STURTS STONY DESERT, CENTRAL AUSTRALIA

With 7 figures and 9 photos

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"Ignorant of the existence of a similar geographical feature in any other part world, I was at a loss to divine its nature" (STURT 1849, 373, on the stony desert that now bears his name).

Zusammenfassung: Sturts Stony Desert, Zentralaustralien

Die Sturts Stony Desert ist Teil der Simpson Desert im zentralen Australien. Der Name Stony Desert belegt, dass es sich überwiegend um eine Hamada bzw. eine Gesteinsschuttwüste (*gibber*) handelt. Diese besteht aus eckigen Bruchstücken von Kieselsäurekrusten *(silcrete)*. Der Schutt stammt aus der Zerschneidung und Zerstörung einer Kieselsäurekruste, die während des Oligozäns und des Miozäns auf jung-mesozoischen Ablagerungen entstanden war. Durch die Denudation der Talhänge blieb eine schwach reliefierte Landoberfläche zurück. Weitflächig handelt es sich dabei um eine Schnittfläche, die von (umgelagerten) *silcrete*-Bruchstücken bedeckt ist. Diese stellen einen Schutz gegen weitergehende Abtragungen dar. Nur dort, wo diese Schuttdecke aufgelöst ist, tritt intensive *gully*-Erosion auf.

Summary: Sturts Stony Desert is part of the Simpson Desert of central Australia, and as its name suggests is dominated by hamada or gibber. The gibber consists of angular fragments of silcrete derived from the dissection and disintegration of a siliceous duricrust developed on later Mesozoic strata during the Oligocene and Miocene. The faceted slopes bordering the valleys of incised streams have been worn back leaving behind a surface of low relief, part of etch type, and carrying lag deposit of silcrete stones which forms a protective veneer. Nevertheless, where the gibber crust has been breached gullying is common.

1 Introduction

During his explorations of central Australia in 1845, CHARLES STURT encountered a desert landscape the like of which he had not previously been aware. It was "… an immense plain, occupying more than half the horizon", and was "… of a dark purple hue and … appeared to be perfectly level" (STURT 1849, 372).

Its surface consisted of "indurated or compact quartz … coated with oxide of iron" (STURT 1849, 375). So flat is the stony plain that where interrupted by sand dunes, the latter were described as abutting upon, and terminating in, the plain "… like so many headlands projecting into the sea" (STURT 1849, 372). He called this "gloomy stone-clad plain" the "Stony Desert" (STURT 1849, 375) and it has since appropriately become known as Sturts Stony Desert. It is part of the Simpson Desert *sensu lato,* which comprises the Stony Desert, the Strzelecki to the east, the Tirari to the west (between the Stony and Lake Eyre), and the Simpson Desert dunefield *sensu stricto* to the north, and essentially in the Northern Territory.

In Australia, the stony carapace is known as gibber, and the plains, gibber plains. Such surfaces are also commonly referred to as stone pavements, but this is in most instances inappropriate. A pavement is a smooth surface and many hamadas, including most of Sturts Stony Desert, are notoriously rough, with angular fragments of rock 10 to 20 cm diameter standing in close proximity on the surface (Photo 1 a). Only a few sectors of the gibber plain, where the stone fragments are 2–5 cm diameter and the spaces between are filled with fines so that the resultant composite surface is comparatively smooth (Photo 1 b), warrant the term pavement.

The gibber plains of arid Australia are an example of a *reg,* an *hamada* or *serir,* depending on whether the constituents of the stone mantle are predominantly coarse or fine. In other parts of the world, the basaltic *hamada* of the Tanezrouft of southern Algeria, the *serir* based in argillaceous country rock in Namaqualand (Western Cape Province) and Namibia, are comparable, but the gibber of Sturts Stony Desert is particularly well known because of the nature of the stony carapace, which is predominantly of silcrete.

Silcrete-dominated gibber plains are found also to the west of Lake Eyre, around Oodnadatta. Gibber plains are common in other parts of the Australian desert, where the composition of the stony carapace reflects the character of the local bedrock – quartzite cobbles and gravels are common, but limestone is found in places, and around the iron-rich Hamersley Ranges
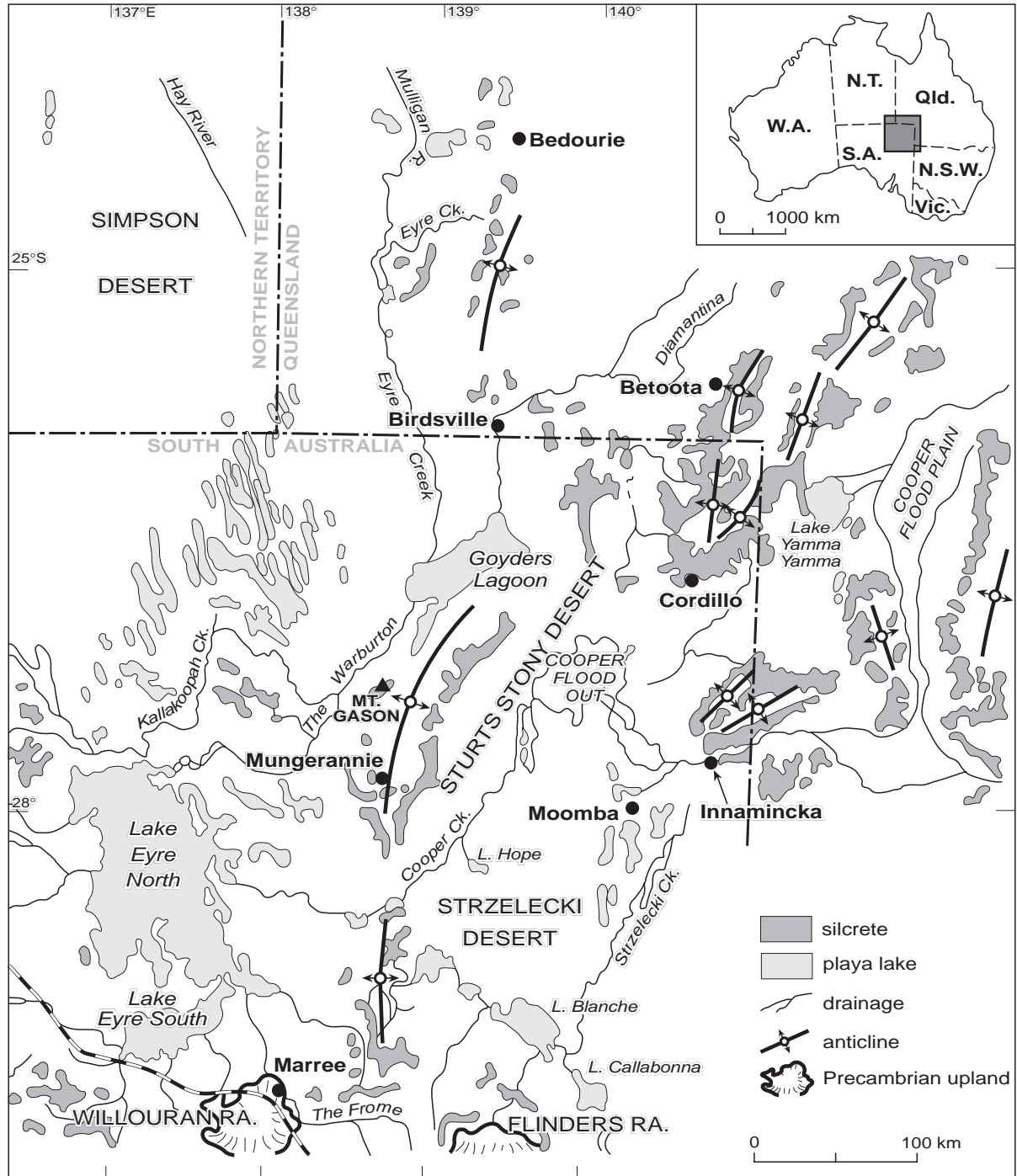
Fig. 1: Location map

Lage des Arbeitsgebietes

Photo 1: Types of gibber (a) coarse hamada (b) fine, close-packed pavement
Typen des *gibber* (a) grobkörnige Hamada und (b) feinkörniges, dicht-gelagertes Pflaster

of the northwest of Western Australia, ferruginous pebbles or fragments coated with iron oxides form a gravel carpet.

