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# Notes on the origin and significance of stone layers

# Notas sobre el origen y significado de las líneas de piedras

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## Abstract

Stone layers are stratiform and consist of thin beds or attenuated lenses of angular clasts. Some are due to wash associated with heavy rain followed by concentration of coarse debris by the winnowing of fines by wash and wind. Others are due to soil-churning hydrophilic clays. The first type reflects the widespread occurrence of 'storm' rains, the second, alternations of wet and dry periods in suitable substrate environments.

**Key words:** stoneline; stone layer; rainwash; winnowing; hydrophilic clay; climatic significance

**Key words:** No-tillage, conventional tillage, cover crops, organic manure, hydraulic conductivity, penetration resistance

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## TERMINOLOGY

Stone layers have been called 'stone lines' (SHARPE, 1938; STOCKING, 1978) presumably because in section they appear to be two-dimensional. The term 'stone line' can imply an elongate, relatively thin feature of limited lateral extent, a string or ribbon of stones, whereas closely spaced incisions indicate that the features referred to are sheets, fans, lobes or attenuated lenses: these 'lines' have an areal dimension. Stone *layers* have width as well as length and depth, and though the concentration of stones varies spatially, stone layers are essentially stratiform.

A stone layer is a bed comprising discretely distributed stones, usually angular, extending over a considerable area but of limited thickness, commonly being no more than a metre from top to base, and frequently much less. Contemporary surface occurrences of stone layers extend over several scores, or even hundreds, of square metres, and stony desert or gibber plains are of regional extent. In some layers the stones are scattered but elsewhere are closely spaced, forming a veritable carpet. Those located at the surface indicate various possible origins for stone layers, but also suggest that though SHARPE's original definition has much to recommend it, certain amendments would be in keeping with reality.

## PROBLEMS AND CRITIQUE

Stone layers can be classified according to whether they are autochthonous or allochthonous, whether they involve external agencies and were subsequently buried, or are due to processes active within the regolith (e.g. HEINZELIN, 1955; BREMER and SPATH, 1989). Little wonder that their formation is controversial. Some explanations involve the local translation of coarse debris (e.g. FAIRBRIDGE and FINKL, 1984). Others emphasise basically *in situ* development with vertical movement dominant within profiles, or with the formation of concretions at water tables or other discontinuities (e.g. TEEUW, 1989). *In situ* precipitates such as calcrete and ferruginous pisoliths are excluded first because many nodules are rounded rather than angular, and continued accumulation of calcrete, for instance, leads to the formation of a hardpan (e.g. NETTERBERG, 1969, 1971; NETTERBERG and CAIGER, 1983) which is either massive or consists of nodules ('golf balls) cemented together (figure 1a). In places travertine also forms a resistant stratum (figure 1b). Similarly the accumulation of ferruginous pisoliths can lead to the development of a distinct massive, if vesicular, horizon within the regolith, giving rise to the familiar laterite-capped plateaux.

Bioturbation is favoured by some workers. For instance, BREMER and SPATH (1989) considered the stone layers they investigated in various tropical lands to be *in situ* developments involving vertical movements due to soil fauna. On the other hand, McFARLANE and POLLARD (1989) emphasise the inputs from quartz veins or stringers and chemical reactions within the profile.

The mechanism, process or driving force invoked as responsible for the concentration of coarse materials in layers or horizons varies within both allochthonous and autochthonous explanations. KERR (1881) attributed stone layers to the settling of coarse debris to the base of a heterogeneous mass by 'frost action', but later work (e.g. TABER, 1928; WASHBURN, 1956) shows that the converse occurs - coarse debris tends to be lifted to the surface, there to form various well-known patterns.

SHARPE (1938, p. 24-25) considered that coarse fragments are shed from outcrops and are drawn downslope at the base of a regolith moving downslope by what has been termed 'soil creep.' PARIZEK and WOODRUFF (1956) questioned the reality of soil creep as a mechanism for particulate motion down slopes; and for good reason, for no convincing explanation has been offered for the process. Bearing in mind the difficulties of particulate

