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DISTRIBUTION, CHARACTER, AND ATTITUDE OF THE DURICRUST IN THE NORTHWEST OF NEW SOUTH WALES AND THE ADJACENT AREAS OF QUEENSLAND

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ABSTRACT. Air reconnaissance and ground inspection in the northwest of New South Wales and adjacent parts of Queensland show that the silcretic duricrust there is associated with a weathering profile up to 180 feet in depth. In places the duricrust is tectonically deformed. On geomorphic and distributional grounds the authors reject the view that silcrete was formed below ground during lateritization and deny the hypothesis that it has been exposed at the surface by general stripping. Although surface silicification is only partly understood, the process appears capable of acting in climatic conditions (apparently past rather than present; see below) generally similar to those of the field area. A review of selected literature and of geologic mapping shows that interpretations of silcrete in particular and of duricrust generally are greatly confused by assumptions both of date and of process.

INTRODUCTION

The term duricrust was proposed by Woolnough (1927) as a comprehensive name for the extensive indurated layers produced in Australia by former weathering. It applies indifferently to ferruginous and to siliceous crusts and could presumably be extended also to include calcareous crusts; these however are usually implicitly excluded from discussion, perhaps on account of their low resistance and their scanty surface exposure. The three terms, ferricrete, silcrete, and calcrete (Lamplugh, 1902, 1907) might be expected to serve as names for the three types; but whereas silcrete is typically siliceous throughout, ferricrete and calcrete have come to be applied to materials cemented by, but not necessarily mainly composed of, iron oxides and calcium carbonate. In consequence, laterite has come into general use for ferruginous crusts, and travertine or kunkar for more or less layered deposits of secondary lime.

Since travertine is preempted for connoting massive tufaceous deposits, we shall use kunkar for those Australian deposits that correspond to the caliche of North America. We shall confine laterite to materials that are highly ferruginous, in accordance with the original usage, and employ silcrete where that term is appropriate. As we shall demonstrate, confusion has arisen from the application of laterite to duricrust in general, regardless of its composition.

A possible cause of additional confusion is the extension of the sense of laterite to include the whole weathering profile. The duricrust is typically associated with a mottled zone, a pallid zone, and a transitional zone to underlying unweathered bedrock, in that order of descent. It is usually clear from the context whether a writer is referring to the whole profile, to the crust, or to that lower portion of a profile that has escaped erosion; but to apply the word laterite where for instance nothing above the pallid zone survives, can obviously be as prejudicial as to apply it to existing siliceous crusts.

Portions of the relevant earlier literature will be mentioned in a later section. A thoroughgoing review is impracticable, because of the great bulk of source material and the wide range of topics involved. The list of references is shortened by the omission from this paper of two topics which we shall treat elsewhere—pedimentation in our field area and the terminology of planation

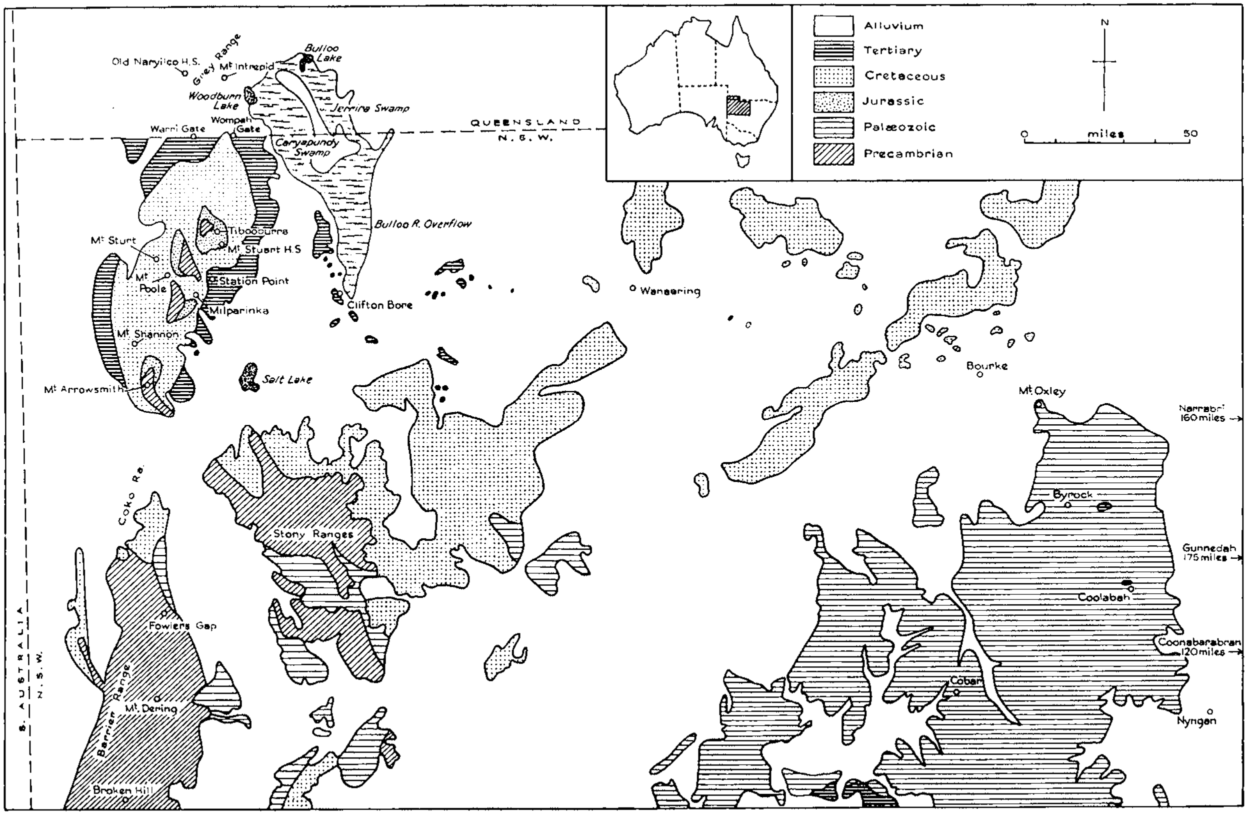


Fig. 1. Location map. Geological distributions are generalized from published maps; they are uncorrected for the errors specified in the text and do not include the boundaries of granite outcrops. Information on the relative distribution of surficial deposits and of rock in place is not available for the Queensland portion.

as it is applied in Australia; nevertheless, the reference list remains highly selective.