Sturts Stony Desert, as usually perceived, is that region about 60,000 km^2 in extent partly traversed by the explorer, in what is now northeastern South Australia, between Mungerannie and Birdsville in the west and extending roughly to the Queensland border (Fig. 1). Similar plains occur in southwestern Queensland between Birdsville and Bedourie, and as far east as the Paroo River (WHITEHOUSE 1941); though in these areas, as in parts of the South Australian sector, the gibber is partly masked by alluvium or by fields of sand dunes. Here we consider Sturts Stony Desert in this broader sense.

2 Description of the Stony Desert

For the most part, and as STURT and other travellers have attested, the Stony Desert is an extraordinarily featureless plain (Photo 2 a). In places however, its regularity is broken on the one hand by low mesas or plateaux standing up to 20–25 m above the adjacent plains (Photo 2 b), and on the other by shallow widely-spaced river valleys (Photo 2 c). Although located some 700–750 km from the sea, the plain is flat as well as low-lying. Around Birdsville, the plain stands some 50–60 m above sea level and is of a similar elevation in the south, around Mungerannie. Its level declines to below 50 m to the west where the downfaulted Lake Eyre stands some 15–16 m below sea level (WOPFNER a. TWIDALE

1967; DULHUNTY 1987). In places, as to the southeast of Cordillo Downs, high red dunes extend on to the gibber surface and marginal to major river flood plains like those of the Diamantina and Cooper, the Stony Desert is dissected and rolling, or broadly undulating. But elsewhere the plain is flat, featureless and at most times devoid of vegetation.

The Stony Desert is located almost entirely within the hyperarid zone around Lake Eyre. Mungerannie, for example, averages only 120 mm per annum, while Innamincka (154.5 mm) and Cordillo Downs (163 mm) are only slightly higher. As STURT's journals attest, and modern records confirm, summer temperatures are scorching with shade maxima averaging just under 40 °C and commonly reaching 45 °C or more, in the shade and much higher – STURT recorded a temperature of 157 °F (55 °C) – in the sun. Potential evaporation is high (over 3,600 mm: see KOTWICKI 1986; ALLAN 1990). Yet averages are misleading for incursions of westerly lows in winter and tropical systems in summer bring heavy local rains after which the desert blooms. Also monsoon rains cause rivers like the Thomson-Cooper, the Diamantina-Warburton and the Georgina to flood and from time to time, and more frequently than was at one time suspected, transform Lake Eyre into a lake (BONYTHON a. MASON 1953; KOTWICKI 1986). The entire area is held under pastoral lease, for cattle can not only survive, but flourish, on the occasional pastures, and the water-holes, or 'billabongs', of such major rivers as the Warburton and the Cooper, fed by headwaters in monsoonal Australia, provide watering points which, if not permanent, are long-lasting.

On the surface are exposed "… sandstone, quartz, and (magnetic) ironstone pebbles, so densely and firmly set together in some places as to have the appearance of an old-fashioned pavement" (WILLS 1863, 160: the "old-fashioned pavement" is presumably the modern crazy paving). The gibbers are, overwhelmingly, of silcrete: a few exotic pebbles and cobbles of quartz or quartzite are found, especially in the valleys of major waterways, and in some areas, small rounded, frequently ovoid, pebbles of white quartz, released by the disintegration of the host rock, are mixed with the blocks, but most of the gibber consists of large angular fragments of silcrete.

Between the stones a hard crust is developed on the fines. It is due to alternations of wetting and drying, the occasional wetting or moistening resulting not so much from rains but from condensation and dew – for winter nights can be cold. Water is adsorbed on to soil particles and on desiccation and heating, cements them together to produce an encrustation (see RUSSELL 1957, 37; SHARON 1962). It is significant for it not only retards winnowing but also reduces the volume of fines in motion, thus reducing the chances of infilling the voids between stones, at least on higher ground that is out of reach of fines transported by wash.

3 Geology

Considered globally, the geological setting of Sturts Stony Desert is unusual, for though most hamadas are "especially prevalent in alluvial fans, bajadas, and terraces composed of sediments derived from metamorphic and volcanic rocks" (ELVIDGE a. IVERSON 1983, 225) it is underlain by gently folded Jurassic and Cretaceous strata which are in some areas succeeded by various flat-lying younger or gently dipping Tertiary strata and by Quaternary sediments (e. g. WILLIAMS 1973; WILLIAMS a. MOND 1973; FORBES 1974; TOWNSEND a. THORNTON 1975; PIRSA 2001). Though they are minor in comparison with the extensive gibber plains all around, the hill country associated with the

(a)

(b)

(c)

Photo 2: (a) Typical gibber plain with silcrete blocks as a lag deposit, Birdsville Track between Mungerannie and Goyders Lagoon. (b) Plateaux capped by silcrete in situ, northeast of Innamincka. (c) Rolling plain protected by veneer of silcrete blocks, Kamaran Downs, west of Bedourie, southwest Queensland. Note the clayey valley floor derived from clays washed from the original weathered mantle

(a) Typische *gibber*-Ebene mit *silcrete*-Blöcken als Residualsediment, Birdsville Track zwischen Mungerannie und Goyders Lagune. (b) Mit *silcrete* in situ bedeckte Ebene nordöstlich von Innamincka. (c) Wellige Ebene, geschützt durch eine dünne Decke verkieselter Blöcke, Kamaran Downs, westlich von Bedourie, Südwest-Queensland. Zu beachten ist der tonige Talboden, der von umgelagerten Tonen der ursprünglichen Verwitterungsdecke gebildet wird

Cooryanna and Gason domes dominate the western part of the stony desert (Fig. 2) and the Innamincka Dome the east. Though they include arenaceous and carbonate strata, argillites dominate these sedimentary sequences which were weathered and reduced to a surface of low relief during the Oligocene and Miocene. The main, crystalline silcrete was formed on this 'Cordillo' surface (WOPFNER 1974). A younger silcrete, distinguished from the more extensive Oligocene-Miocene duricrust by its opaline matrix, is found in the southern parts of Sturts Stony Desert, in the lower parts of the Lake Eyre basin. It is of putative Pleistocene age (WOPFNER a. TWIDALE 1967).

Weathering involved solution, hydration and hydrolysis and altered the country rock at, and for a few metres below, the surface. The resultant regolith consisted of a dense siliceous B horizon, possibly with a thin A-horizon (which may have been clayey, but of which little, if any, has survived erosion by water and wind), and underlain by several metres of kaolinised material. At many sites, no sign of original sedimentary structures such as bedding remains in the upper several metres of this zone, which consist of kaolinised materials. Elsewhere, however, weathered strata with bedding are exposed both in the flanks of mesas (Photo 3 a) and in shallow excavations sunk below the plain (Photo 4). This period of weathering preceded the folding that has produced the hill country associated with the various dome structures (WOPFNER 1960; SPRIGG 1963; also COATS et al. 1969; see Fig. 3). It produced the siliceous capping that protects the mesas and cuestas, and from which, on breaking down, the gibber originates.

4 Origin of the plain

The origin of the landscape can be considered under two headings: first, the evolution of the plain following dissection of the weathered (silcreted) land surface during the earlier Tertiary; and second, the derivation of the gibber.