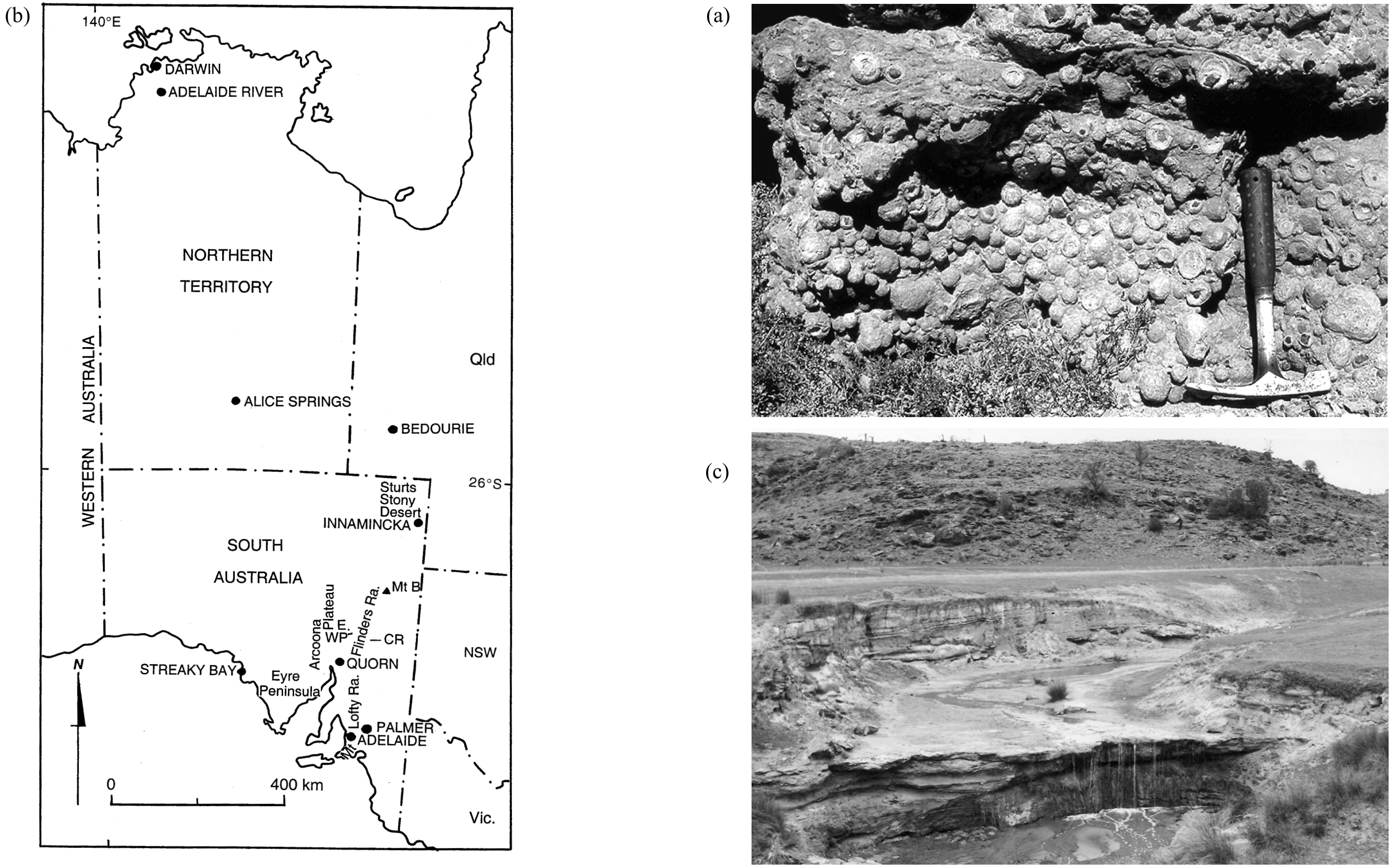

Figure 1 (a) Hardpan calcrete composed of nodules or 'golf balls' and exposed in cliff at Smooth Pool, near Streaky Bay, west coast of Eyre Peninsula, South Australia. See also (b) Map of part of Australia showing locations mentioned in the text and, in particular in the Flinders Ranges, South Australia: CR - Chace Range, E - Edeowie H.S. (homestead), Mt B - Mt Babbage, WP - Wilpena Pound. (c) Waterfall formed by attenuated lens of travertine, Gorge Creek, south of Palmer, eastern Mt Lofty Ranges, South Australia.

debris moving over what are in detail rough surfaces, wash and slippage are more likely explanations of the undoubted downslope transfer of material. Nevertheless, given downslope movement of coarse debris under gravity, migration to the base of such a mobile mass can readily be understood in terms of gravitational sorting (see also IRELAND et al., 1939; EARGLE, 1940; DE DAPPER, 1989).

Later, however, PARIZEK and WOODRUFF (1957) attributed stone layers (or what they called *carpedoliths*) to sheet wash and colluvial, presumably gravitational, movement. They related stone layers to Late Cainozoic climatic changes from phases favourable to what they termed 'aggravated' erosion, to ones conducive to deposition. They evidently did not appreciate that erosion and deposition are faces of the same coin: if there is erosion in one area there must be deposition downslope.

The linking of stone layers to climate received wide support, for many workers have interpreted stone layers as evidence of climatic change. Interpretations vary however. They have been related to cold phases (e.g. in southern Africa - see e.g. RUHE, 1959; ALEXANDRE, 1962; LINTON, 1969), to arid conditions (e.g. in Brazil - e.g. JOURNAUX, 1975; TRICART, 1956, 1985) and to pluvial phases in Africa (TRICART, 1956). Some wish to use stone layers as stratigraphic markers (e.g. FAIRBRIDGE and FINKL, 1984).

In summary, key questions to emerge from studies of stone layers are: whether they originate at the surface or within, or at the base of the soil or regolithic cover; whether they are autochthonous or allochthonous; whether they have climatic connotations and if so what? The thrust of this short note is that stone layers formed and still forming at the present land surface provide significant evidence as to the origin of analogous subsurface features, that such layers have developed in various ways, and that none of the mechanisms is limited to any one climatic regime. Evidence is cited from sites typical of many others found in various parts of Australia.

## EVIDENCE AND INTERPRETATION

At one time quartz residues were interpreted as signs of palaeosurfaces, for they were thought to represent the most durable of the common rock-forming minerals.

### Allochthonous surface stone carpets

Some stone carpets are evidently forming under present conditions. For instance, near Adelaide River township, in the Northern Territory, located in latitude 12°50'S and at an altitude of about 70 m above sea level (figure 2), angular fragments of vein quartz have spread down a slope 10°-15° inclination eroded in a fine-grained micaceous sandstone, to form a carpet of angular gravel. The climate is monsoonal and rainfall averages some 1080 mm.

