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

G. G. MURTHA

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Abstract

A soil survey has been made of *c.* 130 000 ha of the coastal plain immediately north and west of Townsville, north Queensland. The main vegetation is eucalypt and *Melaleuca* open-woodland. Although there appears to be little correlation between structural form or species dominance and soil pattern they have an important bearing on the form of pastoral development that may be initiated. The soils have been mapped as associations at series level. The great majority of soils are developed on alluvium derived from a range of acid and intermediate igneous and metamorphic rocks.

The soil pattern is very closely correlated with the geomorphic development of the plain and is related to the sequence of deposition. A wide range of solodic and solodized solonetz soils occupy the Pleistocene plain deposits; red and yellow podzolics and red and yellow earths occupy the mid-Holocene deposits; red and yellow earths and undifferentiated alluvial soils are common to the younger alluvial levees and terraces. Red, yellow and grey earths are most common on the narrow colluvial slopes and fans fringing the coastal scarp and surrounding the base of low hills scattered throughout the area.

In general, soil fertility levels are very low. All major soils have been sampled and chemical and physical properties of importance to agricultural land use are discussed. A land capability classification is presented but as there appears to be little opportunity for agricultural development in this area it is orientated strongly towards the potential for improved pasture development.

Introduction

For the purpose of this survey the Townsville coastal plain is defined as that area bounded by Rollingstone Creek in the north, the Haughton River in the south and the coastal ranges to the west. These limits define a fairly homogeneous area. North of Rollingstone Creek the coastal plain is very narrow and rainfall increases markedly whilst south of the Haughton River it is replaced by the large delta system of the Burdekin River and Barratta Creeks.

This report covers that part of the coastal plain to the north and west of Ross River. It includes the greater part of the city of Townsville and covers an area of approximately 130 000 ha between 19°00′ and 19°40′S. and 146°20′ and 146°50′E. (Fig. 1).

Previous soils information in this area includes land system mapping (Christian *et al.* 1953), 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).

The chief aim of the present survey was a closer study of the morphological characteristics and field relationships of the range of solodic and solodized solonetz soils which previous mapping had shown to be dominant over the greater part of the coastal plain. In addition, as the population of the city area increases so does the demand for closer settlement of the surrounding district. A detailed knowledge of the types of soils occurring, their nutrient status and their physical properties is necessary to help overcome the problems associated with more intensive development.

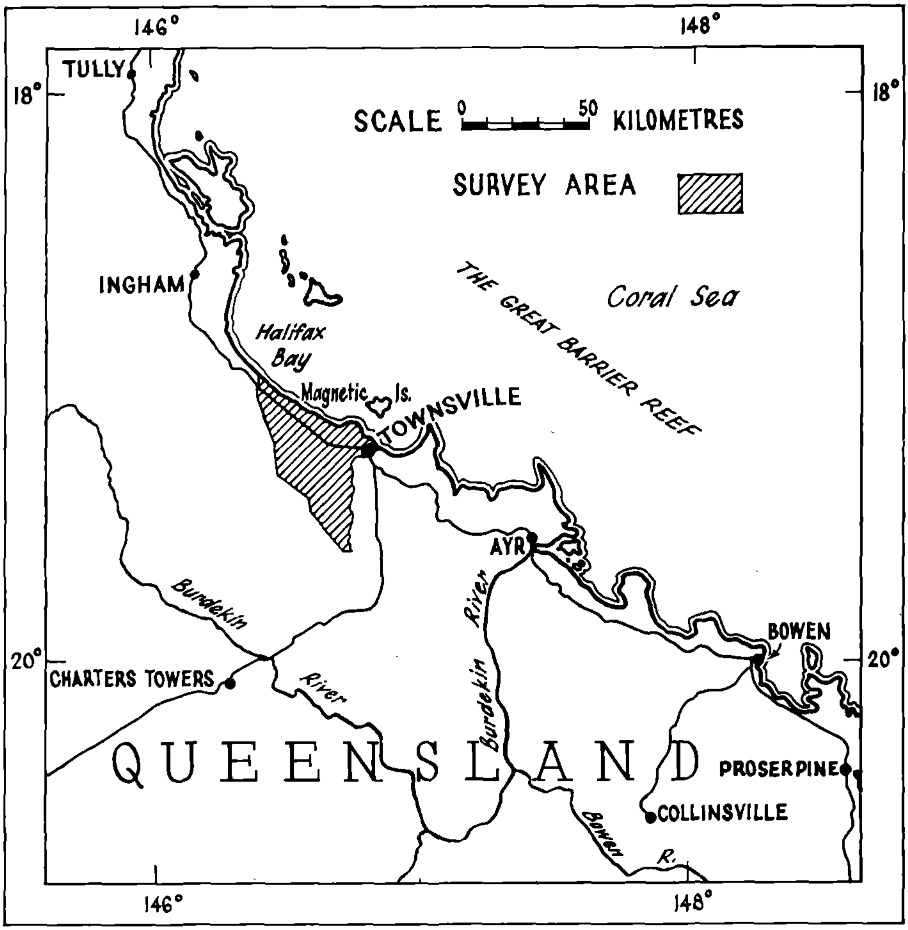

Fig. 1. Locality plan.

Environment

Geology and Physiography

The geology of the area has been described by Wyatt *et al.* (1969). A brief account of the geology is given below in the discussion of each of the physiographic units. The physiography of parts of the survey area has been described in detail by Driscoll and Hopley (1968) and Hopley (1970). A general account covering a much broader area is given by Hedley (1925), Jardine (1928), Christian *et al.* (1953) and Wyatt *et al.* (1969). The distribution of the broad physiographic units is shown in Fig. 2. Fig. 3 gives an aerial view of part of the area.

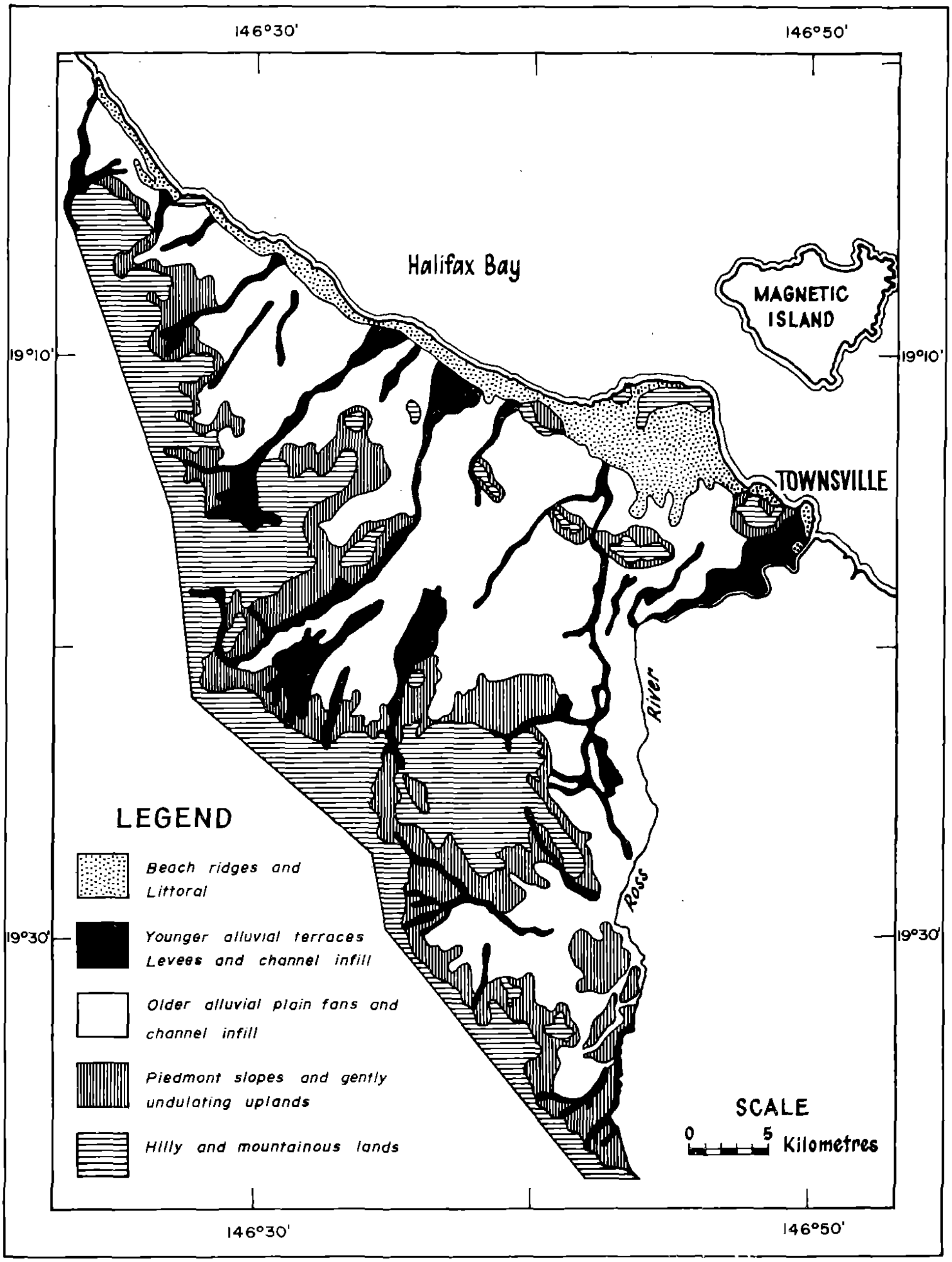

Fig. 2. Distribution of physiographic units.

Beach Ridges and Littoral

A relatively narrow system of beach ridges occurs along almost the entire coastline. The ridges are generally closely spaced, range in height from 1 to 4 m and overlie the coastal plain deposits. A series of older ridges dated as Pleistocene (Hopley 1970) occur 2–9 km inland from the present coastline. They occupy an arc from the mouth of the Bohle River to Mt St John and trend south-easterly to unmapped occurrences south of Ross River.

Small areas of mangroves and salt pans occur adjacent to all the tidal inlets and streams and occupy a large area to the north of Townsville on the shallow marine pro-delta deposits of former mouths of the Ross and Bohle Rivers.

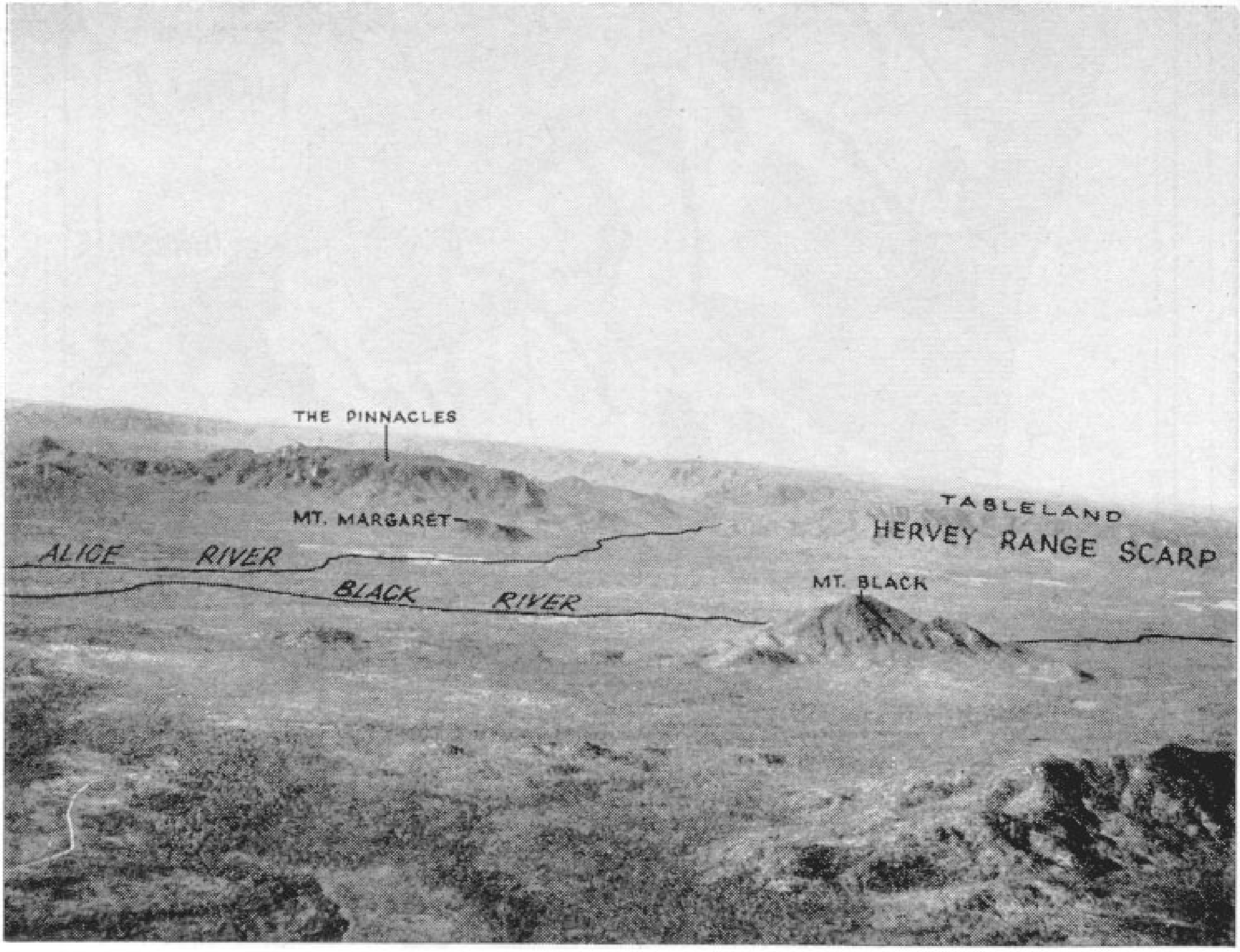

Fig. 3. Aerial oblique showing the generally flat coastal plain, the low inselbergs of Mt Black and Mt Margaret and the plateau remnant of the Pinnacles separated by dissection from Hervey Range tableland. (Photo courtesy M. L. Lamont, James Cook University.)

Younger Alluvial Terraces, Levees and Channel Infill

Levee and terrace development along the streams is extremely variable. Although levees are very pronounced on some streams, in many cases the channel is merely deeply incised in the older plain deposits and there is no current levee or flood-plain development. Terrace development is common towards the headwaters of most streams. Two or three levels occur 1–4 m above the present stream bed. Downstream the terraces either grade into the levees or terminate abruptly where there has been a major change in the course of the stream.

One of the striking features of the coastal plain is the extensive series of abandoned and filled stream channels (Fig. 4). These occur as low elongate rises 0·5–1·5 m above the general level of the plain and can be divided into two broad groups. One group has coarse-textured deposits with very strongly leached sands and leached mottled earthy soils; the other has finer-textured deposits with red earth and red podzolic soils predominating. Hopley (1970) has mapped these as being of Pleistocene and mid Holocene age respectively. The mid Holocene group is included in this unit as the soils are closely affiliated with those of the current levees and terraces. The best example of a channel infill system is a prior course of the Black River. From a point about 19 km upstream of the present Black River mouth the proto-Black flowed in an almost due northerly course through the settlement of Yabulu and skirting the eastern slopes of Mt Saunders. From this point it fanned out to a very distinct delta, the lower end of which is overlain by recent beach-ridge development.

Fig. 4. The low sandy rises of the infilled channels are often marked by very distinct vegetation changes. In this case the infilled channel (left foreground) has giant spear grass and *Xanthorrhoea* ground cover while the duplex soils of the flood-plain are dominantly kangaroo grass.

Older Alluvial Plain, Fans and Channel Infill

This unit occupies by far the largest part of the coastal plain. Although some small areas are subject to local seasonal inundation and deposition, most of the area is above present flood levels and is considered to have received little depositional material since the Pleistocene (Hopley and Murtha 1975). The plain slopes very gradually to the coast. The alluvium at the base of the coastal scarp on the northern part of the plain is 15–30 m above sea level but it attains an altitude of approximately 80 m at the base of the scarp on the headwaters of Ross River. The depth of stream incision ranges from 3·5–4·5 m on the lower part of the plain to 15 m where the streams cut the piedmont slopes in their headwaters.

Bores in the vicinity of Townsville indicate that the alluvial deposits are over 40 m thick in places and consist of bedded clays, sands and waterworn gravels. These are probably all riverine deposits, the greater part of which was laid down during periods of lower sea level.

Some small areas of Pleistocene fans have been preserved on the northern slopes of the Pinnacles while exposures of buried Pleistocene fans occur on the eastern slopes of Mt Douglas and in the headwaters of Bluewater Creek.

The areas of channel infill are most common on the northern section of the coastal plain. Their distribution generally bears some relationship to the present streams and probably indicates the limit of their migration during the Pleistocene.

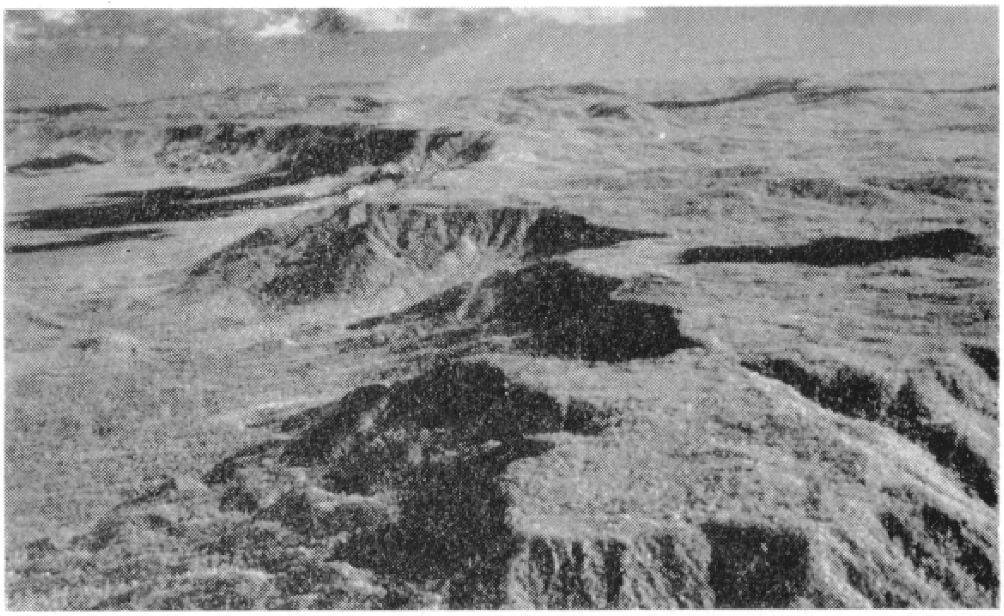

Fig. 5. Aerial oblique of the coastal scarp showing the sharp break in slope from the coastal plain and the moderately to strongly undulating surface of Hervey Range tableland. (Photo courtesy M. L. Lamont, James Cook University.)

Piedmont Slopes and Gently Undulating Uplands

The coastal scarp is fringed by a very narrow piedmont slope 180 m to 2 km wide and with 3–15° slopes. The deposits of these slopes generally grade into, but occasionally overlie, the plain deposits. They consist of 1–2 m of fine earthy materials overlying coarse angular gravels. The thickness of gravels is variable but is known to exceed 10 m in some places. Small areas of very gently undulating land occur as low foothills of the coastal ranges or as low outliers of country rock within the alluvial plain. Local relief is 15–30 m with slopes of 2–5°. The rock types are most commonly coarse-grained acid granites.