The region was reduced to low relief during the Early Tertiary as a result of long-continued weathering and river erosion of weak strata. On this plain the siliceous horizon hardened as a result of desiccation consequent on dissection and lowering of the water table. Such resistant carapaces are known as duricrusts and those of siliceous composition, silcretes. Its occurrence has determined the landscape development in this region. Where remnants of the original silcrete persist, whether developed on Cretaceous argillite or as an orthoquartzitic induration – the "surface quartzite" of FRANKEL a. KENT (1937) – on early Tertiary sandstone, the hard capping has given rise to plateau forms (Photo 3 b). In southwest Queensland and adjacent parts of South Australia, the silcreted surfaces have been folded and dissected, forming cuestas (Fig. 3) but in many areas dips are so slight that plateau forms are dominant (Photo 2 b). Sandstone and other interbedded resistant strata in places give rise to structural benches (Fig. 4 a).

Most of the silcrete-capped surface and the underlying kaolinitic regolith have, however, been dissected and stripped by rivers. The hard caprock induced scarp retreat. Left behind was the present gibber-strewn plain. In some areas, and especially adjacent to major waterways such as the Cooper, the stony carapace is
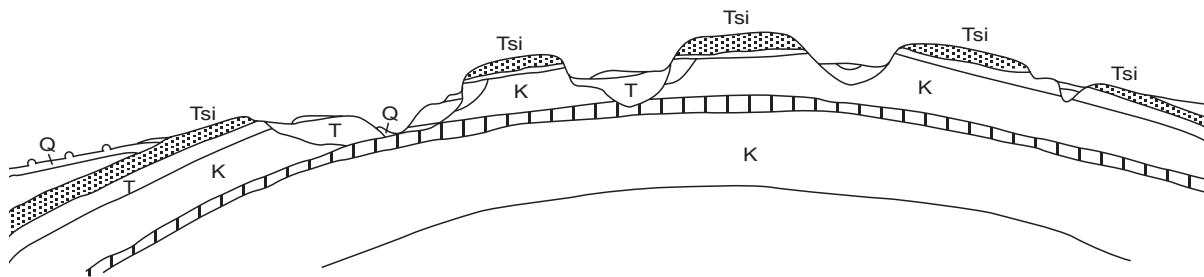

Fig. 2: Diagrammatic section through Gason Dome (after WILLIAMS 1973; see also TOWNSEND a. THORNTON 1975). K – Cretaceous; T – Tertiary; Tsi – silcrete; Q – Quaternary

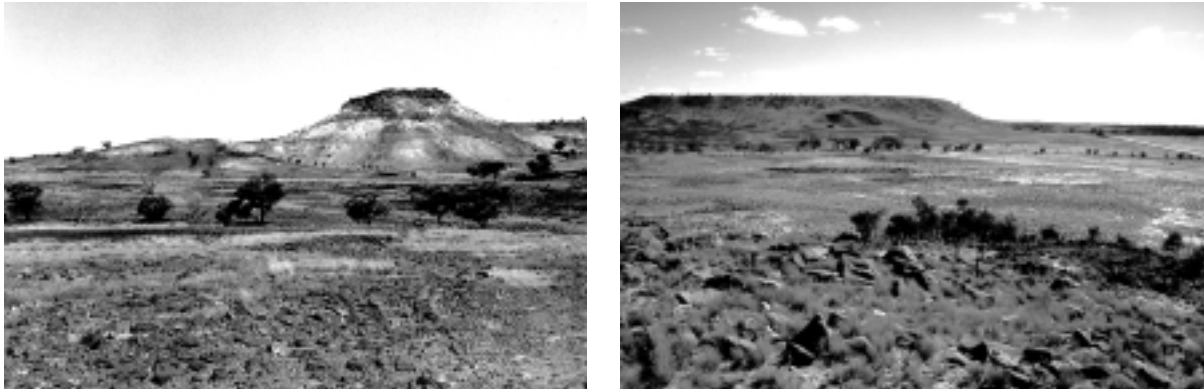Profilschnitt durch den Gason Dome. K – Kreide; T – Tertiär; Tsi – *silcrete* (Kieselsäurekruste); Q – Quartär

Photo 3: (a) Mesa with silcrete capping and exposed kaolinised zone northeast of Innamincka. Note the 'false' cuesta to the left of the mesa and due to streams exploiting the intensely weathered scarp foot zone. (b) Mesa capped by silicified sandstone (orthoquartzite) of the Eocene-Palaeocene Eyre Formation, a few kilometres east of Innamincka

(a) Tafelland mit einer *silcrete*-Überdeckung und einer freigelegten kaolinisierten Zone nordöstlich von Innamincka. Zu beachten ist die ‚falsche' Schichtstufe zur Linken des Tafellandes, die auf Bäche zurückzuführen ist, die den intensiv verwitterten Hangfuß ausräumen. (b) Mit einem silifizierten Sandstein (Orthoquarzit) bedeckte Schichttafel der Eozän-Paläozän *Eyre*-Formation, einige Kilometer östlich von Innamincka

underlain by vesicular or bubbly clays derived from the erosion and translocation of the kaolinised bedrock, and here its level may have been determined by local and regional baselevels (the then current stand of the bed of Lake Eyre) and local baselevels (other salinas and major rivers). However, on the divides between major rivers and particularly adjacent to the Birdsville Track north of Mungerannie and south of Goyders Lagoon shallow quarries ('borrow' pits – so called presumably because material is taken from one site to shore up another) excavated in the gibber plain to obtain material for road foundations, have exposed slightly altered but still cohesive and obviously stratified Mesozoic rocks beneath the thin soil layer (Photo 4). This suggests that much of the gibber plain originated as an etch surface (Fig. 4 b; FALCONER 1911; JUTSON 1914), formed as a result of stripping of the intensely kaolinised rock down to the level where the argillite retained a measure of cohesion. In these terms the regularity of the plain is due to the ease with which the underlying argillites were altered (cf. the Nullarbor Plain: TWIDALE 1990), the uniform thickness of the resultant regolith, and the consequent evenness of the weathering front (MABBUTT 1961), the lower limit of significant weathering, with 'significant' the crucial word, implying susceptibility to erosion under the prevailing conditions.

Thus the gibber plains of northeastern South Australia and adjacent areas of Queensland are in part, and in a broad sense, congeners of the etch plains that are so prominent, and indeed dominant throughout central Australia, having been exposed by the stripping of both laterite and silcrete profiles (MABBUTT 1965). In some areas, etch surfaces have been produced by the stripping of only part of a differentiated regolith (e. g. WRIGHT 1963; TWIDALE 1990, 2002). This has occurred in parts of the Stony Desert, where the lag or veneer of silcrete fragments that give the Stony Desert its characteristics was deposited on a bedrock surface cut in strata which is slightly altered, but retains structure and cohesion.

5   Origin of the gibber

5.1 Silcrete – character and origin

The Stony Desert is underlain by Cretaceous strata most of which are argillaceous, but the pavement is composed overwhelmingly of fragments of silcrete of Oligicene-Miocene age. It is characteristically dark purple or brown on the outside but displays various colours – grey, yellow, orange, brown, red or even white, but typically grey or yellowish brown – on unweathered faces. Silcrete is a dense siliceous rock (96–97% silica) with minor amounts of alumina, iron, titanium, and traces of yttrium, zirconium and niobium (HUTTON et al. 1978); though some silcrete skins, which are up to

Photo 4: Borrow pit with weathered but cohesive strata exposed at shallow depth coincident with plain surface, Birdsville Track between Mungerannie and Goyders Lagoon

Entnahmegrube mit in geringer Tiefe aufgeschlossenen verwitterten, aber kohäsiven Schichten, die mit der Oberfläche der Ebene übereinstimmen, Birdsville Track zwischen Mungerannie und Goyders Lagune

Photo 5: Porphyroclastic texture in skin silcrete on quartzite

Porphyroklastisches Gefüge der *silcrete*-Haut eines Quarzits.