Figure 2 Gravel-clad slope, Adelaide River, Northern Territory.

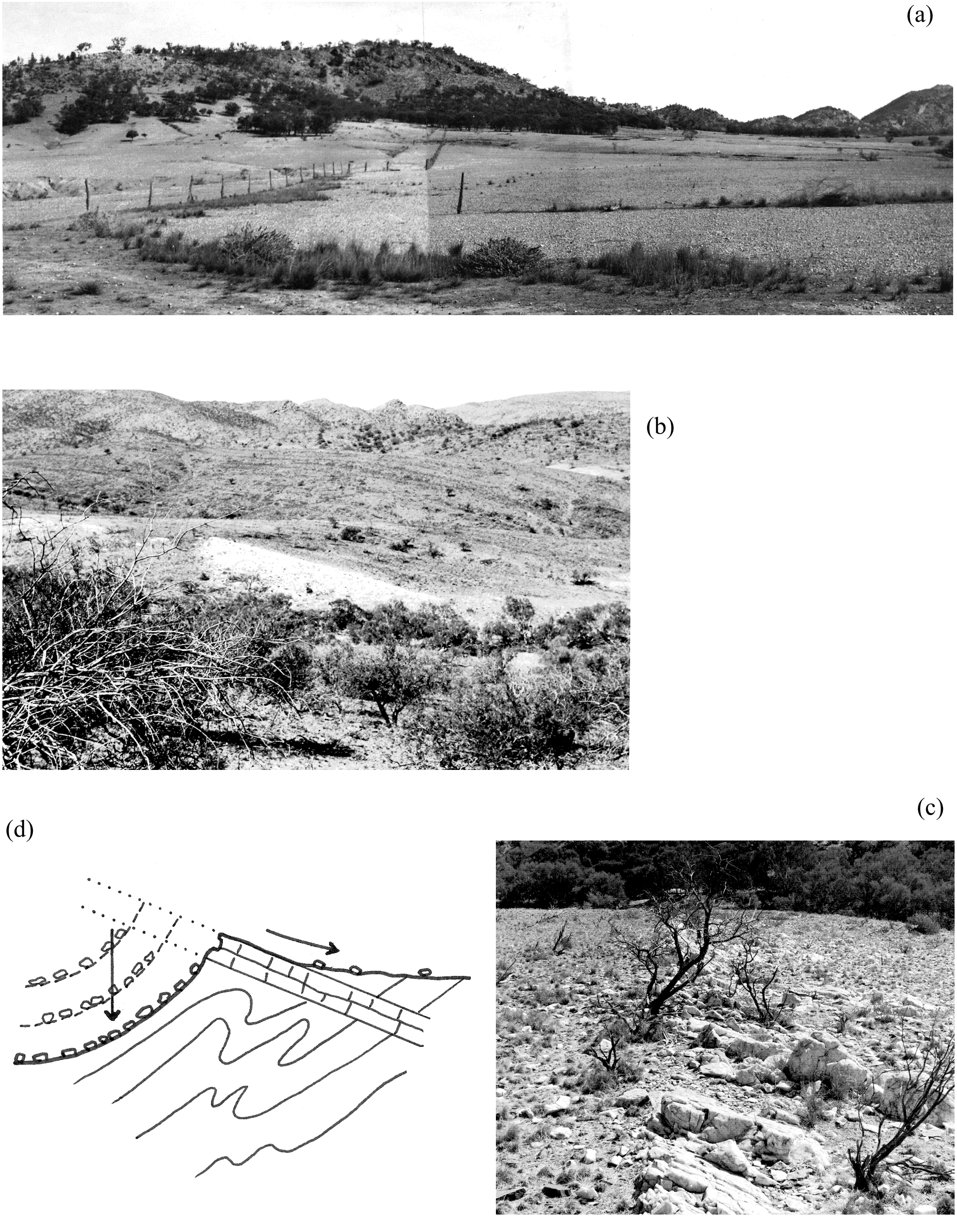

Figure 3. (a) Pediment with gravel veneer, Chace Range, central Flinders Ranges, South Australia. (b) Distant view of quartz vein exposed near Mt Babbage, northern Flinders Ranges. (c) Close view showing dip of vein. (d) Explanatory sketch.

In the piedmont of the Chace Range (latitude 31º40'S, elevation ca 500 m above sea level), in the central Flinders Ranges, South Australia, quartzite exposed in the backing hillslope has shed angular fragments which have spread some tens of metres downslope to form a discontinuous veneer on the upper and middle slopes of the pediment (figure 3a). Their formation can be observed during heavy rains. Fragments are washed from the backing bluff and come to rest on the apex of the pediment or footslope.

Obstacles such as gravel and tufts of grass disturb the sheet flow, creating turbulent eddies. Small rills and rivulets are formed and fines are washed from around and beneath gravel particles. They are undermined and either settle at a slightly lower level with little or no lateral movement or are washed downslope a few centimetres depending on their mass, local slope and volume of runoff. In heavy rains a given particle may be washed several metres downslope once it is in motion. In this way the entire upper and middle slope come to be mantled with gravel. Fines predominate on lower slopes, where coarser fragments are masked.

