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LATERITE IN AUSTRALIA

by

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LATERITE IN AUSTRALIA

SUMMARY

Laterites are widespread throughout Australia. Their origin and occurrence are related to Tertiary tectonic and physiographic history and their distribution accords in a broad way with present-day physiographic regions. Typically, an upper concretionary zone, ferruginous and aluminous, passes downwards to zones of residual weathered rock distinguished by differing proportions of iron oxide, alumina and kaolinitic material. In the drier parts of northern and central Australia and the western plains of Queensland an upper, concretionary, ferruginous zone passes down to a mottled kaolinitic zone, through a pallid kaolinitic zone, to less weathered parent-rock. A zone of secondary silicification may be present. The proportion of Fe_2O_3 decreases from the surface downwards. In the Eastern Highlands, where many of the laterites have formed on basic igneous rocks, the upper concretionary zone may be succeeded in turn by earthy, nodular, and granular laterite, kaolinitic clay and weathered rock. The proportion of Fe_2O_3 below the concretionary zone may remain virtually constant. In areas of relatively high and uniform rainfall, generally along portions of the coast and of the Eastern Highlands, the laterites are markedly aluminous.

Australian laterites typically occur as surface cappings on flat-topped hills and tablelands. These are residuals of an early Tertiary mature erosion surface, commonly referred to as a peneplain. It has generally been accepted that the laterites developed as a result of prolonged weathering and leaching of the surface rocks, possibly under warmer and moister climatic conditions than those that prevail at present. The prolonged weathering postulated for lateritization has been linked with that which led to the development of the very mature early Tertiary surface or peneplain, and following this to a logical conclusion the two surfaces "laterite" and "peneplain" have practically been regarded as synonymous. Epeirogenic uplift and rejuvenation of drainage signified the end of the peneplain and also of the period of lateritization. However, in some areas sheet-like deposits of laterite follow the slopes of pre-laterite valleys, and here at least uplift and rejuvenation of any earlier peneplain must have taken place before the laterites were formed.

Because of the absence of Tertiary sediments that contain suitable fossils the age of the laterites can, in few places, be determined within close limits. They have generally been thought to have developed during the Miocene. However, evidence is accumulating that the period of still-stand to which the lateritization is related dates back at least to the Oligocene. Some laterites formed as early as mid-Eocene time, and in a few restricted localities lateritization appears to have persisted for some time after the end of the Miocene.

INTRODUCTION

Lateritic deposits are known throughout Australia. In occurrence and origin they are linked with Tertiary tectonics and physiographic history. A brief review will be made of the tectonic history of the continent since the Mesozoic and its present-day physiography. This will be based on David, 1950 (edited by W.R. Browne) and the succeeding sections on laterite will be drawn in part from David (1950), Prescott and Pendleton (1952) and Owen (1954). These authors give numerous references of which only a few will be repeated here.

TECTONIC HISTORY

Excepting a small coastal area in southern Queensland where Mesozoic rocks were folded at about the end of the Cretaceous the Australian land mass has not been subjected to orogeny since the end of the Palaeozoic. Epeirogenic movements during the Mesozoic and Tertiary resulted in both uplift and in sinking of the continent as a whole. Portions of the continent experienced greater uplifts than the average and these are included in the principal highlands. It may be assumed that they initially had a somewhat higher elevation than the average, particularly within the boundaries of the area occupied by the folded, intruded and metamorphosed rocks of the Tasman Geosyncline. Other regions lagged behind as lowlands, sunklands and marginal basins. Uplift at the end of the Cretaceous was succeeded by a long period of stability accompanied by weathering and erosion which resulted in the development of very mature or senile land forms early in the Tertiary. The opinions of most Australian geologists in the past go further than this, and imply early Tertiary peneplanation. Over practically the entire continent erosion had become negligible and the surface was encrusted with the products of prolonged weathering and leaching. In other words, over vast areas, it had become lateritized. The surface capping, which Woolnough (1927) termed "duricrust", varies in composition from place to place ranging from ferruginous to siliceous and aluminous. The term "laterite" has been applied in Australia and elsewhere to the ferruginous and aluminous cappings. The siliceous cappings originated through deposition of the silica leached from the weathering rocks. Although it is a product of lateritic weathering many workers prefer not to classify it as a type of laterite. Later this siliceous material will be related more directly to its mode of origin by terming it a silicified zone of a lateritic profile.

Epeirogenic movements during the Tertiary included at least a minor uplift in Eastern Australia during Eocene or Oligocene, continent-wide differential elevation about the end of Miocene and a general uplift towards the end of Pliocene. Throughout most of Australia the very mature or senile erosion surface already described had developed probably early in the Tertiary and certainly before the end of the Miocene. In the Eastern Highlands this erosion surface did not reach such an advanced stage of maturity. The Miocene uplift resulted in dissection of the mature early Tertiary surface. Rejuvenated streams cut wide Pliocene valleys into it. In the interior the valleys widened out as broad plains between flat-topped lateritized remnants of the early Tertiary surface. The late Pliocene uplift resulted in further rejuvenation and erosion.

The Tertiary movements in the Eastern Highland Belt were accompanied by vast outpourings of basalt. "Older Basalts", probably mainly Oligocene but in part older, flowed over large areas in New South Wales and extended into south-eastern Queensland and eastern Victoria. They filled valleys that had been eroded since the early Tertiary uplift. Apparently they were little affected by erosion and their surfaces became lateritized. "Newer Basalts", Pliocene in age, covered portions of Queensland, Victoria and Tasmania. Pliocene basalt at Myalla in north-western Tasmania has apparently been bauxitized but elsewhere the Newer Basalts show no evidence of lateritization.

The epeirogenic movements resulted in local warping, faulting and tilting particularly in the southern part of eastern Australia. Resultant obstruction of drainage and the damming of rivers by basalt flows was followed by lacustrine sedimentation over parts of the early Tertiary mature surfaces and their lateritic cappings.

