Land Zones of Queensland






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Images – clockwise from top left: ancient sandstone formation in the Lawn Hill area of the North West Highlands bioregion – land zone 10 (D. Kelman); coastal estuarine mud flats, Gulf Plains bioregion – land zone 1 (R. Jaensch); granite tor field in the North West Highlands bioregion – land zone 12 (D. Kelman); flat clay plains on the Barkly Tableland – land zone 4 (B. Wilson); metamorphic hills in the Dajarra area of the North West Highlands bioregion – land zone 11 (D. Kelman); Quaternary coastal deposits on a beach, Central Queensland Coast bioregion – land zone 2 (J. Kemp).

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[§] Deceased

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1. Introduction

This publication provides detailed information on the interpretation and application of the land zone component of the regional ecosystem classification system across Queensland. This document should be read in conjunction with the regional ecosystem survey and mapping methodology (Neldner *et al.* 2012).

The regional ecosystem (RE) system is a framework for land classification that was developed in Queensland in the 1990s to assist in planning for biodiversity, both on and off conservation reserve estate. The classification system is a multiple attribute land classification system which describes the entire land surface of Queensland. Regional ecosystems are defined as vegetation communities in a bioregion that are consistently associated with a particular combination of geology, landform and soil (Sattler and Williams 1999). The regional ecosystems classification is based on a hierarchy, which is reflected in the three-part code given to each regional ecosystem. The land is classified by bioregion, then land zone, and then vegetation and/or variations in geology/landform/soils within a land zone

Land zones are categories that describe the major geologies and associated landforms and geomorphic processes of the State of Queensland. The differences between land zones result in marked differences in the function of ecosystems and their associated biodiversity and this is due in part to the effects that geology (lithology, structure, alteration) has on landform, hydrology and landscape processes (geomorphology and soil formation).

One of the main strengths of the regional ecosystem and associated land zone classification is its ease of use. The entire state is classified in terms of twelve land zones and the definitions are, for the most part, uncomplicated. In some environments, determining the land zone will simply involve reference to a geology map and the land zone definition. In other circumstances a basic knowledge of geology and landscape processes (geomorphology and soil formation) is necessary. Once the land zone has been determined, the classification of the vegetation/landform/soils will identify the appropriate regional ecosystem.

The primary land zone differentiation is:

a) Quaternary coastal unconsolidated marine sediments and coastal sand masses developed by wind and wave action (Land Zones 1 and 2).

b) Cainozoic (Tertiary to Quaternary) unconsolidated sediments derived from alluvial and non-coastal aeolian processes and other geologies subject to “deep weathering” processes during the Cainozoic period (Land Zones 3 to 7).

c) Cainozoic (Tertiary to Quaternary) igneous rocks (Land Zone 8).

d) Sedimentary rocks (Land Zones 9 and 10).

e) Metamorphosed Cretaceous and older igneous rocks (Land Zones 11 and 12).

The geological time scale is an important factor when allocating geology units to Land Zones. The geological time scale* with significant geological events relevant to Queensland Land Zones is shown in **Table 1**.

Table 1 Geological Time Scale—Queensland
* Adapted from Gradstein FM, Ogg JG and Smith AG (2004)

ERA Period (Epoch)	Time (years)	NOTES
CAINOZOIC-Cz	0 – 65 m	
Quaternary - Q	0 – 2.5 m	Quaternary events: alluviums, sand dunes, volcanic activity, some lateritisation
(Holocene - Qh)	0 – 10,000	Second of two periods of Quaternary alluvial (Qha) deposition—lower active (current) Holocene alluvium
(Pleistocene – Qp)	10,000 – 2.5 m	
recent Pleistocene - Qp	10,000 – 140,000	Recent part of Pleistocene epoch associated with the first of two periods of Quaternary alluvial (Qpa) deposition in coastal streams within alluvial valleys; now slightly elevated and/or prior and abandoned streams
early Pleistocene - Q	140,000 – 2.5 m	Earlier part of Pleistocene epoch associated with paleo-alluvial deposition (TQ part)
Tertiary – T (Neogene & Paleogene)	2.5 m – 65 m	Tertiary events: lateritisation of erosional surfaces; volcanic activity; deposition in rivers and lakes—paleo-alluvial deposition (T, TQ part)
MESOZOIC - Mz	65 m – 251 m	
Cretaceous - K	65 m – 145 m	Great Artesian Basin formed; terrestrial and marine deposition; coal measures in Ipswich, Surat and Maryborough Basins
Jurassic - J	145 m – 200 m	
Triassic - R	200 m – 251 m	
PALAEOZOIC - Pz	251 m – 542 m	
Permian- P	251 m – 299 m	Close of the Tasman Geosyncline; coal measures in many basins; terrestrial marine and freshwater deposits; volcanic activity and igneous intrusions
Carboniferous - C	299 m – 359 m	
Devonian - D	359 m – 416 m	
Silurian - S	416 m – 444 m	Granite intrusions; marine deposition; Tasman Geosyncline formed
Ordovician - O	444 m – 488 m	Shallow water marine deposition in Georgina Basin
Cambrian - ε	488 m – 542 m	
SUPEREON Eon		
PRECAMBRIAN	542 m – 4600 m	
Proterozoic - Pt	542 m – 2500 m	Precambrian shield areas emerge from the sea.
Archaean - Ar	2500 m – 4600 m	Highly metamorphosed rocks

2. The land surface

Australia is a very old continent of generally low relief. Whilst many events and episodes have shaped the land surface, the low relief of the present day surface is dominantly the result of erosion. Much of the present day Queensland landscape reflects ancient geomorphic processes with unconsolidated deposits derived from various sources, often transported and reworked in various ways.

Rock and unconsolidated deposits

At the most basic level, land can be divided into bedrock landscapes and unconsolidated deposits of varying materials. Rocks at, or near, the earth's surface are subjected to constant weathering processes due to the action of water, wind, ice, extremes of temperature and living organisms. This physical disintegration and chemical decomposition of rocks marks the beginning of the soil forming process. At any stage the weathered rock and the soil itself are susceptible to transport by wind, water, and gravity. Geomorphic processes of the Australian landscapes are described in detail by Twidale and Campbell (2005).

An understanding of hard rock landscapes with in-situ/colluvial soils as opposed to landscapes based on unconsolidated deposits of transported material (ignoring induration during soil formation), is fundamental to land classification. This division is mirrored in the land zone classification: Land Zones 1, 2, 3, 4 and 6 describe unconsolidated deposits of sand, silt, clay and gravel (**Plate 1, 2** and **3**); Land Zone 5 relates to unconsolidated deposits and *in-situ* "deeply weathered" landscapes (**Plate 4**); Land Zone 7 describes the exposed duricrusted "deeply weathered" landscapes and Land Zones 8, 9, 10, 11 and 12 refer to the hard rock landscapes (**Plate 5** and **6**).

Plate 1 Unconsolidated Quaternary marine sediments, Burnett River (Land Zone 1)

Plate 2 Unconsolidated Quaternary alluvium, Burnett River floodplain (Land Zone 3)

Plate 3 Unconsolidated Pleistocene marine quartz sand deposits with organic staining, Maroochydore (Land Zone 2)

Plate 4 Deeply weathered Tertiary basalt, Childers (Land Zone 5)

Plate 5 Fine grained Cretaceous sediments of the Maryborough Basin (Land Zone 9)

Plate 6 Triassic granite, Childers (Land Zone 12)

2.1 Unconsolidated Cainozoic Deposits – Sand, silt, clay, gravel, soil

Unconsolidated sediment deposits form:

- tidal flats (Land Zone 1)
- coastal sand dunes and beach ridges (Land Zone 2)
- river and creek systems (landforms include alluvial plains, channel benches, stream channels, levees, terraces, flood plains, lunettes, etc.) (Land Zone 3)
- “old” alluvial clay plains and rises (Land Zone 4)
- aeolian clays (parna) forming arid plains, rises and low hills (Land Zone 4)
- “old” alluvial sands and loams on plains, rises and low hills (Land Zone 5)
- sand and other non-clay plains not developed *in-situ* from bedrock (Land Zone 5) and
- inland sand dunes (Land Zone 6).

2.1.1 Tidal flats and beaches – Land Zone 1

Contemporary off-shore marine and estuarine deposits are not part of the terrestrial land zones treated in this document. Tidal flats are a result of rivers and creeks depositing fluvial sand, silt and mud in estuarine and coastal areas that may be further mobilised or deposited by wave and current action. Tidal flats occur where coastal waters are protected from strong wave action, such as in estuaries or behind coastal barrier sand deposits and islands along the east coast (**Figure 1**). Extensive tidal flats occur in the protected waters of the Gulf of Carpentaria. Tidal inundation of tidal flats can vary from regular daily to an occasional one to two spring tides per year. The distinction between tidal lands and other lands, such as alluvium, is often gradual. Lands that are not subject to tidal inundation but are subject to storm surge above normal tides or river and creek flood waters are not included in Land Zone 1.

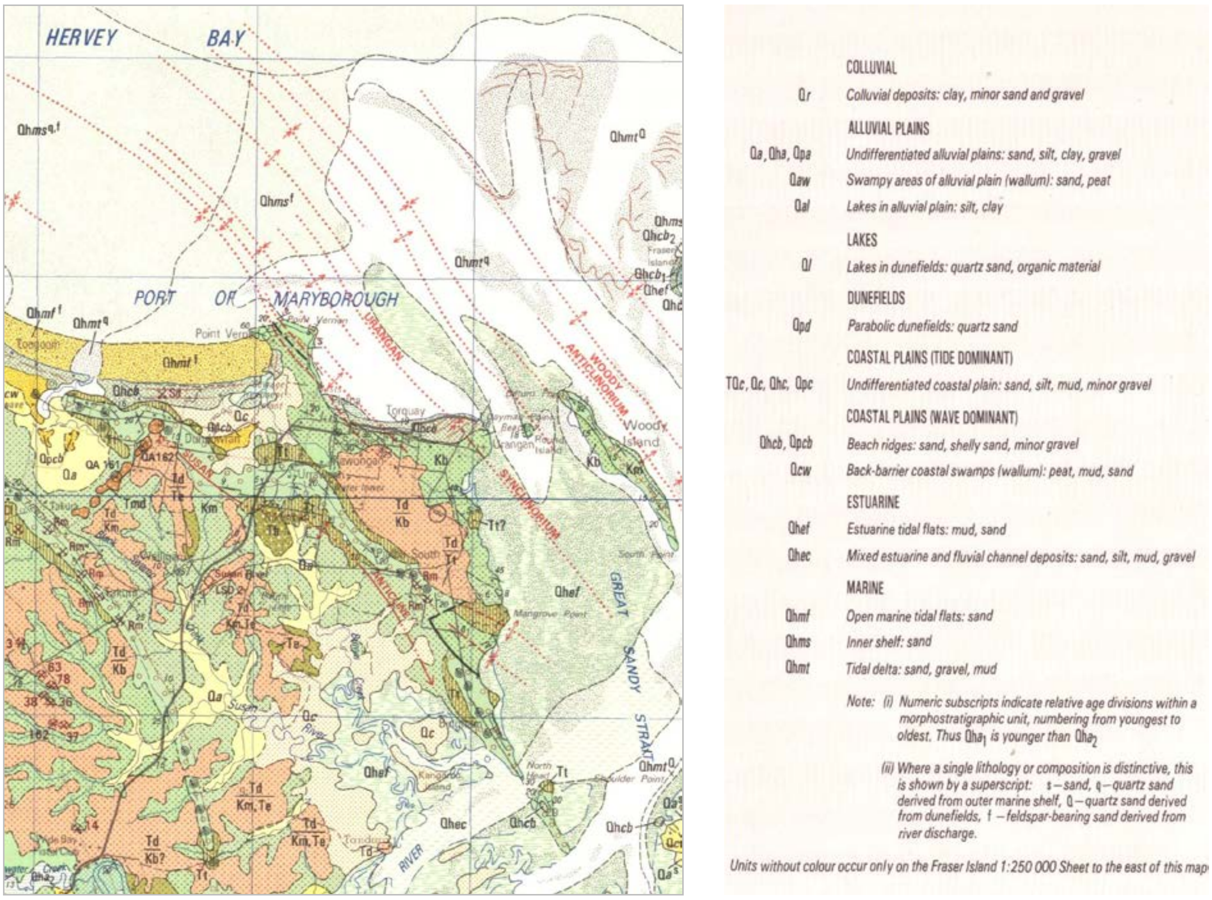

Figure 1 Geology mapping of Hervey Bay with numerous subdivisions of tidal and sub-tidal sediments (1:250 000 geology map)

2.1.2 Coastal sand dunes and beach ridges – Land Zone 2

During the Quaternary Era (Pleistocene and Holocene), sand materials were deposited along the coast. These materials have been reworked by wave and wind actions to form extensive dune fields and beach ridge plains.

During the previous interglacial period within the Pleistocene (140 000 to 120 000 years BP), evidence suggests that the sea level rose 4–6 metres higher than the present (Pickett *et al*. 1985) depositing a series of beach ridges parallel to the current coast mainly by wave action and modified by wind. Many of these "old" beach ridges with well-developed podzol indurated sand horizons (coffee rock) have been fragmented by "recent" sea level rises and alluvial processes, and degraded by wind and stream action. Examples of these old fragmented beach ridges many kilometres inland from the current coast occur in many areas, such as Bribie Island (**Plate 7**), Hervey Bay, Bundaberg, Ayr and Tully. Coarse textured (sand) paleo-estuarine deposits (Pleistocene) elevated above tidal influence and not subject to current alluvial processes are included.

The linear sand dunes typical of Moreton Island, Fraser Island and Cape Flattery (**Plate 10** and **9**) and numerous other areas developed predominantly during the dry Pleistocene glacial and interglacial periods (120 000 to 20 000 years BP) when the sea level receded and then fluctuated between 80 to 126 metres below present (Bloom *et al.* 1974). Prior to the sea level rises in the Holocene (10 000 years BP), sand was blown inland by the prevailing south-easterly winds to form linear dunes. These "old" dunes usually have several well developed podzol indurated sand horizons (coffee rock) reflecting a series of water table fluctuations and associated erosion and deposition phases. Current sea levels and wave action have eroded some of the dune fields.

Plate 7   Pleistocene and Holocene beach ridges on Bribie Island
(Google Earth)

Plate 8   Linear Holocene beach ridges north of Karumba
(Google Earth)

Plate 9   Longitudinal dunes of Cape Flattery
(Google Earth)

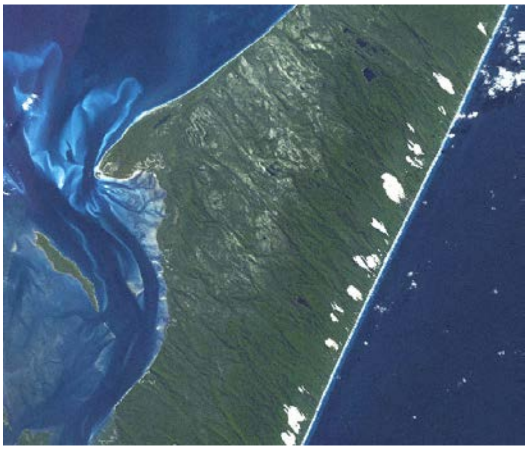

Plate 10 Longitudinal dunes of Fraser Island
(Google Earth)

Sea level rises above current levels in the Holocene around 6500 to 4000 years BP (Thorn and Chappell 1975; Lang et al. 1998) and current sea levels have deposited a series of beach ridges all along the coast from the Gold Coast to the western Gulf (**Plate 8**). Coral cays are included in this process. These “younger” beach ridges and associated low dunes usually have weakly developed podzol horizons where soils are acid. The “younger” frontal beach ridges, calcareous coral cays and dunes may have no or minimal sub-soil horizon development.

2.1.3 River and creek landforms – Land Zone 3

Erosion of uplands (erosion landscapes) and deposition of sediments (sand, silt, clay, gravels) by alluvial processes in relatively low areas (deposition landscapes) have formed a wide variety of alluvial landforms. When flow exceeds the ability of the stream channels to carry the throughput, overbank flow carries sediment away from the channel until the velocity is such that the suspended load is deposited forming alluvial landforms such as levees or alluvial plains.

Alluvial landform patterns as defined by The National Committee on Soil and Terrain (2009) include alluvial fan, alluvial plain, anastomotic plain, bar plain, covered plain, delta, flood plain, meander plain, playa plain, stagnant alluvial plain, and terrace. Each landform pattern contains one or more landform elements including backplain, bank (stream bank), bar (stream bar), channel bench, drainage depression, fan, flood-out, lagoon, lake, levee, lunette, ox-bow, playa, prior stream, scroll, stream bed, stream channel, swamp, terrace flat, terrace plain, or valley flat. In all these landforms, there may be frequent active erosion and aggradation by channelled and overbank stream flow, or the landforms may be relict from these processes (The National Committee on Soil and Terrain 2009).

As described in the coastal sand dunes (Land Zone 2), the high sea levels 4–6 metres higher than the present during the Pleistocene (140 000 to 120 000 years BP) resulted in the deposition of freshwater, estuary and marine sediments along the coast and in river systems. During the recent Pleistocene (120 000 to 20 000 years BP), the sea receded between 80 to 140 metres below present sea level. During this time, rivers and creeks cut deep channels through the previously deposited fluvial, estuarine and marine deposits. Sea level rises up to 1.5 metres above the current sea level in the Holocene (6500 to 4000 years BP) resulted in re-deposition of sediments into the incised and eroded Pleistocene alluvium.

In general terms, coastal streams show two periods of Quaternary alluvial (Qa) deposition within an alluvial valley. The first corresponds to the slightly elevated prior and/or abandoned stream of the recent Pleistocene alluvium (Qpa) (140 000–10 000 years BP). The second corresponds to the lower active Holocene alluvium (Qha) (<10 000 years BP). The recent coastal Pleistocene alluvium are easily recognised by relict alluvial features such as prior stream channels, abandoned channels, relict levees, and alluvial plains and alluvial fans not subject to active channelled or over-bank stream flow. Active Holocene alluvium is usually recognised by landform patterns associated with current stream channels and over-bank stream flow.

Soil developed from the Pleistocene alluvium usually (but not always) has a higher degree of profile development compared to the Holocene alluvium, however both landscapes usually grade into each other making distinction difficult (**Plate 11**). In many cases, the recent Pleistocene alluvium is inundated in part by flood events from creeks draining the local uplands. Because of these difficulties, recent alluvium (140 000 years to present) covers the Holocene (Qha is generally the active alluvial processes) and the recent relict sediments of the associated Pleistocene alluvium (Qpa).

Plate 11 Complex coastal geomorphology on the Townsville coastal plain
This involves: Crystal Creek and associated Holocene alluvium (Land Zone 3) deeply incised into the adjacent recent Pleistocene (140 000–10 000 years BP) alluvium (Land Zone 3). Ollera Creek to the south is incised into the alluvium and relict prior streams associated with recent Pleistocene as well as active Holocene alluvium (<140 000 years BP) (Google Earth). Codes represent soil mapping units.

The recent (<4000 years BP) lowering of sea levels to the current level has exposed previous estuarine and marine sediments, both Pleistocene and Holocene. These recent sediments now form various alluvial plains, flood plains and swamps not subject to current marine tidal influence and are regarded as river and creek alluvium of Land Zone 3.

In inland river systems, erosion of the Tertiary and upland landscapes has delivered large quantities of sediments to the Murray–Darling, Lake Eyre and Bulloo River systems as well as to internal drainage depressions such as the Lake Galilee and Lake Buchannan, and playas (ephemeral salt lakes) of arid Queensland (**Plate 12**).

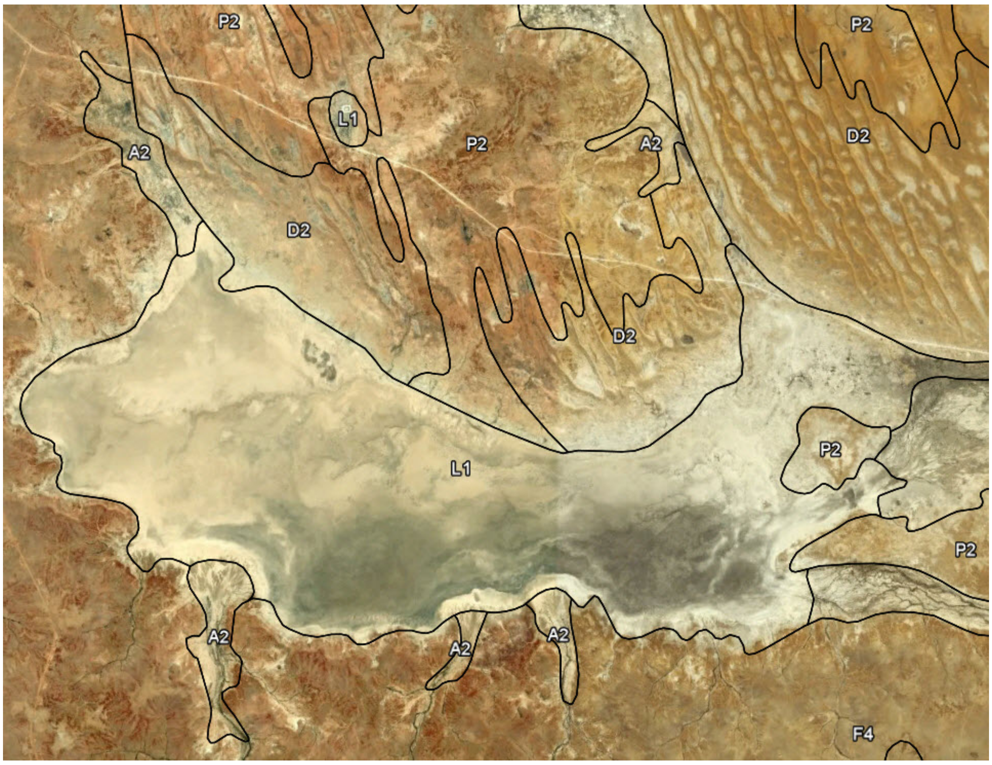

Plate 12 Playa (ephemeral salt lakes) of Land Zone 3 are common landforms in arid Queensland
Codes represent land systems from Wilson and Purdie (1990) (Google Earth).