Near Mt Babbage (latitude 29°50'S, elevation 369 m above sea level) in the northern Flinders Ranges a quartz reef intruding shale and dipping downslope forms a prominent local landmark. Angular blocks mainly of gravel size but including some several centimetres diameter have been shed, mainly, but not entirely, downdip and downslope (figures 3b & 3c). The fragments presumably have been transported by wash during occasional heavy rains whereas those resting on the slope above the reef are lag, deposited when the reef extended further updip (figure 3d).

In the examples cited, the gravel is angular and of local derivation: there is no petrological or morphological evidence of downstream transportation by axial rivers, only of wash down valley-side slopes (footslopes, pediments). Except for some lag components (for instance those related to the Mt Babbage quartz reef) the layers are allochthonous, for the coarse debris has been transported downslope. These occurrences show that stone layers are forming at present and in a range of climatic environments; though in each instance in association with torrential rains, with a 'storm' event (see also FAIRBRIDGE and FINKL, 1984). The carpets contain a mix of coarse and fine fragments, and are only a few centimetres thick. They differ both in thickness and shape (angularity) from the alluvial covers (figure 4a) preserved on the Hayward pediment, north of the Edeowie H.S., in the western piedmont of the Flinders Ranges (TWIDALE, 1979, 1981; BOURNE and TWIDALE, 1998). The latter were deposited by divaricating rivers debouching from the uplands to the east. The scarp-foot areas unaffected by distributary streams, however, are distinguished from the coarse, rounded, partly exotic detritus distributed by debouching rivers by their local origin (the backing limestone scarp), their small calibre and their angularity.

Buried alluvial deposits, such as the interbedded point bar deposits found in fanglomerates pose problems as do accumulations of coarse angular colluvia transported downslope in mass movements (figures 4b & 4c). The former are not precluded from definitions of stone layers for some comprise angular materials. The coarse material is, however, concentrated and most of the lenses are of limited lateral extent. Yet genetically they have much in common with genuine stone layers due to wash.

## Autochthonous carpets: gibber and gilgai

In the Flinders Ranges, valley floors and remnants of valley floors now dissected carry a carapace of more-or-less coarse angular stones, mostly of sandstone or quartzite (figure 5). They are lag deposits, the mass of individual fragments being greater than can be transported by local streams and rivers. Some originated as mass movements from adjacent scarps. Some were carried down scarps by ephemeral streams in flood. Once deposited in the piedmont zone, however, they have remained unmoved, yet have been concentrated as a result of the winnowing of fines by wash and wind.