Photo 6: Basinal form of silcrete capping on mesa on western side of Simpson Desert

Beckenform der *silcrete*-Überdeckung auf dem Tafelland an der westlichen Seite der Simpson Desert

10 cm thick in places (HUTTON et al. 1972), and formed in scarp-foot zones, contain up to 25% titanium oxide (anatase), which shows as pale yellow smears on the rock. Such skins may be due to the concentration of minor elements in the country rock by leaching of more soluble elements (see e. g. WOPFNER a. TWIDALE 1967; WOPFNER 1978; HUTTON et al. 1972, 1978). The rock is typically porphyroclastic, with shards of quartz set in a matrix of finely divided crystalline quartz (Photo 5). The shards are probably due to the splitting and displacement of quartz fragments during crystallisation of the groundmass (WOPFNER 1978).

Silcrete characteristically displays a columnar structure, with grooves prominently developed on the sides of the columns. Whorled shapes – some of them reminiscent of African stone carvings – are common, as are surficial solution hollows and pits. The dense siliceous rock has a well-developed conchoidal fracture, making it ideal for the manufacture of primitive tools such as scrapers, spear points and axes, and it was so utilised by the indigenous inhabitants of the region. Overwhelmingly, silcretes originated in quite extensive horizontal sheets, but how extensive were the sheets of silcrete, and how was the siliceous duricrust formed? The sheet silcretes have been attributed to the weathering of the country rock, but this cannot account for the presence in many silcretes of exotic rounded cobbles and gravels, and for compositional incongruities as between silcrete and country 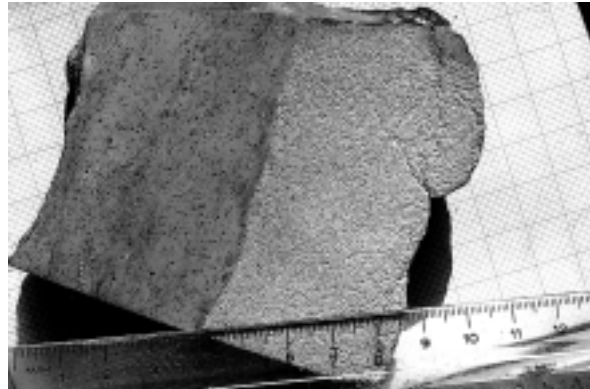rock. The most extreme example of such compositional incompatibility is the occurrence of silcrete on limestone, as can be seen at several sites in the southern Flinders Ranges. Clearly, in some occurrences, silica and other materials and elements have been introduced to the sites where they are presently found, either in surface streams or in groundwaters (YOUNG 1985). Both methods of transport are feasible but that streams and rivers are involved is suggested first by the presence of rounded exotic gravels in the silcretes, second by their preservation in linear or winding and relatively narrow outcrops (Fig. 3 a; TWIDALE 1983, 1985; see also PARTRIDGE a. MAUD 1987), and third by the basinal form in cross-section (normal to the length of outcrop) of some plateau exposures (Photo 6).

The latter morphology can, however, also be construed as reflecting the relative stability of the better-
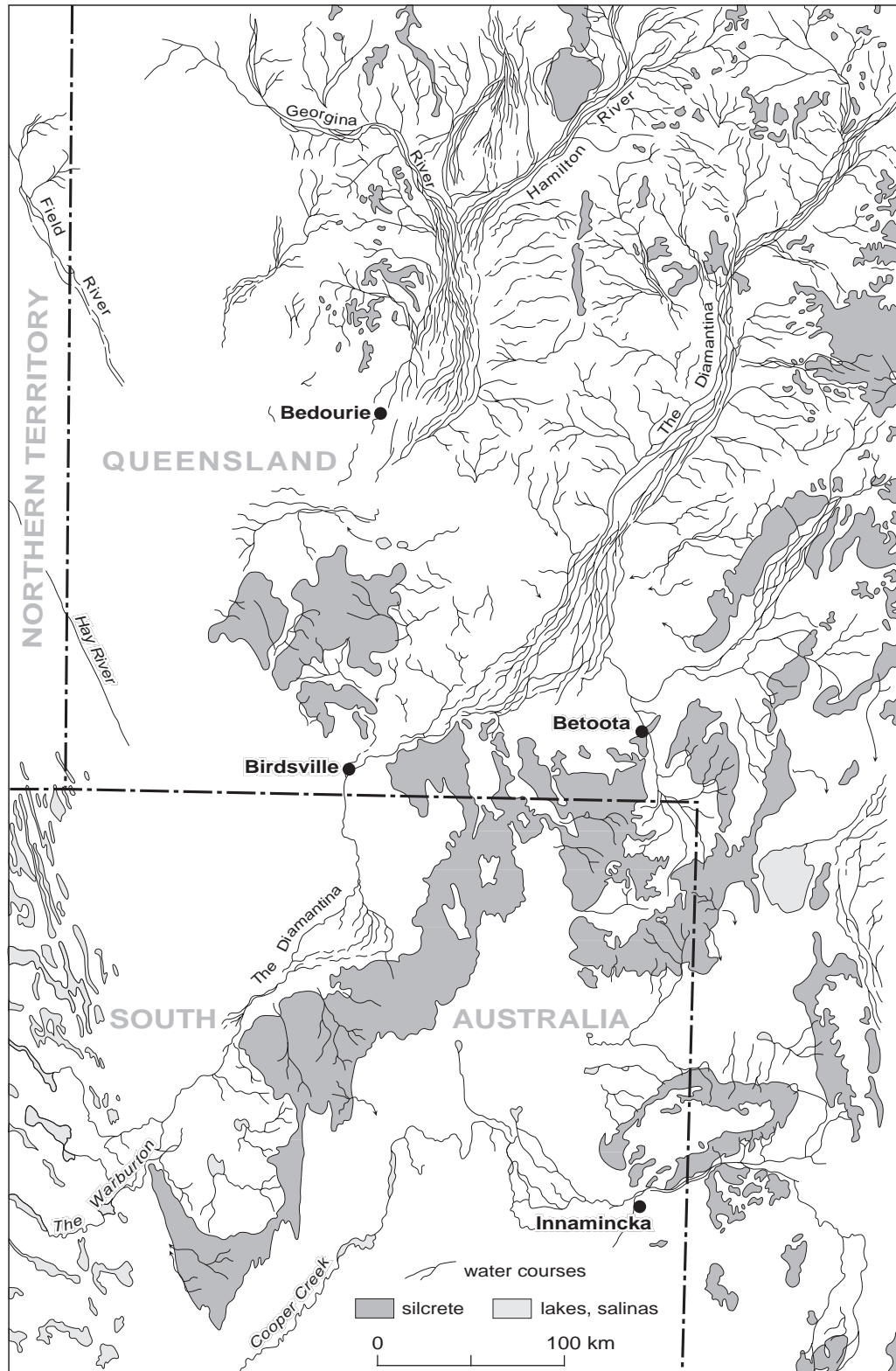
Fig. 3: (a) Map showing folded silcrete in northeastern South Australia and adjacent areas

Karte der gefalteten *silcretes* im Nordosten Südaustraliens und angrenzender Gebiete
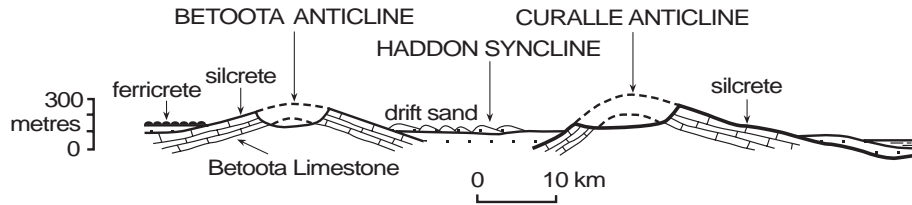
Fig. 3: (b) Diagrammatic section through breached Betoota and Curalle anticlines (after Wopfner 1960; Sprigg 1963)

Profilschnitt der unterbrochenen Antiklinalen Netoota und Curalle

drained exposed margins of dissected silcrete remnants while the interior masses remain subject to moisture attack, solutional evacuation, and volume decrease; a mechanism which is self-perpetuating, for once a depression forms behind the peripheral rim, water gravitates to it (Twidale a. Milnes 1983 a and b). Such an alluvial origin of some silcretes implies that some of the silcrete-capped plateaux that are now prominent relief features were valley floors during the Oligocene-Miocene and that thus there has been relief inversion (Fig. 5).

