overlying steeply dipping siltstone exposed in a river cliff that is from time to time undermined and worn back by the episodically flowing stream, the dry cobble strewn bed of which is clearly seen.

B. An exposed shoal of boulders and blocks forms a ridge in the flood-plain of Windmill Creek. A cobble strewn channel can be seen in the right middle distance.

PLATE 1

← The piedmont zone at Brachina seen (A) from the air, from the southwest; (B) from the ground, also from southwest; and (C) in the piedmont angle.

Key: sandstone ridge — S, limestone ridge — L, dissected main pediment — **M**, older pediment remnants — O, contemporary pediment — P.

ment (pl. 1-A and -B) for a distance of 3 km until they disappear beneath the Cainozoic sediments of the Lake Torrens plains. They carry coarse debris mantles.

In the piedmont zone, the Cambrian sediments are weathered, intensely in the scarp foot, much less so a few score meters downslope. In some sectors, a continuous smooth concave slope links the pediment with the limestone escarpment behind. Many of the relic pediments are separated from the upland by strike valleys excavated in the weathered bedrock. The reverse scarps, the low bluffs delimiting the pediment heads and opposed to the main escarpment (pl. 1), are capped by a debris mantle, though siltstone is exposed over most of the valley side slopes.

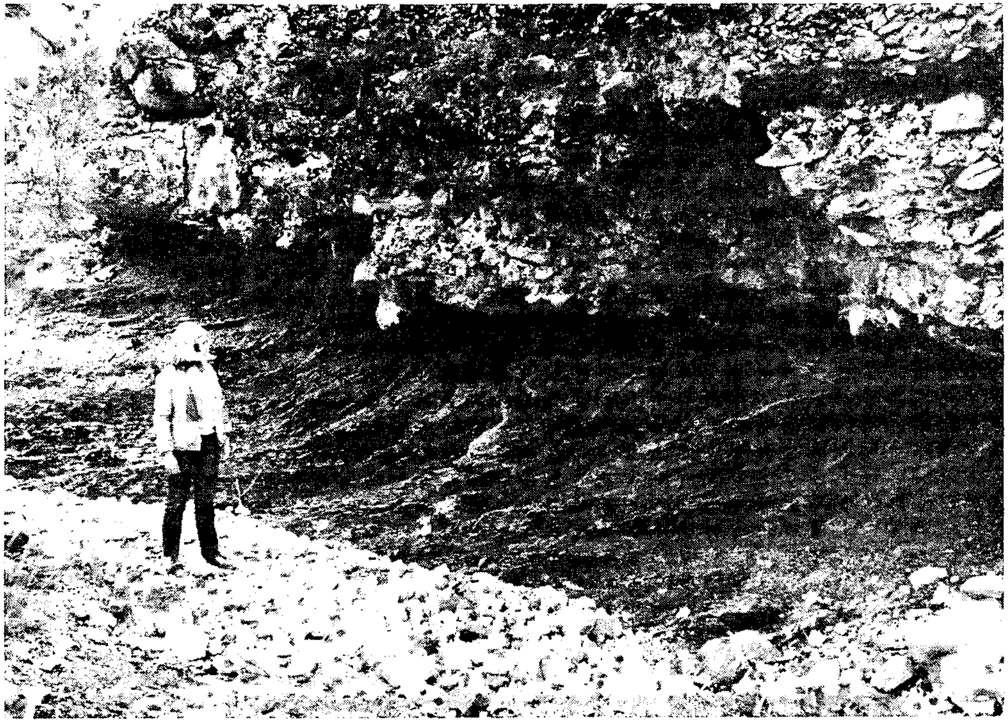
Apart from the alteration observed in the scarp foot zone the siltstones are essentially fresh, though there is some superficial mottling in wet sites and in particularly fissile strata. No paleosol intervenes between the mantle and the fresh siltstone (pl. 3). The cut bedrock surface is in detail irregular, for there are minor ridges on slightly more massive and resistant strata, and channels, up to 1 m deep and filled with boulders, are excavated in the siltstones. But these irregularities are masked by a mantle up to 3 m thick, and the smoothness of the pediment surface is therefore due to deposition, not to erosion.

In creek sections, the mantle consists of boulders of quartzite and fossiliferous Wilkawillina Limestone, plus a few small slabs of siltstones. In some places, the mantle is cemented but elsewhere consists of a loosely cohesive boulder bed without a silt matrix. This appears to be due to the fines having been washed out of the deposit near major drainage lines either by groundwaters percolating laterally to the main stream or by floodwaters in the main valleys. Many of the boulders carry a skin of lime.

In the broad divides between incised valleys, the character of the mantle appears quite different from that observed in creek sections. The pediment mantle apparently consists of small angular fragments of quartzite and limestone set in silt. This contrast between the surface layers and the mantle displayed in creek sections has proved quite misleading (see Twidale, 1967b, 1978a). A reappraisal of the deposit was suggested by the occurrence of ribbons of rounded boulders aligned normal to the mountain front, sloping down the pediment, and analogous with the coarse deposits of the modern "overflows."

Deep pits dug through the mantle and into the siltstone below have shown that the fragmented gravel set in silt extends to depths of 50 to 70 cm. Below this the mantle, up to 1.5 m thick, comprises a mass of rounded boulders, some of them almost a meter in diameter, set in a matrix of silt, and resting on siltstone *in situ*. Thus the creek sections are typical of the whole mantle and are not restricted to the drainage lines. There are, however, contrasts between the near surface zone, the mantle proper, and the mantle as exposed in different creek sections that require explanation.

PLATE 3



A clay-cemented boulder bed — the mantle of the main Brachina pediment — resting unconformably on dipping silstones exposed in a creek section between Brachina Creek and Windmill Creek.

The near surface mantle has been weathered by alkaline waters resulting in the disintegration of many boulders to form innumerable small angular fragments. The planation of quartzite boulders is more frequently complete or nearly complete than it is on those of limestone (Twidale, 1978a). The sides of residual knobs standing above the general level of the minor platforms, cut in some of the quartzite boulders, are flared, indicating soil weathering, and also, since the flares are about 15 cm high, surface lowering of at least that amount (see Twidale, 1962). Such chemical weathering accounts for the difference between the near surface and deeper layers of the mantle.

Both the detailed morphology of the bedrock surface and the character and provenance of the mantle show that the Brachina main pediment was formed in the same way as the modern actively extending pediments. It was eroded by distributary streams emerging from the uplands and behaving like the present Brachina and Windmill creeks. It was formed in the manner described by Gilbert (1877), McGee (1897), Blackwelder (1931), and Rahn (1967) with respect to pediments investigated in the American Southwest.

The streams that carried the mantle deposits also cut the bedrock surface beneath. This suggestion is corroborated by the occurrence, near the pediment heads that have survived scarp foot erosion, and in the divides between debouching streams, of roughly triangular areas lacking rounded exotic debris and occupied by gravelly angular limestone rubble derived from the nearby scarp (fig. 5). They have presumably been reduced by weathering and by occasional washes.

There is no evidence of more than one phase of mantle deposition having been active on this main pediment surface. Doubtless, cut and fill occurred (compare McGee, 1897, p. 88), for the periods of stream activity were probably separated by phases of low flow or even desiccation, but there is no evidence of it in the exposures observed, and, more importantly, no evidence of pauses in the deposition of the sedimentary se-

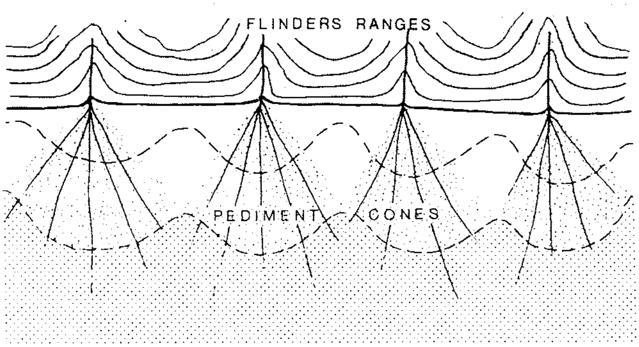


Fig. 5. "Dead triangles" or triangular areas occupied not by fluviatile deposits but by angular limestone rubble derived from the backing scarps and located between the delta-shaped areas of alluvial deposition.

quence. The sediments observed in the Windmill Creek distributary plain are of the same order of thickness as those displayd on the main relic pediment. The caliber of material in the mantle is everywhere comparable to that carried and deposited during brief periods of flooding and now exposed in the river channels.

C. *Higher relic pediment remnants.*—The higher, presumably older pediment remnants at Brachina are also cut across siltstone and carry a mantle of boulders and cobbles. The mantle is mainly quartzitic and lacks a silty matrix, the latter presumably having been flushed out by rains over the years. These high isolated remnants occur some distance from the present piedmont zone, probably because of the weathering of the bedrock close to the scarp foot and its resultant ready erosion. The upper surfaces of the mesa remnants slope gently down to the west at angles of up to 4½° and are more steeply inclined than are either the main relic or the modern pediments (Twidale, 1972).