The findings recorded herein were obtained in a rapid traverse from Nyngan to Broken Hill, air reconnaissance and ground inspection in a belt of country extending northward from the Barrier Ranges into Queensland, and ground reconnaissance from Tibooburra to Bourke and thence to the southeast (fig. 1). The generalized outcrops marked in the figure correspond broadly to types of terrain—pediplains and complexly dissected hills on Paleozoic and older rocks, pediplain-and-mesa country on Cretaceous and Tertiary beds, and subdued relief, variegated by dunes and enclosed depressions, on the materials mapped as alluvium. The outcrop-boundaries selected correspond to those of the geological maps of New South Wales and of Queensland, but they cannot be regarded as wholly accurate since the duricrust itself appears to have been recorded at some points as a solid formation and assigned either to the Cretaceous or to the Tertiary. In addition, as we shall point out below, the separation of Tertiary from Cretaceous materials is not everywhere satisfactory.

THE DURICRUST AND THE ASSOCIATED UNDERLYING PORTIONS OF WEATHERING-PROFILE

Duricrust in the field area is widely developed on, but is by no means confined to, rocks mapped as Cretaceous or Tertiary, and on these rocks, the weathering profile attains its greatest observed depths (table 1). In most places it appears at the surface as rounded chert-like masses (pls. 1-A,B, 2A), although in certain exposures it has a bedded appearance (pls. 2-B, 3-A). In texture it varies from fine-grained to conglomeratic and vesicular. Where it is fine-grained, it consists of particles of quartz cemented by silica (pls. 3-B, 4-A); alternatively, for instance on Jurassic beds, it constitutes partially silicified sandstones. The main pebble content of the conglomeratic variety is white quartz, but pebbles of other materials are also present. Vesicular duricrust is best exposed in the Grey Ranges of Queensland, where it is reddish in color and superficially resembles laterite. However, sectioning (pl. 4-B) and chemical tests show that the color is due to loosely-held iron compounds, which coat individual grains of silica. In the Grey Ranges, as elsewhere, the duricrust consists of silcrete.

The thickness of the duricrust varies from a few feet to at least 40 feet; the depth of the complete profile ranges up to at least 180 feet (table 1). The greatest depth measured was recorded at Station Point, where the complete profile and part of the underlying stratigraphic succession are well exposed in a buttress (pl. 5-A). Away from the mesa country exposures are generally poor, except those of the surface duricrust. On the other hand, silcrete at the surface is readily identifiable in places from Clifton Bore almost to Bourke; along this traverse, the geological map of New South Wales records a number of Tertiary and Cretaceous outcrops (cf. fig. 1), but in actuality the material exposed is siliceous duricrust. No trace of duricrust was located on or near Mount Oxley, 20 miles southeast of Bourke, or on the (?) Silurian rocks exposed at ordinary low flow on the Darling River at Bourke Weir. The outcrop marked as Tertiary on the geological map, 54 miles southeast of Bourke and 10 miles east of By-rock, appears to constitute an error: a surface litter of gray fragments and quartz gravel appears to have been taken for bouldery silcrete and to have been assigned to the Tertiary.

Near Coolabah, 75 to 80 miles southeast of Bourke, railroad cuttings expose materials that, where they have been mapped, are again recorded as Tertiary, but in actuality they include ferricrete, a mottled zone, and a pallid zone which extends into the underlying shales. Shortly to the southeast again, conditions are obscured by sand plains, but temporary exposures indicate the wide occurrence of kunkar.

The road traverse from Nyngan to Broken Hill disclosed no duricrust, typical exposures being those of somewhat rotted bedrock beneath a few inches of soil. However, Andrews (1911, p. 31) reports silcrete from the Cobar district, distinguishing it from outcrops of siliceous Silurian rocks, whereas Mulholland (1940, end-map) and David and Browne (1950, v. 1, fig. 75) record cappings of sandstone, ironstone, and grey billy [*sc.*, silcrete] to the southwest of Cobar, mapping them all as Tertiary (cf. fig. 1). That is to say, the duricrust appears at least in part to be silcretic upon the Cobar block.

Numerous exposures of laterites and their associated weathering profiles occur around Coonabarabran, Narrabri, and Gunnedah, east of the area illustrated in fig. 1. The ferruginous indurated zone, where present, can be highly pisolitic and contrasts strongly with the siliceous duricrust of the country west of Bourke.

ATTITUDE OF THE DURICRUST

In the absence of reliable topographic information and final stratigraphic correlations, the attitude of the duricrust in our field area is not easy to specify throughout. However, it seems to be almost flat lying in the Mount Sturt–Mount Poole–Station Point area where it caps summits in the probable range 870 to 960 feet above sealevel. It occurs here on rocks referred by David and Browne (1950, v. 1, p. 543-544) to the Eyrian Series and placed by them in the Tertiary, but if the geological map of New South Wales is correct in placing some of the occurrences on Cretaceous rocks, then these rocks would seem to belong to the Winton Series of David and Browne (p. 499, 503). We do not doubt that the succession is identical in the two areas, for in both of them, as at the unnamed peak 15 miles north of Mount Sturt, black claystones form cappings to sub-scarps and weather into distinctive gravels and are followed downward by beds that include beds of gypsum. Little warping has occurred in this district since the duricrust was formed. However, northward towards the Queensland border and also eastward from Tibooburra, the duricrust descends gently and eventually disappears beneath sand plains. Marked folding deforms it in the southern end of the Stokes Ranges, where two anticlines and an intervening syncline bridge an east-west distance of 5 miles and exhibit dips as great as 5°; the descent of the duricrust from the western flank of the Grey Ranges and their outliers is exposed in a tank near Old Nariylco Homestead (pl. 5-B), where the underlying pallid zone is also visible. The descent from the summits of the southern Grey Range to this spot is about 500 feet.