Sheet silcrete is due to the concentration of silica in, and possibly essentially at the surface of the regolith. The common occurrence beneath the siliceous horizon of weathered country rock can be misleading for the juxtaposition suggests that the two are genetically linked. So they are, but not in the sense that the siliceous horizon is a weathering product derived from the same parent material as the kaolinised zone, for the silcrete contains rare elements absent both from the kaolinised material and the bedrock (q.v.). The genetic connection is that the silica was introduced in surface flows or shallow groundwaters and those waters caused the alteration of country rock to kaolinite. The details of the silicification must needs remain speculative for no modern analogue has yet been recognised (but see Wopfner 1978, 137; Van Dijk a. Beckmann 1978).

Suffice it to say that many occurrences of sheet silcrete are found in enclosed basins. Thus, and taking a regional perspective, Stephens (1964) suggested that the centripetal drainage of central Australia (due in turn to the recurrent subsidence of the Lake Eyre region: see Wopfner a. Twidale 1967) provided the essential clue, with silica leached from the headwater reaches of such rivers as the Thomson, Barcoo, Diamantina and Georgina, being carried to the lower regions of the interior catchment and there, with no outlet to the ocean, was precipitated in channels and shallow groundwater zones. The concentration of silica implied by silcrete formation has been attributed to its concentration of plants, notably ferns, and then, on the death and decay of the plants, by its preservation in phytoliths, followed by their concentration in soil (e. g. Lovering 1959). Local surficial accumulations of silica-rich rocks may have originated as lacustrine gels. Öpik (1954; Öpik et al. 1973) suggested such an origin for freshwater quartzites (Lee's Waterhole Sandstone, later subsumed in the Polland Waterhole Shale and assigned to the Tambo Formation – Carter a. Öpik 1959) of the Thorntonia region of northwestern Queensland, and silcrete is associated with palaeolake margins elsewhere also, as for example the lake that occupied the northern Willochra Basin of the southern Flinders Ranges in ?Middle Eocene times (Twidale a. Bourne 1996).

Given the prevalent low relief and gradients, the evidence of minor but widespread tectonism in the later Cainozoic (e. g. Youngs a. Wopfner 1972), the apparent low rate of headward regression of streams (Taylor et al. 1985; Young a. McDougall 1993), the occurrence of numerous local and regional but ephemeral basins of interior drainage conducive to surficial silicification can be anticipated. Silica is a common constituent of the dissolved load of rivers (see e. g. Livingstone 1963; Davis 1964; Douglas 1978). Whether such dissolution was encouraged by high temperatures is problematic for the evidence is contradictory. Palaeontological evidence suggests that humid warm ('rain forest') conditions obtained during the Early and Middle Tertiary when the main central Australian silcretes formed (e. g. Stirton et al. 1961; Brown et al. 1968, 307–308; Ludbrook 1969; Wopfner 1978) but the palaeoclimatic evidence favours cooler conditions during that period (Frakes 1979; Frakes et al. 1992). What is certain is that whatever temperature regime favoured silcrete formation, the resultant duricrust is preserved in aridity.

5.2 Derivation of the gibber

Silcrete forms a protective caprock which when dissected gives rise to plateau forms where the surface remains undeformed, or cuestas where gently tilted. Plateaux are everywhere visible within the Stony Desert. The areal extent of such residuals is reduced only by the undermining and collapse of the caprock. This is made possible by the occurrence beneath the silcrete of altered argillaceous country rock. The resultant white kaolinite-rich regolith so prominently exposed in the flanks of many silcrete-capped plateaux (Photo 3 a) is readily eroded by rivulets and streams. The slope is, however, also protected by the blocky debris fallen from the bluff and dissection is in many

places localised to produce 'false cuestas' and 'false flatirons' (Photo 3 a: 'false' because, though morphologically simulating the features named, they are not an expression of gently dipping strata; see TWIDALE 1978).

The gibber of Sturts Stony Desert is derived from the disintegration of silcrete which is a duricrust and hence a surficial accumulation, but which has been dissected as a result of river rejuvenation consequent on the long-term subsidence of the bed of Lake Eyre, the focus of rivers draining the Stony Desert, and indeed much of central and northeastern Australia (WOPFNER a. TWIDALE 1967). Whether the primary silcrete that is the source of the gibber formed in extensive, essentially continuous sheets, or in compara-
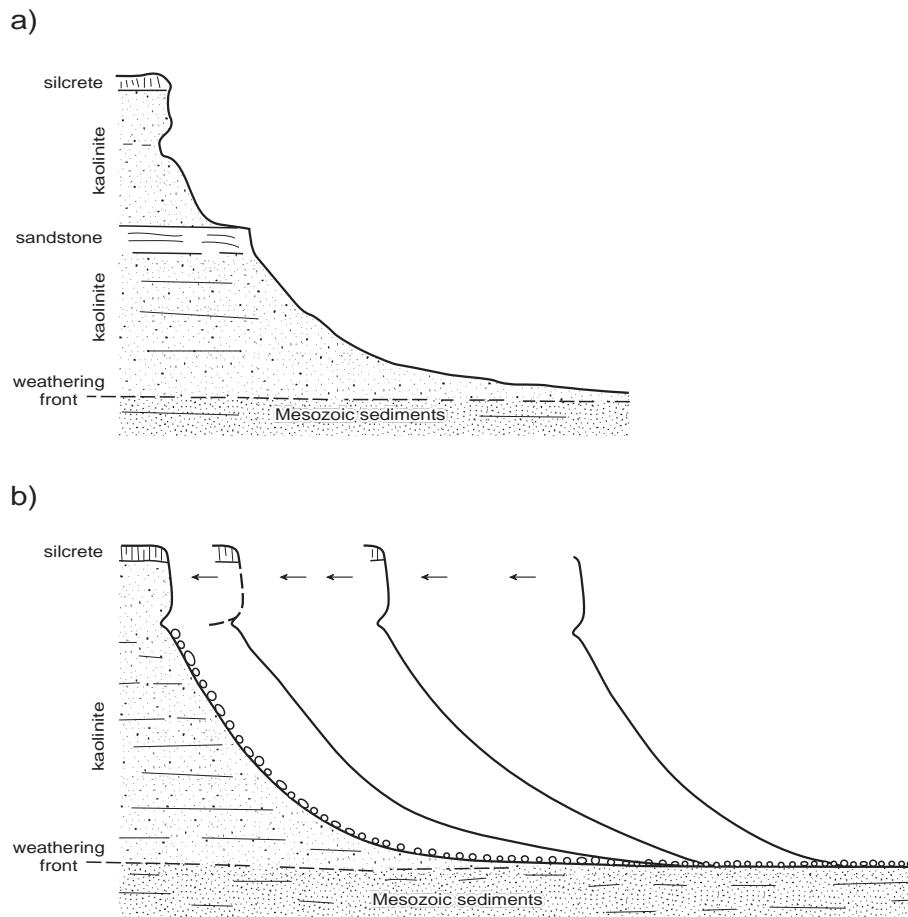

Fig. 4: Diagrammatic sections showing (a) silcrete-capped mesa with structural bench, (b) suggested development of gibber plain as an etch surface

Profilschnitt des (a) mit *silcretes* überdeckten Tafellandes mit strukturgestützter Stufe, (b) Modellvorstellung zur Entwicklung der *gibber*-Ebene als eine Rumpffläche

tively narrow valley floors is of some significance when the distribution and character of the gibber is considered.