Several of the remnants are linear and are oriented east-west, parallel to the direction of flow of present and past streams, and it is suggested that the preserved relics occupy the sites of former shoals where particularly thick deposits of coarse debris were laid down.

D. *Discussion.—Pediments of similar origin:* In the Brachina region, the nature of the mantles has permitted the preservation of several generations of pediments, all cut across inherently weak rocks and all eroded by divaricating streams debouching from the uplands on to the desert plains. Similar planation of weak strata, initially by rills and gullies and subsequently by distributary streams, is evidenced in several other parts of the Flinders Ranges. In the Italowie region of the northern Flinders, for instance, the major rivers divaricate after leaving the confines of the upland (fig. 6). Morphologically and genetically, therefore, Brachina pediments are characteristic of those of the areas marginal to the Ranges. Moreover, similar pediment development has evidently taken place within the uplands, for the mantle debris is commonly rounded.

On the other hand, many small streams confined to single channels emerge from the uplands and spread over the plains without incising any channels of consequence. Many examples are to be seen in the Wilmington area for instance. In addition, a significant number of these intermontane pediments are capped by mantles that consist of coarse angular quartzite blocks. Thus at Rawnsley Bluff, near Mt Brown, and in the upper sectors of the Mt Arden Creek valley, the debris is of this coarse and angular type. The remnants display a distinct slope down from the nearby scarp — near Argadells an inclination of 7½°. In view of this, and the character and likely provenance of the debris, it is difficult to escape the conclusion that the mantles are slump deposits. They fell from the scarps to the lower slopes and pediment heads at a time when the scarps were closer to the remnants than they now are. Some of these falls, to judge by contemporary reports, are seismically in-

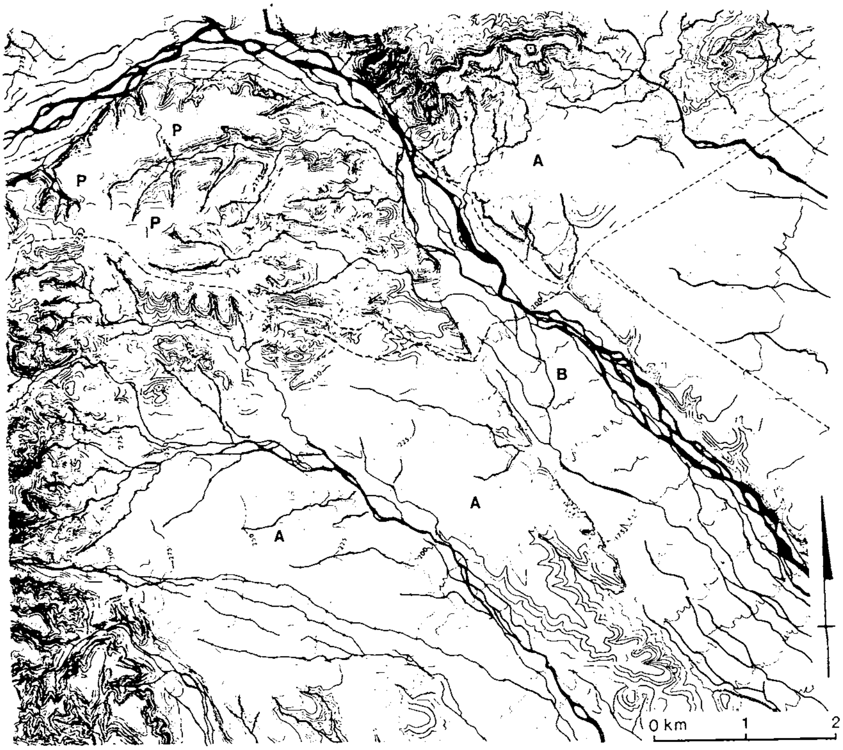


Fig. 6. Topographic map of the Italowie pediment remnant and associated plains: P — pediment remnant, A — alluvial plain, B — braided stream channel. (Based on map prepared by S.A. Lands Department).

duced. Be that as it may, modern intermontane pediments are molded by sheet wash, rills, and streams; and apart from these areas affected by slumped masses, pediments were probably shaped in the same way in the past.

Slope behavior: The western ramparts of the Flinders Ranges at Brachina are formed of dipslope scarps, and in this structural situation scarp retreat is impossible. The hill-plain junction is determined by the lithological contrast between the Wilkawillina Limestone and the argillaceous Billy Creek Formation. As erosion has penetrated to greater and greater depths in the fold structure this lithological junction has been exposed farther and farther to the west. Thus rather than retreating, the scarp has actually advanced as it has extended downward (Twidale, 1972). Within the piedmont zone the resistant nature of the mantle, whether cemented or not, causes the development and maintenance of steep slopes where they are subjected to strong basal attack by streams, and here scarp retreat may reasonably be inferred (Tricart, 1957; Twidale, 1960).

But overall the field evidence suggests that the pediment slopes have declined: the older, higher, remnants slope down from the uplands at angles of up to 4½°, the main pediment at 3° to 4°, and the presently developing surfaces at ½° to 1½°. The etching out of the scarp foot, with the formation of scarp foot valleys, and the isolation of the pediment remnants (see Twidale, 1967a, 1967b), is associated with this decline of planate elements in the piedmont. The progressive decline in pediment slope is a function of stage or time, not of provenance and caliber of stream load. The higher remnants and the modern pediments occur within the same catchments (fig. 4). Moreover there is no variation in pediment slope parallel to the mountain front: it remains constant regardless of whether the streams originate in the piedmont zone (on the scarp) or deep within the uplands.

Similar evidence of the decline of pediment slopes in time has been observed at Mt John, near Arrowie (fig. 7A), Rawnsley Bluff, Wilpena Pound (fig. 7B), near Argadells, in the Mt Arden Creek valley, and in the Pichi Richi Pass in the southern Flinders Ranges where the steeper older slope is inclined at an angle of 11° and is progressively being replaced by a new and gentler slope of 2½° as the hill-plain junction is etched out (fig. 7C). Other sites displaying similar evidence include Mt Conner, Northern Territory (see Twidale, 1967a, fig. 10, p. 410), the piedmont zone between Wilmington and Melrose where old slopes display 3° to 5° inclination compared to ½° to 1½° for the present valley floors, in the Gulnare district of the Mid North region, and just south of Wertaloona on the eastern margin of the northern Flinders Ranges (figs. 1 and 7D), where in the adjacent headwater catchment of Stony Creek, older and higher pediments slope at angles of about 4° from the base of the boulder-capped escarpments, whereas the narrow valley floors associated with contemporary stream channels are inclined at only half a degree in their lower reaches and one and a half degrees in their upper sectors where they are eating into the scarp foot (pl. 4).

Thus in these areas where relevant evidence is preserved the angle of inclination of the pediments has decreased in time. One possible explanation is that the streams responsible for the pediments encounter progressively finer material as they incise their beds, and, as a result, the gradient necessary for the transportation of the available debris diminishes progressively in time. But this does not bear close examination in the areas under discussion.

At Brachina, for example, the local bedrock is dipping, and the strata are essentially uniform in composition. Near Wertaloona, the strata, again dipping, and lithologically uniform, are weathered near the surface and fresher and more cohesive in depth. The intrinsically unweathered strata disintegrate into much coarser fragments than does the altered regolith. Alternatively, the decline in slope might be explained in terms of the gravel mantle rather than the nature of the underlying country rock determining the angle of slope required for the transport of debris. But again, in areas like Wertaloona and Windmill Creek, the modern beds are filled with debris at least as coarse as that of the mantle on the adjacent pediments.

Paige (1912) suggested that the rising baselevel due to the gradual infilling of desert basins caused streams to spread and distribute their loads, and it could be argued that such conditions have contributed to the decline of pediment angles in such areas as Brachina where the rivers run to the Lake Torrens Basin. But the same decline is observed in the Wertaloona area where the streams are still incising, and where,