Hilly and Mountainous Lands

One of the most prominent features of this area is the very abrupt break in slope from the plain to the steep scarp of the Hervey (Fig. 5) and Paluma Ranges and the fairly steep slopes of the numerous low inselbergs that occur on the plain. Most of the inselbergs are remnants of an older land surface isolated by scarp retreat. A small area of the strongly undulating older land surface of the Hervey Range tableland is preserved on the Pinnacles. The height of the coastal ranges varies from 1000 m in the north to 650 m in the south. The main outliers or inselbergs, Mt Louisa, Many Peaks Range and Castle Hill, are 230, 250 and 340 m high respectively.

The geological pattern is complex. A range of granitic rocks make up the largest area but there are also important areas of acid and intermediate volcanics and lesser amounts of interbedded sediments. There are also some small areas of low-grade metamorphics.

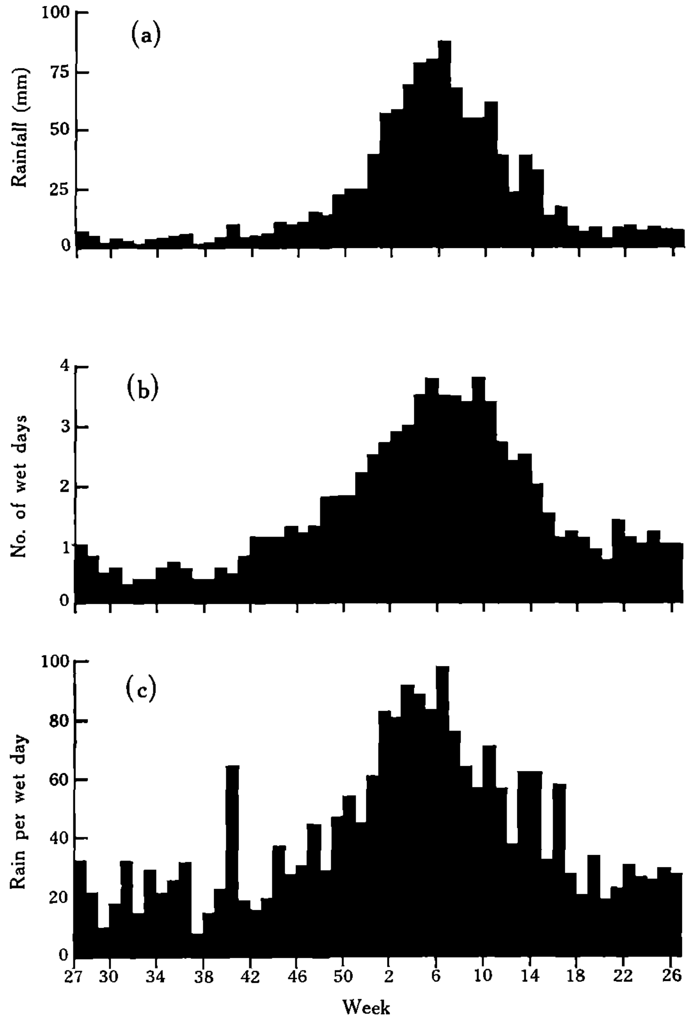

Fig. 6. Histogram showing weekly distribution of (*a*) rainfall, (*b*) number of wet days and (*c*) intensity of rainfall (rain per wet day for all days on which rain was recorded) at Townsville, 1910–60.

Climate

The major features of the climate are: (1) the very marked seasonal distribution of rainfall; (2) the low order of reliability and high variability of rainfall; (3) the

Table 1. Rainfall, temperature and relative humidity data for Townsville[A]

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
Rainfall (mm)—Av.	279	301	197	77	31	31	19	12	17	28	49	122	1163
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
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
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

[A] Temperature and humidity data from Commonwealth Bureau of Meteorology (1970). Rainfall based on 100-year record.

incidence of much of the rainfall as falls of high intensity and short duration; and (4) the hot humid summers and very mild to warm winters.

The only official recording station in the area is at Townsville where the average annual rainfall (over a 100-year period) is 1163 mm (Table 1). Over the survey area the average rainfall varies from *c.* 800 mm in the south-west to *c.* 1400 mm in the north. These figures are estimations only, based on recordings from outside the survey area. There is a very marked seasonal incidence (Fig. 6) with *c.* 70% of the annual rainfall occurring in January–March inclusive.

Annual variability (mean deviation as a percentage of the mean) exceeds 30%; monthly variability in the 'wet season' is 59–66%. Rainfall reliability is best illustrated by the low order of probability (Table 2) when compared with the monthly averages.

Table 2. Rainfall probability, Townsville

Percentage chance of receiving specified amounts of rain or more, based on 100-year record

Rainfall (mm)	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
12	99	98	95	71	56	52	32	25	25	50	63	90
25	98	96	92	62	36	35	19	17	20	25	50	77
76	83	86	70	33	9	12	8	3	8	10	21	50
127	72	75	56	18	5	3	4	—	2	4	13	37
254	46	49	31	7	—	—	—	—	—	1	2	16
381	24	31	14	3	—	—	—	—	—	—	—	5
508	14	20	5	1	—	—	—	—	—	—	—	1

Rainfall intensities are fairly high, averaging about 20 mm per wet day, for the period December–April (Fig. 6), but average figures do not fully reveal the high intensities commonly recorded. In the 50-year period 1910–60 daily falls of >75 mm were recorded on 134 occasions, >130 mm on 50 occasions and >255 mm twice. Falls of 25–50 mm per hour are common.

Christian *et al.* (1953) have made estimates of the length of growing season and length of period of adequate rainfall. These are only a rough guide to average conditions as there is considerable variation in both the time of onset and duration of the 'wet season'. False starts where good December or early January rains are followed by fairly long hot dry spells are common. Although these do not seriously affect perennial grasses, annual species often suffer serious stress and there is always considerable doubt associated with summer cropping.

Mean monthly temperature data are shown in Table 2. The temperature pattern is fairly regular and changes slowly from summer to winter. Very high temperatures are uncommon but the generally high relative humidity can make summer conditions unpleasant. Although frosts have never been recorded at Townsville, very occasional light frost may be experienced in the south-west of the survey area. More detailed meteorological data for the area are given by Commonwealth Bureau of Meteorology (1970).

Vegetation

The coastal plain has a dominant eucalypt open-woodland vegetation but there are considerable areas of *Melaleuca* low open-woodland and lesser areas of eucalypt woodland and open-forest (Appendix 1). The vegetative pattern has some correlation with the geomorphic and soils pattern but over large areas considerable changes in both structural form and species dominance can occur on a single geomorphic unit with a relatively uniform soil pattern.

Although the greater part of the coastal plain still carries native vegetation, most areas have been considerably modified by removal of timber and many current stands are largely seedling or sucker regrowth. Timber treatment as part of a pasture improvement program is becoming increasingly widespread. Pulling, windrowing and burning is probably still the most commonly used method but increasing use is being made of hormone poisons. The latter are particularly effective against *Melaleuca* and most of the eucalypts of this area.

Fig. 7. The introduced shrub chinee apple invading eucalypt open-woodland.

Kangaroo grass (*Themeda australis*) and black spear grass (*Heteropogon contortus*) are by far the most common grasses in the area. Black spear grass is most common on the drier southern end of the coastal plain although kangaroo grass still predominates in many paddocks. These are generally poorly watered paddocks with subsequent lower stocking intensity. This supports the suggestion by Isbell (1969) that cover in these areas in their natural state was mostly kangaroo grass and that management practices have been the major contributing factor in the decline of kangaroo grass and the spread of black spear grass. The wetter northern section of the plain is still largely kangaroo grass with giant spear grass (*Heteropogon triticus*) associated on the more sandy soils. The introduced annual legume Townsville stylo (*Stylosanthes humilis*) is widespread throughout the area. Most of the colonization has been by natural spread but increasing areas are being seeded and fertilized to promote higher pasture production. The introduced shrub chinee apple (*Zisiphus mauritiana*) has become a major pest over a large part of the area (Fig. 7).

The major communities recognized are listed and briefly described in Appendix 1. The structural formations are based on the scheme proposed by Specht (1970).

Soils

General

The soils have been mapped as associations of 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 occurring either as a complex or as a well-defined catenary sequence.

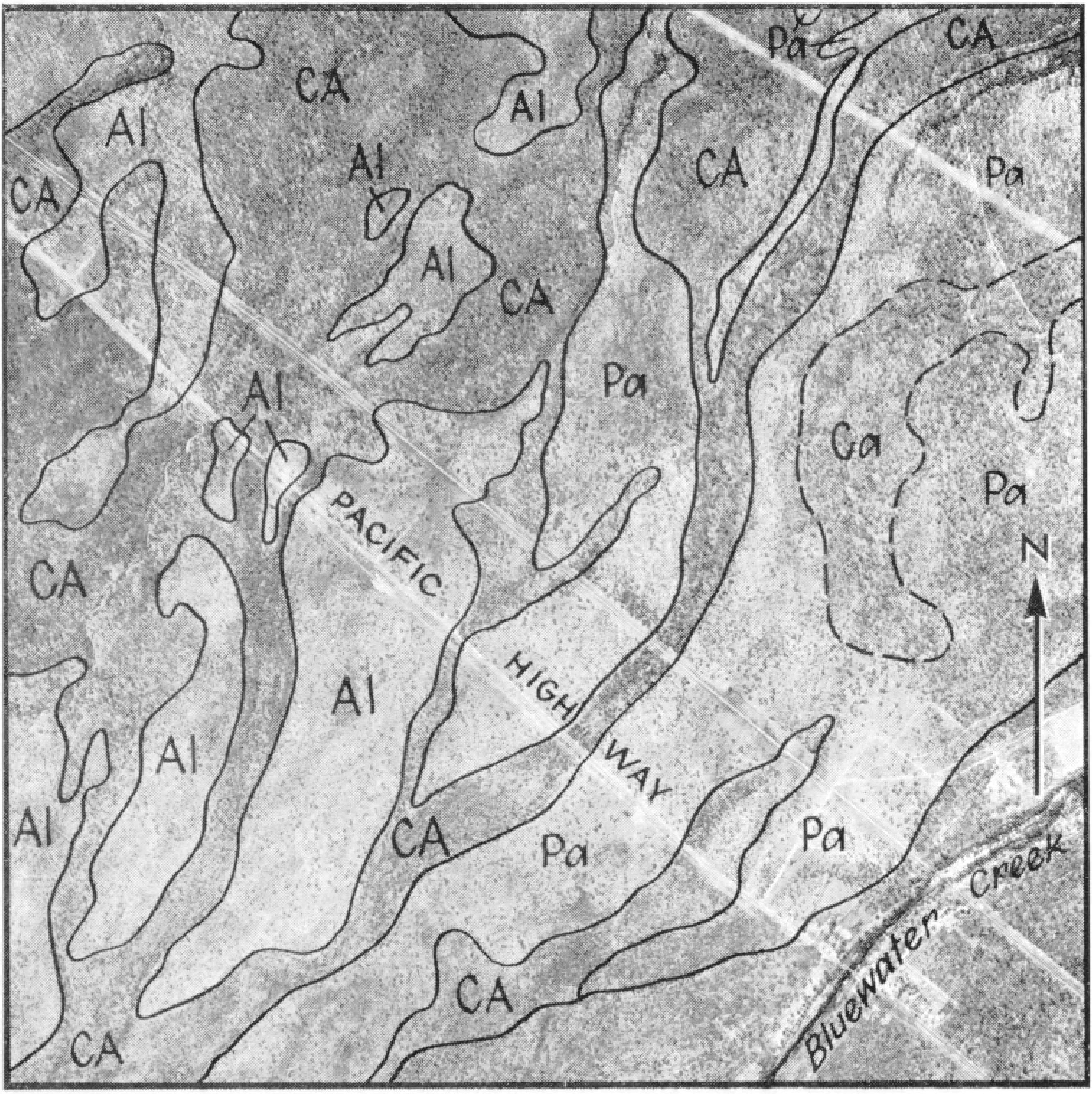

Fig. 8. Vertical aerial photograph of the area immediately to the north of Bluewater Creek showing the photo pattern associated with the infilled channels. Bw, Bluewater association; Pa, Pattel association; CA, Carinya Argea association; Al, Althaus association. (Photo courtesy Surveyor-General, Queensland Department of Lands.)

The soils were not examined on a fixed-grid system but all roads and tracks in the area were traversed with additional specifically designed traverses where further information was required. All field inspection sites and located soil 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 pattern. However, many minor but significant soil differences are not easily recognized and 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 it was only in the Dy soils, particularly Dy3, that further subdivision was necessary to satisfy the requirements of series mapping. 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 morphological features which have also been found to 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 Factual Key PPF, e.g. Dy3.43/4. It should be pointed out 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 this particular survey.

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

In some cases it is also possible for the one series to embrace several principal profile forms. This is particularly so in the gradational textured soils such as the mottled yellow earths.

Description of the Soil Series

Each of the defined soil series has been briefly characterized in Table 3. In Table 4 the series are classified according to the schemes of Northcote (1971) and Stace *et al.* (1968) and where possible they have been correlated with approximate equivalents in the surveys of Burdekin Valley (Hubble and Thompson 1953) and Lansdown (Murtha and Crack 1966).

Description of the Mapping Units

The mapping units are associations of series and 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 very closely related to the geomorphic history of the area it is convenient to discuss the mapping units within the framework of the broad physiographic units described earlier.

Beach Ridges and Littoral

Toolakea association (Ta; Toolakea series Uc1.21). This association is restricted to the frontal beach ridges. In addition to the deep siliceous sands of Toolakea series, other similar undescribed sands that are calcareous (shelly) throughout (Uc1.11, Uc1.12) are common. Dark duplex soils (Dd1.43) of Coonambelah series may occur in the swales. Small areas of mangroves and salt pans are also included in the unit.

Jalloonda association (Ja; Jalloonda series Uc4.21). This is the most widespread association on the younger beach-ridge system. The soil pattern is variable but, generally, the older the beach ridge the greater is the degree of profile development. The deep sands of the Jalloonda series grade to the more juvenile sands of the Toolakea series (Uc1.21) on the seaward ridges and to the more strongly developed soils of the Pallarenda series (Uc4.22) on the inland side of the beach-ridge system. Again there are small areas of mangroves or salt pans and some dark duplex soils of Coonambelah series (Dd1.43) in the swales.

Brolga association (Br; Brolga series Ug5.28). This is a relatively minor unit of moderately to strongly gleyed dark grey cracking clay soils that occur in depressions towards the margins of some areas of salt pan. These soils are inundated for long periods after heavy rains and may occasionally be inundated by tidal waters.

Oolgar association (Oo; Oolgar series Uc2.23). This unit occupies the small remnants of the Pleistocene beach-ridge system that occurs from the mouth of the Bohle River to the south-east of Mt St John. Associated with the strongly leached sands of Oolgar series are similar unnamed soils with a weak gradational texture profile. These ridges are normally underlain by cemented calcareous pans or indurated clayey deposits.

Mangroves (Mg) *and salt pans* (Sp). Mangrove areas are characterized by a mangrove low closed-forest vegetation. They occur as small areas fringing most of the tidal creeks and inlets and are subject to frequent tidal inundation. The soils are undescribed saline muds.

Salt pans also occur adjacent to most of the small tidal inlets and creeks. Soils are undescribed and range from saline clays to saline duplex soils with 2–10 cm of wind-blown sand overlying mottled heavy clay. Small areas of dark duplex soils of Coonambelah series (Dd1.43) occur as islands within the salt pans separated by a low salting cliff 15–30 cm high. Frequency of tidal inundation of the salt pans varies considerably and in some areas it may be as few as 3–5 tides per year. Many areas are inundated for considerable periods after heavy rain.

Younger Alluvial Terraces, Levees and Channel Infill

Bluewater association (Bw; Bluewater series Gn2.14). This association occurs along the minor streams and gullies particularly in the area north of the Bohle River. It is generally confined to the recent terraces and levees and occasionally occupies the deltaic fans of some larger streams. Younger alluvial soils of Windsor series (Um4.22) and Central series (Uc1.21) are common on the narrow lower terraces that are included in some areas. Occasional recently abandoned and infilled stream channels are also included in this unit.

Table 3. A brief description of the soil series arranged according to principal profile form (PPF)

Series	PPF	Physiographic unit	Surface soil	Subsoil	Additional comments
A. UNIFORM TEXTURED SOILS					
Central	Uc1.21	Recent stream terraces	Very dark grey-brown fine sandy loam, massive, weakly coherent; 10–15 cm thick	Grey-brown or pale brown weakly coherent sandy loam grading to coarse waterworn gravels within 2 m	Young alluvial soils with little profile development beyond surface accumulation of organic matter
Toolakea	Uc1.21	Frontal beach ridges	Loose pale brown loamy sand slightly organic-enriched; A_1 to 30 cm deep	Light brown or yellowish brown loose apedal sand	May be some broken shell fragments throughout the profile
Gumlow	Uc2.12	Colluvial fans	Thin light grey-brown loamy sand A_1 horizon overlying strongly bleached sand A_2 horizon. Hard-setting sands, generally massive throughout	A_2 horizon generally overlies coarse waterworn gravels; occasionally a weak B horizon is developed as weakly mottled light yellowish brown sands	Depth to coarse gravel is 10–60 cm; often much fine gravel on the surface and throughout the profile
Argea	Uc2.21	Pleistocene infill channels and piedmont slopes	Thin light grey-brown apedal coarse sand A_1 horizon overlying strongly bleached sand A_2 horizon. Total A horizon thickness 30–60 cm	Pale brown or yellow to light yellowish brown, generally mottled but occasionally whole-coloured. Texture rarely heavier than a sandy loam; usually some ferruginous nodules throughout B horizon	Normally overlie waterworn gravels at 1·5–2 m but occasionally grade to ferruginous or siliceous pans at about the same depth
Granite	Uc2.21	Gently undulating granite uplands	Thin grey-brown or light grey-brown apedal loamy sand A_1 horizon overlying thick strongly bleached loamy sand or sand A_2 horizon. Total A horizon thickness 50–80 cm	Gradual change to generally pale, whole-coloured or mottled yellowish red, yellow, or yellow-grey sand to light sandy loam. Apedal and loose when dry; very friable when moist	May be some soft ferruginous segregations towards the base of A_2 horizon and throughout B horizon

Oolgar	Uc2.23	Pleistocene beach ridges	Thin light grey-brown loamy sand A_1 overlying very strongly bleached sand A_2 horizon. A horizons are apedal, very loose when dry; 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 a coarse weakly coherent sand throughout but may occasionally rise to a light sandy clay loam	Overlie calcareous pans or indurated clayey sediments at 1·5–2 m
Jalloonda	Uc4.21	Holocene beach ridges	Dark grey-brown organic-enriched apedal sand A_1 horizon *c.* 30 cm thick overlying slightly paler weakly developed A_2 horizon	Gradual change at *c.* 40 cm to brown or yellow-brown very loose apedal sand	Thickness of ridges 1·5–6 m. Underlying material ranges from mangrove muds and peat to beach rock and buried duplex soils of the marine plain
Pallarenda	Uc4.22	Holocene beach ridges	Very dark grey-brown loamy sand to sandy loam A_1 overlying paler A_2 horizon; both weakly coherent or friable; total thickness 30–40 cm	Gradual change to reddish brown or yellowish red light sandy loam B horizons; weakly coherent and massive. Gradual change to paler and occasionally mottled sand at *c.* 1 m	Usually restricted to the older of the more recent beach ridges. General profile development stronger than in Jalloonda series
Bobawillie	Uc4.24	Holocene fans	Fairly thick grey-brown apedal loamy sand A_1 horizon overlying slightly paler weakly developed A_2 horizon	Gradual change at 20–30 cm to light yellowish brown or yellow-brown very weakly coherent sand. This grades into coarse waterworn gravels at 1·5–2 m	
Ocke	Uc4.24	Pleistocene fans	Thin light grey-brown sandy loam A_1 horizon overlying pale brown sandy loam or loamy sand apedal A_2 horizon	Gradual change at *c.* 30 cm to reddish brown sandy loam B horizon, massive, porous, very friable when moist	High concentrations of ironstone nodules and iron-impregnated gravels throughout the profile

