SOILS IN THE TOOWOOMBA AREA, DARLING DOWNS, QUEENSLAND

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Soils and Land Use in the Toowoomba Area, Darling Downs, Queensland

By C. H. Thompson and G. G. Beckmann

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By C. H. THOMPSON* and G. G. BECKMANN*

[*Manuscript received July* 22, 1957]

Summary

A soil association map has been made of the area covered by Toowoomba 1-mile military sheet, which is representative of a large part of the basaltic uplands on the Darling Downs in south-east Queensland. An area of some 40,000 acres has been covered by detailed survey to establish and relate the component soil series of the more extensive associations.

The greater part of the Toowoomba area consists of low gently sloping hills separated by numerous small valleys. Along the eastern margin are the steep eastern slopes of the Great Dividing Range and to the west the uplands are flanked by the open plains of the Condamine River system. A small plateau around the city of Toowoomba is also included.

Most of the soils have developed into basaltic material although there are small areas formed on sandstone, limestone, and marl. Shallow to deep dark clay soils (Australian black earths) dominate the area, and occupy most of the open plains and lower hill slopes and extend on to the ridge crests in places. Brown stony skeletal soils cover a large part of the hilltops and upper slopes, and small areas of red soils are found in all positions on the slopes. Deep red soils associated with lateritic materials occupy the Toowoomba plateau.

Agricultural development is extensive and most of the arable soils are cultivated. Dairying for whole milk and cheese production is the main industry of the hilly area with some supplementary grain growing. Farmers on the open plains and valley floors are engaged in grain growing, mostly wheat and sorghum, and use some livestock in their management programme.

A feature of the area is the high fertility of the soils, particularly the black clay types, many of which have been farmed for considerable periods without fertilizer application. These soils contain outstandingly high amounts of phosphorus (1000–2000 p.p.m. P) and adequate to high exchangeable potassium, but nitrogen contents are only moderate and there is evidence of decline under present farming practices. Yields of both grain and forage crops are generally high by Australian standards, and the area is noted for the high-quality wheat produced.

This is a dry-farming area receiving most of its rain during the summer months, and the growth of winter cereals is largely dependent on the storage of moisture under fallow during the wetter period. The normal practice is a short bare fallow of about 6 months' duration between successive winter crops and a 12-month fallow when changing from winter to summer crop or *vice versa*.

Soil erosion is the most serious problem in the upland area, where all farms show evidence of erosion and many have lost large amounts of soil. Improved farm management and soil conservation practices incorporating pasture leys are very necessary. Suitable species are needed for improved pastures in the fields returned to grazing and to raise the carrying capacity of the non-arable areas.

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I. Introduction

The Toowoomba area as discussed in this report is that covered by the Toowoomba 1-mile military map sheet (1m–2088) and forms part of the Darling Downs of south-eastern Queensland. It comprises about 530 sq. miles lying immediately west of the Great Dividing Range about 70 miles west of Brisbane, and includes some of the most fertile soils in Australia. The main business centre, Toowoomba, with a population of about 40,000, lies a few miles inside the north-eastern corner of the area (Fig. 1).

The surveyed area, which is fairly representative of the basaltic uplands of the eastern section of the Darling Downs, is a prosperous farming district at present.