These inland rivers generally have low gradients and frequently braided stream channels, and may have only a defined main channel in the headwaters. Several phases of erosion and deposition during the Tertiary to Quaternary periods and minor tectonic activity have resulted in several "old" and "recent" alluvial landscapes. The "recent" alluvium generally follows current stream channels while the "old" alluviums (Land Zone 4) remain as slightly elevated plains that are divorced from and often dissected by the recent alluvial processes and have a lack of distinct drainage patterns such as channels and levees (active or relict) or over-bank stream flow (flooding) as these features are removed, modified or degraded over time from the Tertiary to early Pleistocene.

Quaternary alluvial fans are prominent landforms in many areas of Queensland. These fans are predominantly very gently to gently inclined with low relief and rapidly migrating alluvial stream channels form a centrifugal to divergent, integrated, reticulated to distributary (fan) pattern. For example, coalescing alluvial fans form a continuous landform at the base of the granitic and metamorphic mountains on the wet tropical coast of north Queensland (**Plate 13**). The gently inclined (<10% slope) upper slopes frequently with incised stream channels (2–3 metres deep) indicating a non-active "older" alluvial system, that grade into very gently inclined (<3% slope) lower slopes with migrating distributary channels that are actively aggrading. In this example, the distinction between the "older" fans and active fans is difficult to distinguish and are combined into "recent" alluvium. These "recent" alluvial fans are often designated as Quaternary alluvium (Qa) on geology maps. Colluvial pediments (often mapped as Qr) are sometimes difficult to distinguish from alluvial fans, but in this example, the landform pattern originating form gullies and creeks draining the adjacent hills and mountains readily identifies fans from pediments.

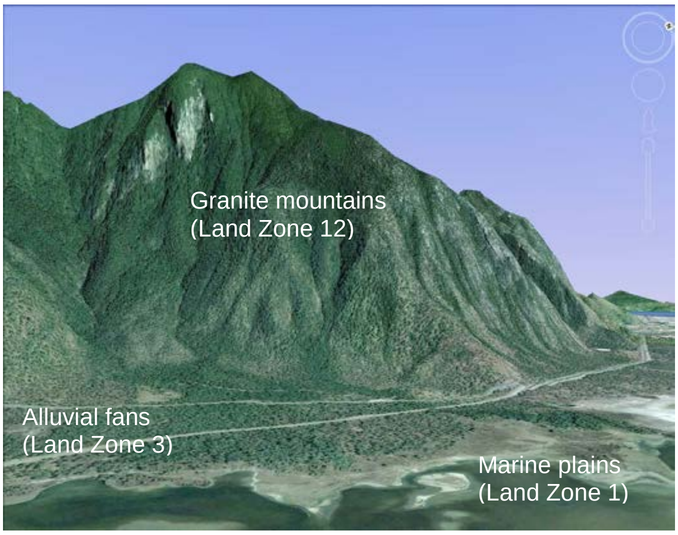

Plate 13 Quaternary alluvial fans of Mt Elliott, south of Townsville with streams and gullies from Mt Elliott aggrading fans onto the coastal marine plains
(Google Earth)

2.1.4 "Old" alluvial clay plains – Land Zone 4

*Paleo**-alluvial clay plains and gently undulating rises originating from "old" alluvial processes cover extensive areas of Queensland (Craig *et al*., 2008). Erosion of the Tertiary land surface (see Land Zone 5 and 7) during the wet interglacial periods of the Tertiary and early Pleistocene have deposited several phases of alluvium over the underlying geologies. Due to sea level fluctuations, tectonic activity, stream migration into basins and general lowering of the landscape by erosion, this "old" clay alluvium is now elevated above the "recent" alluvial valleys and plains. The "old" alluvium is recognised by the undulating landform elevated above recent alluvial landforms, and the lack of distinct drainage patterns such as channels and levees (active or relict) or over-bank stream flow (flooding) as these features are removed, modified or degraded over time from the Tertiary to early Pleistocene. In all cases, the same "old" alluvium that can be many metres thick may cover a range of geologies. For example, the "old" alluvium brigalow clays of the western Fitzroy Catchment have been deposited into the Eyre basin around Tambo and Blackall and continue west to become "old" alluvium supporting gidgee (**Plate 14**). In this example, the "old" alluvium covers a diverse range of Permian to Cretaceous formations.

* See Glossary

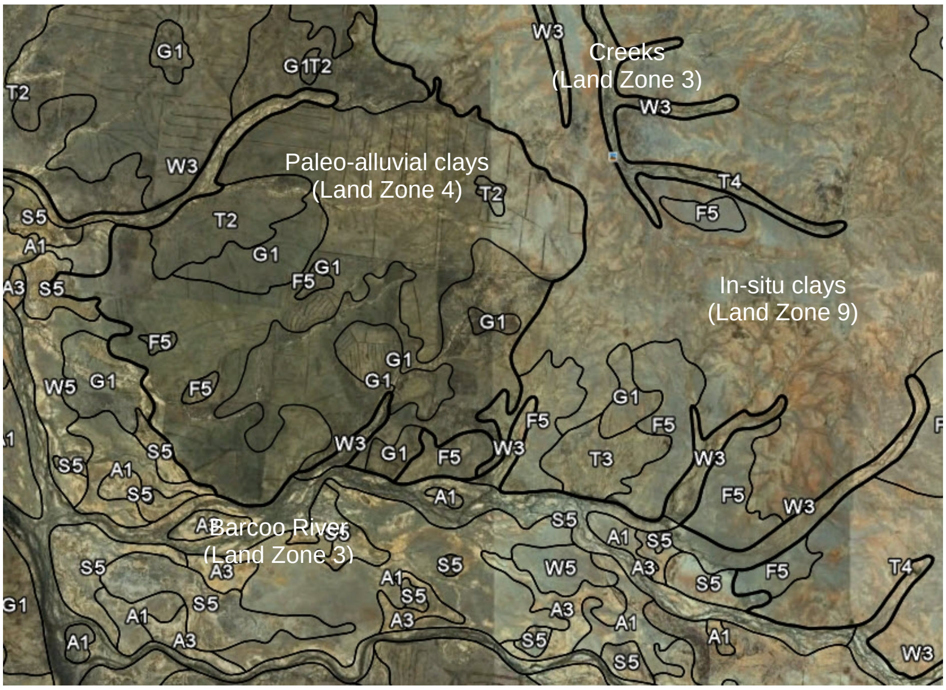

Plate 14 Paleo-alluvial clay soils of Land Zone 4 associated with gidgee (G1, T2)
They are overlying a range of geologies north of Blackall; and clay soils developed in-situ on labile sedimentary rocks of Land Zone 9 associated with Mitchell grass downs (F5, T3, T4). Alluvium of the Barcoo River (Land Zone 3) occurs to the south (Google Earth).

In other examples in far western Queensland, "old" clay alluvium overlies other geologies (**Plate 15**), including older duricrusted deeply weathered geologies.

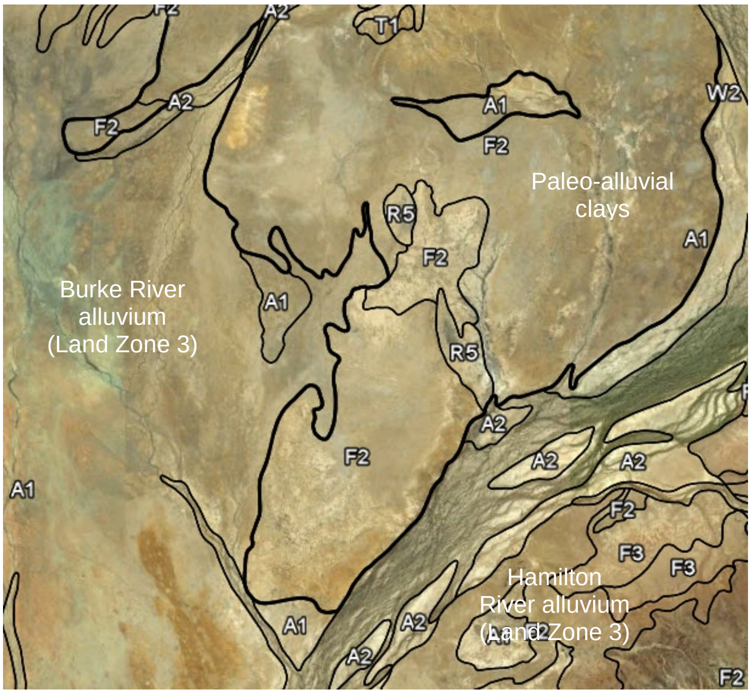

Plate 15 Paleo alluvial clay plains (F2) of Land Zone 4
These overlie Tertiary limestone and other geologies (F2). The paleo clays occur as elevated plains and have a different origin to the current Burke and Hamilton River alluvium (A1, A2 and wooded alluvium) of Land Zone 3 (Google Earth).

In most cases, these clays have surface gravels (coarse fragments) reflecting the underlying geology or transported from geologies where the "old" alluvium originated. In all cases, the gravel concentrates on the surface due to *vertic** (shrink-swell) properties of the clay. Thin veneers (<0.5 m) of non-clay material may be deposited over the clay sediments but due to the *vertic** properties of the underlying clays, this non-clay material is usually mixed to various extents with the clay.

"Old" alluvial sands and loams on plains, rises and low hills (Land Zone 5) are often associated with Land Zone 4.

2.1.5 Aeolian clays (parna) forming arid plains, rises and low hills – Land Zone 4

Aeolian clays (parna*) have influenced many soil landscapes of south-eastern and arid Australia and were first reported by Butler (1958). Parna blankets large areas of western Queensland (Craig et al. 2008), New South Wales, Victoria and South Australia and were deposited over the landscape in a series of events mainly during the cold dry glacial periods (Bowler 1986) of the Quaternary. In arid western parts of the state, this parna overlies all geologies (including duricrusts) except recent alluvium where alluvial processes have removed, mixed or buried the aeolian deposits.

The clays have mainly originated from southern landscapes (Victoria and South Australia) during Tertiary and old Pleistocene low sea level glacial (dry) periods. Minor dust accumulation continues particularly in drought periods. The distribution of the parna has followed the circulating high pressure winds over the continent, with some parna deposited on the Australian Alps and in New Zealand. The clay material has vertic* (shrink-swell) properties resulting in cracking clays that are often gilgaied and thin surfaced texture contrast soils (desert loams), frequently with surface gravel of various origins (mainly silcrete and ironstone) (**Plate 16**). Gravel free clays also exist. In all cases in western Queensland, the clay soils are high in sodium chloride and gypsum salts reflecting their origin (**Plate 17**). The complex polygenetic processes and morphological properties are further discussed by Chartres (1982). These aeolian clays (**Plate 18** and **19**), which are mainly confined to the Channel Country Bioregion, grade into "old" alluvial clays to the north and east and are difficult to separate.

As the parna blankets the landscape, the landform reflects the original landform of gently undulating plains, rises and undulating low hills. Exposed duricrusted scarp retreat areas (Land Zone 7) exist on the edge of Tertiary plateaus where the parna has been removed by erosional processes. Parna is usually recognised by the same clay soil blanketing a range of landforms and geology, the undulating landform elevated above recent alluvial landforms, and the lack of distinct drainage patterns such as channels and levees (active or relict) or over-bank stream flow (flooding), as for paleo-clay alluvium.

Geology maps have not recognised parna as a separate geology code.

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* See Glossary

Plate 16 Gravel pavements on Parna, Birdsville–Bedourie Road
Even after heavy rain, soils remain dry below the pavement.

Plate 17 Deep Parna deposits with gypsum in the lower profile, Windorah–Birdsville Road

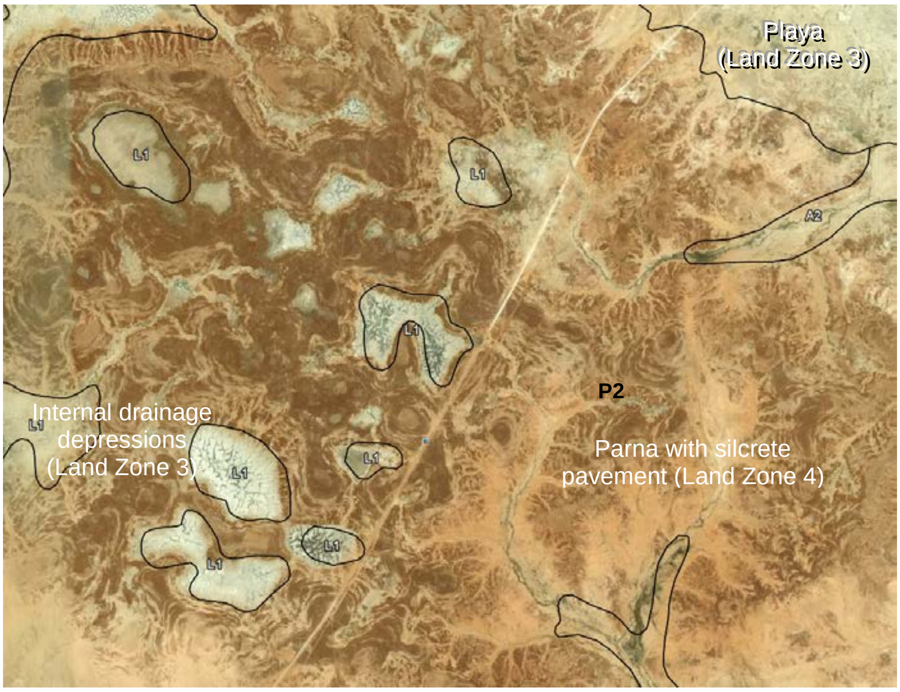

Plate 18 Parna (P2) of Land Zone 4 with silcrete gravel pavements
These overlie deeply weathered Winton Formation, Birdsville–Bedourie Road. Some internal drainage depressions (L1) of Land Zone 3 occur (Google Earth).

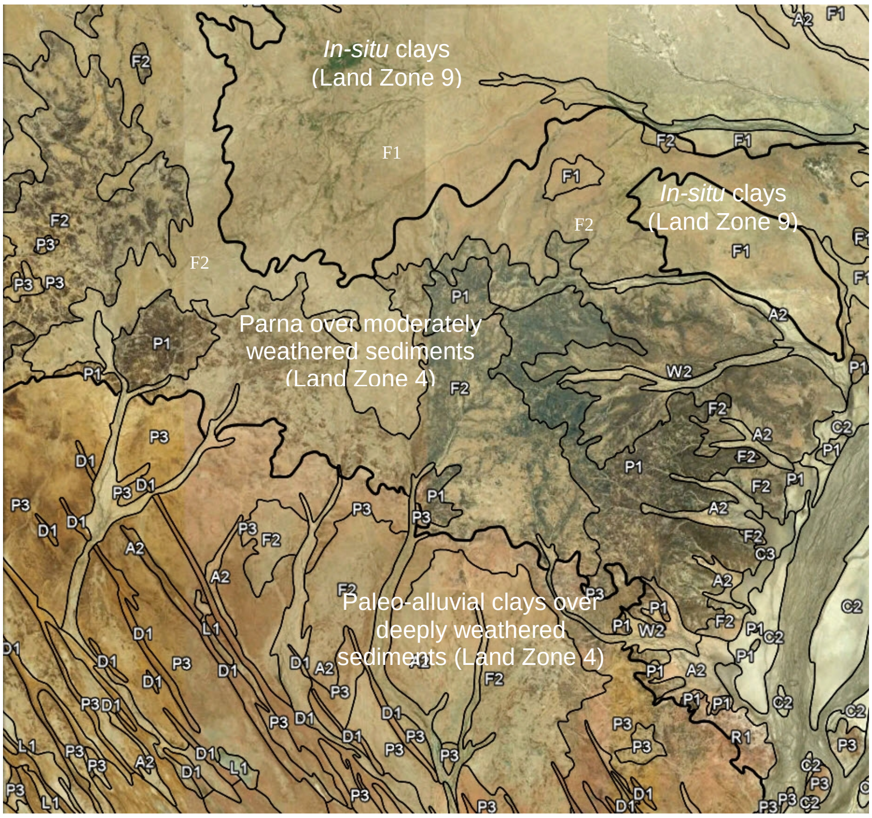

Plate 19 Complex geomorphology south-east of Bedourie
These involve: paleo-alluvial Vertosols (F2) and Sodosols (P3) of Land Zone 4 overlying deeply weathered Winton Formation in the southern half of the image; parna Vertosols (F2) and ironstone over parna (P1) of Land Zone 4 overlying moderately weathered Winton Formation in the northern half of the image; and clays of Land Zone 9 developed in-situ (F1) on moderately weathered labile sediments of the Winton Formation in the far north. Alluvium of the Diamantina River (Land Zone 3) occurs to the east (Google Earth).

2.1.6 “Old” alluvial sands and loams on plains, rises and low hills – Land Zone 5

As described for the “old” (*paleo*[*]) alluvial clays (Land Zone 4), non-clay Tertiary and early Pleistocene alluvium is associated with the paleo-alluvial clays (**Plate 20**) and covers large areas of the state. These non-clay paleo-alluvial sediments have originated by similar process and are now elevated above the “recent” alluvium to form plains and gently undulating rises. In some cases, they have been dissected to persist as remnants on low hills (**Plate 21**). The “old” alluvium is recognised by the undulating landform elevated above recent alluvial landforms, and the lack of distinct drainage patterns such as channels and levees (active or relict) or over-bank stream flow (flooding) as these features are removed, modified or degraded over time from the Tertiary to early Pleistocene. These unconsolidated sediments often contain rounded gravels (coarse fragments) of various origins which are usually not related to the underlying geologies. In some cases, the more siliceous or ferruginous sediments have been indurated by the weathering and soil forming processes. Tertiary and early Pleistocene non-clay paleo-alluvial fans also exist elevated above “recent” alluvium of Land Zone 3.

* See Glossary

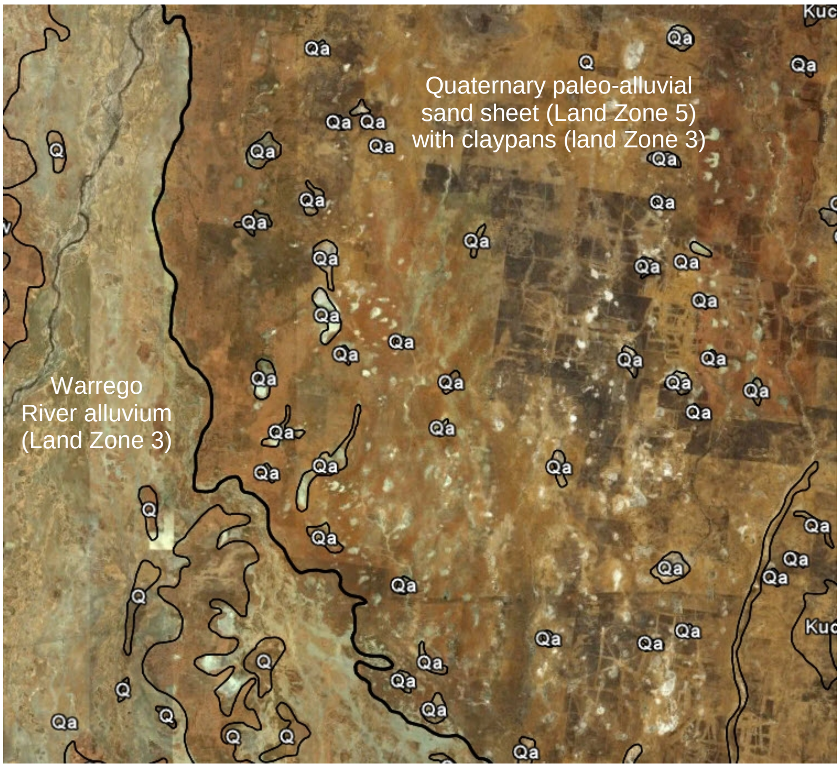

Plate 20 Image of paleo-sandy alluvium of Land Zone 5
This shows "old" degraded non-active alluvial deposition, and associated internal drainage clay pans of Land Zone 3, south of Charleville (Google Earth).

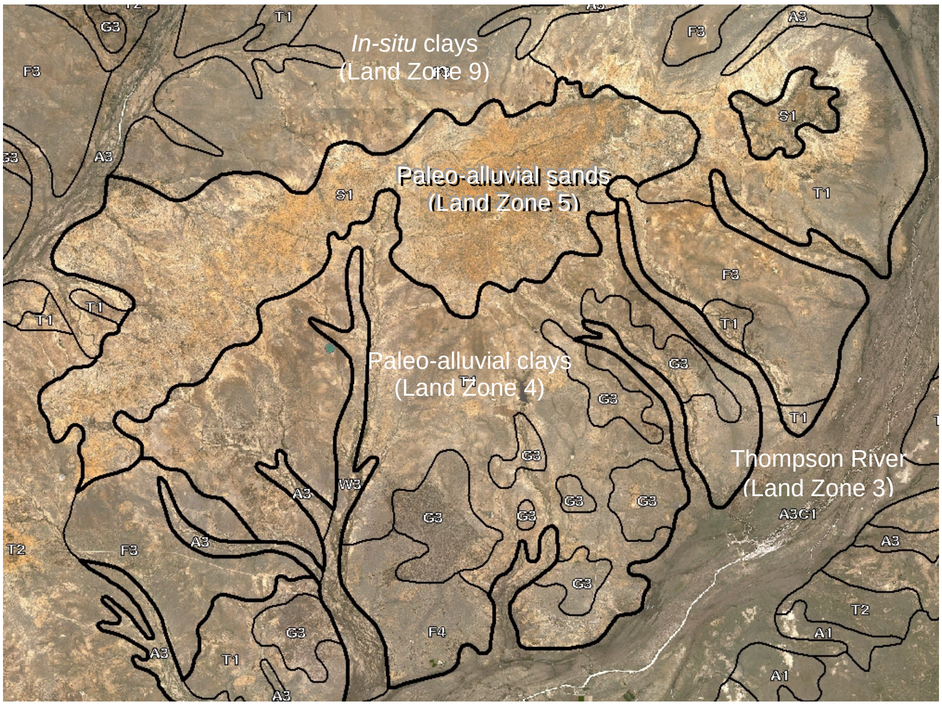

Plate 21 Elevated Tertiary sand alluvia (S1) associated with a paleo-river system not associated with the current Thompson River
The sand deposits (S1) of Land Zone 5 have been deeply weathered and duricrusted in part and eroded. Paleo-alluvial clay of Land Zone 4 is associated with the gidgee (G3, T1) and downs (F4). In-situ clays of Land Zone 9 occur on labile sediments (F3) (Google Earth).