Table 3 *(Continued)*

Series	PPF	Physiographic unit	Surface soil	Subsoil	Additional comments
Halifax	Um2.2	Pleistocene plain	Dark grey-brown silt loam A_1 horizon overlying strongly bleached silt loam A_2 horizon. Total A horizon thickness 30–50 cm	Generally a weakly developed pale brown or reddish brown silt loam B horizon, massive and earthy and underlain by coarse waterworn gravels at shallow depth	In some areas the A horizons are underlain by coarse waterworn gravels with no B horizon development evident
Windsor	Um4.22	Younger levees and terraces	Dark brown or dark grey-brown sandy loam to loam A_1 horizon overlying 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 10–20 cm	Subsoil colour ranges from brown or yellow-brown to yellowish red. Texture is sandy loam to loam throughout but may occasionally rise to light sandy clay loam. B horizons are massive and porous, underlain by coarse waterworn gravels below *c*. 2 m	Similar to Bluewater series but with a uniform rather than a gradational texture profile
Alick	Ug5.28	Pleistocene plain	Dark grey heavy clay; moderate to strong fine angular blocky structure. Surface weakly self-mulching. Some 5–15 mm carbonate nodules on the surface	Dark grey to grey-brown heavy clay; strong coarse blocky structure; may become finely mottled with depth and grade to sandy clay or sand D horizons below 2 m. Some fine ferro-manganiferous and light to moderate carbonate nodules occur throughout	Usually confined to the puffs in areas of gilgai microrelief
Brolga	Ug5.28	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. Total A horizon thickness 15–40 cm	Mottled dark grey and brownish yellow heavy clay; at *c*. 70 cm grades to prominently mottled light grey, brownish yellow and yellowish red plastic heavy clay. Seasonally saturated below *c*. 50 cm	Moderate to strong gley features throughout the profile. Mildly acid throughout

B. Gradational textured soils

Bluewater	Gn2.14	Younger levees and alluvium	Brown or grey-brown sandy loam A_1 horizon overlying a slightly paler weakly developed A_2 horizon; normally massive but occasionally with weak subangular blocky structure. Very friable when moist	Gradual change at 15–20 cm to yellow-red or red sandy loam increasing to light clay loam B horizons which are massive and earthy throughout and friable when moist. Below 1–1·5 m texture decreases to coarse sandy loam; gradual colour change to mottled yellowish red and yellow-brown	Underlain by coarse water-worn gravels usually below *c.* 2 m. In some broader areas of alluvium B horizons may have weak fine to medium blocky structure
Hillview	Gn2.14	Pediment slopes	Dark grey-brown loamy sand to sandy loam A_1 overlying 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 which are massive and earthy with occasionally some fine ironstone nodules throughout. Texture then decreases gradually, grading to coarse angular gravels below *c.* 1 m	Often some fine angular gravels on the surface and throughout the profile. Although generally red or yellowish red in colour many are Gn2.24 soils. Soil reaction mildly acid throughout
Barra	Gn2.14	Metamorphic uplands	Dark grey-brown or dark reddish brown loam A_1 horizon overlying slightly paler A_2 horizon. Massive and friable throughout	Gradual change at 10–15 cm to dark red or yellowish red clay loam B horizons which are massive and earthy throughout and grade to weathered parent material below 40–60 cm	
Langai	Gn2.15	Pediment slopes	Dark grey-brown sandy loam A_1 horizon overlying brown or reddish brown sandy loam A_2 horizon; both are massive and porous; friable when moist	Gradual change at 30–50 cm to dark red sandy clay loam B horizons which are massive and earthy grading to coarse granitic grits at *c.* 90 cm	Similar to Hillview series but generally free of gravel and soil reaction in lower B horizon is neutral

Table 3 (*Continued*)

Series	PPF	Physiographic unit	Surface soil	Subsoil	Additional comments
Yileena	Gn2.24	Pleistocene and Holocene channel infill	Light grey-brown loamy sand to sandy loam A_1 horizon overlying a slightly paler, weakly developed A_2 horizon; both are often loose and apedal but may be weakly coherent and massive	Gradual change at 20–40 cm to yellow or yellow-brown B horizons which have a gradual textural increase from sandy loam to sandy clay loam and are massive and earthy. There may be some soft ironstone segregations throughout lower A and B horizons	Generally restricted to the more inland extremities of the channel fill. Similar to Carinya series but with a much less strongly developed profile
Clemant	Gn2.24	Pediment slopes	Dark grey-brown loamy sand to sandy loam A_1 horizon overlying a paler, well-developed A_2 horizon; both are generally massive and may contain some 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; some soft ironstone segregations throughout	A_2 horizon may occasionally be sporadically bleached
Ross	Gn2.24	Pleistocene 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 20–35 cm	Gradual change to brown or yellowish brown sandy clay loam, occasionally mottled; massive and earthy. Below 40–70 cm a fairly gradual change to faintly mottled yellowish brown and light brownish grey highly pedal medium to heavy clays	Two-storied soil; the pedal clays are part of a buried soil profile. A_2 horizon of the upper profile may occasionally be sporadically bleached. Both earth and pedal clay are mildly acid
Pepperpot	Gn2.24	Granitic uplands	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 *c.* 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 at *c.* 80 cm	Closely associated are similar soils with bleached A_2 horizons; reaction mildly acid throughout

Black	Gn2.42	Low stream terraces	Deep, dark grey-brown, massive, sandy loam A_1 horizon grading to slightly paler A_2 horizon	Gradual change at *c.* 40 cm to light yellowish brown sandy clay loam which grades to brown sandy clay loam or sandy clay; massive, earthy, very friable throughout. Coarse waterworn gravels or stratified sediments at 1–1·5 m	Closely associated with the juvenile soils of Central series; generally similar but with much stronger profile development
Woodridge	Gn2.74	Pleistocene plain	Dark grey-brown loam A_1 horizon overlying thin, slightly paler weakly developed A_2 horizon; both are generally massive but may occasionally have weak fine blocky structure. Total thickness 10–15 cm	Gradual change to faintly mottled yellow-brown and red clay loam to light clay B horizon which is massive and porous, generally with some fine ironstone nodules. Abrupt change to very strongly structured heavy clay D horizon at 80–150 cm	Characteristic feature is a prominent sink-hole microrelief; depressions 10–70 cm in diameter and up to 80 cm deep. Earth profile is mildly acid; the structured clays are strongly alkaline
Wallaroo	Gn2.74	Granitic uplands	As for Pepperpot series	As for Pepperpot series, but B horizons are mottled throughout and may have slightly higher ironstone nodule concentrations	
Stag	Gn2.74	Pediment slopes	Dark grey-brown loamy sand to sandy loam A_1 horizon overlying bleached sandy loam A_2. Usually only sporadic bleach but occasionally conspicuous	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 B horizon. Grades to coarse outwash gravels below 80 cm	Similar to Clement series but profile more strongly developed

Table 3 (*Continued*)

Series	PPF	Physiographic unit	Surface soil	Subsoil	Additional comments
Carinya	Gn2.74	Pleistocene channel infill	Thin light grey-brown loamy sand to sandy loam A_1 horizon overlying thick well-developed A_2 horizon which is generally only sporadically bleached but may occasionally be conspicuously bleached. Thickness of A horizons 20–70 cm, usually 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 light sandy clay. B horizons massive, very porous; variable amounts of soft ferruginous segregations. Grade to coarse sands and waterworn gravels at 1·5–2 m	Grade to bleached sands of Argea series at the lower ends of the channel fill and to the less strongly developed yellow earths of Yileena series on the inland extremities of the channel systems
Flagstone	Gn2.94	Granitic uplands and pediments	Light grey-brown apedal loamy sand A_1 horizon overlying strongly bleached loamy sand A_2. Some soft ferruginous nodules in lower A_2 horizon	Gradual change at 40–60 cm to mottled yellow-brown, yellowish red and dark red sandy clay loam which is generally massive and earthy with occasionally some fine blocky structure developed. Texture becomes coarser and lighter with depth. B horizon grades to weathered granite at *c.* 1 m	Variable amounts of soft ironstone concretions in A_2 and B horizons. A_2 horizon occasionally only sporadically bleached
Pinnacle	Gn2.94	Pediment slopes	Thin light grey-brown fine sandy loam A_1 horizon overlying 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 which is massive, earthy, very friable when moist. Increasing amounts of fine angular gravels below 45 cm	There may be some ironstone nodules in the lower B horizons. Reaction is mildly acid throughout

Tambouki	Gn2.04	Granitic uplands	Deep dark grey-brown loamy sand A_1 overlying very thick bleached loamy sand to sand A_2 horizon. A_2 darkens considerably to light brown or yellowish brown when wet	Gradual or diffuse change at 60 cm to dark red sandy loam increasing to sandy clay loam B horizon, which is massive and earthy, friable when moist, contains much fine quartz grit. At 120–150 cm grades to coarse weathered granitic materials which in some areas appear to be cemented into a weak pan	In some areas B horizon is faintly mottled. Reaction is strongly acid throughout
Alice	Gn3.14	Mid Holocene river deposits	Fairly thick dark brown or dark reddish brown sandy loam to loam A_1 overlying slightly paler weakly developed A_2 horizon; both are massive to weak fine blocky structured; friable when moist	Gradual change at 20–30 cm to dark red or dark reddish brown sandy clay loam to clay loam. Massive to weak fine angular blocky structure. Gradual texture increase to medium clay at 50–70 cm; gradual decrease to coarse sandy C-horizon materials below *c.* 1 m. The heavier textures are accompanied by strong blocky structure with fine to very coarse ped size	Similar to Bluewater series apart from the structural development of B horizon. B horizon colours range from dark red to red-brown, brown and yellow-brown
C. DUPLEX TEXTURE-CONTRAST SOILS					
Yabulu	Dr2.22	Mid Holocene river deposits	Very dark grey-brown sandy loam to loam A_1 horizon with massive to weak fine blocky structure; slightly paler sandy loam A_2 horizon	Clear change at 20–30 cm to dark red strong medium blocky structured B horizons whch become browner and faintly mottled with depth. A gradual texture decrease occurs to coarse sands and waterworn gravels at *c.* 2 m	A_2 development variable; occasionally sporadically bleached. Usually some fine ferruginous nodules in upper part of the profile; much soft diffuse ferruginous material at depth

Table 3 (*Continued*)

Series	PPF	Physiographic unit	Surface soil	Subsoil	Additional comments
Warbooga	Dr2.21	Granitic uplands	Very dark grey-brown sandy loam A_1 horizon with massive to weak fine blocky structure; friable when moist; underlain by reddish brown sandy loam A_2 horizon	Clear change at *c.* 12 cm to dark red medium clay with moderate to strong fine blocky structure; grades to weathered granitic rock at 60–80 cm	Profile generally mildly acid throughout; A_2 development variable and may be absent
Danishman	Db1.43	Pleistocene plain	Thin light grey-brown silty loam A_1 overlying a strongly bleached silty loam A_2 horizon; both are massive and porous; total A horizon thickness 15–25 cm	Abrupt change to dark yellowish brown medium to heavy clay B horizons with moderate medium to coarse blocky structure; at *c.* 60 m grades to dark red heavy clay with strong prismatic breaking to blocky structure. In some areas this grades to waterworn gravels at 1·5–2 m; in other areas the B horizon grades to yellow-brown heavy clay which continues to depths > 4 m	Carbonate nodules not normally present; lower B horizon has moderate to strongly alkaline reaction
Bohle	Dy2.33/4	Pleistocene plain	Very thin dark grey-brown loam to clay loam A_1 horizon overlying light grey A_2 horizon; usually only sporadically bleached but there may be a very thin conspicuous bleach immediately above the clay	Abrupt change to dark grey or dark grey-brown heavy clay B horizons with moderate to strong coarse blocky structure; very hard when dry; some fine ferruginous nodules throughout; carbonate nodules below 10 cm into the clay. At depth the clay becomes faintly mottled and dominantly olive or olive-grey	Total A horizon rarely > 8–10 cm. Below 2–5 m clay grades to strongly stratified sediments with alternating layers of coarse sands and clays

Manton	Dy2.33/5	Pleistocene 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. Both very friable when moist; weak fine blocky structure	Abrupt change to dark grey or dark olive-grey heavy clay with strong coarse blocky structure remaining fairly uniform with only slight colour differences to 2–2·5 m where they overlie coarse sandy sediments and buried soils. Some fine ferruginous nodules occur throughout the profile; light amounts of carbonate nodules occur below *c.* 30 cm	Occur in the depressions in areas of gilgai microrelief. Total A horizon 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	Pleistocene plain	Thin yellowish brown or grey-brown fine sandy loam to loam A_1 horizon overlying a sporadically bleached loam or fine sandy loam A_2 horizon; occasionally a very thin conspicuous bleach at the base of A_2 horizon	Very abrupt change to dark grey-brown or olive-grey, moderate, coarse blocky structured heavy clay B horizons. Some fine ferruginous nodules occur throughout; carbonate nodules usually present below *c.* 50 cm	A horizons 18–25 cm thick; seasonally saturated. Some yellowish brown mottling and linings to fine pores and root channels are characteristic
Purono	Dy2.43/5	Pleistocene plain	Thin dark grey-brown silty loam or fine sandy loam A_1 horizon overlying strongly bleached A_2 horizon. Generally some soft ferruginous nodules occur towards the base of A_2; there may be some faint yellow-brown mottling	Very abrupt change to olive-grey medium to coarse blocky structured heavy clay; brownish grey or light olive-grey coloured clays also common. With increasing depth the clay becomes mottled, generally olive-grey dominant. Some fine ferruginous nodules throughout; carbonate nodules below *c.* 30 cm into the clay	Total A horizon thickness 12–22 cm, most commonly 17–20 cm; A_2 horizons occasionally only sporadically bleached. With depth the clays become lighter-textured and more friable; overlie stratified sediments below *c.* 2 m

Table 3 (*Continued*)

Series	PPF	Physiographic unit	Surface soil	Subsoil	Additional comments
Gulliver	Dy2.43/5	Pleistocene plain	Thin light grey-brown fine sandy loam or silty loam A_1 overlying bleached A_2 horizon; A_2 usually only sporadically bleached with a thin conspicuous bleach immediately above the clay. Fairly distinct yellowish brown patches occur throughout A horizons	Very abrupt change to dark grey or dark brownish grey moderate to strong coarse blocky structured heavy clay. Gradual colour change with depth to olive-brown or yellowish brown, becoming mottled below 1·5–2 m. Overlie coarse sandy sediments at *c.* 2·5 m	Total A horizon thickness 15–20 cm. The chief differences between Gulliver and Purono series are the colour of B horizon clay and a weaker development of A_2 horizon
Lagoon	Dy2.43/6	Pleistocene plain	Thin light grey-brown fine sandy loam to loam A_1 horizon overlying very strongly bleached A_2 horizon	Very abrupt change to light brownish grey, weak to moderate blocky structured medium clay B horizons; may occasionally have fine yellowish brown mottles. B horizon usually underlain by a very strongly cemented pan at 60–150 cm; occasionally grades to coarse sandy sediments at about the same depth	Total A horizon thickness 20–30 cm but may be 40 cm. Reaction of lower B horizon normally alkaline but where the pan occurs at shallower depths it may remain mildly acid throughout
Pall Mal	Dy3.22/5	Granitic uplands	Very dark grey sandy loam A_1 horizon 10–12 cm thick overlying weakly developed brown or pale brown sandy loam A_2 horizon	Abrupt change to mottled yellowish brown and yellowish red weak coarse blocky structured medium to heavy clay B_2 horizon. Much fine quartz grit throughout B_2 horizon. Grades to a sandy clay with depth and to coarse weathered granite at *c.* 75 cm	Total A horizon thickness 15–25 cm. A_2 horizon may be sporadically bleached. Very occasionally yellowish red mottle dominant in B horizon. Reaction trend mildly acid throughout

Garbutt	Dy3.33/5	Pleistocene plain	Very thin light grey-brown loamy A_1 horizon overlying sporadically bleached loamy A_2 horizon. A thin conspicuous bleach may occur immediately above the clay	Very abrupt change to mottled dark grey-brown and yellow-brown strong coarse blocky structured heavy clay. Mottling becomes coarser and very prominent with depth, mainly olive-grey, yellow and yellowish red. Texture grades to sandy clay loam at *c.* 1 m	Total A horizon thickness 10–20 cm. As evidence of seasonal saturation in the A and upper B horizons there are many fine bright yellowish brown mottles or coatings to roots and soil pores
Morngi	Dy3.41/5	Pleistocene plain	Thin light grey-brown fine sandy loam A_1 horizon overlying very strongly bleached fine sandy loam A_2 horizon; massive throughout	Abrupt change to mottled light brownish grey and yellowish brown heavy clay; in the upper part coarse prismatic breaking to coarse blocky structure. At *c.* 50–60 cm gradual change to light brownish grey sandy clay with increasing amounts of coarse waterworn gravels	Total A horizon thickness 15–22 cm. Reaction trend mildly acid to neutral throughout
Hervey	Dy3.41/5	Pediment slopes	Thin light grey-brown sandy loam A_1 horizon overlying strongly bleached sandy loam or fine sandy loam A_2 horizon. Variable amounts of coarse gravel on the surface and throughout A horizons	Very abrupt change to mottled light brownish grey, yellowish brown and yellow medium or heavy clay B horizons. Strongly developed medium to coarse blocky structure. With depth, gradual decrease in texture to sandy or gritty clay; increasing amounts of coarse angular gravels or granitic grits. Thickness of coarse deposits varies, with an observed maximum of 12 m	Total A horizon thickness variable; 20–25 cm most common but may be 50 cm. Reaction trend is mildly acid throughout

Table 3 (*Continued*)

Series	PPF	Physiographic unit	Surface soil	Subsoil	Additional comments
Althaus	Dy3.41/6	Pleistocene plain	Thin light grey-brown loamy sand to sandy loam A_1 horizon overlying thick very strongly bleached loamy sand A_2 horizon. Soft ferruginous nodules may occur in lower A_2 horizon. In some areas surface textures are much finer, ranging from fine sandy loam to silty loam	Abrupt change to mottled light brownish grey and yellowish brown heavy clay; strongly developed very coarse blocky structure; very hard consistence when dry. Below 1 m mottling becomes very coarse with 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 B horizons	Total A horizon thickness 25–60 cm, commonly 35–40 cm. The soils with the thicker surface, and particularly heavier-textured soils, have 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
Noholme	Dy3.42/6	Pleistocene plain (areas subject to some recent deposition)	Dark grey-brown loam or silty loam A_1 horizon overlying a very strongly bleached silty loam A_2 horizon; occasionally some fine yellowish brown mottling through A_2 horizon	Abrupt change to mottled light brownish grey and yellowish brown medium to heavy clay with strong medium to coarse blocky structure. With depth, mottling becomes coarser, light grey dominant; clay grades to coarse sandy sediments	Dark well-developed A_1 horizon; total A horizon thickness 30–60 cm. Reaction trend mildly acid at the surface, rising to neutral in lower B horizon
Sandalwood	Dy3.43/4	Pleistocene plain	Very thin light brownish grey fine sandy loam A_1 horizon overlying bleached fine sandy loam or sandy loam A_2 horizon; usually some yellow-brown patches throughout A horizon	Very abrupt change to faintly mottled dark greyish brown and yellowish brown heavy clay. Upper part of B horizon often has columnar or prismatic structure breaking to coarse blocky units. Gradual change with depth to brown or grey-brown to light grey, either mottled or whole-coloured, heavy clay with strong fine angular blocky structure. Large (up to 8 cm) hard carbonate nodules occur below *c*. 10 cm into the clay	A horizons very thin, rarely >10 cm; A_2 occasionally sporadically bleached; B horizon clays often whole-coloured and overlie stratified sediments and buried soils below 1–2 m. Sandalwood (*Eremophila mitchellii*) dominant vegetation is characteristic