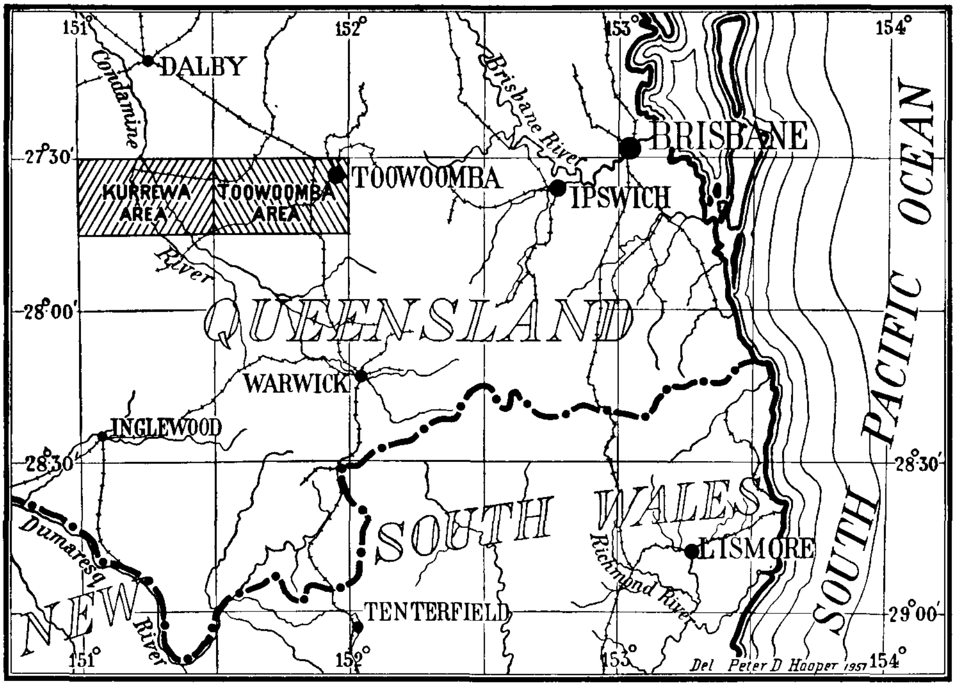


Fig. 1.—Locality plan.

Mixed dairying and grain farming is the main agricultural activity with grain farming—mainly wheat and sorghum—dominant on the plains, portions of which are found along the western margin.

Much agricultural research has been undertaken in this region over a period of years by officers of various sections of the Department of Agriculture and Stock, and a broad-scale survey and soil map of the whole Darling Downs has been made by the Bureau of Investigation, Queensland (Skerman 1952). Recently investigations of the changes in moisture content and in nitrogen in the black clay soils under fallow, crop, and natural grassland have been carried out independently by the Department of Agriculture of the University of Queensland (Waring 1954), and by the C.S.I.R.O. Division of Soils (Martin and Cox 1956*a*, 1956*b*).

This survey is part of a larger project designed to provide more detailed information on the soils of a section across the central Darling Downs west from the crest of the range. The second part covers the Kurrawa sheet further to the west.

The objects of the survey were:

(1) to classify and characterize the more important and extensive soils;

(2) to map the distribution of patterns of soil types (i.e. "soil associations");

(3) to correlate, as far as possible, existing agricultural knowledge and problems with individual soil types;

(4) to study the relationship between the red and black clay soils associated with basalt

II. Environment

(a) *Geology and Physiography*

The Toowoomba area is part of a dissected upland at the eastern limit of the plains of western Queensland and is situated immediately to the west of the scarp of the Great Dividing Range at elevations of 1300–2300 ft. It was one of numerous centres of volcanic activity in this part of Queensland during the Tertiary (Whitehouse, unpublished data) when large quantities of lava, mainly basaltic, were poured out over a landscape of almost flat-lying Mesozoic sedimentary rocks. The outpouring apparently took place in several stages between some of which soils developed. After covering by the later basalt and some baking, these soils have been re-exposed in places by dissection as hardened red clays. Deep lateritic soils have developed on the basalt in the high country along the eastern edge of the plateau during the later Tertiary, and these have persisted.

Dissection and erosion on the basalt and laterite surface during the late Tertiary and Pleistocene have produced the variety of land forms seen today. For convenience these are grouped as follows:

(i) the Toowoomba plateau;

(ii) the basaltic uplands;

(iii) the alluvial plains;

(iv) steep eastern slopes of the range

(i) *The Toowoomba Plateau.*—This unit is of very restricted extent and is found only round the city of Toowoomba, generally above the level of the 2000-ft contour. It consists of a few, almost parallel, low ridges, largely covered by red lateritic soils, the height range now being about 300 ft.