Once the rivers of the region incised their beds, their valley-side slopes and those of their tributaries were scoured by gullies. These were fed by seepages produced by meteoric waters percolating through the pervious silcrete cap and running along the upper surface of the impermeable clay. Sapping at the base of the silcrete bluffs resulted in undermining and collapse of debris on to the slope below. As the gullies cut into the kaolinite their headslopes were steepened and became unstable and slumped mass movements of debris develop producing scalloped depressions, again causing downslope movement of the stony carapace. Thus the steep, faceted slopes bordering the plateaux were undermined and eventually collapsed, and the margins of the plateau residuals were worn back (Fig. 4 b: Twidale a. Milnes 1983 a).

The massive silcrete capping broke down into fragments, especially where the columnar structure is pronounced. The blocks disintegrated into smaller blocks by hitting against each other during collapse and sliding. Water also penetrated along fissures and cracks, weathered the silcrete with which it came into contact by dissolving silica, thus causing the blocks to break apart along the weakened fracture lines. The debris slopes below the bluffs came to be strewn with blocks, or gibbers, derived from the capping. As well as coating most stone fragments and imposing a reddish brown hue to clays derived from the weathered mantle, haematite and goethite became concentrated in some scarp-foot zones.

As scarp retreat continued, and more fines were eroded from the weathered substrate, hillslope inclinations distant from the scarps were reduced. Given the Oligocene-Miocene age of the dominant silcrete of the Stony Desert, the gibber plains derived from it must be of later Cainozoic age, but the gibber plains are diachronic. The plains increase in age with distance from the youthful and penecontemporary scarp-foot zones adjacent to the mesa remnants.

The silcrete detritus became concentrated to form a veneer only one stone thick, and set on and amongst a layer of weathered vesicular or 'bubbly' brown loams (Wright et al. 1990; Photo 7). At the same time, the plains were lowered. Remnants of former plains, protected and preserved by a gibber layer, persist in mesas standing a few metres higher than the present valley floors (Fig. 6).

Near major rivers such as the Diamantina, tributaries have incised a few metres below the general plain level, and the gibber surface is preserved in low convex
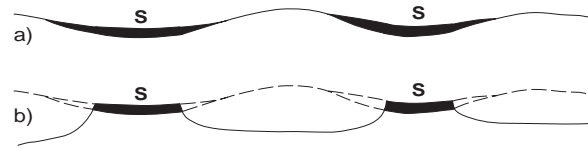

Fig. 5: Inversion of valley silcrete: (a) valley floor development, (b) inversion following preferential degradation of divide. S – silcrete

Reliefumkehr von Tal-*silcretes*: (a) Talboden Entwicklung, (b) einer vorgegebenen Degradierung einer Wasserscheide. S – Kieselkonglomerat
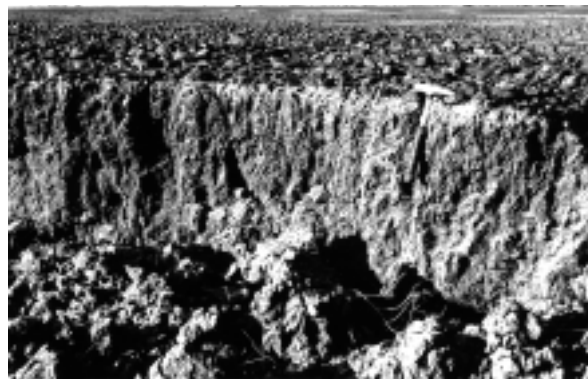

Photo 7: Gibber one stone thick exposed in road cutting north of Innamincka

gibber-Aufschluss an einem Straßeneinschnitt nördlich von Innamincka
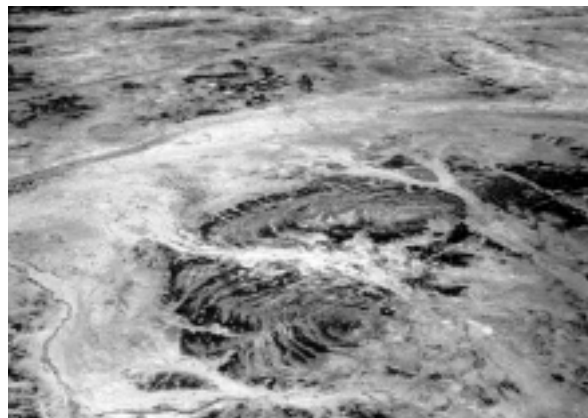

Photo 8: Silcrete rise with concentric crenulated patterns between Birdsville and Bedourie

silcrete-Erhebung mit konzentrisch gewellter Anordnung zwischen Birdsville und Bedourie
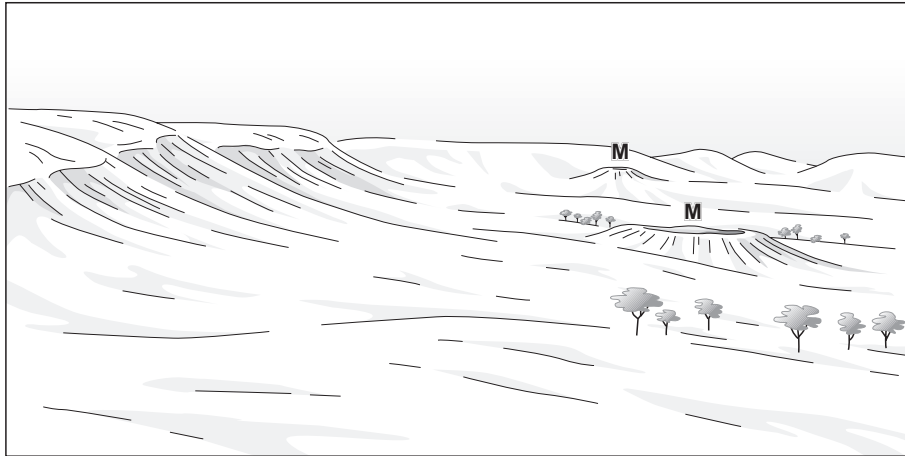
Fig. 6: Sketch of dissected silcrete-capped plateau northeast of Innamincka, showing mesas (M) – old valley floor remnants – capped by silcrete gibber

Skizze einer zerschnittenen, mit *silcrete* überdeckten Schichttafel (M) nordöstlich von Innamincka, alte Talbödenrelikte, die mit verkieselten *gibber* bedeckt sind

upward rises. The lag deposit is preserved as the substrate is preferentially winnowed and the coarse cover is lowered. The stony rises display roughly concentric but crenulated patterns (Photo 8) due to the wash of fines from the crests downslope (TWIDALE 1972).

The red-brown clays beneath the gibber cover are derived from the erosion and transport by wash and streams of the kaolinitic zone of the weathered mantle capped by silcrete. Though predominantly kaolinitic these bubbly clays include smectite and are thus expansive (NORRISH a. PICKERING 1983; WRIGHT et al. 1990). Only in river flood plains has it been buried, and here the surface stony horizon is formed and maintained by the churning due to alternations of wetting and drying of thick cracking clays rich in alkalis such as sodium chloride, calcium carbonate and gypsum (WRIGHT et al. 1990). Thus coarse debris is moved to and remains at the surface, being too large to fall down cracks. Sturt recorded that at slightly lower levels than the Stony Desert he entered on an "earthy plain … resembling in appearance a boundless piece of ploughed land … the earth seemed to have once been mud and then dried" (STURT 1849, 376), and this is consistent with the widespread occurrence beneath the siliceous horizon of an expansive or cracking clay derived from the weathering of the Cretaceous argillites that underlie the region. The gilgai mechanism (ENGLAND, in PRESCOTT 1931; HOWARD 1939; LEEPER 1947, 53–54; HALLSWORTH et al. 1955; SPRINGER 1958; OLLIER

1966; MABBUTT 1977, 123 ff.) can produce a microtopography consisting of puffs bordered by depressions and separating them from the intervening shelves (Fig. 7). On most gibber plains such microtopography is subdued by the density of the stony crust and is most commonly indicated by the presence of small depressions or crabholes. Though the silcrete gibber of the Stony Desert originated as a surface layer (cf. MCFADDEN et al. 1987), the gilgai mechanism ensures that any gibber that falls into a 'crabhole' (a regional name for a depression formed in the cracking clays), or which is buried by alluvium during a flood, for example, is returned to the surface after relatively few alternations of wetting and drying (see JESSUP 1970; COOKE et al. 1993, 74).