Quinda	Dy3.43/4	Pleistocene plain	Thin grey-brown or light grey-brown loamy sand to sandy loam A_1 horizon overlying a bleached sandy loam A_2 horizon; A_2 often only sporadically bleached with thin conspicuous bleach immediately above the clay	Very abrupt change to distinctly mottled pale brown, grey-brown and yellowish brown gritty or sandy heavy clay. Upper part of B horizon has very strongly developed columnar structure (columns up to 15 cm across and 30 cm long); breaks to very coarse blocky units. Below *c.* 50 cm texture grades to a sandy clay; colours generally lighter; low to moderate amounts of hard carbonate nodules	Thickness of A horizons rarely > 10 cm unless columnar structure is strong; in these cases bleached loamy sand A_2 material may extend to 25 cm in spaces between columns. Coarse sandy deposits and buried soils underlie the soils below *c.* 1 m
Kulburn	Dy3.43/5	Pleistocene plain	Very thin dark grey-brown A_1 horizon overlying 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. Some fine ferruginous nodules may occur in lower A_2 horizon	Very abrupt change to mottled dark grey-brown, dark brown and dark yellowish brown heavy clay. Usually strongly developed coarse blocky structure; occasionally weak columnar or prismatic. With depth mottling may become coarser and more prominent, occasionally grading to whole-coloured olive-grey heavy clay. At various depths below 1–1·5 m coarse sandy sediments and buried soils occur. Some fine ferruginous nodules occur throughout B horizon; carbonate nodules usual below 40–50 cm	Total A horizon thickness 15–25 cm, usually 18–20 cm. A_1 horizons very weakly developed; sometimes < 1 cm thick

Table 3 (*Continued*)

Series	PPF	Physiographic unit	Surface soil	Subsoil	Additional comments
Scrubby	Dy3.43/2	Pleistocene plain (areas subject to some recent deposition)	Fairly thick very dark grey-brown sandy loam A_1 overlying bleached A_2 horizon; A_2 usually conspicuously bleached, occasionally only sporadically bleached. Some ferruginous nodules occur throughout A horizons	Abrupt change to mottled greyish brown or dark grey and yellowish brown heavy clay B horizons with moderate coarse blocky structure. The deeper subsoils are variable and often stratified, generally lighter in colour, with increasing amounts of fine weathered granitic materials and fine quartz gravels. Some fine ferruginous nodules occur throughout the clay; occasionally some carbonate nodules in lower B horizon	Total A horizon thickness *c.* 18–25 cm, but may be 35 cm; mottled light yellowish brown A_3 horizons common in soils with the thicker surface. Chief distinguishing characteristic is the dark well-developed A_1 horizon
Healy	Dy3.43/5	Pediment slopes	Thin light grey-brown sandy loam A_1 horizon overlying bleached A_2 horizon; variable amounts of angular gravels on the surface and through A horizons	Similar to Hervey series but lower B horizon has alkaline reaction trend	Thickness of A horizons 20–40 cm
Pattel	Dy3.43/6	Pleistocene plain	Thin light grey-brown or brownish grey fine sandy loam to silty loam A_1 horizon overlying very strongly bleached silty loam A_2 horizon; A_1 generally massive but may have a weak platy structure	Abrupt change to mottled light brownish grey and yellowish brown medium to heavy clay B horizons; normally moderate to strong coarse blocky structure throughout, but a very coarse columnar structure may occur in upper B. Deeper subsoils variable. In some areas overlies buried dark clays below 60–90 cm; in others the mottled clay grades to light brownish grey or light olive-grey heavy clay. All underlain by stratified sediments. Carbonate nodules present below 50 cm	Total A horizon thickness 28–35 cm. Often very similar to Kulburn series but have thicker surface horizons

Frederick	Dy3.81/6	Pleistocene plain	Fairly thin light grey-brown loamy sand A_1 overlying very strongly bleached loamy sand A_2 horizon; some soft ferruginous nodules may occur throughout A_2	Sharp change at 40–60 cm to a fairly strongly cemented light yellowish grey mottled pan 20–40 cm thick, underlain by mottled light yellowish grey, yellow-brown and yellow sandy clay which is generally massive but occasionally has a very weak coarse blocky structure. Reaction of lower B horizon is mildly acid	
Coonambelah	Dd2.43	Pleistocene plain	Very thin light grey-brown loam A_1 overlying strongly bleached fine sandy loam or loam A_2 horizon; occasionally A_2 only sporadically bleached. Often much fine yellowish brown mottling throughout A horizons	Abrupt change at *c.* 10 cm to faintly mottled black or very dark greyish brown and olive heavy clay; strong coarse blocky structure; at *c.* 25 cm fairly sharp change to very prominently mottled olive-grey, bright yellow and dark red sandy clay grading to sandy clay loam. Usually no carbonate is present but the lower part of the clay is strongly alkaline	Many areas are seasonally inundated and moderately to strongly gleyed throughout. Areas adjacent to salt pan are occasionally inundated by high tides. Water-table normally present at *c.* 50 cm

Table 4. Classification of the soil series

Series	Factual Key dominant PPF	Great soil group	Approx. equiv. series Burdekin survey	Approx. equiv. series Lansdown survey	Capability class
Central	Uc1.21	Alluvial soil		Magenta	II
Toolakea	Uc1.21	Siliceous sand			VI(*b*)
Gumlow	Uc2.12	Siliceous sand			VI(*a*)
Argea	Uc2.21	Siliceous sand	Wenlee		VI(*a*)
Granite	Uc2.21	Siliceous sand			VI(*a*)
Oolgar	Uc2.23	Siliceous sand			VI(*b*)
Jalloonda	Uc4.21	Siliceous sand			VI(*b*)
Pallarenda	Uc4.22	Earthy sand			VI(*b*)
Bobawillie	Uc4.24	Earthy sand	Miskin		VI(*a*)
Ocke	Uc4.24	Earthy sand			VI(*a*)
Halifax	Um2.2	No provision			V(*a*)
Windsor	Um4.22	No provision			II
Alick	Ug5.28	Grey clay	Barratta	Gilligan	IV
Brolga	Ug5.28	Grey clay			VII(*b*)
Bluewater	Gn2.14	Red earth		Wyoming	III(*a*)
Hillview	Gn2.14	Red earth			III(*b*)
Barra	Gn2.14	Red earth			VI(*b*)
Langai	Gn2.15	Red earth			III(*b*)
Yileena	Gn2.24	Yellow earth			III(*a*)
Clemant	Gn2.24	Yellow earth			VI(*a*)
Ross	Gn2.24	Yellow earth	Lancer		III(*a*)
Pepperpot	Gn2.24	Yellow earth			V(*a*)
Black	Gn2.42	No provision			II
Woodridge	Gn2.64	Yellow earth		Woodridge	V(*b*)
Wallaroo	Gn2.64	Yellow earth			VI(*a*)
Stag	Gn2.74	Yellow earth			VI(*a*)
Carinya	Gn2.74	Yellow podzolic			VI(*a*)
Flagstone	Gn2.94	Yellow podzolic		Flagstone	VI(*a*)
Pinnacle	Gn2.94	Yellow podzolic			VI(*a*)
Tambouki	Gn2.04	Red podzolic			VI(*a*)
Alice	Gn3.14	Red podzolic	Farencer	Double Barrel	III(*a*)
Yabulu	Dr2.22	Red podzolic			III(*a*)
Warbooga	Dr2.21	Red podzolic	Dalrymple		III(*b*)
Danishman	Db1.43	Solodic			V(*a*)
Bohle	Dy2.33/4	Solodic	Zandor		V(*b*)
Manton	Dy2.33/5	Solodic	Gaynor	Manton	IV
Nightjar	Dy2.33/5	Solodic			V(*a*)
Purono	Dy2.43/5	Solodic	Penatta		V(*a*)
Gulliver	Dy2.43/5	Solodic–solodized solonetz			V(*a*)
Lagoon	Dy2.43/6	Solodic			V(*a*)
Pall Mal	Dy3.22/5	Yellow podzolic			V(*a*)
Garbutt	Dy3.33/5	Solodic			V(*a*)
Morngi	Dy3.41/5	Soloth			V(*a*)
Hervey	Dy3.41/5	Soloth			V(*a*)
Althaus	Dy3.41/6	Soloth			V(*a*)
Noholme	Dy3.42/6	Solodic			V(*a*)
Sandalwood	Dy3.43/4	Solodized solonetz	Dowie	Sandalwood	VII(*c*)
Quinda	Dy3.43/4	Solodized solonetz	Parawie		V(*b*)

Table 4 (*Continued*)

Series	Factual Key dominant PPF	Great soil group	Approx. equiv. series Burdekin survey	Lansdown survey	Capability class
Kulburn	Dy3.43/5	Solodized solonetz–solodic	Kelona	Lansdown	V(*a*)
Scrubby	Dy3.43/2	Solodic			V(*a*)
Healy	Dy3.43/6	Solodic			V(*a*)
Pattel	Dy3.43/6	Solodic			V(*a*)
Frederick	Dy3.81/6	Soloth			V(*a*)
Coonambelah	Dd2.43	Solodic			VII(*b*)

Bobawillie association (Bo; Bobawillie series Uc4.24). This unit occupies fairly broad flat alluvial fans that have formed where streams, particularly Bluewater Creek and its tributaries, emerge from the coastal ranges. Associated soils are yellow massive earths of Yileena series (Gn2.24) and red massive earths of Bluewater series (Gn2.14) occurring on low stream levees and terraces, and red massive earths of Hillview series (Gn2.14, Gn2.24) on small pediments included in the unit. Small depressions within the fans have duplex soils of Althaus (Dy3.41/6) and Pattel (Dy3.43/6) series.

Central association (Ct; Central series Uc1.21). This unit is confined to the low terraces in the headwaters of the major streams. Although only two areas have been mapped, Central series soils occur along almost all streams but in many cases the terraces may be less than 10 m wide. They are frequently inundated by flood waters and are subject to deposition and scouring. More strongly developed soils of Black (Gn2.42), Windsor (Um4.22) and Bobawillie (Uc4.24) series may be included in some areas.

Yileena association (Yi; Yileena series Gn2.24). This association includes a fairly wide range of soils and is not restricted to any single physiographic or topographic unit. The largest occurrences are associated with recently abandoned and infilled stream channels and broader areas of alluvium which are probably fans or sand splays associated with the prior drainage system.

Closely associated with the yellow massive earths of the Yileena series are numerous undescribed coarse uniform sands similar to the Bobawillie series (Uc4.24). Associated on the channel infill are red massive earths of Bluewater series (Gn2.14) and red or brown friable earths of Alice series (Gn3.14, Gn3.24). A range of duplex soils, particularly those of Scrubby (Dy3.43/2) and Pattel (Dy3.43/6) series, occupy slightly lower depressions. The latter are remnants of the older flood-plain neither dissected by the more recent channel development nor covered by a sandy wash from these channels.

Ross association (Ro; Ross series Gn2.24/clay D). This unit is restricted to the present levee banks of Ross River upstream of the Black weir and to older courses of the Ross which meander west to the Bohle River and north towards Mount Louisa. The soils are much more strongly developed and appear to be much older than any others occurring on levee banks of current drainage systems. It would appear that the Ross River has recaptured part of the course taken before its westerly migration to the Bohle River, while its north-easterly course from the Black weir and through the suburbs of Townsville is relatively recent. The soils on the levee banks and abandoned distributary channels along this section of the river are mostly very juvenile alluvial soils.

The depth of the Ross series soils to the underlying pedal clays ranges from 40 cm to 1 m. The thickness of the pedal clays varies from 30 cm to >2 m; in all cases they are underlain by stratified sandy sediments. Duplex soils of Kulburn (Dy3.43/5) and Pattel (Dy3.43/6) series occur in minor depressions while young alluvial soils of Central series (Uc1.21) occur on the narrow low terraces included in the unit.

Black association (Bl; Black series Gn2.42). This association occupies the intermediate terraces and younger alluvial plains of the major streams. The largest areas occur along the upper reaches of Black River where there is a very strongly developed terrace system and on the younger deltaic formation along the lower reaches of Ross River. The latter area is particularly complex with numerous abandoned distributary channels containing coarse sandy soils similar to Central series (Uc1.21) and islands of duplex soils of Gulliver (Dy2.43/5) and Purono (Dy2.43/5) series. The areas of duplex soils are remnants of the Pleistocene plain isolated by recent stream meanders. Red massive earths of Bluewater series (Gn2.14) occur on some higher terraces and on stream levees included in the unit.

Alice association (Ac; Alice series Gn3.14). The largest area of this association occurs towards the upper reaches of the Black and Alice Rivers. It occupies fairly broad areas and although no distinct pattern emerges it is almost certainly part of an older infilled distributary system. Included also is an infilled migratory channel between the Ross and Bohle Rivers.

The Alice series (Gn3.14) soils are transitional between the red massive earths of Bluewater series (Gn2.14) and red duplex soils of Yabulu series (Dr2.21). All three series occur in close proximity and grade from one to the other. Associated also are similar undescribed brown friable earths (Gn3.24) and a range of duplex soils, mainly of Purono (Dy2.43/5) and Scrubby (Dy3.43/2) series. The duplex soils are confined to depressions between the infilled braided stream channels.

Yabulu association (Ya; Yabulu series Dr2.22). The largest area of this unit occurs on the delta of the proto-Black River system. This fans out toward the coast from the settlement of Yabulu and consists of a series of infilled braided stream channels. An older infilled meander of Ross River is also included in this unit. The soil pattern is fairly complex as the channel fill varies in age with a consequent wide range in degree of profile development. The nature of the deposits varies from fine- to very coarse-grained materials. The finer deposits are dominant with red duplex soils of Yabulu series (Dr2.22) occurring most commonly but red massive earths of Bluewater series (Gn2.14) and red friable earths of Alice series (Gn3.14) also occur widely. Coarse leached sands of Argea series (Uc2.21) and leached massive earths of Carinya series (Gn2.74) are most common on the coarser deposits. A range of duplex soils, chiefly Kulburn (Dy3.43/5) and Purono (Dy2.43/5) series, occupies the lower sites between the infilled channels.

Bluewater–Yileena complex (BY). Several areas have been mapped as a complex of Bluewater (Gn2.14) and Yileena (Gn2.24) series. They generally consist of a maze of braided and fairly recently infilled stream channels. The dominant soil may vary from area to area. Minor associated soils of both associations are common.

Yileena–Scrubby complex (YS). This again is a complex associated with an area of infilled braided stream channels occurring in the headwaters of Alice River. Yellow massive earths of Yileena series (Gn2.24) occur on the channel infill; duplex soils of Scrubby series (Dy3.43/2) are common in the intervening depressions.

Older Alluvial Plain, Fans and Channel Infill

Gumlow association (Gu; Gumlow series Uc2.12). This unit occupies a series of broad coalescing fans around the base of the northern slopes of the Pinnacles. The fans generally have gradual 2–4° slopes but in some places are deeply dissected by numerous minor streams and gullies.

The soils are all strongly leached sands, mainly those of Gumlow series (Uc2.12), but other unnamed leached sands with a weak colour B horizon, similar in many regards to the Argea series, are common in areas with generally deeper soils. These soils are all underlain by very coarse gravels which are also common on the higher slopes of the fans.

Ocke association (Oc; Ocke series Uc4.24). This unit occurs on an older series of fans around the northern slopes of the Pinnacles which are at a slightly higher level than the fans of the Gumlow association and are isolated from the Pinnacles by scarp retreat and erosion of the scarp foot zone. The soils are all strongly leached shallow sands containing moderate to high amounts of ferruginous gravel and nodules. Ferruginized gravel outcrops are common on higher slopes.

Carinya–Argea association (CA; Carinya series Gn2.74, Argea series Uc2.21). This unit is very widespread in the northern sector of the surveyed area and consists of a maze of infilled braided distributary channels of prior stream systems. In most cases these have a definite linear trend which shows some relationship to the current drainage pattern. In the extreme north of the area, however, the pattern is not as clear; here the heavier vegetative cover partly obscures the air-photo pattern and much of the older channel infill has been reworked by numerous small gullies that traverse the area.

The soils of this unit show an increasing degree of profile development with increasing distance from the coast. The coarse strongly leached sands of Argea series are common at the seaward extremities. These grade to the leached yellow massive earths of Carinya series (Gn2.74, Gn2.84, Gn2.94), then in turn to the yellow massive earths of Yileena series (Gn2.24) and the red massive earths of Bluewater series (Gn2.14). The age of the deposits and the current drainage status are the chief factors contributing to the pattern of soil development in these infilled channels. The stream migration has been caused mainly by the damming of the mouth by beach-ridge migration which filled the channel with coarser deposits and led to slow retreat inland until a new course was established; hence the apparent chronological sequence. These channels still operate as drainage systems, although entirely underground. The water-table has a marked seasonal fluctuation and presumably remains at a much higher level in the profile for longer periods in the lower part of the channel system.

Woodridge association (Wo; Woodridge series Gn2.64). Although the mapped occurrences of this unit are limited, the yellow massive earths of Woodridge series occur widely on many areas of the Pleistocene plain. They are usually very closely associated with a range of duplex soils and although the soils are morphologically distinct in many instances they appear to have developed from similar alluvial deposits. They are generally confined to the lower sections of the depositional system and to deposits with a relatively low percentage of coarse or medium sand.

The Woodridge series soils usually have prominent sink-hole microrelief. The sink-holes are 10–70 cm in diameter and up to 80 cm deep. There may also occasionally be areas of very weakly developed gilgai with the strongly structured D horizon clays exposed on the puffs. The most commonly associated duplex soils are those of Kulburn (Dy3.43/5), Pattel (Dy3.43/6) and Purono (Dy2.43/5) series.

Danishman association (Da; Danishman series Db1.43). This is a very minor unit of brown duplex soils on alluvium in the headwaters of Central Creek. Associated soils include yellow massive earths of Ross series (Gn2.24) and mottled grey duplex soils of Kulburn series (Dy3.43/5). Parts of this unit are severely affected by recent gully erosion.

Bohle association (Bh; Bohle series Dy2.33/4). This unit is most common in the area between the Bohle and Black Rivers. It has a linear orientation and appears to be associated with several Pleistocene infilled stream channels. It appears that these streams carried a generally fine-grade suspension and the soils have developed on the resultant flood-plain deposits. Although the shallow and heavy surface-textured duplex soils are dominant, grey cracking clays of Alick series (Ug5.28) are common throughout. The latter are particularly abundant on puff sites in the areas of subdued gilgai microrelief common to much of the unit.

Manton gilgai complex (Gc; Manton series Dy2.33/5, Alick series Ug5.28). This unit occupies a similar landscape position to the Bohle association. The soil pattern also is similar. The gilgai microrelief is generally prominent with cracking clays of Alick series on puff sites and more strongly developed duplex soils of Manton series occupying the depressions.