Between Station Point and Clifton Bore the duricrust falls from 870 to about 300 feet above sealevel; near the Bore it is thrown into small sharp folds

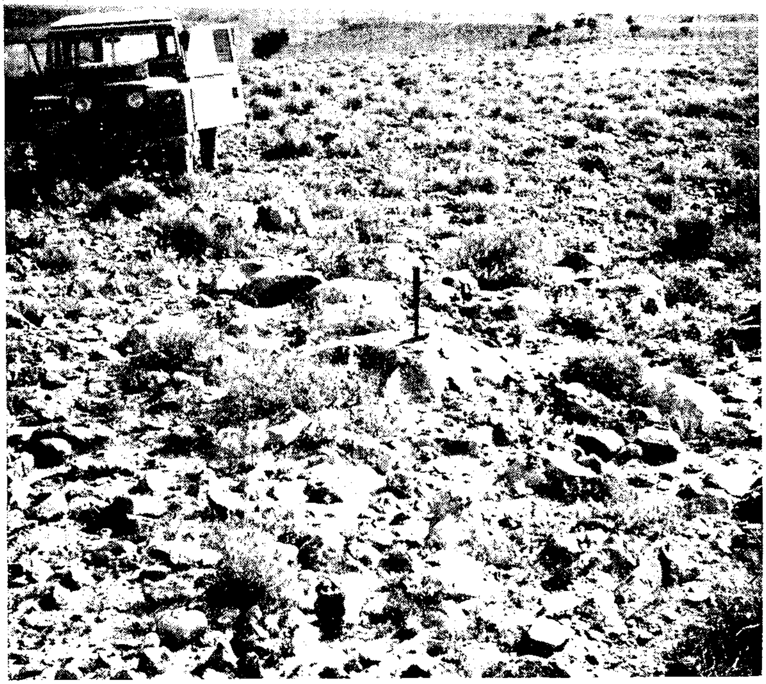
TABLE 1

Summary of characteristics of selected exposures

Locality	Duricrust	Mottled Zone	Pallid Zone	Transition Zone	Bedrock
Near Mt. Dering, 30 miles N of Broken Hill Fowlers Gap, 60 miles N of Broken Hill	Highly siliceous quartz conglomerate and chert-like masses, possibly 6 ft thick, flat-lying on tabular summits	Not seen	Possibly not more than 6 ft thick	Not seen	Precambrian shales
12 miles WSW of Tibooburra	Duricrusted, mottled, and bleached Jurassic sandstones with slight dips ——→		←—— Precambrian shales with steep dips		
2 miles N of Tibooburra	Total depth to base of transition zone, 15 ft ——→				
1 mile N of Tibooburra	10-ft thickness of flat-lying Jurassic sediments ——→				←—— Granite.
Station Point, 14 miles SE of Tibooburra	Highly siliceous chert-like masses at surface, finegrained to conglomeratic, thickness 4 to 6 ft; flat-lying	3 to 5 ft, mainly porcellanite but some coarse sandstone	170 ft of porcellanite and kaolin with some sandstone and conglomerate	About 20 ft of weathered gray shales and claystones	Mudstones and claystones with a high content of salt and gypsum; gypsum beds as much as 6 ins thick. Total exposure of bedrock, about 100 ft
Mt. Poole-Mt. Sturt area, 20 miles SW of Tibooburra; unnamed peak 15 miles N of Mt. Sturt	As at Station Point	Less well exposed than at Station Point, but exposures available indicate very closely similar conditions			
Grey Range, 6 miles S of Warri Gate	2 ft deep, siliceous, highly conglomeratic in places; caps mesa	About 10 ft deep	Not well exposed; perhaps 50 ft	50 ft or more of weathered claystones exposed; flat-lying	

Table 1 (Continued)

Locality	Duricrust	Mottled Zone	Pallid Zone	Transition Zone	Bedrock
Grey Range, 16 miles N of the State Line, near Mt. Intrepid	40 ft deep, vesicular; superficially resembles laterite	60 ft	50 ft	Not seen; mapped as Tertiary, apparently flat-lying	
Near E face of Grey Range, N of State Line	Highly siliceous; occurs in cuestas with dips as great as 45° and also on low ground where it is flat-lying	Not fully exposed ——→	——→	Not seen	
Stokes Range	Highly siliceous; exposed at surface on and near anticlinal crests				
Clifton Bore to near Bourke	Numerous exposures of bouldery silcrete at surface; folded in places				
Near Coolabah, 75 to 80 miles SE of Bourke	Coarse pisolitic conglomerate, lime deficient and containing ferricrete	Present	Present ←——	Present —— Steeply-dipping	Precambrian shales



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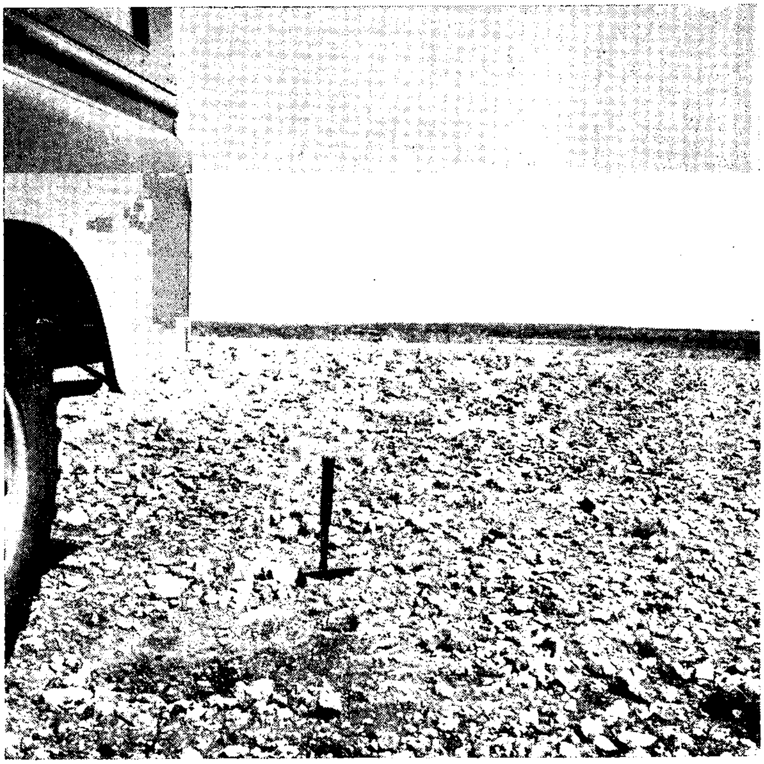

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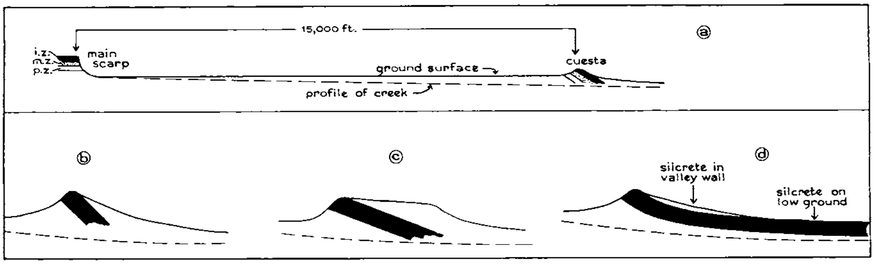

Fig. 2. Relation between silcrete outcrops and the ground surface along the eastern edge of the Grey Range: a, section from main scarp to cuesta—i.z. = indurated zone, m.z. = mottled zone, p.z. = pallid zone; b,c,d, variant relations of silcrete to cuestas and associated forms.

with wavelengths of about 1000 feet. We infer from these and following observations that the Bulloo River Overflow and the associated swamps and lakes are contained in a tectonic depression, in contrast to the view of David and Browne (1950, v. 1, p. 14) that the Overflow reflects the river's inability to persist across dry country. Our conclusion is in accord with the subsurface contours on the tectonic map of Australia.