Thus the gibber is overwhelmingly a coarse lag gravel deposit (e. g. HUBBLE et al. 1983, 28) which has never been extensively or deeply buried but which has been concentrated by wash and wind to form an essentially complete cover to the plains derived from the dissection of the older silcreted surface of which remnants survive in the hill country. The upward migration of stones is of limited importance in Sturts Stony Desert, though soil churning has maintained the gibber cover where the gravel has fallen into crabholes. In this the gibber of the Stony Desert differs from many other hamadas which are underlain by detritus of mixed calibre (e. g. SHARON 1962), because wash and wind, rather than soil churning have maintained the stony
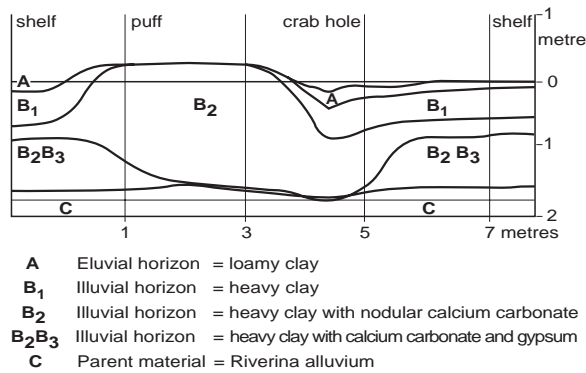
A	Eluvial horizon	= loamy clay
B₁	Illuvial horizon	= heavy clay
B₂	Illuvial horizon	= heavy clay with nodular calcium carbonate
B₂B₃	Illuvial horizon	= heavy clay with calcium carbonate and gypsum
C	Parent material	= Riverina alluvium

Fig. 7: Diagrammatic section through gilgai puff and depression (ENGLAND, in HOWARD 1939)

Profil durch das *gilgai*-Relief

carapace derived from the dissection, undermining, collapse and disintegration of the primary mid Tertiary silcrete horizon.

5.3 Character of gibber

DURY (1970) has claimed that the size of gibber varies in an orderly manner according to distance from source, and in general this appears to be so. There are many exceptions however, with patches of large blocks surrounded by comparatively fine debris. DURY attributes such anomalies to the gilgai effect, but this can only be a minor factor in the Stony Desert for the lag originates as a surficial development and has been lowered to its present position as a result of the winnowing and evacuation of fines produced by the weathering of the country rock. Any anomalies must be related either to the character of the primary silcrete or to the mechanism of breakdown and distribution. For example the fracture density of silcrete varies (perhaps according to thickness and rate of desiccation) and this could be reflected in the size of detritus. Again, gullying of debris slopes causes coarse debris to gravitate into the gullies and to set in train the gully gravure mechanism, so that linear streams of coarser materials are produced (BRYAN 1940; TWIDALE a. MILNES 1983 a; TWIDALE a. CAMPBELL 1986). These could be maintained even after the reduction in slope gradient by the selective evacuation of fines. Certainly old stream channels, identified by their coarser bedload blocks and cobbles, persist on slopes in the Ooraminna Ranges, southeast of Alice Springs (TWIDALE a. MILNES 1983 b), and on covered pediments in the western piedmont of the Flinders Ranges (BOURNE a. TWIDALE 1998).

The calibre of the silcrete gibber varies spatially, but how are the columns and blocks first reduced to angu-

lar fragments and then further reduced in size? Three possibilities suggest themselves. First, although high surface temperatures are undoubtedly experienced in the Stony Desert (surface temperatures are much higher than air temperatures) the experimental evidence (e. g. BLACKWELDER 1933; GRIGGS 1936) argues against insolation alone being effective in breaking down rocks. Nevertheless, in time weak stresses may prove effective: long exposure, with many cycles of heating and cooling may have an impact. The effectiveness of this mechanism varies with lithology but is favoured in principle by many workers (e. g. SHARON 1962; OLLIER 1963). Furthermore, if during recent humid periods the Stony Desert carried some vegetation, the ephemeral but intense heat generated during bushfires induced by lightning strikes, could have caused the splitting even of dense rocks like silcrete.

Second, silcrete fragments commonly display evidence of desilication in the form of bleached and/or iron-stained zones in which the matrix has been reduced and a granular texture introduced. This presumably occurs as a result of water coming into contact with the outer surface or penetrating along cracks and fissures. The alkalinity of desert soils and shallow groundwaters is conducive to such reactions (e. g. JOLY 1901; ACQUAYE a. TINSLEY 1965; BENNETT 1991). Third, clays washed or falling into cracks and in contact with water may swell and exert sufficient pressure to rupture the rock. Or, of course, two or all of these mechanisms may produce splitting and reduction of debris.

6 Extensive sheets or valley floor accumulations?

Though substantial remnants of silcrete-capped hills (mainly plateaus and mesas, but some cuestas) break the monotony of the gibber plains, the latter are extensive. Yet with the exception of the flood plains of major rivers, the silcrete fragments remain angular and quite coarse. The fragments look like lag rather than detritus transported any significant distance by streams. The overall gradual decrease in average size of fragment from known source to valley axis is consistent with this suggestion. Improbable though it may seem, the gibber of the Stony Desert most likely originated in a sheet, probably as extensive as any known, and formed on a plain disturbed by continued gentle warping (WOPFNER 1978). Probably there were also deposits of particularly massive silcrete in major valleys (many of which resisted subsequent erosion to become the present mesas), but the present landscape appears to have evolved through the incision of rivers and subsequent scarp

recession acting on a sheet of siliceous duricrust which was essentially contiguous over huge areas of what is now northeastern South Australia and adjacent parts of Queensland and New South Wales.

The putative Oligocene-Miocene age of the Stony Desert silcrete implies that the extraordinarily flat and compact duricrust found over much of the area has evolved through the winnowing and introduction of fines in the last 20–25 millions of years. Taking the distance the gibber plain extends from the base of silcrete-capped mesas, scarp retreat in the order of one metre per millennium is implied. This order of magnitude does not take account of the outer limits of the gibber being covered by dune sand (e. g. TWIDALE et al. 2001), nor does it make allowance for any decrease in rate of recession with time due to the reduction of catchment and runoff above the mesa scarps (TWIDALE 1978).

7 Some practical considerations

STURT (1849, 375) described the Stony Desert as an adamantine, or impenetrably hard, plain, and certainly silcrete, being composed mainly of quartz, is physically hard and in the present arid environment practically inert. Only in topographic lows (valleys, playa depressions) where saline groundwaters gravitate or in piedmont zones where occasional runoff is concentrated, is silica leached resulting in rinds or fissures from which the matrix has been partly evacuated (in solution), leaving a porous quartzite. The concentration of stones through the winnowing of fines by wind and wash to form a virtually continuous cover is another important factor. Increased stoniness (number of stones per unit area) induces greater accumulation of any fines that are in motion on the wind (PANDASTICO a. ASHAYE 1956) so that the more stones, the more rapidly are the spaces between stones filled and the compactness of the cover increased. Low in the local relief, wash also causes any depressions to be filled in (e. g. DENNY 1967). A compact, smooth surface provides a more effective protection than a rough one with stones projecting and inducing turbulence.