Nightjar association (Nj; Nightjar series Dy2.33/5). This unit occupies a fairly small area east of the Bohle River, adjacent to the marine plain. The soils are probably developed on marine lagoonal sediments exposed by a fairly recent regression of sea level.

A very weak gilgai is present over most of the unit. The gilgai take the form of low broad puffs on an otherwise flat surface rather than a series of puffs and depressions. Grey clays similar to Alick series (Ug5.28) occur on the puffs; duplex soils of Nightjar series occupy the inter-puff areas. Some deeper-surfaced duplex soils of Purono (Dy2.43/5) and Pattel (Dy3.43/6) series are also included.

Purono association (Pu; Purono series Dy2.43/5). This unit appears to bear the same relationship as does the Bohle association to some of the prior stream courses in the area between Ross River and Althaus Creek.

The Purono series soils also are similar in most respects to the Bohle series (Dy2.33/4) but have thicker and lighter-textured surface horizons. Very weak gilgai may occur with grey clays of Alick series (Ug5.28) occupying the puff sites. The Purono series soils in the area between the Black River and Althaus Creek are almost always underlain by buried dark or grey clays. The depth to this clay increases progressively on a traverse inland across the plain. At the lower end of the plain the buried clays are exposed on the gilgai puffs. Red massive earths of Bluewater series (Gn2.14) and yellow earths of Yileena series (Gn2.24) occur on the levees of small watercourses.

Gulliver–Purono complex (GP; Gulliver series Dy2.43/5, Purono series Dy2.43/5). This unit occupies most of the area of the northern and western suburbs of Townsville. The soils are formed on deltaic sediments of the Holocene and Pleistocene mouths of Ross River. As with the Nightjar series (Dy2.33/5), these may be mostly shallow marine sediments fairly recently exposed. The more recent meanders of Ross River have isolated small areas of these soils as islands within the younger delta deposits.

Gulliver and Purono series soils are similar in many respects and make up the largest part of this unit. Garbutt series soils (Dy3.33/5) are more common in slightly depressed areas with poorer drainage conditions. Small areas of undescribed dark cracking clays (Ug5.16) or grey cracking clays of Alick series (Ug5.28) also occur. Small areas of salt pan are included where this unit adjoins the Coonambelah association.

Lagoon association (La; Lagoon series Dy2.43/6). This unit is restricted to the higher terraces or flood-plains of some of the smaller tributaries in the headwaters of Ross River. Some of these areas may still be subject to flooding and deposition.

The Lagoon series soils are somewhat variable, chiefly in the occurrence of and depth to strongly cemented siliceous pans. Small low rises of deep siliceous sands (Uc2.12) similar to Gumlow series are common, particularly in the area adjoining the piedmont slopes of Wallaroo Hill. These are probably remnants of an older fan but may be associated with abandoned and infilled stream channels. Yellow massive earths similar to Yileena series (Gn2.24) occur along the smaller streams and undescribed bleached yellow massive earths (Gn2.34) occur sporadically throughout the unit.

Morngi association (Mo; Morngi series Dy3.41/5). This unit is very limited in area, occurring chiefly in the headwaters of Althaus Creek and Little Bohle River. The soils are coarse-textured and appear to have formed on the lower end of old colluvial fans.

Morngi series soils grade to waterworn gravels at about 60 cm, much shallower than most other soils on the Pleistocene plain. Associated soils include similar deeper-surfaced soils of Althaus series (Dy3.41/6), occasional red massive earths of Bluewater series (Gn2.14) and yellow massive earths of Yileena series (Gn2.24).

Althaus association (Al; Althaus series Dy3.41/6). This association is widespread on the coastal plain north of Althaus Creek. At about this point there is a fairly sharp change from alkaline to acid reaction trends in the duplex soils. For a mile or so on either side of Bluewater Creek acid and alkaline soils appear to occur quite randomly and often in very close proximity. Subsoil pH values of 4·5–8·5 have been found to occur over a distance of 1 m. No clear pattern of their distribution emerges as the alkaline clays of the Pleistocene plain deposits have been extensively reworked by successive meanderings of Bluewater Creek. Three factors, either alone or in conjunction, have probably led to the development of acid duplex soils in this area and to the north. Firstly, the deposits have been laid down under a high-energy environment resulting in coarse, freely draining and readily leached soils. Secondly, the rainfall increases fairly rapidly from this point north and so facilitates leaching. Thirdly, the parent materials from which these deposits are derived are all acid igneous rocks, in contrast with the range of intermediate and basic rocks that are included in the parent materials of the more southerly deposits.

Althaus and Pattel (Dy3.43/6) series form a complex on the southern part of the unit while Althaus and Argea (Uc2.12) series form a complex in the far north of the unit. Elsewhere Bluewater (Gn2·14) and Yileena (Gn2.24) series are common along minor streams.

Noholme association (No; Noholme series Dy3.42/6). This is a fairly minor unit occurring in the headwaters of the small streams north of Bluewater Creek and in the headwaters of Ross River. It occurs at a slightly lower level in the landscape than Althaus association and some areas are subject to regular flooding. Uniform leached loams of Halifax series (Um2.2) are common throughout the unit. Red massive earths of Bluewater series (Gn2.14) occur on the levees of minor streams and mottled yellow massive earths of Carinya series (Gn2.74) occur on the low sandy rises of infilled channels. Undescribed grey and dark clays occupy the small swampy depressions included in this unit.

Sandalwood association (Sa; Sandalwood series Dy3.43/4). Sandalwood series soils occur as small discrete areas over large parts of the Pleistocene plain, most commonly in the catchments of the Ross and Bohle Rivers. Since few of these areas are large enough to delineate at the scale of mapping, most are included as minor components of other associations.

Quinda association (Qu; Quinda series Dy3.43/4). This unit is restricted to an area west of the Bohle River and south of Mt Bohle. It appears to be an area of alluvium of slightly higher elevation than the surrounding Pleistocene deposits and is being dissected by numerous small gullies. Much of the unit is very gently undulating.

Quinda series soils are somewhat variable, chiefly in the degree of development of columnar structure and mottling in the top of the B horizon. Although a duplex profile persists in areas that have been weakly dissected, the A horizons are heavier-textured and the upper B is lighter in colour and much more friable. Small areas of Sandalwood series (Dy3.43/4) occur throughout.

Kulburn association (Ku; Kulburn series Dy3.43/5). This is the most widespread unit on the Pleistocene plain, occurring from Bluewater Creek to the headwaters of Ross River.

Two soil types have been recognized in the Kulburn series. One has a sandy loam and the other a silty loam surface texture. The silty loam type is more common on the lower end of the coastal plain although both types do occur in all situations.

Almost all other duplex soils can occur as minor associates throughout the unit. Yellow massive earths of Woodridge series (Gn2.64) are particularly common in the area between the Bohle and Black Rivers. Small areas of more recent gradational soils, chiefly Bluewater (Gn2.14) and Yileena (Gn2.24) series, occur along minor streams.

Kulburn–Woodridge complex (KW; Kulburn series Dy3.43/5, Woodridge series Gn2.64). Several areas between the Bohle and Black Rivers have been mapped as a complex of Kulburn and Woodridge series. The duplex soils of Kulburn series are dominant but in some areas the mottled yellow earths of Woodridge series may occupy up to 60% of the area. Sink-hole microrelief is usually prominent in areas of Woodridge series soils.

Scrubby association (Sc; Scrubby series Dy3.43/2). This unit occupies restricted areas in the headwaters of the Alice and Black Rivers. It occurs on the older Pleistocene plain but at a slightly lower level and may be subject to flooding and deposition.

Other deep-surfaced duplex soils, chiefly Purono (Dy2.43/5) and Pattel (Dy3.43/6) series, occupy small areas while yellow massive earths of Yileena series (Gn2.24) and uniform sands similar to Bobawillie series (Uc4.24) occur on low infilled channel rises.

Pattel association (Pa; Pattel series Dy3.43/6). This unit is fairly restricted and occurs most commonly in the area between Black River and Bluewater Creek. There are some small occurrences immediately to the north of Bluewater Creek in close association with the acid duplex soils of Althaus series (Dy3.41/6). In this area leached sands of Argea series (Uc2.12) and leached massive earths of Carinya series (Gn2.74) are also included. Elsewhere, duplex soils of Kulburn (Dy3.43/5) and Purono (Dy2.43/5) series are the most commonly associated soils.

Frederick association (Fr; Frederick series Dy3.81/6). This unit is restricted to an area around the base of the fan system north of the Pinnacles. These are deep sandy-surfaced duplex soils with a strongly cemented pan at the base of the A_2 horizon. The pans are often very hard and quite impenetrable by augering during the dry season, when the soil may be mistakenly classified as Uc2.3. Other deep sandy-surfaced duplex soils, chiefly Althaus (Dy3.41/6) and Pattel (Dy3.43/6), are the most common associated soils.

Coonambelah association (Co; Coonambelah series Dd2.43). This unit occurs marginal to most areas of salt pan and occupies an extensive area on and around the Townsville town common. A large part of the unit may occasionally be inundated by tidal waters.

The duplex soils of Coonambelah series are separated from the salt pan by a low salting cliff 10–40 cm high. Numerous small areas of salt pan are included in the unit. Some areas of gleyed cracking clays of Brolga series (Ug5.28) are also included.

Piedmont Slopes and Gently Undulating Uplands

Granite association (Gr; Granite series Uc2.21). This unit occupies a large area of gently undulating country between Central Creek and Ross River. The area has been mapped as Quaternary alluvium by Wyatt *et al.* (1969) but coarse-grained granitic rock outcrops in streams traversing it and soil characteristics strongly suggest *in situ* development on a coarse-grained granite. All soils grade to strongly weathered granite grit although this could possibly be redeposited material. The unit also occupies gently sloping pediments surrounding some coarse granitic outcrops.

A fairly wide range of soils occurs in this unit and they appear to have a random distribution without any recognizable catenary sequences. Coarse sandy soils of Granite series may occupy ridge crests, slopes or drainage lines. Soils on the drainage lines are much more strongly bleached and may have siliceous pans developed in the B horizon. Yellow and grey massive earths of Pepperpot (Gn2.24), Wallaroo (Gn2.64) and Flagstone (Gn2.94) series are the most commonly associated soils but the red massive earths of Hillview (Gn2.14) and Tambouki (Gn2.04) also occur. The red earths are more common on middle and upper slopes with the leached earths occupying the lower slopes.

Hillview association (Hv; Hillview series Gn2.14). This unit occurs on short piedmont slopes particularly in the northern part of the survey area. It is often strongly dissected by numerous small gullies. The soils grade to coarse angular or slightly waterworn gravels by 0·5–1·5 m. Yellow massive earths of Clemant series (Gn2.24) are the most commonly associated soils but leached mottled yellow and grey massive earths of Stag (Gn2.64) and Pinnacle (Gn2.94) series and undescribed leached yellow massive earths (Gn2.34) also occur. Coarse sandy and gravelly deposits on small colluvial fans are also fairly common.

Barra association (Ba; Barra series Gn2.14). This is a relatively minor unit on gently to moderately undulating lands of the dissected area between the Pinnacles and Hervey Range.

Soils are largely sedentary and have developed on fairly coarse-grained metamorphic rocks. Although Barra series (Gn2.14) is dominant, similar undescribed red massive earths (Gn2.11) are prominent in some areas. Shallow coarse sands (Uc4.22, Uc1.43) occur on higher slopes and occasional duplex soils similar to Healy series (Dy3.43/5) or yellow massive earths of Clemant series (Gn2.24) on lower slopes.

Langai association (La; Langai series Gn2.15). This unit is restricted to a small area of very gently sloping colluvial apron in the headwaters of Ross River. The soils are very similar to the red massive earths of Hillview series (Gn2.14) except that they have a neutral reaction trend in the lower B horizon. Associated soils include both acid and alkaline yellowish red variants (Gn2.24, Gn2.25).

Pepperpot association (Pp; Pepperpot series Gn2.24). This unit occurs on gently undulating granite country in the headwaters of Ross River. Although most soils are sedentary some may be developed on locally derived colluvium. Chief associated soils are similar undescribed bleached yellow massive earths (Gn2.34) and mottled yellow massive earths of Wallaroo series (Gn2.64). Acid and alkaline duplex soils (Dy3.41, Dy3.43) occasionally occur on lower slopes and in drainage lines.

Clemant association (Cl; Clemant series Gn2.24). This unit also is restricted to the piedmont slopes but is more common on the drier parts of the coastal plain particularly in the headwaters of Ross River and Central Creek. It is often strongly dissected by numerous small gullies.

Soils are often gravelly throughout and grade to coarse colluvial gravels at about 1 m. Minor associated soils of Hillview association and the Hillview series also occur in this unit together with small areas of acid duplex soils of the Hervey series (Dy3.41/5).

Stag association (St; Stag series Gn2.74). This unit occurs on long gentle colluvial slopes in the area between Central Creek and Ross River. Closely associated with the leached mottled yellow massive earths of Stag series are similar grey massive earths of Pinnacle series (Gn2.94) and occcasional undescribed leached yellow massive earths (Gn2.34). Small areas of deep sandy-surfaced duplex soils similar to Althaus (Dy3.41/6), Purono (Dy2.43/5) and Kulburn (Dy3.43/5) series occupy minor depressions and are common on the lower extremity of the colluvial slopes.

Pinnacle association (Pi; Pinnacle series Gn2.94). This unit also occurs on long gently sloping colluvial slopes in close proximity to the Stag association. The areas occupied by this unit appear to be somewhat more poorly drained and are characterized by dense low tea-tree vegetation.

The soils are dominantly very strongly leached grey earths but all soils common to Stag association occur as minor associates.

Flagstone association (Fs; Flagstone series Gn2.94). This unit occurs on gently undulating foot slopes and colluvial slopes derived from coarse-grained granite. Soils are of both sedentary and colluvial origin. Granite tor outcrop is common.

Although the leached grey massive earths of Flagstone series are most common, a wide range of similar soils occur as minor associates. These include uniform sands of Granite series (Uc2.21), yellow massive earths of Pepperpot (Gn2.24) and Wallaroo (Gn2.64) series and undescribed shallow coarse sands.

Warbooga association (Wa; Warbooga series Dr2.21). This unit occupies several very small areas. All occur on footslopes or gently undulating foothills of the Hervey Range scarp. Yellow duplex soils similar to Pall Mal (Dy3.22) and Hervey (Dy3.41/5) series are the most commonly associated soils and may in places be co-dominant.

Pall Mal association (Pm; Pall Mal series Dy3.21). This unit occurs only on a small area of gently undulating granitic country near the headwaters of Ross River. The soils are all acid duplex soils with varying degrees of profile development, mainly differences in depth, and development of an A_2 horizon. Similar soils with dominantly red mottled B horizons are prominent over part of the unit.

Hervey association (Hy; Hervey series Dy3.41/5). This unit occurs on gently sloping colluvium and is widely distributed with a particularly common occurrence in the Black River catchment. Most areas are strongly dissected by numerous small gullies.

Although the acid duplex soils are most prominent, a wide range of other soils is included. Almost all soils included in Hillview and Clemant associations occur as minor associates.

Healy association (Hy; Healy series Dy3.43/6). This is a minor unit occurring on very gently sloping colluvium around Mt Margaret and the Pinnacles. These slopes grade into the Pleistocene plain deposits and the change is often difficult to delineate.

Acid duplex soils of Hervey series (Dy3.41/6) and other alkaline duplex soils similar to Kulburn (Dy3.43/5) and Pattel (Dy3.43/6) series are the most common associates.

Hilly and Mountainous Lands

Two units have been delineated. One includes all the mountainous scarp and scattered low hills and the other a small area of strongly undulating country on top of the Pinnacles.

The soils have been examined in some areas but difficulty of access and complexity of geology prevented accurate delineation of soil boundaries. Also as there appears to be little land-use potential for this country due to topographic limitations, the usefulness of such soil information is limited.

Mountainous areas (M1). The broad soil pattern established is that of shallow to deep uniform sands (Uc1.21, Uc4.21, Uc4.22), coarse sandy massive earths (Gn2.14, Gn2.24) and occasional red duplex soils (Dr2.21, Dr2.61) on the coarse granites; shallow gravelly leached loams (Um2.12, Um2.21, Um2.22) on acid volcanics and metamorphics; and a range of red duplex soils and lesser gradational soils on the smaller areas of basic intrusives.

Strongly undulating area (M2). This area is a plateau remnant isolated by dissection from the Hervey Range plateau. It has not been examined but the soil pattern is expected to be similar to that of the main plateau. Here acid yellow duplex soils (Dy3.21, Dy3.41) are dominant; associated are a range of coarse bleached sands including Uc2.12, Uc4.22, Uc4.24, Uc2.21 and Uc2.23 soils.

Chemical and Physical Properties of the Soils

The lack of intensive development within the survey area despite its proximity to a reasonably large city is ample evidence of the low fertility status and poor physical characteristics of the majority of the soils. The factors limiting agricultural production of particular groups of soils will be dealt with more fully under the land capability classification.

Profile samples from each of the major soils were subjected to routine laboratory examination. The physical and chemical properties are briefly discussed below while the data for the A horizon and main B horizon are summarized in Table 5. Detailed morphological and chemical data for the major soils of the area are presented in Appendix 2. Laboratory methods employed are also briefly described in Appendix 2. More complete data for the solodic soils are presented by Crack and Isbell (1970). Reeve *et al.* (1959) and Murtha and Crack (1966) provide data for a wider range of companion soils sampled outside the survey area but within the limits of acceptable extrapolation.

Soil Reaction and Exchangeable Cations

As might be expected in an area of soils of differing age and diverse profile morphology, there is a fairly wide range in pH profiles. With only one exception surface soils are all mildly acid, within the range pH 5·5–6·0. The uniform clay soils of Alick series often have carbonate nodules on the surface and a pH range of 8·0–8·5. The uniform coarse-textured soils and all the gradational textured earths with the exception of Langai series are mildly acid throughout. In Langai series the subsoil pH rises to 7·5. Neutral red massive earths are very uncommon in this environment and as this soil has developed largely on granitic colluvium some enrichment from basic intrusives may have occurred. The pH profile in the duplex soils varies from mildly acid throughout to acid at the surface and very strongly alkaline at depth. In the alkaline soils the pH reaches a peak 30–40 cm into the clay B horizon with a range of 8·5–9·0 but pH 10·0 has been recorded in some Sandalwood series soils.

Calcium is invariably the dominant exchangeable cation in the surface horizons. Exchangeable calcium contents are variable but most soils have fairly low amounts, in the range 0·2–6·0 m-equiv./100 g soil. The younger alluvial soils such as Black and Central series have values up to 13·0 m-equiv./100 g.

On the basis of subsoil exchangeable cations there are three broad groups of soils. In the coarse-textured uniform and gradational soils exchangeable magnesium increases with depth, accompanied by a decrease in exchangeable calcium. Total exchangeable basic cations are low, in the range 2–9 m-equiv./100 g; base saturation ranges from 60 to 80%. In the Dy2 soils, i.e. Purono, Bohle, Manton, Pattel and Gulliver series, calcium and magnesium levels rise considerably in the upper part of the B horizon and either cation may be dominant. The levels of exchangeable sodium are generally low (<4 m-equiv./100 g) in these soils. In the rather more strongly developed Dy3 soils the upper parts of the B horizon are invariably magnesium-sodium dominant with sodium becoming more prominent with depth. From 50 to 60% of the total exchangeable sodium, i.e. up to 18 m-equiv./100 g, is not uncommon in the B_2 horizon of Sandalwood and Kulburn series soils.