PHYSIOGRAPHY

The Australian continent comprises three main topographic regions - the Great Western Plateau, the Central Eastern Lowlands, and the Eastern Highlands. The Great Western Plateau occupies more than half the continent and much of it is underlain by a pre-Cambrian shield. Its surface elevation is mainly less than 2,000 feet. Throughout its area topographic relief is provided mainly by flat-topped, lateritic residuals of the mature early Tertiary surface or peneplain. The Central Eastern Lowlands has an elevation generally less than 800 feet. Much of it is underlain by Cretaceous and early Tertiary sediments. Its surface extends as broad expances of plain above which rise lateritic remnants essentially the same as those in the Western Plateau. The Eastern Highlands consist of differentially uplifted portions of the early Tertiary erosion surfaces, deeply dissected in the eastern margin, and sloping down gradually on the west to the Central Eastern Lowlands. The Highland Belt is underlain in part by folded geosynclinal sediments, metamorphic rocks and granites and in part by Tertiary basalts. In Queensland the greater part of the surface is below 2,000 feet.. It attains greater elevations in New South Wales, Victoria and Tasmania. The highest altitudes exceed 6,000 feet in the Kosciusko Plateau of southern New South Wales.

LATERITE

General

Lateritic deposits are known throughout each of the three physiographic regions. They have all been formed in situ by weathering of the underlying rock. Alkalis and alkaline earths and much of the combined silica have been removed by leaching and the residual material is composed essentially of varying proportions of ferric oxide usually hydrated, hydrated alumina, and titania. Hydrous aluminium silicate, kaolinitic in type, persists where lateritization is incomplete. Where drainage has been poor, generally in the hot and arid interior, silica has been re-deposited and forms an additional component of the lateritic terrain.

Typical Australian laterites consist of an upper ferruginous and aluminous concretionary zone that merges downwards through a mottled zone in which ferric oxide is irregularly distributed to a pallid or bleached zone in which the proportion of ferric oxide may be markedly reduced. The concretionary zone commonly consists of a pisolitic capping of hydrated iron and aluminium oxides and this may be succeeded by a tubular, vermiform or massive layer similar in composition. The mottled zone may also be dominantly ferruginous and aluminous or it may consist simply of mottled clay in which the proportion of free alumina as distinct from hydrous aluminium silicate is quite low. The pallid zone may be entirely kaolinitic and almost devoid of ferric oxide. In other areas its upper portion is granular where developed over basic igneous rocks and contains a high proportion of free alumina and ferric oxide as well as hydrous aluminium silicate or kaolin. The ferric oxide of the concretionary zone in damp climates occurs largely as hydrated oxide covered broadly by the term limonite. In more arid climates the oxides tend towards goethite, turgite and haematite. The alumina is present partly in the crystalline form as gibbsite $Al(OH)_3$ and partly amorphous as cliachite which has the composition of gibbsite modified by a small proportion or staining of hydrated ferric oxide. Boehmite, AlO.OH, occurs in some Australian laterites e.g. in dry inland areas and in the Eastern Highlands where the trihydrate has been partly dehydrated by basalt flows. Silica is present as quartz derived from the parent rock, as amorphous and cryptocrystalline silica precipitated from ground water, in aluminium silicates residual from decomposed parent rock, and in hallaysite formed from the re-silication of gibbsite and cliachite. Many investigators consider that the concretionary zone of a laterite is the B horizon of a fossil soil, the A horizon, having been removed by erosion. In certain localities in Queensland (Bryan, 1939), western Victoria, north-eastern Tasmania, South Australia and Western Australia (Stephens, 1941, 1946) the pisolitic layer is overlain either by sand or by a red loam which is thought to represent the A horizon.

Laterites are not affected by sub-aerial weathering and their preservation means essentially freedom from erosion. The most extensive deposits now remain in the stable Great Western Plateau and in the Central Eastern Lowlands. In the Eastern Highlands lateritic deposits persist along divides and near the headwaters of streams. Some of them in the less elevated areas of Queensland are very extensive. Other deposits further south remain under protective covers of basalt and of fresh-water sediments.

Climate, Drainage, and Parent Rock

Apart from the pre-requisite of prolonged weathering free from mechanical erosion the thickness, internal structure and composition of the laterite that has developed in any area has been influenced by rainfall and temperature, drainage, and parent rock. The effects of these agents are not completely separable. Adequate drainage to dispose of the products of leaching, in particular of silica, is possible only if an outlet is available, and only if rainfall is sufficient in hot tropical and inland areas where the rate of evaporation is high. The character of the laterite depends on the type and composition of parent rock, but a particular rock-type responds differently to lateritic weathering under different conditions of rainfall, temperature and drainage. In tropical Australia weathering has proceeded to greater depths than in the temperate or cool temperate areas of the south. Furthermore in the tropical climates lateritization has proceeded over practically all types of rocks, sedimentary, igneous and metamorphic. In the cooler climates, it seems to have been largely restricted to basic igneous rocks.that are susceptible to weathering. In the inland where the climate is hot and the rainfall intermittent or seasonal resulting in periods of dessication the surface capping is highly ferruginous and the proportion of free alumina is low. The absence of good drainage in these areas has resulted in widespread re-deposition of silica and the formation of siliceous laterites or of silicified zones within and below the laterite. In regions of more continuous rainfall, which in Australia are essentually in the coastal regions and in the Eastern Highlands, the proportion of ferric oxide in the laterite is lower and that of alumina higher.

The composition of the parent rock is commonly reflected in that of the laterite. In the warmer regions aluminous sediments and igneous and metamorphic rocks of granitic composition, viz., rocks that do not contain an exceptionally high proportion of iron oxide, yield typical laterites. Basic rocks generally yield highly ferruginous laterites. On sandstones and quartzites the laterite is poorly developed as a thin zone of ferruginous pisolites or concretions passing down into iron-stained weathered parent-rock. A silicified zone may be formed above or within the weathered sandstone.