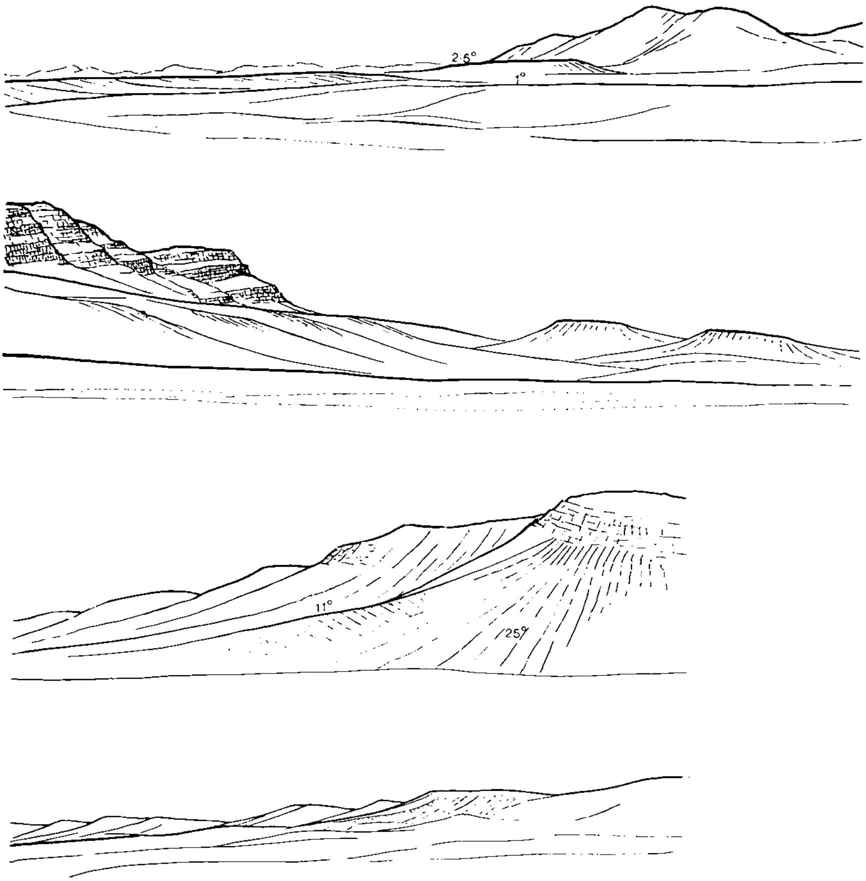
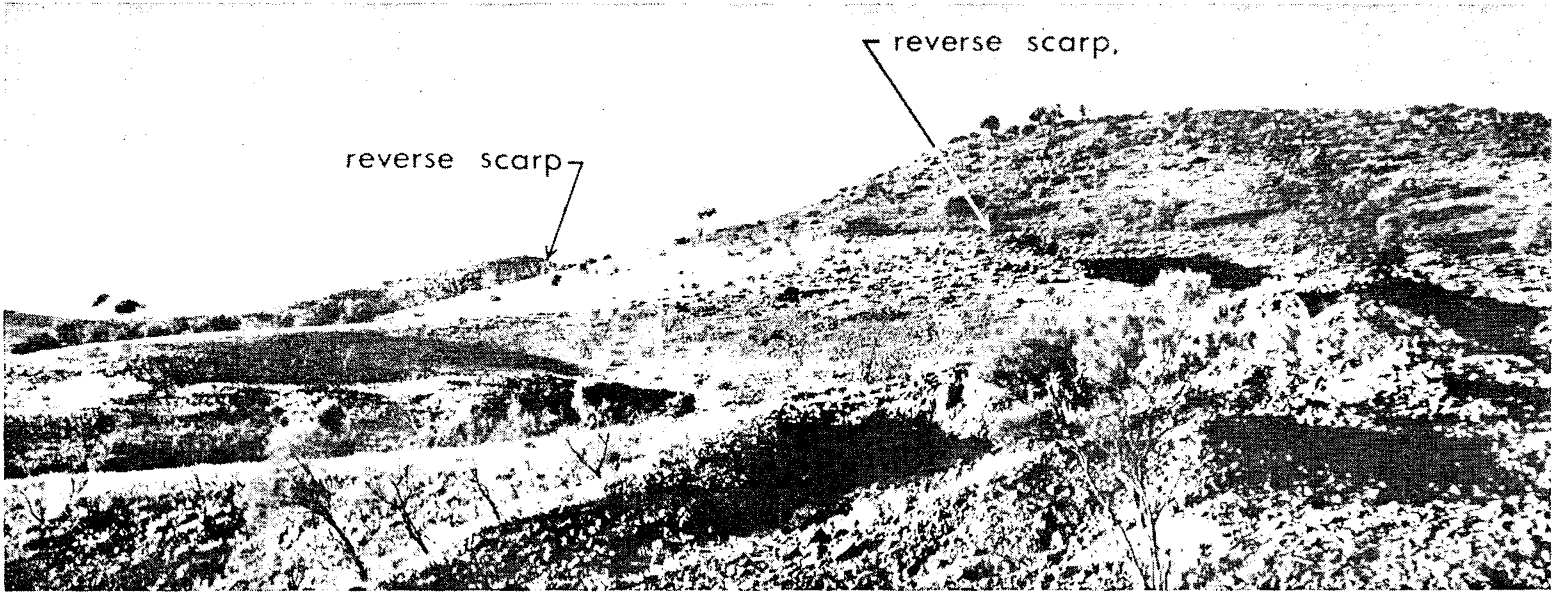


Fig. 7. Sketches of (A) Mt John, an inselberg in the east-central Flinders Ranges, showing a scarp foot depression, dissected pediment with a slope of 2½°, and modern pediment inclined at an angle of only 1°; (B) isolated debris-capped mesa remnants at Rawnsley Bluff, Wilpena Pound, separated from the sandstone bluff by a scarp foot valley; (C) remnant of an older, more gentle (11°) slope being replaced by a steeper 25° valley side slope in the Pichi Richi Pass, near Quorn, southern Flinders Ranges; and (D) similar replacement of more gentle by steeper slopes in minor valley south of Wertaloona, northern Flinders Ranges.

PLATE 4



Part of Stony Creek Valley, south of Wertaloona in the northern Flinders Ranges, showing two generations of pediments, the older inclined at 4° steepening to 11° near the head but now dissected, the present valley floors which are incipient pediments sloping at 1½° to 2°, and reverse scarps.

on a local scale, the baselevel is still being lowered. Similarly, the intermittent streams and rivers of the Flinders Ranges are actively incising their beds with no suggestion, in this tectonically positive region, of rising baselevel.

On the contrary, the most reasonable explanation of decline of pediment slopes appears to be related to the stability of the escarpments that delineate the pedimented basins. At Brachina the scarps are structural, and at Wertaloona they are protected and exist by virtue of caprocks, but in both instances there is evidence of considerable stability. The limestone scarp at Brachina has been worn back only a few meters in several million years, and similar slow rates of change are argued elsewhere in this paper.

The major outlines of relief are demonstrably of long standing, and subsequent developments have modified rather than drastically changed this ancient framework (Twidale, 1966). The present stream systems are capable of erosion only where they attain a certain critical volume or where they are acting upon weak rocks. Hence the scarps have remained virtually untouched, but the valley floors, where the streams are of appreciable volume, and particularly the scarp foot zones of intensely and frequently deeply weathered rock have been eroded: the effect has been to etch out the floors and the toes of the hillslopes so that instead of drainage amphitheatres, like that at Wertaloona, having the form of saucers, they have taken on the aspect of steep-sided and relatively flat-floored saucepans.

As a corollary to the suggestion that slope lowering is dominant, many of the pediments in the areas described are not associated with any significant scarp retreat. On the contrary, the evidence in dip-slope situations, as at Brachina, point to the lowering or decline of slopes being characteristic of pediment genesis.

At some sites, however, where the scarps are of obsequent rather than dip-slope type, retreat has occurred concurrently with decline. Thus at Rawnsley Bluff (fig. 8) only scarp retreat can account for the slumped regular blocks being located so far from the present escarp-

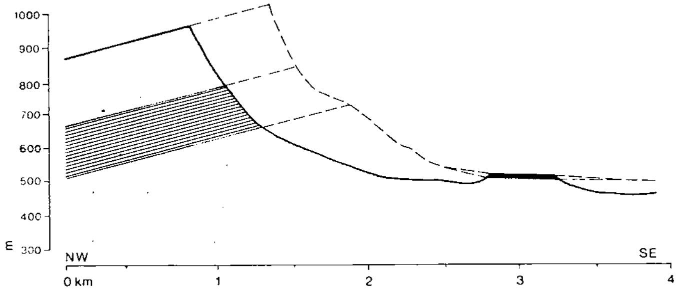


Fig. 8. Section through Rawnsley Bluff showing suggested development of mesa capping as a result of slumping at a stage when the scarp was located to the southeast of its present location. The mesa mantle is coarse slumped debris.

ment. The areas protected by rock falls have been isolated and left as high points in the local relief as a result of repeated periods of scarp foot weathering and erosion related to various stages of scarp recession (Twidale, 1967a).

Possible causes of stream incision: The phases of incision between periods of pediment development might be attributed either to uplift of the Ranges or to climatic changes or to a combination of the two (see Campana, 1958; Webb, 1958; Twidale, 1966, 1967b, 1969, 1976a, p. 484-486; Sutton and White, 1968). However, the flights of pediment remnants preserved in the Brachina piedmont are susceptible to explanation without recourse to either changes in the internal or external environment, for the surfaces are preserved and stabilized by their mantle cappings and may be regarded as discontinuous elements developed within an essentially continuous geomorphic history.

The pediments are surfaces of transportation cut by the same rivers that carried and deposited the coarse debris mantles. This detritus is derived from the uplands to the east. Structural, topographic, and climatic-vegetational conditions favored, and still favor, intense weathering of the argillaceous sediments located in the scarp foot (Twidale, 1967a). As the major rivers incised their beds and scarp foot valleys were etched from the weathered bedrock, the pediments became separated from the adjacent upland, and their mantles were isolated from their source of supply.