Deformation is most marked along the eastern flank of the Grey Ranges, where the duricrust forms small cuestas, offset by minor faults and exhibiting eastward dips as great as 45° (pls. 2-B, 3-A; fig. 2). As figure 2 records, the outcrops of duricrust are somewhat variably related to the form of the ground. We interpret the quite strong folding in this area as monoclinal and as associated with the depression that contains the Bulloo River Overflow and other enclosed basins.

DISCUSSION

Some previous workers have taken the silcrete for the uppermost horizon of a complete weathering profile, whereas others have identified it as the stripped remains of a laterite from which the ferruginous zone has been removed. The relevant arguments overlap with those about laterite itself, the indurated zone of which has been regarded by some writers as formed underground. Others again look on silcrete as due to the silicification of former laterite. However, the change in a northerly direction in our survey area, from gray silcrete to silcrete strongly reddened by grain coatings, suggests to us that silcrete very poor in iron may pass laterally into highly ferruginous laterite very poor in silica. The contrast between the two extreme types may result from differences in locale of induration, with differences in the types of rocks affected a powerful ancillary factor. There is room for inquiry into the original relative heights of ferruginized and silcreted expanses and into the connection (if any) between the silcrete duricrust and the former lakes described for our field area. Alternatively or in addition, the distribution of silcrete as opposed

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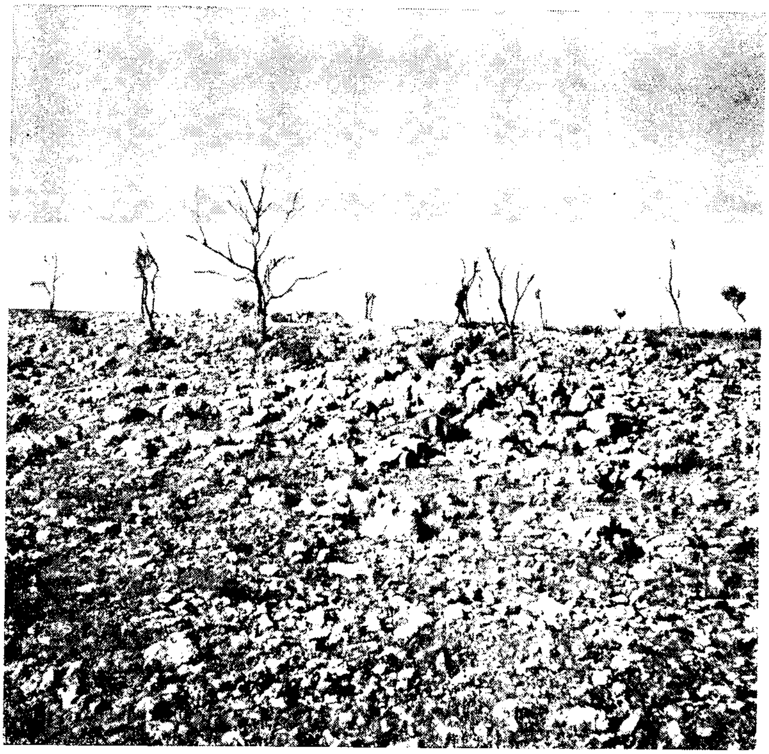
PLATE 1

A. Surface silcrete, on summit near Mt. Dering, Barrier Range.

B. Surface silcrete on mesa summit at Station Point, illustrating result of spalling.



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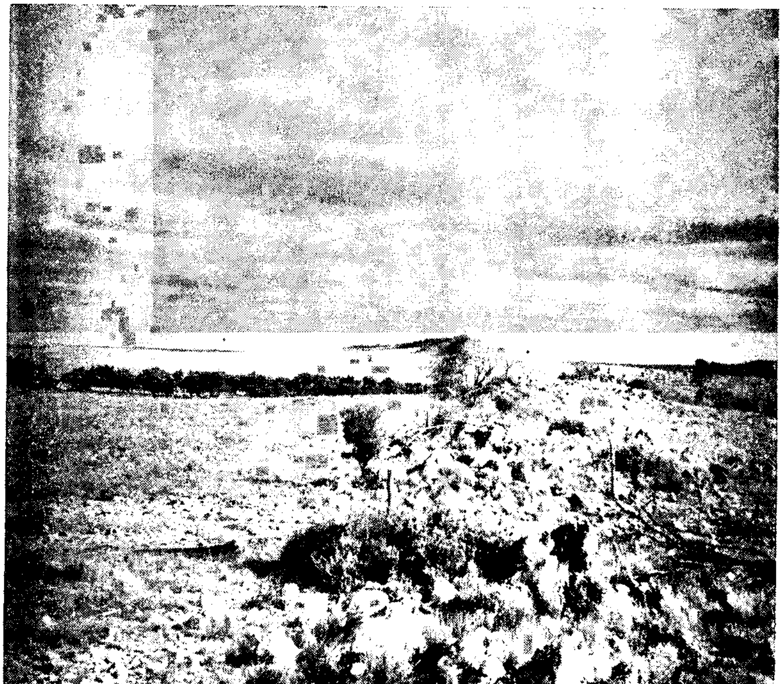

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to laterite seems to require study in the light of the findings of Coonah and Hubble (1960; see below) for Queensland, and also of the change in our field area from silcrete near Bourke to laterite in the Eastern Highlands and their western slopes.

Woolnough (1918) early associated laterite with extensive erosional platforms, following Simpson (1912) in noting a variation in composition with variation in the underlying bedrock. However, in the paper (Woolnough, 1927) where he introduced the term *duricrust* and claimed for it the rank of a stratigraphic unit, Woolnough observed that the laterite of Western Australia is dominantly siliceous (p. 25, 40). His association of duricrusting with peneplanation was not, in our view, especially fortunate, since it tends to prejudge the interpretation of conditions in which duricrust formed. By definition, the peneplain is the end-product of the normal, or fluvial, cycle of erosion—that is to say, of erosion in a climate not less than subhumid.