LATERITES OF THE MAIN PHYSIOGRAPHIC REGIONS

THE GREAT WESTERN PLATEAU

General

The Great Western Plateau covers nearly all of Western Australia and the Northern Territory and north-western South Australia. Little of its surface attains an elevation of more than 2,000 feet. It is highest in the interior and slopes very gradually towards the coast on the north, west and south and towards the Central Eastern Lowlands on the east. In the interior, mesa-like lateritic residuals of the early Tertiary mature erosion surface or peneplain rise above very extensive Pliocene plains. In Western Australia the residuals commonly have heights of 30 to 100 feet, and where dissection has been deeper, in the Kimberley region of the north, the heights approach 300 feet. At Darwin on the north coast of the Northern Territory the lateritic surface is only 30 feet above sea level. Farther east at Cobourg Peninsula it slopes beneath the sea. East of the Macdonnell Ranges, in Central Australia the lateritized surface is cut up into mesas and tablelands rising to 400 feet above plains and broad, alluviated valleys. Similar type of country extends into South Australia where it is well-developed in the Central Eastern Lowlands.

Northern and Central Parts of Plateau

Excepting some aluminous or bauxitic deposits along the Arnhem Land coast these laterites have not been examined in detail and no analyses of them are available. In the inland parts of Northern Australia (Noakes and Traves, 1949) a fully developed or completely intact lateritic profile may contain four zones, excluding an A horizon of surface soil. They are summarized in Table I.

TABLE I. GREAT PLATEAU. TYPICAL LATERITIC PROFILE

IN NORTHERN AND CENTRAL REGIONS

Zone	Composition and Texture	Remarks	
Ferruginous	High proportion of iron and aluminium oxides. Ranges from massive material to scattered ironstone concretions. Generally red or brown in colour.	May extend down to 12 feet, and merges into mottled zone.	
Mottled	Kaolinic material with patches of iron-stainings. May show traces of structure and texture of parent rock.	Staining becomes less evident with depth & mottled zone passes down into pallid zone.	Mottled and pallid zones may extend to depths of 40 to 50 feet.
Pallid	White kaolinitic material; little iron staining. May show traces of structure and texture of parent rock.	Merges downward into parent rock.	
Silicified	Zone of secondary silicification in any part of mottled and pallid zones, or as a basal horizon.	Position in profile not regular. May even occur in ferruginous zone or as silicification of parent rock.	

Durable cappings to tablelands and mesas are formed of the resistant ferruginous and siliceous zones including silicified pallid zone, and in places the mottled zone.

Ferruginous laterites are widespread in the northern and central regions of the Great Western Plateau. Silicified pallid zone developed on Lower Cretaceous shales forms the resistant cappings of residuals in the Northern Territory between Katherine and Darwin (Noakes 1949) and in parts of the Barkly Tableland. Silicified sandstone or quartzite which has been termed "billy" and "desert sandstone" is commonly grey and vitreous. It has been described by Woolnough (1927) as opaline quartzite or sandstone. It occurs in northern Queensland and is found mainly as boulders at many places in the central and southern portions of the Northern Territory. Because of their resistance to erosion the boulders and fragments of "billy" remain strewn across plains and ridges and concentrated in creek gravels after other evidence of lateritization has been removed. These siliceous fragments contribute largely to stony plains of the arid interior called "gibber" plains.

Region of the Ord and Victoria Rivers. In the region of the Ord and Victoria River systems on either side of the border between Western Australia and Northern Territory, Traves (1955) has mapped two types of laterite. One, developed on fine-grained sediments, displays the four typical zones in its profile, viz. ferruginous, mottled, pallid, and silicified. In the other type, developed on basic volcanic rocks, the ferruginous zone is generally vermicular rather than concretionary. The "mottled" zone has a fairly even reddish-brown colour with little or no mottling but rather a fine speckled appearance. There is no definite pallid zone. The colour fades through pink to the grey of the decomposed volcanics. This profile resembles in a general way those noted by Owen (1954) over basic igneous rocks in Eastern Australia (see Table 5).

Arnhem Land Coast

Along the coast of Arnhem Land the rainfall appears to be more evenly distributed than in other portions of Northern Australia. A closer cover of vegetation helps to ensure moisture in the soil and proximity to the coast has permitted more efficient drainage and leaching than farther inland. The laterite here is better described as aluminous than ferruginous and deposits that have been investigated in recent years (Owen 1954; Gardner, 1957) have large reserves of bauxite suitable for the production of aluminium. Laterites have been derived from Archaean granitic rocks and from Upper Proterozoic shales, felspathic sandstones, and felspathic and micaceous siltstones. A typical section from Gove Peninsula at the north-east tip of Arnhem Land is given in Table 2:

TABLE 2. GOVE PENINSULA, NORTH-EAST ARNHEM LAND

TYPICAL SECTION THROUGH LATERITE

Section	Thickness
Oolitic and pisolitic bauxite	Up to 15 feet
Nodular bauxite	Approx. 2 feet
Compact amorphous bauxite	Up to 1 foot
Tubular laterite	Up to 12 feet
"Pseudo-conglomerate"	Up to 10 feet
Lithomarge (?)	Approx. 2 feet
Weathered felspathic sediment	Thickness not observed.

A typical pisolite is spherical, about ¼ inch in diameter, and is formed of concentric shells of brick-red, dull, earthy cliachite (?) surrounding a red-brown sub-vitreous or resinous core of cliachite. The nodules are ½ inch to ⅝ inch diameter, almost spherical, and they closely resemble the pisolites in texture and structure. Some nodules enclose groups of pisolites. Compact amorphous bauxite occurs at many localities on Gove Peninsula as an approximately horizontal sheet at the base of the nodular bauxite. It is textureless and dense and resembles in appearance the cores of the pisolites, although it is very pale brown rather than reddish-brown in colour. The tubular laterite is reddish or reddish brown and traversed by vesicles and tubes disposed mainly vertically. The tubes and cavities are coated by buff, yellow red and brown ochreous material which gives the hand specimen a variegated appearance. Towards the bottom of the tubular zone the tubules become restricted and lose their continuity. The tubular zone passes into a lateritic material composed of semi-angular fragments commonly 1 inch to 1½ inch in their major dimensions. Each fragment is coated by a limonitic skin. A broken fragment is porous and leached, and in places remnants of felspathic shale or sandstone can be recognised in it.