Occasionally, a thin veneer (>0.5m) of transported non-clay sediment can overlie *in-situ* soils or “old” alluvial *vertic*[*] (shrink-swell) clays. In some cases, the underlying soil or clay sediments can be strongly *vertic** resulting in melon hole gilgai with non-clay surfaces up to approximately one metre thick. Land Zone 5 would apply here.

2.1.7 Sand and non-clay plains not developed *in-situ* from bedrock – Land Zone 5

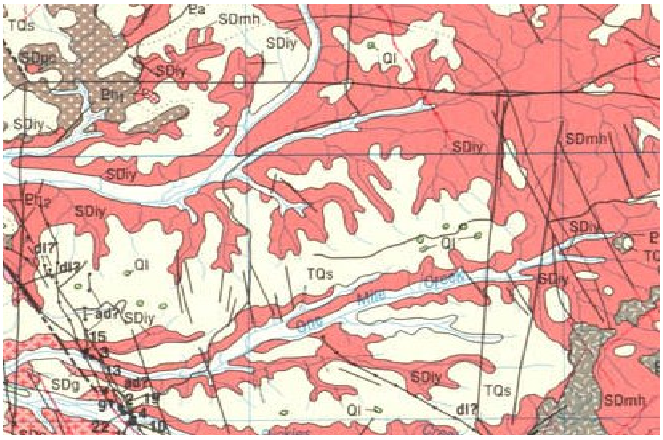

Figure 2 Deep transported sands (TQs) overlying granite (SDIy) and other geologies

Erosion of any Tertiary landscape, including “old” alluvial sands and loams and deeply weathered geologies, has resulted in redeposition of sandy to loamy material lower in the landscape as colluvium and diffuse overland sheet wash. These sandy to loamy sediments overlie a range of geologies and have not developed *in-situ*.

For example, large areas of Cape York Peninsula have transported sands (TQs) overlying a range of geologies, including granite (**Figure 2**). These transported sands may have originated from granite but have not developed *in-situ* from the underlying geology. This is reflected by deeper soils, different vegetation communities and different radiometrics (K, Th and U radioisotope signature of the earth’s surface) compared to soils developed *in-situ* on granites.

Also, large areas of Cape York Peninsula have loams containing pisolotic nodules and fine gravels (originating from erosion of the Tertiary landscape) overlying clays with no gravel developed *in-situ* from the underlying labile sedimentary rocks **(Plate 22**, **23** and **24)**.

[*] See Glossary

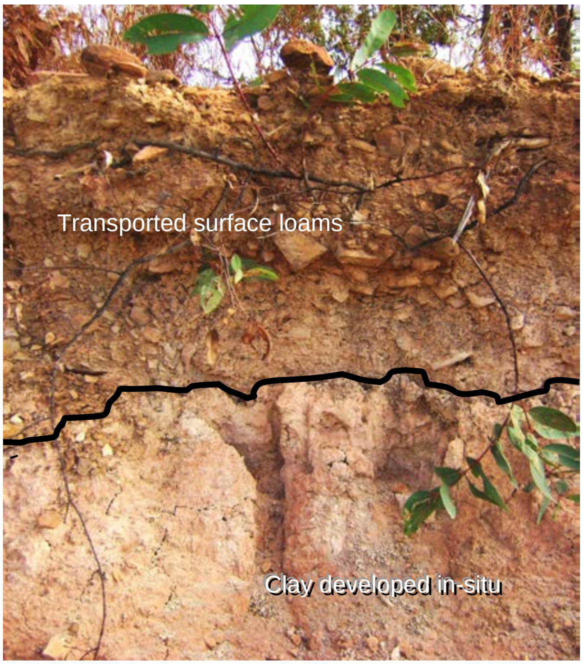

Plate 22 Batavia soil (Land Zone 5) on Cape York Peninsula
It has surface loams >0.5 m containing pisolotic nodules and fine gravels (originating from erosion of the Tertiary landscape) overlying clays with no gravel developed in-situ from the underlying labile sedimentary rocks.

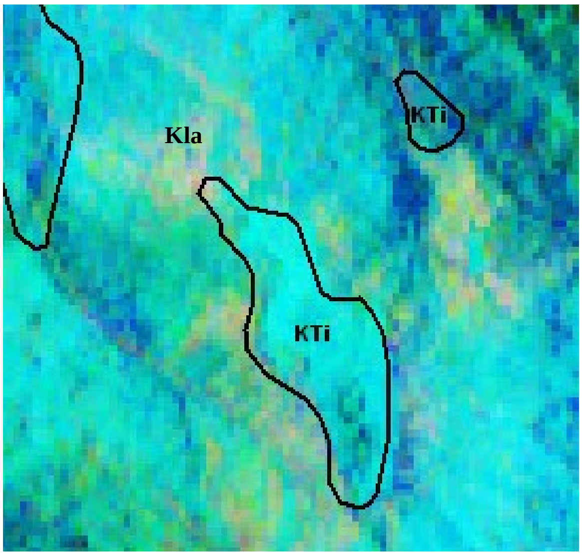

Plate 23 Geology and radiometrics (K, Th and U radioisotope signature of earth's surface) of Batavia Downs, Cape York Peninsula.
The high Th signature (blue) indicates deeply weathered geology (KTi) and associated colluvial material. The high K signature (pink) indicates K feldspars associated with the moderately weathered labile sediments (Kla).

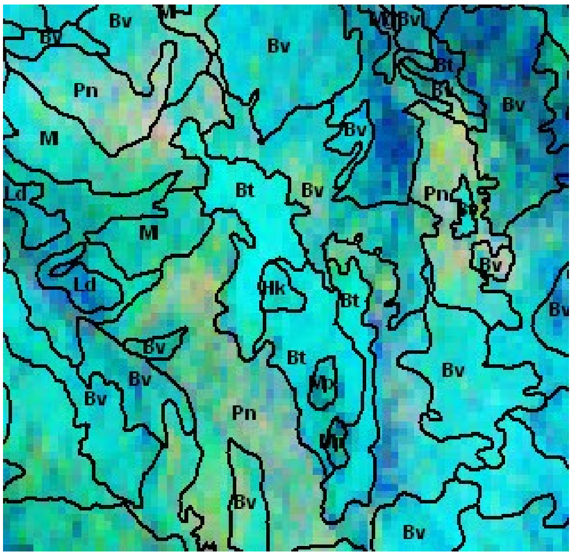

Plate 24 Picanninny (Pn) and Myall (Ml) clay soils developed *in-situ* on labile sediments of the Rolling Downs Group (Kla) (Land Zone 9) both have high K radiometrics.
The Batavia soil (Bv) (Land Zone 5) with high Th signature has colluvial material (see Plate 22) from erosion of the deeply weathered sediments (Bt) (Land Zone 5 and 7) being deposited over the labile sediments of the Rolling Downs Group (Kla).

Some sediment, particularly in semi-arid and arid areas, has been reworked and moved by wind to form level to gently undulating sandplains (**Plate 25**). Any substrate reworked by wind to form sandplains is included, for example, reworking of sandy colluvium and sheet wash originating from non-deeply weathered quartz rich bedrock. Dunefields are excluded (refer *Inland sand dunes – Land Zone 6*).

Plate 25 Wind-blown sand plains (S2) of Land Zone 5 overlie paleo-alluvial clay plains (F6) of Land Zone 4 south of Winton.
The clay plains grade into mulga lands (H1, M1) on deeply weathered sediments of Land Zone 5. Minor wooded alluvial plains (W3). Reworking of Quaternary alluvium by wind has resulted in sandplains (and associated dunefields of Land Zone 6) overlying the "recent" alluvium or other geologies. In this example, the sand sediments are not developed directly from the "recent" alluvial processes, such as water deposited sandy levees or floodplains. (Google earth)

Sandy material developed *in-situ* (and associated colluvium) on deeply weathered or bedrock geologies (see Section 3.1.2) are excluded from this process.

2.1.8 Inland sand dunes – Land Zone 6

Erosion of the Tertiary landscape and quartz-rich substrates has deposited large amounts of sediments containing sand that have been reworked by wind to form sand dunes and associated sandplains. Dunes become more common to the west corresponding to dryer climatic conditions. Parallel dunes typical of the Simpson Desert (**Plate 26**) are the most common while reticulate dunes enclosing claypans are confined to alluvial landscapes (**Plate 27**). Isolated semi-stable and mobile dunes are associated with many river systems in western Queensland. The dunes follow the direction of the prevailing south-easterly winds with the mobile crests being steeper on the eastern side due to the westerly winds in winter.

The difference between sand dunes and the associated sand plains may be less obvious at times. In general, dunes predominate when the convex dune crests and concave dune flanks dominate over the level inter-dune sand plains

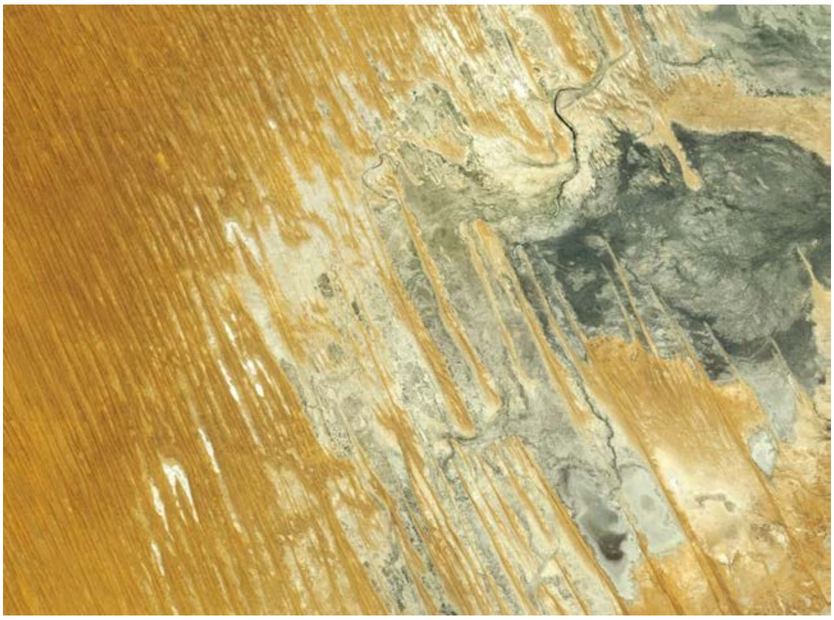

Plate 26 Longitudinal dunes of the Simpson Desert
The leading edge (south-east end) of the dunes on alluvium are frequently deflated (eroded by wind) and cemented (due to clay). In general, dunes are predominantly pale coloured on the north western side of the large alluvial plains of the Channel Country where the sand originates and becoming redder to the north-west. The red colour is due to the gradual oxidation of the iron minerals coating the sand grains (Google Earth).

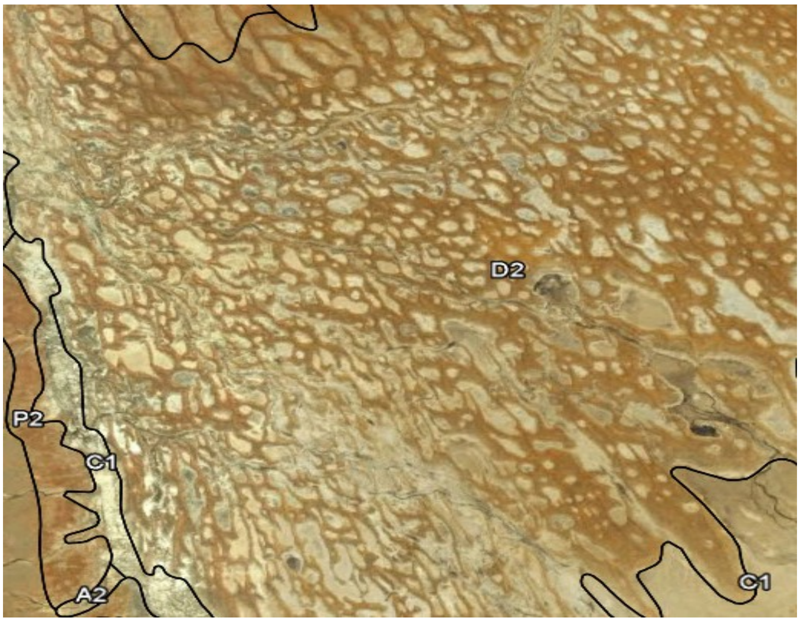

Plate 27 Reticulate dunes on alluvium south of Betoota (Land Zone 6)
Deflated (wind eroded) dunes composed predominantly of sodium salts and gypsum frequently occur on the north western edge of playas (ephemeral salt lakes). The gypsum becomes recrystallised and cemented to some extent by rain making the gypsum/sand mixture resistant to wind movement. These gypsum dunes grade into normal sand dunes further from the playas (Google Earth).

Lunettes deposited by wave action on lakes are excluded and allocated to Land Zone 3.

2.2 Deep weathering and duricrusts

During the Tertiary, up-warp and erosion of the original landscape, and deposition of sediments over extensive areas occurred, followed by a stable phase in which planation (flat or level) surfaces were common, and deep weathering under prolonged wet climatic conditions was the main process. Ferruginous, siliceous, or other types of duricrust formed during these stable phases. Because of their indurated nature, these surfaces are commonly still preserved (Day *et al.* 1983)

In general usage, the term "deep weathering" is considered synonymous with lateritisation* – the process of transformation of a (near) surface layer (rock or soil) into lateritic regolith (Eggleton 2001). In un-dissected profiles, the regolith typically has a red soil (*in-situ* or transported) over completely weathered* bedrock high in iron and/or aluminium oxides and kaolin clays and may contain quartz, and may be strongly mottled or pallid (pale) in colour in the lower part (**Plate 28**). Profiles are often very deep and can be >10 metres deep over the underlying moderately fresh bedrock. Typically, all rock structure, including bedding, has been destroyed and all minerals have been chemically weathered to kaolin with or without resistant quartz. In extreme weathering, gibbsite (aluminium hydroxides) and sesquioxides (iron and aluminium oxides) remain as the dominant material. The lower part of the deeply weathered profile grades to very highly weathered* rock. Very highly weathered bedrock is produced by the thorough decomposition of the rock mass but retains the structure of the original rock and all rock minerals have decayed. The deep weathering process is independent of rock type.

In many situations, the red soil (*in-situ* or transported) or the red upper part of the deep weathered profile is lacking due to landscape processes or erosion in part. Under wet conditions, the oxidised iron becomes reduced and soluble, and can be rapidly removed from the profile leaving pallid (pale) colours. Also, erosion processes can partially remove the upper part of the deeply weathered profile.

Very highly weathered bedrock then grades at depth to "moderately" weathered bedrock (**Plate 31**).

Plate 28 Lateritic profile (Land Zone 5) with iron-rich deep soil and lower pallid zone on deeply weathered sediments of the Maryborough Basin, Maryborough

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* See Glossary

Plate 29 Duricrusted deeply weathered sediments of the *Winton Formation* (Land Zone 7), south-west of Winton
This involves: the level indurated Tertiary surface (background), talus slopes and pediments. Ironstone lag gravels originate from the ferruginous duricrust and iron-rich layers in the deeply weathered profile.

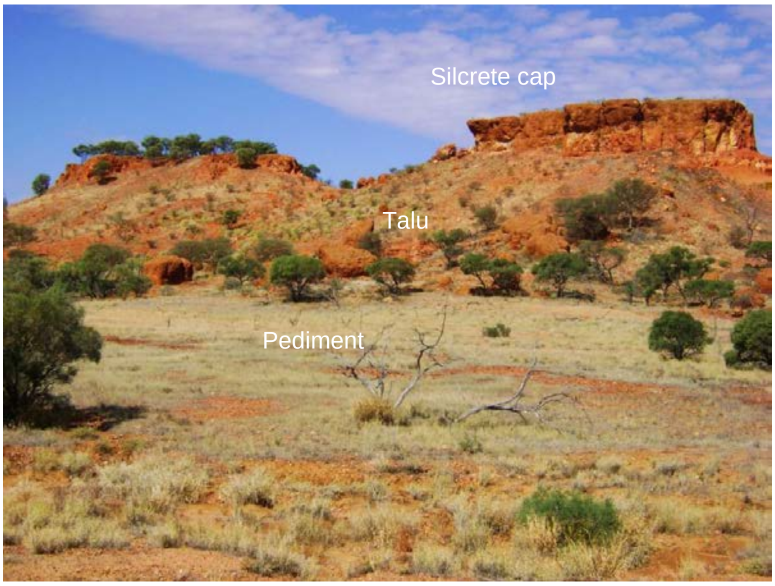

Plate 30 Duricrusted deeply weathered *Winton Formation* (Land Zone 7), west of Winton
This has a silcrete cap and talus slopes. Pediments with lag gravels (<0.5 m) overlie clay soil developed in-situ on moderately weathered labile sediments (Land Zone 9).

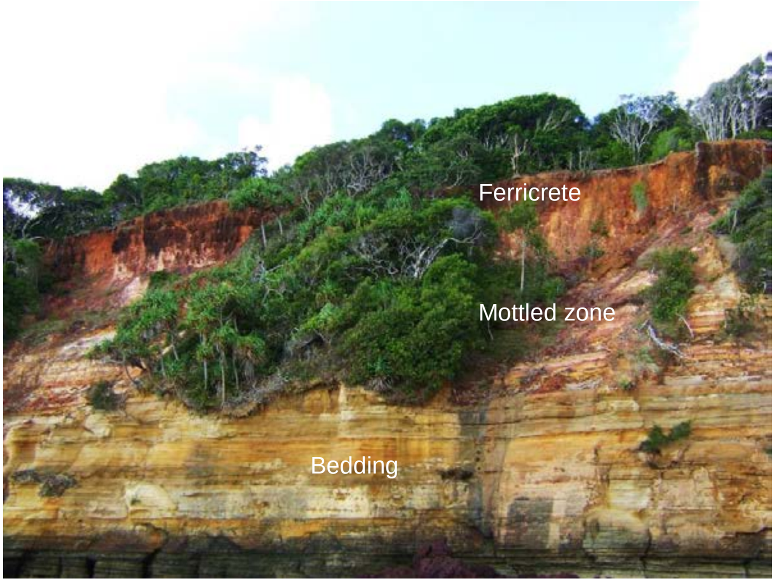

Plate 31 Deeply weathered *Helby Beds* (Land Zone 5) on Cape York Peninsula
Has deep soil over ferricrete over a mottled zone grading into moderately weathered sediments with distinct bedding at depth.

During the intense and prolonged weathering of the Tertiary landscape, many but not all of the deeply weathered profiles became indurated (cemented) due to the residual accumulation of secondary minerals within the profile, or due to the lateral mobilisation, accumulation and precipitation of soluble minerals such as silica (silcrete) and/or iron (ferricrete) (**Plate 29** and **30**). Accumulation and cementation are commonly a response to climate or drainage status (Craig *et al*. 2008). Silicification of carbonates during deep weathering may result in chalcedony and an indurated surface, such as the Tertiary limestone deposits in the Georgina Basin. Accumulation of calcareous indurated layers (calcrete) is not part of the deep weathering process because carbonates are partially soluble and are removed during the intense weathering process, but they may accumulate in profiles due to landscape processes post deep weathering. Indurated surfaces are commonly still preserved (Day *et al*. 1983).

While the deep weathering profile may have arisen low in the landscape, subsequent uplifting and erosion of the Tertiary landscape has resulted in elevated tablelands and plateaus now often high in the topography; a process termed 'relief inversion'. The current landscape has resulted in a remnant Tertiary surface with dissected plateaus, mesas, buttes and scarp retreat areas remaining over large areas of western Queensland (**Plate 29)**. Stripping of the soil or other unconsolidated material off the duricrusted profile, particularly at the edge of plateaus and mesas, has exposed the duricrust and non-duricrusted deeply weathered profile (Land zone 7).

The distinction between the lower part of a deeply weathered profile and the upper part of a "moderately" weathered geology (**Plate 31**) can be difficult, especially where remnants of the deeply weathered profile remain as low rises surrounded by other land zones developed on bedrock. In this case, examination of rock specimens and reference to geology maps and accompanying notes is essential. Complete removal of the deeply weathered landscape exposes the underlying "moderately" weathered landscapes typical of Land Zones 8, 9, 10, 11 and 12. The erosion products have contributed to the development of the unconsolidated materials discussed earlier (typical of Land Zones 1, 2, 3, 4, 5 and 6).

The persistence of ancient deeply weathered surfaces to this day has greatly influenced contemporary landscapes over much of the state (**Figure 3**). Deeply weathered soil profiles may be tens of metres deep such as that formed on the Binjour Plateau (between Gayndah and Mundubbera) where the whole profile is 65 m deep (CSIRO, 1983).

