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Soils and Land Use on the Southern Section of the Townsville Coastal Plain, North Queensland

G. G. Murtha

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Abstract

A soil survey has been made of *c.* 110000 ha of the coastal plain immediately to the south and east of Townsville, north Queensland. The soils have been mapped on a free survey basis as associations of soil series. Many of the soil series and their distribution patterns are similar to those on the northern part of the coastal plain, and the reports of both areas are complementary.

Although solodized solonetz and solodic soils are dominant on the old high level alluvium, grey and black cracking clays are closely associated and widely distributed. Red and yellow earths, red and yellow podzolic soils, and leached siliceous sands occupy areas of channel infill with red earths and brown soils with gradational or duplex texture profiles on levees and terraces, and undifferentiated alluvial soils on younger alluvia. Coarse, uniform and gradational textured soils are dominant on the fans and piedmont slopes of the granitic uplands.

In general, soil fertility levels are very low. All major soils have been sampled, and chemical and physical properties of significance to agricultural land use are discussed. The main primary industry in the area is beef production with subsidiary pockets of cultivation on the younger alluvial soils. Owing to its proximity to Townsville, the area is subjected to increasing pressure for urban development, and particular attention has been paid to the suitability of soils for this purpose, principally for low density residential development.

Introduction

Soil and land use studies have been carried out on some 240000 ha of the Townsville coastal plain. The area to the north and west of Ross River has been described previously (Murtha 1975), while this report covers an area of approximately 110000 ha to the south and east of Ross River. It is bounded by the Ross River watershed in the south-west and by Mount Elliot and Emmett Creek in the south. The area lies between 19° 10′ and 19° 40′ S. and 146° 40′ and 147° 10′ E. (Fig. 1); all localities mentioned in the text are shown on the soils map.

Although approximately half of the Townsville city administrative area lies to the south of Ross River, residential development is limited with less than 10% of a total population of 80000 residing in the area (June 1974 figures). The suburbs of Douglas and Murray, however, are relatively new growth centres, and will have a significant influence on population growth. The area includes some of the city's major centres of employment, including the copper refinery, cement works, two meat-processing plants, university, college of advanced education, army barracks and miscellaneous heavy industry. In addition, the proposed new harbour development is situated on the western side of Cape Cleveland. The Burrumbush, part of Mount Elliot and the newly gazetted Cape Cleveland National Parks lie within the survey area.

Previous soils information includes land system mapping of Christian *et al.* (1953), the broad scale reconnaissance mapping as part of the Atlas of Australian Soils, sheet 7 (Isbell *et al.* 1968), and reconnaissance soil mapping of the Burdekin–Townsville region (Isbell and Murtha 1970). Murtha and Reid (1976) have discussed some of the constraints that soils may impose on urban development in part of the area. The detailed soil mapping of the CSIRO Pasture Research Station 'Lansdown' (Murtha and Crack 1966) abuts the south-western margin of the area.

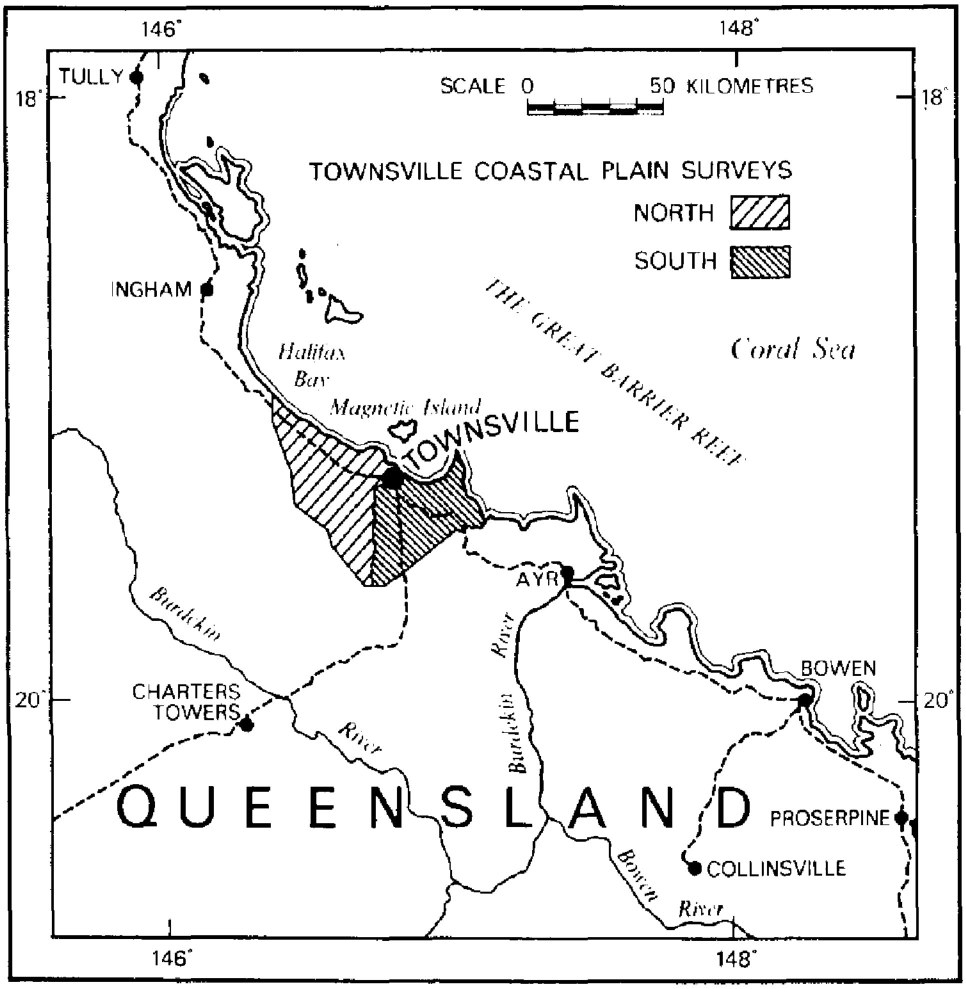

Fig. 1. Locality plan.

The chief aim of this study was to try to establish some rationale for the origin and distribution of the range of solodized solonetz and solodic soils which previous reconnaissance mapping had shown to be dominant over the greater part of the coastal plain. In addition a detailed knowledge of the types of soil, their nutrient status and their physical properties is necessary to minimize some of the problems associated with more intensive development for both rural and urban usage. There is a growing awareness of the constraints that soils may place on urban development, and soils information gained in the course of the coastal plain surveys has already been extensively used in the Townsville regional growth centre studies (National Urban and Regional Development Authority 1973; Australian Government Cities Commission 1975), in the preparation of a development strategy plan for Thuringowa Shire (unpublished) and in the Ross River dam catchment study (Queensland Department of Local Government 1978).

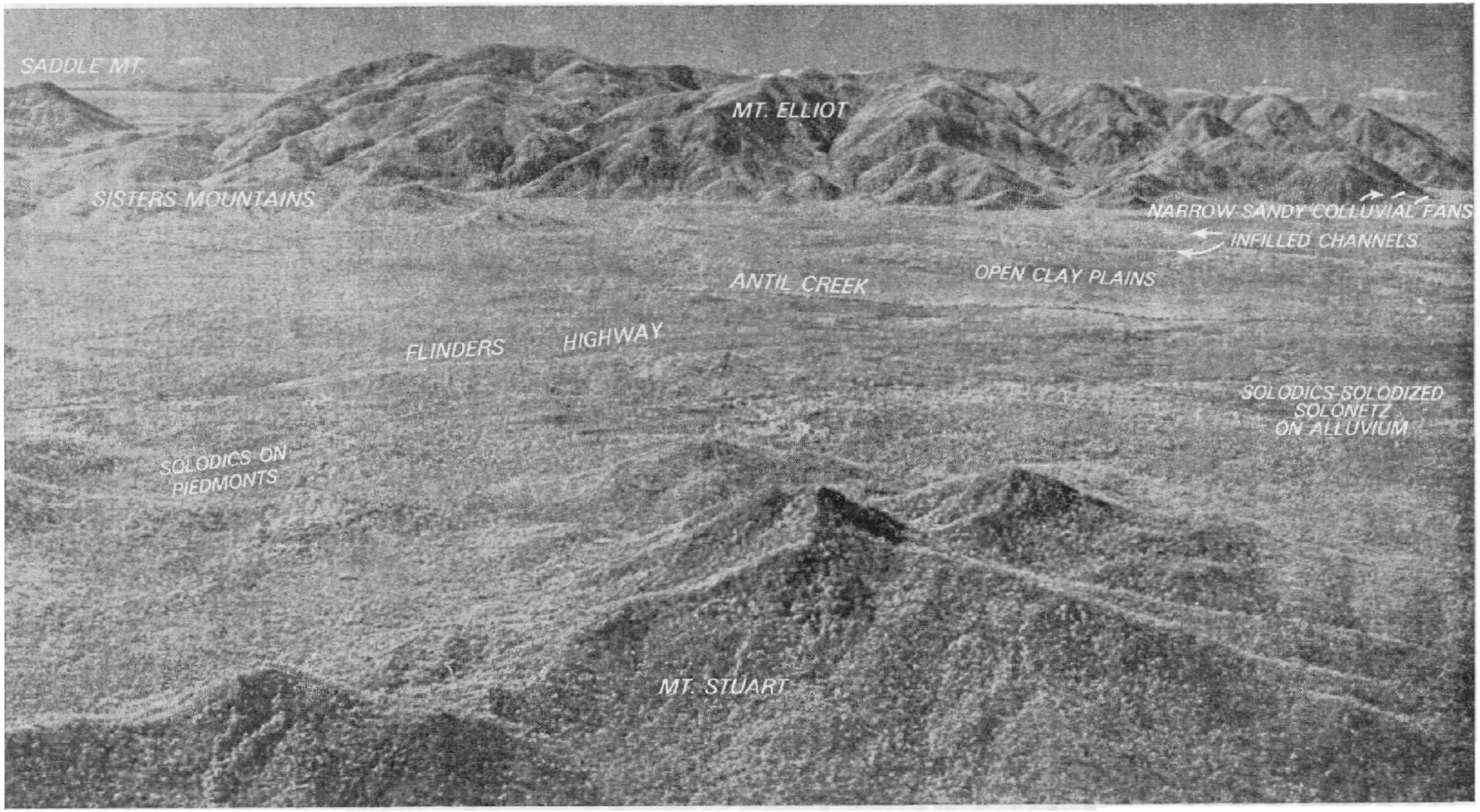

Fig. 2. Aerial oblique from Mount Stuart looking south to Mount Elliot.

Environment

Geology and physiography

The general physiographic features and their mode of development are very similar to those of the area to the north of Ross River where they have been described in some detail by Hopley and Murtha (1975). The chief difference is that the true coastal plain is very narrow, although the broad corridor linking the Ross and Haughton alluvial systems, between Mounts Elliot and Flagstone, and the alluvia west to the Mingela Range, is generally considered as part of the coastal plain. Fig. 2 presents one view of the area.

The geology of the area has been described by Wyatt (1972). Granite and acid volcanic rocks predominate, and there are smaller areas of intermediate volcanics, interbedded sediments and granodiorite. The granites and acid volcanics occur as hilly to high hilly lands generally with very steep slopes and much rock outcrop, while the more basic rocks have weathered to a much more subdued landscape.

General accounts of the physiography of the area have been given by a number of authors (Hedley 1925; Jardine 1928; Christian *et al.* 1953; Wyatt *et al.* 1970). The Haughton and Burdekin delta systems immediately to the south of the survey area have been described in more detail (Hopley 1970*a*), while Driscoll and Hopley (1968) and Hopley (1970*b*) have described the processes and sequence of coastline development.

The catchment of the Ross River has a complex geomorphic history and warrants much closer study than can be given in this report. Several features described below are of particular significance, and have had a major influence on the kind and pattern of soils that have resulted.

The swamps along Surprise Creek (just outside of the survey area, north-east of Woodstock) and between Barringha and Mount Elliot appear to be remnants of what was once a very extensive system of swamps or shallow lakes extending through to the area now drained by the Bohle River, i.e. to the west of Ross River along its northerly course adjacent to Mt Stuart. A low energy depositional environment is indicated for much of this area by the extent of fine-textured deposits. Although heavy clay soils occupy only relatively small areas, they almost invariably occur as buried soils underlying the coarser more recent deposits. The clay deposits occur at altitudes of approximately 35–60 m, and were probably very extensive swamps during the period of higher sea-level associated with the series of Pleistocene beach ridges to the west of Townsville (Hopley 1970*b*). A subsequent lowering of sea level reduced the base level of Ross River, resulting in a deeper incision by the river and its tributaries into the previous alluvial deposits and to the draining of most of the swampy areas.

In addition, the swampy areas have been partially filled by coarse sandy alluvial fan deposits. Most of these fans originated from the granites and granodiorites of Mt Flagstone and the minor residuals between Stanley and Antill Plains. There is some doubt whether all of the area mapped as fan in Fig. 3 is in fact depositional material. Some areas may in fact be underlain by deeply weathered granitic bed-rock, but no rock outcrops were observed in the area and in all of the sections examined, in erosional gullies and by deep drilling, the sands have been found to overlie dark clay alluvial deposits that contain lenses of rounded gravels.

These fans have influenced the drainage pattern and are probably largely responsible for the diversion of Lansdowne Creek from its former easterly course, to Majors Creek and thence to the Haughton River, to a northerly course to Five Head Creek and Ross River. The divide between the Haughton and Ross catchments is ill-defined,

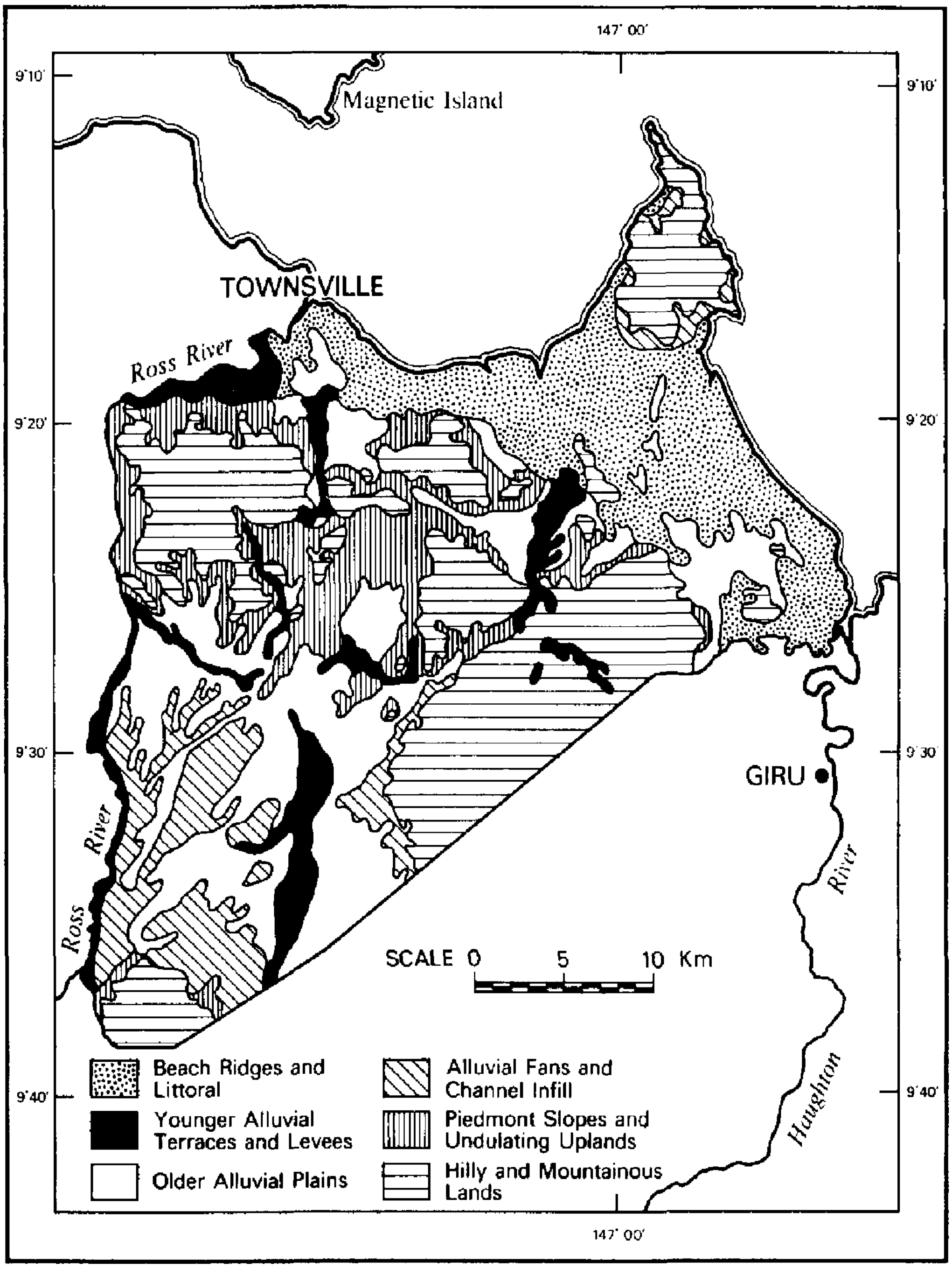

Fig. 3. Distribution of physiographic units.

and many local streams appear to have alternated from one catchment to the other at different times. In the Woodstock area the interfluve is an infilled channel trending south-westerly from Mt Elliot. Infilled channels are a common feature on the gentle piedmonts surrounding Mt Elliot, and all have a south-west trend which is opposed to the pattern of the modern drainage.

The divides between the Stuart and Alligator Creeks and the Ross River catchments are also ill defined. It is likely that the headwater of Stuart Creek once formed part of Antill Creek catchment, and the diversion to a northerly flowing stream is relatively recent. Recent studies on the geohydrology and geochemistry of the Ross River Basin aquifers has done little to elucidate the geomorphic history of the area. Radford (1973) suggested that, although there is some evidence of marine influence in the ground waters, most of the saline aquifers appeared to be due to evaporative lake processes. On the other hand Weller (1974) has postulated that the saline waters are a result of concentration following *in situ* clay mineral weathering reactions.

Six broad physiographic units have been recognized (Fig. 3).

Beach Ridges and Littoral

There is a very large beach ridge system developed between Saddle Mountain and Cape Cleveland and around the shores of Cleveland Bay. Driscoll and Hopley (1968) and Hopley (1970*a*) have described in detail two stages of ridge development recognized on the basis of degree and kind of soil profile development; however, more recent field evidence does not entirely support their findings. Firstly, the ridges immediately to the south of Woodstock Hill are very similar to the Mount St John, Bohle River Pleistocene beach ridges (Hopley 1970*a*), but the small ridge remnant immediately to the east of the Cluden racecourse has soil development essentially similar to that of the inland ridges of the Pallarenda beach ridge system (Hopley and Murtha 1975) and of the Bowling Green Bay Holocene series (Hopley 1970*a*). On the basis of the degree of profile development as used by Driscoll and Hopley (1968), all of the ridges examined in the Cleveland Bay sequence are of Holocene age.

Secondly, some of the ridge remnants inland of the recurved, spit-forming ridges of the Bowling Green Bay sequence have much more clayer textures than the other beach ridges, and there are occasional well-developed duplex texture soil profiles. It is possible that these ridges formed the initial spit development linking Cape Cleveland to the mainland and had as their source more feldspathic sands of local origin, possibly from Killymoon Creek rather than from a northerly meander of the Haughton River.

Fairly large areas of saltpan and shallow freshwater swamps occur inland of the Bowling Green Bay ridges, and extensive areas of mangrove, saltpan and mudflats occur both to the seaward and inland of the widely spaced Cleveland Bay ridges.

The Cleveland Bay coastline is characteristic of a low wave-energy environment. The shelter provided by the beach ridges linking Cape Cleveland to the mainland from the prevailing south-easterly winds and the generally low tidal range (1–3 m) provides an ideal environment for the formation of mud flats. While Ross River and local streams are an obvious source of sediment there is also accretion from streams as far south as the Burdekin River.

Younger Alluvial Terraces and Levees

The development of younger alluvial terraces and levees is highly variable. Most of the streams running to Cleveland Bay are deeply entrenched in the older alluvial plain and have well-defined younger alluvial terraces. Levees commonly form the high banks of most of these streams, but the soils on the levees are moderately to strongly differentiated and show no evidence of modern deposition except at a few isolated spots.

In the Ross catchment, narrow well-defined terraces are common along most streams, which are incised in the deposits of the steeper grades adjacent to the uplands. However, no terraces are apparent and stream channels are poorly defined and may anastomose as grades decline on entering the area associated with the relic swamps. Lansdowne Creek is a good example; in its upper reaches it is incised some 6–8 m, has two terrace levels, and minor levee development. In the area from Woodstock to Barringha the depth of channel incision decreases and the two terrace levels apparently merge and eventually become indistinguishable from what has been previously interpreted as relic swamp deposits, and the channel is poorly defined and weakly anastomosing.

Older Alluvial Plains

Most of the older alluvial plains appear to be above present flood levels; however, records are both short and incomplete, and some areas may still be subject to deposition. Soils of these areas certainly show no evidence of modern deposition; however, little is known of the rate of incorporation of depositional materials into the soil surface. The alluvium has a very gradual slope up to the piedmonts (2–3 m/km) and reaches an altitude of approximately 60 m around the foothills of Mt Elliot. The depth of alluvium is variable, but in excess of 50 m of unconsolidated sediments have been recorded in bore logs in the Stuart Creek and Antill Plains areas. Fine-textured deposits that have been interpreted as being associated with the relic swamps are also included in this unit.

Alluvial Fans and Channel Infill

There are two distinct series of fans. The most prominent are a series of coalescing fans forming the piedmonts principally in areas of granite outcrop. In general, these fans are relatively young, although the current drainage lines are incised into them, so there is some doubt if much deposition is currently taking place. The most significant fan development is around the base of Mount Elliot, where the coarse sandy soils of Hillview association are developed on a series of coalescing fans. Small rock fans with granite boulders to 2 m in diameter are common in the apex of many of the fans.

There is also a series of older, broad, low-angle fans, the origin and occurrence of which has already been discussed. They consist chiefly of coarse siliceous sands but may contain some rounded gravel layers. Numerous small streams have dissected the fans to a gently undulating landscape. In most cases the fans terminate fairly abruptly, and it appears that their margins may have been truncated. The fan thickness at the margins is of the order of 3–5 m, but in the main body of the fans is usually in excess of 20 m.

The areas mapped as Pepperpot and Granite associations north of Ross River form part of this series of fans and have been mistakenly interpreted as being developed *in situ* on granite (Murtha 1975). This was based largely on the C horizon material which has the appearance of deeply weathered granite. Similar materials have been encountered in this area, but in deep sections they are found to invariably overlie clayey deposits and it is now assumed that the same is true for those north of Ross River.

Channel infill deposits also are subdivided into two groups and, as on the northern section of the coastal plain, they have been loosely referred to as the younger and older series based wholly on the degree of soil profile development.

Soils on the younger series are largely red earths and red podzolic soils, and are confined almost entirely to prior the courses of Ross River east of the present channel and flowing towards Five Head Creek.

The older infilled deposits have weathered to mottled yellow earths and leached sands, and are confined to the small drainage lines flowing from Mt Elliot. They have no obvious relationship to the present drainage system as is the pattern elsewhere on the Townsville coastal plain. Many have a south-westerly trend, i.e. opposed to the north to north-easterly trend of current streams, and as suggested earlier these may have flowed to the Haughton River or emptied into the relic swamps.