Whitehouse (1940), to whom is due the term *pallid zone*, appears to have assumed from the outset that the silicified layer formed below ground, sometimes as a basal horizon and sometimes at levels above the base (p. 8, 13). Reasoning from the presence of silcrete boulders in a laterized late Tertiary sediment in the Flinders valley, he concluded that the silicification of the base of the ferruginous zone must be later than the laterite and accordingly that there were two periods of formation (p. 17-18). However, it seems at least possible that he was misled by reworked laterite, especially since the duricrust in the relevant area is known to have been tectonically deformed (Woolnough, 1927, p. 32-33), or by lateritization which succeeded and was distinct from silcreting, as inferred by Wopfner for inland South Australia (Wopfner, 1961; see below.)

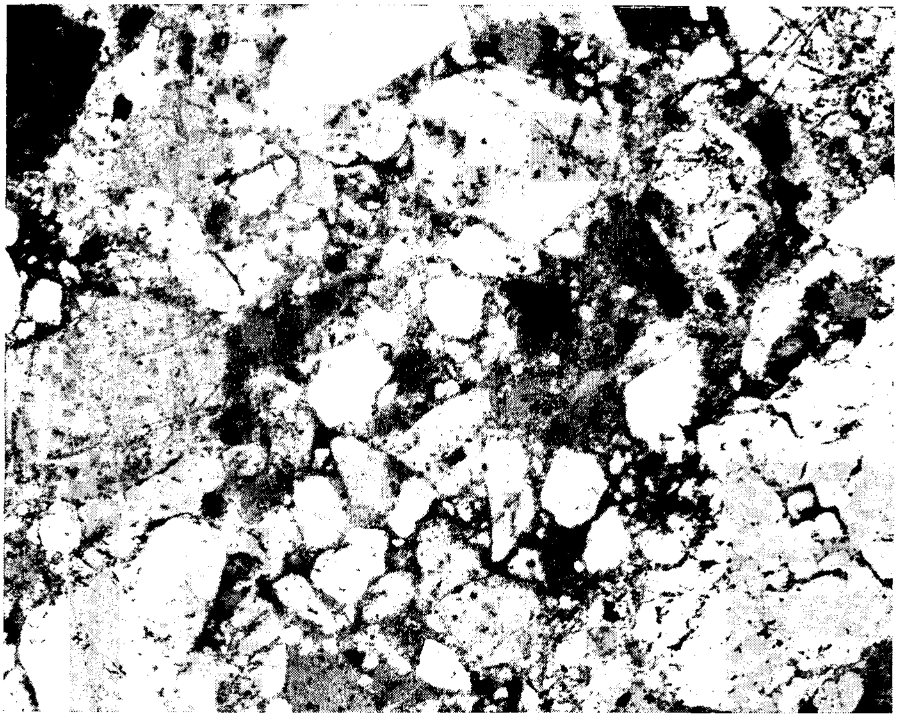
David and Browne (1950, v. 1, p. 565-566) referred the silica of siliceous duricrust to decomposition of silicates and its reemplacement to the leached region, stating that removal of pisolitic laterite has in certain places laid bare a surface of the leached zone and frequently of the siliceous layer. Stephens (1946) identified the lateritic profiles of South Australia as essentially podsol profiles, regarding the indurated layer as formed at or near the boundary of the A_2 and B horizons (p. 9-10, fig. 2). Prescott and Pendleton (1952, p. 43) also identified laterite as essentially the exposed illuvial horizon of an ancient soil for which they postulated original eluvial horizons above. These several views agree generally with those of Mohr (1933) that a siliceous horizon in a fully developed laterite profile is due to cementation by siliceous weathering products. Teakle (1936), Prescott and Pendleton (1952, p. 33), and Litchfield and Mabbutt (1962) described siliceous hardpans, which Prescott and Pendleton ascribed to inundation by silica-rich floodwater, but Jackson (1957) discriminated between these hardpans and the massive silcrete of the interior.

PLATE 2

A. Silcrete at surface on low ground, near eastern scarp of Grey Range, Queensland; outcrop occurs immediately east of main monoclinal downblending to eastward.

B. Silcrete cuesta near Grey Range; view is to south, dip to east. Portion of main scarp is visible on extreme right of the view.

A.



B.

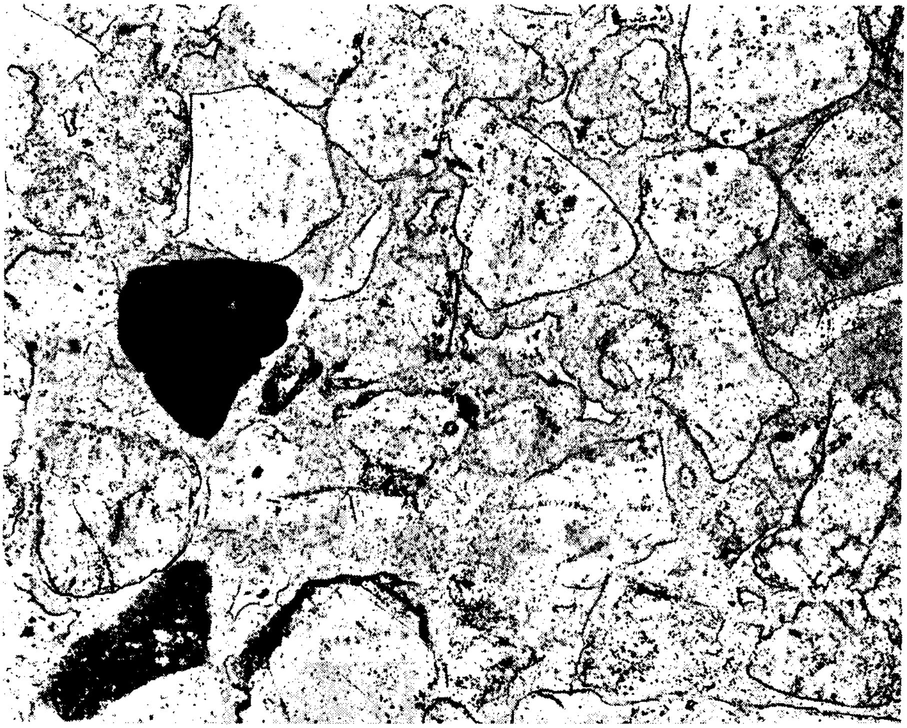
Prescott and Pendleton concurred in previously-expressed opinions, for which they cited authorities, that duricrust residuals need not be part of a former continuous sheet, but may correspond to former topographic depressions (1952, p. 25-26); they concluded, moreover, that desert basin topography could have been favorable to duricrusting, if the climate changed in the direction of increased rain. Playford (1954) recalled that most previous authors held laterite to have formed under a humid climate, whereas Jackson (1957) outlined the way in which climatic change came to be invoked in explanation of siliceous crusts. But, as Jackson observed, such crusts are characteristic of present-day arid environments throughout the world, and the widespread calcareous crust on the southern fringe of the Australian arid zone and in the contiguous semi-arid belt has its homologues in very large areas of other continents. White (1954) envisaged laterites either as weathering products in place or as illuvial horizons with the end-products of weathering constituting duricrusts or immature laterites. True laterites he ascribed to illuviation. While this is by no means the only possible cause of the difference between silcrete on the one hand and the indurated (ferricreted) zone of a weathering profile which contains laterite, White usefully drew attention to the difference itself.