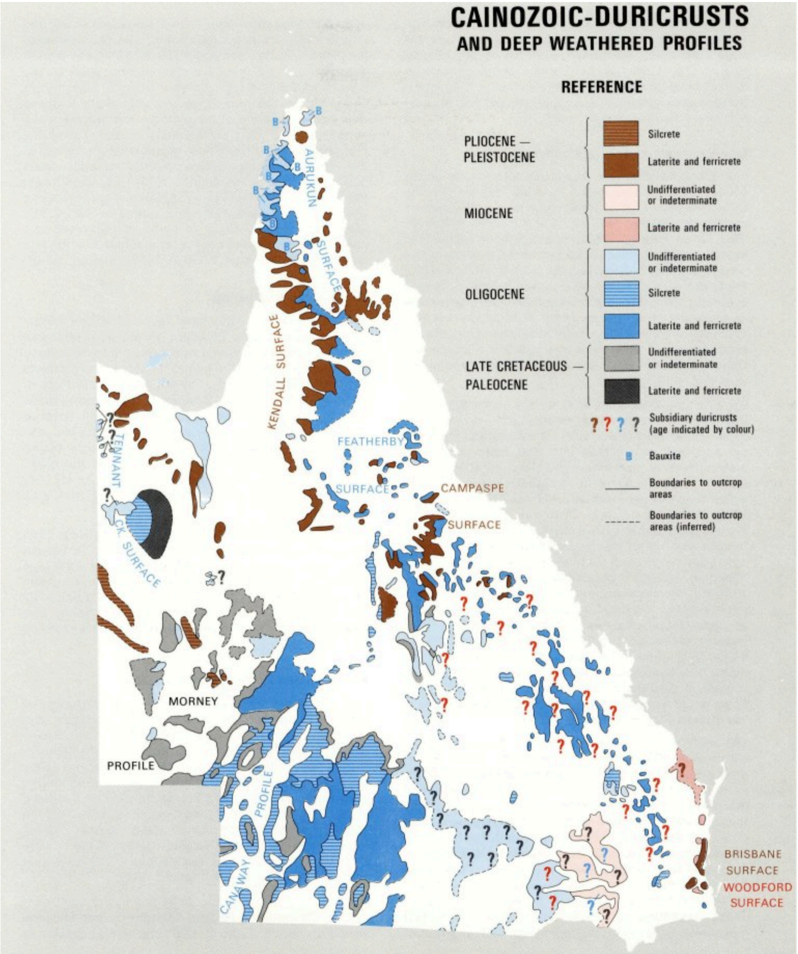

Figure 3 Cainozoic duricrusts and deep weathering profiles in Queensland (Day *et al.* 1983)

Many of the intact duricrusted remnants have scarp retreat areas where erosion of the underlying softer "moderately" weathered bedrock causes undercutting and collapse of the resistant upper part. Colluvial slopes in the scarp retreat areas often have a shallow (<0.5 m) surface veneer of weathered gravels covering soils developed in-situ. Colluvial slopes of deep weathered landscapes, including pediments, with colluvial material >0.5 metres thick are allocated to the deeply weathered land zones. Colluvial slopes with material <0.5 metres thick overlying soils developed *in-situ* are allocated to the adjoining land zone with *in-situ* soil (**Plate 30**).

2.3 Sedimentary, igneous and metamorphic rocks

Rocks are consolidated materials composed of one or more minerals originating from igneous, sedimentary and metamorphic processes. Landforms vary greatly from gently undulating plains to steep mountains, plateaus and ranges.

Rocks at, or near, the surface of the earth, break down under the influence of wind, water, ice, temperature extremes and living organisms. Fragments of varying sizes, produced by this weathering process, may remain on site or be transported by wind, water, ice and gravity.

In general, the bedrock is weathered to varying degrees and includes unweathered rock∗, slightly weathered*, moderately weathered* and highly weathered*. In all cases, the rock structure and primary minerals (e.g. feldspars) are not completely weathered and are hereafter collectively referred to as “moderately weathered”.

2.3.1 Sedimentary rocks

Sedimentary rocks originate from the consolidation of the sediments (fragmental material) transported and deposited by wind, water, and ice, chemically precipitated from solution, or secreted by organisms, and which forms in layers. Some deposits accumulate to great depth and are subjected to physical pressures, chemical change and heat over millions of years. The result is that a new rock type is formed from the deposit – a sedimentary rock. Sedimentary rock types generally reflect the deposition environment and grain size. Common sedimentary rocks include sandstones, siltstones, mudstones, shales, conglomerates and limestone.

Rocks formed primarily by volcanic activity and deposited in water or air but not transported by water (pyroclastics, pillow larva, and volcaniclastic conglomerate and agglomerates) are excluded and allocated to Land Zones 8 or 12. These volcanic deposits, such as the Neara Volcanics, are by definition sedimentary rocks as they were deposited in water, but are primarily formed from volcanic activity and do not show sedimentary layering. Sedimentary Land Zones (Land Zones 9 or 10) are allocated where volcanics are subdominant within sedimentary rocks.

2.3.1.1 *Fine grained sedimentary rocks with little or no deformation – Land Zone 9*

Fine grained sedimentary rocks refer to the grain size only and include siltstones, mudstones and shales. Sediments chemically precipitated or secreted by organisms include chert, chalk, limestones and dolomites, as well as oolitic sediments.

Depending on the lithology (mineral composition) of the lithic fragments, these fine grained sedimentary rocks are labile (readily decompose to clays) to sublabile (composed of quartz and clay forming minerals) forming clayey soils or soils with clay subsoils. Due to the general “soft” nature of the sedimentary rocks and the readily weathered nature of the lithology, the landforms are dominated by very gently undulating to undulating plains and rises.

Sandstones, arenites and other coarse grained sedimentary rocks with a high proportion of labile or sublabile lithology are included in the fine grained sedimentary rock group as these rocks weather to clayey soils. For example, the labile sandstones of the Winton Formation in the Great Artesian Basin form very gently undulating plains with cracking clay soils.

Little or no deformation corresponds to an interlimb angle* (angle between adjacent limbs of a fold* - 180° is planar or no fold) of 180° to 120° (Blyth and de Freitas, 1994). Moderately deformed* (folded) bedrock is excluded and allocated to Land Zone 11. Most un-deformed to weakly deformed bedrocks are younger than early Permian, but can include older sedimentary rocks such as the Carboniferous limestones and dolomites of the Georgina Basin and the gently deformed western part of the Bowen Basin.

Deeply weathered geologies are excluded and allocated to Land Zone 5 or 7.

∗ See Glossary

2.3.1.2 *Medium to coarse grained sedimentary rocks with little or no deformation – Land Zone 10*

Medium to coarse grained sedimentary rocks (sandstones, arenites, conglomerates) composed predominantly of resistant quartz form undulating to steep rises and hills, plateaus, and precipitous cliffs, and scarps (**Plate 32, Figure 4**) especially where "soft" easily eroded sediments underlie the sandstones. Interbedded fine grained sedimentary rocks and volcanics may be included but are subdominant. Soils are predominantly "shallow to moderately deep" sandy soils formed in-situ. Deep sandy soils may occur on colluvial slopes (**Plate 33**).

Overlying unconsolidated sediments, either transported or reworked by wind, and "deeply weathered" medium to coarse grained sedimentary rocks are excluded.

Little or no deformation corresponds to an interlimb angle∗ (angle between adjacent limbs of a fold*; 180° is planar or no fold) of 180° to 120°. Moderately to strongly deformed* (folded) bedrock is excluded and allocated to Land Zone 11. Most un-deformed to weakly deformed bedrocks are younger than early Permian, but older sedimentary rocks are occasionally included in Land Zone 10.

Plate 32 Cliffs and gorges of Jurassic quartzose sandstones typical of Land Zone 10 in the Carnarvon NP.
The gently undulating plains and rises in the north are typical of Land Zone 9 (Google Earth).

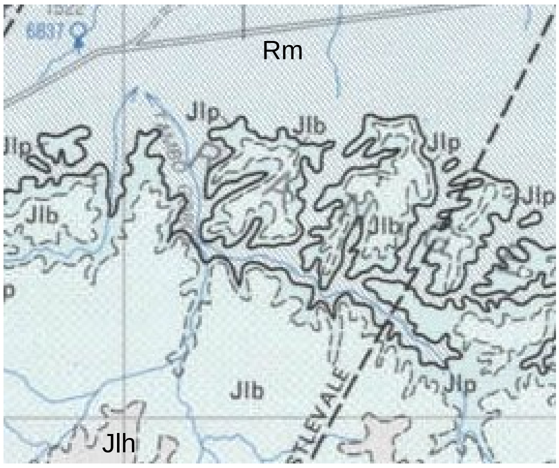

Figure 4 1:250 000 geology map of same area as Plate 32
The Jurassic Precipice Sandstone (Jlp), Evergreen Formation (Jlb) and Hutton Sandstone (Jlh) form the cliffs and gorges (Land Zone 10) in Plate 32. The labile sediments of the Moolayember Formation (Rm) in the north form gently undulating plains and rises typical of Land Zone 9.

∗ See Glossary

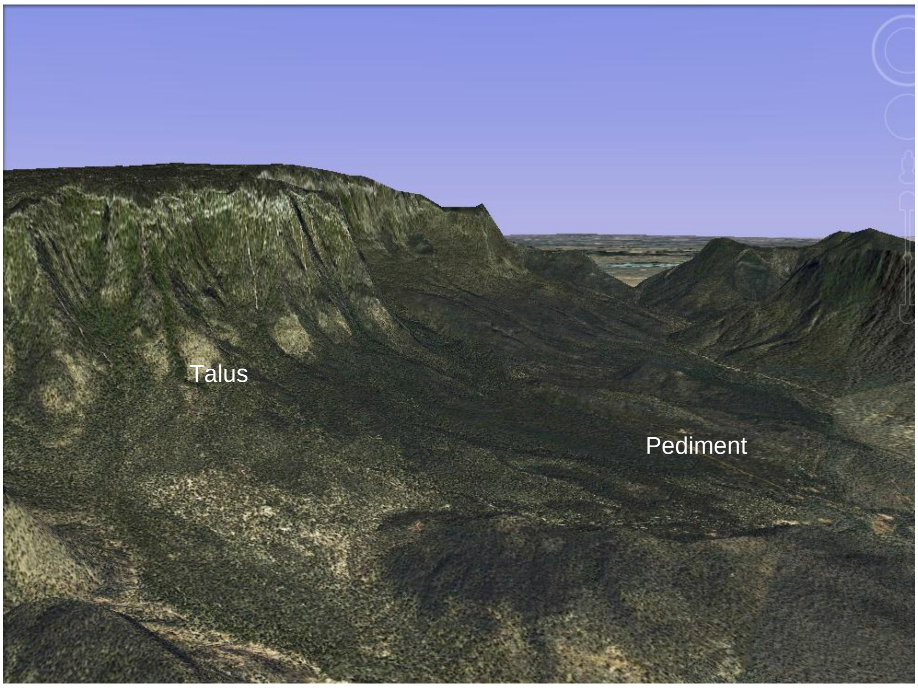

Plate 33 Sandstone cliffs, talus and sandy pediments of the Blackdown Tablelands are all Land Zone 10
(Google Earth)

2.3.2 Metamorphosed rocks – Land Zone 11

Existing rock may be subjected to extremes of heat and pressure sufficient to change their chemical and physical properties and a different type of rock is formed – *metamorphosed rock.* The degree of metamorphism, either alteration or *deformation**, is subjective. In general terms, moderately to strongly metamorphosed rocks show signs of partial or complete recrystallisation changed by the solid-state application of heat, pressure and fluids (excluding weathering and *diagenesis*).*

Metamorphic rocks are associated with orogenic* phases where regions are subject to folding, faulting and deformations, and granitic intrusions, and intensive volcanic activity, usually associated with continental plate tectonic activity. The main metamorphic regions described by Day et al. (1983) are the Proterozoic rocks of Mt Isa Inlier of the north-west Highlands (**Plate 34**), Coen Inlier on Cape York Peninsula and the Georgetown Inlier of the Einasleigh uplands. Post Proterozoic metamorphism is associated with the Thompson Orogen (Townsville south through central Queensland), the Hodgkinson–Broken River Orogen (Cooktown to west of Ingham), and the New England Orogen along the coast/near coast of Queensland (Proserpine to the New South Wales border). The various Inliers and Orogens are shown in the geological structural framework for Queensland (**Figure 7**).

Some sedimentary basins have been moderately deformed (folded) but the rocks have not been significantly altered or recrystallised. Moderately to strongly deformed* (folded) sedimentary rocks are included in the metamorphosed land zone and have an interlimb angle* (angle between adjacent limbs of a fold*; 180° is planar or no fold) of less than 120° (Blyth and de Freitas 1994). The interlimb angle can operate as a site expressed as a foliated rock sample, or can be at a regional scale expressed on geology maps, geology notes and satellite imagery.

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* See Glossary

For example, the Bowen Basin was affected by the closing phases of the New England Orogeny and moderately deformed (moderately folded) in the eastern part in contrast to the relatively gently deformed western part (**Plate 35** and **Figure 5** and **6**). Most sedimentary formations older than Permian are moderately to extensively deformed and are associated with the various Inliers' and Orogens' as shown in the geological structural framework for Queensland (**Figure 7**).

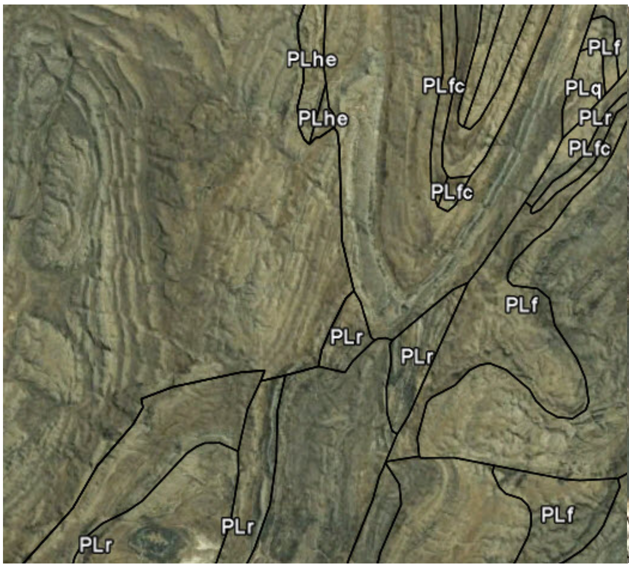

Plate 34 Strongly folded and strongly metamorphosed geologies
(Land Zone 11) of the Mt Isa Inlier (Google Earth)

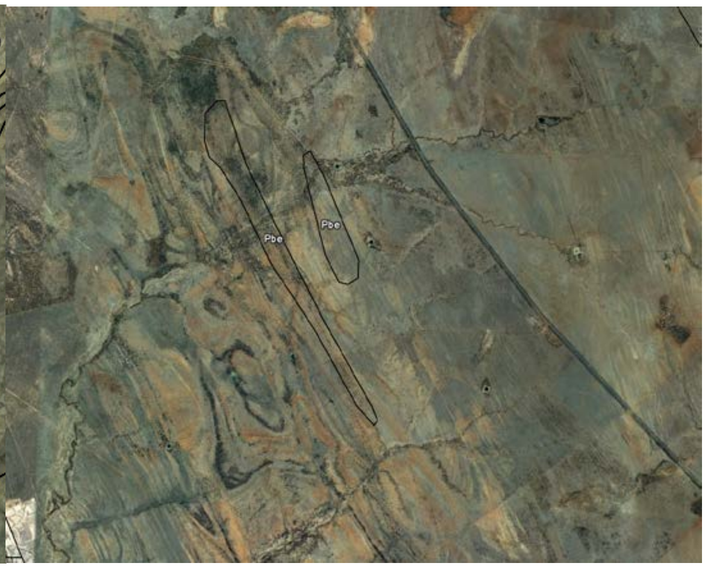

Plate 35 Strongly folded fine grained sedimentary rocks of the Blackwater Group (Puw) in eastern Bowen Basin
(Land Zone 11) (Google Earth)

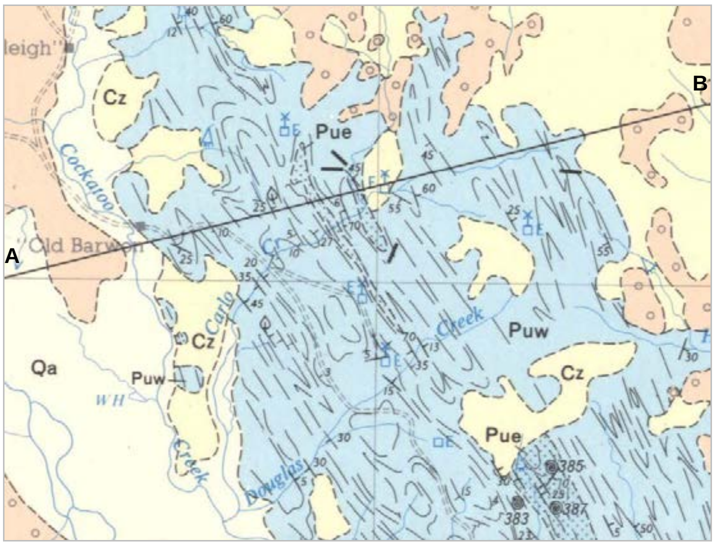

Figure 5 1:250 000 geology map of the same area as Plate 35 showing surface strike, dip and trend lines

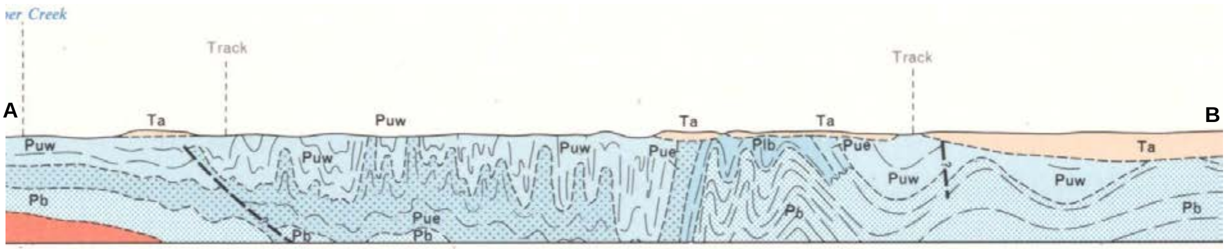

Figure 6 Cross section (A–B) showing strongly folded sediments of Blackwater Group (Puw) *(1:250 000 geology map)*

Metamorphic rock type is reflected in the degree of mineral alteration, crystallisation or deformation (excluding weathering and *diagenesis**) and does not reflect the mineral composition. For example, slate is a compact, fine grained metamorphic rock possessing cleavage, generally originating from metamorphosed shale. Limestone turns to crystalline marble through the process of metamorphism. Schist is a strongly foliated crystalline rock that has well developed lamellar minerals such as micas. Gneiss is an equivalent strongly foliated rock but has coarse mineral structure (often granitic origin). Phyllite is between slate and schist. Mylonite is a fine grained, intensely deformed rock. Quartzite is highly metamorphosed, recrystallised quartz sandstone.

Metamorphosed rocks are generally harder and more resistant to erosion when compared to similar unmetamorphosed rocks. Landforms derived from metamorphosed rocks are typically steeper and more elevated with shallower soil compared to those derived from similar unmetamorphosed rocks.

All metamorphosed rocks including metamorphosed igneous rocks are included in Land Zone 11.

* See Glossary

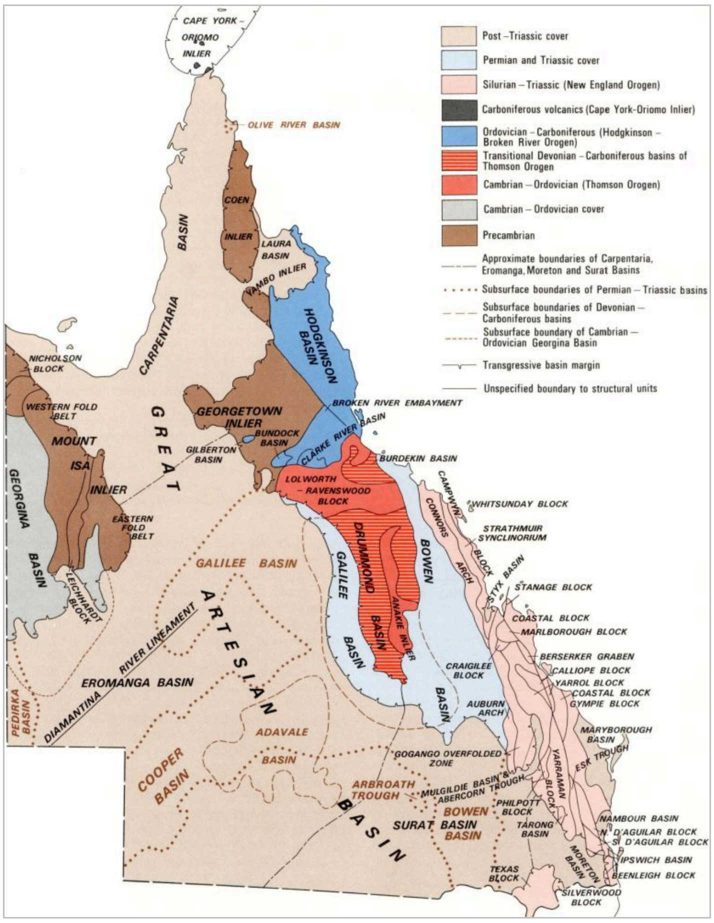

Figure 7 Geological structural framework (1: 2 500 000 Queensland Geology, Day *et al.* 1983)

2.3.3 Igneous rocks – Land Zones 8 and 12

Igneous rocks cover all rocks that solidified from molten or partly molten material originating from magma. Metamorphic rocks, Proterozoic to Mesozoic (Cretaceous and older) acid, intermediate and basic igneous rocks are associated with *orogenic** phases where regions are subject to folding, faulting and deformations, granitic intrusions, volcanic activity, and metamorphism, usually associated with continental plate tectonic activity.