The oolitic, pisolitic, nodular, and presumably the compact amorphous bauxite contain approximately 50% Al_2O_3 and 17% Fe_2O_3. Silica is commonly about 4% and ranges from less than 2% up to about 6%. The tubular laterite and the pseudo conglomerate commonly contains more than 20% SiO_2 though locally the composition of the tubular zone is not noticeably different from that of the concretionary bauxite above it.

Bauxite at Marchinbar Island off the Arnhem Land coast (Owen, 1954) has developed from sericite-quartz siltstone. Compositions of samples of parent rock and of bauxite are given in Table 3.

TABLE 3. MARCHINBAR ISLAND, COMPOSITIONS OF BAUXITE AND OF PARENT ROCK

	Sericite-quartz siltstone	Bauxite
SiO_2 Total	64.6	4 to 8
Quartz	45	1 to 4
Al_2O_3	19.3	48 to 53
MgO	1.5	
Fe_2O_3	2.5	10 to 19
TiO_2	1.3	2 to 3.2
K_2O	5.9	
Na_2O	0.1	
SO_3	0.1	
Ign. loss	4.2	26 to 27

Further analyses of this bauxite are given in Table 5.

South-Western Part of Plateau.

Simpson (1912) states that immense lateritic deposits occur in extra-tropical regions of Western Australia. They have developed from granites, greenstones, amphibolites, chlorite schists and other similar rocks of pre-Cambrian age. Wherever investigated they are found to overlie "an almost pure pipe-clay and this in turn crystalline rock". He divides the extra-tropical portion of Western Australia into two provinces. One, the Darling Plateau, lies within 50 to 100 miles from the western coast, where average annual rainfall is 20 to 40 inches, distributed between well-defined wet and dry seasons. The other province which embraces the inland areas of the southern half of the State has no defined annual wet and dry seasons. The average rainfall is between 7 and 12 inches, irregularly distributed. Ranges in composition of typical samples of laterite from the two provinces are given in Table 4:

TABLE 4. SOUTH-WESTERN PART OF GREAT PLATEAU.

COMPOSITIONS OF TYPICAL LATERITES

Locality	Al_2O_3	Fe_2O_3	SiO_2	TiO_2
Near Coast (Darling Plateau)	31 to 47	10 to 40	6 to 17	0.6 to 4.3
Interior	4 to 13	60 to 80	1.8 to 2.7	2 to 6

The laterites are nearly all pisolitic, the concretions ranging in size from a pin head to about 1 inch diameter and averaging 1/8 to 1/4 inch. The spaces between are partly filled with amorphous material similar to the pisolites and are partly unfilled. Some of the more ferruginous laterites are devoid of concretionary structure but they contain numerous visible pores. Alumina is present in all laterites but is most abundant in those overlying granite and other less ferruginous rocks. Ferric oxide is present as limonite, turgite, and probably in some samples as goethite and hematite. Wherever laterite overlies greenstone (in the interior) ferric oxide is the predominant constituent. TiO_2 is always present in appreciable amounts. Silica is present as quartz and in combination, probably as halloysite.

Terrill (1950) showed that laterite overlying a quartz-dolerite dyke in the Darling Plateau developed in situ from the quartz-dolerite and there was no appreciable lateral or vertical migration of its constituents. The ratio of Al_2O_3 to Fe_2O_3 in a section downwards through the laterite remains nearly constant and very nearly the same as in the underlying quartz-dolerite. A sharp contact was observed between laterite and remnants of quartz-dolerite within it. Terrill considers that the laterite overlying the surrounding granitic country developed similarly in situ from the granite.

Recent mapping within the coastal province (Playford, 1954) has revealed that in a distance of several miles laterites occur at elevations ranging from 210 feet to 860 feet above sea level. In river valleys they follow valley-slopes, having inclinations up to 10 degrees. In effect they developed on a surface which had much the same topography as the present-day surface. The early Tertiary erosion surface or peneplain had already been uplifted and incised by rivers.

In some inland regions of the south-west the surface of the Great Plateau is formed of extensive, flat or gently undulating sand plains. Varying proportions of pisolitic and nodular ironstone occur within the sand. Laterite-like deposits exposed at shallow depth consist of similar ferruginous concretions containing angular grains of quartz and held together by a ferruginous and aluminous cement (Ellis, 1939). After a detailed study of their heavy minerals, Carroll (1939) concluded that the sands were formed in situ by weathering of the underlying rocks, pre-Cambrian granitic gneiss and metamorphics. Teakle and Samuel (1930) found that the sand-plain soils are acidic even though they occur in an area of low rainfall and cannot have formed by weathering in the present-day climate. It appears likely that the sands and the underlying laterite represent the A and B horizons, respectively, of a fossil soil.

CENTRAL EASTERN LOWLANDS

General

The Central Eastern Lowlands extend as a roughly meridional belt from the northern coast at the Gulf of Carpentaria to the southern coast. They cover nearly all the western half of Queensland and New South Wales and much of the eastern half of South Australia. In the Cretaceous the northern part was first inundated by the sea and later occupied by a lake. In early Tertiary time large areas were again occupied by fresh-water lakes. These were drained as a result of Tertiary uplift and during a succeeding long period of crustal stability the surface sediments, Cretaceous and Eocene, were lateritized. The Lowlands were not greatly elevated during the Tertiary epeirogenic uplifts.

Laterite

Nearly all the southern half of the Lowlands is covered by post-Tertiary sediments, lacustrine, aeolian and alluvial. Excepting small areas in the marginal country rising towards the Western Plateau and the Eastern Highlands the lateritic deposits have been removed by erosion or buried beneath the post-Tertiary sediments.