Undulating Uplands Including Piedmonts

Short piedmonts with the slopes of 3–10° surround all of the upland country. Apart from the granitic areas it is not obvious that these piedmonts are all formed by coalescing fans, and it is for this reason that a distinction has been made. In most cases the soils developed on the piedmont slopes are very similar to those developed on the adjacent hard-rock uplands.

Some acid volcanic and granitic areas are included in the undulating uplands, but the largest occurrence is that of the intermediate volcanics of the low range south of the Bruce Highway between the Sisters Mountains and Stuart. Slopes range from 5° to 15°, soils are moderately deep to deep and rock outcrop is rare.

Hilly and Mountainous Lands

This unit is dominated by the large granitic intrusions of Mounts Elliot, Stuart and Cleveland. These rise very abruptly from the alluvial plain to heights of 1235, 582 and 558 m respectively. Slopes are steep to very steep and rock outcrop is common. Spectacular tor topography is a feature of much of the granite country particularly in the Cape Cleveland area. Acid volcanic rocks make up the balance of hilly country.

There is some evidence to suggest that a small area near the crest of Mount Stuart is a remnant of an old land surface which may once have been continuous with the Harveys Range plateau. The soils are markedly different from those found on the remainder of the Mount Stuart complex in that they are very strongly differentiated acid duplex soils, and are similar to those on parts of the Harveys Range plateau (Isbell *et al.* 1968).

Climate

The climate of the area is characterized by hot humid summers and dry mild winters. A detailed account of the climate has been compiled by the Commonwealth Bureau of Meteorology (1970), and only the more important aspects will be dealt with here.

Mean annual rainfall in the area varies between 1250 and 870 mm, but its seasonal distribution is the most important climatic element influencing agricultural and pastoral production. Approximately 70% of the annual rain occurs in the January–March period and the sum of the average values for the eight months April–November is well below average figures for both January or February. The average monthly and annual rainfall for three stations is shown in Table 1. Figures

Table 1. Rainfall, temperature and relative humidity data

Data from Commonwealth Bureau of Meteorology (1970)

Station			Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year	Years of record
Townsville	Rainfall (mm)	Av.	284	302	198	74	31	30	16	14	16	30	49	129	1171	105
		Max.	1142	904	612	592	206	181	226	113	247	274	335	616	2482	
		Min.	9	2	1	0	0	0	0	0	0	0	0	0	267	
Antil Plains		Av.	281	265	199	72	31	18	20	10	5	17	58	85	1060	17
		Max.	1071	660	581	342	212	71	150	45	54	50	391	340	2140	
		Min.	34	44	7	0	0	0	0	0	0	0	0	0	451	
Woodstock		Av.	221	218	150	41	29	27	12	12	9	16	44	91	871	65
		Max.	809	821	430	301	346	184	127	120	151	153	505	357	1756	
		Min.	0	5	0	0	0	0	0	0	0	0	0	0	277	
Giru		Av.	292	355	254	61	30	33	25	15	7	20	53	111	1256	40
		Max.	1196	1148	778	242	276	183	265	82	91	123	305	516	2365	
		Min.	32	66	9	0	0	0	0	0	0	0	0	0	274	
Townsville	Temp. (°C)	Av. max.	30·7	30·6	30·3	29·3	27·3	25·2	24·4	25·3	26·9	28·4	29·6	30·6	28·2	100
		Av. min.	24·6	24·2	23·3	21·4	18·6	16·6	15·4	16·4	18·8	21·4	23·2	24·2	20·7	
	3 p.m. R.H. (%)	Av.	69	69	66	62	59	59	59	59	61	61	64	66	63	

Table 2. Rainfall probability Townsville and Woodstock

Percentage chance of receiving specified amounts of rain or more

Rainfall (mm)	Place	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
0	Townsville	99	98	96	74	60	65	37	32	28	56	70	92
	Woodstock	97	98	95	69	60	52	38	28	21	46	57	89
25	Townsville	98	96	92	62	36	35	19	17	20	25	50	77
	Woodstock	99	97	89	43	32	35	17	14	12	25	48	82
75	Townsville	83	86	73	34	9	14	8	3	6	10	20	51
	Woodstock	80	77	63	17	11	11	3	3	1	5	18	42
125	Townsville	72	76	58	18	4	4	2	—[A]	1	4	13	39
	Woodstock	69	62	43	6	1	1	1	—	1	1	6	31
250	Townsville	47	50	33	7	—	—	—	—	—	1	2	17
	Woodstock	35	31	23	1	1	—	—	—	—	—	3	11
400	Townsville	22	31	13	3	—	—	—	—	—	—	—	5
	Woodstock	14	21	6	—	—	—	—	—	—	—	1	—
600	Townsville	10	10	2	—	—	—	—	—	—	—	—	1
	Woodstock	6	1	—	—	—	—	—	—	—	—	—	—

[A] Amount has not been recorded.

for Giru, which is some 8 km south of the survey area, are included as a guide to what might be expected in the south-eastern section of the survey area. Although Townsville–Giru annual figures differ by only some 85 mm over the complete period of records (1871–1972), Townsville received 127 mm less over the 1933–1972 period. Mount Elliot and Saddle Mountain also influence precipitation, and although there are no figures available there is almost certainly a narrow fringe of better-watered lowland country immediately to the east of these features.

Annual variability (expressed as mean deviation as a percentage of the mean) exceeds 30%, while monthly variability in the 'wet season' ranges over 59–66%. Rainfall reliability is illustrated by the low order of probability (Table 2) and particularly when considered in relation to monthly means (Table 3).

Table 3. Rainfall probability

Percentage chance of receiving the monthly average rainfall or more

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Townsville	42	42	40	32	31	30	26	28	26	33	32	38
Woodstock	46	40	41	35	30	36	38	27	22	38	30	40
Giru	38	48	35	38	30	32	28	32	25	30	35	42

Rainfall intensities are fairly high, averaging about 20 mm per wet day for the period December–April, but average figures do not fully reveal the high intensities commonly experienced. In the 50 year period 1910–1960 daily falls of >75 mm were recorded on 124 occasions, >130 mm on 50 occasions and >255 mm twice. Short period intensities of 25–50 mm per hour are common, and are of particular significance when they occur early in the 'wet season'. Ground cover is usually very sparse after the long dry winter, and most of the surface soils are highly susceptible to erosion.

Hail associated with thunderstorm activity is a reasonably rare occurrence, and should not be a significant hazard to horticultural cropping. High winds associated with cyclonic activity may cause severe windfall loss in tree crops.

Further information on rainfall intensity, temperature and humidity data, and length of growing season is included in Murtha (1975).

Flora and Fauna

The broad vegetation patterns for the area have been mapped and described by Isbell and Murtha (1972). The major communities are listed and briefly described in Appendix 1; structural formations follow (Specht 1970).

Almost all the vegetation units apart from those on the very hilly country have been considerably modified by timber-cutting and ring-barking. Timber treatment (clearing or hormone poisoning) as part of pasture improvement programs received considerable attention in the late 1960's–early 1970's, but the down-turn in the beef industry in the mid 1970's resulted in a marked decline in pasture improvements.

Black speargrass (*Heteropogon contortus*) and kangaroo grass (*Themeda australia*), together with the introduced annual legume Townsville stylo (*Stylosanthes humilis*), are by far the most important pasture species. Little attempt has been made to establish introduced grasses on any scale, although guinea grass (*Panicum maximum*) has colonized some of the more fertile soils of the lower alluvial terraces. The main emphasis in pasture improvement in this area has been the sowing of Townsville stylo to those areas where it had not naturally colonized.

The introduced shrub chinee apple (*Ziziphys mauritiana*) has become a major pest. It grows on most soils, but seems to prefer a fairly open canopy and is particularly common on the more sparsely timbered clayey soils. Rubber vine (*Cryptostegia grandiflora*), a climber and also an introduced species, is becoming increasingly widespread along watercourses, and often occurs in association with chinee apple thickets on the clay plains.

In addition to the major vegetation communities described in Appendix 1 there are many minor but nonetheless important communities which add to the diversity of habitat for a wide range of bird and animal fauna occurring in the area. Some 229 bird species (Lavery 1968) and 53 animal species (Lavery and Johnston 1968) have been recorded in the Townsville district. Of these some 86 bird species and 35 mammals, including 1 Monotremata and 12 Marsupiala are known to have viable populations in the survey area (Blackman, personal communication). The coastal beach ridge systems and their associated salt-water and freshwater marshes are areas with particularly rich and diverse fauna. The pondage area of Ross River dam will have a major influence on the fauna of the area. Since its initial filling in late 1973, it has already become a major nesting and feeding area for waterfowl, and the exclusion of cattle from the buffer area assures an abundant food supply for native herbivores.

The feral pig (*Sus scrofa*) is a major pest, particularly to cultivation land, and the dingo (*Canis dingo*) is relatively common, although reports of stock losses are fairly rare.

Soils

General

The soil pattern of the mapped area is very similar to the area of the north of Ross River, and many of the soil series and soil associations are virtually unchanged in this report. There have been some minor changes in the proportional distribution of soils, e.g. coarse sands formed on alluvial fans and heavy clay soils formed in floodplain back-swamp areas are more widely distributed. The acid duplex soils have a lesser representation owing to the drier climate for the major part of the area, and a more detailed examination has been made of the upland soils, since there are significant areas of gently to moderately undulating upland country.

The soils have been mapped as associations of soil series. In most cases the series from which the association is named is dominant, but occasionally there is a co-dominance of two or more series which occur either as a complex or in a well-defined catenary sequence. Two units have not been named after soil series: one is the Gilgai Complex with cracking clays on the mounds and duplex soils in the depressions, the other is Landers Complex, which is a mixture of duplex soils formed on older alluvium and coarse sandy soils formed on infilled channels.

A free survey technique was used for field examination. All roads and tracks in the area were traversed with additional specifically designed traverses where further information was required. All field inspection sites and field located boundaries were plotted on 1 : 25 000 aerial photographs. Extrapolation of soil boundaries was based on photo pattern. Over most of the area major soil differences are readily distinguishable by photo patterns, but many minor soils are not easily distinguished; consequently the position of some soil boundaries is inferred.

The field classification of soils was based on the Factual Key (Northcote 1971). Although at this level of mapping each principal profile form (PPF) can embrace a number of soil series or alternatively a soils series can range over a number of PPF's, it was only in the Dy soils, particularly Dy 3, that further subdivision was necessary to differentiate the soils on other important morphological characters. The subdivision was based on the thickness of the A horizons and the depth and value chroma rating of the A_1 horizon. These criteria were selected because they are easily recognized features which bear some relationship to other morphological chemical or physical characteristics (Murtha and Crack 1966; Crack and Isbell 1970; McCown 1971).

The subdivision used is indicated below and is expressed by adding an oblique and the appropriate number to the PPF, e.g. Dy 3·43/4. It should be noted that this subdivision is not intended as an addition to the key, but has simply been used as an aid in the classification of soils for the Townsville coastal plain surveys.

Dark A_1 horizon has a value chroma rating 1 and is at least 5 cm thick.
- Total A horizon thickness <11 cm PPF/1
- Total A horizon thickness 11–25 cm PPF/2
- Total A horizon thickness >25 cm PPF/3.

Pale A_1 horizon has a value chroma rating 2, 3 or 4; if the value chroma rating is 1, the horizon is less than 5 cm thick.
- Total A horizon thickness <11 cm PPF/4
- Total A horizon thickness 11–25 cm PPF/5
- Total A horizon thickness >25 cm PPF/6.

Description of the soil series

Each of the defined soil series has been characterized in Table 4. The terminology adopted generally conforms with the United States Department of Agriculture soil survey manual (Soil Survey Staff 1951) and Stace *et al.* (1968). In Table 5 the series are classified according to the schemes of Stace *et al.* (1968), Northcote (1971) and Soil Survey Staff (1975).

It should be noted that in classifying the soils according to soil taxonomy, some extrapolation was necessary owing to lack of data and the use of analytical methods that differ from those specified. Because of a lack of micromorphological data, the presence of an argillic horizon was decided solely on the basis of particle-size specifications. Soil moisture and temperature data are lacking, and the identification of soil moisture regimes in particular is subjective. Soil temperature regimes have been estimated from Townsville air temperatures. Thus the equivalents given in Table 5 are to be regarded as approximate only.

Descriptions of the mapping units

The mapping units are associations of series and, apart from the two soil complexes, have been named after the dominant series present. The units are described in terms of their physiographic locations, their variability and the occurrence of component soils. As the broad soil pattern is closely related to the landforms of the area, it is convenient to discuss the mapping units within the framework of the physiographic units shown in Fig. 3. Only the dominant PPF for each soil series is listed.

Table 4. A brief description of the soil series arranged according to Principal Profile Form

(a) Uniform-textured Soils

Series	PPF	Physiographic unit	Surface soil	Subsoil	Additional comments
Central	Uc 1·21	Recent stream terraces	Very dark grey-brown fine sandy loam, massive and weakly coherent; 10–15 cm thick	Grey-brown or pale brown weakly coherent sandy loam grading to coarse water-worn gravels within a depth of 2 m	Young alluvial soils with little profile development beyond surface accumulation of organic matter
Magenta	Uc 1·21	Recent stream terraces	Dark grey-brown loamy sand, weak fine blocky; 8–10 cm thick	Grey-brown or brown loamy sand, massive, weakly coherent. High amounts of large rounded gravels from 40 cm	Young alluvial soils with little profile development beyond surface accumulation of organic matter
Toolakea	Uc 1·21	Frontal beach ridges	Loose pale brown loamy sand with slight organic enrichment to 30 cm	Light brown or yellowish brown loose single grain sand	May have some broken shell fragments throughout the profile
Argea	Uc 2·21	Older infill channels and piedmont slopes	Thin light grey-brown single grain coarse sand A_1 horizon overlying a strongly bleached sand A_2 horizon. Total thickness of A horizon range: 30–60 cm	Colour varies from pale brown or yellow to light yellowish brown, generally mottled but occasionally whole coloured. Texture is rarely heavier than sandy loam. There are usually some ferruginous nodules throughout the B horizon	These soils normally overlie round gravels at 1·5–2 m and occasionally grade to ferruginous or siliceous pans at about the same depth
Granite	Uc 2·21	Gently undulating fan deposits	Thin grey-brown or light grey-brown single grain loamy sand A_1 horizon overlying a thick strongly bleached loamy sand or sand A_2 horizon. Total A horizon thickness ranges over 50–80 cm	Gradual change to generally pale, whole coloured or mottled yellowish red, yellow, or yellow grey sand to light sandy loam. Single grain and loose when dry, very friable when moist	May have some soft ferruginous nodules towards the base of the A_2 horizon and throughout the B horizon

Oolgar	Uc 2·23	Older beach ridges	Thin light grey-brown loamy sand A_1 overlying very strongly bleached sand A_2 horizon. A horizons are single grain, very loose when dry and range from 50–60 cm thick	Gradual change to weakly developed B horizons. These may be whole coloured or mottled, very pale brown, with yellow-brown, or yellowish red. Texture usually remains as coarse, weakly coherent sand throughout but may occasionally rise to a light sandy clay loam	These soils overlie calcareous pans or indurated clayey sediments at depths 1·5–2 m
Antill	Uc 2·34	Piedmont slopes	Thin, grey-brown, loose, loamy sand A_1 horizon and very strongly bleached sand A_2 horizons	Abrupt change at 45–60 cm to strongly cemented pans. Moderate to high amounts of ironstone nodules and some fine quartz gravels. Pans may be mottled within a very pale brown matrix	The pans are usually very strongly cemented and impenetrable by hand auger
Jalloonda	Uc 4·21	Younger beach ridges	Dark grey-brown organic enriched single grain sand A_1 horizon about 30 cm thick overlying a slightly paler weakly developed A_2 horizon	Gradual change at about 40 cm to brown or yellowish brown very loose single grain sand	Thickness of the beach ridges range from 1·5 to 6 m. Nature of the underlying material varies from mangrove muds and peat to beach rock and buried duplex soils of the marine plain (Coonambelah series)
Pallerenda	Uc 4·22	Younger beach ridges	Very dark grey-brown loamy sand to sandy loam A_1 overlying a paler A_2 horizon. Both are weakly coherent; total thickness range: 30–40 cm	Gradual change to reddish brown or yellowish red light sandy loam B horizons. These are weakly coherent and massive. At about 1 m there is a gradual change to paler and occasionally mottled sand	General profile development is somewhat stronger than for the Jalloonda series. The soils are usually restricted to the older of the more recent beach ridges

Table 4 (*Continued*)

Series	PPF	Physiographic unit	Surface soil	Subsoil	Additional comments
Elliot	Uc4·22	Piedmont	Deep (10–12 cm) dark grey-brown loamy sand A_1 horizon overlying slightly paler loamy sand A_2 horizon. A horizons are weakly coherent and contain much fine quartz gravel; total thickness range: 30–40 cm	Gradual change to reddish brown or yellowish red loamy sand to sandy loam B horizon. These are weakly coherent to massive and below 80 cm grade to coarse alluvial fan gravels	These soils are similar in many attributes to the gradational textured Hillview series. They occur most commonly on the young alluvial fans on the northern slopes of Mount Elliot
Cungulla	Uc5·11	Beach ridges	Dark grey-brown loamy fine sand, single grain, loose when dry	Gradual change at 20–35 cm to dark brown or dark yellowish brown loamy fine sand; very weakly coherent. Below 60–70 cm they grade to pale yellow and white sand	The dark brown hues appear to be of organic origin. Occasional soft FeMn nodules may occur in the lower part of the B horizon
Windsor	Um4·22	Younger levees and terraces	Dark brown or dark grey-brown sandy loam to loam A_1 horizon overlying a slightly paler weakly developed A_2 horizon. A horizons are generally massive, but there may be some weak blocky structure developed in the A_1. Total thickness range: 10–20 cm	Subsoil colour ranges from brown or yellow-brown to yellowish red. Texture is normally sandy loam to loam throughout, but may occasionally rise to light sandy clay loam. B horizons are massive and porous and underlain by coarse rounded gravels below about 2 m	These soils are similar in many respects to the Bluewater series but have a uniform rather than a gradational texture profile
Sachs	Ug5·16	Alluvial plain	Very dark grey to black heavy clay. Strong fine blocky structure firm when moist, very hard when dry. Slight amounts fine FeMn nodules	From 60 cm there is a gradual change to brown or dark greyish brown, coarse blocky structured, heavy clay. Some hard carbonate nodules occur below 80 cm. With depth there is a gradual colour change to light grey or light yellowish brown	Lower B horizon materials are extremely variable. They may be occasionally mottled and alluvial stratification is often clearly evident. Buried soil profiles can occasionally be seen in gully exposures

Vantasell	Ug 5·25	Alluvial plain	Dark grey or dark grey-brown, medium to coarse blocky structured, heavy clay. Firm to hard when dry, few fine FeMn nodules	Gradual change at 20 cm to greyish brown or grey heavy clay; very coarse blocky with some prominent slickensides; few fine FeMn nodules and slight fine carbonate nodules from 120 cm; gradual change at about 120 cm to brown or yellowish brown heavy clay	These soils are associated with the puff sites of weak to moderate gilgai microrelief. In some areas the surface is very weakly self-mulching. Dy 2 soils of Manton series occur in the depressions
Alick	Ug 5·28	Older alluvial plain	Dark grey heavy clay, moderate to strong fine angular blocky structure. Surface is weakly self-mulching. Some 5–15 mm carbonate nodules on the surface	Dark grey to grey-brown heavy clay, strong coarse blocky structure. With depth may become finely mottled and grade to sandy clay or sand D horizons below 2 m. Some fine FeMn and low to moderate carbonate nodules occur throughout	These soils are usually confined to the puffs in areas of gilgai microrelief
Brolga	Ug 5·28	Marine plain generally confined to slightly depressed areas	Very dark grey medium to heavy clay, strong coarse blocky structure. Many fine yellowish brown patches and root tracings. Thickness of A horizon range: 15–40 cm	Mottled dark grey and brownish yellow heavy clay. At about 70 cm this grades to prominently mottled, light grey, brownish yellow, and yellowish red plastic heavy clay. These soils are seasonally saturated below about 50 cm	These soils have moderate to strong gley features throughout the profile and are mildly acid throughout
Gilligan	Ug 5·29	Older alluvial plain	Dark grey-brown, strong fine blocky structured, light to medium clay A horizon	Gradual change at 10–15 cm to olive brown heavy clay with coarse blocky structure; at 80 cm gradual change to dark yellow-brown heavy clay with coarse lenticular structure. Some hard carbonate nodules below 50 cm	In some areas there are moderate amounts of 5–15 cm rounded gravels on the surface. Soil reaction is moderately alkaline throughout

Table 4 (*Continued*)

(*b*) *Gradational-textured Soils*

Series	PPF	Physiographic unit	Surface soil	Subsoil	Additional comments
Bluewater	Gn 2·14	Younger levees alluvium and channel infill	Brown or grey-brown sandy loam A_1 horizon overlying a slightly paler weakly developed A_2 horizon. These are normally massive but occasionally have weak subangular blocky structure and are friable when moist	At 15–20 cm there is a gradual change to yellow-red or red sandy loam increasing to light clay loam B horizons. These are massive and earthy throughout and friable when moist. Below 1–1·5 m texture decreases to coarse sandy loam and there is a gradual colour change to mottled yellowish red and yellow-brown	These soils are underlain by coarse rounded gravels usually below depths of about 2 m. In some of the broader areas of alluvium the B horizons may have weak fine to medium blocky structure
Hillview	Gn 2·14	Piedmont slopes	Dark grey-brown loamy sand to sandy loam A_1 overlying a slightly paler reddish brown A_2 horizon. Weak fine blocky structure throughout	Gradual change at 15–30 cm to dark red or yellowish red sandy clay loam to light sandy clay B horizons. These are massive and earthy and occasionally have some fine ironstone nodules throughout. Texture decreases gradually, grading to coarse angular gravels below about 1 m	There are often some fine angular gravels on the surface and throughout the profile. Although generally red or yellowish red in colour many of these soils are Gn 2·24. Soil reaction is mildly acid throughout
Clemant	Gn 2·24	Piedmont slopes	Dark grey-brown loamy sand to sandy loam A_1 horizon overlying a paler, well-developed A_2 horizon. Both are massive and may contain few fine angular gravels	Gradual change at 20–30 cm to yellow, yellow-brown or reddish yellow sandy loam increasing to sandy clay loam. Massive and earthy throughout. Coarse angular gravels occur at 1–1·5 m, and there may be soft ironstone nodules throughout	The A_2 horizon is occasionally sporadically bleached