Rock type reflects specific lithology (mineral content) and the environment in which it formed (grain size). As with other rock types, coarse grained rocks weather faster than fine grained rocks; and mafic (generally dark coloured magnesium–iron clay forming) minerals weather faster than feldspars (aluminium silicate clay forming minerals) which weather faster than siliceous minerals.

2.3.3.1 Extrusive igneous rocks

Extrusive rocks are fine grained rocks which form as a result of volcanic activity at or immediately adjacent to the earth's surface. Structures include lava plains, vents and volcanic plugs. Common rock types include basalt, andesite, rhyolite, trachyte and tuffs (pyroclastics). Landforms are commonly plains, rises, craters, steep hills and mountains on the plugs, and dissected tablelands.

* See Glossary

Cainozoic (Tertiary to Quaternary) igneous rocks typical of Land Zone 8 occur as flood basalts and associated vents and volcanic plugs (**Plate 36**). Proterozoic to Mesozoic (Cretaceous and older) extrusive rocks are allocated to Land Zone 12.

Plate 36 Quaternary crater lakes of Coulstoun Lakes and cropping on the associated lava plains (Land Zone 8)
(Google Earth)

2.3.3.2 Intrusive igneous rock

Intrusive rocks of Land Zone 12 occur where magma emplaces in pre-existing rock and cools relatively slowly (compared to extrusive rocks) forming crystalline rocks. Intrusive structures include batholiths, sills and dykes. Common rocks include acidic (granite, adamelite), intermediate (granodiorite, diorite, syenite, monzonite), and basic (gabbro and dolerite) rocks (**Plate 37** and **38**). Landforms are dominated by undulating to steep rises, hills and mountains.

These intrusive rocks may have formed many kilometres below the earth's surface, but tectonic activity and subsequent erosion of the land surface over often hundreds of millions of years has now exposed these rocks at the surface. All Cretaceous or older intrusive igneous rocks are allocated to Land Zone 12.

In all cases metamorphosed igneous rocks are allocated to Land Zone 11, and deeply weathered geologies are allocated to Land Zone 5 or 7.

Plate 37 Granitic boulders, Eulo, western Queensland

Plate 38 Granite landscape west of Childers

3. Land Zones

The land zones have been distinguished on geology and geomorphic processes which influence landform, hydrology and soils, all of which influence the structure and function of ecosystems. The following section describes the major features of the 12 land zones and should be used in conjunction with Section 2 describing the land surface (geomorphology).

3.1 Land Zone 1 – Deposits subject to periodic tidal inundation

Definition

 **tidal flats and beaches**	Quaternary estuarine and marine deposits subject to periodic inundation by marine waters. Includes mangroves, saltpans, off-shore tidal flats and tidal beaches. Soils are predominantly Hydrosols (saline muds, clays and sands) or beach sand.

Clarification

Land Zone 1 includes the sands and/or muds deposited by wind and waves in the inter-tidal zone* and higher supratidal* areas under the periodic influence of sea water (**Plate 39**). The substrate materials have been transported and deposited by river and ocean currents, waves and wind. This does not include sub-tidal areas, rock shelves, and rocky outcrops and headlands adjacent to the inter-tidal zone.

Beaches, tidal mud flats and sand deposits which are subjected to direct and repeated tidal influence and which support little or no vegetation other than seagrass communities, are dynamic. They are part of Land Zone 1, but are not mapped on remnant regional ecosystem maps due to community dynamics and water clarity issues for obtaining good quality imagery for mapping. Mangroves (rarely samphire forbland), bare salt pans and terrestrial plant communities tolerant to high salt levels from occasional tides (marine couch) delimit the seaward extent of this mapping programme.

* See Glossary

Plate 39 Mangroves and mud flats, Moreton Bay

Areas inundated by abnormally high tides during storm surges are not part of this land zone.

Extent

The extent of deposits subject to tidal inundation in Land Zone 1 is best indicated by evidence of the extent of tidal inundation and a consideration of the plant species present, with particular weighting being given to the plants in the ecologically dominant layer.

Highest Astronomical Tide

To avoid confusion, the landward extent of Land Zone 1 does not correlate well with the level of Highest Astronomical Tide* (HAT). Differing combinations of astronomical conditions may cause considerably higher tidal levels to occur. Consequently, the landward extent of Land Zone 1 may be higher than HAT.

Investigation in the Tinchi Tamba wetland reserve and the Bundaberg coastal district using differential GPS accurate to within centimetres, has shown that HAT does not correlate closely with obvious ecological boundaries, namely the distribution of halophytic plant species in the field such as *Casuarina glauca* (swamp sheoak) and/or *Sporobolus virginicus* (marine couch) (Tim Ryan pers. comm.).

Field determination

Difficulties arise in establishing the extent and effect of tidal influence in some field situations where saltwater competes with freshwater input. During rain fall events, the freshwater input to the coastal ecosystems increases, while abnormally high tidal surges increase the saltwater input to otherwise brackish or even freshwater environments. Furthermore, salinity can vary over time and often increases as areas dry out.

In most instances, the vegetation is used to clearly indicate which is the predominant influence and, hence, the appropriate Land Zone. Environments influenced by both saltwater and freshwater usually support plants which may indicate salty or freshwater

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* See Glossary

environments respectively; for example, *Melaleuca* spp. (tea-trees) dominate the canopy and occur in association with mangroves and *Sporobolus virginicus* (marine couch). In this case, the dominant layer (the ecologically dominant layer – that layer or strata which conditions the habitat of the other layers) is dominated by tea-trees which indicate a freshwater, or, at best slightly brackish, environment. On this basis, ecosystems of this nature would be assigned to a land zone other than Land Zone 1, such as Land Zone 3 – Quaternary alluvial systems. *Eleocharis*[‡] communities, while tolerating some saltwater input, prefer a predominantly freshwater environment and indicate that Land Zone 3 is the appropriate choice. *Schoenoplectus litoralis* (bulrush) is generally influenced by tides and taken to indicate Land Zone 1 when associated with tidal waters.

Saltwater exclusion

Human disturbance to the near-coastal environments has induced significant change.

The exclusion of saltwater by placement of levees or bunds near the salt–fresh interface has allowed agricultural and pastoral pursuits to be extended towards the coast. Such activities have resulted in the conversion of a salty environment to a freshwater one. The Queensland Herbarium mapping methodology (Neldner *et al.* 2005) allows for these areas to be reclassified on the basis of the altered substrate and the corresponding freshwater plant assemblages. Such changes have occurred in the coastal parts of the Brigalow Belt where *Sporobolus virginicus* (marine couch) grasslands have been replaced by freshwater grasses and sedges, and where previously brackish wetlands have become exclusively freshwater wetlands.

The Environment

The geomorphology of coastal tidal sediments is covered in Section 2.1.1.

Soils are dominated by various tidal Hydrosols, typically salty with no agricultural potential.

The vegetation varies widely, both floristically and structurally. Communities are dominated by mangroves, samphire, marine couch and frequently bare salt pans. *Casuarina glauca* and/or *Schoenoplectus litoralis* often occur at the interface of fresh and salt water influence.

[‡] Plant names follow Bostock and Holland (2010).

3.2 Land Zone 2 – Quaternary coastal sand deposits

Definition

 coastal dunes	Quaternary coastal dunes and beach ridges. Includes degraded dunes, sand plains and swales, lakes and swamps enclosed by dunes, as well as coral and sand cays. Soils are predominantly Rudosols and Tenosols (siliceous or calcareous sands), Podosols and Organosols.

Clarification

Land Zone 2 includes unconsolidated coastal and near coastal sand deposits originating from wind and wave action during the Quaternary period.

On-shore winds and wave action have transported marine and estuarine sands to above the high-tide level where they accumulate and form dunes and beach ridges which are often stabilised by vegetation tolerant of salt spray but generally intolerant of salty water.

The drainage system of the dune environment and the “swales, lakes and swamps” are considered part of Land Zone 2.

Coarse textured (sand) paleo-estuarine and tidal delta (Pleistocene and Holocene) deposits now elevated above tidal influence are not subject to current alluvial processes and have plant communities and soils (Podosols) similar to beach ridges, are included in Land Zone 2 (see Section 2.1.2).

Medium to fine textured (loams to clay) paleo-estuarine deposits, both Pleistocene and Holocene, make-up part of the contemporary alluvial system of Land Zone 3 (see Section 3.3). These recent sediments that are now not subject to marine tidal influence form various alluvial plains, flood plains and swamps.

Extent

The Queensland coast consists of three major linear dune process dominated regions as identified by Lees (2006) (**Figure 8**).

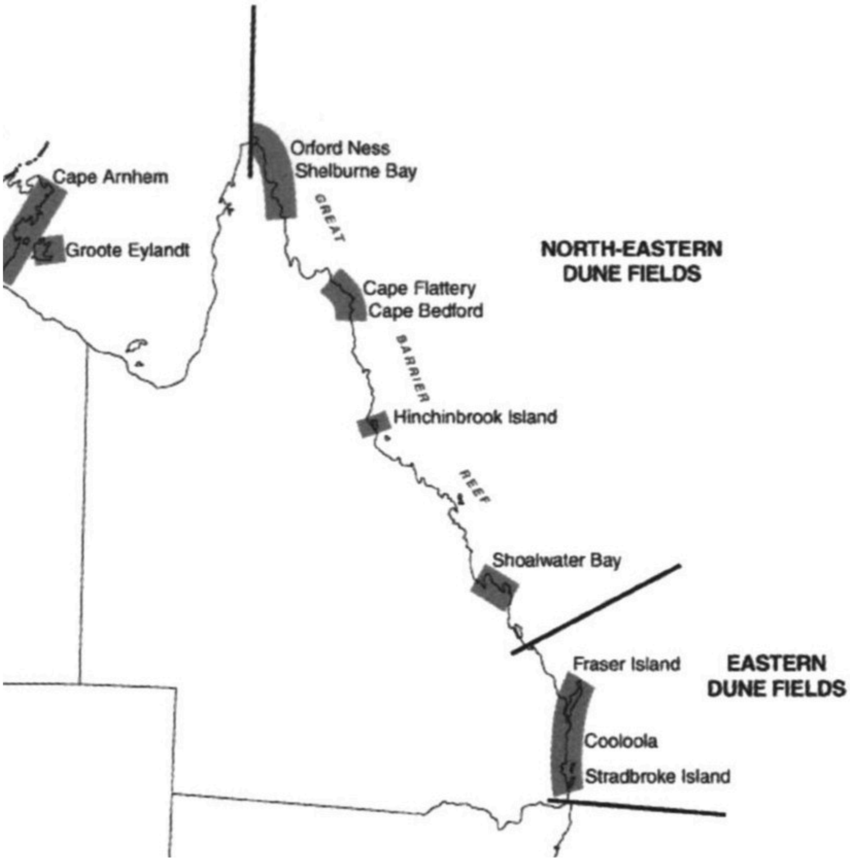


Figure 8 Location of major coastal dune fields in northern and eastern Australia (Lees 2006)

The south-east Queensland coast is characterised by dominant sand-moving winds from the south-east in a wave-dominated environment.

The north eastern and central Queensland coasts are dominated by strong and persistent southeast trade winds and are protected from ocean waves by the Great Barrier Reef.

The western side of Cape York is dominated by the winds of the northwest monsoon and is a tide-dominated environment.

The landward boundary of the dunefields of Land Zone 2 may be actively aggrading or subject to deflation. The seaward extent of Land Zone 2 is discussed in Section 3.1.

Quaternary beach ridges parallel to the current coast developed mainly by wave action and minor modification by wind occur all along the Queensland coast from the Gold Coast to the western Gulf. Many of the older Pleistocene beach ridges have been fragmented by recent Holocene sea level rises and alluvial processes, and degraded by wind and stream action.

The environment

The geomorphology of coastal dune fields and beach ridges is discussed in Section 2.1.2.

Acid sulfate soils originating from the accumulation of iron sulfides under marine environments pose a major constraint to land use practices in Land Zone 2. These soils are benign while they remain under anaerobic conditions such as below the water table however if exposed to oxygen they can release toxic quantities of sulfuric acid and heavy metals such as iron and aluminium into the environment. The highly permeable aerated sands above the water table and any wind-blown sands are of lower risk as the iron sulfides will have oxidised and any sulfuric acid will have been leached from the sand. The oxidised soil horizons may retain some residual acidity in the presence of *jarosite** which may also have implications for management.

The dominant soils are Podosols where soil organic matter and iron has leached from the surface and accumulated at depth corresponding to permanent or fluctuating water tables. Indurated Podosol B horizons (coffee rock) develop due to the precipitation of organic–iron compounds in aluminium–rich strongly acidic waters. These Podosols are typical of the older Pleistocene dunes, beach ridges and coarse textured (sand) paleo-estuarine deposits now under freshwater influence. Rapidly drained red and yellow sands (Tenosols) occasionally occur on older Pleistocene dunes and beach ridges. Podosols with a colour B horizon (stronger colour than the horizons above or below and no pan development) are typical of the younger Holocene beach ridges and dunes while siliceous sands (Rudosols) with minimal development (if at all) are typical of the frontal dunes, beach ridges and coral cays. Coral cays usually have no profile development but may have cemented pans (beach rock/calcrete) developed. Hydrosols with organic rich surfaces form in organic rich environments such as swamps within the swales.

Soils are generally not developed for agriculture due to low soil moisture availability and low fertility. Soils in low lying areas and swamps are often poorly drained further limiting productivity.

The vegetation communities of Land Zone 2 are diverse both floristically and structurally. Heathlands and Corymbia/Acacia dominant forests and woodlands are the dominant vegetation communities. Rain forests and vine forests may be locally dominant while turpentine (Syncarpia hillii) tall forests are prominent in Southeast Queensland, particularly on Fraser Island and the Cooloola sand mass. Melaleuca forests/woodlands and various low heathlands/sedgelands occur in the swamps.

* See Glossary

3.3 Land Zone 3 – Recent Quaternary alluvial systems

Definition

 Alluvial river and creek flats	Recent Quaternary alluvial systems, including closed depressions, paleo-estuarine deposits currently under freshwater influence, inland lakes and associated wave built lunettes. Excludes colluvial deposits such as talus slopes and pediments. Includes a diverse range of soils, predominantly Vertosols and Sodosols; also with Dermosols, Kurosols, Chromosols, Kandosols, Tenosols, Rudosols and Hydrosols; and Organosols in high rainfall areas.

Clarification

Alluvium is “sediment mass deposited from channelled stream flow or over-bank stream flow” (Speight and Isbell, 2009). Land Zone 3 includes Quaternary alluvium (Qa), comprising active Holocene alluvium (Qha) (<10 000 years BP) associated with active alluvial processes, and recent Pleistocene alluvium (Qpa) (140 000 to 10 000 years BP) usually occurring adjacent to and in association with current alluvial systems (see Section 2.1.3).

Coarse, medium to fine textured (sand to clay) paleo-estuarine deposits, both Pleistocene and Holocene that are now above tidal influence make-up part of the contemporary alluvial system of Land Zone 3 (see Section 2.1.3). These recent sediments form various alluvial plains, flood plains and swamps. Coarse textured (sand) paleo-estuarine (Pleistocene and Holocene) deposits under freshwater influence that have plant communities and soils (Podosols) similar to beach ridges and dunes are an exception and are included in Land Zone 2.

Quaternary alluvial systems include landform patterns such as alluvial fan, alluvial plain, anastomotic plain, bar plain, covered plain, delta, flood plain, meander plain, playa plain, stagnant alluvial plain, and terrace. Each landform pattern contains one or more landform elements including backplain, bank (stream bank), bar (stream bar), channel bench, drainage depression, fan, flood-out, lagoon, lake, levee, lunette, ox-bow, playa, prior stream, scroll, stream bed, stream channel, swamp, terrace flat, terrace plain, and valley flat. In all these landforms, there may be frequent active erosion and aggradation by channelled and overbank stream flow, or the landforms may be relict from these processes (The National Committee on Soil and Terrain 2009).

Colluvial deposits, where the net movement of weathered material is down-slope primarily under the influence of gravity, are excluded.

Notwithstanding the difficulty incurred in determining the nature of transported sediment masses in some field situations, the conceptual distinction between alluvium and colluvium is clear. The distinction is made on the basis of the primary agent of transport: alluvium is due to stream or over-bank deposition; colluvium is unconsolidated material at the base of a slope due mainly to gravity which includes sheet wash as a result of diffuse overland sheet erosion and deposition.

To some degree, colluvial material is deposited at/near the bottom of any slope. Recently deposited colluvium at the lower slopes of bedrock landforms is considered to be the land zone of the parent material. Alluvial material deposited in a fan shape issuing from a constriction and built-up by flowing water is an alluvial structure and therefore Land Zone 3. Occasionally, alluvial fans are difficult to distinguish from pediments of Land Zones 5 to 12 (see Section 2.1.3) (**Plate 40** and **41**).

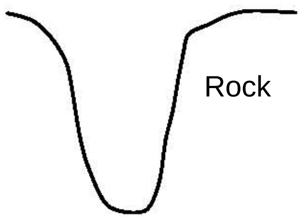
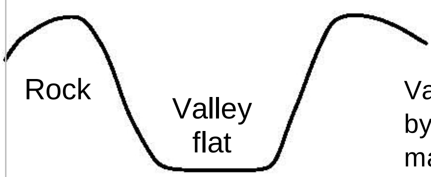
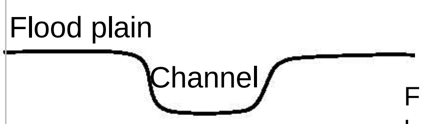
The classification of watercourses based on morphological type generally related to relative position between the source and end/mouth of the watercourse is presented in **Table 2**.

The alluvial systems of Land Zone 3 are confined to Quaternary age. Land Zone 3 includes contemporary active alluvial systems subject to deposition and/or erosion. Relict "recent" Pleistocene (140 000–10 000 years BP) alluvial landforms, such as older higher river alluvial plains and abandoned stream channels, are also included in Land Zone 3 (see Section 2.1.3). These relict alluvial systems occur adjacent to and in association with the active Holocene (<10 000 years BP) alluvium. A typical cross section is illustrated in **Figure 9** and **Plate 42**.

In all cases, geology codes (for example Qa, Qha, Qpa) are a guide to the identification of Land Zone 3. The recent alluvium usually has easily recognisable landform features such as lakes, stream channels (active or relict), levees (active or relict), and alluvial plains (active or relict) or alluvial fans. Playa lakes, clay pans and closed depressions are also included in Land Zone 3.

The drainage system of the dune environment (with vegetation and soils similar to the beach ridges and dunes) including swales, swamps enclosed lake systems, coarse textured (sand) paleo-estuarine deposits and lake deposits (Pleistocene and Holocene) that are elevated above tidal influence and not subject to current alluvial processes are excluded and considered part of Land Zone 2.

Table 2 Watercourse classification at various stages in a catchment

Morphological type	Notes
	Deeply incised valleys and gullies with little or no water transported sediments deposited in the valley floors. The substrate is dominated by exposed rock or other parent material from the surrounding geology. Vegetation influenced by the parent material (not Land Zone 3).
	Valley flat: level alluvial plain with/without a stream channel enclosed by surrounding hills. May have channel benches. Rocky outcrops may occur, especially in stream channel. Soils are generally deep with rudimentary layered alluvial soils (Rudosols) or minimal soil development (Tenosols). Alluvial transported gravels frequently occur in the soil profile.
	Flood plain with channel benches and terraces. The flood plain has broadened and the stream channel is meandering. Soils are generally very deep Rudosols, Tenosols, Dermosols and minor Vertosols on the channel benches, with a diverse range of soils on the occasionally flooded terraces (Dermosols, Kandosols, Sodosols, Kurosols, Chromosols, Vertosols). Gravel deposits uncommon.

Broad flood plain or delta with one or more stream channels, levees, scroll plains, prior streams and swamps. A very diverse range of soil with predominantly Vertosols and Sodosols; also with Dermosols, Kurosols, Chromosols and Hydrosols; and Organosols in the swamps in high rainfall areas.

Plate 40 Alluvial fan (mid-ground) issuing from a gully constriction (Land Zone 3)

Plate 41 Colluvial pediment deposit above alluvial flat (not Land Zone 3)

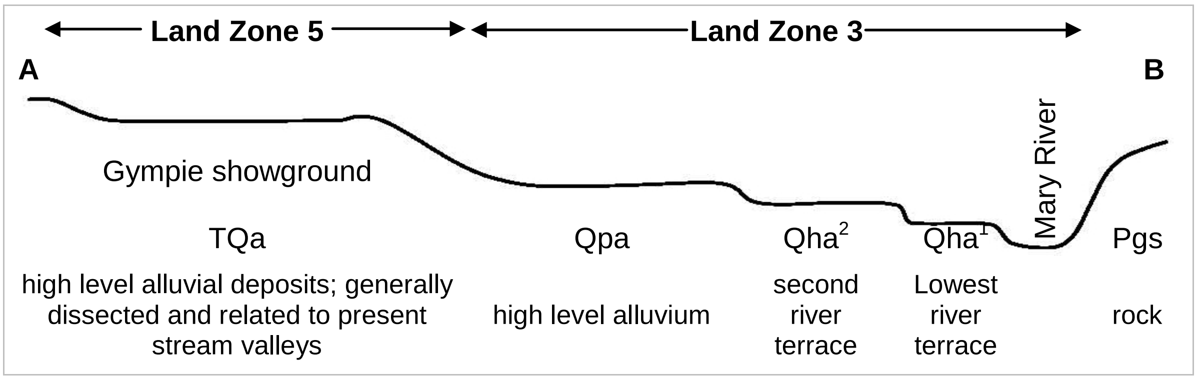


Figure 9 Cross-section (A-B) across the Mary River to Gympie showground (see Plate 42)

Plate 42 Cross-section (A-B) of the Mary River, Gympie
(see Figure 9) This involves elevated paleo-alluvial deposits (TQa) of Land Zone 5 elevated above the recent alluvium (Qha, Qpa) of Land Zone 3. Pgs rock represents Land Zone 11 (Google Earth)

Seepage areas in bedrock landscapes which support hydrophytes and/or vegetation characteristic of alluvial systems are also excluded and attributed to the parent land zone.