In its northern half, in Queensland (Whitehouse, 1940; 1948; 1951) the Lowlands form wide plains that rise very gradually from sea level at the north coast and near Lake Eyre to a maximum elevation of about 800 feet. Above them reddish flat-topped residuals of the early Tertiary erosion surface or peneplain rise to heights of 100 feet and more. Some of these have areas of many hundreds of square miles. The lateritic profile is essentially the same as that in the inland areas of northern Australia, consisting of ferruginous, mottled, pallid, and silicified zones. As in northern Australia the silicification is irregularly distributed both vertically and horizontally. (Whitehouse avoids the use of the term "zone" when referring to it.) The ferruginous zone ranges in its constitution from a red loam containing scattered small, limonitic nodules to a nodular layer loosely held by a little ferruginous cement. It is poorly coherent and nearly everywhere has been eroded from the flat-topped hills. The mottled zone is composed generally of a white kaolinic material irregularly mottled in red and 20 to 30 feet thick. Commonly it is vermicular. The transitional material between the ferruginous and mottled zone is relatively resistant to erosion and forms the top few feet of most of the mesas and buttes in western Queensland. The pallid zone in its upper part is a kaolinitic material essentially the same as that in the mottled zone. It grades downward to parent rock depleted of lime and iron oxides. The silicification ranges from slight impregnations within any of the lateritic zones to irregular nodules of "billy" and great sheets of "billy" formed by the uniform cementation of a horizon.

As in the inland regions of the Western Plateau, where a lateritic mass has been removed by erosion the surface of the plain is commonly covered with tightly packed stones or "gibbers" derived mainly from the silicified zone. An unusual form of silicification is seen in the opal deposits of south-western Queensland and adjoining parts of New South Wales and South Australia. Opal is formed in the mottled and pallid zones commonly by replacement of calcite in calcareous bands, concretions and fossils.

EASTERN HIGHLANDS

General

The Eastern Highlands are underlain mainly by folded Palaeozoic rocks and granitic intrusives, in part covered by Tertiary basalt flows. In northern Queensland extensive plateaus were formed by basalt lavas in Pliocene and post-Pliocene times. Large areas of New South Wales were covered by thick flows of early Tertiary basalt. Early Tertiary basalts occur in southern Queensland, eastern Victoria and in parts of Tasmania. Towards the end of the Pliocene, in the final stage of uplift, the highlands were raised to elevations ranging in Queensland from 1000 to more than 2000 feet, in New South Wales from 4000 to more than 6000 feet, and in north-eastern Victoria up to more than 5000 feet.

It was pointed out earlier in a discussion of tectonic history that in the Highlands the early Tertiary erosion surface did not reach the advanced stage of maturity that is evident elsewhere in Australia. However, it did develop to a mature land surface, and laterites were formed on it.

In Tasmania the topographic relief is due partly to Tertiary uplift and partly to the occurrence of resistant Mesozoic dolerite sills which must have formed monadnocks on any early Tertiary surface. In other parts of the Australian Eastern highlands residuals of earlier erosion surfaces ranging in age probably from Cretaceous to early Tertiary rise above the level of the mature lateritic surface. They include granitic masses, folded Palaeozoic strata, horizontally-bedded Mesozoic sediments and flat-topped hills or tablelands of early Tertiary basalt.

The early Tertiary mature erosion surface can be recognised in many parts of the Highland belt as differentially uplifted plateaux of varying dimensions, in part capped by laterite. It persists as a prominent physiographic feature in parts of the highlands of New South Wales and Queensland. In Victoria, although the older surfaces are much dissected, remnants of the same surface continue southwards from New South Wales at an elevation of more than 5000 feet, decreasing in height towards the south. In the faulted blocks of Jurassic strata that make up the Southern Uplands (or South Gippsland Highlands), the early Tertiary erosion surface is marked approximately by remnants of early Tertiary basalt. In Tasmania it can be recognised in sunkland areas and in several plateau and highland regions. Nearly all the known Tasmanian laterites occur within Tertiary basins and sunklands. Although at quite low elevations they occur within the region of pronounced differential elevation, faulting and warping that sharply distinguishes the Eastern Highlands from the other two main physiographic regions.

Laterite.

Large lateritic deposits within the Eastern Highlands belt occur in the far north in Cape York Peninsula, in central and southern Queensland and in northern and central New South Wales. Smaller deposits are known in southern New South Wales, Victoria and Tasmania. In Cape York Peninsula very large deposits of bauxite were discovered during 1956. Details of their occurrence are not available. On the Alice Tablelands north of the Tropic of Capricorn sub-horizontal beds covering an area of about 20,000 square miles are largely covered by laterite. The underlying rocks include sandstones, shales, and limestones ranging in age from Carboniferous to Cretaceous. The plateau is formed partly of pisolitic laterite and partly of the lower leached material. Farther south lateritization appears to have affected mainly basic igneous rocks, although in New South Wales and Victoria a few lateritic deposits are known to occur on Palaeozoic sediments and granite and on sediments of later age. The laterites of the Eastern Highlands are on the whole aluminous rather than ferruginous, and silicified zones comparable to those in the inland regions of the Western Plateau and the Lowlands have not been recorded. They have been thoroughly investigated as a possible source of bauxite and are desceibed in detail by Owen (1954). In most areas the lateritic profile observed in northern and inland Australia is not readily recognisable. Instead, Owen describes five zones summarised below in Table 5 which is a slightly abridged copy of his Table 42. An ideal section in which all five zones are observed is rare.

Owen states that both the pisolitic and massive or tubular zones are formed under strongly oxidizing conditions which fix the iron as ferric oxide or hydroxide. There is little difference in the composition of the two zones in any one locality but their appearance is markedly different and commonly the boundary between the two zones is sharp. The upper zone is made up wholly of pisolites which are roughly spherical and range between 5 and 10 mm. in diameter. They consist of concentric shells of cliachite built on a nucleus which may consist of a minute grain of quartz, a crystal of gibbsite, or a small mass of granular bauxite. In some instances the nucleus of granular bauxite constitutes half or more of the total mass of the pisolite and it may retain clear evidence of the parent rock texture. The pisolites may be loose, loosely held in an earthy or oolitic cement, or firmly cemented in a tough matrix of cliachite.

The tubular laterite is usually fairly hard, red or dark-brown to nearly black, and is penetrated by solution channels which are roughly circular or elliptical in cross section and generally 10 to 30 mm. in diameter. They are mostly vertical or steeply inclined.

Earthy laterite in the mottled zone is textureless, soft and usually lighter in colour than the concretionary laterite above it. The colour, commonly light brown, buff or pinkish-brown is irregularly distributed and red ferruginous patches give the zone a coarsely mottled appearance.