Pepperpot	Gn 2·24	Gently undulating fans	Light grey-brown loamy sand to sandy loam A_1 horizon overlying paler well developed sandy loam A_2 horizon. Both are massive and friable	Gradual change at about 30 cm to yellowish brown sandy loam increasing to sandy clay loam or light sandy clay massive and earthy. Some fine yellowish red mottles and soft ironstone nodules below 60 cm. Weathered granitic materials occur below about 80 cm	Closely associated are similar soils with bleached A_2 horizons (Gn 2·34). Reaction is mildly acid throughout
Ross	Gn 2·24	Older river levees	Dark grey-brown massive sandy loam A_1 horizon overlying a paler, fairly well-developed sandy loam A_2 horizon; total A horizon thickness range: 20–35 cm	Gradual change to a brown or yellowish brown sandy clay loam. This may occasionally be mottled, and is massive and earthy. Below 40–70 cm there is a fairly gradual change to faintly mottled yellowish brown and light brownish grey, strongly pedal, medium to heavy clays	This is a two-storied soil; the pedal clays are part of a buried soil profile. The A_2 horizon of the upper profile may occasionally be sporadically bleached, and both earth and pedal clay are mildly acid
Yileena	Gn 2·24	Older channel infill	Light grey-brown loamy sand to sandy loam A_1 horizon overlying a slightly paler, weakly developed A_2 horizon. Both are usually loose and single grain but may occasionally be weakly coherent and massive	Gradual change at 20–40 cm to yellow or yellow-brown B horizons. These have a gradual textural increase from sandy loam to sandy clay loam and are massive and earthy. There may be some soft ironstone nodules throughout the lower A and B horizons	These soils are generally restricted to the more inland extremities of the channel fill. They are similar to the Carinya series, but have much less strongly developed profiles
Black	Gn 2·45	Younger alluvium	Deep, dark grey-brown massive, sandy loam A_1 horizon grading to a slightly paler A_2 horizon	Gradual change at about 40 cm to light yellowish brown sandy clay loam, which grades to brown sandy clay loam or sandy clay; massive, earthy and very friable throughout. At 1–1·5 m coarse rounded gravels or stratified sediments occur	These soils are closely associated with the juvenile soils of Central series; they are generally similar but have much stronger profile development. There is frequently no A_2 horizon development

Table 4 (*Continued*)

Series	PPF	Physiographic unit	Surface soil	Subsoil	Additional comments
Wallaroo	Gn 2·64	Gently undulating fans	As for Pepperpot series	As for Pepperpot series but the B horizons are mottled throughout, with slightly higher concentrations of ironstone nodules in some profiles	Similar to Pepperpot series distinguished by mottled B horizons and higher nodule concentrations
Woodridge	Gn 2·64	Older alluvial plain	Dark grey-brown loam A_1 horizon overlying a thin, slightly paler, weakly developed A_2 horizon. Both are generally massive, but may occasionally have weak fine blocky structure; total thickness range: 10–15 cm	Gradual change to a faintly mottled yellow-brown and red clay loam to light clay B horizon. This is massive and porous, and generally contains some fine ironstone nodules. At depths ranging from 80 to 150 cm there is an abrupt change to a very strongly structured heavy clay D horizon	A characteristic feature of these soils is the occurrence of a prominent sink-hole microrelief. The depressions are 10–70 cm in diameter and up to 80 cm deep. The earth profile is mildly acid, but the structured clays are strongly alkaline
Carinya	Gn 2·74	Older channel infill	Thin light grey-brown loamy sand to sandy loam A_1 horizon overlying a thick well developed A_2 horizon. This is usually conspicuously bleached, but may occasionally be sporadically bleached. Thickness of A horizons range 20–70 cm and are commonly 40–50 cm	Gradual change to mottled pale brown, yellow, or yellowish brown sandy loam increasing to sandy clay loam. Texture may occasionally rise to a light sandy clay. B horizons are massive and very porous and contain variable amounts of soft ferruginous nodules. They grade to coarse sands and rounded gravels at 1·5–2 m	These soils occupy the mid portion of a soil continuum in the channel infills between Yilleena series at the higher inland end and Argea series on the lower end

Stag	Gn 2·74	Piedmont slopes	Dark grey-brown loamy sand to sandy loam A_1 horizon overlying a bleached sandy loam A_2; total thickness of A horizons 15–25 cm	Gradual change at 15–25 cm to finely mottled yellow, yellow-brown, and yellowish red sandy loam increasing to sandy clay loam, occasionally to sandy clay. Massive and earthy throughout. Some ferruginous nodules in the lower part of the B horizons. Grades to coarse colluvial gravels at depths below 80 cm	These soils are similar to the Clemant series but have stronger profile development
Flagstone	Gn 2·94	Gently undulating fans and piedmonts	Light grey-brown single grain loamy sand A_1 horizon overlying a strongly bleached loamy sand A_2. Some soft ferruginous nodules at the base of the A_2 horizon	Gradual change at 40–60 cm to mottled yellow-brown, yellowish red, and dark red sandy clay loam. This is generally massive and earthy, but weak fine blocky structure occurs in some profiles. Texture becomes coarser and lighter with depth and the B horizon grades to weathered granite (or reworked granitic sands) at about 1 m	Variable amounts of soft ironstone nodules in the A_2 and B horizons. A_2 horizon may occasionally be only sporadically bleached
Pinnacle	Gn 2·94	Piedmont slopes	Thin light grey-brown fine sandy loam A_1 horizon overlying a strongly bleached fine sandy loam A_2 horizon. Both are massive and friable	Gradual change at 25–30 cm to mottled light brownish grey and brownish yellow light sandy clay loam. This is massive and earthy and very friable when moist. Increasing amount of fine angular gravels below 45 cm	Ironstone nodules occur in the lower B horizon of some profiles. Reaction is mildly acid throughout

Table 4 (*Continued*)

Series	PPF	Physiographic unit	Surface soil	Subsoil	Additional comments
Alice	Gn 3·14	Younger channel infill	Dark brown or dark reddish brown sandy loam to loam A_1 (10–12 cm) overlying a slightly paler weakly developed A_2 horizon. Both have massive or weak fine blocky structure and are friable when moist	Gradual change at 20–30 cm to dark red or dark reddish brown sandy clay loam to clay loam. Massive or weak fine angular blocky structure. With increasing depth there is a gradual texture increase to a medium clay at 50–70 cm, then a gradual decrease to coarse sandy C horizon materials below about 1 m. The heavier textures are accompanied by strong blocky structure with ped size ranging from fine to very coarse	These soils are similar to the Bluewater series, apart from the structural development of the B horizon. Similar undescribed soils with brown or yellow-brown B horizons (Gn 3·24) are closely associated. These have been referred to as a brown variant of Alice series
Double Barrel	Gn 3·15 Gn 3·25	Younger stream levees	Dark grey-brown sandy loam to loam A_1 horizon overlying weakly developed sandy loam A_2 horizon. Structure is massive to weak subangular blocky throughout; total thickness range: 20–35 cm	Clear change to red-brown or brown sandy medium clay B horizon; moderate coarse blocky structure; firm to hard consistency. Some soft ferruginous nodules in the lower B horizon. Grades to coarse alluvial sands and gravels at about 120 cm	Most profiles are mildly acid to neutral, but carbonate occurs in the lower B horizon where these soils are grading to the more strongly developed duplex soils on the levee backslope. Similar in many attributes to the brown variant of Alice series

(c) *Texture-contrast Soils*

Stuart	Dr2·22	Uplands (Intermediate volcanics)	Very dark grey or grey-brown loam A_1 horizon overlying a weakly developed dark brown loam to clay loam A_2 horizon. Weak fine blocky structure; firm consistence; total A horizon depth range: 15–30 cm	Clear change to dark red or yellowish red medium to heavy clay B horizons. Moderate to strong fine subangular blocky structure; firm when moist, few fine ferruginous nodules in lower B horizon. Grades slowly to weathered parent material below 60 cm	Variable amounts of coarse gravel on the surface and throughout the A horizons. In areas of steeper topography there is evidence of soil creep and considerable movement of surface materials
Julago	Db1·13	Coalescing fans on piedmont slopes	Very dark grey-brown loam to clay loam; weak fine subangular blocky structure; friable consistence	Clear change at 8–15 cm to dark brown medium to heavy clay B horizons. Strongly developed coarse blocky structure; hard when dry; fine ferruginous nodules. Some carbonate nodules from 60 cm in the deeper soils	Some profiles have weak A_2 horizon development. As these soils have developed on alluvial slopes the depth to, and nature of underlying materials is variable. Gravels and sands have been encountered as shallow as 1·5 m, while in other areas the dark brown clays continue below 3 m
Barringha	Db1·41	Alluvial plain	Very dark grey-brown loam A_1 horizon overlying very strongly bleached sandy loam to loam A_2 horizon. Massive structure and firm consistence throughout; total A horizon depth range: 30–35 cm	Clear change to brown or dark yellowish brown medium to heavy clay B horizons. Weak to moderate fine blocky structure, few fine soft ferruginous nodules. Grades to alluvial sands and gravels at about 80 cm	Although all profiles examined were shallow and were mildly acid in the lower B horizon, similar deeper soils with an alkaline reaction probably occur

Table 4 (*Continued*)

Series	PPF	Physiographic unit	Surface soil	Subsoil	Additional comments
Stanley	Dy2·21	Gently undulating uplands and piedmonts	Dark grey-brown to grey-brown silty or sandy clay loam A_1 horizons over slightly paler A_2 horizon. Weakly developed subangular blocky structure and hard consistence when dry	Clear change at 12–20 cm to yellowish brown sandy clay or medium clay B horizon; weak to moderate blocky structure and hard consistence. Generally shallow soils grading to weathered parent material below 50–60 cm	A variable group of soils—A_2 horizons may be absent or developed to the extent of a sporadic bleach. Some mottling occurs in the B horizon clays. Deeper profiles may have neutral to mildly alkaline reaction. Often some lag gravels on the surface and through the A horizons
Manton	Dy2·33/5	Older alluvial plain	Thin dark grey or dark brown clay loam A_1 horizon overlying a sporadically bleached clay loam A_2 horizon. May be some fine yellowish brown mottling. When moist both are very friable and have weak fine blocky structure	Abrupt change to dark grey or dark olive-grey heavy clay with strong coarse blocky structure which continue to depths of 2–2·5 mm where they overlie coarse sandy sediments and buried soils. There are some fine ferruginous nodules throughout the profile and low amounts of carbonate nodules occur below about 30 cm depth	These soils occur in the depressions in areas of gilgai microrelief. A horizon depth range: 10–25 cm, being deepest towards the centre of the depression. A conspicuously bleached A_2 horizon is common in soils with a thicker surface
Nightjar	Dy2·33/5	Older alluvial plain	Thin yellowish brown or grey-brown fine sandy loam to loam A_2 horizon overlying a sporadically bleached loam or fine sandy loam A_2 horizon. Some profiles have a very thin conspicuous bleach at the base of the A_2 horizon	Very abrupt change to dark grey-brown or olive-grey, moderate coarse blocky structure heavy clay B horizon. There are some fine ferruginous nodules throughout and carbonate nodules are usually present below about 50 cm	A horizons are 18–25 cm thick and are seasonally saturated (some yellowish brown mottling and linings to fine pores and root channels are characteristic)

Purono	Dy 2·43/5	Older alluvial plain	Thin dark grey-brown silty loam or fine sandy loam A_1 horizon overlying a strongly bleached A_2 horizon. There are generally some soft ferruginous nodules towards the base of the A_2 and there may be some faint yellow-brown mottling. Total A horizon thickness range: 12–22 cm; most commonly 17–22 cm	Very abrupt change to olive-grey medium to coarse blocky structured, heavy clay. Brownish grey to light olive-grey coloured clays are also common. With increasing depth the clay becomes mottled, generally olive-grey dominant. Fine ferruginous nodules occur throughout and carbonate nodules are present below about 30 cm into the clay	A_2 horizons are occasionally only sporadically bleached. With depth the clays become lighter textured and more friable and overlie stratified sediments below about 2 m
Beefwood	Dy 2·43/5 Dy 2·33/5	Older alluvial plain	Thin light grey-brown sandy loam on fine sandy loam A_1 over a very strongly bleached fine sandy loam A_2 horizon. A sporadic bleach may occur through the A_1 horizon; total A horizon depth range: 15–20 cm	Abrupt change to dark grey-brown or light olive-brown heavy clay (sandy). Moderate to strong medium or coarse blocky structure and very hard consistence. Hard carbonate nodules from about 30 cm	Distinguishing feature is the distinct sand fraction in the heavy clay B horizon. Often grades very quickly to a sandy clay
Gulliver	Dy 2·43/5	Older alluvial plain	Thin light grey-brown fine sandy loam or silty loam A_1 overlying a bleached A_2 horizon. The bulk of the A_2 is usually only sporadically bleached with a thin conspicuous bleach immediately above the clay. Fairly distinct yellowish brown patches occur throughout the A horizons; total A horizon thickness range: 15–20 cm	Very abrupt change to dark grey or dark brownish grey heavy clay with moderate to strong coarse blocky structure. With depth there is a gradual colour change to olive-brown or yellowish brown and some mottling below 1·5–2 m. The clays overlie coarse sandy sediments at about 2·5 m	The chief differences between Gulliver and Purono series are the colour of the B horizon clay and a weaker development of the A_2 horizon

Table 4 (*Continued*)

Series	PPF	Physiographic unit	Surface soil	Subsoil	Additional comments
Lagoon	Dy2·43/6	Older alluvial plain	Thin light grey-brown fine sandy loam to loam A_1 horizon overlying a very strongly bleached A_2 horizon. Total A horizon thickness is normally 20–30 cm but may be as much as 40 cm	Very abrupt change to light brownish grey, weak to moderate blocky structured medium clay B horizons. May occasionally have fine yellowish brown mottles. In most soils the B horizon is underlain by a strongly cemented pan (Siliceous?) at depths ranging from 60–150 cm. Where the pan is absent they grade to coarse sandy sediments at about the same depth	The reaction of the lower B horizon is normally alkaline, but where the pan occurs at shallower depths it may remain mildly acid throughout
Woodlands	Dy2·43/6	Older alluvial plain adjacent to granitic fans	Thin light grey-brown loamy sand A_1 horizon overlying a strongly bleached loamy sand A_2. Massive throughout, and there may be some ferruginous nodules in the base of the A_2; total A horizon depth range: 24–45 cm	Very abrupt change to grey-brown or dark grey-brown sandy clay with very weakly developed coarse blocky structure. From 60–70 cm there is a gradual change to light grey or light grey-brown sandy clay with increasing amounts of fine quartz gravel and fine soft FeMn nodules. This grades to unconsolidated sands and gravels from about 1 m	Similar profiles with prominent fine yellowish brown mottling in the upper part of the B horizon have been included in this series. Reaction is mildly alkaline in the lower B horizon. The B horizon of Woodlands series often appears massive, and the weak blocky structure is only evident on exposure and drying
Pall Mal	Dy3·22/5	Granitic uplands	A very dark grey sandy loam A_1 horizon 10–12 cm thick overlying a weakly developed brown or pale brown sandy loam A_2 horizon; total A horizon thickness range: 15–25 cm	Abrupt change to mottled yellowish brown and yellowish red weak coarse blocky structured medium to heavy clay B_2 horizon. There is much fine quartz grit throughout the B_2 horizon. With depth the texture grades to a sandy clay and to coarse weathered granite at about 75 cm	A_2 horizon may occasionally be sporadically bleached. In some profiles the yellowish red mottle may be the dominant B horizon colour. The reaction trend is mildly acid to neutral throughout

Hervey	Dy 3·41/5	Piedmont slopes	Thin light grey-brown sandy loam A_1 horizon overlying a strongly bleached sandy loam or fine sandy loam A_2 horizon. Variable amounts of coarse gravel on the surface and throughout the A horizon. Total A horizon thickness is variable; 20–25 cm is most common but may be as great as 50 cm	Very abrupt change to mottled light brownish grey, yellowish brown and yellow, medium or heavy clay B horizons. Structure is strongly developed medium to coarse blocky. With increasing depth there is a gradual decrease in texture to sandy or gritty clay and increasing amounts of coarse angular gravels or granitic grits. The thickness of these coarse deposits varies with an observed maximum of 12 m	Reaction trend is mildly acid throughout
Five Head	Dy 3·41/6	Older alluvial plain	Thin grey-brown massive fine sandy loam A_1 horizon overlying a strongly bleached fine sandy loam A_2 horizon. May be some fine gravels or ferruginous nodules near base of A_2. Total A_2 horizon thickness range: 30–55 cm	Clear change to mottled pale brown and brown or yellowish brown medium clay. Weak to moderately developed fine blocky structure,. The soil mass is very porous and may often have an earthy appearance. At about 70 cm there is a gradual change to mottled light grey and brownish yellow strong fine blocky medium clay. At depths of 1–1·5 m this grades to coarse angular gravels	In soils with the deeper surface there is commonly a well-developed A_3 horizon. This is mottled yellow or brownish yellow and very light grey, slightly heavier in texture than the A_2 horizon and has more fine ferruginous nodules. Reaction is mildly acid throughout
Althaus	Dy 3·41/6	Older alluvial plain	Thin light grey-brown loamy sand to sandy loam A_1 horizon overlying a thick, very strongly bleached loamy sand A_2 horizon. There may be some soft ferruginous nodules in the lower A_2 horizon. In some areas the surface textures are much finer, ranging from fine sandy loam to silty loam. Total A horizon thickness range: 25–60 cm but is commonly 35–40 cm	Abrupt change to mottled light brownish grey and yellowish brown heavy clay with strongly developed very coarse blocky structure. Consistence when dry is very hard. Below 1 m the mottling becomes very coarse, and there is a gradual decrease in texture. Coarse sandy or gravelly sediments occur below 2 m. Light to moderate amounts of soft ferruginous nodules and diffuse segregations occur throughout the B horizons	In the soils with thicker surface and in particular with heavier-textured soils, there is a well-developed A_3 or B_1 horizon of mottled pale brown and yellowish brown silty clay loam to silty clay. Reaction trend is mildly to strongly acid throughout

Table 4 (*Continued*)

Series	PPF	Physiographic unit	Surface soil	Subsoil	Additional comments
Ettrick	Dy 3·42 Dy 3·32 Dy 3·22	Piedmont slopes and undulating uplands	Very dark grey brown sandy loam to loam A_1 horizon over sandy loam to loam A_2 horizon. Massive and friable throughout. A_2 horizon development is extremely variable and changes over very short distances. Most soils have a thin conspicuous bleach, but soils with sporadic bleach or a weakly developed slightly paler A_2 are common	Clear change at 25–45 cm to mottled yellowish brown, light grey, pale brown, and yellowish red medium to heavy clay B horizons. Weakly developed coarse blocky structure and hard consistence. B_2 horizons are thin, grading into sandy clay to sandy clay loam similarly mottled BC horizons below 60 cm	Reaction is mildly acid in the A horizon and neutral in the B_2 horizon. There is occasionally some lag gravel on the surface and throughout the A horizons
Bently	Dy 3·43/3	Older alluvial plain	Very dark grey-brown massive or weak subangular blocky, fine sandy loam A_1 horizon to 15 cm thick over a bleached fine sandy loam A_2 horizon	Clear change at 25–35 cm to finely mottled brownish grey and yellowish brown medium to heavy clay B_2 horizon. Gradual change at about 60 cm to light olive-brown medium clay containing much fine feldspar. Well-developed medium blocky structure throughout. Some fine ferruginous nodules from 40 cm and carbonate nodules below 60 cm	The distinguishing feature of this soil is the well-developed dark A_1 horizon. Soils with deeper A horizons often have well-developed yellowish clay loam A_3-B_1 horizon

Scrubby	Dy 3·43/2	Older alluvial plain (areas subject to some recent deposition)	Fairly thick very dark grey brown sandy loam A_1 overlying a bleached A_2 horizon. This is most often conspicuously bleached, but may occasionally be only sporadically bleached. Some ferruginous nodules occur throughout the A horizons. Total A horizon thickness is generally about 18–25 cm, but may be as thick as 35 cm	Abrupt change to mottled greyish brown or dark grey and yellowish brown sandy clay B horizons with moderate coarse blocky structure. The deeper subsoils are variable and often stratified; generally they are lighter in colour and contain increasing amounts of fine-weathered granitic materials and fine quartz gravels. Some fine ferruginous nodules occur throughout the clay, and there are occasionally some carbonate nodules in the lower B horizon	Mottled light yellowish brown A_3 horizons are common in soils with the thicker surface. The chief distinguishing character of these soils is the dark well-developed A_1 horizon. B horizons are sandy, usually porous and free draining
Sandalwood	Dy 3·43/4	Older alluvial plain	Very thin light brownish grey fine sandy loam A_1 horizon overlying a bleached fine sandy loam or sandy loam A_2 horizon. Usually some yellow-brown patches throughout the A horizon. A horizons range from 5–10 cm thick	Very abrupt change to faintly mottled dark greyish brown and yellowish brown heavy clay. In the upper part of the B horizon there is often a columnar or prismatic structure breaking to coarse blocky units. With depth there is a gradual change to brown or grey-brown to light grey, either mottled or whole coloured, heavy clay with strong fine angular blocky structure. Large hard carbonate nodules (up to 8 cm) occur below about 10 cm into the clay	The A_2 is occasionally sporadically bleached. The B horizon clays are often whole coloured, and overlie stratified sediments and buried soils below 1–2 m depth

Table 4 (*Continued*)

Series	PPF	Physiographic unit	Surface soil	Subsoil	Additional comments
Kulburn	Dy 3·43/5	Older alluvial plain	Very thin dark grey-brown A_1 horizon overlying a very strongly bleached A_2 horizon. Surface texture ranges from sandy loam to silty loam. A horizons are generally massive but may be platy in the upper part. There may be some fine ferruginous nodules in the lower A_2 horizon; total A horizon thickness range: 15–25 cm, usually 18–20 cm.	Very abrupt change to mottled dark grey-brown, dark brown, and dark yellowish brown heavy clay, usually with strongly developed coarse blocky structure but sometimes with a weak columnar or prismatic development. With depth the mottling may become coarser and more prominent but occasionally they grade to whole coloured olive-grey heavy clay. At various depths below 1–1·5 m coarse sandy sediments and buried soils occur. There are some fine ferruginous nodules throughout the B horizon and carbonate nodules are usually present below 40–50 cm	A_1 horizons are very weakly developed and may be less than 1 cm thick
Lansdown	Dy 3·43/5	Older alluvial plain	As for Kulburn series	Very abrupt change to faintly mottled brownish yellow or yellowish brown and light brownish grey heavy clays. B horizon clay often has a prominent sand fraction. Other features as for Kulburn series	These soils are very similar to Kulburn series apart from the prominent yellowish colour of the B horizon clays

Healy	Dy 3·43/5	Piedmont slopes	Thin light grey-brown sandy loam A_1 horizon overlying a bleached A_2 horizon. Variable amounts of angular gravels on the surface and through the A horizons; thickness of the A horizons range: 20–40 cm	Very abrupt change to mottled brownish grey, yellowish brown or yellow heavy clay B horizons with strong medium to coarse blocky structure. Texture decreases with depth grading to sandy or gritty clay below about 1 m and most profiles grade to coarse angular colluvial gravels below about 2 m	Similar in most respects to the Hervey series except that the lower B horizon has an alkaline reaction trend
Pattel	Dy 3·43/6	Older alluvial plain	Thin light grey-brown or brownish grey fine sandy loam to silty loam A_1 horizon overlying a very strongly bleached silty loam A_2 horizon. Although generally massive the A_1 may have a weak platy structure; total A horizon thickness range: 28–35 cm	Abrupt change to mottled light brownish grey and yellowish brown medium to heavy clay B horizon. There may be a very coarse columnar structure in the upper B but they are normally moderate to strong coarse blocky throughout. In some areas this soil overlies buried dark clays below 60–90 cm, while in other areas the mottled clay grades to light brownish grey or light olive-grey heavy clay. In all cases they are underlain by stratified sediments. Carbonate nodules are present below 50 cm	These soils are very similar to the Kulburn series but have thicker surface horizons

Table 4 (*Continued*)