Owen (1954, p. 171-172) recorded the extension of *laterite* to apply not only to the indurated zone but to all products of the process of lateritization. While accepting this extension, he condemned the practice of calling siliceous rocks laterite. Connah and Hubble (1960) protested against the extension of the term *laterite* to a complete profile, urging its restriction to the indurated zone or its equivalent. They described the laterites of Queensland as highly ferruginous with varying bauxite content—including commercial bauxite in places (cf. also Owen, 1954). They considered laterites to be essentially the illuvial horizon of ancient soil profiles, with highly siliceous forms developed from parent rocks high in quartz—silcrete developing in sandy materials and porcellanite from clay sources. They associated great sheets of silcrete with dry inland regions with insufficient drainage for the removal of silica and (following a personal communication from Reynolds) possibly with a phase of particular aridity, sheet-flooding, and the development of a siliceous gel. Their map (1960, p. 379, fig. 54) recorded no ferruginous indurated zone in the southwestern third of Queensland but numerous occurrences in this area of silcrete and of mottled and pallid zone. As mapped by Coonah and Hubble, exclusive occurrences of silcrete appear to be confined to the inland basins and to the Grey and neighboring Ranges, roughly within the present-day annual isohyet of 10 inches. The presence of ferruginous crusts between this southwestern area and the coast recalls the difference in New South Wales between the silcrete westward from Bourke and the laterites of the Eastern Highlands and their bordering slopes.

PLATE 3

A. Detail of silcrete in cuesta near the Grey Range, illustrating steep eastward dip of monoclinal fold.

B. Silcrete from near Mt. Dering, in thin section between crossed nicols; actual width of field is 2 mm. Material shown is mainly quartz.



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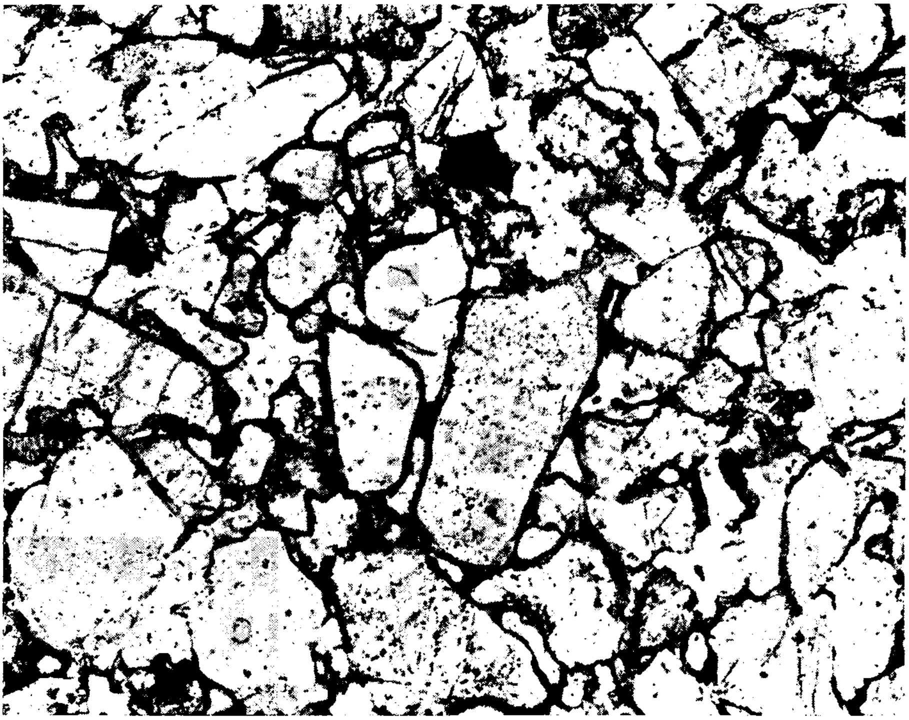

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Williamson (1957) recalled that Frankel and Kent (1938) took the silcretes of the Grahamstown area in South Africa to have been derived from subsoils of residual deposits, colloidal solutions of silica migrating upward and, in all probability, water enriched with sea salt migrating downward. Frankel and Kent (p. 39) concluded that the process of silicification was discontinuous in time, probably on account of climatic variations, since a seasonally-fluctuating water table is essential for the formation of silcrete. In a later paper, Frankel (1952) clarified certain textural variations of silcrete and confirmed the earlier conclusion that silcrete forms in regions of poor drainage. Williamson himself (1957), reviewing terminology and site conditions, distinguished among silicified aeolian sands, silcretes, and sub-basaltic quartzites. It is the second and third of these forms that are commonly referred to in Australia as *billy* or *grey billy*; these terms are exchangeable and synonymous in ordinary usage, despite some attempts to restrict the one to silcrete and the other to sub-basaltic quartzite.

Indiscriminate application of the term *laterite* to highly siliceous duricrusts and their associated weathering profiles, such as is usual with certain of the earlier authors whom we have mentioned, seems to us at least in part responsible for the many attempts to reconstruct former horizons above the silcrete. Furthermore, as Playford (1954) pointed out, material frequently overlying laterite, and as frequently taken for a fossil illuvial horizon, is in Western Australia commonly the sediment of sand plains. Additional observations relevant to this matter will shortly be noticed from Wopfner; in our field area, as we have already stated, the duricrust is in places downbent and passes beneath considerable thickness of sediment which we take to be younger than the duricrust, whereas in other places it is thinly buried by sheets of sand. In opposition to most previous writers (Prescott and Pendleton, 1952, and references therein) Playford contended that laterite formed on a surface already uplifted and dissected. It is not necessary to accept this contention in order to resist the hypothesis of general stripping—stripping of a conjectural layer of unconsolidated material from the indurated layer which is all that now remains.