Nodular bauxite consists of unevenly distributed nodules of hard bauxite, mainly gibbsitic, embedded in a matrix of buff, brown, or light red siliceous clay. The nodules may be several inches in dimensions, range from nearly spherical to irregular in shape and possess a smooth outer surface. Some are wholly concretionary, others display relict texture of parent rock internally. These nodules differ from those already described from the bauxite at Gove Peninsula, north-east Arnhem Land. The Gove nodules are concretionary and appear at the bottom of the pisolitic layer. The nodules described by Owen are below the concretionary zone of the laterite and are embedded in siliceous clay. Possibly the clay originated through silicification of earlier laterite or bauxite and the nodules are remnants that were not silicified, perhaps because of a protective limonitic coating. Owen's nodular zone probably is the equivalent of the "pseudoconglomerate" at Gove.

The mottled zone passes gradually into the pallid zone by diminution of the gibbsitic nodules or ferruginous patches.

TABLE 5. ZONES IN THE LATERITIC PROFILE (AFTER OWEN, 1954)

(Excepting the laterite from Wessell Islands the deposits occur within the Eastern Highlands belt).

Zones: Lacroix (1913)	Zones: Walther (1915)	Zones: Ideal Bauxite Section	Common thickniss	Typical Composition: SiO_2	Al_2O_3	Fe_2O_3	Free Al_2O_3	See footnote
		Derived soil	Feet 1 to 5	% 4.0	% 35.5	% 35.2	% 29.8	BT
				9.3	31.3	34.1	21.0	BN
Concretionary	Ferruginous	Pisolitic	4 to 20	3.3	52.4	13.8	49.7	SW
				2.5	42.7	31.6	33.7	BN
				3.6	38.5	36.4	27.9	BN
				2.9	28.0	50.0	-	BT
		Tubular and massive	4 to 8	2.5	48.4	19.6	47.8	SW
				4.6	34.2	36.9	32.4	BN
				1.3	26.7	47.1	25.8	BN
				3.4	38.7	33.2	36.5	DT
Leached	Mottled	Earthy; with or without poorly preserved relict texture, variegated	10 to 20	3.9	37.9	32.1	32.3	BN
				3.8	55.3	4.2	50.3	BN
				2.4	44.9	24.7	42.7	DT
		or Nodular; hard gibbsitic nodules in soft clayey matrix (Nodular zones uncommon and poorly developed in Australia.		8.0	38.7	27.0	32.7	BT
				9.1	36.9	28.5	29.6	BQ
				11.1	48.3	13.5	37.8	DT
				9.7	40.4	23.8	30.1	DT
	Pallid	Granular; relict texture well preserved.	5 to 10	18.3	25.5	39.9	7.2	BN
				3.7	43.8	26.5	40.6	DT
				12.8	39.2	22.4	28.1	DT
		Clay zone	0.5 to 40	30.5	35.5	12.5	11.2	BN
				24.0	23.2	34.2	-	DT
				30.3	28.7	23.7	-	DT
		Parent rock (total iron expressed as Fe_2O_3)		64.6	19.3	2.5	-	SW
				45.6	14.8	11.7	-	BN
				53.4	14.7	10.3	-	DT
				54.8	14.5	11.3	-	DT

Explanation of letter symbols:

B, basalt; D, dolorite; Q, Queensland;
S, micaceous siltstone; T, Tasmania,
N, New South Wales; W, Wessel Islands, Northern Territory.

Granular bauxite occurs near the base of the profile and constitutes part of the pallid zone. The texture of the parent rock is well preserved. In some cases not only the original texture but also the original grain size are retained.

The clay zone is a residual product of kaolinitic weathering of the bedrock and usually retains traces of the original rock texture. It is a ferruginous clay containing a few per cent of free alumina.

It may be noted that the lateritic profile observed by Owen mainly in the Eastern Highlands does not closely resemble that observed in northern and inland Australia. In the north, mainly within the Great Plateau and in western Queensland, mainly within the Central Eastern Lowlands, the iron-content steadily decreases downwards from the ferruginous to the mottled and to the pallid zones. This is not the case for the laterites shown in Table I. The ratio of Al_2O_3 to Fe_2O_3 in the several zones of these laterites (excluding the samples from Wessel Islands) is summarized below:

TABLE 6. LATERITES OF THE EASTERN HIGHLANDS BELT

Ratio of Al_2O_3 to Fe_2O_3

Lateritic Zone Walther (1915)	 Owen (1954)	Ratio Al_2O_3/Fe_2O_3	Iron content compossed with parent rock
Ferruginous	Pisolitic	0.9	Increase 44%
	Tubular and Massive	0.8	Increase 62%
Mottled	Earthy, or	2.3	Decrease 44%
	Nodular	1.8	Decrease 28%
Pallid	Granular	1.2	Increase 8%
	Clay zone	1.2	Increase 8%
	Parent rock	1.3	

Hanlon (1944) states that in many New South Wales deposits the proportions of alumina and iron oxide are similar in the ferruginous bauxite, the underlying clay and the parent rock. Apart from the difference in the distribution of iron in the profile, the absence of a silicified zone is notable.

The laterites or bauxites of Victoria have in part been buried beneath lacustrine lignitic sediments and have been altered by percolating water containing organic matter and silica. Because of the reducing action of the ground-water some bauxites are characterized by a relatively high content of ferrous iron developed from the earlier ferric oxides. Others have been re-silicated, the aluminium hydroxide being converted to halloysite. The Victorian bauxites differ from those of other States in colour and texture as well as in chemical composition. Light brown, pink, buff and cream-coloured near the surface, it passes at depth to white, grey, and bluish-grey. Mottling is not apparent. Textures range from that of a fine earth which may contain small, irregular, hard gibbsitic masses showing basaltic texture to a coarsely gritty earth which crumbles when wet. Most of the bauxite is finely cellular and the higher grade material contains veinlets and numerous fine crystals of gibbsite. Massive or tubular zones are not represented.