(ii) *The Basaltic Uplands.*—This unit occupies about three-quarters of the Toowoomba area. It is made up of a series of almost parallel layers of basaltic rock on which denudation has proceeded to a fairly advanced stage, slopes on the whole being gentle. The central portion, through Wyreema and Westbrook, has the form of low flat-crested ridges with numerous narrow, flattish spurs projecting from the slopes below the crests. East and west of this zone are regions of fairly high hills with comparatively steep slopes in the upper portions and fairly gentle slopes below these. The upland district also includes the narrow drainage lines of the numerous creeks. These are bordered by deposits of dark unconsolidated alluvium and are continuous with the plains of the Condamine River.

(iii) *The Alluvial Plains.*—The alluvial plains are very extensive west of the Toowoomba sheet, but extend into it up the valleys of creeks along the western margin. There appears to have been more than one age of deposition of the sediments making up these plains. The younger and more extensive of the sediments seems to have been derived almost exclusively from basaltic material. The older, which is found at slightly higher levels, appears to be made up of mixed basaltic and sedimentary material.

Table 1

Standard-period normal monthly and annual rainfalls* for Toowoomba, Pittsworth, and Oakey (1911–1940)

Month	Toowoomba	Pittsworth	Oakey
January	5·15	3·69	3·64
February	4·29	2·33	2·62
March	3·36	2·24	1·95
April	2·62	1·62	1·51
May	1·85	1·22	0·98
June	2·54	1·86	1·77
July	2·06	1·73	1·44
August	1·16	0·96	0·85
September	1·69	1·30	1·21
October	2·39	2·08	2·22
November	3·34	2·70	3·12
December	4·74	3·89	3·39
Year	35·19	25·62	24·70

*Meteorological data from "Rainfall Observations in Queensland", Commonwealth Bureau of Meteorology, 1940; and "Book of Normals—No. 1, Rainfall", Commonwealth of Australia, Meteorological Branch.

(iv) *The Steep Eastern Slopes of the Range.*—Along the eastern edge of the range, intensive erosion by coastal streams has produced a series of steep slopes extending over a height of 1000 ft. Two distinct units are found here—an upper zone of mainly steep slopes with occasional flatter platforms (mostly basalt), and a lower zone of narrow spurs with flat crests and fairly steep side slopes (mainly Mesozoic sandstones and shales).

(*b*) *Climate*

The climate of the upland area of the Darling Downs is temperate and sub-humid, with warm to hot, moist summers and cool, fairly dry winters. The main features of each of the elements recorded are described below.

(i) *Rainfall.*—The mean annual rainfall for the greater part of the uplands is about 24–26 in., two-thirds of this rain falling between October and March. Table 1 gives standard-period normal monthly and annual rainfalls for three stations within and adjacent to the area, viz. Toowoomba, Pittsworth, and Oakey. The