Series	PPF	Physiographic unit	Surface soil	Subsoil	Additional comments
Stockyard	Dy 3·43/6	Older alluvial plain	Thin light grey-brown sandy loam to loamy sand A_1 horizon over a very strongly bleached loamy sand A_2 horizon. Massive throughout; friable when moist but hard when dry. Total A horizon thickness range: 40–60 cm	Abrupt change to mottled light grey or light brownish grey and yellowish brown sandy or gritty medium to heavy clay. May be some weakly developed columnar structure but more commonly it is prismatic breaking to coarse blocky units. Texture decreases with depth to coarse sandy clays, and from about 1 m there is a gradual change to coarse alluvial gravels or fine stratified sediments. Some fine ferruginous nodules throughout and carbonate nodules from 75 cm	Reaction is mildly acid in the A horizons and alkaline in the B horizon. In some profiles there is a well-developed pale yellow light sandy clay loam A_3 horizon
Frederick	Dy 3·81/6	Older alluvial plain	Thin (< 5 cm) light grey-brown loamy sand A_1 overlying a very strongly bleached loamy sand A_2 horizon. There may be some soft ferruginous nodules throughout the A_2 horizon	At 40–60 cm there is a sharp change to mottled light, yellowish grey strongly cemented pan (siliceous?). The pan is 20–40 cm thick and is underlain by mottled light yellowish grey, yellow-brown, and yellow sandy clay. This is generally massive but may occasionally have a very weak coarse blocky structure	Reaction of the lower B horizon is mildly acid

Toonpan	Dd 1·33	Younger alluvium	Very dark grey-brown loam A_1 horizon with weak fine blocky structure overlying a brownish grey loam A_2 horizon with sporadic bleach; total A horizon thickness range: 12–30 cm	Abrupt change to very dark grey or black strong medium blocky structured heavy clay B horizons. There is usually no carbonate present but the lower B horizon has moderately strong alkaline reaction. With depth they grade to stratified sandy sediments	Similar soils with conspicuously bleached A_2 horizons are closely associated
Doughboy	Dd 2·13 Dd 1·13	Marine plain swamps	Thin (4–5 cm) very dark grey to black sandy loam to sandy clay loam A_1 horizon; massive, prominent rusty staining to root lines and fine pores	Clear to abrupt change to very dark grey or black medium or heavy clay B horizons. Prominent rusty staining to root lines. Gradual change at 20–30 cm to strongly mottled light grey and brownish yellow sandy clay decreasing through sandy loam to sand. Permanent water table from 60 to 80 cm	Mottling of the upper part of the B horizon is a gley feature, the intensity and extent of mottle varies with the degree of gleying. Surface textures in some areas are very organic
Coonambelah	Dd 2·43	Older alluvial plain	Very thin light grey-brown loam A_1 overlying a strongly bleached fine sandy loam or loam A_2 horizon. Occasionally the A_2 horizon may be only sporadically bleached, and there is often much fine yellowish brown mottling throughout the A horizons	Abrupt change at about 10 cm to faintly mottled black or very dark greyish brown and olive heavy clay. Strong coarse blocky structure. At about 25 cm there is a fairly sharp change to very prominently mottled olive-grey, bright yellow, and dark red sandy clay grading to sandy clay loam. There is usually no carbonate present, but the lower part of the clay is strongly alkaline	Many areas of these soils are seasonally inundated and are moderately to strongly gleyed throughout. Areas adjacent to salt pan are occasionally inundated by high tides. A water table is normally present at about 50 cm

Table 5. Classification of the soil series

Series	Factual key dominant PPF[A]	Great Soil Group[B]	Soil Taxonomy[C]
Central[D]	Uc 1·21	Alluvial soil	[E]
Magenta	Uc 1·21	Alluvial soil	[E]
Toolakea[D]	Uc 1·21	Siliceous sand	[E]
Argea[D]	Uc 2·21	Siliceous sand	[E]
Granite[D]	Uc 2·21	Siliceous sand	Haplustalf
Oolgar[D]	Uc 2·23	Siliceous sand	[E]
Antill	Uc 2·34	Siliceous sand	[E]
Jalloonda[D]	Uc 4·21	Siliceous sand	[E]
Elliot	Uc 4·22	Earthy sand	[E]
Pallarenda[D]	Uc 4·22	Earthy sand	[E]
Cungulla	Uc 5·11	Podzol	[E]
Windsor[D]	Um 4·22	No provision	[E]
Sachs	Ug 5·16/·15	Black earth	Typic Pellustert
Vantasell	Ug 5·25	Grey clay	Typic Chromustert
Alick[D]	Ug 5·28	Grey clay	Typic Chromustert
Brolga[D]	Ug 5·28	Grey clay	Entic Pellustert
Gilligan	Ug 5·29	Grey clay	Typic Chromustert
Bluewater[D]	Gn 2·14	Red earth	Ustalf[F]
Hillview[D]	Gn 2·14	Red earth	Ustalf
Clemant[D]	Gn 2·24	Yellow earth	Oxic Haplustalf
Pepperpot[D]	Gn 2·24	Yellow earth	Haplustalf[F]
Ross[D]	Gn 2·24	Yellow earth	Haplustalf[F]
Yileena[D]	Gn 2·24	Yellow earth	Haplustalf[F]
Black[D]	Gn 2·45	No provision	Mollisol
Wallaroo[D]	Gn 2·64	Yellow earth	Haplustalf[F]
Woodridge[D]	Gn 2·64	Yellow earth	Ustalf[F]
Carinya[D]	Gn 2·74	Yellow podzolic soil	Haplustalf[F]
Stag[D]	Gn 2·74	Yellow podzolic soil	Oxic Haplustalf
Flagstone[D]	Gn 2·94	Yellow podzolic soil	Haplustalf[F]
Pinnacle[D]	Gn 2·94	Yellow podzolic soil	Haplustalf[F]
Alice[D]	Gn 3·14	Red podzolic soil	Oxic Haplustalf
Double Barrel	Gn 3·15	Red podzolic soil	Ultic Haplustalf
Stuart	Dr 2·22	Non-calcic brown soil	Udic Paleustalf
Julago	Db 1·13	No provision	Oxic Haplustalf
Barringha	Db 1·41	No provision	Paleustalf[F]
Stanley	Dy 2·21	Yellow podzolic soil	Natrustalf[F]
Manton[D]	Dy 2·33/5	Solodic	Ustalf
Nightjar[D]	Dy 2·33/5	Solodic	Natrustalf[F]
Purono[D]	Dy 2·43/5	Solodic	Typic Natrustalf
Beefwood	Dy 2·43/5	Solodic	Typic Natrustalf[F]
Gulliver[D]	Dy 2·43/5	Solodic	Typic Natrustalf
Lagoon[D]	Dy 2·43/6	Solodic	Durustalf[F]
Woodlands	Dy 2·43/6	Solodic	Typic Natrustalf[F]
Pall Mal[D]	Dy 3·22	Yellow podzolic soil	Oxic Paleustalf
Hervey[D]	Dy 3·41/5	Soloth	Natrustalf[F]
Five Head	Dy 3·41/6	Soloth	Natrustalf[F]
Althaus[D]	Dy 3·41/6	Soloth	Aquic Natrustalf
Ettrick	Dy 3·42	Yellow podzolic–solodic intergrade	Ustalf[F]
Bently	Dy 3·43/3	Solodic	Haplustalf
Scrubby[D]	Dy 3·43/2	Solodic	Ustalf
Sandalwood[D]	Dy 3·43/4	Solodized solonetz	Typic Natrustalf

Table 5 (*Continued*)

Series	Factual key dominant PPF[A]	Great Soil Group[B]	Soil Taxonomy[C]
Kulburn[D]	Dy 3·43/5	Solodized solonetz-solodic	Typic Natrustalf
Lansdown	Dy 3·43/5	Solodized solonetz	Typic Natrustalf
Healy[D]	Dy 3·43/6	Solodic	Natrustalf[F]
Pattel[D]	Dy 3·43/6	Solodic	Typic Natrustalf
Stockyard	Dy 3·43/6	Solodic	Typic Natrustalf
Frederick[D]	Dy 3·81	Soloth	Durustalf[F]
Toonpan	Dd 1·33	Solodic	Paleustalf[F]
Doughboy	Dd 2·13	No provision	Haplustalf[F]
Coonambelah[D]	Dd 2·43	Solodic-solonchak intergrade	Aquic Natrustalf

[A] Northcote (1971).
[B] Stace *et al.* (1968).
[C] Soil Survey Staff (1975).
[D] These series also occur on the northern section of the Townsville Coastal Plain.
[E] No profile data available.
[F] No profile data available, classification at order, suborder or great group level is based on similar soils in this area.

Beach Ridges and Littoral

Jalloonda association (Ja; Jalloonda series Uc 4·21)

The broken line of beach ridges fronting Cleveland Bay, those occurring in the small bays around Cape Cleveland, and the frontal ridges on the northern part of the large sandmass to the south of Cape Cleveland have been mapped in this association. Calcareous (shelly) sands of Toolakea series (Uc 1·21) are common on the frontal ridges and in fact may possibly be dominant in all areas except to the south of Cape Cleveland. Limited access makes confirmation difficult. Profile development becomes progressively stronger with increasing age of beach ridge, and there is a gradual change from the light brown sands of Toolakea series through sands with yellow or yellowish brown B horizons (Jalloonda series Uc 4·21) and to the older sands on the innermost ridges with reddish brown or red B horizons (Pallarenda series Uc 4·22). Small areas of mangroves and saltpans and areas of dark duplex soils of Coonambelah series (Dd 2·43) occur in the swales.

Cungulla association (Cg; Cungulla series Uc 5·11)

This unit occupies the bulk of the large sandmass to the south of Cape Cleveland. These beach ridges have built up over a considerable period, and it is obvious from their orientation that the mode of deposition has changed with time. Source material has also possibly varied considerably. As a consequence of these factors and the existing range of environments from freely draining ridge crests to poorly drained and often ponded swales there is considerable variation in degree and kind of profile development.

Coarse sandy soils with uniform-texture profiles occur over most of the unit. In the northern parts, soils with yellow or yellowish brown B horizons (Jalloonda series Uc 4·21) and red or reddish brown B horizons (Pallarenda series Uc 4·22) are dominant. Towards the central and southern parts of the unit, weakly developed *podzols* (Cungulla series Uc 5·11) are dominant. On the frontal ridges, organic enrichment of the B horizon of these soils is minimal; moving inland the B horizon development becomes progressively stronger, with some small cemented patches but never reaching the organic pan cementation typical of many *podzols*. Minor associates include a range of unnamed and undescribed strongly bleached uniform sands (Uc 2·2) and sandy duplex soils (Dy 2·6) which occur on the lower slopes of some beach ridges and in the larger swales. Some areas of undescribed brown duplex soils (Db 1·21) occur on very low discontinuous ridges on the inland extremity of this complex.

Mangroves (Mg) and *Saltpans* (Sp)

The mangrove unit is characterized by a low closed forest consisting chiefly of *Avicennia*, *Ceriops* and *Rhizophora* spp. The mangroves occur as an almost continuous narrow fringe along all of the tidal creeks and inlets, and on the mud flats bordering Cleveland Bay. All of these areas are subject to frequent tidal inundation—estimated by Macnae (1966) at approximately 117 tides each year. Soils are chiefly undescribed saline muds and mangrove peats, but the areas on the eastern side of the sand ridges to the south of Cape Cleveland are largely sands, occasionally with a thin (2–4 cm) veneer of mud on the surface.

Large areas of salt pan occur between Cape Cleveland and Muntalunga Range with smaller areas adjacent to most of the tidal inlets and creeks. Soils are undescribed and range from saline clays to saline duplex soils with 2–10 cm of windblown sand overlying mottled heavy clay. Small areas of dark duplex soils of Coonambelah seies (Dd 2·43) occur as islands within the salt pan separated from the latter by a low salting cliff 15–30 cm high. Frequency of inundation varies, but most of the salt pans are covered by tides in excess of 3·0 m M.L.W.S. Many areas are also inundated for considerable periods after heavy rains.

Brolga association (Br; Brolga series Ug 5·28)

This is a relatively minor unit of strongly gleyed, dark grey cracking clays which occur in minor depressions on the margins of the salt pans and are flooded for long periods after heavy rains. They may occasionally be inundated by tidal waters. The largest area mapped occurs in the marshes to the east of Clevedon.

Younger Alluvial Terraces and Levees

Black association (Bl; Black series Gn 2·45)

This association occupies the low terraces and younger alluvial plains of the modern stream channels. The largest areas occur on the south bank of Ross River and along Alligator Creek, but there are numerous smaller occurrences along most major and minor streams.

The largely undifferentiated sands of Central series (Uc 1·21) occupy the lower terraces of most streams. These have not been mapped separately, as it is only along Ross River that they occupy any appreciable area. Many occurrences are less than 10 m wide. All areas are frequently flooded and subject to deposition and scouring. Dark uniform loams of Windsor series (Um 4·22, Um 5·52) occur on the low terraces of Alligator Creek and on the high terraces of some minor streams. The dark, gradational-textured soils of Black series (Gn 2·45) occupy the high terraces and broader floodplains. Also included in the unit are some areas of *red earths* of Bluewater series (Gn 2·14) on some of the narrow stream levees.

Toonpan association (To; Toonpan series Dd 1·33)

This unit occupies the floodplain of Lansdowne Creek and the limited floodplain of the lower reaches of Ross River. The latter is typical of river floodplains, having lighter-textured soils (Black association) on the levees, the dark duplex soils (Toonpan series Dd 1·33) on the floodplain proper and dark cracking clays (Ug 5·16 similar to Sachs series) in the lower back swamp areas.

The Lansdowne Creek floodplain, however, is very complex. In the upper reaches there is a well-defined channel with two distinct terrace levels. Here gradational-textured soils (Double Barrel series Gn 3·15, 3·25) and uniform sands (Magenta series Uc 1·21) occupy the upper and lower terraces respectively. Towards its middle reaches the stream breaks up into a series of ill-defined braided channels and a complex of small alluvial fans and sand splays. A distinct channel again reforms not far from its confluence with Antill Creek. In these areas the dark duplex soils (Toonpan series Dd 1·33) occur on the floodplain with a range of undescribed coarse sands and buried soils in the fan areas. Again some dark cracking clays (Sachs series Ug 5·16) occur in the lower areas and dark gradational soils similar to Black series (Gn 2·45) on low rises which are probably relic stream levees.

Barringha association (Ba; Barringha series Db 1·41)

This is a minor unit confined to a broad high terrace of Lansdowne Creek. This may be at a higher level, and therefore is possibly an older surface than that on which the Double Barrel series occur. However, the field relationship has not been confirmed.

The brown duplex soils of Barringha series (Db 1·41) occur in close association with the Alice series red (Gn 3·14) and brown variant (Gn 3·24) gradational-textured soils. Some alkaline duplex soils occupy minor depressions, while lighter, gradational-textured soils (Black series Gn 2·45) occur on leaves along the Lansdowne Creek margin on the unit.

Bently association (By; Bently series Dy 3·43/3)

This unit is restricted to an area of high alluvium along the north bank of Alligator Creek. The weaker development of soil profile features has led to the interpretation that this area is somewhat younger than most of the high alluvium, even though it appears to be above present flood levels. The Bently series differs from most other yellow and grey duplex soils of the coastal plain in that it has a deep dark loamy A_1 horizon and a relatively thin bleached A_2 horizon.

Minor areas of Purono series (Dy 2·43/5) occur in shallow depressions, while red earths of Bluewater series (Gn 2·14) or structured soils of Alice series (Gn 3·14) are found along the levee on the high bank of Alligator Creek.

Ross association (Ro; Ross series Gn 2·24)

This unit is restricted to part of the present levee of Ross River, chiefly upstream of the Five Head Creek junction. These soils generally are much more strongly developed, and therefore are probably older, than those of Bluewater series found on most of the levees along Ross River. It is assumed that Ross series soils have received little deposition since the Ross River resumed its present course following its migration northwards across to the Bohle River.

Depth of the yellow earth profile of the Ross series to underlying pedal clays ranges from 40 cm to 1 m, while the thickness of the pedal clay varies from 30 cm to about 2 m. The clays are underlain by stratified predominantly sandy sediments. The levees merge with the deposits of the older alluvial plain, and some soils of Purono association and the Gilgai Complex may be included in these areas. Undifferentiated sands of Central series (Uc 1·21) occur on the small areas of lower terrace, while massive *red earths* (Bluewater series Gn 2·14) occur on the narrow high terraces that have been included.

Older Alluvial Plains

Coonambelah association (Co; Coonambelah series Dd 2·43)

This unit occurs marginal to most areas of salt pan and occupies extensive areas immediately to the south of the mouth of Ross River and to the east of Clevedon. It is characterized by open grasslands of salt water couch (*Sporobolus virginicus*) and parts at least may occasionally be inundated by tidal waters.

Although the alkaline dark duplex soils of Coonambelah series (Dd 2·43) are dominant, similar soils with whole coloured or mottled dark grey heavy clay B horizons (Dy 2·33,2·43, Dy 3·33,3·43) are commonly associated. Acid and neutral variants of these soils also occur. Small areas of salt pan, gleyed cracking clays of Brolga series (Ug 5·28), and dark duplex soils of Doughboy series (Dd 2·13) are also included.

Many of the minor streams traversing this unit have discontinuous channels. The channels often terminate in small fans spreading over the Coonambelah series soils and may reappear as a well-defined channel in the tidal zone. Dark duplex soils similar to Toonpan series (Dd 1) are common in the area of fan influence. Yellow duplex soils of Nightjar series (Dy 2·33/5) occupy the occasional small areas of slightly higher elevation which carry stunted *Melaleuca* vegetation.

Doughboy association (Dy; Doughboy series Dd 2·13)

This is a minor unit which is confined to the margins of the marshy areas around The Cone and Mount Burrumbush. It occurs at a level slightly higher than that of the Brolga association, and although it is frequently flooded by fresh water, there is no evidence of salt-water flooding.

Associated with the dark duplex soils of Doughboy series (Dd 2·13) and similar (Dd 1·13) soils are small areas of gleyed cracking clays (Brolga series Ug 5·28). Some low sand ridges with the sandy soils of Cungulla association are also included.

Sachs association (Sh; Sachs series Ug 5·16)

Only two small areas of this unit have been delineated, but the dark cracking clays of Sachs series (Ug 5·16) occur commonly as a major component of the Gilgai Complex. They are formed largely on local alluvium derived from the intermediate and basic phases of the Permocarboniferous volcanics, and also occur as small areas of back swamp deposits on the modern alluvial plains. Prominent linear gilgai microrelief is common in the area to the west of the Sisters Mountains where these soils extend onto the lower piedmont slopes.

Gilgai Complex (GC)

This unit occurs sporadically over most of the plain country occupying open grassland or lightly timbered clay plains. These soils were once much more widespread, but in many areas have been buried by subsequent floodplain and fan deposits. Buried dark grey and black clays are exposed in many of the gullies, particularly in the Ross River catchment area. The area to the north of Alligator Creek may be floodplain back swamp deposits.

Weakly to moderately developed, round gilgai microrelief occurs over almost the entire unit. In most areas there is a complex of soils with cracking clays on the mounds and duplex soils in the depressions. In some areas, however, the clays occupy both mound and depression sites over the central part of the area with the duplex soils being restricted to the depression sites only around the margin of the unit. The grey clays of Alick (Ug 5·28), Vantasell (Ug 5·25), and Gilligan (Ug 5·29) series may occur individually or in close association and jointly occupy the largest areas. The black clays of Sachs series (Ug 5·16) are dominant only in the areas to the north of Alligator Creek and in the headwaters of Antill Creek. The duplex soils of Manton series (Dy 2·33/5) are the most common soils of the depressions, with some darker duplex soils (Dd 1·33) similar in many respects to Toonpan series associated with the black clays.

Althaus association (Al; Althaus series Dy 3·41/6)

This unit is found only in the south-eastern part of the area and occurs on a very narrow fringe of coastal plain between Saddle Mountain and the swamplands to the east.

Although the acid duplex soils of Althaus series (Dy 3·41/6) are dominant, neutral and alkaline variants of these soils are common and may occur in very close association. The depositional environment, parent material, and rainfall regime are similar here to that on the northern part of the coastal plain where the soils were originally recognized. The unit is characterized by a surface microrelief of low (10–20 cm) elongate mounds and occasional areas of prominent 'debil-debil'—a term used locally to identify a form of microrelief common to areas subject to seasonal ponding of water. This form of the microrelief varies considerably, but it is most commonly expressed as mounds with vertical sides 15–40 cm high and 20–40 cm in diameter. The formation of similar microrelief elsewhere has been variously attributed to biological and/or erosional factors (Haantjens 1965; Lee 1967). Leached sandy earths of Carinya series (Gn 2·74) occur on sandy levee and channel infill deposits, and some *red earths* of Hillview series (Gn 2·14) may be included where this unit abuts the piedmont slopes.

Five Head association (Fh; Five Head series Dy 3·41/6)

This is a minor unit occurring in only two small areas, one to the north of Five Head Creek near the junction with Ross River, and the other to the west of Lansdowne Creek near Toonpan. The Five Head series soils have an acid reaction trend, and appear to be much more strongly leached than other duplex soils in this area.

Associated soils include duplex soils of Purono (Dy 2·43/5) and Kulburn (Dy 3·43/5) series and a range of gradational-textured soils similar in many respects to Woodridge (Gn 2·64) and Stag (Gn 2·74) series.

Frederick association (Fr; Frederick series Dy 3·81)

Only one area of this unit has been mapped, and it occurs to the north-east of Muntalunga Range. It is situated downslope of the coarse sandy soils of the piedmont slopes, and the formation of these soils is probably influenced by the numerous seepages that emerge from these slopes. The Frederick series are deep, sandy-surfaced duplex soils with a cemented pan at the base of the A_2 horizon. The pans are often very hard and impenetrable by hand augering during the dry season, when the soil may be classified as Uc 2·3. When the soils are moist the pans, although much softer, are clearly evident, and the presence of mottled yellowish sandy clay subsoils clearly places the soil as an extreme example of Dy 3·81.

Sandalwood association (Sa; Sandalwood series Dy 3·43/4)

Solodized-solonetz soils of the Sandalwood series generally occur as discrete areas, many of which are too small to delineate at the map scale. They are confined to the older alluvial deposits and are particularly common, with some fairly large occurrences, in the Toonpan and Woodstock areas. They were originally characterized by a low open woodland of sandalwood (*Eremophila mitchellii*), but in most places this has now been completely cut out; however, the areas may still be recognized by a short annual grass cover dominated by *Chloris* sp.

In general this association is relatively pure, but small amounts of the duplex soils of adjacent units may be included. Sandalwood series soils commonly occur as minor components of most associations on the older alluvium.

Purono association (Pu; Purono series Dy 2·43/5)

This association occurs extensively on the older alluvium in the headwaters of Ross River. Here it appears to have occupied the greater part of the floodplain deposits but has no apparent relationship to present or prior streams as is the case on the northern part of the coastal plain. Some areas have been re-exposed by dissection of the sandy fans of the Granite and Pepperpot associations.

Although *solodic soils* of the Purono series are dominant, a range of closely related duplex soils, principally Kulburn (Dy 3·43/5), Lansdown (Dy 3·43/5) and Woodlands (Dy 2·43/6) series, are closely associated. Numerous small areas of Sandalwood (Dy 3·43/4) and Beefwood (Dy 2·43/5) series occur throughout. There are also some small areas of weak gilgai microrelief with the grey clays of Alick series (Ug 5·28) occupying the mound sites.