Despite their protected character, however, gibber plains in general and Sturts Stony Desert in particular, are not immune to erosion. On the contrary, as well as an almost imperceptible but nevertheless real general lowering of the surface by wash and wind (e. g. CHEPIL 1950; SHARON 1962; SYMMONS a. HEMMING 1968) on higher areas – but accumulation of fines between gibbers downslope of downwind – gullying develops through natural erosion on even the gentlest of inclines

(1° or more) following heavy rains. The brownish clays derived from transported kaolinite are vesicular and prone to piping and collapse. Once the protective gibber veneer is breached, erosion is rapid (Photo 9 a). Wheels or pads cause localised compaction of the substrate, producing linear zones of reduced infiltration capacity, which stand in contrast with adjacent areas. Wheels depress the surface and create comparatively smooth hydraulically efficient linear depressions. Windrows (the ridges of detritus built up at the margins of tracks by graders) impede and control drainage, but when they are breached give rise to miniature floods. Animal pads concentrated along fences, for example, or converging on watering points, have similar physical effects.

Whatever their causation, such compacted zones are readily eroded by the occasional runoff – for no desert is rainless and the Australian deserts are no exception – to produce gullies (e. g. WEBB 1983). Washed-out tracks (Photo 9 b) are frequently encountered in the Stony Desert, as they are throughout the Australian arid zone. They attest to the reality of erosion being induced by soil compaction. The fines transported during the formation of gullies is spread on lower slopes, and in some instances gives rise to shallow but distinct alluvial fans (Photo 9 c).

In addition water evidently flushes through the soil just beneath the stony veneer with its associated hardened clay crust, for fines are washed downslope, in places forming a thin spead of alluvium downslope but elsewhere creating scallop-shaped depressions which extend from the stream line upslope.

In some areas the regeneration of eroded hamada results from stones being encountered as the surface is lowered, or are thrust to the surface by expansive clays (e. g. ELVIDGE a. IVERSON 1983; ENGEL a. SHARP 1958), but in the Stony Desert lack of a mixed calibre substrate below the surficial stone carapace rules out such repair and healing.

The physical characteristics of the gibber plains make road construction difficult. Unless the road surface can be raised above the level of adjacent areas, and drainage channels constructed on either side, sealed (bituminised) road construction is difficult in such areas. Sturts Stony Desert is traversed by the Birdsville Track, a gravel road which runs SSW unsealed for more than 500 km between just east of Birdsville, from its junction with the west-east Birdsville Developmental Road, and Marree, and another 80 km south to the bitumen at Lyndhurst. Road engineers are faced with a dilemma the solution of which is costly. The road has to be cleared of gibber, for the irregular surface produced by the scattered coarse blocks not only play havoc with the

Photo 9: (a) Gullies in bluff developed in kaolinised rock beneath silcrete capping and on gibber-strewn slope, near Bedourie, southwest Queensland. (b) Washed out track near Cordillo Downs, between Birdsville and Innamincka. (c) Gully developed on seismic shotline, and related alluvial fan, northeast of Innamincka

(a) *Gullies* in einer Felsenklippe, entstanden in kaolinisiertem, von *silcrete* überdecktem Gestein; der Hang ist mit *gibber* überzogen; in der Nähe von Bedourie, Südwest Queensland, (b) ausgewaschener Pfad in der Nähe der Cordillo Downs, zwischen Birdsville und Innamincka. (c) *gully* mit Schwemmfächer entlang einer seismischen Bruchlinie, nordöstlich von Innamincka

suspension of motor vehicles but the sharp edges of the silcrete fragments cut tyres. Thus, the track bed must be excavated and lowered. In rain, however, it becomes a ready-made drain, and is converted into a muddy morass which is susceptible to scouring and gullying. If, on the other hand, the road surface were to be raised by building up the bed with fines they would be washed away unless artificially confined by roadside walls. Bituminising a raised surface is the only practical solution, but in order to avoid or minimise disruption by gilgai effects, a thick (more than one metre) stable foundation would have to be constructed (HALLSWORTH et al. 1955; HUBBLE et al. 1983). Moreover, water draining from the sealed surface would have to be directed safely to surface or subsurface collecting and storage sites. Such reservoirs would be useful for livestock. Nonetheless, such road construction would be expensive. On the other hand, the present dirt roads are unreliable, dangerous, hard on vehicles and drivers, and expensive to maintain.

8　Conclusion

The gibber plains that constitute Sturts Stony Desert are protected and preserved by a carapace that in most areas consists of coarse fragments of silcrete derived from the disintegration of extensive sheets of that material. Only in a few areas has the gibber been reduced to small fragments and the intervening spaces filled by fines to produce a stone pavement. The gibber mantle has been spread over what is possibly an etch plain during an extended period of scarp retreat, during which the disintegrated silcrete capping was deposited under gravity as a lag.

According to some evidence, silcrete is a humid warm climate development, but it is preserved in aridity. The hamada or stony desert derived from it, however, is a desert feature, and is due to the presence of massive country rocks which break down into coarse fragments and form a lag deposit. Wind and water maintain the lag on higher ground though alluviation occurs on lower slopes and in river valleys. Churning takes place in the stony deserts of central Australia but is not critical to the development of gibber plains. Sturts Stony Desert is an hamada that is deservedly notorious for the problems it has posed and still presents to travellers. It is a forbidding region, "an unearthly prismatic landscape" (MOOREHEAD 1963, 212), which, however, holds considerable geomorphological interest for the silcrete hamada is unusual, if not unique, and produces distinctive characteristics in detail.

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BUCHBESPRECHUNGEN

Adler, Elchanan Nathan: Von Ghetto zu Ghetto. Berichte eines jüdischen Reisenden ausgangs des 19. Jahrhunderts. Nachwort und Erläuterungen von Joachim Schlör. 240 S. und 73 Abb., Jüdische Memoiren 6. Hentrich und Hentrich, Teetz 2001, € 20,–

Der englische Jurist Elchanan Nathan Adler, Zeitgenosse des Geographen Alfred Philippson, aber anders als dieser enger dem jüdischen Glauben und Leben verbunden, bereiste im ausgehenden 19. Jahrhundert in einem Zeitraum von zwanzig Jahren die weltumspannende jüdische Diaspora. Seine Reiseberichte legte er in einer Geographica Judaica nieder, in der er mit ethnographisch genauem Blick und im Jurastudium geschulter wissenschaftlicher Akuratesse das Leben der jüdischen Gemeinden in den unterschiedlichsten Ländern beobachtete und, dies macht die besondere Stärke des Buches aus, aus der inneren Perspektive des Judentums heraus beschrieb: Adler war stets mehr als der wissenschaftliche Beobachter, da er den soziokulturellen Kontext von innen heraus, als Jude unter Juden lesen konnte.

Aus der akutellen Sicht ist sein Blick auf die jüdischen Gemeinden im Nahen Osten und ihre arabischen Nachbarn von besonderem Interesse. Nicht weniger aufschlussreich sind seine Beschreibungen des jüdischen Lebens in Persien, Russland, Indien und Argentinien. Was Adlers Werk für den (historischen) Geographen so besonders macht, ist der „sozialgeographische" Blick des Autors. Seine Reisen nutzte der bibliophile Adler auch zum Sammeln von hebräischen Inkunablen und Altdrucken, die seit 1923 als Sammlung im Jewish Theological Seminary in New York liegen.

Adlers Werk, 1909 erstmals – im englischen Original unter dem neutraleren Titel "Jews in many Lands" – erschienen, wurde neu aufgelegt und mit einem informativen Nachwort von Joachim Schlör versehen, das Wissenslücken schließt, biographische Eckdaten nennt und in einem Glossar weniger zugängliche Begriffe erläutert.   Astrid Mehmel