In Tasmania Owen (1954) has suggested that the occurrence of laterite on dolerites and basalt and its apparent absence on nearby Mesozoic sediments throws doubt on the hypothesis that peneplanation is a necessary pre-requisite for lateritization. In addition to the usual type of lateritic deposit that occurs as a remnant of a former widespread sheet he has recorded lenticular deposits which apparently formed in situ from the dolerite or basalt in depressions with restricted horizontal extent. Some deposits of this type in the City of Launceston were formed on dolerite in narrow valleys considerably below the crests of the interfluves. This is in accordance with similar observations along the west coast of Western Australia (Playford, 1954) and perhaps with observations of Whitehouse (1948) who records laterites in Pliocene valleys cut below the early Tertiary mature erosion surface.

FORMATION OF LATERITE

In many localities throughout Australia it has been shown that the laterites have formed by weathering in situ of the underlying rocks. Where the lateritization has proceeded to completion practically all the constituents apart from the oxides of iron, aluminium and titanium have been removed by leaching. Present-day lateritic weathering has been reported from several tropical countries of the world, and lateritic podsols are in process of formation in the Katherine-Darwin region. As far as is known lateritic weathering is not proceeding elsewhere in Australia. This suggests that the Australian climate may have been warmer and moister early in the Tertiary than it is now. David (1950) remarks that the Tertiary fauna and flora indicate a warmer climate during the Miocene. Possibly the coincidence of such a climate with a period of relative stability and the development of a relatively subdued topography accomplished the lateritization.

It is not at all clear whether the laterites developed directly from the underlying rocks or whether the initial product of weathering of those rocks was kaolinitic in composition. In many localities laterites seem to have developed directly from basic igneous rocks. Where a laterite preserves both the original texture and grain size of the parent rock it seems unlikely that it could have formed from kaolinitic material, even though underlain by kaolinitic clay derived from the parent rock. The conflicting evidence suggests that some laterites have formed directly from the parent rock, others from kaolin. Apparently when the downward progress of weathering is fairly rapid a kaolinitic material results. Possibly if the downward rate of weathering became extremely slow, e.g. under peneplain conditions, a kaolinitic mantle would be converted to laterite through slow leaching of its silica. Progression of the slow weathering beneath the kaolinitic mantle would result in direct lateritization of the parent rock.

After the cessation of lateritic weathering, several secondary changes may take place in and below the laterite. The underlying rock may become kaolinized. The laterite may become silicified by percolating ground waters that have derived silica from such sources as weathering basalt and siliceous organisms in lacustrine sediments. Ferric iron may be reduced to ferrous iron and be precipitated as siderite or leached from the laterite. Removal of ferric iron results in the breaking down of original texture and the bleaching of the laterite, as noted in the case of Victorian bauxites.

AGE OF AUSTRALIAN LATERITES

Throughout the greater part of Australia an absence of Tertiary sediments containing diagnostic fossils makes it impossible to assess directly the age of the laterite. It is ubiquitously associated with the early Tertiary mature erosion surface which had been thought to have reached a very advanced stage of development during the Miocene and has commonly been termed the Miocene Peneplain. Woolnough (1927) considered that the laterites were a "chemical criterion" of peneplanation and he regarded them as Miocene in age. Work in recent years indicates that in both eastern and western Australia conditions of stability and associated lateritization had developed earlier than the Miocene. Bauxite in Victoria is overlain by fresh-water sediments that range back in age to mid-Eocene and it must have been formed in lower or mid Eocene time. Tasmanian laterites and bauxites in part overlain by similar fresh-water sediments are probably of the same age. In New South Wales lateritized basalt overlies early Tertiary sandstone and is probably Oligocene in age. Elsewhere in the same State lateritized basalt is covered by lignitic sediments that appear to be lower Pliocene. Fairly mature valleys had been eroded through the laterite before the sediments were laid down and the end of the period of lateritization must considerably antedate the Pliocene. Lateritized basalt in southern Queensland can probably be correlated with similar basalts in New South Wales although they were regarded as Pliocene before the early Tertiary age of the New South Wales basalts was established. In the Central Eastern Lowlands 1 laterite has formed over Eocene sediments and in the Great Western Plateau over Tertiary lake beds, but the position of these beds in the Tertiary has not been determined. In each case the upper limit to their age is set by the late Miocene uplift. In Exmouth Gulf area laterite, developed on Eocene is overlain by lower Miocene beds (Condon, Johnstone, Prichard, and Johnstone, 1956).

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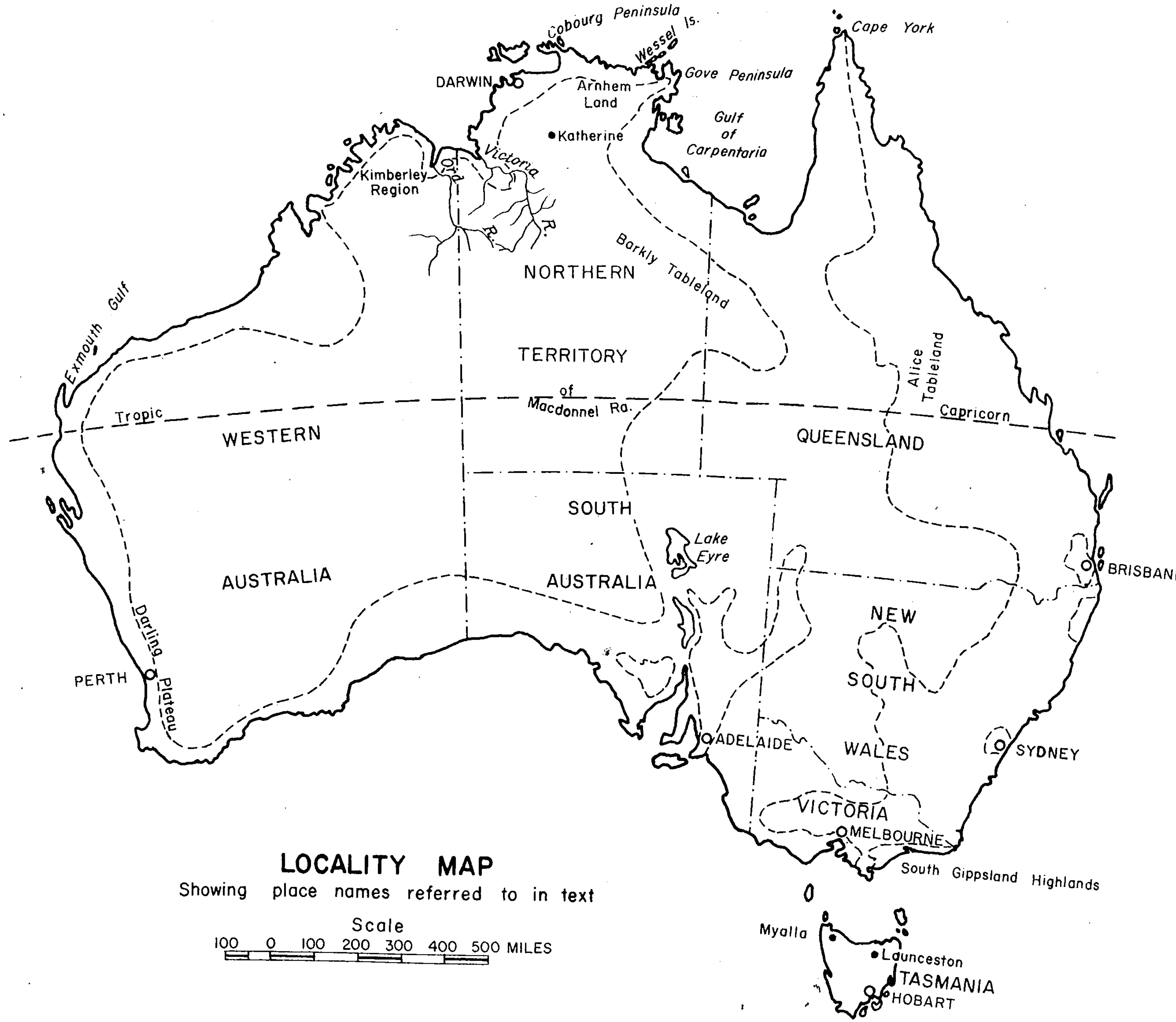
PLATE I.