Beefwood association (Be; Beefwood series Dy 2·43/5)

This unit is particularly common east of the Flinders Highway in the Antill Plains–Toonpan area. Together with Stockyard association it occupies most of the older higher floodplains in this area, but it also occurs on the very gentle (<1–$1·5°$) slopes running up to the short piedmont slopes at the foot of Mount Elliot. These could be floodplain deposits, but they may also be associated with a series of older and more gently sloping piedmont deposits which in part are overlain by the coarser modern deposits.

Solodic soils of the Beefwood series (Dy 2·43/5) are dominant. A range of other duplex soils are closely associated, the most common being the shallow surfaced Sandalwood series (Dy 3·43/4) and the much deeper surfaced Stockyard series (Dy 3·43/6). A minor component of this unit is a range of coarse sandy soils formed on infilled channels (described in Landers Complex).

Gulliver–Purono Complex (GP;)

This is a minor unit occupying two small areas near Cluden and Stuart. The soils have developed on older alluvial deposits of Ross River and Stuart Creek, and occur at a level only slightly above that of the Coonambelah association on the marine plains.

Gulliver (Dy 2·43/5) and Purono (Dy 2·43/5) series soils are similar in many respects and occur closely intermingled. Small areas of dark grey cracking clays of Vantasell (Ug 5·25) and Alick (Ug 5·28) series occupy slightly lower areas, and some small areas of salt pan and dark duplex soils may be included where this unit adjoins the Coonambelah association.

Woodlands association (Wo; Woodlands series Dy 2·43/6)

This unit occurs adjacent to minor streams draining the alluvial fans of granitic detritus between Ross River and Lansdowne Creek. The soils are developed on deposits that have been exposed following erosion of the fans. They may have a thin veneer of the coarse sandy fan sediment resulting in coarser and lighter surface textures than is normal for the floodplain deposits. Some lag gravels are also found in the A horizons.

Although the coarse sandy duplex soils of Woodlands series (Dy 2·43/6) are dominant, other duplex soils, principally Purono (Dy 2·43/5) and to a lesser extent Kulburn (Dy 3·43/5) and Lansdown (Dy 3·43/5) series, are common throughout. Small areas of Sandalwood series (Dy 3·43/4) also occur. Duplex soils with a prominent siliceous pan similar to those of Lagoon series (Dy 2·43/6) are found adjacent to some of the streams. Coarse uniform sands and gradational soils of Granite and Pepperpot associations occur on the small fan remnants that are included.

Kulburn association (Ku; Kulburn series Dy 3·43/5)

Unlike the northern section of the coastal plain where this unit is widespread, in the south it is restricted to small areas on the older alluvium of Sachs and Stuart Creeks.

Kulburn series (Dy 3·43/5) duplex soils with sandy loam on fine sandy loam surface textures, are dominant, although small areas of Sandalwood series (Dy 3·43/4) occur throughout. Bluewater (Gn 2·14) and Yileena (Gn 2·24) soils occupy the levees of small streams traversing the unit.

Pattel association (Pa; Pattel series Dy 3·43/6)

This unit is widely distributed on the northern part of the coastal plain, but in the south is restricted to a small area on the floodplain of Killymoon Creek. The deep-surfaced, mottled duplex soils of Pattel series are strongly dominant, and they are a common minor associate of most of the other floodplain units. Small areas of Sandalwood series (Dy 3·43/4) and Beefwood series (Dy 2·43/5) are included in the unit.

Stockyard association (Sd; Stockyard series Dy 3·43/6)

This unit occurs in very close association with the Beefwood association and has developed on both level floodplains and on very gentle slopes. In the latter situation it usually occupies a position upslope of the Beefwood association.

Stockyard series (Dy 3·43/6) soils are dominant; minor associated soils include the duplex soils with a deep dark surface (Scrubby series Dy 3·43/2) and small areas of uniform sands (Elliot series Uc 4·22) where this unit shares a common boundary with the Hillview association.

Landers Complex (Ld)

This is a complex unit with many similarities to the Alice–Carinya association. It occupies both the older high alluvial plain and infilled channel systems in the Ross River catchment. The chief difference between it and the Alice–Carinya association is that the soils of the alluvial plain are dominant and the infilled channels occupy about 25–35% of the unit. The latter are generally very clearly defined and easily identifiable, but the distribuiton pattern is far too intricate to allow separate delineation at the map scale.

Woodlands (Dy 2·43/6), Stockyard (Dy 3·43/6), Beefwood (Dy 2·43/5) and possibly Purono (Dy 2·43/5) series respectively are the dominant soils in individual occurrences of the unit. Small areas of the shallow surfaced duplex soils of Sandalwood series (Dy 3·43/4) occur in all areas.

Mottled *yellow earths* of Carinya series (Gn 2·74) are the most common soils on the infilled channels, but leached sands of Argea series (Uc 2·21) and *red* and *yellow earths* of Bluewater (Gn 2·14) and Yileena (Gn 2·24) series also occur. Small areas of acid duplex soils with a cemented siliceous pan similar to those of Frederick series (Dy 3·81/6) are found in this unit in the headwaters of Ross River.

Woodridge association (Wo; Woodridge series Gn 2·64)

Although the mapped occurrences of this unit are limited, the dominant soils, the *yellow earths* of Woodridge series, are widely distributed over the older alluvial plain. They are very closely associated with a range of duplex soils, and although the soils are morphologically distinct it appears that they have developed from the same suite of alluvial deposits. Small 'islands' of these soils as little as 2 m in diameter are common throughout many of the duplex soil units.

Soils of the Woodridge series are often underlain by a strongly pedal, highly sodic clay D horizon at 50 cm to 1 m depth, and in these areas a prominent sink hole microrelief is characteristic. The sink holes are 10–70 cm in diameter and up to 50 cm deep. Areas of weakly developed gilgai with the strongly structured D horizon clays exposed on the mounds occur throughout the unit. The most commonly associated soils are duplex soils of Kulburn (Dy 3·43/5), Purono (Dy 2·43/5), and Manton (Dy 2·33/5) series.

Alluvial Fans and Channel Infill

Hillview association (Hv; Hillview series Gn 2·14)

This unit occurs on the short piedmont slopes of the granitic uplands, and in many areas is strongly dissected by numerous small gullies.

Red earths of Hillview series (Gn 2·14) are dominant in most areas, but the red *siliceous sands* of Elliot series (Uc 4·22) are prominent in some areas and are probably the dominant soil in those mapped on the north-western slopes of Mount Elliot and on the northern slopes of Mount Flagstone. *Yellow earths* of Clement series (Gn 2·24) are the most commonly associated soils and locally may be dominant. Mottled yellow and grey massive earths (Stag Gn 2·74 and Pinnacle Gn 2·94 series), and undescribed bleached yellow earths (Gn 2·34), occur as minor associates on lower slopes. Recent coarse sandy and gravelly fan deposits and some boulder fans are common around Mount Elliot.

Alice–Carinya association (AC; Alice series Gn 3·14, Carinya series Gn 2·74)

This is a complex unit occupying a system of infilled braided distributary channels in the headwaters of Ross River. This unit spans both the younger and older channel infill deposits as described on the northern part of the coastal plain (see Murtha 1975; Alice association and Carinya–Argea association). In the south, however, they occur intimately intermixed, and their distribution is not sufficiently clear to allow separate delineation at the map scale.

Red podzolic soils of Alice series (Gn 3·14) and the brown variant (Gn 3·24) are dominant on the younger infilled channels. *Red* and *yellow* earths of Bluewater (Gn 2·14) and Yileena (Gn 2·24) series respectively are commonly associated soils. Mottled *yellow earths* of Carinya series (Gn 2·74) and, occasionally, the leached sands of Argea series (Uc 2·21) occur on the older infilled channels. Small areas of the older alluvial plain are also included in the unit. These now lie at a slightly lower level than the infilled channels and contain a range of alkaline duplex soils, chiefly Purono (Dy 2·43/5) and Sandalwood (Dy 3·43/4) series.

Granite association (Gr; Granite series Uc 2·21)

The Granite association is one of the two units which occur on the gentle undulating fans between Ross River and the Flinders Highway. The topography and soil pattern are very similar to those in the areas to the west of Ross River, although there is now no doubt that these soils have developed on reworked granitic materials.

A wide range of soils occur in this unit, but in general have no predictable or recurring distribution pattern, since soil development is largely controlled by drainage, influenced more by subsoil factors than landscape position. For instance, in this area weakly cemented siliceous pans and cemented ferruginous horizons at 1–3 m depth create waterlogged conditions on what is otherwise a freely draining ridge crest.

Coarse uniform sands of Granite series (Uc 2·21) are dominant and may occur on all landscape positions. *Yellow earths* and grey earths of Pepperpot (Gn 2·24, Gn 2·34), Wallaroo (Gn 2·64, Gn 2·74) and Flagstone (Gn 2·94) series are common throughout the unit. Pepperpot series are more common on upper slopes, while Wallaroo and Flagstone series are confined to lower slopes, drainage lines and seepage areas. Areas of *red earths* similar to Hillview series (Gn 2·14) occur occasionally on broad ridge crests.

In some places dissection has exposed a black, highly manganiferous, compound nodular material, but it is not clear whether this formed in the fan material or is a remnant of an older surface buried by the fan deposits.

Pepperpot association (Pp; Pepperpot series Gn 2·24)

With the Granite association this unit occurs on the coarse sandy fan deposits, but generally occupies slightly lower ridges representing different phases in the fan development.

A wide range of gradational-textured soils make up the greater part of the unit. They are all very similar in general characteristics, differing chiefly in the degree of development of A_2 horizons and in the amount and dominance of mottling in the B horizon. The range includes Pepperpot series (Gn 2·24) and bleached variant (Gn 2·34), Wallaroo series (Gn 2·64) and bleached variant (Gn 2·74), and grey earths (Gn 2·94) of Flagstone and Pinnacle series. Small areas of Woodridge series (Gn 2·64) are included, along with a range of alkaline duplex soils. Many of the latter have a moderately to strongly developed siliceous pan at about 60 cm depth.

Piedmont Slopes and Undulating Uplands

Flagstone association (Fs; Flagstone series Gn 2·94)

This unit occurs on the gently sloping piedmont slopes on the eastern flanks of Mount Flagstone and Muntalunga Range. The soils are derived from coarse-grained granites and may be of both sedentary and colluvial origin.

Although the leached grey earths of Flagstone series are most common, a wide range of similar soils are closely associated. Most prominent are the uniform sands of Granite series (Uc 2·21), *yellow earths* of Pepperpot (Gn 2·24) and Wallaroo (Gn 2·64) series, and some undescribed shallow coarse sands.

Antill association (At; Antill series Uc 2·34)

This unit occupies several small granitic rises to the south of Mount Jack. The dominant soils are coarse uniform sands of Antill series (Uc 2·34) formed largely *in situ* on granite and generally less than 1 m deep. Leached gradational-textured soils similar to Stag (Gn 2·74) and Flagstone (Gn 2·94) series occur on the lower slopes. Although the soils are shallow, granite outcrop is restricted to the crests of the low conical hills.

The granite of these rises in the source material of the coarse sandy soils of Granite association which occurs immediately to the south-east.

Pall Mal association (Pm; Pall Mal series Dy 3·22)

This is a minor unit occupying small areas of gently undulating granitic country to the east of Mount Flagstone. Pall Mal series are moderately deep *yellow podzolic soils* (75–90 cm to weathered parent material) largely developed *in situ*, although the A horizons show some evidence of surface movement (e.g. stone lines in base of A_2). Though most soils have neutral reaction in the lower B horizon, the shallower profiles are generally mildly acid, and some deeper soils on basal slopes are mildly alkaline. The Pall Mal series soils are mottled yellowish brown and yellowish red, but variants with the dominant mottle colour ranging from yellow to red, occur throughout the unit. Similar soils with sporadically to conspicuously bleached A_2 horizons also occur throughout the unit.

Healy association (He; Healy series Dy 3·43/6)

This unit occurs on gently sloping piedmonts of the acid volcanic uplands of Muntalunga Range and of Mount Stuart, and also fringes some of the granites of Mount Stuart. These piedmonts grade into the alluvial plains and their lower extremities are often very difficult to accurately delineate.

Although the alkaline duplex soils of Healy series (Dy 3·43/6) are dominant, areas of similar but acid duplex soils of Hervey series (Dy 3·41/5) are also common. The latter soils may be older and more strongly leached, but it is possible that the reaction trend differences are due in part to parent material influences.

The area along the northern face of Mount Stuart is particularly complex with numerous small fans and elongate channel infill deposits spilling over the dissected piedmont slopes. Very gravelly *red* and *yellow earths*, Hillview (Gn 2·14) and Clement (Gn 2·24) series, occupy the fans, while deep sandy *yellow* and *red* earths similar to Yileena series (Gn 2·24) occupy the channel infills. Several small areas on the eastern flanks of Mount Flagstone have been included in this unit, although here the Lansdown series (Dy 3·43/5) may be locally dominant.

Small areas of other duplex soils, chiefly Sandalwood (Dy 3·43/4), Beefwood (Dy 2·43/5) and to a lesser extent Stanley (Dy 2·21) series, are distributed throughout the unit.

Stanley association (Sy; Stanley series Dy 2·21)

This unit occurs on gently sloping piedmonts of the acid volcanics in the Mount Jack, Sisters Mountains and Saddle Mountain areas. The soils are largely of colluvial origin, and there are variable amounts of coarse lag gravels on the surface and throughout the A horizons.

The soils of Stanley (Dy 2·21), Julago (Db 1·23), and Ettrick (Dy 3·42) series occur in close association and each is locally dominant in various parts of the unit. Ettrick series (Dy 3·42) are more common on the slopes to the south of Alligator Creek, while Julago series (Db 1·13) are dominant on the slopes along the Bruce Highway immediately south of Stuart. Throughout the unit there are soils which would have to be regarded as variants of these series. Their population does not warrant the establishment of new series. A_2 horizons in particular vary widely, from weakly developed to sporadically and occasionally conspicuously bleached; B horizons may be whole coloured or mottled and colour dominance varies within fairly narrow limits. Acid, neutral or alkaline reaction trend variants also occur. Minor associated soils include those of Hillview and Healy associations.

Stuart association (Su; Stuart series Dr 2·22)

This unit occurs on the piedmont slopes and gently undulating to low hilly foothills of the Sisters Mountains and the spur running north-west towards Stuart.

The Stuart series soils are similar in most attributes to the red duplex soils of the Warbooga series (Murtha 1975). The chief difference is that these soils have developed on fine-grained, intermediate to basic members of the Permocarboniferous volcanics, while the Warbooga series have formed on granodiorite or similar coarse-grained rocks. Major associated soils include yellow and brown duplex soils of Stanley (Dy 2·21) and Julago (Db 1·23) series, while smaller areas of dark cracking clay soils of Sachs series (Ug 5·16) occur on some of the lower piedmont slopes. Shallow gravelly loams occupy areas adjacent to rock outcrop on the more hilly terrain. Alkaline duplex soils similar to Kulburn series (Dy 3·43/5) occur on the alluvial flats and soils of Black association on the levees of minor streams that traverse the unit.

Hilly and Mountainous Lands

Three units have been delineated in the hilly and mountainous terrain. The soils have been examined in some areas, but difficult access and complexity of geology prevents accurate delineating of soil boundaries apart from the unit around the Sisters Mountains.

Unit M1

This unit includes almost all of the hilly and mountainous lands apart from the Sisters Mountains. Slopes are generally steeper than 20°, and rock outcrop is common. Shallow to deep uniform sands (Uc 1·21, Uc 4·21, Uc 4·22), coarse sandy massive earths (Gn 2·14, Gn 2·24) and occasional red duplex soils (Dr 2·21, Dr 2·61) occur on the coarse-grained granites; shallow gravelly leached loams (Um 2·12, Um 2·21, Um 2·22) on the acid volcanics, and a range of red duplex soils on the basic intrusives. Very small areas of alluvium with soils of Black association may occur along some of the minor streams. The complexity of this unit and the influence of lithology on soil development is well illustrated in the cuttings along the road up Mount Stuart.

Unit M2

This unit occupies a very small area at the summit of Mount Stuart. Although it is difficult to delineate any unit on the basis of topography alone, there is a distinct change in soils at about 500 m altitude. Above this level there is a predominance of strongly developed, acid duplex soils (Dy 3·41) similar to those found on the Harvey Range plateau. This change does not appear to bear any relationship to lithology, and since the soil pattern and altitude is similar to that of the Harvey Range plateau, it is assumed that this area is a small outlier of that older land surface.

Unit M3

This area of hilly and mountainous land has a reasonably uniform soil cover. Red duplex soils of Stuart series (Dr 2·22) are dominant, although they tend to be somewhat shallower than those of Stuart association, generally <1 m deep, with moderate to high amounts of coarse gravel on the surface and through the A horizons. Slopes are usually steeper than 15°, and rock outcrop is common in the steeper areas. Soils of Black association occupy small areas of alluvium along minor streams.

Gullied Lands

This unit is restricted almost entirely to the region of piedmont slopes, and is more common in areas with duplex soils but is not restricted to these soils. In most cases, gullying appears to be part of the natural landscape evolution, but there is no doubt that in certain areas new gullies have been initiated since settlement. Some gullying has resulted from the concentration of water by cattle pads or roads works and by denudation of ground cover around watering points.

Chemical and Physical Properties of the Soils

Soil sampling in the study area has been restricted to those soils occupying appreciable areas and not adequately represented in the reports on 'Lansdown' (Murtha and Crack 1966), the northern part of the coastal plain (Murtha 1975) and the study on north Queensland solodic soils (Crack and Isbell 1970). The following discussion of the chemical and physical properties of the soils draws on data from all these sources, in addition to the data obtained on soils sampled within the present survey area. Detailed morphological and chemical data for selected soils is presented in Appendix 2, where laboratory methods are also briefly discussed.

Soil Reaction and Calcium

There are no general trends apparent in the soil reaction profiles. Inherent soil parent material differences seem to have had the major influence, but some differences can also be attributed to the relative age of particular soils and to a lesser extent to current rainfall and drainage conditions.

Most surface soils are mildly acid, pH 5·5–6·0, but some of the heavy clay soils, in particular Alick and Gilligan series, are mildly alkaline, pH 8·0–8·5, at the surface. In areas of gilgai microrelief, carbonate nodules are often present on the surface of the mound sites. All of the cracking clay soils are mildly to strongly alkaline at depth, with the exception of Brolga series which is mildly acid throughout, probably as the result of prolonged flooding and possibly some salt intrusion. The gradational-textured soils are also usually acid throughout, with the exception of some of the younger alluvial soils; the B horizon of Bluewater and Alice series ranges from mildly acid to neutral while, in the Black series it is usually near neutral.

The pH profile of the duplex soils varies from mildly acid throughout to acid at the surface and very strongly alkaline at depth. The moderately deep sedentary soils such as Stuart and Pall Mal series are generally neutral in the main B horizon. In the alkaline alluvial soils the pH reaches a peak of 8·5–9·0 some 30–40 cm into the clay B horizon, and pH 10·0 has been recorded in some Sandalwood series soils. The duplex soils with acid B horizons occur in the slightly higher rainfall area to the east of Saddle Mountain on small remnants of what appear to be an older depositional surface and in seepage areas subject to prolonged saturation and leaching. Surface pH is not expected to limit the growth of species suited to this climate.

While most surface soils are calcium dominant (Table 6), the exchangeable calcium contents are extremely variable, ranging from 1·2 m.e./100 g on the leached granitic sands (Flagstone and Granite series) to 28·7 m.e./100 g on the black earths of Sachs series; most soils lie in the range of 2·0 to 7·0 m.e./100 g. While Leeper (1964) suggested that the figure of 5 m.e./100 g might be regarded as a low level, Jones and Crack (1970) found no response to calcium on soils with exchangeable calcium levels ranging from 1·7 to 4·2 m.e./100 g. They used a range of duplex soils, some of which are represented in the survey area (their 'Black River' is identical with the Kulburn series; their 'Lansdown' is identical with the Lansdown series). Both Russell (1978) and Adams (1978) confirm that levels as low as 1 m.e./10 g may be sufficient in some tropical soils, although it is clear that the calcium absorption capabilities of different species and possibly cultivars can vary widely.

Potassium

Exchangeable potassium has been accepted as a reasonable measure of the potassium status of soils, although it has been shown that plants can obtain potassium

Table 6. Exchangeable cation status of selected soils

Expressed as m.e./100 g

Series	PPF	Depth (cm)	Hori-zon	pH	Total	Ca	Mg	K	Na	H	Sat. (%)
Granite	Uc 2·21	0–10	A1	6·5	4·55	2·0	0·8	0·13	0 12	1·5	67
		20–30	A2	6·5	2·19	1·0	0·3	0·05	0·14	0·7	68
		75–90	B2	5·8	2·83	0·8	1·0	0·17	0·16	0·7	75
Sachs	Ug 5·16	0–10	A1	7·8		28·7	20·9	0·40	0·35		
		30–60	B	9·1		27·3	26·0	0·13	1·84		
		90–120		9·0		19·0	27·7	0·17	8·08		
Bluewater	Gn 2·14	0–10	A1	6·0	9·47	5·3	1·7	0·43	0·14	1·9	80
		10–20	A2	6·1	6·33	2·9	1·0	0·27	0·16	2·0	68
		30–45	B	6·3	5·25	2·5	1·2	0·19	0·16	1·2	77
Black	Gn 2·45	0–10	A1	6·2	26·16	12·9	3·5	0·83	3·73	5·2	81
		60–90	B	7·0	8·80	6·1	1·8	0·16	0·24	0·5	94
		90–120	B-C	6·8	10·96	7·5	1·9	0·09	0·27	1·2	89
Stuart	Dr 2·22	0–10	A1	6·8		13·5	5·3	1·02	0·13		
		30–45	B2	6·5		9·5	6·5	0·28	0·10		
		45–60	B2	6·5		10·8	6·1	0·04	0·22		
Julago	Db 1·13	0–8	A1	6·5		9·5	8·0	0·40	0·17		
		8–20	B1	6·4		9·6	8·4	0·10	0·35		
		30–45	B2	7·3		10·8	9·4	0·09	0·69		
Pall Mal	Dy 3·22	0–10	A1	6·2	10·19	6·8	1·5	0·27	0·12	1·5	85
		10–20	A2	6·5	4·38	2·8	0·8	0·16	0·12	0·5	89
		30–45	B2	6·4	13·50	7·1	3·6	0·31	0·19	2·3	83
Althaus	Dy 3·41	0–4	A1	6·4	8·32	3·9	1·6	0·37	0·25	2·1	74
		10–20	A2	6·1	5·14	1·2	1·2	0·19	0·25	2·3	55
		45–60	B2	6·2	10·92	1·5	3·8	0·26	1·36	4·0	63
Bently	Dy 3·43	0–10	A1	5·8		3·5	1·6	0·55	0·03		
		35–50	A3	6·2		5·6	5·9	0·11	0·46		
		50–60	B2	6·5		5·4	5·6	0·11	0·72		
Sandalwood	Dy 3·43	0–8	A1/A2	5·8	6·10	1·7	1·0	0·30	0·50	2·6	57
		8–18	B2	7·7	15·31	4·8	4·7	0·21	4·8	0·8	95
		18–45	B22	8·5	14·56	3·6	5·0	0·06	5·9	0	100
Kulburn	Dy 3·43	0–10	A1/A2	5·6	9·88	2·7	1·9	0·43	0·45	4 4	55
		10–17	A2	6·1	8·82	2·9	2·6	0·40	0·82	2·1	76
		30–50	B2	9·3	20·94	7·2	6·8	0·12	6·82	0	100
Lansdown	Dy 3·43	0–4	A1	5·4	7·53	1·6	0·8	0·23	0·20	4·7	37
		4–20	A2	5·8	3·38	0·8	0·5	0·03	0·15	1·9	42
		60–90	B2	8·7	10·78	1·6	4·6	0·08	4·5	0	100
Stockyard	Dy 3·43	0–6	A1	5·6	7·18	2·0	0·7	0·23	0·05	4·2	41
		6–20	A21	5·7	4·82	1·6	0·7	0·12	0·10	2·3	52
		53–70	B21	7·2	13·33	5·8	4·1	0·13	1·7	1·6	88
Coonambelah	Dy 3·32	0–5	A1-2	5·3		2·7	3·3	0·15	0·89		
		5–10	B1	6·0		2·9	11·0	1·10	2·97		
		20–30	B2	7·3		2·9	11·1	0·80	5·23		

from non-exchangeable forms (Leeper 1964). The values obtained for surface soils in this area range from 0·13 to 1·50 m.e./100 g soil. Using the generally accepted figure of 0·2 m.e./100 g as the criterion for sufficiency, it is obvious that deficiencies are likely in some soils. This has been confirmed by Jones and Crack (1970) for some of the duplex soils in this area. Their study also confirmed the use of 0·2 m.e./100 g as a general guide of sufficiency, but suggested that potassium deficiencies may be encountered in some of the duplex soils if used for intensive cropping.