The depth of incision may have been controlled by baselevel, but in view of the downstream convergence of pediment profiles, the gradual infilling of the Lake Torrens Basin, and the consequent rise of baselevel (compare Lawson, 1915), this is unlikely. The caliber of debris in the mantles and flood plains is similar at all levels, so that change in the stream regime resulting from either climatic change or tectonism cannot be invoked in explanation of the phases of incision evidenced in the landscape.

Recently developed gullies in the Mount Lofty and Flinders ranges are restricted to weakly consolidated or to weathered sediments, and the streams have scarcely penetrated fresh rock. In the Brachina piedmont, the various stages of incision may have been controlled by the depth of weathering: the streams cut down to the lower limit of weathering, and there essentially stabilized as the debris mantle was deposited in the broad, extending flood plains. Weathering proceeded, and another regolith was developed until, possibly during heavy rains and flooding, the rivers eroded through their own bed loads and etched out this second zone of weathering, and so on.

Alternatively such flights of pediments, which together with the intervening scarps form a stepped topography, may have developed partly as a result of climatic accidents, namely floods, partly in consequence of the stabilizing effect of the coarse debris mantles. The latter are resistant to both weathering and erosion, but major streams in flood are able to breach them. Once they have cut through their own channel deposits the streams erode deeply into the underlying relatively weak folded strata, so that narrow linear trenches are excavated below the level of the mantled surface. Henceforth running water, and hence erosion, is concentrated in these narrow gorges. But the mantle-capped surfaces are left high and dry, virtually untouched by the rivers. They are reduced in area as the newly formed channels and flood plains become broader and eventually become sufficiently extensive to be considered new actively developing pediments, but this takes place only very slowly through the recession of the mantle-capped valley side slopes.

In time, however, a new lower-level pediment, carrying a veneer of coarse fluvial debris develops and extends until the next major flood causes the particular river again to erode its own bed below the level of the debris veneer. Another new channel is eroded, the erstwhile new pediment is abandoned, and another new pediment is initiated.

The higher surfaces are older than those at lower levels, but all relic forms are preserved and stabilized by virtue of their mantle deposits and are only slowly destroyed. Thus although the processes responsible for shaping the pediments are in essence continuously active insofar as neither climatic change nor tectonism is necessarily involved, discontinuous planate forms separated by escarpments have nevertheless evolved.

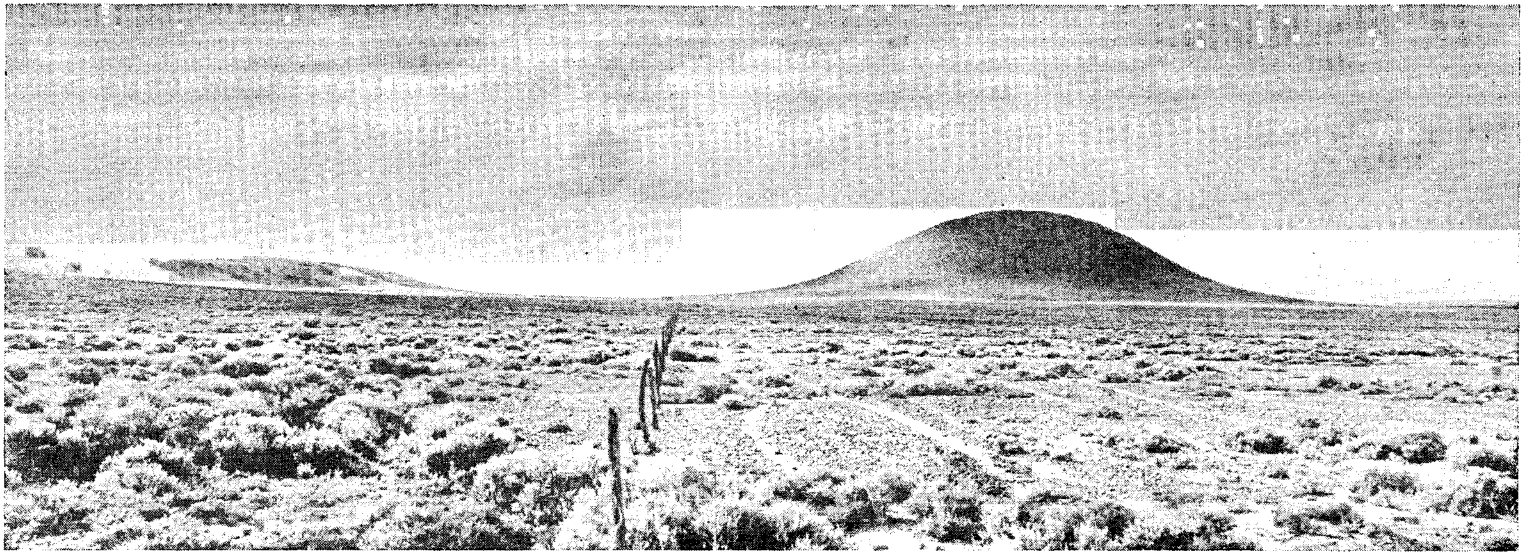
TENT HILL REGION

General setting

The Tent Hill region extends from the vicinity of Whyalla in the south as far as the northern extremity of Lake Torrens (figs. 1 and 2). It is underlain by Late Proterozoic and Cambrian sediments which are delimited on the east by the Torrens Fault. The sediments dip very gently northward and thin out to the west, so that near the eastern shore of Lake Gairdner they are only 2 to 5 m thick and rest unconformably on an uneven surface eroded in the porphyritic dacites and rhyolites of the Gawler Ranges (Twidale, Bourne, and Smith, 1976). The sedimentary sequence includes several quartzite members which, where dissected, form resistant cappings to the plateau forms that characterize much of the region.

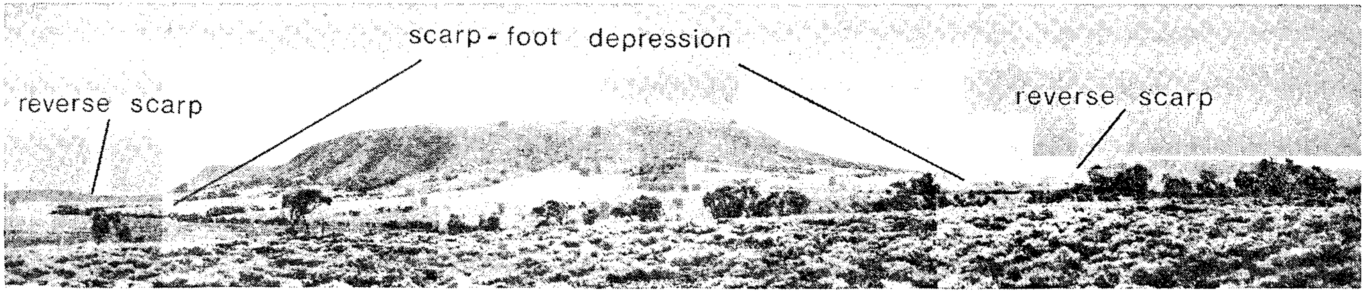
In detail, the summit surface of the Tent Hills plateau, which stands at about 300 m above sea level in the south but declines to 200 m and less in the north, transects the local bedding and is thus of erosional origin. It is of probable Cretaceous age (Twidale, Shepherd, and Thomson, 1970; Twidale, Bourne, and Smith, 1976). Where the local caprock has been eliminated, the weaker sediments in the sequence, particularly shale, siltstone, and cross-bedded micaceous sandstone, give rise to rounded uplands as in Corraberra Hill and Sugarloaf Hill (pl. 5) and the Arcoona Hills (Twidale, Shepherd, and Thomson, 1970), but where such sediments are preserved above the caprock, domed plateaus (King, 1968) are formed.

PLATE 5



Sugarloaf Hill, a rounded residual from which the quartzite capping has all but been eliminated. Note the plateau in the left background and the gibber plain in the foreground.

PLATE 6



South Tent Hill is a quartzite-capped mesa surrounded by pediments. The older higher pediment has been dissected, and the intensely weathered scarp foot zone has also been eroded, isolating the remnants of the former pediment fringe and forming a distinct scarp foot depression. Note the reverse scarps.

Scarps

The plateaus are bounded by steep scarps which are everywhere of similar form and inclination (fig. 9). This may be interpreted either as implying scarp retreat or as indicating that the escarpments tend toward a form that is in equilibrium with the environment.