Exchangeable potassium values for surface soils are in the range 0·05–0·83 m-equiv./100 g soil. If we use the figure of 0·2 m-equiv./100 g soil as criterion for sufficiency, it is obvious that some soils would have acute potassium deficiency. Piper and de Vries (1960), however, have shown that plant extractable potassium varies from site to site and although some soils, particularly those with heavier surface textures, may appear to have adequate levels, site testing would be necessary to determine plant response.

Phosphorus

All soils apart from some of the younger alluvial soils are grossly deficient in phosphorus. Total P contents determined ranged from 30 to 230 ppm while 0·01N H_2SO_4 extractable 'available' P ranged from 3 to 12 ppm. The younger Black and Central series soils have much larger reserves with up to 160 ppm available P in the surface soil. Other soils on alluvium such as Bluewater and Alice series are marginal and would certainly require phosphatic fertilizers under continuous and intensive cropping. Although the levels of available P are very low in the solodic and solodized solonetz soils, Jones (1968) in his work on similar soils in the region has suggested that application of 3 cwt per acre of superphosphate is sufficient to overcome deficiencies in Townsville stylo pastures for a period of two to three years.

Nitrogen and Organic Carbon

Except in some of the younger alluvial soils, total soil nitrogen and organic carbon contents are low, with total nitrogen ranges of 0·01–0·09% and organic carbon 0·13–1·5%. Nitrogen and organic carbon gradually decrease with depth in both the uniform and gradational textured soils but in the duplex soils there is a general depression in the A_2 horizon, a slight rise in the top of the B horizon and then a gradual decrease with depth.

The carbon/nitrogen ratio of most surface soils ranges from 8 to 15 but for occasional very coarse sandy textured soils may exceed 25. Crack (1972) has shown that nitrogen mineralization in the duplex soils of this area is low.

Total Soluble Salts

Except for soils subject to tidal inundation and occasional very thin-surfaced solodics, salt contents of surface soils are low to very low. Values of 0·008–0·030%

Table 5. Summary of chemical data for selected soils

Series	Sample no.	Depth (cm)	pH	T.S.S. (%)	N (%)	Org. C (%)	P (p.p.m.)	Avail. P (p.p.m.)	K (%)	S (p.p.m.)	Exchangeable cations[A] Ca	Mg	K	Na	Total	Saturation (%)	Clay (%)
Granite	T191.1	0–10	6·5	0·008	0·041	1·33	100	3	2·05	60	44	17	3	3	4·55	67	3
	.5B	75–90	5·8	0·008	n.d.[B]	0·05	80	< 2	2·30	30	28	35	6	6	2·83	75	17
Alick	T188.1	0–10	8·4	0·051	0·089	0·86	150	4	1·20	190	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
	.3	20–30	8·9	0·051	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Bluewater	T113.1	0–10	6·0	0·022	0·101	1·30	n.d.	8	n.d.	n.d.	56	18	5	1	9·47	80	13
	.4	30–45	6·3	0·007	n.d.	n.d.	n.d.	3	n.d.	n.d.	48	23	4	3	5·25	77	22
Hillview	T112.1	0–10	5·9	0·011	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
	.7	35–50	6·2	0·007	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Clemant	T194.1	0–10	6·4	0·012	0·097	1·32	230	10	1·55	100	59	16	3	2	9·13	80	13
	.4A	30–45	6·3	0·009	n.d.	n.d.	140	2	1·15	70	49	22	3	3	6·76	76	33
Ross	T190.1	0–10	6·4	0·012	0·073	1·57	130	8	2·45	70	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
	.4A	30–50	6·5	0·008	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Black	T106.1	0–10	6·2	0·023	0·208	2·76	760	160	2·5	210	49	13	3	14	26·16	81	18
	.6	60–90	7·0	0·006	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	69	20	2	3	8·80	94	14
Woodridge	T185.1A	0–4	6·4	0·014	0·131	1·76	160	6	0·65	140	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
	.3	20–30	6·0	0·009	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Carinya	T182.1A	0–4	6·1	0·006	0·066	1·70	60	5	4·2	60	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
	.4B	45–60	5·8	0·006	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	6	45	7	6	3·10	65	n.d.
Stag	T193.1	0–10	6·1	0·010	0·069	0·75	90	3	0·75	50	47	17	4	3	4·08	71	6
	.4B	45–60	6·1	0·007	n.d.	n.d.	70	3	0·75	50	36	39	5	5	3·35	85	32
Tambouki	T192.1	0–10	6·0	0·006	n.d.	0·36	100	3	1·95	40	44	19	4	4	3·15	71	4
	.5B	75–90	6·0	0·009	n.d.	n.d.	180	5	1·25	35	18	48	6	4	3·35	76	33
Alice	T111.1	0–5	6·4	0·015	0·131	2·02	410	28	2·90	150	56	13	3	1	14·34	74	13
	.5	30–45	6·4	0·009	n.d.	n.d.	190	5	2·65	50	55	24	4	2	6·71	85	33
Yabulu	T183.1	0–10	6·1	0·011	0·080	0·90	230	5	2·65	80	44	23	5	3	7·07	75	12
	.3	20–30	6·5	0·006	n.d.	0·50	210	3	3·15	100	47	29	3	2	11·39	82	41
Bohle	T107.1	0–10	6·8	0·027	0·095	1·18	150	7	0·90	120	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
	.2	10–20	7·6	0·029	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	57	37	< 1	6	25·95	100	n.d.
Manton	T187.1	0–10	6·0	0·011	0·083	0·89	140	6	1·45	120	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
	.2B	14–20	6·7	0·018	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	53	29	< 1	6	28·66	88	n.d.
Purono	T110.1	0–10	6·4	0·025	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
	.3	17–30	8·0	0·111	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	41	40	< 1	18	17·40	100	n.d.
Gulliver	T186.1	0–10	5·3	0·021	0·128	1·09	170	10	2·15	120	23	21	2	3	12·38	49	19
	.4B	45–60	9·2	0·184	n.d.	0·15	130	n.d.	1·75	70	49	38	< 1	12	27·30	100	41
Pall Mal	T195.1	0–10	6·2	0·018	0·084	1·34	130	6	3·10	100	67	15	3	1	10·19	85	9
	.3B	24–30	6·5	0·022	n.d.	0·36	110	< 2	1·95	70	55	27	3	2	11·46	87	49
Althaus	T181.1A	0–4	6·4	0·013	0·106	1·24	80	7	2·50	110	47	19	4	3	8·32	74	14
	.4B	45–60	6·2	0·008	n.d.	n.d.	50	< 2	1·80	40	14	35	2	12	10·92	63	54

Sandalwood	T189.1	0–10	6·2	0·037	0·086	0·72	110	8	1·55	110	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
	.2	10–20	6·9	0·143	n.d.	0·36	90	3	1·35	180	23	40	1	33	18·90	97	n.d.
Quinda	T109.1	0–10	6·6	0·008	0·014	0·13	30	5	1·25	25							3
	.2	10–20	6·3	0·058	0·047	0·44	60	3	0·09	80	15	32	1	31	13·59	79	48
Kulburn	T108.1	0–10	5·6	0·031	0·119	0·91	180	12	2·00	130	27	19	4	9	9·88	55	17
	.3	17–30	7·1	0·033	0·028	0·32	120	4	1·70	60	35	38	< 1	21	14·10	96	36
Scrubby	T104.1	0–8	5·9	0·016	0·080	0·80	210	8	1·90	80	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
	.3	17–30	6·5	0·022	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	69	12	< 1	8	24·11	90	n.d.
Pattel	T184.1	0–10	6·0	0·006	0·066	0·56	90	3	3·95	60	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
	.4A	30–45	6·2	0·121	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	7	20	1	61	8·40	89	n.d.

[A] Exchangeable cations expressed as percentage of total cations. Total exchangeable cations expressed as m-equiv./100 g soil. [B] n.d. = not determined.

total soluble salts are common for most soils. In the uniform and gradational textured soils there is usually a gradual decrease with depth. In the duplex soils the total salt levels are more variable. As a general rule they build up to a maximum at some depth in the B_2 horizon and then slowly decrease. Except for those soils that are gypseous total salts rarely exceed 0·3%. Occasional areas of Manton and Alick series soils contain gypsum and here salt levels may reach 1·5–2·0%. McCown (1971) has shown a relationship between soil profile morphology, moisture status and salt profile on solodic soils at Lansdown. This relationship is being investigated on a wider range of solodic soils within the surveyed area.

Other Elements

Little information is available on trace-element deficiencies on these soils. Jones and Crack (1970) demonstrated marked sulphur and lesser molybdenum responses in *Phaseolus lathyroides* on similar solodic soils at Lansdown. Similar responses may be expected on all but the youngest alluvial soils. Other deficiencies such as copper may occur on some of the strongly leached coarse sandy soils, e.g. the Granite, Argea and Carinya series.

Physical Properties

Adverse physical properties of the duplex soils is 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 can 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 clay B horizons are very effective barriers against water entry and McCown (1971) has shown that in many of these soils little soil moisture recharge occurs below depths of 50–60 cm into the clay B horizon.

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 show 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 may contribute to the hard-setting character.

Clay Mineralogy

Although all soils analysed have developed from the same suite of parent materials, it is evident from Table 6 that their clay mineralogy may vary considerably even within the one series. These differences are almost certainly associated with the depositional history of the older flood-plain. This history is very complex and most of the older depositional sequences are completely masked by more recent additions. Morphological evidence of layering occurs in the B horizon of many soils and is supported by the data for one of the Scrubby series (Table 6) which changes from kaolin–illite to montmorillonite dominance in the clay B horizon. The nature of the deposits has been influenced by changes in source material due to complete denudation of geological units during scarp retreat or by stream migration.

Land Use

Present and Past Land Use

Settlement of the Townsville district was begun in the early 1860s by pastoral interests with the introduction of both sheep and cattle. The sheep industry was short-lived. A combination of factors including disease (foot rot), dingoes, high labour requirements, spread of spear grass, high transport costs of wool and a falling wool market in the late 1860s led to a fairly rapid change-over to cattle.

Table 6. Mineralogical analyses of the clay fraction for selected soils

Series[A]	Horizon	Depth (cm)	Clay (%)	Kaolin[B]	Illite[B]	Montmor-illonite[B]	Quartz[B]	Inter-stratified minerals[B]
Kulburn	A_1–A_2	0–10	14	Much	Little	—	Trace	Mod.
	B_2	20–30	35	Mod.	Trace	Much	Trace	—
	B_2	30–40	35	Mod.	Little	Much	Trace	—
	B_2	90–100	34	Mod.	Little	Much	Trace	—
Kulburn	A_1	0–2	13	Mod.	Little	—	Little	Little
	B_2	17–30	34	Much	Trace	—	Trace	Mod.
Scrubby	A_1	0–10	10	Mod.	Much	—	Trace	Little
	B_2	30–40	25	Mod.	Mod.	—	Trace	Little
	B_2	70–80	31	Mod.	Mod.	Much	Trace	—
	B_2	120–130	33	Mod.	Little	Much	Trace	—
Scrubby	B_2	20–30	35	Much	Little	—	Trace	Mod.
	B_2	30–40	46	Mod.	Little	—	Trace	Much
	B_2	60–70	45	Mod.	Little	—	Trace	Much
Pattel	B_2	20–30	31	Mod.	Little	Much	Trace	—
	B_2	50–60	24	Mod.	Mod.	Mod.	Trace	—
	B_2	90–100	32	Little	Mod.	Much	Trace	—
Pattel	A_1–A_2	0–10	9	Mod.	Much	—	Trace	Mod.
	B_2	20–30	47	Much	Mod.	—	Trace	Mod.
	B_2	50–60	34	Much	Mod.	—	Trace	Mod.
	B_2	100–110	35	Mod.	Mod.	—	Trace	Mod.

[A] Data for one profile of other series are also available. Sandalwood, Bohle, Purono and Gilligan series have montmorillonite-dominant B horizons; Quinda and Althaus series have kaolin–illite-dominant B horizons.
[B] Trace, $<5\%$; little, 5–20%; mod., 20–40%; much, $>40\%$.

In 1865 plans for the establishment of a boiling-down works on Ross Creek led to the development of Townsville. Expansion of the port and township was rapid as they provided better access to the hinterland than the ports of Cardwell and Bowen. The development of mining centres to the west and north-west provided added impetus for Townsville's development and helped to stabilize the beef industry which had suffered a rapid decline with falling markets and closure of the boiling-down works in Townsville and Bowen in 1870.

There has been little intensive land-use development in the survey area during the 110 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 received timber treatment by hormone poisoning. On a very limited scale the production from naturally colonized Townsville stylo pastures is being promoted by application of phosphatic fertilizer and some areas have been seeded and fertilized into both treated and untreated timbered areas. Small areas of sorghum for seed and hay are grown chiefly around the Black River and along the wetter northern section.

Other forms of agricultural production have waxed and waned over the years. Large areas of Black association soils along the Ross River were utilized as market gardens or for dairying. Dairying declined as transport improved and supplies were more readily obtainable from better producing areas on the Atherton Tableland. The market gardeners have been gradually pushed out by the spread of urban development and there is currently only one garden operating in the area. A minor amount of small crops and horticultural crops is produced in the areas of Upper Ross and Yabulu and along Rollingstone Creek. Small acreages of sugar-cane and cotton have been grown along Ross River and in the Upper Ross area. Tropical legume and grass-seed production is confined to several properties in the Bluewater Creek–Black River area.

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

With the ready market available in Townsville the opportunity exists for considerable expansion of small cropping. Continuity of supply may be difficult as the high temperatures of early summer severely limit production during this period. Sufficient areas of suitable soils are present but most are unavailable because they are held as part of large grazing holdings.

Land Capability Classification

General

In this section an attempt has been made to rate the soils in terms of their agricultural and pastoral use potential. The rating is based on the broad potential of the whole area and does not take into account specialized uses to which small areas of otherwise unsuitable soils may be adapted by special management techniques. For instance, market gardening on a limited intensive scale may be very successful on some areas of duplex soils which are generally regarded as very marginal agricultural soils. Elsewhere in north Queensland sugar-cane and rice are also successfully grown on similar soils, but as the needs of these crops are fairly specific and as it seems unlikely that either will be introduced to this area they have received no consideration in the following capability classification. It has been assumed that apart from some limited market gardening and horticultural cropping the potential of this area lies in further development of the pastoral industry based on improved pastures or fodder crops and it is on this basis that the soil capability groupings have been made.

The classification used is broadly the USDA scheme defined by Klingebiel and Montgomery (1966). The initial subdivision is the capability class, graded I–VIII indicating progressively greater limitations and a narrower choice for practical use. The capability classes I–IV are generally regarded as arable lands while classes V–VIII are non-arable.

In many instances it may not be the severity of any one particular limitation but the combination of several contributing factors that determines the class in which a group of soils or a land unit is classified. The map units delineated are identified firstly by the Roman numeral of the class followed by a letter symbol indicating an increasing degree of limitation or risk within the class.

The cost of seed and fertilizer and their application, timber density and the desirability or otherwise of timber treatment, expected stocking rates and so on are not considered in this classification. It merely indicates those soil factors which are expected to limit a given form of land use. Technological advances in soil amelioration, improved plant species or changing economic conditions may necessitate the upgrading of some capability groups. For example, at present it appears that the seeding and fertilization of Townsville stylo into the native pastures is the most successful method of improving pasture production. The production from this species has been found to vary markedly with differing soil conditions such as depth and texture of A horizons. It is on this experience that capability class V soils have been rated. More recently introduced grasses and legumes that are currently being tested appear to hold much more promise for the dry tropics. As the production from these may not be limited by the same soil attributes, future re-rating or regrouping of soils may be necessary.

Capability Class Definitions

Class I. Few limitations restrict use.

Class II. Some limitations reduce choice of crops or require moderate conservation practices.

Class III. Severe limitations that reduce the choice of crops or require special conservation practices or both.

Class IV. Very severe limitations further reduce choice of crops and/or require very careful management.

Class V. Although subject to little or no erosion, other limitations limit use largely to grazing, woodland or wildlife.

Class VI. Severe limitations; generally unsuited to cultivation; use limited largely to grazing, woodland or wildlife.

Class VII. Very severe limitations; unsuited to cultivation; use restricted to grazing, woodland or wildlife.

Class VIII. Limitations of soils and landforms preclude use for agricultural and pastoral production; use restricted to recreation, woodland, wildlife or water supply.

Capability Class Descriptions

Class I. No soils of this class have been recognized in this area.

Class II. These are the most attractive agricultural soils of the area. The most important are those of Black, Central and Windsor series. The limitations of the mapping scale led to the inclusion of those areas of Bluewater series occurring on the narrow stream levees but these are less fertile and would not be expected to perform as well. No further subdivision has been made of class II soils. The size of workable area is probably the chief limitation as these soils occupy narrow levees and terraces along most major streams and are often dissected by gullies or older meander channels. Coarse gravel deposits may also further limit workable areas. These areas are often flooded and as stream-flow velocity is high the erosion hazard would also be high.

There are reasonably large areas along Bluewater Creek and Black and Ross Rivers that would be ideally suited to vegetable cropping.

Class III. Soils in this class are considered to be well suited to cultivation but would not be expected to perform as well as class II soils and may require more careful management. Included are the red earths and red podzolics of Hillview, Bluewater, Langai, Alice and Yabulu series and the yellow earths of Ross series.

With fertilization and irrigation these soils are well suited to vegetable and horticultural cropping. They are well drained, easily worked and generally responsive to fertilizer applications. In most years reasonable results should be obtained from dry-land summer grain and hay crops.

Subclass (*a*) includes the areas of Bluewater, Alice, Yabulu and Ross series. The chief limitations are susceptibility to flooding in some areas and for broad-scale use the low degree of uniformity of soil type which may result in very uneven crop growth and maturity.

Subclass (*b*) includes the areas of Hillview and Langai series occurring on colluvial slopes. The main limitations are susceptibility to erosion because of slope, the stoniness of some areas and the generally small workable areas.

Class IV. This class is restricted to the small areas of Alick clay and to the gilgai complex with Alick clay on the puff and Manton series or similar duplex soils in the depressions. The chief problems in the cropping of these soils are associated with land preparation and the unevenness of crop maturity. Although the microrelief does not prevent the use of any machinery the depressions remain wet and boggy for considerable periods after rain. For grain crops, however, the unevenness of maturity is the chief problem. Chiefly because of the moisture regime, but also because of higher nutrient levels, the crop in the depression site is much taller and much later in maturing. This unevenness usually persists even after land levelling. No comparison has been made of the nutrient status of puff and depression sites in this area but Thompson and Beckmann (1959) found considerable differences in nitrogen and potassium status on dark clay soils on the Darling Downs. No further subdivision of class IV soils has been made.

Class V. This is by far the largest unit in the survey area. It includes most of the acid and alkaline duplex soils and in the northern area includes the coarse sands of Argea series and gradational soils of Carinya series. The latter are more typical of class VI soils but the pattern of distribution is so intricate that alternative methods of development or management of improved pastures would be impracticable. Although the duplex soils occur on generally flat alluvial plains and there is little erosion hazard or restriction on the use of machinery, the soils have a very low agricultural potential. They have very low fertility and generally very poor physical properties. The A horizons set very hard when dry, powder when worked and have rather slow water-acceptance rates. The dense high-sodium clay B horizons are only very slowly permeable. A horizons are very boggy when wet and McCown (1971) has shown that recharge of subsoil moisture does not occur below *c.* 40–60 cm into the clay.