Table 2
CLIMATIC DATA* FOR PITTSWORTH

Representing the greater part of the basaltic uplands of the Toowoomba area

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
Standard period normal rainfall (in.) (P)	3·69	2·33	2·24	1·62	1·22	1·86	1·73	0·96	1·30	2·08	2·70	3·89	25·62
Relative humidity (%)	62	64	63	62	65	71	69	62	57	55	56	61	—
Average max. temperature (°F)	85·9	84·8	82·0	76·1	68·5	62·6	61·4	65·3	72·0	78·5	83·1	85·2	75·5
Average min. temperature (°F)	62·4	61·8	59·2	53·5	47·0	43·2	41·3	42·8	48·0	53·5	58·3	60·9	52·7
Saturation deficit (in. Hg) (*s.d.*)	0·32	0·29	0·27	0·24	0·17	0·12	0·12	0·16	0·22	0·29	0·33	0·32	
Calculated evaporation from a free water surface $E_w = 16$ *s.d.*	5·12	4·64	4·32	3·84	2·72	1·92	1·92	2·56	3·52	4·64	5·28	5·12	
$P/E_w^{0\cdot75}$	1·08	0·74	0·75	0·59	0·58	1·14	1·06	0·47	0·50	0·66	0·78	1·14	
Growing period for plants of low transpiration	→	→			winter growing period					summer growing period			
$E_{tr} = 1{\cdot}2E_w^{0\cdot75}$ (for pastures and crops of average transpiration)	4·08	3·79	3·59	3·29	2·54	1·96	1·96	2·43	3·08	3·79	4·18	4·08	
Moisture deficit (in.) ($P - E_{tr}$)	−0·39	−1·46	−1·35	−1·67	−1·32	−0·10	−0·23	−1·47	−1·78	−1·71	−1·48	−0·19	
Length of growing season for winter grain crops planted on fallow as indicated by monthly depletion of moisture reserves: Shallow upland soils (4·50 maximum soil storage)						+4·40	+4·17	+2·70	+0·92	0			
Deep plains soils (9·00 maximum soil storage)						+8·90	+8·67	+7·20	+5·42	+3·71	+2·97		
Length of growing season for summer grain crops (sorghum) planted on fallow, as indicated by monthly depletion of moisture reserves: Shallow upland soils	+3·92	+2·46	+1·11	0								4·50 +4·31	
Deep plains soils	+8·42	+6·96	+5·61	+3·94								9·00 +8·81	

*Meteorological data from "Rainfall Observations in Queensland", Commonwealth Bureau of Meteorology, 1940; and "Book of Normals—No. 1, Rainfall", Commonwealth of Australia, Meteorological Branch.

figures for Toowoomba are representative only of the high country around the Toowoomba plateau on the crest of the range. Beyond this area there is an abrupt decrease to a mean annual rainfall of about 25 in., which is general for the basaltic uplands and the plains to the west. The rainfall data for Pittsworth are therefore considered to be representative of the greater part of the area and have been used in the subsequent discussion of climate in relation to cropping.

(ii) *Season of Effective Rainfall for Plant Growth.*—To decide whether the rainfall is adequate to supply sufficient soil moisture for plant growth, values for the climatic index $P/E_w^{0.75}$* (Prescott, Collins, and Shirpurkar 1952) have been calculated from monthly meteorological data for Pittsworth.

On this basis according to their criteria ($P > 0{\cdot}4\ E_w^{0.75}$ for the break of the season and $P > 0{\cdot}8\ E_w^{0.75}$ for the continuation of the season) there are annually two short seasons of effective rainfall for plants of low transpiration (see Table 2). These are a short summer season of 4 months from October to January and a winter season of 3 months from May to July.

If the calculated potential evapotranspiration for crops of average transpiration, e.g. wheat, is compared with the mean monthly rainfall, it is found that there is insufficient rain in any month to support such crops. This conclusion may be a little misleading as the rainfall varies from year to year in seasonal distribution and in annual total. Even in years of average rainfall, the monthly distribution may be such that summer or winter grain crops could be grown on seasonal rainfall alone, but such seasons would occur so infrequently that this practice is not likely to be followed. In wetter than average years, cropping on rainfall alone may often be possible.

Notwithstanding this, the index figures determined from mean monthly data do indicate that there is little chance on rainfall alone of maintaining a stable agriculture using such crops. This is borne out by the agricultural experience on the Downs where the practice of fallowing to conserve soil moisture for both summer and winter crops is well established.

In the lower part of Table 2 a further estimate of the length of growing period for crops of average transpiration is made by taking into account the maximum amount of "available soil moisture"† that can be stored in the soil under fallow at the time of planting.

On this basis with planting at the end of May or early June, the growing season for winter crops on the shallow upland soils is $4\frac{1}{2}$ months; it is terminated

*In the calculation of evaporation (E_w) from saturation deficit (*s. d.*) for the determination of this index, the formula $E_w = 16$ *s. d.* (Farmer, Everist, and Moule 1947) has been used for this inland station instead of $E_w = 21$ *s. d.* as used by Prescott.