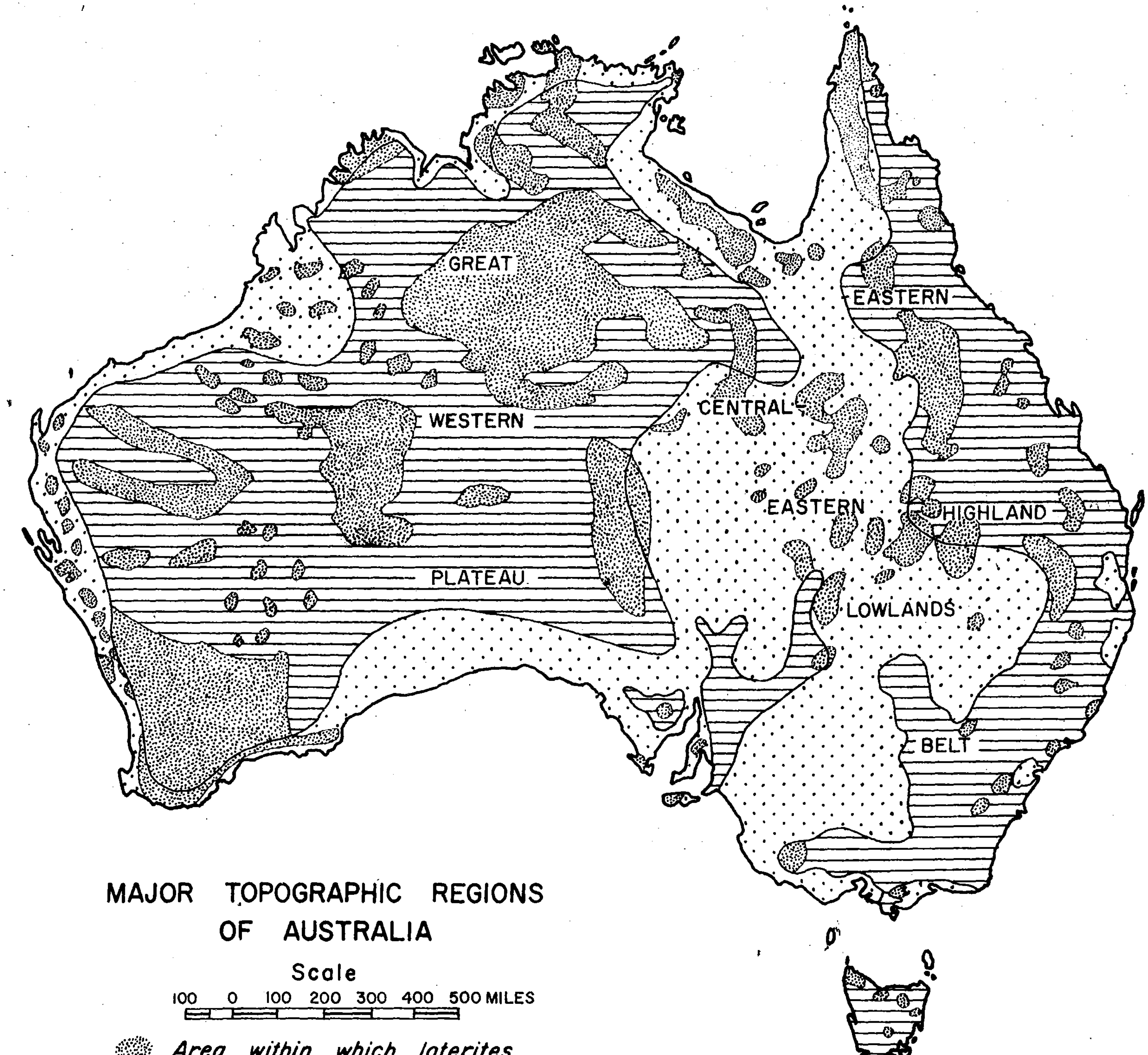


LOCALITY MAP

Showing place names referred to in text

G 27-56

F.J.R.
F.U.K.



MAJOR TOPOGRAPHIC REGIONS OF AUSTRALIA

Scale

100 0 100 200 300 400 500 MILES

Area within which laterites have been recorded.

G 27 - 57

F.J.R.