Subclass (*a*) includes all those duplex soils with moderately thick to thick A horizons with sandy or silty loam surface textures. Providing adequate levels of superphosphate are applied, these soils are well suited to Townsville stylo-based pasture development. Some small areas of the solodics, e.g. the Scrubby series with a well-developed A_1 horizon and a thick A_2, are used for sorghum as a grain, hay or forage crop with moderate success.

Subclass (*b*) includes most of the duplex soils with very thin sandy textured A horizons and those with heavier-textured clay loam to light clay A horizons. The thin-surfaced duplex soils generally have higher salt and exchangeable sodium levels in the upper B horizon, apparently sufficient to markedly depress both grass and stylo growth as ground cover is usually sparse annual *Chloris* and *Aristida* spp. The moisture regime also is not as favourable to pasture production.

Although good stands of Townsville stylo can be established by cultivation on heavier-textured soils this species does not appear to be able to regenerate naturally and after 2–3 years only scattered plants persist. This problem is not yet fully understood and for this reason Townsville stylo cannot be recommended for these soils. Some small natural stands can be found around areas of very heavy cattle concentrations such as water points, cattle camps, etc.

Class VI. These are all very coarse deep sandy soils. They are extremely infertile but their chief limitation is their droughty character. Soil water-holding capacity is very low and water stress can occur very shortly after rain. However, with adequate fertilizer and a well-distributed rainfall high pasture yields can be obtained from these soils. Two units have been delineated.

Subclass (*a*) includes all the deep sandy uniform and gradational-textured soils on both granitic colluvium and gently undulating granite uplands. Many of these areas are suitable for Townsville stylo-based pastures but production would not be as good as class V soils and would be much more dependent on seasonal conditions.

Subclass (*b*) includes all the deep uniform sands on stabilized beach ridges. These are very infertile and apart from areas where there is a very shallow water-table the growing season is short and often interrupted by periods of water stress.

Class VII. No particular soil attribute is common to the units mapped in this class. They have very low potential for development other than the present fairly limited grazing of volunteer pastures.

Subclass (*a*) includes all the badly gullied lands. It appears that most of these are naturally occurring and have been very little influenced by land management since settlement. The gullies are generally gently sloping and are fairly well grassed. They would, however, prevent the use of machinery and would have to be excluded from any development program apart from those where aerial seeding and fertilization is employed.

Subclass (*b*) areas are very low-lying salt-water couch marsh and salt pan. The areas of salt-water couch offer very good grazing but improvement potential is very limited. In some areas low levees with flood control gates have been built to prevent intrusion of salt water. Production improves as salts are leached from the soil, but as soils are generally heavy-textured the leaching is fairly slow.

Subclass (*c*) is a minor unit of very thin-surfaced duplex soils (Sandalwood series) that occur sporadically throughout the drier area of the coastal plain. Total salt and exchangeable sodium levels in the upper B horizons together with poor moisture regime considerably suppress stylo and grass growth. The cost of soil amelioration does not warrant further development on these soils.

Class VIII. Two broad groups have been recognized in this class.

Subclass (*a*) includes all the steep scarp of Paluma and Hervey Ranges and the low hills scattered throughout the area. Cattle may occasionally graze the lower slopes and narrow valleys while fairly good stands of both hardwood and softwood timbers occupy valley bottoms and more favourable slope sites.

Subclass (*b*) comprises the areas of mangroves along the coast and adjacent to the coastal streams. These are frequently inundated by tidal waters and offer no potential for land development.

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Appendix 1

Vegetation Communities

Closed-forest or Low Closed-forest

Although few species have been identified, this community is a fairly typical vine thicket (Webb 1968). *Acacia* spp. are very common in some areas and hoop pine (*Araucaria cunninghamii*) commonly occurs as an emergent. The forests occur as small areas in sheltered valleys on Many Peaks, Hervey and Paluma Ranges.

Mangrove Low Closed-forest

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

Eucalypt Open-forest

Carbeen or Moreton Bay ash (*Eucalyptus tessellaris*) is dominant over most of the unit with grey bloodwood (*E. polycarpa*) and narrow-leaf ironbark (*E. drepanophylla*) prominent in some areas. Tea-tree (*Melaleuca leucadendron* and *M. viridiflora*) are common on lower poorly drained sites. *Acacia* spp. and *Pandanus* spp. understorey is common throughout the unit and *Lantana camara* 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. This community is common on the stabilized beach ridges fringing the coastline. In some places it is interspersed with areas of grassland or salt pans which occupy the interdune swales.

Bloodwood Woodland

Although dominantly grey bloodwood, this is a fairly mixed community (Fig. 9) with poplar gum (*E. alba*), narrow-leaf ironbark and ghost gum (*E. papuana*) occurring consistently throughout. In most areas there is a fairly prominent understorey of broad-leaved tea-tree (*M. viridiflora*), cockatoo apple (*Planchonia careya*) or *Acacia* spp. The ground cover is fairly sparse with giant spear grass (*Heteropogon triticus*) most common in the northern areas and black spear grass in the southern areas. Kangaroo grass is commonly associated. Grass-tree (*Xanthorrhoea johnsonii*) is common on more sandy soils. This community occurs on all the areas of channel infill. The tree cover is generally more open and the grass sward much more dense on the mid-Holocene channel infill.

Quinine Low Woodland

This grades in places to low open-woodland. Quinine (*Petalostigma banksii*) is the most common species but there are large areas of both narrow-leaved (*M. nervosa*) and broad-leaved tea-tree. Narrow-leaf ironbark, bloodwood and poplar gum commonly occur as taller emergents throughout the community. Groves of *Pandanus* spp. are very common on more poorly drained sites. Ground cover is very sparse and is dominated by short annual *Chloris* and *Aristida* spp. Black and giant spear grasses are also common throughout. This community occurs on deep sandy soils, particuarly on granite uplands, and on outwash fans or slopes derived from coarse granitic bed-rock.

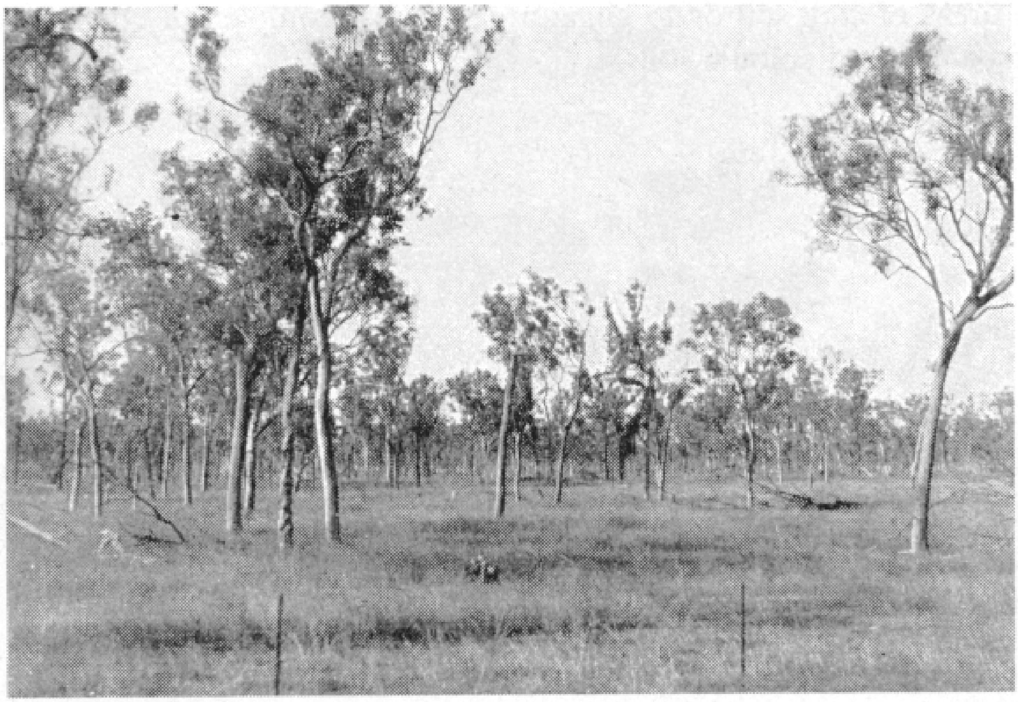

Fig. 9. Bloodwood and poplar gum woodland with black spear grass and Townsville stylo ground cover.

Narrow-leaf Ironbark Open-woodland

This is the most widespread community and grades in places to woodland. Narrow-leaf ironbark is dominant throughout but poplar gum, ghost gum and grey bloodwood are almost always closely associated. Broad-leaved tea-tree and cocky apple often occur as a prominent understorey. 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 to kangaroo grass with giant spear grass the most common associate. This community is widespread on the solodic soils of the Pleistocene plain, the earthy soils of the outwash 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. Poplar gum is occasionally monospecific, but there is also usually some carbeen, bloodwood or narrow-leaf ironbark. Ground cover is as for the previous community. This community occurs most commonly on the solodic soils of the Pleistocene plain but is generally restricted to those areas subject to occasional flooding.

Ghost Gum Open-woodland

This is a very open community. Ghost gum is dominant but carbeen, poplar gum and beefwood (*Grevillea striata*) are common throughout. The grass sward is moderate to dense and variable in composition. Black spear grass is probably most common but there are important areas of forest blue grass (*Bothriochloa bladhii*), with lesser pitted blue and kangaroo grass. This community is restricted almost entirely to areas of clay soil or to gilgai areas with a complex of cracking clays and heavy surface-textured solodic soils.

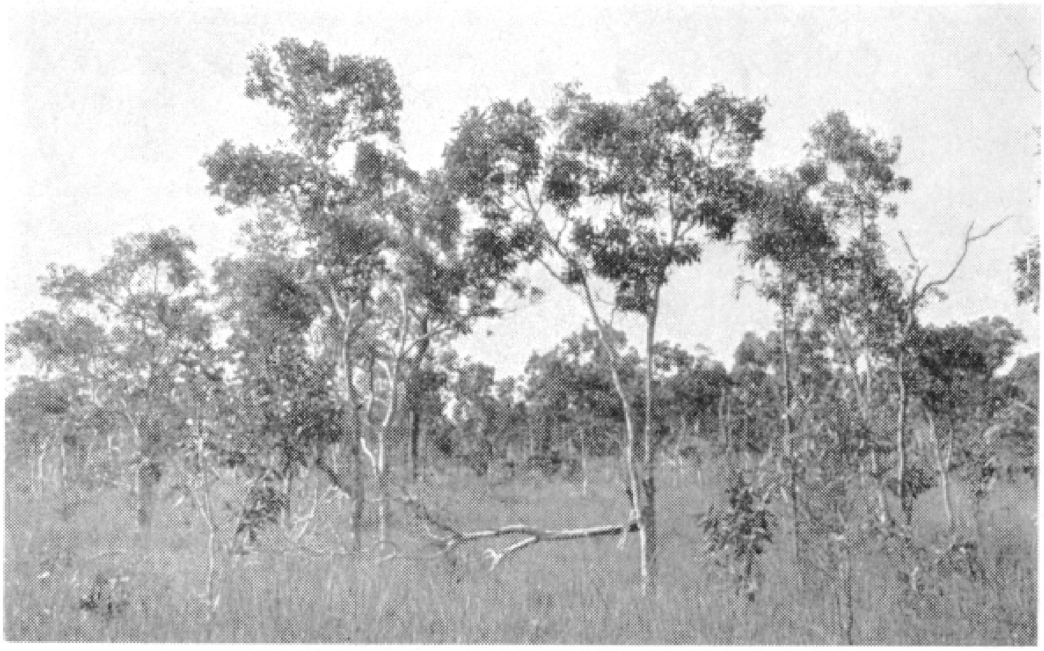

Fig. 10. Broad-leaved tea-tree low open-woodland with black spear grass and kangaroo grass ground cover.

Broad-leaved Tea-tree Low Open-woodland

This community may grade to low woodland. In many areas it is monospecific but poplar gum, carbeen or narrow-leaf ironbark may occur as emergents. Most areas are characterized by dense kangaroo grass although black spear grass may occasionally be prominent (Fig. 10). Giant spear grass is also common throughout. This community is more common on the lower areas of the coastal plain particularly in the northern section, but there are also large areas on the lower piedmont slopes in the Ross River catchment.

Sandalwood Low Open-woodland

Sandalwood (*Eremophila mitchellii*) is dominant but beefwood and occasionally narrow-leaf ironbark or poplar gum emergents are associated. Ground cover is very sparse, usually kerosene grass (*Aristida browniana*) is dominant with lesser annual *Chloris* spp. and black spear grass. This community occurs as small isolated areas and is restricted to very shallow-surfaced solodic soils.

Salt-water Couch Grassland

Salt-water couch (*Sporobolus virginicus*) forms a low dense sward. The most commonly associated species are salt-water paspalum (*Paspalum vaginatum*) and

Fimbristylis polytrichoides. The introduced *Parkinsonia aculeata* has invaded many of the very heavily grazed portions of this unit which occurs on low-lying plains adjacent to the coast, usually bordering salt pans.

Appendix 2

Analytical Data

Methods

pH. Determined on a 1 : 5 soil/water suspension with glass and calomel electrodes and a Philips direct reading pH meter.

Total soluble salts (*T.S.S.*). 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 0·01N H_2SO_4 for 16 hr.

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 oven-dry basis. Unless otherwise specified, all horizon boundaries in the morphological descriptions are gradational.

Soil series. Granite
Great soil group. Siliceous sand
Principal profile form. Uc2.22
Location. Townsville, 1 : 100 000, 818573

Sample No.	Horizon	Depth (cm)	Morphological Description
T191.1	A_1	0–10	Dark grey-brown (10YR4/2m) loamy sand; massive; loose; non-coherent (dry)
.2	A_2	10–20	Light brownish grey (10YR6/2m) (7/2d) loamy sand; massive; loose (dry)
.3	A_2	20–30	Pale brown (10YR6/3m) (8/3d) sand; massive; loose (dry)
.4	A_2	30–60	As above
.5A	B_1	60–75	Distinctly mottled light yellowish brown (10YR6/4m) and reddish brown clayey sand; massive; firm (dry)
.5B	B_2	75–90	Mottled pale olive (2·5YR6/4m) and yellowish red coarse sandy loam; massive; firm (dry); fine 5-mm Fe–Mn nodules
.6	BC	90–120	Mottled light yellowish brown (10YR6/4m) light grey and yellowish red clayey coarse sand; massive; very porous
.7	BC	120–150	As above
.8	C	150–180	Soft weathered granite

ANALYTICAL DATA

No.	pH	T.S.S. (%)	NaCl (%)	H_2O (%)	Org. C (%)	N (%)	Avail. P (p.p.m.)	Total P (%)	K (%)	S (%)	Particle size CS (%)	FS (%)	S (%)	C (%)	Exchangeable cations (m-equiv./100 g) Total	Ca	Mg	K	Na	H	Saturation (%)
1	6·5	<0·02	<0·01	1·6	1·3	0·04	3	0·010	2·1	0·01	61	31	4	3	4·6	2·0	0·8	0·1	0·1	1·5	67
2	6·2	<0·02	<0·01	1·2																	
3	6·5	<0·02	<0·01	1·1	0·1	0·02	<2	0·007	2·3	<0·01	55	37	2	3	2·2	1·0	0·3	0·5	0·1	0·7	68
4	6·1	<0·02	<0·01	1·6																	
5A	5·9	<0·02	<0·01	2·0																	
5B	5·8	<0·02	<0·01	1·7	0·1		<2	0·008	2·3	<0·01	54	22	6	17	2·8	0·8	1·0	0·2	0·2	0·7	75
6	5·8	<0·02	<0·01	1·3																	
7	5·9	<0·02	<0·01	2·1																	
8	5·8	<0·02	<0·01	2·4																	

Soil series. Bluewater
Great soil group. Red earth
Principal profile form. Gn2.14
Location. Townsville, 1 : 250 000, 465597

Sample No.	Horizon	Depth (cm)	Morphological Description
T113.1	A_1	0–10	Dark brown (7·5YR4/2m) loam; weak fine blocky; friable (moist)
.2	A_2	10–20	Brown (7·5YR4/4m) loam; weak fine blocky; friable (moist)
.3	B_1	20–30	Reddish brown (5YR4/4m) loam; massive; earthy; friable (moist)
.4A	B_2	30–45	Reddish brown (5YR4/4m) sandy clay loam; massive; earthy; friable (moist)
.4B	B_2	45–60	As above
.5A		60–75	Mottled reddish yellow (5YR5/6m) and light yellowish brown light clay; massive; earthy
.5B		75–90	As above
.6		90–120	As above. Some fine quartz gravels

ANALYTICAL DATA

No.	pH	T.S.S. (%)	NaCl (%)	H_2O (%)	Org. C (%)	N (%)	Avail. P (p.p.m.)	Total P (%)	K (%)	S (%)	Particle size CS (%)	FS (%)	S (%)	C (%)	Exchangeable cations (m-equiv./100 g) Total	Ca	Mg	K	Na	H	Saturation (%)
1	6·0	<0·022	<0·01	2·3	1·3	0·10	8	0·014	4·0	0·01	12	50	22	13	9·5	5·3	1·7	0·4	0·1	1·9	80
2	6·1	<0·02	<0·01	1·6	0·6	0·06	5	0·011	4·2	0·01	6	52	22	17	6·3	2·9	1·0	0·3	0·2	2·0	68
3	6·4	<0·02	<0·01	2·1																	
4A	6·3	<0·02	<0·01	2·3			3	0·008	4·1	<0·01	5	54	25	22	5·3	2·5	1·2	0·2	0·2	1·2	77
4B	6·3	<0·02	<0·01	2·6																	
5A	6·2	<0·02	<0·01	2·8											6·4	3·1	1·8	0·2	0·2	1·1	83
5B	6·3	<0·02	<0·01	2·7																	
6	6·4	<0·02	<0·01	3·3																	

Soil series. Stag
Great soil group. Yellow earth
Principal profile form. Gn2.74
Location. Townsville, 1 : 100 000, 747587

Sample No.	Horizon	Depth (cm)	Morphological Description
T193.1	A_1	0–10	Greyish brown (10YR5/2m) sandy loam; massive; friable (moist)
.2	A_{21}	10–20	Light brownish grey (10YR6/2m) loamy sand; massive; friable (moist)
.3	A_{22}	20–30	Light brownish grey (10YR6/2m) (8/2d) loamy sand; friable (moist); few fine Fe–Mn nodules
.4A	B_1	30–45	Light brownish grey (10YR6/2m), with few yellowish brown (10YR5/6m) mottles light sandy clay loam; massive
.4B	B_2	45–60	Distinct fine mottle, brownish yellow (10YR6/5m) and dark yellowish brown (10YR4/8m) sandy clay loam; massive; earthy; few fine Fe–Mn nodules
.5A	B_2	60–75	As above
.5B		75–90	Distinct mottle, light brownish grey (2·5Y6/2m) and yellowish brown (10YR5/8m) sandy clay loam; massive
.6		90–120	As above
.7		120–150	Mottled light grey (10Y6R/1m) and yellowish brown (10YR5/8m) light clay (sandy); weak fine blocky