Tertiary and early Pleistocene unconsolidated alluvial and lacustrine deposits (see Section 2.1.4) are erosional surfaces in their own right and are discussed in detail in Land Zone 4. These are often depicted as Tertiary (T) or Tertiary–Quaternary (TQ) or Cainozoic (Cz) age on geology maps.

Extent

Quaternary alluvial deposits corresponding to alluvial systems (alluvial landform patterns and elements) are shown in **Figure 10**. The largest expanses occur on the western and northern plains, and the Eyre and Murray–Darling Basins. Broad alluvial deposits are absent from all upland areas such as in the Northwest Highlands and the Great Dividing Range.

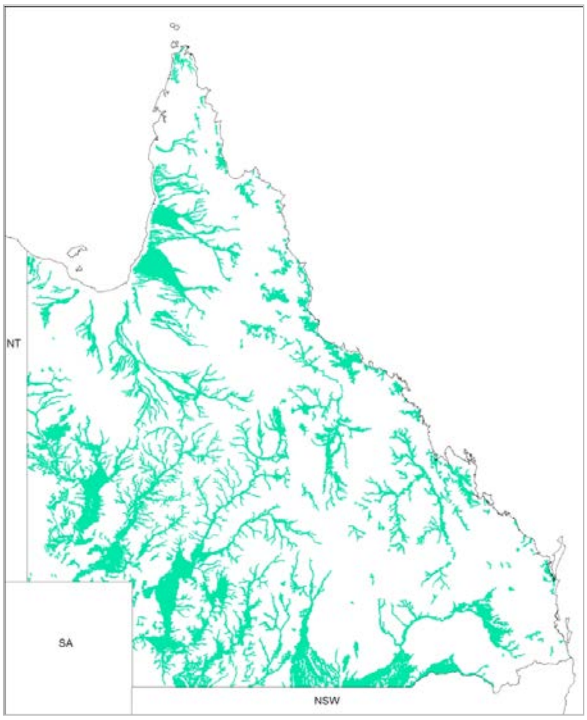


Figure 10 Major Quaternary alluvial deposits (Queensland Geology 1:2 500 000)

Due to scale limitations of the available geology mapping, much of the smaller and narrower deposits are not shown. The distribution of alluvial deposits in landscapes with marked relief is obvious in the field. Material eroded from rises, hills or mountains is transported downstream. When flow exceeds the ability of the stream channels to carry the throughput, over-bank flow carries sediment away from the channel until the velocity is such that the suspended load is deposited forming alluvial landforms such as levees or alluvial plains. In the field situation, the extent of alluvium is indicated by the break in slope between the deposit (± flat) and the steeper footslopes of the higher land. As terrain slope decreases, difficulties in determining the alluvial, or alternative, nature of the regolith arise. Where landscape features are uncertain, the soil profile will determine the nature of the regolith. Field observation alone is not always reliable.

The environment

The geomorphology of alluvial landscapes is discussed in Section 2.1.3.

Recent Quaternary alluvial landforms are mostly flat to gently undulating with active alluvial deposition in some part of the landscape. Levees, bars, stream bed and banks exhibit minor local relief. Stream channels may be incised into the alluvial plains and terrace deposits.

For a comprehensive list of alluvial landform elements and patterns refer to The National Committee on Soil and Terrain (2009).

Riparian vegetation on alluvial deposits immediately adjacent to watercourses exhibits higher species diversity than that of the surrounding landscape and is often denser due to water availability making it clearly visible on aerial photographs and satellite images. **Plate 43** shows riparian vegetation of Lawn Hill Creek as it flows from the Northwest Highlands to the Gulf Plains.

Plate 43 Actively growing riparian vegetation adjacent to Lawn Hill Creek
(Google Earth)

Floodplains can exhibit rapid vegetation growth after floods (**Plate 44**). This significantly improved moisture regime is greatly reduced away from watercourses due to deeper water tables, heavier textured soils with reduced effective rooting depth, and often *vertic** properties of soils causing physical damage to tree and shrub root systems.

Plate 44 Channel Country alluvium of the Diamantina River after flood

Soils on alluvial sediments are very diverse, usually related to the parent material in the upper catchment. Soil developed from Pleistocene alluvium usually (but not always) has a higher degree of profile development (pedological development including horizon differentiation, colour, structure and segregations). The soils are dominated by Vertosols and Sodosols but include a diverse range of other soils including Dermosols, Kurosols, Chromosols, Kandosols, Tenosols, Rudosols and Hydrosols; and Organosols in high rainfall areas.

Soils are usually fertile (chemically and physically) resulting in extensive clearing and development for agriculture and pastures. Soil fertility reflects the chemical properties of the geology and soils of the catchment from which they are derived.

A diversity of species utilise the alluvial environment ranging from rain forests, vine thickets, eucalypt forests and woodlands, grasslands, sedgelands, forblands and shrublands. Prominent species include River red gum (*Eucalyptus camaldulensis*), Queensland blue gum (*E. tereticornis*), coolibah (*E. coolabah*), river sheoak (*Casuarina cunninghamiana*), Leichhardt pine (*Nauclea orientalis*), lignum (*Muehlenbeckia florulenta*), and tea-tree (*Melaleuca* spp.) communities.

* See Glossary

3.4 Land Zone 4 – Tertiary-early Quaternary clay plains

Definition

 clay plains	Tertiary-early Quaternary clay deposits, usually forming level to gently undulating plains not related to recent Quaternary alluvial systems. Excludes clay plains formed *in-situ* on bedrock. Mainly Vertosols with gilgai microrelief, but includes thin sandy or loamy surfaced Sodosols and Chromosols with the same paleo-clay subsoil deposits.

Clarification

Land Zone 4 includes paleo-clay unconsolidated sediments originating from "old" alluvial processes and aeolian clays (parna) forming predominantly level to gently undulating plains, but includes lesser rises and low hills particularly in arid areas. These paleo-clay deposits are now elevated above and usually isolated from the alluvial valleys and plains of Land Zone 3. In all cases, the same "old" alluvium and parna, that can be many metres thick, may cover a range of geologies (see Sections 2.1.4 and 2.1.5)

The Land Zone 4 substrate is fine textured clay sediments deposited in lakes, basins or by over-bank river flow during the Tertiary to "early" Pleistocene Period (refer Table 1). Due to sea level fluctuations, tectonic activity, stream migration into basins and general lowering of the landscape by erosion, these paleo-clay sediments are now elevated above the active Holocene and recent Pleistocene alluvial valleys and plains. Consequently, the function of the landscape has changed from an active depositional system to that of an erosional landscape. The paleo-clay surfaces have only poorly defined drainage lines developed (**Plate 45**).

Aeolian clays (*parna**) have influenced many soil landscapes of south-eastern and arid Australia as first reported by Butler (1958). Parna was deposited over the landscape in a series of events mainly during the cold dry glacial periods (Bowler 1986) of the Quaternary. Parna blankets large areas of western Queensland and overlies all geologies (including duricrusts) except recent alluvium (see Section 2.1.3). Exposed duricrusted scarp retreat areas exist on the edge of Tertiary plateaus where the parna have been removed by erosional processes. The clay material has *vertic** (shrink-swell) properties resulting in cracking clays that are often gilgaied and thin surfaced texture contrast soils (desert loams), frequently with surface gravel of various origins (mainly silcrete and ironstone). Gravel free clays also exist. In all cases, the clay soils are high in sodium chloride and gypsum salts reflecting their origin. These aeolian clays grade into "old" alluvial clays of Land Zone 4 in the north and east of western Queensland and are difficult to separate.

* See Glossary

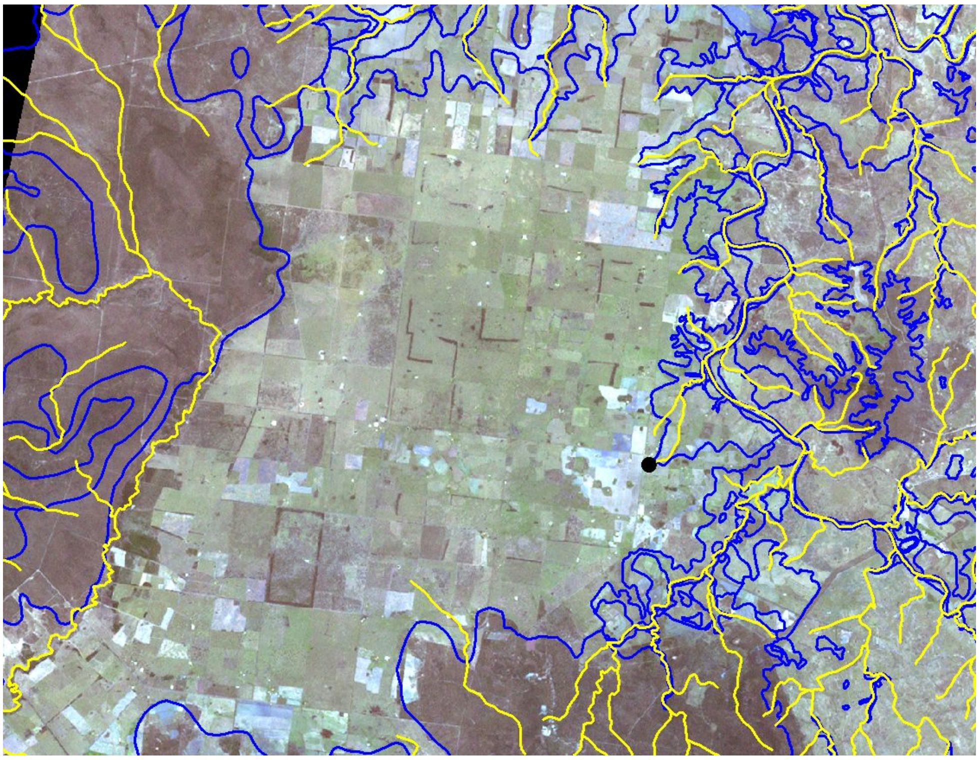


Plate 45 Brigalow clay plain (the large cleared area) near Durong, west of Kingaroy
This shows drainage system (yellow lines) and geology (blue lines). The clays were originally flood plain deposits of the Condamine River during the Tertiary to early Pleistocene Periods. The elevated nature of the clay plain is clearly demonstrated by the avoidance of local streams (yellow lines).

Extent

Paleo-clay deposits occur extensively throughout Queensland (Craig *et al*., 2008). Significant areas of Land Zone 4 have been mapped in the Desert Uplands, Brigalow Belt, Mulga Lands, Gulf Plains, Mitchell Grass Downs, Northwest Highlands and Channel Country Bioregions. The distribution of the clay plains is not clearly indicated in geological mapping. Extensive areas of Tertiary clay plains in the Brigalow Belt are shown as undifferentiated Cainozoic cover which includes various unconsolidated sediments with symbols Cz, Cza and Czs. These units may contain areas of alluvium, clay plain, sand plain, (Land Zones 3, 4 or 5) and even hard rock geologies.

Aeolian clays (*parna**) blankets large areas of the western Queensland landscape (Craig *et al*., 2008) where the landform reflects the original underlying landform of gently undulating plains, rises and undulating low hills.

Reference to additional land resource data, in particular geomorphology in reports, together with interpretation of satellite imagery, aerial photographs and soil information is necessary to determine Land Zone 4.

The Environment

The geomorphology of paleo-clay unconsolidated sediments form the "old" alluvial and aeolian clay landscapes is discussed in Section 2.1.4.

* See Glossary

Soils are dominated by Vertosols with gilgai microrelief, often with a thin veneer of surface gravels originating from the Tertiary landscape accumulating on the mounds. Gravels mainly include silcrete, ironstone, chalcedony and chert. Shallow (<0.5 metres) sandy to loamy surfaced Sodosols and Chromosols are associated with the Vertosols as indicated by the same paleo-clay subsoils material.

These clay soils have been extensively cleared for introduced pastures and cropping in higher rainfall areas due to their relatively high soil moisture availability and high fertility. Soils usually have restricted rooting depth due to the adverse effects of high sodium levels.

Land Zone 4 environments are typically gently undulating plains, with clay soils and texture-contrast soils derived from fine-grained sediments deposited in Tertiary to early Pleistocene lakes, basins and alluvial plains, and from aeolian clays (parna). These support brigalow (*Acacia harpophylla*) (**Plate 46**), gidgee (*A. cambagei, A georginae*), belah (*Casuarina cristata)*, blackwood (*A. argyrodendron*), and some box (*Eucalyptus populnea, E. brownii, E. moluccana*) communities, grasslands (*Astrebla pectinata,* various bluegrasses) herblands, and semi-evergreen vine thicket in more favourable areas.

Plate 46 Brigalow clay plains, Tara

3.5 Land Zone 5 –Tertiary-early Quaternary loamy and sandy plains and plateaus

Definition

 old loamy and sandy plains	Tertiary-early Quaternary extensive, uniform near level or gently undulating plains with sandy or loamy soils. Includes dissected remnants of these surfaces. Also includes plains with sandy or loamy soils of uncertain origin, and plateau remnants with moderate to deep soils usually overlying duricrust. Excludes recent Quaternary alluvial systems (land zone 3), exposed duricrust (land zone 7), and soils derived from underlying bedrock (land zones 8 to 12). Soils are usually Tenosols and Kandosols, also minor deep sandy surfaced Sodosols and Chromosols. There may be a duricrust at depth.

Clarification

The unconsolidated deposits which make-up Land Zone 5 are the result of several processes as described in Sections 2.1.6 and 2.1.7:

1. Paleo-sandy and loamy unconsolidated sediments originating from “old” alluvial processes during the Tertiary and early Pleistocene (**Plate 47**) have deposited several phases of alluvium over the underlying geologies. Due to sea level fluctuations, tectonic activity, stream migration into basins and general lowering of the landscape by erosion, these paleo-sandy to loamy alluviums are now elevated above the “recent” alluvial valleys and plains of Land Zone 3. The “old” alluvium can be >0.5 metres to many metres thick and may cover a range of geologies, overlie soils developed *in-situ* or cover “old” (paleo) alluvial clay sediments.

Plate 47 Quaternary paleo-alluvial sand plains, south of Charleville

2. Sand plains not developed *in-situ* include:

Erosion of any Tertiary landscape, including “old” alluvial sands and loams and deeply weathered geologies, resulting in redeposition of sandy to loamy material lower in the landscape as colluvium and diffuse overland sheet wash (**Plate 48** and **49**). These sandy to loamy sediments overlie a range of geologies and have not developed *in-situ*. Some sediment, particularly in semi-arid and arid areas, have been reworked and moved by wind to form level to gently undulating sandplains (and associated dunefields of Land Zone 6).

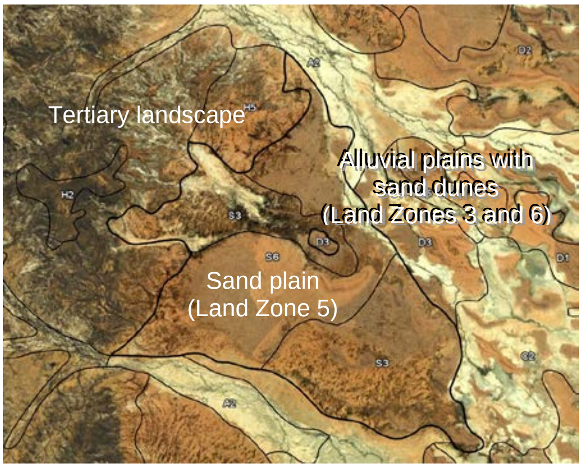


Plate 48 Sheet wash sand plains (Land Zone 5) southwest of Windorah developed from the erosion of the Tertiary landscape *(western side of image) (Google Earth)*

Plate 49 Mulga sheet wash sand plains east of Charleville (Land Zone 5)

- Any sandy substrate reworked by wind to form sandplains is included, for example, reworking of paleo-alluvium or sandy colluvium and sheet wash originating from any geology including non-deeply weathered quartz rich bedrock (see **Plate 25**).
- Reworking of recent Quaternary alluvium by wind resulting in sandplains overlying the “recent” alluvium or other geologies. In this example, the sand sediments are not developed directly from the current alluvial processes, such as water deposited sandy levees or floodplains.

3. During deep weathering, the bedrock is *completely weathered** resulting in “deep” profiles high in iron and/or aluminium oxides and kaolin clays. The profiles may also contain quartz, and may be strongly mottled and/or pallid (pale) in colour in the lower part. Typically, all rock structure, including bedding, has been destroyed and all minerals have been chemically weathered to kaolin with or without resistant quartz. In extreme weathering, gibbsite (aluminium hydroxides) and sesquioxides (iron and aluminium oxides) remain as the dominant material. During the intense and prolonged weathering of the Tertiary landscape, many (but not all) of the deeply weathered profiles became indurated (cemented) due to the residual accumulation of secondary minerals within the profile or due to the lateral mobilisation, accumulation and precipitation of soluble minerals such as silica (silcrete) and/or iron (ferricrete) (**Plate 50** and **51**). The deep weathering and duricrust processes are independent of substrate type. Some of the more common parent materials include unconsolidated sediment of various origins, quartz sandstones, sub-labile and labile sedimentary rocks, granites and basalt. Soils can be developed *in-situ* or the deeply weathered profile can develop from transported old (paleo) unconsolidated sediments. Soils are >0.5 metres deep.

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* See Glossary

Plate 50 Deep soil with ferricrete over deeply weathered Tertiary volcanics, Red Clay Island, south-east of Sarina (Land Zone 5)

Recent alluvial processes (as described in Sections 2.1.3 and 3.3) that have deposited sands and loams in alluvial landforms (such as fans, levees, plains) are excluded and are allocated to Land Zone 3. Also, landscapes developed *in-situ* (including colluviums) on non-deeply weathered bedrock (as described in Section 3.1.3) are excluded and allocated to Land Zones 8 to 12.

Stripping of the soil or other unconsolidated material off the duricrusted profile, particularly at the edge of plateaus and mesas, has exposed the duricrust. In many situations, erosion has removed the duricrust or removed the deep soil on the deeply weathered surface to expose the non-duricrusted deeply weathered profiles. Exposed duricrust or deeply weathered profiles with soils <0.5 metres deep are excluded and allocated to Land Zone 7.

In many situations, multiple processes are involved. For example, unconsolidated sandy Tertiary alluvial sediments can be deeply weathered, duricrusted and then the sandy soils reworked by wind or eroded by water resulting in sandy material deposited down-slope as colluvium over adjacent landscapes (see **Plate 21**).

Reworking of sandplains and Quaternary alluvium by wind has resulted in dunefields (Land Zone 6). The difference between sand dunes of Land Zone 6 and associated sand plains of Land Zone 5 may be indistinct. In general, sand plains predominate when the area of the level inter-dune sand plains dominate over the convex dune crests and concave dune flanks.

Plate 51 Duricrusted *Glendower Formation* south of Blackall with Land Zone 5 in the centre of the plateau and Land Zone 7 on the edges
(Google Earth)

Plate 51 shows moderately deep soils of Land Zone 5 and exposed duricrust of Land Zone 7 on the edges.

A common feature of tropical northern Australia is the occurrence of “creek rock” often associated with induration of Holocene river sediments of Land Zone 3 and gully sediments in the siliceous lithologies of Land Zones 12. This “creek rock” is associated with “recent” precipitation of iron and/or silica cementing sediments on exposure to the atmosphere. It is not to be confused with “deep weathering” and requires reference to geological maps and associated notes to determine if the substrate is deeply weathered (**Plate 52**). Soil pans (duripan, ferric, calcrete) are also excluded.

Plate 52 Indurated Quaternary alluvium at Hann River, Cape York Peninsula, showing “creek rock” fully encasing old bottles.

Extent

Sandsheets, deeply weathered and duricrusted land surfaces, and sandy to loamy old alluvium cover extensive areas of the state (**Figure 11** and **12**).

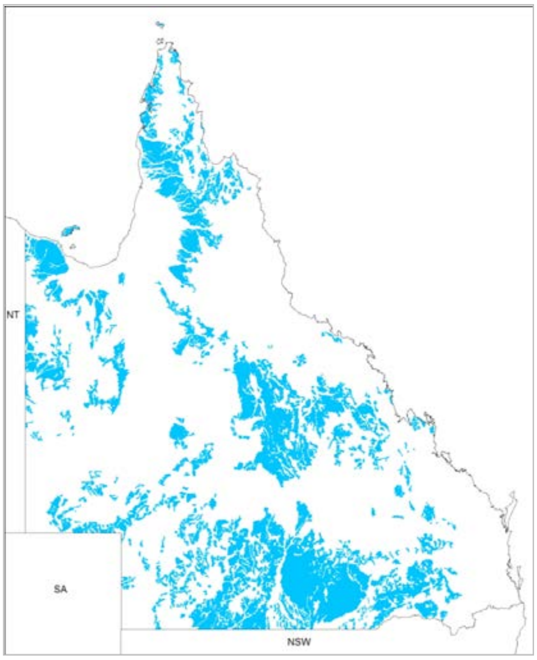


Figure 11 Late Cainozoic floodout and residual sand, soil and gravel

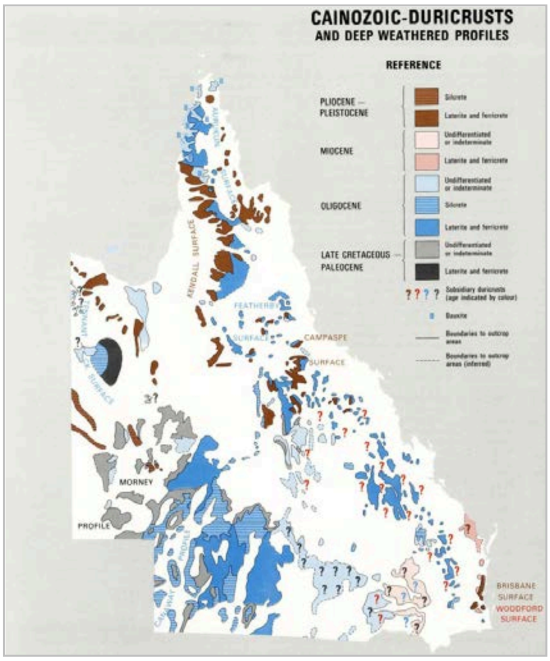


Figure 12 Cainozoic duricrusts and deeply weathered profile (Day *et al*. 1983)

All available resource data (geology, soils, geomorphology, land systems) needs to be reviewed to achieve some understanding of the true nature of unconsolidated Tertiary to Quaternary paleo-deposits, and deeply weathered landscapes.