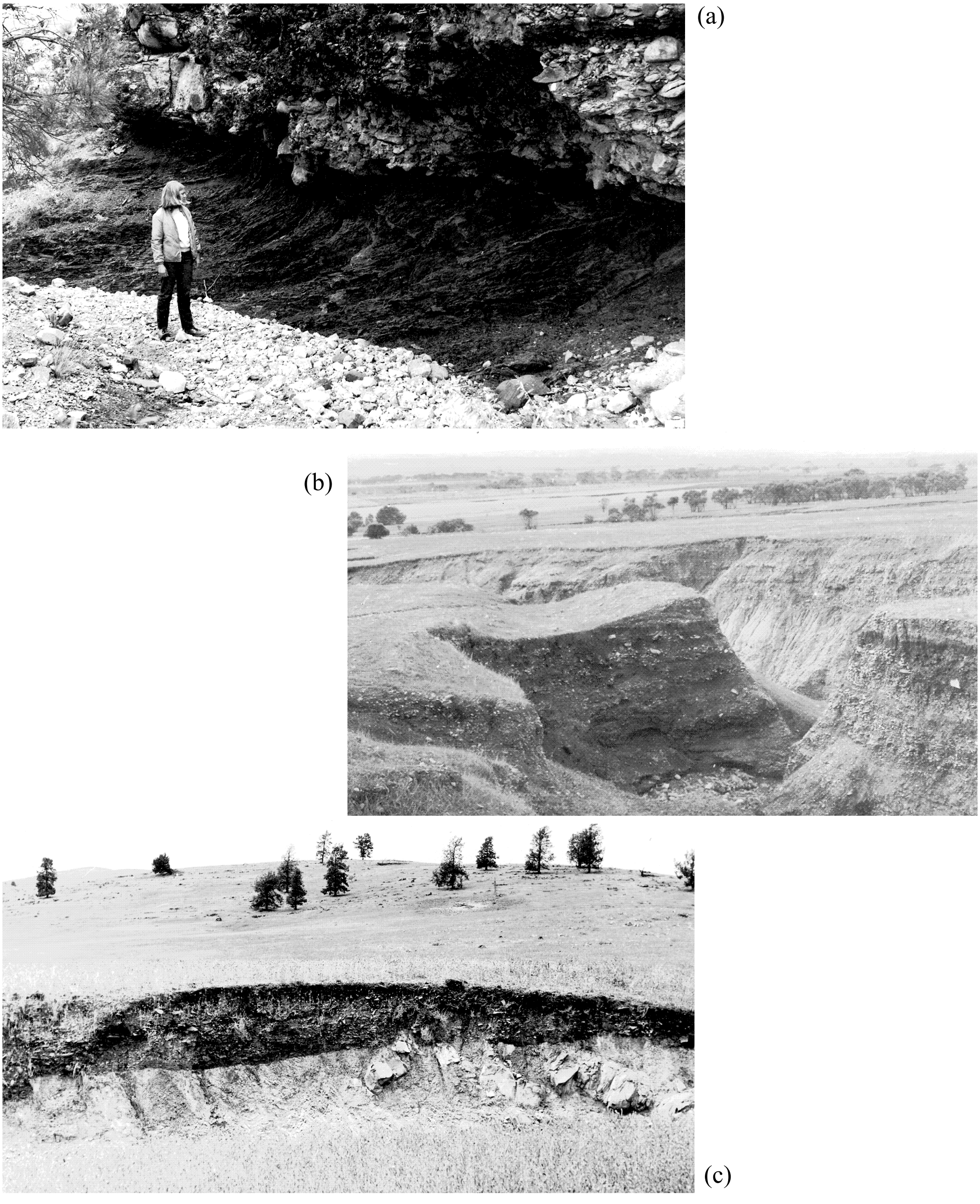

Figure 4. (a) Coarse, rounded Hayward pediment cover, north of the Edeowie H.S. in the western piedmont of Flinders Ranges, South Australia. (b) Point bar lenses exposed in Late Pleistocene fanglomerate, Sellicks Hill, south of Adelaide, South Australia. (c) Colluvium transported downslope on smooth gliding surface, near Upalinna Homestead, north of Wilpena Pound, central Flinders Ranges, South Australia.

Figure 5. Quartzite lag strewn over valley floor within anticlinal structure between the Chace Range and Wilpena Pound, central Flinders Ranges, South Australia.

Similar stone-clad surfaces are well developed in the midlatitude arid zones where the reg, or stony deserts, are so named because they carry a mantle, usually one stone thick, of locally derived, usually angular stones. They are known in Australia as gibbers, and the plains as gibber plains. Sturts Stony Desert is such a region (TWIDALE and BOURNE, 2002). They are due in part to the undermining of capped plateaux or high plains (figure 6a), the recession of the scarps and the deposition of the coarse fraction of the caprock as a lag deposit (TWIDALE and MILNES, 1983; TWIDALE and BOURNE, 2002). The coarse fraction of this mantle is concentrated as a result of the evacuation of fines by wash and wind; though the more concentrated the stone veneer becomes, the more protected is the surface against surficial attack (PANDASTICO and ASHAYE, 1956).

Winnowing is a significant factor causing the concentration of coarse debris on gibber plains, but other factors are at least as important. Channel and road cuttings reveal that the gibber is one stone thick (figure 6b). It is rare to find a gibber in the subsoil, except in resorted alluvial deposits within the stony desert. The reason is that in some areas the gibbers are concentrated by soil churning and sorting consequent on wetting and drying, and the absorption and shedding of moisture, in hydrophilic clays such as smectite (H.N. ENGLAND *in* PRESCOTT, 1931; HOWARD, 1939). Sorting occurs because when wet, the swelling clays thrust particles of all sizes upwards, the only direction of pressure relief. But on drying and cracking, only the fines fall down the fissures, leaving coarse debris at the surface. Such churning produces minor swells and depressions, frequently forming rings or garlands in plan, though they are elongate on slopes. Such patterns are known by various regional names (e.g. 'Bay of Biscay' soils in South Australia because of the bumpy ride such soils impose, 'crab holes' in Victoria) but more generally as gilgai. The stones are locally derived. For instance, Sturts Stony Desert is carpeted with fragments of silcrete, but veneers of quartzite and limestone occur adjacent to outcrops of those rock types. Most of the fragments are angular though some patches of surrounded gravel, possibly derived from the wash of ephemeral streams, can be found (figures 6c & 6d).