The plateaus have been greatly reduced in area, for the caprocks were formerly contiguous and extended over the entire region. It can be argued on general grounds (Tricart, 1957; Twidale, 1960) that the scarps have been maintained by the protective caprock and that they have retreated and are still being modified. In particular, the caprock

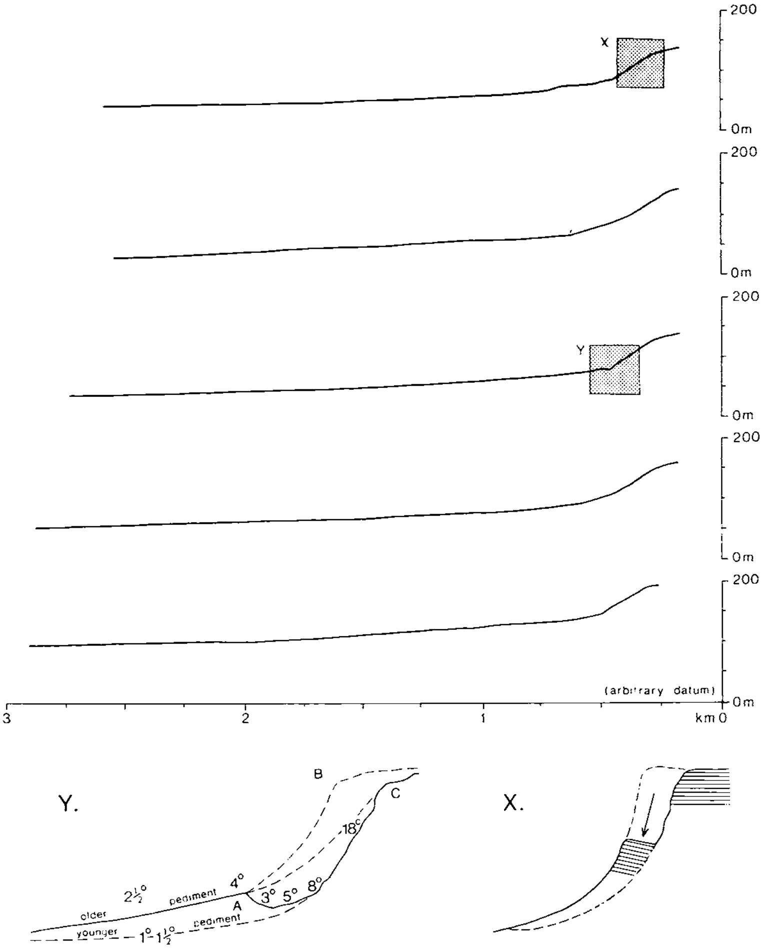


Fig. 9. Cross sections through the western scarp of View Point plateau, with detail of slumping shown in diagrammatic section (X), and scarp foot depression also indicated (Y). (Based on Military Survey Topographic Series 1:25000 sheet *Corraberra Hill*, 6432-IV, and field surveys).

is being undermined as a result of gullying on the debris slope below the bluff and also in consequence of slumping (Thomson, 1965). The slumps carry the capping quartzites well below their normal stratigraphic level, and the usually horizontal strata dip down toward the hill as a result of rotation during the collapse (X in fig. 9). In these ways, the quartzite cappings are undermined, and the scarp recedes.

Such recession may occur in a series of discontinuous catastrophic events caused perhaps by heavy rains or possibly by Earth tremors. The whole region lies near a major active fault zone, but in contrast with the Flinders Ranges (see earlier) no first-hand evidence of seismic events causing cliff collapse is available here.

In the Tent Hill region quartzite from the caprock and bluff tumbles down the debris slope where it persists as angular joint blocks. In time, however, as a result of weathering, and in consequnce of attrition and disintegration during the collapse and rolling down the debris slope, the blocks are reduced to gravel. This creeps and is washed downslope into the piedmont zone and a few score meters out on to the plains to form a discontinuous but nevertheless resistant capping which protects the underlying siltstone and shale.

Piedmont zone

In detail, some of the piedmont plains consist of single pediments (pl. 6), but most are complex. Near the head of Spencer Gulf, streams have been affected by Quaternary shifts of sea level (Twidale, Shepherd, and Thomson, 1970), so that plains have developed at several distinct levels (pl. 6). Also an older and steeper pediment surface commonly stands above the present stream channels and associated pediments. The older pediments slope at a maximum of 4° to 5° compared to the 1° to 1½° of the contemporary forms (Y in fig. 9C); similar decreases in inclination in time are recorded from those areas of the Flinders Ranges where flights of pediments are preserved (see above, p. 4).

Apart from the discontinuous gravel mantle, patches of silcrete are preserved near the head of the older pediment. Silcrete is a relic feature, and its development suggests an early-middle Tertiary, possible Miocene, age for the pediment remnants (Wopfner and Twidale, 1967; Wopfner, Callen, and Harris, 1974).

Besides being dissected by streams flowing normal to the scarp face the older pediment remnants are also separated from the backing escarpment by scarp foot valleys developed in zones of intensive weathering (Twidale, 1967a). Thus the older pediments are delineated by reverse scarps near their heads (pl. 6), but their lower slopes or toes gradually decline and merge with the present plains and pediments. The older pediments have been isolated from the source of the gravel, namely the caprock, since the development of the scarp foot valleys. While the fines have probably been washed and blown away, the coarser debris has become more and more concentrated and has formed an increasingly effective capping.

Even on the modern pediments having flat (½°) slopes, there is little evidence of planation or lateral transport of debris. Thus at the Tregalana Quarry, the local siltstone is weathered to a depth of 8 to 10 m but near the surface is masked by a red gypsiferous silty soil. There is no colluvium, no exotic fragments indicative of downslope transport. Slopes are uniformly gentle, and it is only in and immediately adjacent to the stream channels that transport and erosion are evident.

A similar situation obtains at the southern end of View Point plateau in Lincoln Gap. There the local siltstone, intrinsically flat-lying, but again distorted by near-surface processes, is overlain by red silt with carbonate nodules and little or no evidence of introduced debris, though the plateau is less than a kilometer distance.

Discussion

Although there has been active, if slow, erosion by streams in and near their channels (compare Crickmay, 1932, 1959, 1968, 1969, 1971; Twidale, 1976b) the rest of the land surface appears to have been remarkably stable. The steeper, older pediment slopes are well and widely preserved.

The older pediment surface cannot have been lowered and only recently stabilized by the addition of the gravel mantle, because the source area of the gravel, namely the quartzitic caprock, is now isolated from the pediment heads by the scarp foot valleys. Thus the incision of the streams, both those in the scarp foot and those running normal to the scarp, must have occurred only recently. Such recent dissection surely implies that there has been etching out of the scarp foot zone and a steepening of the scarp rather than a recession of the slopes (AC to present state in fig. 9C (Y) rather than AB). However, scarp degradation has taken place through slumping and gullying so that the bluffs have not remained entirely static. Moreover, it is unlikely that the weathered scarp foot zones have remained immune to attack. More probably they have suffered incision and have been progressively dissected, causing the scarp to be steepened to the maximum inclination commensurate with stability (Twidale, 1967a and b).

In essence, however, the landscape is and has recently been stable, in contrast to an earlier period of pronounced changes, probably involving scarp retreat, when considerable reduction of the plateau was achieved. Why this change in geomorphological activity? One possibility is climatic change, to which earlier reference has been made. Another is the undoubted stabilizing influence of the silcrete duricrust and gravel mantles accumulated in the piedmont zone. A third is a reduction in the effectiveness of erosion on the migrating escarpments during the progress of the geomorphic cycle (fig. 10).

Immediately after initial stream incision (1 in fig. 10), the downstream sectors of the streams tributary to the main drainage lines were high volume streams, since they derived from a catchment of considerable areal extent (fig. 10). They were capable of considerable erosion

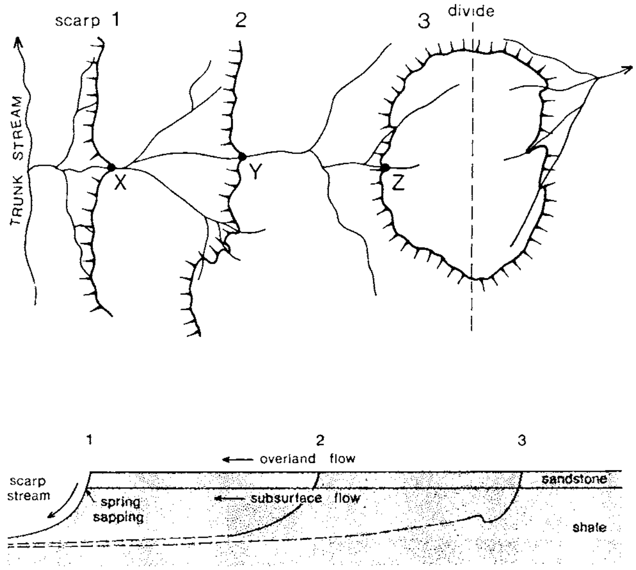


Fig. 10. Variation of scarp profiles in time in Tent Hill region. Q = discharge: at stage (1) Q = 10x at X, at (2) 6x at Y, and at (3) 2x at Z.

and scouring of slopes. Moreover the volume of any subsurface drainage (for example, at the base of the sandstone cappings) would also be commensurately high, so that spring sapping may have been significant in shaping slopes soon after stream incision had been achieved.