In practice, determination of the extent and nature of unconsolidated deposits can be problematic as field observation and landscape interpretation may be misleading and can only be accurately determined with the aid of soil cores. The nature and extent of regolith in landscapes with a long and complex history requires knowledge of what is happening at depth (Gibson 2004).

Geological mapping reliably shows areas of consolidated geologies however it does not reliably show unconsolidated surface layers. Phrases such as “alluvial, colluvial and residual deposits” in the lithological summaries of published geology maps contribute little to an understanding of *in-situ* or transported regolith. The information is less informative when the age of the deposits is denoted as Cainozoic age (65 million years BP to present).

The environment

The geomorphology of paleo-sandy to loamy unconsolidated sediments from the “old” alluvial, sandplains and deeply weathered landscapes is discussed in Section 2.1.6 and 2.1.7.

Typically, western expressions of Land Zone 5 are flat to gently undulating plains, plateaus and dissected tablelands. In coastal catchments, dissected “old” alluvial landscapes often occur as undulating rises and low hills (**Plate 53**). Deeply weathered basaltic landscapes frequently occur as plateaus, dissected tablelands, and undulating to steep hills.

Plate 53 Tertiary–Quaternary alluvial deposits overlooking the Brisbane River valley, Moggill

The loamy and sandy Tertiary surfaces occur in twelve of the thirteen bioregions (excluding the New England Bioregion). Soils vary depending mainly on origin of the parent material. In western Queensland, all Tertiary landscapes are predominantly sandy to loamy red Kandosols and Tenosols. The deeply weathered basalts are dominated by red Ferrosols with yellow to brown Ferrosols or Dermosols in wetter landscape positions. Coastal catchments with deeply weathered and “old” transported landscapes have a very diverse range of soils, including Kandosols, Dermosols, Chromosols, Sodosols and in minor situations Podosols, Hydrosols, Kurosols and Tenosols.

Land development is limited with some clearing in higher rainfall areas for cropping, particularly on deeply weathered well drained geologies. In lower rainfall areas, cropping is occurring where irrigation is available. Fertility is generally low due to the highly weathered and leached soils.

A broad diversity of vegetation communities exploit the environments provided within Land Zone 5. These are driven by climate, past and present, and soil attributes. Present day climates vary from tropical and monsoonal in the north and northwest to humid and subhumid in coastal and subcoastal areas and arid in the west. Eucalypts predominate in the humid to semi-arid coastal and sub-coastal bioregions; cypress pine and *Melaleuca* species are characteristic of deep sands and wet soils respectively. Rainforests are typical of the high rainfall basalt landscapes while vine forests occur in a range of landscapes often with relatively lower rainfall and fertile soils. Inland, semi-arid conditions favour mulga and poplar box communities. *Acacia* species are common in arid to semi-arid landscapes. Heath and eucalypt communities are common on Cape York Peninsula.

3.6 Land Zone 6 – Quaternary inland dunefields

Definition

 inland dunefields	Quaternary inland dunefields, interdune areas, degraded dunefields, and associated aeolian sandplains. Excludes recent Quaternary alluvial systems, which may traverse this zone, and intermittent lakes and claypans (land zone 3).Soils are predominantly Rudosols and Tenosols, some Kandosols and minor Calcarosols.

Clarification

Most of the Australian arid zone is covered by sand sheets, often in the form of dunes, with sand being derived mainly from the weathering of ancient laterites, and partly from sandstones or from alluvial deposits laid down along watercourses or in basins (Beadle 1981)

Continental dunefields (**Plate 54**) occupy about 40% of the surface of Australia. At the continental scale, the dunes form a giant anticlockwise whorl with dunes in South Australia orientated from west to east; western New South Wales from south to north; western Queensland from south-east to north-west, northern Western Australia from east to west. Despite the size of this whorl, most sand in it has not been moved very far by wind from its source, often only a matter of kilometres (McKenzie *et al.* 2004).

Plate 54 Longitudinal dunes of western Queensland

As described in Section 2.1.8, erosion of the Tertiary landscape and quartz–rich substrates has deposited large amounts of sediments containing sand that have been reworked by wind to form sand dunes and associated sandplains. Parallel dunes typical of the Simpson Desert are the most common while reticulate dunes enclosing claypans are confined to/and overlie alluvial landscapes (Land Zone 3). In general, dunes are predominantly pale coloured on the north western side of the large alluvial plains of the Channel Country where the sand originates and become redder in colour to the north-west. The red colour is due to the gradual oxidation of the iron minerals coating the sand grains. Isolated semi-stable and mobile dunes are associated with many river systems in western Queensland.

The difference between sand dunes and associated sand plains may be indistinct. In general, dunes of Land Zone 6 predominate when the area of convex dune crests and concave dune flanks dominate over the level inter-dune sand plains of Land Zone 5. For example, land unit 9 in the Badalia (S2) land system in the Georgina Basin (Wilson and Purdie 1990) comprises "level plains with low rounded dunes and sand rises (<4m high)" while the remainder of the land units in the land system are sand plains. In this example, land unit 9 only is Land Zone 6 while the remainder is Land Zone 5.

The leading edge (south-east end) of the dunes on alluvium are frequently deflated (eroded by wind) and cemented (due to clay).

Recent Quaternary alluvial systems and ephemeral lakes within dunefields are excluded and allocated to Land Zone 3 because sand dunes overlie alluvial plains and lower dune flanks are occasionally buried by alluvium.

Extent

In Queensland the dunes are restricted to the south-western corner of the state and form part of the Simpson and Strezlecki Dunefields (**Figure 13)** with minor occurrences in the Northwest Highlands Bioregion.

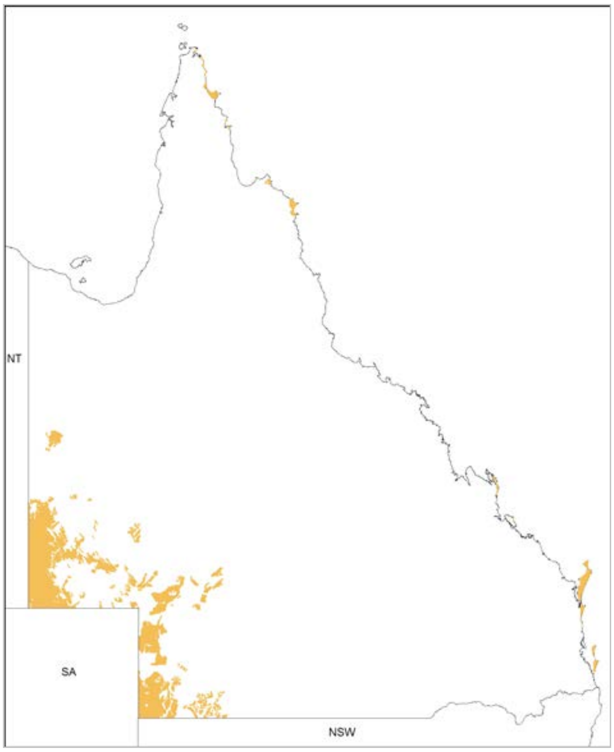


Figure 13 Location of major coastal (Land Zone 2) and inland (Land Zone 6) dunefields

Geology mapping, land system mapping, aerial photographs and satellite images clearly indicate their extent.

Isolated stable to semi-stable dunes are associated with western river systems often forming low (<4m) isolated to interconnecting sand rises overlying alluvial plains.

The environment

The geomorphology of the western sand dunes is described in Section 2.1.8.

Landforms are mobile parallel dunes and associated inter-dune areas, reticulate dunes with inter-dune claypans and isolated semi-stable to stable dunes on alluvial plains.

Soils are dominated by red, yellow and grey Rudosols on dune crests, and red, yellow and grey Tenosols and some sandy surfaced Kandosols on inter-dune areas. Pale grey and yellow dunes frequently occur on alluvial plains, particularly on the north western side of the plains. These pale colours become redder to the north-west. Minor saline (mainly gypsum) Rudosols occur on the north western edge of playas (ephemeral salt lakes). Minor cemented Rudosols also occur on eroded lower dune flanks and leading south-eastern edge of dunes, particularly on alluvial plains.

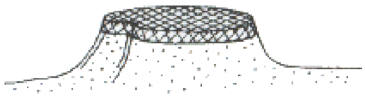
Development is very limited due to very low soil water availability and low fertility.

In arid areas, mobile crests are dominated by sparse to scattered sandhill canegrass (*Zygochloa paradoxa*) and ephemeral herbs and shrubs, while upper dune flanks and semi-stable crests frequently have grevilleas, whitewood (*Atalaya hemiglauca*); areas of forbland with isolated stunted trees and shrubs, and large bare areas of wind-blown sand. There are also more stable isolated dunes in the more eastern river systems are frequently dominated by eucalypts.

On inter-dune areas, the vegetation is dominated by spinifex (*Triodia* spp.) hummock grassland ± wattles (*Acacia* spp.), *Senna* spp., grevilleas and eucalypts (including *Eucalyptus pachyphylla* in the Georgina Basin). In the Georgina Basin and northern Simpson Desert, Georgina gidgee (*Acacia georginae*) is a prominent species.

3.7 Land Zone 7 – Cainozoic duricrusts

Definition



ironstone jump-ups

Cainozoic duricrusts formed on a variety of rock types, usually forming mesas or scarps. Includes exposed ferruginous, siliceous or mottled horizons and associated talus and colluvium, and remnants of these features, for example low stony rises on downs. Soils are usually shallow Rudosols and Tenosols, with minor Sodosols and Chromosols on associated pediments, and shallow Kandosols on plateau margins and larger mesas.

Clarification

During the intense and prolonged weathering of the Tertiary landscape, many (but not all) of the deeply weathered profiles became indurated (cemented) due to the residual accumulation of secondary minerals within the profile or due to the lateral mobilisation, accumulation and precipitation of soluble minerals such as silica (silcrete) and/or iron (ferricrete). Silicification of carbonates during deep weathering may result in chalcedony and an indurated surface. Because of their indurated nature, these surfaces are resistant to erosion and are commonly still preserved.

Stripping of the soil or other unconsolidated material off the duricrusted profile, particularly at the edge of plateaus and mesas, has exposed the duricrust and non-duricrusted deeply weathered profiles (**Plate 55**). The eroded non-duricrusted mottled and pallid zones of the deeply weathered profile may become cemented on exposure resulting in resistant low remnants. Soils are <0.5 metres deep.

Many of the intact duricrusted remnants have scarp retreat areas where erosion of the underlying softer “moderately” weathered bedrock causes undercutting and collapse of the resistant upper part. Colluvial slopes (talus) with shallow soils (<0.5 m) over deeply weathered rock in the scarp retreat areas are included in Land Zone 7.

Colluvial slopes and pediments with a thin surface veneer (<0.5 m thick) of weathered gravels covering soils developed *in-situ* are excluded and allocated to the adjacent land zone. Pediments with >0.5 metres of detritus material from erosion of the deeply weathered profile are allocated to Land Zone 5.

All available resource data (geology, soils, geomorphology, land systems) needs to be reviewed to achieve some understanding of the true nature of the deeply weathered landscapes. Due to the resistant and exposed nature of the duricrusts, recognition is usually rapid.

Plate 55 Cemented mottled zone of an eroded deeply weathered profile

Extent

Land Zone 7 is closely associated with the deeply weathered and duricrusted land surfaces of Land Zone 5 which covers extensive areas of the state (Figure 12).

The environment

The geomorphology of the duricrusts and subsequent exposure is described in Section 3.1.2.

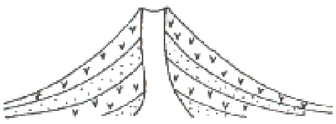
Landforms are dominated by steep sided mesas, buttes and edges of dissected tablelands and plateaus and inclined lower scree (talus) slopes. Gravels are dominated by the parent material, including silcrete, ironstone and lateritic gravels. Eroded undulating remnants are included.

Soils are either absent (exposed rock) or dominated by shallow (<0.5 m) Rudosols and Tenosols, with Kandosols on plateau and tableland margins where they grade to Land Zone 5. Sodosols and Chromosols may occur on the pediments. Soils have minimum development potential as they are typically shallow infertile soils or exposed rock.

Vegetation is extremely variable depending on climatic conditions, depth of soil and position in the landscape. The absence of vegetation on the bare rock and scarp areas is typical. In western areas, lancewood (*Acacia shirleyi*) and bendee (*A. catenulata*) and Spinifex (*Triodia* spp.) are dominant communities on the edges of the exposed duricrusts. Mulga (*A. aneura*) and bastard mulga (*A. clivicola*) are dominant on shallow soils on the level to gently undulating flat tops, especially where grading to Land Zone 5. Lower slopes range from *Acacia* shrublands, including gidgee (*A. cambagei*) to various eucalypt communities, including *Eucalyptus normantonensis* and mountain yapunyah (*E. thozetiana*)

3.8 Land Zone 8 – Cainozoic igneous rocks

Definition



basalt plains and hills

Cainozoic igneous rocks, predominantly flood basalts forming extensive plains and occasional low scarps. Also includes hills, cones and plugs on trachytes and rhyolites, and associated interbedded sediments, and talus. Excludes deep soils overlying duricrust (land zone 5). Soils include Vertosols, Ferrosols and shallow Dermosols.

Clarification

Extrusive rocks form as a result of volcanic activity at or immediately adjacent to the earth's surface. Structures include lava plains, vents and volcanic plugs. Common rock types are typically fine grained or porphyritic (containing phenocrysts in a fine grained matrix) due to rapid cooling of the magma, and include acid, intermediate and basic rocks such as basalt, andesite, rhyolite, trachyte and tuffs. Intrusive rocks, such as gabbros and syenites, associated with the volcanic plugs are included.

The definition of Land Zone 8 is simple, unequivocal and without exceptions to the rule: all Cainozoic (Tertiary to Quaternary) igneous rocks of whatever type are Land Zone 8.

Interbedded sedimentary rocks, such as shales, siltstones and sandstones, are included as long as the volcanic rocks are dominant within the formations. Springs originating directly from the lava flows are included but any springs originating in alluvial systems which drain the volcanic landforms are excluded and are allocated to Land Zone 3. Deeply weathered Cainozoic volcanic geologies are excluded and allocated to Land Zone 5.

Extent

The extent of Cainozoic igneous rocks, predominantly flood basalts, is shown in **Figure 14**.

There are three major areas, each of which is less than 250 kilometres from the coast:

- north and northeast of Hughenden;
- the Springsure – Clermont area; and
- the Main Range – Lamington Basalt Province.

The most recent are the Tertiary–Quaternary basalt flows north of Hughenden; the Great Basalt Wall being the most recent event at about 13 000 years ago.

The central and south-east Queensland volcanic activity dates from the Tertiary although minor more recent eruptions have occurred, for example, the Coulstoun Lakes volcanic activity, the most recent in south-east Queensland, whose age is estimated at about 600 000 years (Geological Society of Australia Queensland Division 1976).

Field examination of fresh rock type, landforms and soils readily determine the land zone.

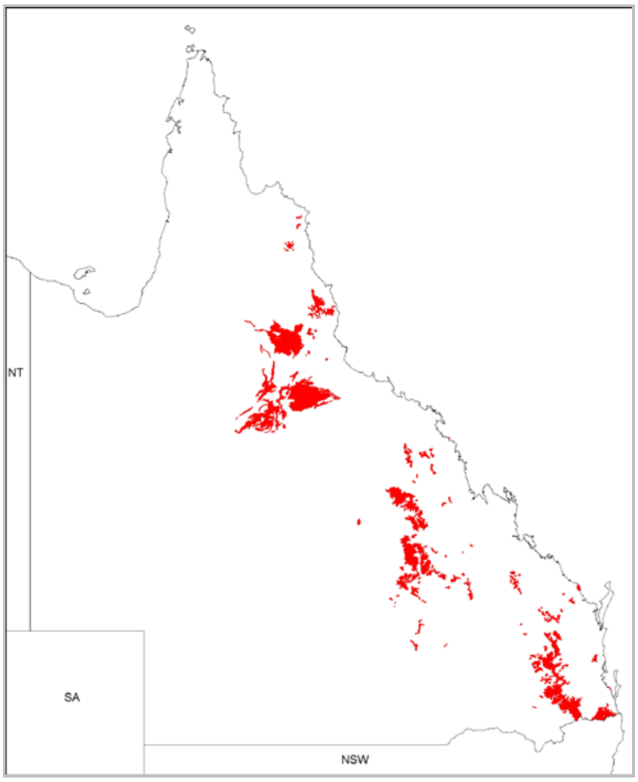


Figure 14 Location of Cainozoic igneous rocks

The environment

Land Zone 8 is the Tertiary to Quaternary lava plains and associated volcanic cones and plugs (**Plate 56**). The flood basalts form extensive undulating plains broken occasionally by low scarps, hills, and plateaus. Tertiary lava flows (mainly basalts and rhyolites) frequently occur as elevated dissected tablelands and plateaus with steep scarps due to the hard resistant rock overlying softer more easily eroded bedrock (**Plate 57**). Rhyolitic flows are particularly resistant due to the high quartz content (**Plate 58**).

Plate 56 Coulstoun Lakes National Park Pleistocene volcano (~ 600 000 years)

Plate 57 Tertiary basalt plateau remnants and gently undulating plain, Minerva Hills, north of Springsure

Plate 58 Tertiary rhyolite cliffs, Springbrook

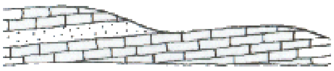
Soils on basalt are predominantly black and brown Vertosols on the level to gently undulating landscapes grading to black and brown Dermosols/Ferrosols on steeper and/or rocky landscapes associated with erosion of lava landscapes or younger flows. Red and brown and occasionally yellow Ferrosols predominate in well drained elevated landscape positions in higher rainfall areas. These Ferrosols overlie fresh basalt or contain basalt floaters (rounded rocks surrounded by soil). Soils developed on the more basic andesite are generally similar to basalts while soils on the more acidic andesites and trachytes include Sodosols. Soils on rhyolites are predominantly shallow Tenosols and Sodosols, and occasionally Hydrosols in higher rainfall areas.

Basaltic soils have been extensively developed for cropping and introduced pastures due to their high fertility and generally high soil moisture availability (depending on soil depth). Rhyolite landscapes generally have limited development due to shallow infertile soils.

The vegetation includes vine forest in more favourable sites, eucalypt open forest and woodland, and open woodlands and grasslands.

3.9 Land Zone 9 – Fine grained sedimentary rocks

Definition

 undulating country on fine grained sedimentary rocks	Fine grained sedimentary rocks, generally with little or no deformation and usually forming undulating landscapes. Siltstones, mudstones, shales, calcareous sediments, and labile sandstones are typical rock types although minor interbedded volcanics may occur. Includes a diverse range of fine textured soils of moderate to high fertility, predominantly Vertosols, Sodosols, and Chromosols.

Clarification

Sedimentary rocks are consolidated fragmental material transported and deposited by wind, water, and ice, chemically precipitated from solution, or secreted by organisms, and that form in layers. Sedimentary rock types generally reflect the deposition environment and grain size (see Section 3.1.3). Consolidated fine grained sedimentary rocks of Quaternary age are not known to occur.

Fine grained sedimentary rocks refer to the grain size only and include sediments transported by water (alluvial and marine) such as siltstones, mudstones and shales, and those sediments chemically precipitated or secreted by organisms including chert, chalk, limestones and dolomites, and oolitic sediments.

Sandstones, arenites and other coarse grained sedimentary rocks composed of lithic fragments (rock fragments) with a high proportion of labile or sublabile lithology (feldspars and mafic minerals) are included in the fine grained sedimentary rock group as these rocks weather to clayey soils or soils with clayey subsoils. For example, the labile sandstones of the *Winton Formation* in the Great Artesian Basin form very gently undulating plains with cracking clay soils.

Plate 59 Gentle dipping Cambrian limestones (Land Zone 9), Lawn Hill Gorge

Most un-deformed to weakly deformed unaltered fine grained bedrocks are Permian and younger, but can include older sedimentary rocks such as the Carboniferous to Ordovician limestones of the Georgina Basin (**Plate 59**) and the Proterozoic fine grained sedimentary rocks of the Nicholson Basin north west of Mt Isa. *Moderately deformed*[*] (folded) unmetamorphosed bedrock is excluded and allocated to Land Zone 11. Sedimentary strata that are not deformed or altered by orogenesis, but are deeply dipping sediments due to basin slumping, are included in Land Zone 9.

In all cases, the rock structure (bedding and lithic fragments) and primary minerals (e.g. feldspars) are not completely weathered. In general, this land zone includes *unweathered rock*[*], *slightly weathered**, *moderately weathered** and *highly weathered** bedrock.

Rocks formed primarily by volcanic activity and deposited in air or water but not transported by water (pyroclastics, pillow larva, and volcanic conglomerates and agglomerates) are excluded and allocated to Land Zone 8 or 12. For example, the Triassic volcanic conglomerates and agglomerates of the *Neara Volcanics* in the inland Burnett are allocated to Land Zone 12.