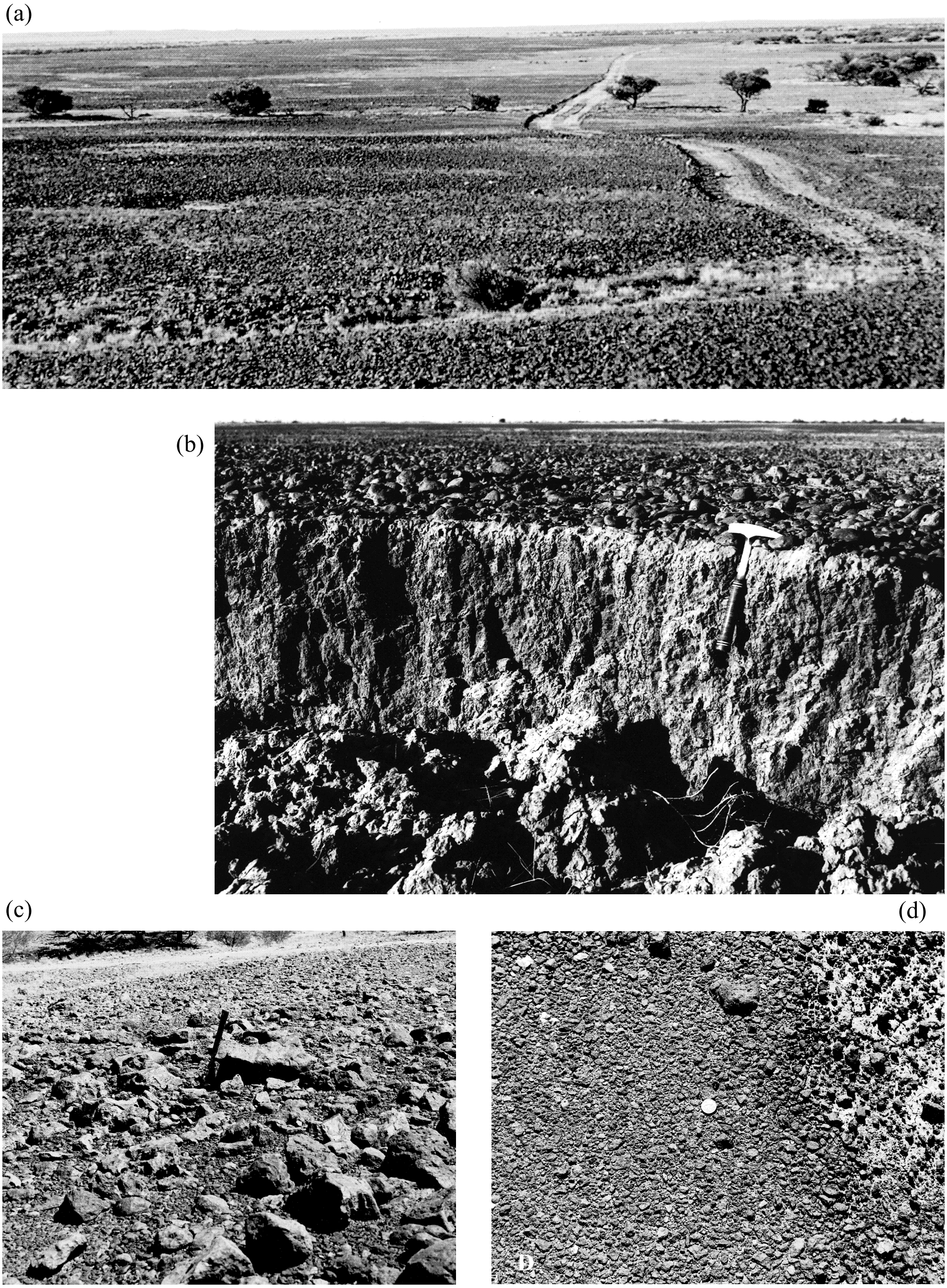

Figure 6. (a) Silcrete gibber, near Bedourie, southwest Queensland. (b) Road-side exposure showing gibber one-stone-thick north of Innamincka, northeastern South Australia. (c) Angular silcrete gibber near Innamincka, South Australia. (d) Subrounded silcrete gibber, near Innamincka, South Australia.

The development of gilgai is favoured by seasonal or episodic rainfall, and the occurrrence of such clays as smectite, at least 60 cm thick (HUBBLE et al., 1983). They are found in a wide range of climatic conditions (HALLSWORTH et al., 1955): the only essential is contrasted wet and dry periods, whether these be seasonal or episodic. They have their congeners in nival lands where the driving force is not wetting and drying but freezing and thawing (WASHBURN, 1956). Stone carpets also are produced in periglacial environments by the wind winnowing fines, and ventifacts shaped by sand and ice crystals are reported from such cold desert regs (e.g. BOYE, 1950; DERRUAU, 1956; KING, 1956; NICHOLS, 1969).

The gilgai mechanism produces stone layers which involve either transported or lag detritus which has, however, been concentrated at the surface *in situ* partly by churning and partly by winnowing. Soil movements resulting in cracked walls and disturbed fence posts indicate that the mechanism is active at present. Large diameter wooden fence posts are said to be disturbed within a few weeks given alternations of wet and dry weather. Such rapidity of action could account for the completeness of sorting implied by the scarcity or absence of coarse detritus.

On slopes such soil churning may have not only concentrated gravel at the surface but also triggered its downslope migration. In the Arcoona Plateau in the arid interior of South Australia, for example, pediments carry a carpet of angular quartzite lag, some of which has migrated downslope, for distinct lobes and tongues can be distinguished (figures 7a & 7b). As in the piedmont of the Chace Range (*q.v.*) some has been transported a short distance downslope but some is essentially *in situ*, for it is lag from flat-lying strata long since undermined and collapsed (figure 7c).

Thus, in summary, what can be construed as stone layers are forming at present in arid, semiarid, and monsoon climates under the influence of torrential rains, winnowing by water and wind, and churning by hydrophilic clays.

## SUBSURFACE STONE LAYERS

Excavations have revealed regolithic veneers in which one or more stone layers are exposed. At some sites subsurface stone layers appear to be in situ but buried. Multiple layers of angular quartzite fragments interbedded with fine-grained colluvium are exposed in an old railway cutting in the Pichi Richi Pass, southwest of Quorn, in the southern Flinders Ranges (latitude 32º26'S, elevation 290 m above sea level; figure 8a). Their formation can plausibly be attributed to slope wash. Quartzite crops out on the crest of the slope, and this is the source of the coarse detritus. The fines are derived from the weathering of the argillites on the middle slope. The section is interpreted as recording long periods of downslope movement, under wash and gravity, of fines interrupted by at least two (the section provided a view of only part of the colluvial apron) storm episodes with heavy rains and runoff. Coarse debris was transported downslope to form a stone layer during these rainstorms. The fines were washed downslope during the longer intervals between storms. Whether the depositional debris slope is of a similar constitution along its entire length is not known; the coarse deposits could well be in the form of lenses or lobes. Comparison with modern faceted slopes subject to recession suggests that undermining and failure of bluffs, the source of bedrock fragments is irregular and uneven (figure 8b).