However, as the new low-level drainage basins expanded, the scarps delimiting the new drainage basins were ever more distant from the main streams and were affected by streams that were of lower volume since they served high level catchments of diminishing areal extent (2 in fig. 10). So they tended toward more gentle inclination, and the rate of recession decreased until the scarps were virtually, although not quite, stationary (3 in fig. 10).

Scarp foot weathering and erosion became significant. There was time for silcrete to develop (Hutton and others, 1972; Hutton, Twidale, and Milnes, 1977; Milnes, Hutton, and Twidale, 1978). Gravel mantles accumulated and became concentrated as fines were preferentially evacuated. The scarps were attacked basally and were steepened to a maximum inclination commensurate with stability (Twidale, 1960). Thus although Baulig (1956, p. 30) has claimed that slopes will not change provided climate and structure are constant, they may do so because of variations in energy distribution within drainage basins. The volume of the tributary streams at work on escarpments decreases as the latter retreat away from the trunk streams and toward the watersheds or divides. This in turn reduces the rate of scarp retreat, which in its turn allows time for weathering processes to take greater effect, and may go some way to explain why very old erosional remnants are preserved in the interiors of such subcontinental masses as southern Africa (King, 1962).

The dissected piedmont zones in the Tent Hill region resemble those found at Brachina and elsewhere in the Flinders Ranges. Both sets develop in association with a stable scarp, but in the Ranges the stability is due to structural control, whereas in the plateau region it is related to the advanced stage of plateau dissection. In the Tent Hill region weathering eventually compensates for the relative ineffectiveness of riverine erosion, and the scarps near the end of the phase of incision are similar to those developed in relation to the newly formed streams, so that although the processes vary in stage and time, and although the scarp foot is etched out and the bluff made steeper, the end result, overall, is scarp retreat.

NORTHERN EYRE PENINSULA

General setting

Most of northern Eyre Peninsula (figs. 1 and 11) is underlain by Precambrian granite. Near the west coast, the crystallines are overlain by Pleistocene calcarenite deposited in large coastal foredunes (Crocker, 1946), and over wide areas the bedrock is masked by late Pleistocene sand ridges and calcrete (Twidale, Bourne, and Smith, 1974). But granite, with minor occurrences of gneiss and schist, underlies the whole area.

The area under discussion consists of a rolling plain standing 80 to 100 m above sea level. Isolated granite hills and ridges of sandstone, generally considered to be outliers of the Precambrian sediments and meta-sediments exposed in the Cleve Hills (see Johns, 1961), stand above the general plain level. The granite hills vary in size and shape from high, stepped domes (Twidale and Bourne, 1975) like Carappee Hill and Mt Wudinna, domes or bornhardts like Ucontitchie Hill, ruwares or whalebacks such as Polda Rock, Little Wudinna Rock, Pildappa Rock, and the Dinosaur, and boulder-strewn but stepped residuals in Waulkinna, Tcharkuldu, Cocata, and Corrobinnie hills. But whatever their size and shape they are built of fresh massive granite. This stands in marked contrast to the weathered granite that underlies the plains to depths of 20 to 40 m.

Pediments

The granite residuals are surrounded by undissected low angle cones or pediments characteristically sloping at ½° to 1½° down from the piedmont angle at the base of the hills and giving way downslope to flat or nearly flat plains traversed by linear relic dunes and underlain by massive calcrete (fig. 12; pls. 7-B and 8). These are *fringing* pediments comparable to those described for the Brachina region and elsewhere.

In some of the pediments, granite is exposed over much of the planate surface, and these are *rock platforms* or *rock pediments,* but others, the great majority, are *covered pediments,* for they carry a mantle of granite sand and gravel.

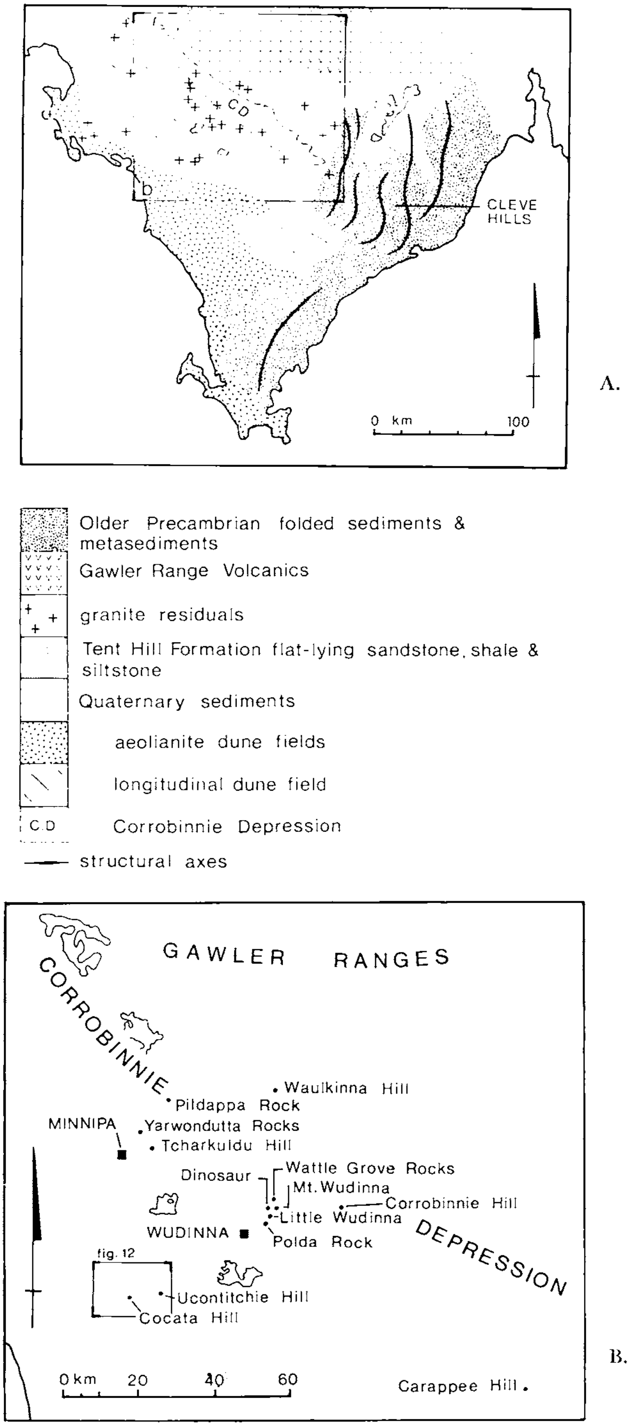


Fig. 11. (A) Geological map of Eyre Peninsula. The area detailed (B), a detailed map of the Minnipa and Wudinna districts, is shown, and the area depicted in figure 12 is indicated.

PLATE 7

A. Ucontitchie Hill is a granite bornhardt surrounded by a low angle pediment cone also cut in granite (also fig. 12).

B. Mt Wudinna and the Dinosaur, northwestern Eyre Peninsula, seen from the Plio-Pleistocene Koongawa Surface. Only the low dimpled and rounded top of the Dinosaur is visible.

A. *Rock platforms.*—Rock platforms (Twidale, 1978b) fringe the uplands, occur on the crests of low hills and rises, and form integral parts of many covered pediments. They are mostly narrow and occupy only a few score square meters, but in and adjacent to the Corrobinnie Depression, a structurally determined topographic low (Bourne, Twidale, and Smith, 1974) they attain considerable widths. Those bordering Corrobinnie Hill for instance are up to 700 m from head to toe and slope gently down from the piedmont zone to the depositional plains. These platforms or rock pediments are merely exposed weathering fronts (Twidale, 1978b) and are lateral extensions of flared slopes (Twidale, 1962). The platforms are etch surfaces, for they are revealed by the stripping of the grus mantle. Erosion must, therefore, recently have outstripped weathering. The many boulders scattered over the platform are residual corestones, and the numerous pits and channels represent zones of intense chemical attack at the former weathering front (see Twidale and Bourne, 1976a).

The Eyre Peninsula platforms are limited in area and are not to be compared with the extensive rock pediments *(glacis de denudation)* which occur for example in parts of the central Sahara (see Rognon,

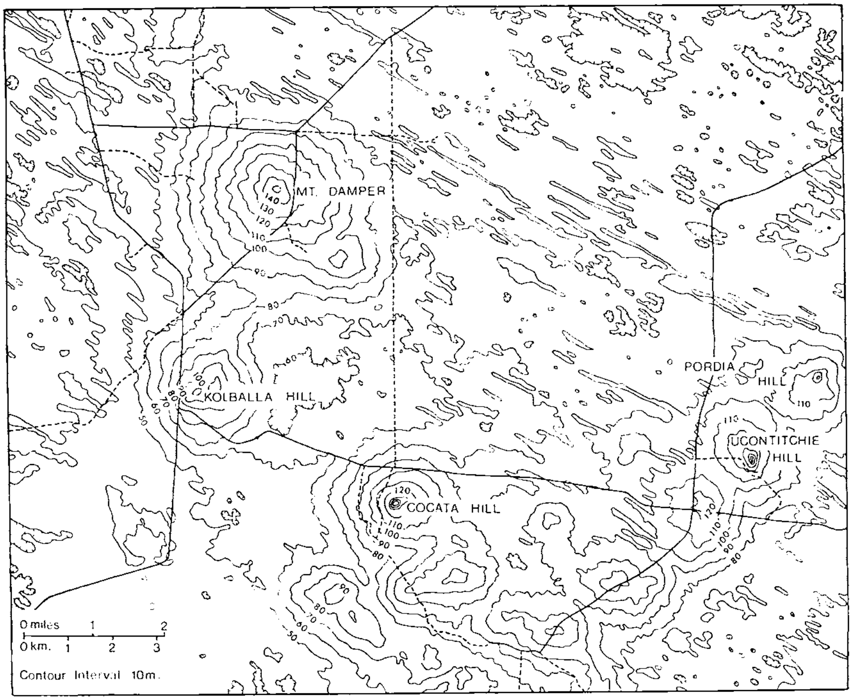


Fig. 12. Extract from South Australian Lands Department Topographic Map Series 1:50000 sheet *Pordia,* 5921-IV, showing isolated granite inselbergs, low angle pediment cones or fringes, and relic dunes in the valley floors.