It has been shown however that potassium status of soil is influenced by soil pH (Rich and Black 1964) and by the levels of exchangeable calcium and magnesium (Beckett 1964), and it is suggested that cation ratio $K/\sqrt{(Ca+Mg)}$ may be a better indicator of availability. The higher the cation ratio, the more readily will potassium be available for plant uptake. Some low cation ratios (Table 7) are accompanied by what appear to be acceptable levels of exchangeable potassium, e.g. Sachs, Gilligan, and Montor series. It needs to be determined if these soils do in fact indicate a potassium deficiency and where the threshold value lies.

Table 7. Exchangeable potassium status of surface soils[A]

Soil series	Exch. K[B]	Cation ratio[C]	Soil series	Exch. K[B]	Cation ratio[C]
Sandalwood	0·14	0·057	Flagstone	0·20	0·231
Sachs	0·40	0·080	Sandalwood	0·30	0·258
			Kulburn	0·43	0·284
Manton	0·20	0·108	Black	0·83	0·290
Gilligan	0·37	0·110	Double Barrel	0·70	0·291
Granite	0·13	0·110	Landsown	0·28	0·295
Gulliver	0·20	0·121	Stockyard	0·60	0·316
Pall Mal	0·27	0·132	Woodridge	0·44	0·319
Julago	0·40	0·135	Stuart	1·02	0·333
Clemant	0·29	0·156	Bently	0·55	0·344
Stockyard	0·30	0·198	Stuart	1·17	0·365
Lansdown	0·23	0·210	Woodridge	0·45	0·387
Althaus	0·37	0·223	Brolga	1·23	0·468
Hillview	0·43	0·230	Coonambelah	1·50	0·866

[A] Ranked in order of cation ratio.
[B] m.e./100 g soil.
[C] $K/\sqrt{(Ca+Mg)}$.

Exchangeable Sodium

A feature of many of the duplex soils is their high levels of exchangeable sodium in the upper parts of the B horizon. In Sandalwood, Kulburn and Lansdown series soils, in particular, exchangeable sodium may account for up to 50–60% of exchangeable basic cations. Values as high as 18 m.e./100 g are not uncommon. Although there does not appear to be any direct relationship between levels of exchangeable sodium and plant performance, it has been shown that there is a close relationship with the soil water storage capacity and thereby a potential restriction of plant growth (McCown *et al.* 1976).

The highly dispersive nature of these materials is also of engineering significance; many have a dispersion index of 16 (Loveday and Pyle 1973), which is the maximum value representing complete dispersion. Dispersion on wetting renders these highly susceptible to erosion and considerably reduces their bearing strength (Bathos 1976).

Phosphorus

The levels of total and available phosphorus in the surface soils examined is extremely variable. The amount of total phosphorus is extremely low (30–200 ppm) in all the *solodized-solonetz* and *solodic soils*, and in the coarse sandy soils developed on granite colluvium. The younger alluvial soils have low to moderate values (150–760 ppm), and of these Black and Central series soils, formed on the low terraces, are the only ones which may have adequate levels for intensive cropping. The only soils with reasonably high levels (> 1300 ppm) are the red duplex soils of Stuart series.

The pattern for available phosphorus (0·01 N sulfuric acid extractable) is similar to that for total phosphorus. Apart from some of the younger alluvial soils and the red duplex soils, most have extremely low levels, between 3 and 12 ppm.

Nitrogen and Organic Carbon

The total nitrogen and organic carbon content of most soils is generally low. In the *solodized-solonetz* and *solodic soils* and in the coarse sandy soils developed on granitic colluvium, nitrogen contents are from 0·01 to 0·09% and organic carbon from 0·13 to 1·5%. Some soils have reasonably high levels of total nitrogen and organic carbon, e.g. the younger alluvial soils. Some of the younger alluvial soils and the red and brown duplex soils (Stuart and Julago series) developed on intermediate volcanics or on colluvium derived from the volcanics. In these soils nitrogen may exceed 0·25% and organic carbon ranges over 2·0–3·7%.

The carbon/nitrogen ratio of most surface soils ranges from 8 to 15. Although it is generally accepted that soils with low carbon/nitrogen ratios readily mineralize nitrogen, Crack (1972) found that nitrogen mineralization rates on the duplex soils at 'Lansdown' is very low. Some of the sandy granitic soils, e.g. Granite and Flagstone series, have much wider carbon/nitrogen ratios (up to 32). With low levels of total nitrogen and slow mineralization, acute deficiencies may occur on these soils.

Salinity

The data indicate that salt concentrations high enough to affect plant growth seldom occur within the main rooting depth of plants. Exceptions are those soils subject to tidal inundation and Sandalwood series. The latter may have up to 0·4% total soluble salts and 0·24% sodium chloride within 45 cm of the soil surface. Almost all the duplex soils have low to moderate levels of salt at some depth in the B2 horizon. A close correlation between the depth of the salt peak, thickness of A horizon and the soil water profile has been found in the *solodized solonetz* and *solodic soils* (McCown *et al.* 1976).

Small areas of clay soils (Alick and Gilligan series) and the Manton series duplex soils associated with the Gilgai Complex are occasionally gypseous. The gypsum occurs below about 50 cm depth and total salt levels range from 1·5 to 2·5%. No predictable pattern has been found for the occurrence of gypsum.

Other Elements

Marked sulfur and lesser molybdenum responses in *Phaseolus lathyroides* have been obtained on *solodized solonetz* and *solodic soils* from Lansdown (Jones and Crack 1970). Similar responses may be expected on all but the younger alluvial soils. Other deficiencies such as copper may occur on some of the strongly leached coarse sandy soils, e.g. Granite and Flagstone series.

Acute iron deficiencies commonly occur in lawn grasses on almost all soils of the Townsville City area. Symptoms (pronounced yellowing) are usually evident only during the wet season when soils are saturated, although it can be induced at any time by over-watering or by heavy liming. Applications of iron sulfate or iron chelate correct the deficiency. Iron deficiency has not been reported in field crops or pastures.

Physical Properties

Adverse physical properties of the duplex soils are probably the chief factor limiting their land-use potential. Although the physical properties apart from particle-size distribution have not been measured, some general comments may be made. The surface soils are very boggy when wet, extremely hard-setting when dry, and if worked in the dry state powder to 'bulldust'. The dense, sodium affected clay B horizons are very effective barriers against water entry, and in many of these soils little soil moisture recharge occurs below depths of 50–60 cm into the clay B horizon (McCown 1971).

Many of the coarse, gradational and uniform-textured soils are very porous and extremely droughty because of their low water-holding capacity.

Particle-size analyses show a fairly close correlation with field textures. However, the contrast between A and B horizons in the heavier surface-textured soils does not appear as marked as field textures suggest. In these soils field textures of heavy clay frequency have particle-size contents as low as 30% clay, but have high silt and fine sand fractions.

A feature of the surface of most of the duplex soils is the high silt and fine sand content which contribute to the hard-setting character.

Clay Mineralogy

No clay mineralogical analyses has been carried out on soils from the survey area, but it is apparent that the pattern of soil development, particularly on the older alluvial plains, is similar to that on the northern section of the Townsville coastal plain and the data presented there (Murtha 1975, p. 44) are valid for this area.

Expansive clays of the montmorillonite type are certainly more extensive than on the northern section of the coastal plain indicated by the extensive areas of gilgai complex. It should be emphasized that many of the duplex soils on the older alluvium are also expected to be montmorillonite dominant in their B horizon or to overlie montmorillonite clays at shallow depth.

Land Use

Brief History

Settlement of the area began in 1861, when J. M. Black took up Woodstock holding and introduced both sheep and cattle. The sheep industry was shortlived owing to a combination of foot rot, dingoes, high labour requirements, spread of spear grass, high transport costs, and a falling wool market in the late 1860's.

As cattle numbers increased in the north, alternative markets to the limited requirements of the mining centres had to be found. This led in 1865 to the establishment of a boiling down works on Ross Creek and the beginnings of Townsville. Expansion of the port and township was rapid, since Townsville provided better access to the hinterland than the ports of Cardwell and Bowen. The development of further mining centres to the west and north-west, in particular the discovery of gold at Charters Towers in 1871, and the government decision of 1877 to build a rail line servicing the western centres, provided added impetus for the further development of Townsville. These also helped to stabilize the beef industry which had suffered a rapid decline with falling markets leading to the closure of the boiling down works in Townsville and Bowen in 1870.

Further permanency was afforded the beef industry in 1890 when a meat extract company was established on the site of the old boiling down works on Alligator Creek and again in 1900, when the Queensland Meat Export Agency Company established the Ross River freezing works. Collectively these plants could then process upwards of 40 000 head annually.

Severe drought conditions in the early 1900's and the spread of cattle tick (*Ixodes bovis*) through the Townsville district in 1895 decimated many beef and dairy herds. Losses of upwards of 80% to individual herds were common, and resulted in bankruptcy of many pastoralists, particularly those on smaller holdings.

There has been little intensive land-use in the survey area during the 117 years since settlement. The largest part of the area is under grazing by beef cattle, and until very recently, fencing and provision of watering points were the only improvements adopted. In recent years, relatively small areas have been cleared or have received timber treatment by hormone poisoning. On a very limited scale, the production from naturally colonized Townsville stylo pastures was being promoted by application of phosphatic fertilizer, while other areas had been seeded and fertilized. With the advent of anthracnose in the mid 1970's many of these pastures have been severely decimated. There is currently little pasture development taking place, although (*Stylosanthes hamata*) cv. Verano is resistant to the anthracnose and is suited to most of the soils of the area.

Other forms of agricultural production have waxed and waned over the years. Dairying, chiefly as a milk supply for Townsville, occupied much of the area from Stuart to Woodstock till about the mid 1930's. Poor pastures, particularly during the long dry season, must have had a very detrimental effect on milk production, and dairying declined as transport improved and supplies were more readily obtainable from better producing areas on the Atherton Tableland.

Limited areas of potatoes, other small crops and occasional summer grain crops, are grown along Lansdowne Creek and, for a short period (about 1925–1935), tobacco was grown on the sandy fan soils around Mount Elliot.

Pig and poultry raising are conducted on a small scale, but lack of locally grown grain and high transport costs of imported grains are probably the chief factors limiting expansion.

Current Land Use and Further Developments

The lack of intensive agricultural development within the survey area, despite its proximity to a reasonably large city, is ample evidence of the low nutrient status and poor physical characteristics of the majority of the soils. There are some small areas (total about 50 ha) of cropping on the young alluvial soils of Lansdowne Creek. Other areas of soils suitable for intensive agriculture are extremely small, and are further limited by the resumption of land as a buffer area surrounding the Ross River Dam pondage and possibly by restrictions on usage of lands within the dam catchment. The maintenance of water quality may necessitate some restriction on use of fertilizer, herbicide, insecticide, etc. Only minor areas of arable soils restricted to younger alluvium along minor streams are available beyond that within the dam catchment.

Soils that are considered suitable or marginally suitable for agricultural and horticultural usage, together with a summary of their major constraints, are listed in Table 8. In compiling this table no account is taken of the limited areal extent of

Table 8. Soils suitable or marginally suitable for agriculture

Soil series	Major agronomic constraints
Central Magenta Windsor	No limitation other than susceptibility to flooding
Pallarenda Cungulla	Severe limitations, very low fertility, low water-holding capacity
Sachs Vantasel	Low to moderate fertility, slow internal drainage, poor surface drainage where there is gilgai, difficult to work when wet
Alick Gilligan	Low fertility, often moderately to strongly alkaline, moderate gilgai with considerably different moisture characteristics between mound and depression site, poor surface drainage in depressions, difficult soils to work to fine tilth
Bluewater	Moderate fertility, some areas may be subject to flooding, no other major limitations
Hillview Clemant	Low to moderate fertility, on some slopes erosion control may be necessary
Pepperpot	Low fertility, low water-holding capacity
Ross	Low fertility, poor internal drainage where D horizon clays occur at shallow depth
Yileena	Low fertility, no other major limitation
Black	Some areas subject to flooding
Alice	Moderate fertility, no other limitation
Double Barrel	Moderate fertility, some areas subject to flooding
Stuart	Slopes and erosion hazard preclude any extensive usage of these soils
Julago	Moderate fertility, impeded internal drainage
Barringha	Low fertility, impeded internal drainage
Stanley	Low fertility, impeded internal drainage, severe erosion hazard even on very gentle slopes
Pall Mal	Low fertility, impeded internal drainage, moderate erosion hazard
Bently	Low fertility, impeded internal drainage, may be subject to occasional flooding
Scrubby	Low fertility, may be subject to occasional flooding, moderate internal drainage
Toonpan	Subject to frequent flooding, no other limitation
Doughboy	Subject to frequent and prolonged flooding

some soils. Many areas are too small, and the soil pattern too complex to be considered as commercial areas, but they may be suitable for the hobby farmer. A commercial area in this context is considered to be in excess of 10 ha. In addition, this assessment has been made on the requirements of a broad range of crops and reassessment may be necessary for particular crops. For example, if adequate water supplies were available, sugar cane and rice could be successfully grown on many soils in the area utilizing available technology and the levels of fertilizer applications in general use in these industries.

Cattle grazing of native and limited areas of improved pastures is the main rural pursuit. The significance of the area as a beef producer, however, is diminishing rapidly. For this reason no attempt has been made to prepare a land capability map similar to that compiled for the northern section of the coastal plain.

A number of factors are responsible for the changing land use pattern. Some 15000 ha have been resumed for the pondage area and road and rail deviations associated with Ross River Dam. The Commonwealth Department of Administrative Services has resumed or has declared its intention to resume considerable areas for the Mount Stuart army training complex and for an extension to the Cape Cleveland National Park. The most significant factor, however, is the pressure being placed on the grazing lands for closer subdivision. The urban population growth of Townsville has been the major influence, but the recent down-turn in the beef industry has precipitated many of the subdivisions. The grazier is now much more willing to capitalize on the high prices offered for large lot residential and hobby-farm lands.

It would seem useful now to prepare land capability maps in relation to urban development ('urban' used here in a very broad sense to include large lot residential and hobby-farms from 0·5 to 10 ha). However, until such time as appropriate legislation is proclaimed to prevent alienation of prime agricultural lands for urban use, or to prevent the development of lands unsuited to urban usage, such capability maps are likely to have little impact. The Thuringowa Shire Council is currently preparing a development strategy plan which considers many factors other than soils and should provide a planning framework to ensure that the land is utilized to its best advantage.

Undue pressure for high density urban development to the south and south-east of Townsville seems unlikely, since the natural population spread is to the north and west where transport corridors, water and sewerage services etc. are firmly established. There is a growing demand, however, for an alternative life style on large residential lots or hobby farms. Much of this area is well suited to development of this kind, although from both the agronomic and engineering viewpoint there are some soils which require special inputs for their satisfactory utilization.

From an agronomic viewpoint soil suitability differs markedly between the large lot residential and hobby farm usage, and in the case of the latter the range of uses to which these lots are put. Few soils apart from those subject to tidal inundation could be excluded for purely residential purposes. On some soils, however, e.g. Sandalwood, Alick, Gilligan and Sachs series, the constraints are so severe, and ameliorative measures so difficult or expensive, that wherever possible they should be excluded from this kind of development. Many of the larger lots, regardless of zoning, however, are purchased with the intention of grazing one or more horses for recreational purposes. Although the maximum lot size under the town plan zoning scheme is not regulated in any way, the minimum lot size must generally be adhered to.

Naturally enough, developers are looking for maximum financial return so wherever possible lots are of minimum permissible size. Under the Thuringowa Shire Council's current town planning scheme, several zonings may be used which would allow minimum lot sizes ranging from 0·5 to 2·0 ha. Very few soils in this area are capable of maintaining a pasture under the grazing pressure of one horse per ha. In addition only rarely is stocking limited to one horse, up to six horses are being carried on some lots. Under these conditions pastures deteriorate rapidly, annual weeds and forbs dominate, and the ground is bare for much of the year. As a result, the soils are extremely susceptible to both wind and water erosion. Deflation is only of minor importance, but in a predominantly residential area dust will be a considerable nuisance. Water erosion could be a serious problem, particularly on gently sloping terrain such as that of Stanley association.

It is important therefore that some measures be taken to prevent overstocking, and in the catchment area of the dam it may be imperative if water quality is to be maintained. Apart from a restriction on minimum lot size (possibly to the order of 10–15 ha) and a by-law control over the number of animals kept on any given lot size, there is little that can be done. Both of these measures would be unpopular because most developers are chiefly interested in maximizing returns, and many residents would regard it as yet another infringement upon personal liberties. Unfortunately, few would-be purchasers are well enough acquainted with the agronomic limitations of the soils, and there is little redress due to misrepresentation by selling agents.

It must be emphasized that almost all of the duplex soils will experience considerable runoff, owing to the highly impermeable nature of their B horizons and possibly to the hard setting character of their surface horizons under the generally high intensity rainfall experienced in this area. Some sheet wash may occur, but the major problem will be gully erosion. Gullies may form at any place where there is a concentration of flow or may initiate from development works such as road table-drains. Once the highly sodic B horizons of the duplex soils are exposed, gully formation is rapid and usually proves very difficult to contain and stabilize.

From an engineering viewpoint, there are no soils that would have to be excluded from this kind of development. There are, however, some soils which require special engineering practices or design to minimize maintenance problems. Some of the engineering problems of these soils have been discussed previously (Murtha and Reid 1976), and only the more important features will be outlined here.

The most obvious engineering problems are those associated with expansive clays (Ingles and Metcalf 1972) in the areas of gilgai clays and in the gilgai complexes, e.g. Sachs association and the Gilgai Complex. Many of the duplex soils may also have expansive clay subsoils which are not often evident from a development of a surface microrelief or cracking. The limited mineralogical data available show considerable variation even within narrowly defined groups of duplex soils, and all need to be treated with caution as they may contain more than 20% montmorillonite or randomly interstratified clay minerals. Design criteria for both road and building foundations on expansive clay soils are given in several recent publications (Aitchison 1953; Richards and Gordon 1972; Yeates 1972; Aitchison and Tokar 1973; Richards 1973).

The high level of exchangeable sodium in the B horizons of many duplex soils also create some engineering problems, particularly erosion associated with road and drainage works. The best approach would be to avoid exposure of the B horizon clays, but this is impossible in road works, so the clays need to be stabilized as soon as possible after they are exposed. Grass establishment is probably the only reasonably economical measure that can be taken in road table drains and shallow broad storm-water drains. A good ground cover will be difficult to achieve, and it will reduce the efficiency of the drains. However, as the primary purpose of drainage in large lot subdivisions is to prevent or minimize pondage rather than alleviate flooding, the lower efficiency should not be a major concern.

Problems in establishing a ground cover are concerned mainly with the timing of constructional works, although on many soils top dressing will be necessary to provide a reasonable rooting medium. The working of heavy equipment on most of these soils is virtually impossible during the wet season, so construction is staged to begin soon after the wet season and to terminate before commencement of the next. Early storm rains are of high intensity, so ground cover should be established before their onset. However, seed germination and plant establishment during the dry months is almost totally reliant on applied moisture, probably by truck watering, which is expensive and inefficient. Various other methods of grass stabilization (Nebauer and Good 1973) are possible, but hydromulching (Good and Nebauer 1970) or bitumen and straw mulching (Clothier and Condon 1968) may be most suitable.

Deep drains with steep batters are extremely susceptible to erosion in the dispersive clays; even with extremely low water velocities, there may be widening and deepening of the channel and erosion control measures may be necessary (cf Fig. 4).

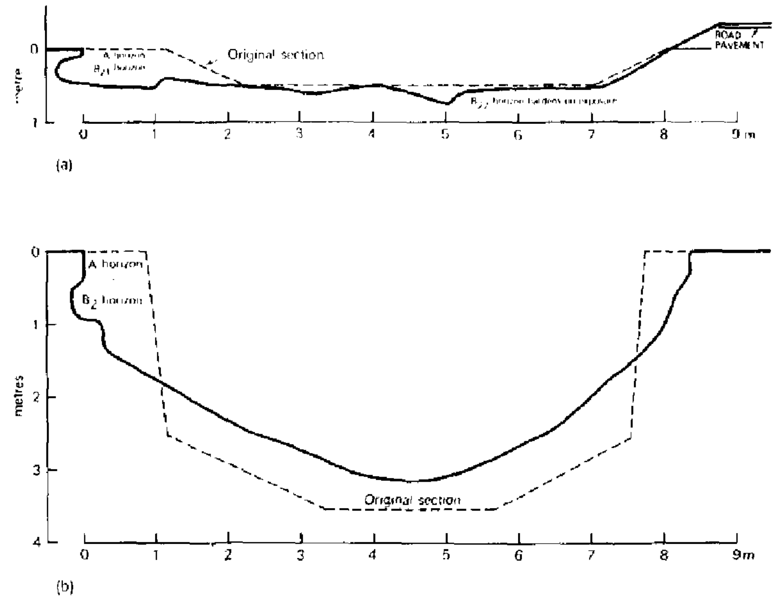

Fig. 4. (*a*) Road table drain showing erosion after one wet season. (*b*) Open drain showing erosion after three wet seasons. This section is at a point where lateral flow into the drain is controlled.

It is unlikely that vegetative stabilization would be successful in this situation owing to the chemical and physical properties of the exposed B horizon clays. Stone pitched or concrete scour checks frequently fail owing to tunnel erosion beneath or around the structure. Similarly stone pitching, by hand or by sandwiching the stone in steel mesh matting for the full length and cross section of the drain, is unlikely

Fig. 5. Erosion of the wall of an open drain due to dispersion of the sodic B horizon and subsequent collapse of the overhanging A horizon.

Fig. 6. Erosion of the wall of an open drain by gully head erosion. This is common where lateral surface drainage is allowed unrestricted and uncontrolled entry to the drain.