Burial is natural, partly through wash, partly as a result of heavy runoff generated by torrential rains (see also PARIZEK and WOODRUFF, 1957). However, runoff may be enhanced by human activities such as vegetation clearance. Yet though the exposure is explicable, the Pichi Richi section gives cause for concern. For without the railway excavation the slope would have seemed a standard faceted slope with debris slope consisting of a veneer of detritus overlying bedrock, below a quartzite bluff. How many other faceted slopes that appear simple in reality have a relatively complex history?

Other subsurface lines may similarly be buried, but others may be due to the gravitation of coarse clasts to the base of a mobile colluvial regolith, in the manner suggested by SHARPE (1938).

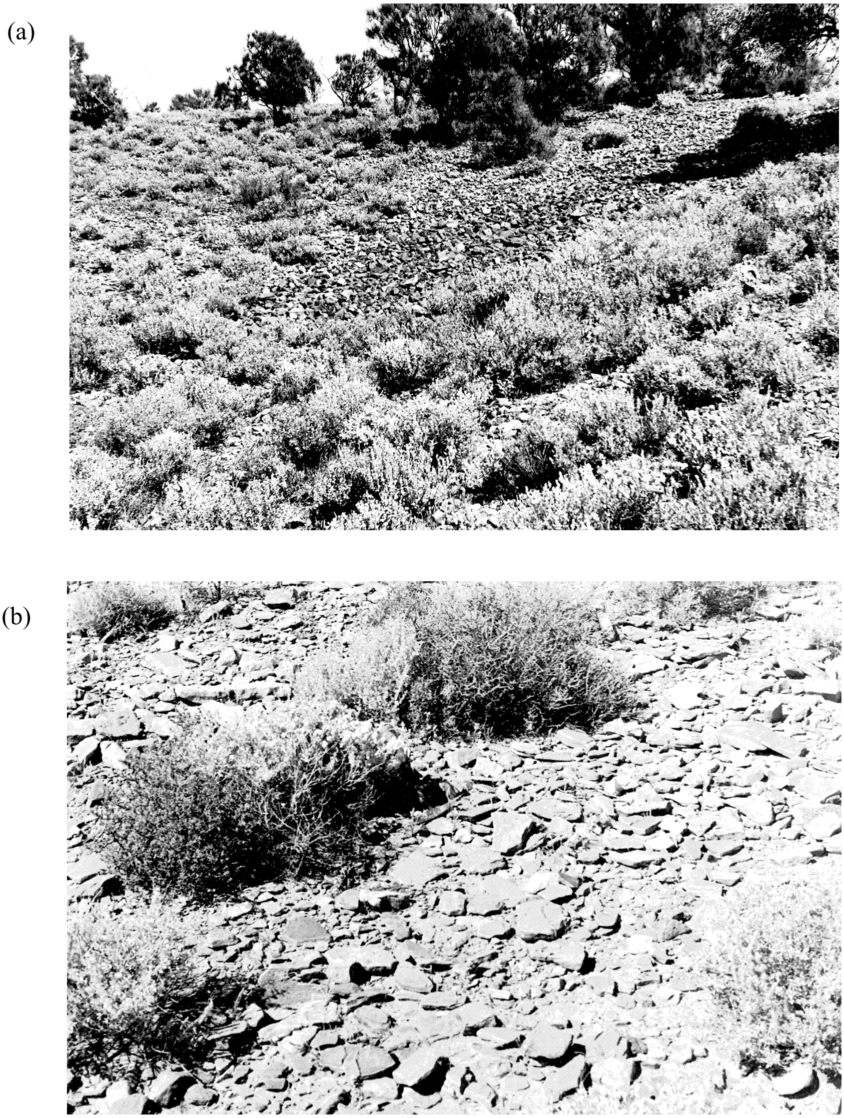

Figure 7. (a) Lobe of quartzitic stones, Beda valley, southern Arcoona Plateau, South Australia. (b) Lag deposit, Beda valley.