Coarse grained siliceous (quartzose) sedimentary rocks, primarily quartz sandstones, are excluded and allocated to Land Zone 10. Deeply weathered fine grained sedimentary rocks are excluded and allocated to Land Zone 5 and 7.

Extent

Tertiary to Proterozoic (Cretaceous and older) fine-grained sedimentary rocks, generally with little or no deformation, cover extensive areas of the state including the Great Artesian, Moreton, Maryborough, Bowen, Laura and the Georgina basins (see Figure 5).

Coarse grained quartzose sedimentary rocks may be associated with outcropping fine grained sedimentary rocks. In Southeast Queensland, the ortho-quartzite (sedimentary quartzite) beds in the *Myrtle Creek Sandstones* form prominent hills and cliffs but are only a minor component of the predominant sub-labile lithology. Therefore, the composite Land Zone 9/10 in the Southeast Queensland Bioregion replaces Land Zones 9 and 10.

The environment

Due to the general "soft" nature of the sedimentary rocks and the readily weathered nature of the lithology, the landforms are dominated by very gently undulating to undulating plains and rises (**Plate 60**). Some limestones form undulating to steep rises and low hills (**Plate 59**).

[*] See Glossary

Plate 60 Mitchell grass downs on labile sediments of the Great Artesian Basin

Depending on the lithology (mineral composition) of the lithic fragments, these fine grained sedimentary rocks are labile (readily decompose to clays) to sub-labile (composed of quartz and clay forming minerals) forming clayey soils or soils with clay subsoils. Soils are predominantly Vertosols, Sodosols, and Chromosols. A diverse range of other soils can occur, including Dermosols and Kurosols. Calcarosols are restricted to the Cambrian–Ordovician limestones of the Georgina Basin and Tertiary limestones of western Queensland.

Soils have been extensively developed for introduced pastures or cleared to increase native pasture production, or developed for cropping in higher rainfall areas. The Mitchell grass downs and herbfields of western Queensland have been used traditionally for grazing by sheep and cattle. Soil fertility is generally moderate to high.

The vegetation includes a diverse range of eucalypt open forest and woodland, *Acacia* woodlands (gidgee, brigalow), grasslands and herbfields, and some vine forest in more favourable sites.

3.10 Land Zone 10 – Coarse grained sedimentary rocks

Definition

sandstone ranges

Medium to coarse grained sedimentary rocks, with little or no deformation, forming plateaus, benches and scarps. Includes siliceous (quartzose) sandstones, conglomerates and minor interbedded volcanics, and springs associated with these rocks. Excludes overlying Cainozoic sand deposits (Land Zone 5). Soils are predominantly shallow Rudosols and Tenosols of low fertility, but include sandy surfaced Kandosols, Kurosols, Sodosols and Chromosols.

Clarification

Sedimentary rocks are consolidated fragmental material transported and deposited by wind, water, and ice, chemically precipitated from solution, or secreted by organisms, and that form in layers. Sedimentary rock types generally reflect the deposition environment and grain size (see Section 3.1.3). Consolidated quartzose sedimentary rocks of Quaternary age are not known to occur.

Medium to coarse grained sedimentary rocks refer to the grain size only and include sediments transported by water (alluvial and marine) such as sandstones, arenites, conglomerates and breccia. Only coarse grained quartz rich sedimentary rocks apply to Land Zone 10. Subdominant thin interbedded fine grained sedimentary rocks and volcanics that cannot be mapped separately may be included.

In all cases, the rock structure (bedding and lithic fragments) and primary minerals (e.g. feldspars) are not completely weathered. In general, includes *unweathered rock**, *slightly weathered**, *moderately weathered** and *highly weathered** bedrock.

Most un-deformed to weakly deformed unaltered bedrocks are Permian and younger. *Moderately deformed** (folded) unmetamorphosed bedrock is excluded and allocated to Land Zone 11. Sedimentary strata that are not deformed or altered by orogenesis, but are deeply dipping sediments due to basin slumping, are included in Land Zone 10.

“Deeply weathered” medium to coarse grained sedimentary rocks are excluded and allocated to Land Zone 5 or 7.

In the Southeast Queensland Bioregion, the ortho-quartzite (sedimentary quartzite) beds in the *Myrtle Creek Sandstones* (and some other siliceous sandstone formations) form prominent hills and cliffs but are a minor component of the predominant sub-labile lithology. Therefore, the composite Land Zone 9/10 replaces Land Zones 9 and 10.

Extent

Distribution is mainly restricted to the massive quartz sandstone formations, such as the Jurassic *Precipice Sandstone* of central Queensland. Occurrences occur elsewhere, such as the Proterozoic sandstones in the South Nicholson Basin north-west of Mt Isa.

Due to their resistant nature and level to gently inclined bedding, outcrops frequently occur as continuous plateaus or dissected remnants.

* See Glossary

The environment

Medium to coarse grained sedimentary rocks (sandstones, arenites, and conglomerates) composed predominantly of resistant quartz form undulating to steep rises and hills, plateaus, and precipitous cliffs and scarps, and talus. Cliffs and scarps and associated gorges (**Plate 61**) occur especially where "soft" easily eroded sediments underlie the gently dipping sandstones result in under-cutting and collapse of the massive sediments. Colluvial talus and pediments (>0.5 m of colluvial material over the underlying bedrock) at the base of the scarps and cliffs are common features of Land Zone 10.

Plate 61 Sandstone cliffs of the *Precipice Sandstone Formation*, Carnarvon Gorge

Soils are predominantly "shallow to moderately deep" sandy Tenosols and Rudosols formed *in-situ* on the bedrock. Sandy surfaced Kandosols, Kurosols, Sodosols and Chromosols are common on colluvial slopes. Rock outcrops are typical of the cliffs and immediate edges.

A broad diversity of vegetation communities exploit the environments provided within Land Zone 10. These are driven by climate and the low fertility sandy soils, and occasionally the micro-climates within gorges. Climates vary from tropical and monsoonal in the north to dry summer dominated rainfall in central Queensland. Eucalypts predominate in all bioregions; with cypress pine on some deep colluvial sands.

3.11 Land Zone 11 – Metamorphic rocks

Definition

 hills and lowlands on metamorphic rocks	Metamorphosed rocks, forming ranges, hills and lowlands. Primarily lower Permian and older sedimentary formations which are generally moderately to strongly deformed. Includes low- to high-grade and contact metamorphics such as phyllites, slates, gneisses of indeterminate origin and serpentinite, and interbedded volcanics. Soils are mainly shallow, gravelly Rudosols and Tenosols, with Sodosols and Chromosols on lower slopes and gently undulating areas. Soils are typically of low to moderate fertility.

Clarification

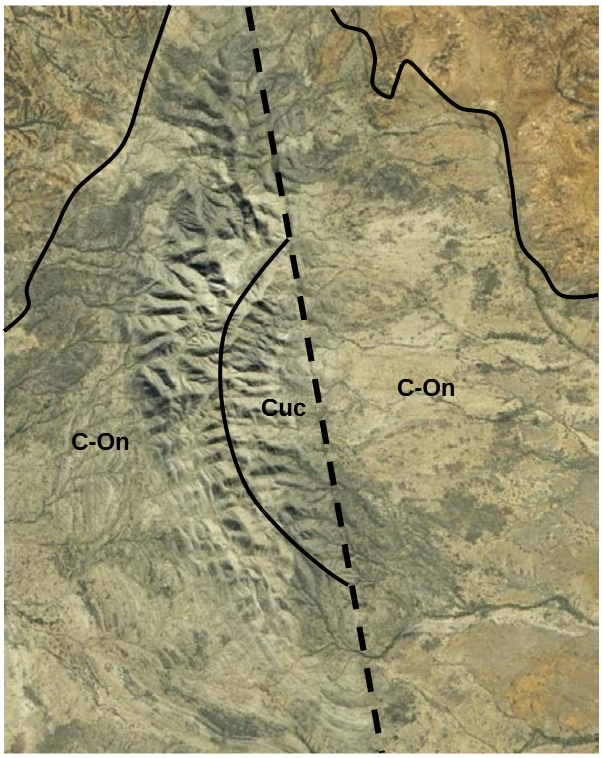
Metamorphic rocks include all rocks that have been subjected to extremes of heat and pressure sufficient to change their chemical and physical properties. Metamorphic rocks are associated with orogenic phases where regions are subject to folding, faulting and deformations, and granitic intrusions, and intensive volcanic activity, usually associated with continental plate tectonic activity (see Section 3.1.3). Hydrothermal metamorphism as a result of the interaction of a rock with a high-temperature fluid from volcanic activity or granitic intrusion is included.

Metamorphic rock type is reflected in the degree of mineral alteration, crystallisation or deformation and does not reflect the mineral composition. For example, moderately to strongly metamorphosed rocks are relatively easy to determine based on the degree of foliation, lamellation of minerals, and degree of crystallisation, and include slate, marble, quartzite, phyllite and schist. All metasediments (metamorphosed sedimentary rocks) are included. Associated interbedded volcanics are also included. All metamorphosed igneous rocks such as metavolcanics (metamorphosed volcanics including metabasalt), greenstone (metamorphosed basic igneous rocks), gneiss (which is often of granitic origin) and serpentinite (which was originally of plutonic origin) are included.

The differentiation between non-metamorphosed and weakly metamorphosed rocks is difficult considering all formations are subject to some degree of heat and pressure alterations when buried by more recent formations. The degree of metamorphism is subjective. In general terms, moderately to strongly metamorphosed rocks show signs of re-crystallisation and lamellation, changed by the solid-state application of heat, pressure and fluids (excluding weathering and *diagenesis**). Reference to geological maps and associated notes is essential. In general, metamorphosed rocks are harder and more resistant to erosion resulting in landforms that are typically steeper and more elevated with shallower soil compared to similar unmetamorphosed rocks. For example, the slightly metamorphosed sediments of the Gympie Group (*Tamaree Formation, South Curra Limestone* and *Rammutt Formation*) have also been moderately deformed and folded but still retain their sedimentary structures resulting in undulating landscapes that are more undulating than expected on equivalent non-metamorphosed sedimentary rocks. The Gympie Group is allocated to Land Zone 11.

* See Glossary

Moderately to strongly deformed* (folded) formations, but not necessarily subject to the heat and pressure sufficient to change their chemical or physical properties such as recrystallisation or evidence of lamellar minerals, are included. Moderately to strongly deformed* (folded) sedimentary or volcanic rocks have an interlimb angle* (angle between adjacent limbs of a fold*; 180° is planar or no fold) of less than 120°. For example, the Bowen Basin was affected by the closing phases of the New England Orogeny resulting in deformed (folded) sedimentary rocks in the eastern part in contrast to the relatively gently deformed western part. Many formations older than Permian are moderately to extensively deformed and allocated to Land Zone 11. Younger metamorphosed sedimentary rocks are rare but the Triassic Kin Kin Beds at Gympie are an exception where the rocks are composed predominantly of phyllites. Moderate to strong deformation along faults or adjacent to intrusions are included (**Plate 62**).



The scale of deformation or the distance over which the folding occurs is undefined. In general terms, if strata show characteristic landform features of moderate to steep dipping (interlimb angle <120^o) beds with associated steep, rises, hills and mountains, the geology should be considered deformed. For example, **Plate 62** shows moderately deformed sediments with associated steep hills up to 4 kilometres from the fault. Beyond this distance, the interlimb angle is >120^o and is not considered moderately to strongly deformed.

In the Drummond Range of central Queensland, the Devonian – Carboniferous sediments of the Drummond Basin (Thompson Orogeny) have been deformed with the crests of the folds occurring up to 20 kilometres apart. In this example, broader scale landform features need to be considered with reference to the dip angles on the geology map and reference to the associated geology notes.

Plate 62 A fault north east of Boulia with moderately deformed sediments of Land Zone 11 to the west and weakly deformed sediments of Land Zone 9 to the east
The Burke River Structure (fault) north east of Boulia is shown with moderately deformed Cambrian–Ordovician limestones (C-On, Cuc) of Land Zone 11 occurring west of the fault while weakly deformed sediment of Land Zone 9 occur east of the fault (Google Earth)

Extent

The extent of Land Zone 11 is directly related to the various Inliers and Orogens as shown in the geological structural framework for Queensland (**Figure 6**). Deformed sedimentary rocks in sedimentary basins (such as Bowen and Georgina Basins) are determined by reference to geological maps and associated notes, and local interpretation (as defined above).

* See Glossary

In many cases, the distinction between unmetamorphosed and metamorphosed formations may be unclear and reference to geological maps, associated notes, land form features, imagery and soils is fundamental to determining the land zone.

The environment

Land Zone 11 forms extensive undulating to steep hills, ranges and mountains, and associated gently undulating colluvial slopes and pediments. Linear ridges, associated with strong folding of relatively hard and soft geologies, are common features of the Mt Isa Inlier (Northwest Highlands Bioregion) (**Plate 34**) and Coen Inlier (Cape York Peninsula Bioregion).

Soils are greatly influenced by the lithology (mineral content). In general terms, the acidic rocks form mainly shallow gravelly Rudosols and Tenosols on steeper slopes with Chromosols and Sodosols on lower slopes and gently undulating areas. Other rocks with more clay forming minerals such as micas, feldspars and mafic minerals form a very diverse range of soils, ranging from shallow Tenosols, Chromosols and Dermosols on steeper slopes to Sodosols and Vertosols on lower slopes.

The vegetation includes a diverse range of eucalypt open forest and woodland, with spinifex (*Triodia* spp.) shrublands and open woodlands in arid areas, and rainforests and vine forest in more favourable sites.

3.12 Land Zone 12 – Mesozoic to Proterozoic igneous rocks

Definition

hills and lowlands on granitic rocks

Mesozoic to Proterozoic igneous rocks, forming ranges, hills and lowlands. Acid, intermediate and basic intrusive and volcanic rocks such as granites, granodiorites, gabbros, dolerites, andesites and rhyolites, as well as minor areas of associated interbedded sediments. Excludes serpentinites (Land Zone 11) and younger igneous rocks (Land Zone 8). Soils are mainly Tenosols on steeper slopes with Chromosols and Sodosols on lower slopes and gently undulating areas. Soils are typically of low to moderate fertility.

Clarification

Land Zone 12 includes all Mesozoic to Proterozoic (Cretaceous and older) unmetamorphosed igneous rocks (see Section 2.3.3). Extrusive rocks have formed as a result of volcanic activity at or immediately adjacent to the earth's surface and include rock types such as basalt, andesite, rhyolite, trachyte and tuffs. Intrusive rocks occur where magma emplaces in pre-existing rock and cools relatively slowly (compared to extrusive rocks) forming coarse crystalline rocks. Intrusive structures include batholiths, sills and dykes with crystalline rocks such as granite, adamelite, granodiorite, diorite, syenite, monzonite, gabbro and dolerite. Pyroclastic rocks/tuffs and ignimbrites are included.

The definition of Land Zone 12 is simple, unequivocal and without exceptions to the rule; all pre-Cainozoic non-metamorphosed igneous rocks of whatever type are Land Zone 12. In many cases, the distinction between un-metamorphosed and metamorphosed formations may be unclear and reference to geological maps and associated notes is fundamental to distinguishing the land zone.

Cainozoic (Tertiary–Quaternary) igneous rocks of Land Zone 8 and metamorphosed igneous rocks (such as metavolcanics, greenstones, granitic gneiss and serpentinite) of Land Zone 11 are excluded. Deeply weathered igneous rocks of Land Zone 5 or 7 are also excluded.

Extent

Mesozoic and older igneous intrusive rocks are associated with the Mt Isa, Coen and Georgetown inliers, the Thompson Orogen (Townsville south through central Queensland), the Hodgkinson–Broken River Orogen (Cooktown to west of Ingham), and the New England Orogen along the coast/near coast of Queensland (Proserpine to the New South Wales border) as described in Section 3.1.3. Some of these older volcanic and intrusive rocks have been metamorphosed.

Field examination of fresh rock type with reference to geological mapping and associated notes readily determines the land zone.

The environment

Landforms of Land Zone 12 form extensive gently undulating rises to steep mountains (**Plate 63**). Fine grained rocks and siliceous rock types are generally more resistant to weathering and subsequent erosion resulting frequently in steeper to more undulating landscapes compared to more basic or coarse grained rocks of equivalent age and climatic conditions.

Soils are greatly influenced by the lithology (mineral content). In general terms, the acidic rocks (such as granites and rhyolites) form mainly shallow Tenosols on steeper slopes (Plate 64) with Chromosols and Sodosols on lower slopes and gently undulating areas. In high rainfall areas, Kandosols and Podosols can occur on colluvial slopes. Intermediate rocks (such as granodiorite, diorite, syenite, monzonite) form a very diverse range of soils depending on their mineral content, ranging from shallow Tenosols, Chromosols and Dermosols on steeper slopes to Sodosols and Vertosols on lower slopes. On mafic rocks types (such as gabbro, dolerite and pre-Cainozoic basalts), soils are predominantly black and brown Vertosols on the gently undulating landscapes grading to black and brown Dermosols/Ferrosols on steeper and/or rocky landscapes.

Plate 63 Granitic mountains, Mt Walsh, Biggenden

Plate 64 Shallow soils on a granite hill, quarry at The Gap, Brisbane

The vegetation includes a diverse range of eucalypt open forest and woodland, with rainforests and vine forest in more favourable sites.

4. Glossary

Completely weathered: Completely weathered rock retains no structure from the original rock. There are no corestones, but there may be mottling. It is composed completely of earth material.

> Completely weathered sediment retains no structures from the original sediment. It is composed completely of earth material. There may be mottling.

Deformation: A geological process in which the application of force causes a change in geometry, such as the production of a fold, fault or fabric, often associated with metamorphic reactions.

Diagenesis: All physical, chemical and biological processes that occur in a sediment after deposition and before metamorphism, during which time interstitial pore fluids react and attempt to reach equilibrium with their evolving geochemical environment.

Fold: A curved or angular shape of an originally planar geological surface.

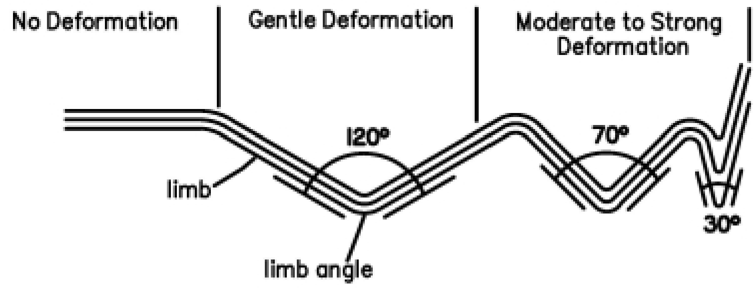
Gentle Folding: A fold with an *interlimb angle* of 180° to 120°.

Highest Astronomical Tide: The highest levels which can be predicted to occur under average meteorological conditions and any combination of astronomical conditions. HAT is not the extreme levels which can be reached, as storm surges may cause considerably higher levels to occur.

Highly weathered: Highly weathered rock has strong iron staining, and more than 50% earth material. Corestones, if present, are free and rounded. Nearly all feldspars are decayed, and there are numerous microfractures. The material can be broken apart in the hands with difficulty.

> Highly weathered sediment has strong iron staining, and more than 50% earth material. All except the largest particles are weathered right through. Boulders have thick weathering skins.

Interlimb angle: The angle between the fold limbs



Inter-tidal zone: The land between high and low tide levels.

Jarosite: an acidic pale yellow iron sulfate mineral $KFe_3(SO_4)_2(OH)_6$. Jarosite is a by-product of the acid sulfate soil oxidation process, formed at pH less than 3.7; commonly found precipitated along root channels and other soil surfaces exposed to air.

Lateritisation: A prolonged process of chemical weathering which produces a wide variety in the thickness, grade, chemistry and ore mineralogy of the resulting soils.

Moderately weathered: Moderately weathered rock has strong iron staining, up to 50% earth material. Corestones, if present, are rectangular and interlocked. Most feldspars have decayed, and there are microfractures throughout. It can be broken by a pick, but not by the hand.

Moderately weathered sediments have strong iron staining, and up to 50% earth material. Labile particles up to gravel size are completely weathered. Larger particles have thick weathering skins. Most feldspars in larger particles have decayed.

Moderate to Strong Folding: A fold with an interlimb angle of less than 120°.

Orogenic or orogeny: The process of formation of mountains – the process by which structures within fold belt mountainous areas were formed, including thrusting, folding, faulting, metamorphism and plutonism.

Paleo: Old or ancient.

Parna: A wind-blown clay, mobilised from inland Australia as the result of a series of intermittent high wind events during the Quaternary. Parna can be recognised on the basis of colour, texture, distributional patterns, and pedology.

Slightly weathered: Slightly weathered rock has traces of alteration, including weak iron staining, and some earth material. Corestones, if present, are interlocked, there is slight decay of feldspars and a few microfractures. It is easily broken with a hammer.

Slightly weathered sediments have traces of alteration on the surfaces of the sedimentary particles, including weak iron staining. Some earth minerals may be present, filling voids between coarse particles.

Supratidal: Lands subject to infrequent (spring tides) tidal inundation, normally bare of vegetation except for halophytes such as samphires.

Unweathered: Regolith with no visible signs of weathering (normally confined to some transported regolith types).

Vertic: Soil material with a clayey texture (35% or more clay), which cracks strongly when dry and has slickensides and/or lenticular peds – shrink-swell properties.

Very highly weathered: Very highly weathered rock is produced by the thorough decomposition of rock masses due to exposure to land surface processes. The material retains structures from the original rock. It may be pallid in colour, and is composed completely of earth material. Corestones, if present, are rare and rounded. All feldspars have decayed. It can easily be broken by hand.

Very highly weathered sediment is thoroughly decomposed, but still retains the shapes of the original sediment particles, as well as laminations and bedding. It is completely composed of earth material.

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