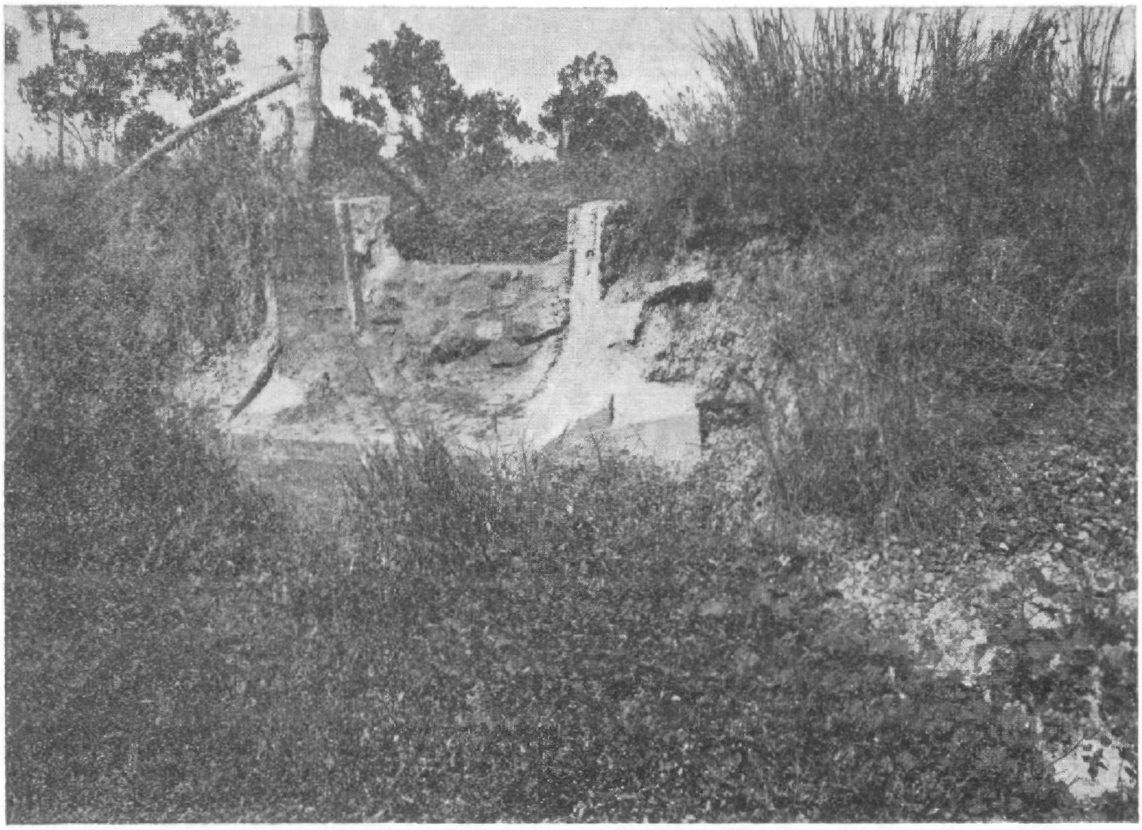

Fig. 7. A typical stone pitched-concrete scour check. This scour check has been undermined and by-passed on a number of occasions. The successive concrete pours to rectify the failures are evident on the photo.

Fig. 8. Typical failure of a scour check. In this case it has been undermined and by-passed.

to be successful. This technique still allows water access to the highly dispersive B horizon clays, resulting in removal of material from beneath the stone pitching, in turn resulting in the subsequent collapse of the structure. It appears that in deep drains the only satisfactory treatment would be a lining of completely impervious material such as concrete. (See Figs 5–8.)

Many road pavement failures may also be attributed to the use of these highly dispersive clays as foundation materials. If moisture enters the foundations by lateral seepage or through cracks in the bitumen seal, the clays disperse and bearing strength is considerably reduced. Bathos (1976) working on some of these materials stated '. . . true Canadian bearing ratio values are lower than those expected . . . drop fairly significantly when soaked as compared to unsoaked, indicating what poor quality material they would make as sub-base in wet conditions . . .'.

Road construction projects use as much on-site material as possible. If alternative materials are not available, precautions similar to those taken on the expansive clays to prevent loss or gain of moisture to the base grade may need to be employed. While road construction is probably the major cost item in large lot residential subdivision, road maintenance costs are an ongoing problem, and design criteria must find a balance between the two.

The low hilly and hilly terrain should not present any major problems in development. Some small earth slides may result from deep cuttings before they are effectively stabilized, but no movement in the country rock is anticipated. Engineering costs in some areas will be high, but development will probably be restricted only by the would-be customers' ability to pay.

Table 9 lists those soils which are considered to be unsuitable or only marginally suitable for large lot residential development. Their major engineering and agronomic constraints are summarized. No attention has been given to their susceptibility to, or the frequency and duration of, flooding in determining suitability.

Hobby farming in this context is restricted to those enterprises incorporating vegetable or tree crops on a purely supplementary income basis. The suitability of soils is not as critical as in the wholly commercial farm situation, and the area required is very dependent on the enthusiasm of the operator. Many of the smaller areas of soils which are otherwise suitable for crops (Table 8) may be effectively utilized on hobby farms, but attention must be given to the specific requirements of individual crops.

Prominent Soils of the Townsville Coastal Plain, their Classification and Field Relationships

This section summarizes the classification of the major soils and briefly discusses some of the relationships between particular groups of soils or between soils and particular physiographic or environmental factors. The discussion covers the soils on both the northern (Murtha 1975) and southern sections of the Townsville coastal plain.

The soils have been classified by PPF (Northcote 1971) and Australian Great Soil Groups (Stace *et al.* 1968), and in addition those of the southern section have been placed where possible to the great group or subgroup level of U.S.D.A. Soil Taxonomy (Soil Survey Staff 1975). In the soil series defined, some 42 PPF's and 14 Great Soil Groups are represented, but classification into Great Soil Groups has been done on a 'best fit' basis, and some are not necessarily typical or modal

Table 9. Soil limitations in large lot residential development

Soil series	Engineering limitations	Agronomic limitations
Toolakea, Granite, Pallarenda, Antill, Jalloonda, Oolgar, Cungulla	Subject to erosion and storm surge on beach fronts, may require compaction and stabilization for foundations	Severe. Extremely low fertility and low water holding capacity. Little restriction on adapted species with supplementary irrigation and fertilization
Sachs, Vantasell, Alick, Gilligan, Brolga, Woodridge	Expansive clays cause problems in all engineering applications. Surface drainage very slow in some areas	Moderately severe. Low to moderate fertility, slow internal drainage, poor surface drainage and ponded water in gilgai areas. Few adapted species and difficult plant establishment
Sandalwood	B horizon clays have very poor drainage and low bearing capacity when wet. They are highly dispersive clays, hence susceptible to severe gully erosion. May have high salt and/or sulfides causing corrosion of underground services	Very severe. Low fertility, poor physical properties, impeded drainage, moderate to high salt in the clay B horizon. Few adapted species, soil amelioration difficult and costly
Stanley, Hervey, Ettrick, Pall Mal, Healy	Similar to Sandalwood series but most problems are less severe. Particular attention needs to be paid to erosion control on sloping terrain	Severe. Low fertility, poor physical properties, impeded drainage, limited adapted species, need to import loam for lawn establishment
Nightjar, Purono, Beefwood, Gulliver, Kulburn, Lansdown	Similar to Sandalwood series, but as depth of A horizon increases engineering properties improve. May be some expansive clays in the B horizon and many are highly dispersive	Severe. Low fertility, poor physical properties, impeded drainage, limited adapted species, need to import loam for lawn establishment
Lagoon, Woodlands, Five Head, Althaus, Pattel, Stockyard, Bently, Scrubby	Similar limitations as above but generally less severe	Limited by low fertility, generally poor physical properties, clay subsoils in some soils are relatively free draining and deeper A horizon in all soils results in generally better drainage
Coonambelah	Subject to occasional tidal floodings, dispersive and expansive clays, severe corrosion due to high salt levels, permanent water tables at generally less than 70 cm depth	Very severe. High salt levels, low fertility, poor drainage, species adaptability limited to those with high salt tolerance

for the group. In addition, there are six soil series for which there is no adequate provision in the great soil groups as defined.

At this stage more experience is required in the use of Soil Taxonomy before an appraisal can be made of its applicability in this environment. It is of interest to note, however, that although there are four series classified as Oxic Haplustalfs (Table 5) that embrace four PPF's and four Great Soil Groups, in terms of land use all four soils would have similar constraints.

For general discussion, the soils have been combined into six broad groups of related soils or soil sequences. The grid references refer to type areas for particular soils or sequences of soils.

Uniform-textured Sands

This group includes soils occurring on the beach ridges fringing the coastline, on older stranded beach ridges and on colluvial fans that have emanated from the granitic uplands.

A range of soils with uniform sand textures occur on the fringing beach ridges and show an increasing degree of profile development with age, but the pattern is not consistent over the length of the coastline. In general, shelly *calcareous sands* with little profile development beyond some surface accumulation of organic matter occur on the frontal ridges. On succeeding ridges profile development is more marked with a more organic and darker A_1 horizon, weakly developed A_2 horizon, and yellowish brown or yellowish red B horizons. As the degree of profile development increases there is a gradual change from *siliceous sands* to weakly coherent *earthy sands*. The full sequence can be found in the beach ridges south of Cape Pallarenda (Townsville 1 : 100 000; 890895) and south of Cape Cleveland (Bowling Green Bay 1 : 100 000; 180765). Elsewhere, the ridge systems are discontinuous, and some of the older ridges may have been reworked. The beach ridges north of the Bohle River are probably younger since they are not as well developed, red *earthy sands* are absent, and there are very limited areas of yellow *siliceous sands*.

The increasing rainfall to the north and south of Townsville is reflected in the soils developed in the beach ridges; east of Clevedon, and to a lesser extent around Balgal, weakly developed *podzols* occur on some of the inland ridges. These soils have a very dark organic sand A_1 horizon to 30 cm depth and occasionally have a weakly developed sand A2 horizon. The B horizons are brown to dark brown (organic stained) sand, contain some soft ferromanganiferous segregations and grade into unaltered sand below about 1 m depth. The best examples of these soils can be found on the road to Cungulla (Bowling Green Bay 1 : 100 000; 235710).

Strongly leached sands occur on the older stranded beach ridges. They overlie beachrock, mangrove muds and peats, and solonchak's of the marine plain or duplex soils of the old alluvial plain at depths of 1–5 m. The sands have thin, light grey-brown sand A_1 horizon over a deep (40–80 cm), very strongly bleached sand A_2 horizons underlain by pale, mottled, yellow, yellow-brown and red, clayey sand B horizons. Examples may be seen on relict beach ridges near the mouth of the Bohle River (Townsville 1 : 100 000; 800915).

The profile form of the sands on the colluvial fans reflect their various ages and current drainage status. On the younger fans, the dominant soils are coarse sands with thin dark A_1, weakly developed A_2, and red or yellowish red B horizons. Seepage areas are common on the lower slopes where the soils often have strongly bleached A_2 horizons and mottled yellow or grey sandy B horizons. The soils on the older fans are generally similar but contain moderate to high amounts of ironstone nodules and/or gravels through the profile.

The Elliot series soils of Hillview association on the piedmont slopes of Mount Elliot are characteristic of the younger fans, while Ocke association to the north of the Pinnacles occurs on the older fans.

The leached sands of the older beach ridges and fans were previously classified as *Siliceous sands* (Murtha 1975). However, the presence of a strongly bleached A_2 horizon and a weakly developed colour B horizon may exclude them from this group. They could be regarded as minimal or very weakly developed *podzols*, although this is not supported by their other morphological features, e.g. there is no apparent organic and/or iron accumulation in the B horizon. Other soils which are readily recognized as being minimal podzols, e.g. Cungulla series, have a weakly developed B horizon in which the organic accumulation appears as a brown staining on individual sand grains and A_2 horizons are only very weakly developed.

Studies on similar sands to the north of Townsville (Murtha, unpublished data) indicate that where soils have a prominent bleached A_2 horizon they also have a prominent podzol B horizon, i.e. organic and/or iron accumulation. The combination of strong horizonation such as a bleached A_2 horizon and minimal podzol B horizon development has not been observed in this environment.

In view of the above and to retain consistency with Murtha (1975), all soils with a bleached A_2 horizon and weakly developed colour B horizons have been classified as *Siliceous sands*.

Cracking Clays

The *grey clay* member of the *grey*, *brown* and *red clay* group and *black earths* are restricted to the alluvium of streams that have intermediate volcanics in their catchments. The *black earths* appear to be restricted to alluvium, which is almost wholly of intermediate volcanic origin and are particularly common along streams draining the Sisters Mountains. Where there is some mixture of parent materials, *grey clays* are dominant and they occur chiefly as back swamp deposits on the older alluvial plains, e.g. in the lower reaches of the Bohle and Ross Rivers, or as shallow relic lake and swamp deposits in the Ross River catchment.

Moderate normal or round gilgai is common to most areas of cracking clay soils. The mounds range from 1 to 2 m across and vertical interval between mound and depression varies up to 90 cm. Weak linear gilgai is common in cracking clays on the lower piedmont slopes in the Stuart Creek catchment.

Gilgai is not as well developed in the *black earths*, and clay soils usually occupy both mound and depression sites. The *black earths* have a very dark grey or black, strongly fine blocky, heavy clay A horizon, over very dark grey or black, strong coarse blocky, heavy clay subsoils. Moderate to high amounts of nodular or diffuse calcium carbonate occur below 30 cm. Subsoils may become grey or brown at depth and overlie sandy sediments or colluvial gravels.

The *grey clays* invariably occur as a soil complex occupying the gilgai mounds with duplex soils in the depressions. They have dark grey or dark greyish brown, strong blocky, heavy clay A horizons over grey or grey-brown, coarse blocky, heavy clay B horizons. At depth they may become finely mottled and usually grade to sandy stratified sediments below 3 m. Calcium carbonate nodules, and in some areas angular alluvial gravels, may be present on the surface of the mounds. The area to the west of the Bohle River mapped as Manton gilgai complex (Townsville 1 : 100 000; 805760) is characteristic of the *grey clays*.

Small areas of grey clays also occur in shallow depressions on the marine plain and are subject to inundation for long periods during and after each wet season. In these situations, the clays develop gley features such as bright yellowish mottles and linings to root channels in the A horizon and strongly mottled, olive-grey, orange and red subsoils. Brolga series soils occupy these wetter sites (Townsville 1 : 100 000; 860905).

Soloth, Solodic and Solodized Solonetz Soils

The *soloths*, *solodics* and *solodized solonetz* soils have very similar profile forms. They are characterized by thin, light grey-brown sandy loam A_1 horizons over very strongly bleached A_2 horizons of similar texture. Depth of A horizons ranges from 5 to 70 cm, but the great majority fall within the 15–25 cm range. There is a very abrupt change to sandy clay or heavy clay B horizons which range in colour from light grey through yellow and brown, to black, and may be whole-coloured or mottled. Structure ranges from strong, medium or coarse prismatic to blocky in the *soloths* and *solodics* to strong columnar in the *solodized solonetz*. Columns are usually 10–15 cm in diameter, but some are in excess of 1 m with about 25 cm depth differential between centre and edge of the domed column. Thickness of B horizon clay is variable, depending on topographic position and depositional history. On piedmont slopes, the clays grade to coarse angular gravels with a sandy clay matrix at 1·5–2 m, but clays deeper than 25 m have been observed. On the alluvial plain, B horizon clays grade to unconsolidated sandy sediments or overlie buried soil profiles at depths between 1 and 6 m.

The *soloths* are acid throughout and are generally restricted to the wetter northern and southern extremities of the survey area. The acid profile may be due to the stronger leaching effect of the wetter environment, but there may also be some parent material influence in that the alluvium of these areas is derived wholly from acid igneous rocks. If the pH difference is due mainly to climatic conditions, one would expect a gradual pH change as rainfall increases. In the Bluewater Creek area of the northern section, this is not so; mildly acid and strongly alkaline profiles occur in close proximity, but it is difficult to determine their relationship owing to the numerous migrations of Bluewater Creek obliterating the older depositional patterns.

In the drier areas, mildly acid duplex soils also occur on many of the piedmont slopes, and on small areas of alluvium which are slightly elevated and may represent an older depositional surface.

Although sedimentary layering is clearly evident in the B horizon of many of these soils, there is no field evidence to suggest that the duplex profile is a result of deposition. The depth of A horizon ranges from 5 to 70 cm and the textures from clay loam to coarse sand. Neither the depth nor texture seem to bear any relationship to depositional patterns. The only points of significance in relation to the A horizons are that those soils with a deep dark A_1 horizon have free-draining B horizons, e.g. Scrubby series (McCown *et al.* 1976). They may also be occasionally flooded and are possibly subject to deposition. In some areas subject to prolonged saturation, there is evidence that the A_2 horizons are being formed from the B horizon clays. In these situations, although there is an abrupt change from A_2 to B horizon materials, the boundary is very uneven and pockets of unaltered clay are found in the A_2 horizon or alternatively pockets of A_2 materials occur in the B horizon clays. The processes involved in this alteration are not known, but others have suggested that factors other than clay eluviation and sedimentation may be involved in the development of texture-contrast profiles (Brewer 1968; Brewer and Walker 1969). The general impression gained from some 2000 observations is that the duplex profile is the result of soil genesis but that most soils are in a 'steady state' condition, i.e. in most cases the factors influencing duplex profile development are in equilibrium with those tending to destroy it, e.g. biological activity, and it is only in sites with unusual water regimes that change is taking place.

The origin of the small islands of Sandalwood series soils with their more saline and highly alkaline B horizons is not clear. In some areas, they have a roughly linear form which bears some relationship to prior drainage patterns and they may be developed on the back slopes of relic levees, while in other areas seepage waters may have contributed to the salt accumulation. Small temporary springs are a common feature over much of the coastal plain following seasons of exceptionally high rainfall, and some areas of Sandalwood soils may owe their origin to salt accumulation by spring seepage. A modern example may be seen along the northern abutment of Ross River dam where seepage waters from the dam are translocating subsoil salts to the surface.

The variability of clay mineralogy within many of the duplex soils is unexplainable. While most of the Dy 2 soils are expected to have expansive clay subsoils, no pattern has been established in the occurrence of montmorillonite in the clays of the Dy 3 soils. Although there is little evidence of surface cracking and gilgai microrelief has not developed, the swell-shrink properties of these soils is clearly evident from the strong slickenside development in the B horizons. Where the B horizon clays have been exposed at the surface, gilgai mound development is inhibited by the extremely dispersive nature of the clay.

Red and Yellow Podzolic Soils

Duplex profile differentiation in the podzolic soils is weaker than in the *solodic soils*, the A_2 horizons may or may not be bleached, and there is usually a clear rather than abrupt change to the clay B horizon. The B horizons range from light grey, yellow or yellow-brown to red, and may be whole coloured or mottled; structure is moderate to strong, fine or medium blocky.

The *podzolics* may occur as sedentary soils on intermediate rocks, but are more commonly developed on some of the young colluvial fans and alluvium of the channel infills. The soils with the greyer B horizons occur on the lower slopes of the fans, while the yellow and red soils occupy the better drained sites.

Pall Mal series (Mingela 1 : 100 000; 809513) is characteristic of the sedentary soils, while Alice series (Townsville 1 : 100 000; 464579) and Flagstone series (Townsville 1 : 100 000; 655885) are characteristic of the *red* and *yellow podzolics* respectively.

Saline Soils

This group includes only those soils which are inundated by tidal waters: the saline muds of the mangroves, salt pan soils, and *solonchaks* of the salt water couch marine plain.

The mangrove areas are inundated daily by salt water and very little is known of their soils. Most are dark brown muds of unknown depth; however, those on the shoreline to the south of Cape Cleveland are predominantly sands with only a thin (5 cm) veneer of mud. Many of the mangrove muds contain high amounts of organic matter (largely partially decomposed mangrove roots), while some are underlain by mangrove root peat.

The *solonchaks* are salty duplex soils of the saltwater couch plains (Bowling Green Bay 1 : 100 000; 189694) and are inundated by saline waters only on the four or five very high tides of each year. They have thin (5–12 cm), strongly bleached, silty loam to clay loam A horizons and an abrupt change to strongly structured, dark grey, heavy clay B horizons. These have faint gley mottling in the upper part, and become strongly mottled with yellow and red at about 60–80 cm or just above the permanent water table.

The frequency of inundation of the salt pans varies, but most are covered by tides in excess of 3 m, i.e. the spring tides. The soils range from saline muds similar to those of the mangroves to eroded *solonchaks* of the saltwater couch plain from which they are separated by a low 'salting cliff' 15–25 cm high. Most of the salt pan soils (Townsville 1 : 100 000; 795925) are yellow-brown or yellow-grey clays with prominent bright yellow and red mottles below 15–20 cm and permanent water tables at 50–80 cm depth. A veneer of wind-blown sand overlies the clays in many areas.

Soils on Recent Alluvium

This group embraces a range of soils that occurs on younger alluvial floodplains, terraces, and levees. Soils range from uniform coarse sands to brown gradational-textured soils.

The uniform sands occur on the lower alluvial terraces and are subject to frequent inundation. They have very dark grey-brown sandy loam A horizons and grey-brown or pale brown, weakly coherent sandy loam or coarse sand subsoils. Coarse, water-worn gravels occur at depths of 1–2 m.

The gradational soils occupy the higher terraces. They have dark grey-brown, massive, sandy loam A_1 horizons and slightly paler, weakly developed A_2 horizons. At about 40 cm there is a gradual change to brown or yellowish brown sandy clay loam to light sandy clay B horizons. These are massive, porous, and friable, and grade into water-worn gravels at 1–1·5 m.

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Appendix I. Vegetation Communities

Closed Forest—Low Closed Forest

Closed forests are the dominant vegetation community on Mount Elliot and Cape Cleveland, and there are many smaller areas in sheltered valleys on rocky scree slopes on most of the upland country. The lower communities are dominated by *Acacia* spp. or by numerous semi-deciduous softwood species, while the taller communities are typical of the tropical rain forests with a predominantly Indo-Malaysian flora. Hoop pine (*Araucaria cunninghamii*) commonly occurs as an emergent in the lower community particularly in the Cape Cleveland area.

Mangrove Low Closed Forest

Mangroves occur as a narrow fringe to all small tidal inlets and creeks, and there are some larger areas on off-shore mudflats. The height and density of the mangroves vary with species and location. Macnae (1966) has described a distinct species zonation for the mangroves of this area, with heights ranging from 2 to 10 m; common genera include *Ceriops*, *Bruguiera*, *Rhizophora* and *Avicennia*.

Eucalypt Open Forest

This community is common on the stabilized beach ridges in the Cape Cleveland area, and is interspersed with areas of grassland or salt pans in the interdune swales. Carbeen or Moreton Bay ash (*Eucalyptus tessellaris*) is dominant over most of the unit, and grey bloodwood (*E. polycarpa*), narrow-leaved ironbark (*E. drepanophylla*) and poplar gum (*E. alba*) are the most common associated species and may be dominant in some areas; *Acacia* spp. and some *Pandanus* spp. groves are prominent in the understory. Introduced *Lantana gamara* has invaded large areas. The ground cover is normally very sparse with black spear-grass (*Heteropogon contortus*) and pitted blue grass (*Bothriochloa decipiens*) most common. Tea-trees (*Melaleuca leucadendron* and *M. viridflora*) are common on lower slopes of the beach ridges and in poorly drained swales, but only in those areas where there is no tidal inundation.