†From measurements of moisture contents of these dark clays soils (Waring 1954) it has been calculated that they have a storage capacity for available soil moisture equal to 0·18 in. of water per inch depth of soil. A mean depth of soil of 24 in. with a moisture storage equal to approximately 4·5 in. of rainfall is assumed for the shallow soils of the uplands, and double this soil depth and moisture storage for the deep soils of the colluvial slopes and alluvial plains. Waring's data show that a wheat crop growing on these deep soils withdrew some soil moisture from depths below 48 in., but this amounts to a very small fraction of the total needs of the crop.

by exhaustion of soil moisture reserves about the middle of October. On the deeper soils stored moisture is available for longer periods and extends past normal harvest time.

The length of the growing season for summer grain crops (mainly sorghum) planted about the end of November or early December is very similar to that for winter crops. On shallower upland soils the growing season is terminated by exhaustion of soil moisture, while on the deep soils of the colluvial slopes and plains there would still be some subsoil moisture available at the end of 5 months, by which time the crop has matured.

These estimates based on mean data show that on the shallower upland soils with a maximum storage of moisture by fallowing, there is barely enough moisture for summer or winter grain crops. Yields below average will be more frequent on these than on the deeper soils, and crop failures may be fairly common on soils of less than the average depth considered. The estimates of potential evapotranspiration also indicate that, on the average, the best time for planting winter cereal crops is about the end of May, and for summer grain crops about the end of November.

The rainfall necessary during the fallow period to replenish the soil moisture storage for the following winter cereal crops, and the chances of receiving both this and adequate planting rains, are discussed in the land use section of this report (Section IV).

(iii) *Temperature, Humidity, and Wind.*—Temperature and humidity data for Pittsworth included in Table 2 are fairly representative of this part of the Darling Downs. Moderately high temperatures are fairly common during midsummer months, the mean maximum for the hottest month being 85°F, but the Toowoomba area as a whole does not suffer severely from heat waves. The frequency of high temperature occurrence increases west and north of the area.

The minimum temperatures for the winter months are slightly above 40°F. Frosts are infrequent, the period of maximum danger from frost being from June to September. Some parts of the district, particularly the low lying areas, are more likely to suffer frost damage than others.

The Toowoomba district is not very windy, but strong cold westerly winds are fairly common during the late winter months—July to September—in the western portion of the uplands.

(*c*) *Vegetation*

Brief descriptions of the vegetation on the Darling Downs have been presented previously by Hart (1949) and Skerman *et al.* (unpublished data). These cover the Darling Downs as a whole, whereas the description of vegetation given in Table 3 is restricted to the Toowoomba area. The natural vegetation of this area has been considerably altered by man, and there are few remnants which have not been modified to some extent. No detailed study of the vegetation was made, but from observations during the soil survey a number of formations have been recognized. These are presented and described in Table 3 using the nomenclature of vegetation units according to Wood (unpublished data). A list of the most common vegetation is presented in Appendix I.