If stripping has taken place, it would need to be remarkably constant over vast areas and to have removed the entire cover from uniform sheets of silcrete. In our field area it would need to have been completed before the duricrust was folded but to have been followed by very little erosion on the summits subsequent to folding. The mechanics of a process that could cleanly strip the silcrete throughout an area of 40,000 square miles are difficult to imagine, and this is but a small sample of the occurrence of surface silcrete not only in Australia but also in other continents. Bassett (1954) described widespread

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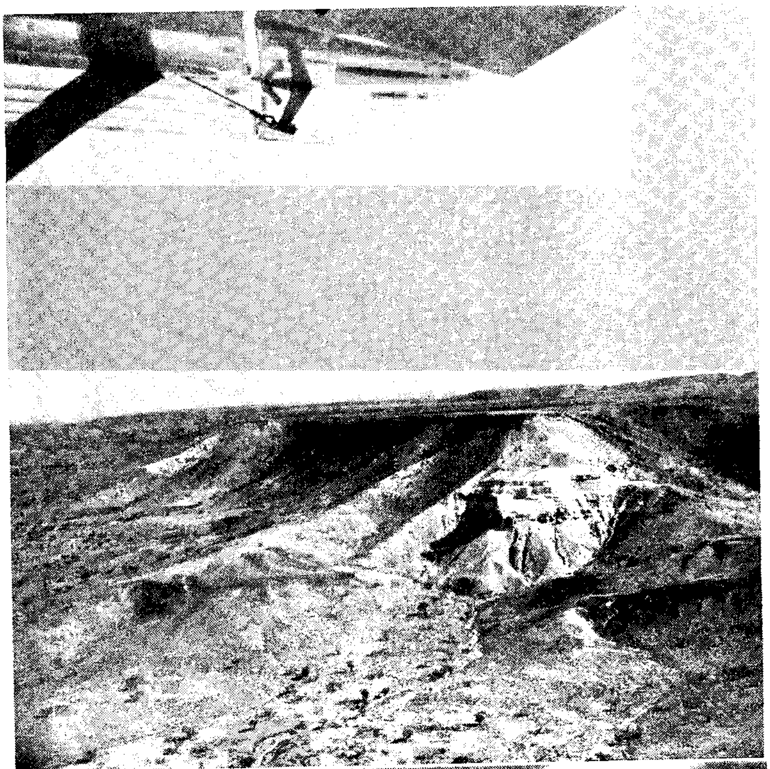
PLATE 4

A. Silcrete from Station Point, in thin section under plane-polarized light; actual width of field is 2 mm. Material present is mainly quartz, with one grain of (?) leucoxene; quartz grains are cemented by interstitial quartz and are slightly iron-stained on their faces.

B. Silcrete from the Grey Range, in thin section under plane-polarized light; actual width of field is 2 mm. Material present is mainly quartz; the grains are cemented with interstitial quartz and are considerably iron-stained on their faces.



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B.

surface silicification of rocks in Tanganyika, ascribing it to laterally moving alkaline solutions produced by the weathering of basic rocks. Similarly, d'Hoore (1954) noted that free colloidal silica can be highly mobile in alkaline surroundings. d'Hoore illustrated (p. 25) an increase in mobile silica with depth in the profile and also a marked increase, depth for depth, in the downslope direction, inferring a riverward migration; he also concluded (p. 74) that its vertical transport results very largely from the action of plants.

Jessup (1960a) referred at several points to truncated laterites and maintained that silicified layers commonly occur within the pallid zone. He constructed what seems to us to be a needlessly complex sequence, namely (p. 100) truncation of laterites, deposition of ferruginous and silicified materials on the exposed mottled and pallid zones, and silicification of the uppermost layer of these deposits. Ollier (1961) has further criticized Jessup's interpretation of lag gravel. In Jessup's view, all the silcreted mesa-tops must formerly have been bordered by still higher ground, which formerly supplied the silica but which has subsequently been eroded away in its entirety—unless the silica moved upward through the profile, a supposition presumably denied by Jessup's assignment of the silicified layers to the pallid zone (Jessup, 1960b, p. 106; 1961c, p. 203).

Although most early writers assumed that laterite (and siliceous duricrust) was produced on surfaces of low relief, there is now evidence of simultaneous development on plateau-tops and alongside rivers incised into the plateaus (d'Hoore, 1954) and of laterization on slopes as great as 8° (Mulcahy, 1960) or 10° (Playford, 1954). For all that, Jessup's inference (1961b, p. 112) that the duricrusted surface of the Grey Range had considerable original relief and that dissection has left remants of varying height seems to overlook the evidence of strong tectonic deformation which we have reported. Jessup's association (1961c, p. 201) of the youngest erosion surface with the lower part of the pallid zone or with unweathered rocks beneath could not apply on the margins of the Grey Range.

Wopfner (1960) reported from part of the Great Artesian Basin, west of our field area, combined thicknesses of mottled and pallid zones from 100 to 250 feet and an average thickness of 13 to 30 feet for siliceous duricrust. Similar thicknesses were listed for inland sites in Queensland by Connah and Hubble (1960). Wopfner provisionally related the folds by which duricrusted rocks are affected to Cretaceo-Tertiary tectonic activity and to transcurrent movements in the basement. In this area also, folding postdates the duricrusting. Wopfner used borehole records to show that the duricrust descends as much as 280 feet below ground on the north side of Lake Yamma Yamma and stated that, in structural depressions, the silcrete is overlain by laterite and

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PLATE 5

A. Station Point from the air, showing the complete weathering profile exposed in a buttress. Depth from summit to base of pallid zone is 180 ft, depth to base of buttress is about 280 ft.

B. Westward-dipping silcrete exposed in tank near Old Nariylco Homestead, Queensland. The observer (the senior author) stands at the top of the silcrete layer.

laterized sands with a maximum observed thickness of 120 feet. In a succeeding paper (Wopfner, 1961) the same writer stated that the duricrust in northeasternmost South Australia forms extensive dip slopes, approximately half way down which there comes in dark brick-red, nodular (pisolitic) laterite, thickening towards the synclines. He described the contact between the laterite and the duricrust either as conformable or, where dips are steep, erosionally disconformable. Wopfner concluded that the laterite is younger than and has been formed on top of the silcrete, to the formation of which it is not directly related. Laterization he regarded as having affected late Tertiary to early Pleistocene soils, developed on sands and silts younger in age than the duricrust.