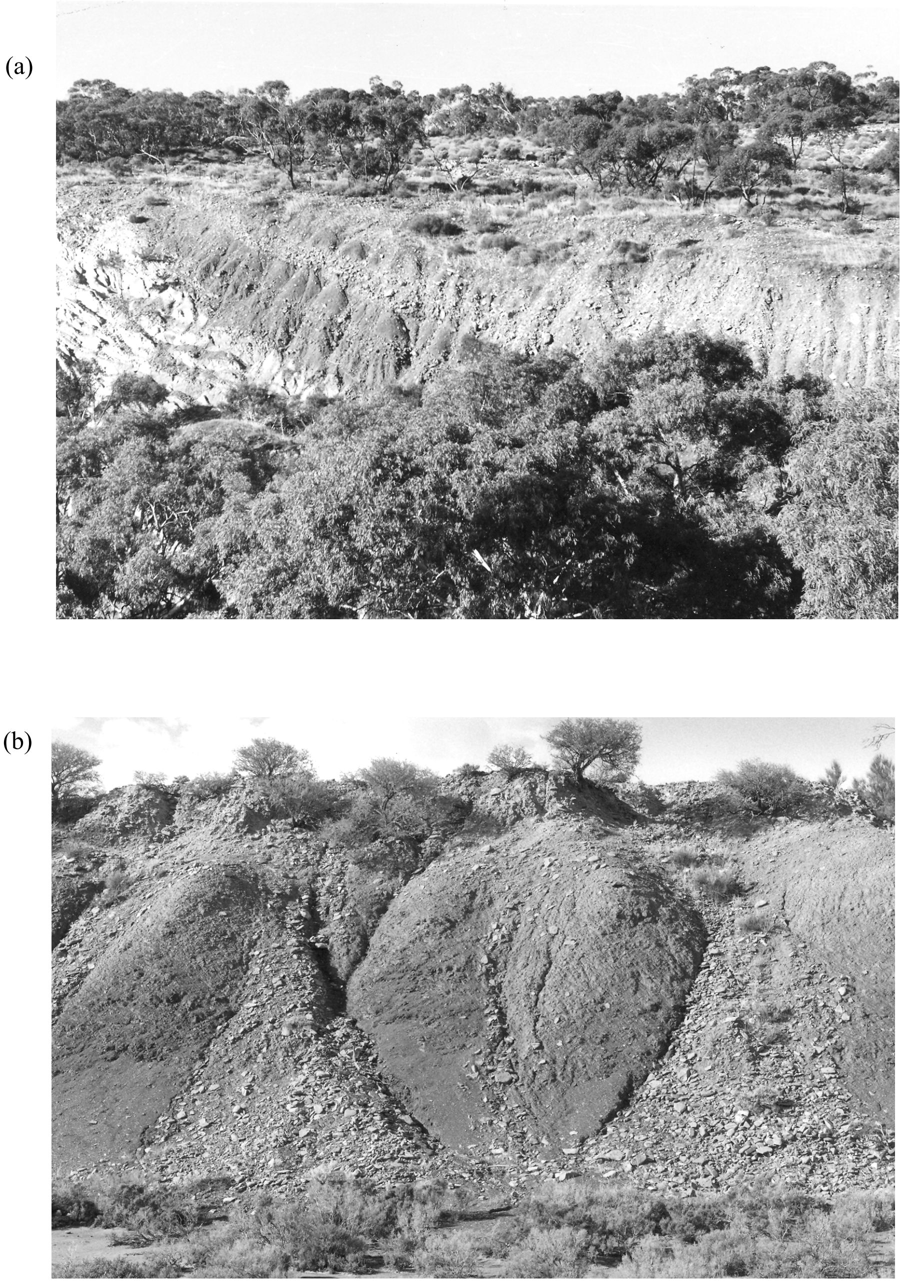

Figure 8. (a) Colluvial deposit with coarse and fine horizons exposed in railway cutting, Pichi Richi Pass, southwest of Quorn, southern Flinders Ranges. (b) Tongue of gravel flowing down gully (gully gravure mechanism; see BRYAN, 1940; TWIDALE and CAMPBELL, 1986) Swallow Cliffs, southern Arcoona Plateau, South Australia.

## CONCLUSIONS

Stone layers are attenuated beds or lenses of coarse debris. They undoubtedly form in cold environments where ground ice mobilises clasts, but in the midlatitude and tropical lowlands frost and ice are not significant. Rainstorms are experienced in a wide range of climatic conditions, and their impact may be enhanced by such human activities as vegetation depletion. Most buried occurrences are of this origin. They are due not to *in situ* chemical precipitation within the regolith. They are of a clastic origin and the word 'clastic' surely has a place in any definition of stone layers: thus, paraphrasing SHARPE's original definition of a stone-line, the features under review are, as several authors overtly acknowledge, *layers* "of angular to subangular clastic fragments which parallel a sloping surface at a depth of several feet" (SHARPE, 1938, p. 24). This separates them from the stone-lines and garlands of nival areas (e.g. WASHBURN, 1956), and the narrow strings and tongues of coarse debris developed on steep slopes during gully gravure (BRYAN, 1940; TWIDALE and CAMPBELL, 1986; figure 8b). This definition also precludes dense accumulations of rounded stones whether alluvial or marine. *In situ* chemical precipitates related to fluctuations of the water table are also excluded (figures 1a & 1c).

The stone layers investigated can be classified as due to torrential rains generated in occasional storms which are characteristic of most conventionally defined climates. The 'colluvial processes' of some authors involve mass movements induced by churning and also wash, which are not peculiar to hillslopes. Alternatively, they may be residual or lag deposits, the concentration of which is due partly to winnowing by water and wind, partly to soil churning - the gilgai effect.

Such local but nevertheless allochthonous deposits are a function of weather rather than climate. Winnowing of fines and concentration of coarse stones by wind and water play a part in their development, and soil churning is significant for the *in situ* formation of stone layers on exposures of hydrophilic clays in areas with alternations or wet and dry weather. Gilgai-based stone layers can be regarded as autochthonous and are found in a considerable range of climates from the hyperarid areas of central Australia to Mediterranean semiarid southern areas and monsoonal northern Australia (see map *in* HUBBLE et al., 1983, p. 29 - which presents a conservative picture of gilgai distribution in Australia). Soil composition (heterogeneity, type of clay) and thickness, plus alternations of wet and dry conditions, determine the associated formation of stone layers.

Whether concerning clastic deposits due to wash or of lag type, interpretations of old stone layers in terms of climatic change are likely to be tenuous.

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