ANALYTICAL DATA

No.	pH	T.S.S. (%)	NaCl (%)	H_2O (%)	Org. C (%)	N (%)	Avail. P (p.p.m.)	Total P (%)	K (%)	S (%)	Particle size CS (%)	FS (%)	S (%)	C (%)	Exchangeable cations (m-equiv./100 g) Total	Ca	Mg	K	Na	H	Saturation (%)
1	6·1	<0·02	<0·01	3·8	0·8	0·07	3	0·009	0·8	0·01	26	56	14	6	4·1	1·9	0·7	0·2	0·1	1·2	71
2	6·0	<0·02	<0·01	1·1																	
3	6·0	<0·02	<0·01	1·1	0·2	0·03	<2	0·006	0·8	<0·01	25	57	10	9	1·4	0·4	0·3	0·2	0·1	0·4	71
4A	6·1	<0·02	<0·01	0·4																	
4B	6·1	<0·02	<0·01	0·5			3	0·007	0·8	0·01	21	37	9	32	3·4	1·2	1·3	0·2	0·2	0·5	85
5A	6·1	<0·02	<0·01	6·9																	
5B	6·2	<0·02	<0·01	3·1																	
6	6·0	<0·02	<0·01	3·6			2	0·012	0·9	<0·01	15	33	11	42	5·3	0·6	2·5	0·2	0·3	1·7	68
7	6·0	<0·02	<0·01	3·3																	
8	6·0	<0·02	<0·01	2·8																	

Soil series. Alice
Great soil group. Red podzolic
Principal profile form. Gn3.14
Location. Townsville, 1 : 250 000, 464579

Sample No.	Horizon	Depth (cm)	Morphological Description
T111.1A	A_{11}	0–5	Very dark reddish brown (5YR2/2m) sandy loam; weak fine granular; friable (moist)
.1B	A_{12}	5–10	Dark reddish brown (5YR3/2m) sandy loam; weak fine blocky; friable (moist)
.2	A_2	10–20	Dark reddish brown (5YR4/3m) sandy loam; massive to weak fine blocky; friable (moist)
.3	B_1	20–30	Dark reddish brown (2·5YR3/4m) sandy clay loam; massive to weak fine blocky; friable (moist)
.4A	B_{21}	30–45	Dark red (2·5YR3/6m) light clay (sandy); weak fine blocky; friable (moist)
.4B	B_{22}	45–60	Dark red (2·5YR3/6m) medium clay (sandy); moderate fine blocky; friable (moist)
.5A	B_{23}	60–75	Dark red (2·5YR3/6m) sandy clay; weak coarse blocky; friable (moist)
.5B	BC	75–90	Dark red (2·5YR3/7m) gritty sandy clay loam; massive; friable (moist). Light quartz gravel to 20 mm
.6A	BC	90–113	Red (2·5YR3/8m) coarse sandy loam; massive; friable (moist)

ANALYTICAL DATA

No.	pH	T.S.S. (%)	NaCl (%)	H_2O (%)	Org. C (%)	N (%)	Avail. P (p.p.m.)	Total P (%)	K (%)	S (%)	Particle size CS (%)	FS (%)	S (%)	C (%)	Exchangeable cations (m-equiv./100 g) Total	Ca	Mg	K	Na	H	Saturation (%)
1A	6·4	<0·02	<0·01	1·3	2·0	0·13	2	0·041	2·9	0·02	44	26	11	13	14·3	8·1	1·9	0·4	0·2	3·8	74
1B	6·4	<0·02	<0·01	2·0																	
2	6·5	<0·02	<0·01	1·8	0·6	0·05	6	0·022	3·0	0·01	42	29	16	17	6·8	3·5	1·0	0·2	0·1	2·0	71
3	6·4	<0·02	<0·01	1·5																	
4A	6·4	<0·02	<0·01	3·2			5	0·019	2·7	<0·01	35	23	11	33	6·7	3·7	1·6	0·3	0·1	1·0	85
4B	6·3	<0·02	<0·01	3·6																	
5A	6·2	<0·02	<0·01	3·3							31	21	14	35	8·7	4·6	2·0	0·3	0·2	1·6	82
5B	6·0	<0·02	<0·01	2·7																	
6A	6·3	<0·02	<0·01	2·2																	

Soil series. Yabulu
Great soil group. Red podzolic
Principal profile form. Dr2.22
Location. Townsville, 1 : 100 000, 465597

Sample No.	Horizon	Depth (cm)	Morphological Description
T183.1	A_1	0–10	Very dark grey-brown (10YR3/2m) sandy loam; massive; friable (moist)
.2	A_2	10–20	Brown (7·5YR4/2m) sandy loam; massive; friable (moist); few 2-mm Fe–Mn nodules, abrupt change to
.3	B_2	20–30	Dark red (5YR3/6m) medium clay; strong moderate blocky; firm (moist)
.4A	B_2	30–45	Yellowish red (5YR4/8m) medium heavy clay; strong moderate blocky; hard (dry)
.4B	B_3	45–60	Reddish brown (5YR4/4m) medium clay (fine sandy); strong coarse blocky; hard (dry); free 2-mm Fe–Mn nodules
.5A	B_3	60–75	As above
.5B	BC	75–90	Brown (7·5YR4/4m) sandy clay; strong coarse blocky; hard (dry); some diffuse Fe–Mn
.6	BC	90–120	As above

ANALYTICAL DATA

No.	pH	T.S.S. (%)	NaCl (%)	H_2O (%)	Org. C (%)	N (%)	Avail. P (p.p.m.)	Total P (%)	K (%)	S (%)	Particle size CS (%)	FS (%)	S (%)	C (%)	Exchangeable cations (m-equiv./100 g) Total	Ca	Mg	K	Na	H	Saturation (%)
1	6·1	<0·02	<0·01	2·1	0·9	0·08	5	0·023	2·7	0·01	3	69	15	12	7·1	3·1	1·6	0·4	0·2	1·8	75
2	6·3	<0·02	<0·01	3·7	0·6	0·06	4	0·020	3·1	0·01	10	58	14	20	7·8	3·5	1·8	0·3	0·2	2·0	74
3	6·5	<0·02	<0·01	7·3	0·5		3	0·021	3·2	0·01	7	42	13	41	11·4	5·4	3·3	0·3	0·3	2·1	82
4A	6·6	<0·02	<0·01	8·5																	
4B	6·7	<0·02	<0·01	6·1							6	41	13	42	11·6	5·8	3·8	0·2	0·3	1·5	87
5A	6·8	<0·02	<0·01	5·4																	
5B	7·0	<0·02	<0·01	5·3																	
6	7·2	<0·02	<0·01	4·8																	

Soil series. Gulliver
Great soil group. Solodic
Principal profile form. Dy2.43
Location. Townsville, 1 : 100 000, 858826

Sample No.	Horizon	Depth (cm)	Morphological Description
T186.1	A_1–A_2	0–10	Dark grey-brown (10YR4/2m) silty loam; massive; firm (dry)
.2	A_2	10–20	Greyish brown (10YR5/2m) silty loam; massive; firm (dry); few soft Fe–Mn nodules, abrupt change to
.3	B_2	20–30	Dark greyish brown (2·5Y5/2m) heavy clay; strong coarse blocky; very hard (dry); few 10–20-mm carbonate nodules
.4A	B_2	30–45	Olive brown (2·5Y4·5/4m) heavy clay; moderate coarse blocky; very hard (dry); light 20–40-mm carbonate nodules
.4B	B_2	45–60	As above
.5		60–90	Yellowish brown (10YR5/4m) heavy clay; strong coarse blocky; very hard (dry) moderate 20–60-mm carbonate nodules
.6		90–120	As above
.7		120–150	Mottled greyish brown (10YR5/2m) and dark yellowish brown heavy clay; moderate coarse blocky
.8		150–180	As above

ANALYTICAL DATA

No.	pH	T.S.S. (%)	NaCl (%)	H_2O (%)	$CaCO_3$ (%)	Org. C (%)	N (%)	Avail. P (p.p.m.)	Total P (%)	K (%)	S (%)	Particle size CS (%)	FS (%)	S (%)	C (%)	Exchangeable cations (m-equiv./100 g) Total	Ca	Mg	K	Na	H	Saturation (%)
1	5·3	0·02	<0·01	3·1		1·1	0·13	10	0·017	2·2	0·01	3	48	32	19	12·4	2·9	2·6	0·2	0·4	6·3	49
2	6·2	<0·02	<0·01	3·2		0·3	0·05	2	0·014	2·0	0·01	4	46	29	26	14·0	4·6	4·7	1·1	0·5	3·1	78
3	8·5	0·09	<0·01	4·5	1·0	0·3		16				3	41	26	37	23·6	12·6	8·8	0·2	2·1		100
4A	9·2	0·11	0·02	3·8	4·4																	
4B	9·2	0·18	0·05	4·9	3·8	0·2			0·013	1·8	0·01	6	32	25	41	27·3	13·5	10·5	0·1	3·2		100
5	9·3	0·30	0·11	5·2	3·3																	
6	9·4	0·30	0 10	5·2	1·6							6	35	20	41	27·4	9·3	10·7	0·2	7·2		100
7	9·4	0·31	0·08	5·4	2·1				0·010	1·9	<0·01											
8	9·2	0·29	0·09	6·0	0·9																	

Soil series. Pall Mal
Great soil group. Yellow podzolic
Principal profile form. Dy3.22
Location. Mingela, 1 : 100 000, 809513

Sample No.	Horizon	Depth (cm)	Morphological Description
T195.1	A_1	0–10	Very dark grey (10YR3/1m) sandy loam; massive; friable (moist)
.2	A_2	10–20	Brown (7·5YR5/4m) (6/4d) sandy loam; massive; friable (moist)
.3A	A_2	20–24	As above
.3B	B_2	24–30	Mottled yellowish brown (10YR5/6m) and yellowish red heavy clay; moderate coarse blocky; firm (moist)
.4A	B_2	30–45	As above
.4B	B_3	45–60	Mottled yellowish brown (10YR5/6m) and yellowish red sandy clay; weak coarse blocky; firm (moist)
.5A	BC	60–75	Mottled yellow, white, yellowish brown and yellowish red sandy clay; massive; very firm (moist)
.5B	C	75–90	Weathered granite

ANALYTICAL DATA

No.	pH	T.S.S. (%)	NaCl (%)	H_2O (%)	Org. C (%)	N (%)	Avail. P (p.p.m.)	Total P (%)	K (%)	S (%)	Particle size CS (%)	FS (%)	S (%)	C (%)	Exchangeable cations (m-equiv./100 g) Total	Ca	Mg	K	Na	H	Saturation (%)
1	6·2	<0·02	<0·01	2·3	1·3	0·08	6	0·013	3·1	0·01	45	38	6	9	10·2	6·8	1·5	0·3	0·1	1·5	85
2	6·5	<0·02	<0·01	1·2	0·4	0·04	3	0·007	3·1	0·01	56	31	5	7	4·4	2·8	0·8	0·2	0·1	0·5	87
3A	6·8	<0·02	<0·01	1·7																	
3B	6·5	<0·02	<0·01	5·4	0·4		<2	0·011	2·0	0·01	32	14	5	49	11·5	6·3	3·1	0·4	0·2	1·5	87
4A	6·4	<0·02	<0·01	6·6	0·3		<2	0·011	1·7	0·01	26	11	8	56	13·5	7·1	3·6	0·3	0·2	2·3	83
4B	6·7	<0·02	<0·01	7·1																	
5A	6·7	<0·02	<0·01	4·4			<2	0·006	2·0	<0·01											
5B	6·7	<0·02	<0·01	4·6																	

Soil series. Althaus
Great soil group. Soloth
Principal profile form. Dy3.41
Location. Rollingstone, 1 : 100 000, 574013

Sample No.	Horizon	Depth (cm)	Morphological Description
T181.1A	A_1	0–4	Very dark grey-brown (10YR3/2m) silty loam; massive; friable (moist), hard (dry)
.1B	A_2	4–10	Greyish brown (10YR5/2m) silty loam; massive; friable (moist)
.2	A_2	10–20	Light brownish grey (10YR6/2m) (8/2d) loam; massive; friable (moist); few 10–20-mm Fe–Mn nodules
.3	A_3	20–30	Mottled light yellowish brown (10YR6/4m) (8/4d) and yellowish brown silty clay loam; massive; friable (moist) abrupt change to
.4A	B_1	30–45	Mottled pale brown (10YR6/3m) and yellowish brown silty clay; weak medium blocky; firm (dry)
.4B	B_2	45–60	Mottled light brownish grey (10YR6/2m) and yellowish brown heavy clay; strong coarse blocky; hard (dry)
.5A	B_2	60–75	As above
.5B	B_2	75–90	As above
.6		90–120	Greyish brown (10YR5/2m) heavy clay; strong coarse blocky; hard (dry); few 5-mm Fe–Mn nodules
.7	B–C	120–150	Mottled greyish brown (10YR5/2m) and yellowish brown fine sandy clay; weak coarse blocky; hard (dry)

ANALYTICAL DATA

No.	pH	T.S.S. (%)	NaCl (%)	H_2O (%)	Org. C (%)	N (%)	Avail. P (p.p.m.)	Total P (%)	K (%)	S (%)	Particle size CS (%)	FS (%)	S (%)	C (%)	Exchangeable cations (m-equiv./100 g) Total	Ca	Mg	K	Na	H	Saturation (%)
1A	6·4	<0·02	<0·01	2·6	1·2	0·11	7	0·008	2·5	0·01	10	29	44	14	8·3	3·9	1·6	0·4	0·3	2·2	74
1B	6·2	<0·02	<0·01	0·9	0·7	0·07	5	0·005	2·5	0·01											
2	6·1	<0·02	<0·01	1·2	0·4	0·05	3	0·004	2·5	0·01	3	33	41	19	5·1	1·2	1·2	0·2	0·3	2·3	55
3	6·1	<0·02	<0·01	3·6																	
4A	6·0	<0·02	<0·01	4·9			<2	0·006	2·0	<0·01											
4B	6·2	<0·02	<0·01	7·3				0·005	1·8	<0·01	1	23	26	54	10·9	1·5	3·8	0·3	1·4	4·0	63
5A	6·3	<0·02	<0·01	5·8																	
5B	6·1	<0·02	<0·01	5·0				0·005	2·4	<0·01	4	32	32	36	12·7	2·3	5·5	0·2	2·1	2·6	79
6	5·7	0·04	0·02	4·7																	
7	5·8	0·11	0·05	4·7																	

Soil series. Quinda
Great soil group. Solodized solonetz
Principal profile form. Dy3.43
Location. Townsville, 1 : 100 000, 839779

Sample No.	Horizon	Depth (cm)	Morphological Description
T109.1	A_1–A_2	0–10	Greyish brown (10YR5/2m) (10YR8/2d) loamy sand; massive; friable (moist), hard (dry); light fine quartz gravel; abrupt change to
.2	B_2	10–20	Distinctly mottled pale brown (10YR6/3m) and dark grey-brown (10YR4/2m) heavy clay (sandy); coarse columnar structure; hard (dry); some A_2 material between columns
.3	B_2	20–30	As above
.4A	B_2	30–48	Greyish brown (2·5Y5/2m) heavy clay (sandy); strong medium blocky; hard (dry); fine 5–10-mm Fe–Mn nodules
.4B	B–C	48–60	Greyish brown (2·5Y5/2m) sandy clay; weak coarse blocky; hard (dry); trace 10-mm carbonate nodules
.5	B–C	60–90	As above
.6	D	90–120	Distinctly mottled greyish brown (2·5Y5/2m) and brown heavy clay; strong coarse blocky
.7	D	120–150	Mottled greyish brown (2·5Y5/2m), dark brown and white sandy clay; massive; firm (dry)

ANALYTICAL DATA

No.	pH	T.S.S. (%)	NaCl %)	H_2O (%)	$CaCO_3$ (%)	Org. C (%)	N (%)	Avail. P (p.p.m.)	Total P (%)	K (%)	S (%)	Particle size CS (%)	FS (%)	S (%)	C (%)	Exchangeable cations (m-equiv./100 g) Total	Ca	Mg	K	Na	H	Saturation (%)
1	6·6	<0·02	<0·01	0·8		0·1	0·01	5	0·003	1·3	<0·01	48	44	5	3	1·7	0·2	0·5	0·1	0·2	0·7	58
2	6·3	0·06	0·02	4·2		0·4	0·05	3	0·006	0·9	0·01	22	26	3	48	13·6	2·1	4·4	0·1	4·2	2·8	79
3	6·5	0·09	0·02	3·4																		
4A	7·4	0·13	0·03	3·3	<0·1				0·005	1·3	0·01	25	36	8	35	13·0	1·2	4·2	0·1	7·6		100
4B	9·6	0·27	0·04	5·0	1·9																	
5	9·6	0·24	0·06	3·9	0·4																	
6	9·4	0·30	0·09	4·7	<0·1							33	23	27	21	24·3	2·5	5·5	0·2	16·2		100
7	9·2	0·17	0·06	2·5	<0·1																	

Soil series. Kulburn
Great soil group. Solodic
Principal profile form. Dy3.43
Location. Townsville, 1 : 100 000, 797742

Sample No.	Horizon	Depth (cm)	Morphological Description
T108.1	A_1	0–10	Very dark grey-brown (10YR3/2m) fine sandy loam; massive; friable (moist), hard (dry)
.2	A_2	10–20	Greyish brown (10YR5/2m) (10YR8/2d) fine sandy loam; massive; friable (moist); few 3-mm Fe–Mn nodules; abrupt change to
.3	B_2	20–30	Faintly mottled dark greyish brown (10YR4/2m) and dark brown (10YR3/3m) heavy clay; strong coarse blocky
.4A	B_{21}	30–50	Faintly mottled dark greyish brown (2·5Y4/2m) and dark grey (10YR4/1m) heavy clay; strong medium blocky
.4B	B_{22}	50–60	Transition to horizon below
.5	B_{22}	60–90	Greyish brown (2·5Y5/2m) heavy clay; strong medium blocky; firm (dry); few 10–40-mm carbonate nodules
.6		90–120	Distinctly mottled dark greyish brown (2·5Y4/2m) and yellowish brown (10YR5/8m) medium clay; as above
.7A		120–138	As above
.7B		138–150	Greyish brown (2·5Y5/2m) heavy clay; strong coarse blocky; firm (dry); few fine Fe–Mn nodules
.8		150–180	As above

ANALYTICAL DATA

No.	pH	T.S.S. (%)	NaCl (%)	H_2O (%)	$CaCO_3$ (%)	Org. C (%)	N (%)	Avail. P (p.p.m.)	Total P (%)	K (%)	S (%)	Particle size CS (%)	FS (%)	S (%)	C (%)	Exchangeable cations (m-equiv./100 g) Total	Ca	Mg	K	Na	H	Saturation (%)
1	5·6	0·03	<0·01	2·5		0·9	0·12	12	0·018	2·0	0·01	16	28	34	17	9·9	2·7	1·9	0·4	0·5	4·4	55
2	6·1	0·02	<0·01	2·9		0·3	0·03	3	0·012	1·9	0·01	18	29	21	27	8·8	2·9	2·6	0·4	0·8	2·1	76
3	7·1	0·03	<0·01	4·2		0·3	0·03	4	0·012	1·7	0·01	10	28	31	36	14·1	5·0	5·4	0·1	3·0	0·6	96
4A	9·3	0·14	0·02	4·7	0·1	0·2			0·013	1·9	0·01					20·9	7·2	6·8	0·1	6·8		100
4B	9·5	0·26	0·05	4·6	2·4																	
5	9·6	0·29	0·07	3·7	1·5							25	30	18	32	23·3	7·9	7·1	0·1	8·2		100
6	9·6	0·30	0·08	4·3	0·7																	
7A	9·1	0·25	0·09	3·7	0·2																	
7B	9·3	0·27	0·09	3·9	0·1																	
8	8·8	0·23	0·09	4·7	0·2																	