1967, p. 329 and following, also pl. XVIII. 3) and which are also probably of etch character.

B. *Covered pediments.*—Most of the pediments are covered in that they carry a mantle consisting of a few centimeters of grus and soil. The composition of this mantle suggests that it is derived from the weathering of the local granite bedrock. The aggregate consists of quartz, kaolinite, and chlorite, all with a patina of red oxide derived from the breakdown of biotite. In many places, corestones persist within the matrix of grus, and in deeper sections, such as are exposed in excavations in the scarp foot zone, they are both larger and more numerous in depth (compare Ruxton and Berry, 1957).

Near the surface, and particularly in topographic lows and in the scarp foot zone, calcrete, either in nodular or hardpan form, has developed in the grus. This lime may have been carried as aeolian dust from the calcarenite dune outcrops to the west and distributed over the land surface, although some may be derived from the weathering of plagioclase feldspars in the granite. The lime is the only possibly exotic material found in the weathering profiles: all other minerals could have been derived from the weathering of the rock *in situ*. The weathered granite is permeable, so that there is considerable subsurface infiltration of water, especially where the calcrete is thin or absent. Minor shallow gullying is evidenced on several pediments, and downslope wash has been observed during heavy rains; yet it is difficult to demonstrate significant downslope movement of debris.

The thickness of the mantle varies. It attains 4 m at some sites, and 2 m thickness is quite common in the piedmont zone, but the mantle then shallows, and it is not unusual to find outcrops some distance from the hill-plain junction. Downslope the mantle, with thick calcrete and some dune sand as a veneer, thickens again so that in valley floors the depth to fresh granite is of the order of 30-40 m. These variations result from the scarp foot zone being a wet site and therefore more deeply weathered than the pediment proper (Twidale, 1962, 1967a). The increased volume of wash downslope causes a concomitant increase in erosion and thinning of the regolith from the head toward the mid point of the pediment. However, such erosion does not extend to the toe of the pediment where control exerted by a stable or rising baselevel leads either to decreased incision and greater lateral planation or to deposition of detritus (see Gilbert, 1877; Johnson, 1932).

As noted also in the intermontane areas of the Flinders Ranges, pediment mantles are only thin. On Eyre Peninsula, the intermittent rains are evidently more effective in scouring and washing the surface soil than they are in altering the bedrock; erosion has outpaced weathering, and the slightly weathered bedrock is never far beneath the pediment surface.

Alternatively, the shallow soils and mantles may be attributed to anthropogenic disturbance of vegetation combined with climatic extremes or accidents — torrential rains and droughts. The granite outcrops offer possibilities of water conservation (Twidale and Smith, 1971), and better soils are developed on the pediments than elsewhere. For these reasons, settlement and agriculture on northern Eyre Peninsula have concentrated on these sites. Thus, the pediments may have been stripped of much of their mantle, and the thin contemporary cover may thus be a consequence of very recent erosion. A lowering of the pediment is implied, particularly at the scarp foot and pediment head, where agricultural activity has been most concentrated and of longest duration. Hence the scarp foot depressions exposed at Mt Wudinna, Wattle Grove, Yarwondutta and Pildappa rocks (compare Clayton, 1956), and the low flared basal scarp developed on some of the residuals (Twidale and Bourne, 1976a and b).

Relic pediments

Few remnants of older pediments occur on northern Eyre Peninsula. The flattish topped whalebacks like Pildappa Rock and the Dinosaur are older platforms or covered pediments now stripped of their grus cover and brought into relief by the erosion of the surrounding masses of weathered rock (pl. 7-B; fig. 13). No remnants of covered pediments survive, because the granite does not weather to a coarse debris, only to sand, but several generations of relic rock pediments have been recognized. Evidence for the subsurface origin of these forms is found in excavations in which it is seen that incipient flared slopes are developing in the subsurface, beneath the regolith, and as part of the weathering front in the scarp foot zone (Twidale, 1962, 1971, p. 90-96). These steep sections of the front flatten out at shallow depths to form gently inclined potential platforms (Twidale, 1978b).

Flared slopes and platforms are not, however, restricted to the present piedmont. They occur in horizontal and subhorizontal zones at various elevations on the granite residuals of northern Eyre Peninsula.

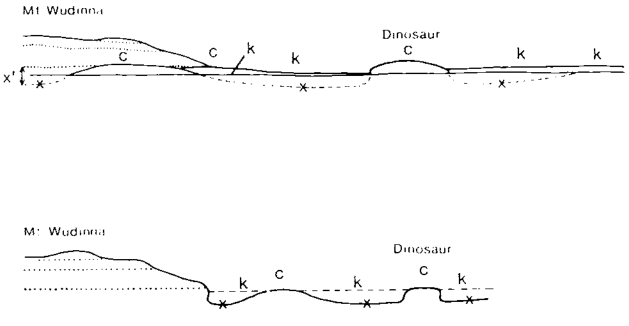


Fig. 13. (A) Explanatory sketch of plate 8, showing relationship of Mt Wudinna and Dinosaur with various levels of weathering and erosion. (B) Cross section through Mt Wudinna and the Dinosaur.

Key: c — low granite residuals, platforms standing above Koongawa Surface (Plio–Pleistocene) — k. x — Wudinna Surface — late Quaternary. Dotted lines represent various former piedmont zones located on Mt Wudinna.

PLATE 8

Later erosion has however worn away the weathered granite from the bases of both the Dinosaur and Mt Wudinna, exposing the steep and flared bounding scarps. See also figure 13.

Interpreted as former piedmont zones, they developed when relatively stable conditions permitted fairly deep and intense scarp foot weathering and indicate episodic exposure of the various inselbergs (Twidale and Bourne, 1975).

Correlation with paleosurfaces has allowed a tentative dating of these levels preserved on the most resistant granite compartments. The inselbergs are structural features (*Hartlinge*) coincident with the occurence of masses or compartments of rock that are resistant because of the virtual absence of open joints: the masses are essentially monolithic (Twidale, 1964, 1971, p. 50 and following, 1976a, p. 42 and following.). The high residuals are topographic forms of considerable antiquity, for though immune to weathering and erosion the granite residuals are being reduced only very slowly (compare Bain, 1923; Wahrhaftig, 1965).

Their stepped form and "multicyclic" or multiphase character precludes their being *Fernlinge* or residuals that have not been reached by erosion, for if they were structurally similar to the rest of the mass they would have been weathered to the same degree. They would not have survived through two cycles: they would have been baselevelled during the early part of the N + 1 cycle or phase, despite possible diminution of erosion in headwater regions.

The areas between the granite residuals have been eroded by streams working in weathered granite. They have either been lowered with the successive plain surfaces developing in subhorizontal parallelism to one another, or there has been etching out of the scarp foot zone and gradual exposure of the inselbergs accompanied by a decline in the pediment slopes. The granite weathers to a grit or sand, so that little coarse debris is produced. For this reason remnants of covered pediments have not been preserved, and it is not possible to deduce the cause of pediment development from sedimentological data as it is at Brachina and in the Tent Hill region.

However, weathering is not only destructive. In some circumstances weathering results in the formation of duricrusts. If this had happened in the granite areas of Eyre Peninsula, the duricrusts would arguably have formed caprocks, and scarp retreat would have taken place, as it has in the Tent Hill region. There is no theoretical reason why duricrusts cannot form on granite; silcrete is developed on such material in the north of South Australia, and laterite widely on granite in Western Australia. But on Eyre Peninsula these two, older, duricrusts are preserved only on non-granitic rocks. There are small patches of very thin ferricrete (ferruginous capping lacking the profile development of true laterites) developed on granite and gneiss in the northeast of the Peninsula (Twidale, Bourne, and Smith, 1976). Calcrete of later Pleistocene age is widely represented, but it does not give rise to escarpments; it blankets the rolling plains, which are thus stabilized.