Another eucalypt open forest community occurs on the steep hilly country of Saddle Mountain and fringing the rain forests on Mount Elliot and Cape Cleveland. Little is known of this community, and few species identifications have been made. Bendoo (*E. exerta*) is dominant in some areas, and other prominent species include bloodwood (probably *E. intermedia*), stringybark (*E. umbra*) and narrow-leaved iron bark (*E. drepanophylla*).

Bloodwood Woodland

Although dominantly grey bloodwood (*E. polycarpa*), this is a fairly mixed community with poplar gum (*E. alba*), narrow-leaved ironbark (*E. drepanophylla*) and ghost gum (*E. papuana*) occurring consistently. In many areas there is a prominent understory of broad-leaved tea-tree (*M. viridiflora*), cockatoo apple (*Planchonia careya*) and *Acacia* spp. The ground cover is fairly sparse, with giant speargrass (*H. triticeus*) most common in the wetter areas and black speargrass (*H. contortus*) in the drier areas. Kangaroo grass (*Themeda australis*) is a common associate. This community occurs on all the areas of channel infills, although the trees are fewer and larger and the grass sward is denser on the younger channel infills.

Quinine Low Woodland or Low Open Woodland

Quinine (*Petalostigma banksii*) is dominant overall, but there are considerable areas where both narrow-leaved (*M. nervosa*) and broad-leaved tea-tree (*M. viridiflora*) are closely associated. Narrow-leaved ironbark (*E. drepanophylla*), bloodwood (*E. polycarpa*) and poplar gum (*E. alba*) commonly occur as taller emergents through the community. Groves of *Pandanas* spp. are also common on poorly drained sites. Ground cover is very sparse and is dominated by short annual *Chloris* and *Aristida* spp. Black speargrass (*H. contortus*) and giant speargrass (*H. triticeus*) are also common. This community occurs on the deep coarse sandy soils on granitic uplands, and on colluvial fans derived from coarse granitic bed-rock.

Narrow-leaved Ironbark Open Woodland

Narrow-leaved ironbark (*E. drepanophylla*) is dominant throughout, but poplar gum (*E. alba*), ghost gum (*E. papuana*) and grey bloodwood (*E. polycarpa*) are almost always closely associated. Broad-leaved tea-tree (*M. viridiflora*) and cockatoo apple (*Planchonia careya*) often occur as a prominent understory. On the hilly country this community is generally lower, and more open and red bloodwood (*E. dichromophloia*) is the most common associated species. There is generally a dense grass sward throughout; species dominance varies from black spear grass (*H. contortus*) to kangaroo grass (*T. australia*) with giant speargrass (*H. triticeus*) the most common associate. This is the most widespread community and commonly occurs on the solodic soils of the older alluvial plain, the earth soils of the piedmont slopes and the shallow gravelly soils of the hilly country.

Poplar Gum Open Woodland

This community generally occurs as small discrete areas within the narrow-leaf ironbark open woodland. It is most common on the duplex soils of the older alluvium where these are subject to occasional flooding. Poplar gum (*E. alba*) is occasionally monospecific, but there is also usually some carbeen (*E. tessellaris*), grey bloodwood (*E. polycarpa*) or narrow-leaved ironbark (*E. drepanophylla*). Ground cover is similar to that of the narrow-leaved ironbark open woodland.

Ghost Gum Open Woodland

This is a very open community restricted to areas of clay soil and to gilgai areas with a complex of cracking clays and heavy surface-textured solodic soils. Ghost gum (*E. papuana*) is dominant, but carbeen (*E. tessellaris*), poplar gum (*E. alba*) and beefwood (*Grevillea striata*) are common associates. The grass sward is moderate to dense and variable in composition; black spear grass (*H. contortus*) is probably most common, but there are appreciable amounts of forest blue grass (*B. bladhii*), pitted blue grass (*B. intermedia*) and kangaroo grass (*T. australis*).

Broad-leaved Tea-tree Low Open Woodland

In some areas this community may grade to low woodland. In many areas broad-leaved tea-tree (*M. viridiflora*) is monospecific, while in others, poplar gum (*E. alba*), carbeen (*E. tessellaris*) or narrow-leaved ironbark (*E. drepanophylla*) may occur as emergents. Most areas are characterized by a dense kangaroo grass (*T. australis*) sward, although black speargrass (*H. contortus*) may occasionally be prominent. Giant speargrass (*H. triticeus*) is also common throughout. This community is most common on the low, poorly drained country adjacent to the coast, but also occurs on seepage areas and lower piedmont slopes.

Sandalwood Low Open Woodland

This community occurs as small isolated areas restricted to very shallow-surfaced solodic soils; many areas have been almost completely cut out, as sandalwood is a highly regarded fencing timber. Sandalwood (*Eremophila mitchellii*) is dominant, but beefwood (*G. striata*) and ghost gum (*E. papuana*) emergents are associated. Ground cover is sparse, with kerosene grass (*Aristida browniana*) usually dominant, although annual *Chloris* spp. and black spear grass (*H. contortus*) may be prominent in some areas.

Salt-water Couch Grassland

This unit occurs on the low-lying plains adjacent to the coast, usually bordering salt pans. Salt-water couch (*Sporobolus virginicus*) forms a low dense sward. The most commonly associated species are salt-water paspalum (*Paspalum vaginatum*) and *Fimbristylis polytrichloides*. The introduced shrub *Parkinsonia aculeata* has invaded some of the very heavily grazed portions of these grasslands.

Salt-pan

Most areas of salt-pan are completely devoid of vegetation, but in some areas there are scattered samphires (*Arthrocnemum leiostachyum*, *A. halocnemoides* var. *pergranulatum* and *Salicornia quinqueflora*).

Freshwater Swamps

Extensive freshwater swamps occur immediately behind the beach ridges in the Clevedon area. Little is known of their flora. The sedges of *Eleocharis* spp. and *Scirpus* spp. are dominant, and rice grass (*Leersia hexandra*) is common around the margins.

Appendix II. Analytical Data

Methods

pH. Determined on a 1 : 5 soil/water suspension using glass and calomel electrodes and a Philips direct reading pH meter after shaking in a reciprocating shaker for 1 h.

Total soluble salts (*TSS*). Calculated from conductivity measurements on the above 1 : 5 suspension at 25°C. A factor of 336 × conductivity was applied.

Total nitrogen. Determined by the Honda (1962) modification of the Kjeldahl method.

Organic carbon. Readily oxidizable organic matter was determined by the method of Walkley and Black (1934). No factor has been applied.

Available phosphorus. Determined by the method of Kerr and von Stieglitz (1938) by extracting with 0·01 N sulfuric acid for 16 h.

Total P, K and S. Determined by X-ray spectrography as described by Stace *et al.* (1968).

Exchangeable cations. Exchangeable basic cations were extracted with N ammonium chloride at pH 7·0. Exchangeable acidic cations were determined at the same pH using a modification of Piper's (1944) 'exchangeable hydrogen' method. Cation exchange capacity was obtained by the summation of exchangeable basic and acidic cations.

Particle size. The plummet balance method of Hutton (1955) was used for particle-size analysis, but the 5% correction for silt and clay in this method was omitted.

Note: All results are reported on an over-dry basis. Unless otherwise specified, all horizon boundaries in the morphological descriptions are gradational.

Representative morphological and analytical data for the Granite, Bluewater, Stag, Alice, Gulliver, Pall Mal, Althaus and Kulburn series are included in Murtha (1975) and for the Gilligan, Flagstone, Woodridge, Double Barrel, Sandalwood, Lansdown, Stockyard and Manton series in Murtha and Crack (1966). A further seven series of areal or agronomic significance are described in this appendix.

Soil series:	Brolga	Great Soil Group:	Grey clay	Vegetation:	Sedgeland
Location:	Bowling Green Bay, 1 : 100000, 175773	Principal Profile Form:	Ug5.28	Rainfall:	1300 mm
		Soil taxonomy:	Entic Pellustert	Land use:	Grazing of native pastures

Sample No.	Horizon	Depth (cm)	Morphological description
T217.1	A	0–3	Light grey (10YR7/1m) heavy clay; massive; hard; very prominent yellow-brown root tracings
	B1	3–10	Very dark grey (10YR3/1m) heavy clay; strong medium blocky; hard; root tracings as above
.2	B2	10–20	Very dark grey (10YR3/1m) with few red (2·5YR4/6m) mottles; heavy clay; strong fine blocky; firm
.3		20–30	Prominent mottle grey (10YR4/1m) red (2·5YR4/6m) and olive (5YR5/3m) heavy clay; strong fine blocky; plastic; lenses
.4A		30–45	of pale brown sand between structural units
.4B	B3	45–60	Prominent mottle dark grey (10YR4/1m) and brownish yellow (10YR6/6m) heavy clay; moderate coarse blocky; plastic
.5	B3	60–90	
.6	C	90–105	Mottled grey, light grey and brownish yellow; fine sandy clay; massive; plastic and sticky; free water from 90 cm

No.	pH	TSS (%)	NaCl (%)	Org. C (%)	N (%)	P A (ppm)	P Total (%)	Particle size (%) CS	FS	Si	C	Exchangeable cations (m.e./100 g) Ca	Mg	K	Na
.1	5·7	0·14	0·04	1·40	0·11	39		1	34	25	41	5·4	8·4	1·23	1·7
.2	6·0	0·12	0·03												
.3	5·7	0·17	0·04			22		1	25	24	50	6·1	9·5	1·16	2·0
.4A	5·7	0·22	0·07												
.4B	5·6	0·24	0·07												
.5	5·3	0·23	0·07			7		1	35	19	46	6·2	9·4	0·95	2·2
.6	5·1	0·26	0·11												

Soil series:	Sachs	Great Soil Group:	Black earth	Vegetation:	Grassland
Location:	Townsville, 1 : 100000, 081710	Principal Profile Form:	Ug 5.16	Rainfall:	1150 mm
		Soil taxonomy:	Typic Pellustert	Land use:	Grazing of native pastures

Sample No.	Horizon	Depth (cm)	Morphological description
T219.1	A	0–10	Very dark grey (10YR3/1m) heavy clay; moderate medium blocky; hard; slight 5–20 mm rounded quartz gravel
.2		10–20	Very dark grey (10YR3/1m) heavy clay; moderate coarse blocky; hard; slight 5–20 mm carbonate nodules
.3		20–30	
.4		30–60	Very dark grey (10YR3/1m) heavy clay; strong coarse blocky; hard; slight carbonate and few fine FeMn nodules
.5		60–90	
.6		90–120	Grey (10YR4/1m) heavy clay; strong coarse blocky; firm; slight carbonate and FeMn nodules as above
.7		120–150	
.8		150–180	Faintly mottled grey (10YR5/1m) and light yellowish brown (10YR6/4m) heavy clay; strong medium blocky; firm; nodules as above; very prominent slickensides

No.	pH	TSS (%)	NaCl (%)	S (%)	K (%)	Org. C (%)	N (%)	P A (ppm)	P Total (%)	Particle size (%) CS	FS	Si	C	Exchangeable cations (m.e./100 g) Ca	Mg	K	Na
.1	7·8	0·08	0·01	0·02	0·56	1·43	0·14	28	0·036	4	12	25	59	28·7	20·9	0·40	0·4
.2	8·7	0·05	<0·01														
.3	8·8	0·05	<0·01	0·11	0·54				0·019								
.4	9·1	0·05	<0·01					17		8	10	21	61	27·3	26·0	0·13	1·8
.5	9·4	0·11	0·02														
.6	9·0	0·42	0·22					41		7	11	22	59	19·0	27·7	0·17	8·1
.7	9·0	0·52	0·25	0·01	0·61				0·017								
.8	8·9	0·57	0·28														

Soil series:	Julago	Great Soil Group:	No provision	Vegetation:	Eucalypt open woodland
Location:	Townsville,	Principal Profile Form:	Db1.13	Rainfall:	1150 mm
	1 : 100000, 043712	Soil taxonomy:	Oxic Haplustalf	Land use:	Grazing of native pastures

Sample No.	Horizon	Depth (cm)	Morphological description
T215.1	A1	0–8	Very dark greyish brown (10YR3/2m) clay loam; weak fine blocky; friable; clear change
.2	B1	8–20	Dark brown (10YR3/3m) medium to heavy clay; strong medium blocky; hard; few fine FeMn nodules
.3	B2	20–30	Dark brown (10YR3/3m) heavy clay; strong coarse blocky; hard; few fine FeMn nodules
.4		30–60	Dark brown (10YR4/2m) heavy clay; strong coarse blocky; hard; few fine FeMn nodules
.5		60–90	Dark reddish brown (5YR3/2m) heavy clay; strong coarse blocky; hard; low 2–5 mm carbonate nodules
.6		90–120	
.7		120–150	Dark brown (7·5YR3/2m) heavy clay; strong coarse blocky; hard; slight 2–5 mm carbonate nodules
.8		150–180	
.9		180–210	Brown (7·5YR4/2m) heavy clay (sandy); strong coarse blocky; hard; slight carbonate nodules to 25 mm
.10		210–240	

No.	pH	TSS (%)	NaCl (%)	S (%)	K (%)	Org. C (%)	N (%)	P A (ppm)	P Total (%)	Particle size (%) CS	FS	Si	C	Exchangeable cations (m.e./100 g) Ca	Mg	K	Na
.1	6·5	<0·02	<0·01	0·03	0·40	2·13	0·15	14	0·049	6	29	31	32	9·5	8·0	0·40	0·2
.2	6·4	<0·02	<0·01					4	0·024					9·6	8·4	0·10	0·4
.3	6·9	<0·02	<0·01	0·02	0·47												
.4A	7·3	<0·02	<0·01					30		6	18	19	52	10·8	9·4	0·09	0·7
.4B	8·0	0·05	<0·01														
.5	9·1	0·08	0·01							17	30	19	34	23·1	9·7	<0·01	1·7
.6	9·3	0·19	0·04														
.7	9·1	0·26	0·09	<0·01	0·64					9	29	25	44				
.8	9·1	0·28	0·11														
.9	9·0	0·31	0·13														
.10	9·0	0·31	0·14														

Soil series:	Stuart	Great Soil Group:	Non-calcic brown soil	Vegetation:	Eucalypt woodland
Location:	Townsville, 1 : 100000, 023712	Principal Profile Form:	Dr 2.22	Rainfall:	1150 mm
		Soil taxonomy:	Udic Paleustalf	Land use:	Grazing of native pastures

Sample No.	Horizon	Depth (cm)	Morphological description
T221.1	A1	0–10	Very dark grey (10YR3/1m) loam; weak fine blocky; firm; slight 5–10 cm gravel
.2A	A2	10–16	Dark reddish grey (5YR4/2m) loam; weak fine blocky; firm; many fine FeMn nodules, clear change
.2B	B2	16–20	Dark red (2·5YR3/6m) light medium clay; moderate medium blocky; firm; slight 2–5 mm FeMn nodules
.3	B2	20–30	
.4	B2	30–60	Dark red (2·5YR3/6m) medium-heavy clay; strong medium blocky; firm; slight andesite gravel
.5	B3	60–90	Faintly mottled yellowish red (5YR5/6m) and light yellowish brown (10YR6/3m), otherwise as above
.6A	B–C	90–113	Distinct mottle yellowish red (5YR5/6m) and light brownish grey (10YR6/2m) medium clay; moderate coarse blocky; firm; moderate soft weathered andesite
.6B	C	113–120	Soft weathered andesite

No.	pH	TSS (%)	NaCl (%)	S (%)	K (%)	Org. C (%)	N (%)	P A (ppm)	P Total (%)	Particle size (%) CS	FS	Si	C	Exchangeable cations (m.e./100 g) Ca	Mg	K	Na
.1	6·4	<0·02	<0·01	0·03	1·38	3·75	0·21	153	0·130	15	27	27	31	15·1	5·4	1·17	0·1
.2A	6·2	<0·02	<0·01							13	29	26	31				
.2B	6·2	<0·02	<0·01							16	28	24	32				
.3	6·3	<0·02	<0·01	0·01	1·46			12	0·058	14	27	23	37	9·0	3·1	0·47	0·1
.4	6·7	<0·02	<0·01														
.5	7·0	<0·02	<0·01							6	12	18	63	10·9	7·1	0·09	0·2
.6A	7·2	<0·02	<0·01														
.6B	7·3	<0·02	<0·01	0·01	1·13			652	0·082								

Soil series:	Healy	Great Soil Group:	Solodized solonetz	Vegetation:	Eucalypt woodland
Location:	Townsville, 1 : 100 000, 881787	Principal Profile Form:	Dy 3.43	Rainfall:	1170 mm
		Soil taxonomy:	Typic Natrustalf	Land use:	Nil

Sample No.	Horizon	Depth (cm)	Morphological description
T1.1	A1	0–9	Dark greyish brown (10YR4/2m) loamy sand; massive; slightly hard (dry); slight fine quartz gravel
.2	A2	9–22	Yellowish brown (10YR5/4m) (7/2d) loamy sand; massive; slightly hard (dry); very fine porous; abrupt change
.3	B21	22–30	Faintly mottled yellowish brown (10YR5/4m) and dark brownish grey (10YR5/4) sandy clay; moderate coarse columnar; hard; dark brown staining to ped faces; gradual change
.4	B22	30–40	Distinct mottle brown (10YR5/3m) and yellowish brown (10YR5/6m) sandy clay; moderate coarse blocky; hard; gradual change
.5	B2	40–60	As above with slight FeMn nodules to 10 mm size
.6	B2	60–90	Distinct mottle pale brown (10YR6/3m) and yellowish brown (10YR5/4m) sandy clay; weak coarse blocky; hard; low amounts 10–50 mm carbonate nodules and slight 5–10 mm FeMn nodules
.7		90–120	Distinct mottle brown (10YR5/3m) and yellowish brown; sandy clay; massive; hard; low 10–50 mm carbonate nodules
.8		120–150	As above, sandy clay loam texture

No.	pH	TSS (%)	NaCl (%)	CaCo₃	Org. C (%)	N (%)	P A (ppm)	P Total (%)	Particle size (%) CS	FS	Si	C	Exchangeable cations (m.e./100 g) Ca	Mg	K	Na
.1	5·2	0·04	0·02		0·8	0·08	5	·011	25	48	14	12	1·3	0·7	0·67	0·5
.2	5·2	0·01	<0·01		0·3	0·03	3		24	50	15	15	1·0	0·5	0·08	0·5
.3	6·4	0·03	0·01		0·3	0·04	4	·010	20	30	11	37	1·6	5·2	0·12	2·2
.4	7·4	0·05	0·02				4						1·4	5·4	0·12	2·5
.5	9·2	0·11	0·06				2						1·8	6·2	0·14	3·6
.6	9·4	0·14	0·08				2		33	31	13	23	2·0	4·8	0·16	5·3
.7	9·2	0·10	0·10	0·6			2						2·0	6·1	0·16	6·0
.8	9·2	0·19	0·12	0·3			4	·007					2·4	6·5		7·0

Soil series:	Bently	Great Soil Group:	Solodic	Vegetation:	Cleared eucalypt woodland
Location:	Townsville	Principal Profile Form:	Dy 3.42	Rainfall:	1150 mm
	1 : 100 000, 096704	Soil taxonomy:	Haplustalf	Land use:	Grazing of improved pastures

Sample No.	Horizon	Depth (cm)	Morphological description
T218.1	A1	0–10	Dark grey (10YR4/1m) silty loam; massive; firm; some bleached patches near base of A1
.2	A2	10–20	Greyish brown (10YR5/2m) (7/2d) silty loam; massive; firm; slight soft FeMn nodules to 5 mm size gradual change
.3	A2	20–30	
.4A	A3	30–35	Yellowish brown (10YR5/4m) (7/4d) silty clay loam; massive; firm; some bleached patches throughout; abrupt change
.4B	B2	35–50	Faintly mottled yellowish brown (10YR5/6m) and light brownish grey (10YR6/2m) heavy clay; moderate medium blocky; hard; slight 2–5 mm FeMn nodules
.4C	B2	50–60	
.5	B2	60–90	Distinct mottle yellowish brown (10YR5/8m) and light brownish grey (10YR6/2m) as above
.6	B–C	90–120	Distinct mottle yellowish brown (10YR5/6m) and grey (10YR5/1m) grading to sandy clay; weak coarse blocky; hard; moderate soft FeMn nodules to 10 mm size

No.	pH	TSS (%)	NaCl (%)	S (%)	K (%)	Org. C (%)	N (%)	P A (ppm)	P Total (%)	Particle size (%) CS	FS	Si	C	Exchangeable cations (m.e./100 g) Ca	Mg	K	Na
.1	5·8	<0·02	<0·01	0·01	2·12	0·94	0·09	21	0·027	13	41	32	12	3·5	1·6	0·55	<0·1
.2	5·8	<0·02	<0·01														
.3	5·6	<0·02	<0·01					4		13	41	30	16				
.4A	5·8	<0·02	<0·01														
.4B	6·2	<0·02	<0·01	0·01	1·35				0·025	7	22	16	56	5·6	5·9	0·11	0·5
.4C	6·5	<0·02	<0·01											5·4	5·6	0·11	0·7
5	6·9	<0·02	<0·01														
.6	7·6	<0·02	<0·01	0·01	2·12				0·024	25	24	21	33	5·2	4·9	0·11	1·1

Soil series:	Coonambelah	Great Soil Group:	Solodic–Solonchak (Intergrade)	Vegetation:	Grassland
Location:	Bowling Green Bay, 1 : 100 000, 189694	Principal Profile Form:	Dy 3.32	Rainfall:	1300 mm
		Soil taxonomy:	Aquic Natrustalf	Land use:	Grazing of native pastures

Sample No.	Horizon	Depth (cm)	Morphological description
T216.1A	A1–A2	0–15	Dark grey (10YR4/1m) with some bleached patches; loam; massive; firm; some faint rusty mottles and root tracings; abrupt change
.1B	B1	5–10	Faintly mottled dark grey (10YR3/1m) and dark greyish brown (10YR4/2m) heavy clay; strong fine columnar; hard; gradual change
.2	B2	10–20	Distinct mottle; dark grey (10YR4/1m), dark greyish brown (10YR3/2m) and yellowish red (5YR4/8m) heavy clay; strong coarse blocky; hard; slight fine FeMn nodules
.3	B2	20–30	
.4	B3	30–60	Distinct mottle grey (10YR6/1m) and yellowish brown (10YR5/4m) heavy clay (fine sandy); massive; wet plastic; few bright ochre mottles
.5	C	60–90	Light grey (10YR6/1m) fine sandy clay; massive; plastic
.6		90–105	As above with water table at 100 cm

No.	pH	TSS (%)	NaCl (%)	S (%)	K (%)	Org. C (%)	N (%)	P A (ppm)	P Total (%)	Particle size (%) CS	FS	Si	C	Exchangeable cations (m.e./100 g) Ca	Mg	K	Na
.1A	5·3	0·23	0·09	0·05	1·5	2·80	0·27	40	0·032	3	55	23	16	2·7	3·3	0·15	0·9
.1B	6·0	0·16	0·06					16						2·9	11·0	1·09	3·0
.2	6·9	0·17	0·05	0·04	1·9				0·041	2	34	29	44				
.3	7·3	0·27	0·14											2·9	11·1	0·80	5·2
.4A	7·0	0·52	0·26	0·04	1·9				0·024								
.4B	6·3	0·74	0·37														
.5	6·0	0·89	0·54														
.6	5·3	1·38	0·79											2·3	10·4	0·72	10·4