Wopfner's interpretation, in addition to emphasizing the need which we ourselves urge to consider the silcrete for its own sake rather than to attempt to force it into some hypothetical weathering profile, could dispose immediately of the need to postulate general stripping of laterite from horizons above the silcrete, in order to account for lateritic material at low topographic levels. In addition, Wopfner (1961) placed travertines [*sc.*, kunkar] still later than the lateritic material. In the light of the comments of Jackson (1957, above), it seems better to look to climatic shifts and climatically-controlled pedogenesis to explain the wide distribution of kunkar in southern parts of Australia (including portions of the Cobar block) than to appeal primarily to specific source areas of lime (cp. Crocker, 1946; Jessup, 1960c, 1961a).

Efforts to assign a single and particular date to the duricrust appear to have been less than conclusive, and if Wopfner's discrimination between silcrete and laterite is valid, they have also been confused by the assumption that the two are everywhere variant forms. Some later writers have unwarrantably ascribed to some earlier writers a precision not present in the relevant texts. Thus Woolnough (1927, p. 40, 42-50) associated the duricrust with a peneplain produced in *or about* [our italics] Miocene time. If the word *about* has any significance, it must surely admit a range at least from late Oligocene to early Pliocene. Bryan (1939, p. 30) makes a tentative and partial time-correlation between the Red Earth residuals of southeastern Queensland and the duricrust, assigning to these residuals an age *no later than Pliocene* [our italics]; on the strength of this, Whitehouse (1940) cited Bryan as indicating a Pliocene age more likely than Miocene and, as previously stated, inferred at least two periods of lateritization in the Pliocene. David and Browne (1950, v. 1, p. 566; v. 2, p. 6) suggested a lower and Middle Miocene age, whereas Glaessner and Parkin (1958, p. 44) described the laterization of the Flinders country of South Australia as early Mesozoic. Hallsworth and Costin (1953) inferred two episodes of laterization for New South Wales, one in the Miocene responsible for deep weathering profiles and one in the Pliocene responsible for shallow laterites in valleys and for the younger laterites of the uplands. They associated both with humid tropical or subtropical climate. Jessup somewhat inconsistently assigned the laterization of his two areas to both the Pliocene (1960c) and the early to middle Tertiary (1960c). Connah and Hubble (1960, p. 375-377) reviewed proposals of dating additional to those mentioned here, including a claim that laterite is forming at the present time in part of Queensland; they concluded that there is no evidence of pre-Tertiary laterization in that state and that the process possibly ranged over a considerable part of the Cenozoic.

The general difficulty throughout is that duricrusted rocks of post-Jurassic age are typically unfossiliferous and that dates not only for the duricrust but also for critical parts of the stratigraphic succession are conjectural. We have signalized above what appears to be a confusion of Cretaceous with Tertiary outcrops in the northwest of New South Wales; even the detailed work of Wopfner (1960) must rely on lithology for correlation of unfossiliferous strata of assumed Tertiary age. Similarly, folded and duricrusted beds in South Australia, which are also unfossiliferous, can be assigned but tentatively to the early Tertiary (Glaessner and Parkin, 1958, p. 97). In all this, there is no means of obtaining a critical fix for the onset of duricrusting, if indeed the duricrust ought to rank as a stratigraphic unit. King (1950) went further than any other writer in the general correlation of erosion-surfaces in the southern hemisphere, but whereas he identified high-level [that is, non-detrital] laterite as the regolith of his Gondwana (pre-Cretaceous) and Indian (Cretaceous to mid-Tertiary) land surfaces, he also affirmed that locally it may be of highly variable age. The confusion in portions of the Australian literature is exacerbated by the implicit or explicit assumption that the duricrust, and especially the siliceous duricrust, is part of a sedimentary sequence. This assumption has been carried over from the days when the formation was described and mapped as Desert Sandstone and still appears wherever silcrete is recorded as Tertiary sediment on the geological map of New South Wales and where the silcrete is mapped as laterite and classed as Tertiary on the corresponding map of Queensland. In any event, the present tendency of available evidence to place duricrusting somewhere in the Tertiary raises formidable problems of palaeoclimatology, for the diagram reproduced by Bullard (1964, fig. 10) shows Australia as moving progressively away from the South Pole throughout the interval from late Permian to the present day.

The problems in question may find at least a partial solution in the evidence obtained by Dorman and Gill (1959a,b), who use the results of oxygen-isotope analysis to indicate a significant decline in temperature, at about 38° S lat, from about mid-Oligocene times onward; the steepest part of the decline appears to have set in about the mid-Miocene. At the same time, the scope and effects of changes in humidity remain obscure. Perhaps the most that can be said at present is that the evidence available as yet is not inconsistent with hypotheses of deep weathering in sub-tropical climates—or rather, climates of existing sub-tropical types—during the middle Tertiary.

CONCLUSIONS

As our review of selected literature demonstrates, interpretations of silcretic duricrust are frequently complicated by the loose assumption that it belongs to a weathering profile associated with laterite. Hypotheses of laterization have been made to depend on assumptions of peneplanation and have led to ancillary hypotheses of climatic shift. Attempts at dating relied at first on the assumption that the duricrust is a sedimentary formation—a view that still affects the mapped records of its distribution—and later upon postulates of planation and of correlations among strata that are almost or entirely unfossiliferous.

The hypothesis that surface silcrete has been exposed by the partial stripping of a laterite profile raises grave geomorphic difficulties; it can however be disposed of by recognizing that silcrete, as opposed to laterite, is characteristic of dry inland areas, even though the mechanics and chemistry of surface silicification are not fully explored. Although lithology and site characteristics exert their influence, it is scarcely to be disputed that the transition bauxite–laterite–silcrete–kunkar not only typifies the latitudinal range from the Gulf of Carpentaria to the southern part of the Cobar block but can also be paralleled from other continents in generally similar climatic settings. This latitudinal succession may well however be complicated by vertical changes, in accordance with Wopfner's time-separation of silcrete, laterite, and kunkar, in that order of formation. Wopfner's evidence of laterization distinct from and subsequent to silicification resolves the problem posed by lateritic materials at low levels where surface silcrete occurs at higher levels and is a further challenge to the hypothesis of stripping.

We ascribe the monoclinal folding of the silcrete at the eastern margin of the southern Grey Range to the continuing subsidence of a tectonic depression. Anticlines and synclines of modest amplitude and wavelength occur in the Stokes Ranges and near Clifton Bore, whereas gentle warping accounts for part at least of the descent of the silcrete toward and beneath the present ground surface.

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