The older duricrusts, if they ever developed on granite on Eyre Peninsula, were probably only thin and so were rapidly undermined and eliminated by rejuvenated stream systems. General considerations of slope behavior argue against retreat being dominant in areas of crystalline rocks. Ruxton and Berry (1957) and many others have shown weathering is most intense in the near surface zones, so that unless thick duricrusts have developed and persisted — and none has — the duricrusts survive on nongranitic rocks in areas adjacent to that discussed here — there are no caprocks to hold up and maintain steep slopes. Thus slope decline is inherently likely (Tricart, 1957; Twidale, 1960), and, although as at Brachina there may have been some local and ephemeral scarp retreat in response to caprock protection, on Eyre Peninsula the overall tendency has probably been for the weathered granite to have been stripped away and for the plain to be lowered.

Summary

The foregoing suggests that the landform assemblages of Eyre Peninsula are best interpreted as resulting from the episodic or phased lowering of the weathered land surface with the structurally determined more resistant compartments being gradually brought into relief as they intersect the land surface.

It is true that as lowering of the plains has proceeded resistant masses of granite have either been exposed or those already existing as topographic features have been placed further in relief. However, the evidence of duricrusted paleosurfaces of low relief and the development of platforms on compartments of intrinsically fresh granite surely argue for pauses in the process of planation and not a continuous baselevelling (Twidale and Bourne, 1975; Twidale, Bourne, and Smith, 1976).

DISCUSSION AND CONCLUSION

Pediment development and slope behavior

The development of pediments evidently varies from region to region. Generally speaking, slope decline has been dominant in the Flinders Ranges, though in caprock situations retreat has been locally significant. In the Tent Hill region with caprock structure, scarp retreat has been prevalent. Even here, however, the piedmont zone has been etched out, and older pediment remnants are more steeply inclined than those grading to modern stream channels. In the crystalline areas of northern Eyre Peninsula the evidence is equivocal, though general argument favors development through the lowering of the plains and the etching out of the scarp foot zones around inselbergs and other granite residuals.

Faceted slopes develop on well jointed granite, but generally the rock is intensely weathered near the surface and becomes less altered with depth (Ruxton and Berry, 1957). Thus when baselevel is lowered the rivers wear away the upper layers of weathered friable rock for there is no resistant caprock that might induce the development of and maintain steep slopes or protect the upper surface (Tricart, 1957;

Twidale, 1960). This new lower surface of low relief is eroded down to the weathering front or to baselevel, whichever is the higher.

Erosion of the plains exposes compartments of more massive, resistant granite, though as jointing varies vertically as well as laterally these need not persist in depth (Brajnikov, 1954; Twidale, 1971, fig. 18b). In these terms, the weaker compartments are stripped away in several stages or phases of erosion separated by periods of relative still-stand, when scarp foot weathering and local steepening of the margins of the inselbergs take place.

Thus though overall trends can be defined, none of the landscapes investigated has evolved exclusively by decline or recession of slopes — where decline has predominated, situations where retreat probably occurred can be identified and vice versa.

Pediments as fluvial forms

Whatever the overall mode of landscape evolution, pediment development in all areas has been achieved and still involves erosion and deposition by running water. The pediments are the *Spülpedimente* of German workers (but see Mensching, 1958) and the *glacis d'épandage* of French investigators (see Tricart and Cailleux, 1957, p. 23 and following). The only exceptions are the rock pediments developed and preserved on granite residuals.

The field evidence shows that various forms of diffuse or distributary flow are responsible for shaping pediments and for depositing their mantles, but the character of the flow varies from location to location. Thus the high volume — if spasmodic — rivers debouching from extensive uplands on to the plains deposit coarse debris and simultaneously erode smooth conical pediments that are protected and preserved by the bed load of the divaricating streams. It is this debris mantle that endows the cut bedrock surfaces with their characteristic smoothness.

The rills, wash, and minor streams spawned by lesser residuals such as mesas or bornhardts carry only comparatively fine debris but nevertheless erode pediments. However, the deposition of coarse debris by streams, falls of coarse rock, cementation of debris by silica, and emerging masses of fresh cohesive rock have all caused remnants of older pediments to be preserved.

Structural control

Pediments are essentially confined to outcrops of weaker rock: siltstone and other argillaceous strata in the Flinders Ranges, shale in the Tent Hill region, slightly weathered granite on Eyre Peninsula. The planate forms do not extend on the resistant rocks. Where platforms have developed on intrinsically fresh granite (on Eyre Peninsula) or on sandstone (in the Flinders Ranges — see Twidale, 1977a and b; Twidale and Bourne, 1976b) the surfaces are demonstrably of etch character.

Structural considerations preclude any possibility of elevationally separate surfaces distinguished in any one area being merely expressions of rock resistance, and any suggestion that all the different pediments are equilibrium forms evolving simultaneously can also be ruled out. At Brachina for example, the pediments are eroded in the same folded sedimentary sequence yet stand at different elevations. There is no evidence that different processes are responsible for the various pediments; on the contrary the nature of the mantles point to all the pediments in this area, whether active or abandoned, having formed in the same way. In the Tent Hill region the various pediments cut across the same sequences of near-horizontally disposed sediments. Again there is no structural control, but on the crystalline areas of Eyre Peninsula, it is the massive compartments that survive weathering and erosion as do remnants of rock pediments. Moreover, the probable weakening of rocks by weathering in the intervening compartments surely suggests that lowering has prevailed there rather than scarp retreat.

Models of development

The pediments described have not evolved cyclically. The landscape has never returned to the state of widespread planation that had been achieved in this region by the late Cretaceous. On the contrary the relief amplitude has probably increased as the valleys and plains and particularly the piedmont zones have been etched out (Twidale, 1966, 1976b; Twidale and Bourne, 1975; Twidale, Bourne and Smith, 1974).

The older pediments are preserved largely by virtue of coarse mantle deposits and at some sites by silcrete. The development of such protective veneers introduces a discontinuous element, a stable aspect, into an otherwise continuous and continuing erosional cycle (see Twidale, 1972, p. 68-70). The major streams are clearly capable of incising their beds through even the thickest mantles, but other processes of sculpture, particularly those on the divides, are relatively ineffective (Crickmay, 1932, 1968; Twidale, 1976b).

Definition of pediment

What then is a pediment?—In the Flinders Ranges the piedmont zones are weathered and deeply etched, so that the smooth valley floors or pediments meet the adjacent uplands in a sharp piedmont angle or nick (Twidale, 1967a). Likewise in the Tent Hill region the hill-plain junctions are abrupt, and the valley floors are made smooth and are protected by mantles of coarse debris. But the angular junction is no more abrupt there than it is at the base of the Chalk scarps in southeastern England or at the foot of sandstone escarpments in the Appalachians. Many of the valley floors are smoother and less dissected than are their equivalents in the temperate regions cited and so are called pediments, but this difference is in large measure attributable to the blanketing and protection afforded by the coarse mantles. Climate and river regime are only partly responsible, for in flood the Flinders streams run as high and are more devastating than are those of the temperate areas mentioned.

On Eyre Peninsula, fringing pediments related to contemporary baselevel meet inselbergs and other residuals in well-defined piedmont angles. The distinctive smooth and unbroken pediment fringes merge with convex-crested rises separated by shallow broad valleys which together form the broadly rolling landscape typical of so much of the region, and which from a morphological point of view surely constitutes an authentic example of a Davisian peneplain (see Davis, 1909, especially p. 350-380). The relic dunes are anomalous, as are the inselbergs, but the former are expressions of climate and climatic change, and the latter are manifestations of structure. The rolling plain is a fine example of a peneplain eroded in weathered granite. The slightly less weathered, but still not fresh, rock has been shaped into pediments, which form inclined aprons or fringes around the compartments of intrinsically fresh rock which stand above the plains as bornhardts and other inselbergs.

The difficulty is that where inselbergs or other residuals have been eliminated (or have not yet emerged — Twidale, 1971, p. 57; Twidale and Bourne, 1975), the pediment slopes are indistinguishable from the valley side slopes of a peneplain. Geomorphologists appear to have painted themselves into a semantic corner. The only criterion whereby to differentiate pediment from peneplain is surely the piedmont angle, which is basically a structural form though it is probably better and more widely developed and preserved in arid and semiarid lands than elsewhere (Twidale, 1967a). However, where upland residuals have been eliminated there can be no piedmont angle, so that the crucial characteristic is lost. It follows that the only planate forms that can be identified as pediments are fringing pediments. The pediplain, resulting from the coalescence of many pediments, seems indistinguishable from the peneplain, so that again, unless there are residuals surviving and the pediplain comprizes numerous and extensive fringing pediments, the term ought not be used.

This reality ought to be recognized. The term pediment ought to be restricted to smooth gently sloping bedrock remnants fronting uplands. Extensive surfaces of low relief might then be called *peneplains,* which has both the advantages and disadvantages of long usage, or *old-lands* (Hills, 1955; Öpik, 1961, p. 30-31), either term to be used merely to denote surfaces of low relief resulting from long continued fluvial erosion, but without implication or prejudice as to mode of development.

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