TABLE 3

VEGETATION FORMATION, DISTRIBUTION, AND RELATIONSHIP TO TOPOGRAPHY AND SOILS

Formation	Characteristics	Dominant Species	Topography	Soils	Distribution
Major Importance					
Forest	Tall trees generally more than 40–60 ft high, close spacing. Scattered shrub and small tree understory and sparse ground cover	Eucalypts—stringy bark, bloodwoods, gums, and box trees	Gently sloping ridge crests and very steep slopes	Red soils associated with lateritic materials, dark grey shallow clay soils on basalt, and red and yellow soils formed in sandstone	Crest and upper slopes of the Toowoomba plateau, and parts of the upper and lower slopes of the steep range scarp
Grassy forest to tall woodland	Trees 30–40 ft tall with a wider spacing than above. Dense grass ground cover. A light scatter of softwood scrub species throughout	Variable—narrow-leaved ironbark, silver-leaved ironbark, and mountain coolibah	Gently sloping crests and slopes (2–7°) of the rounded and flat-topped hills, and very steep slopes in some places	Brown, red, and dark-coloured sedentary soils formed on basalt. Mountain coolibah is generally, but not always, found on the dark clay soils, and there is usually a predominance of ironbarks on the brown and red soils	Very wide distribution throughout the uplands and also on the steep eastern slopes of the range scarp
	As above but tending towards a wider tree spacing	Poplar box	Very gently sloping to almost flat plains	Grey poorly structured heavy clay soils formed in mixed alluvium	South-western corner of the survey, around Yarranlea
Grassland	Dense grass cover up to 3–4 ft tall	Native oat and blue grasses dominant, and yabila, plains, satin-top, and wheat grasses common	Very gently sloping to almost flat plains and lower hill slopes (2–5°)	Very dark brown to very dark grey self-mulching clay soils formed in basaltic alluvium or colluvium	Western margin of the area and to a lesser extent throughout the area
Minor Importance					
Rain-forest	Closely spaced tall trees with a dense understory	—	Steep slopes	Generally shallow dark-coloured clayey soils formed on basalt	Patchy occurrence along some of the gorges and steep slopes of the range scarp

Table 3 (*Continued*)

Formation	Characteristics	Dominant Species	Topography	Soils	Distribution
Minor Importance—(Continued)					
Depauperate rain-forest	Dense softwood scrub 15–20 ft high with some scattered taller trees such as mountain coolibah, and narrow-leaved ironbark	Variable—more common species include: *Heterodendron* sp., *Capparis* sp., *Canthium* sp., *Flindersia* sp., *Pittosporum* sp., kurrajong, red ash, scrub wilga, currant bush, hop-bush	Crest of hills and moderate and steep slopes (2–14°)	Shallow dark clayey soils formed on basalt, with a limited occurrence on brown skeletal and red sedentary soils	Central western section of the area between Linthorpe and Irongate. Minor occurrence in the eastern section of the survey
Layered forest	Trees 30–40 ft tall and closely spaced. Scattered understory of softwood scrub species and very few grasses in a sparse ground cover	Brigalow and belah	Very gently sloping plains and lower hill slopes	Deep, dark grey, heavy clay soils and sandy soils with red-brown clays. Parent materials are of mixed origin and sandstone in places	Western section of the area mostly around the Irongate and Scrubby Mountain centres
Low-layered woodland	Dense cypress pine stands (20–30 ft high) with a scatter of softwood scrub species, and some tall eucalypts	Cypress pine	Gently sloping hill crests and upper slopes (2–5°)	Generally brown skeletal and red sedentary soils formed on basalt	Restricted occurrence in the western section, mostly south of Mt. Tyson and north of Wallingford

KEY

SOILS OF THE PLAINS AREA

Waverley Clay, gilgai complex	Wc
Waco Clay, gilgai complex	Wc
Waco Clay, gilgai complex, yellow-brown subsoil phase	$\frac{Wc}{YB}$
Edgecombe Clay Loam	Ecl
Yargullen Clay	Yc
Dalkeith Clay, gilgai complex	Dc
Miscellaneous Soils, group 1	1
Miscellaneous Soils, group 2	2

SOILS OF THE UPLAND AREA

Knapdale Clay, linear gilgai complex	Kc
Irving Clay, linear gilgai complex	Ic
Type B Clay, gilgai complex	B
Charlton Clay	$C^{h}c$
Type A	A
Type C	C
Type D	D

EROSION

Significant sheet erosion by water	**2**
Shallow gullies which can be filled by cultivation and crossed by implements	**4**
Gullies penetrating parent material, cannot be crossed by implements	**5**
Frequent gullies less than 5 ch apart	**F**
Deep steep-sided gullies	**V**
Slight wind erosion	**8B**
Slight accumulation along fence lines, result of wind erosion	**8A**
Gullies	

SOIL SURVEYOR: C. H. THOMPSON

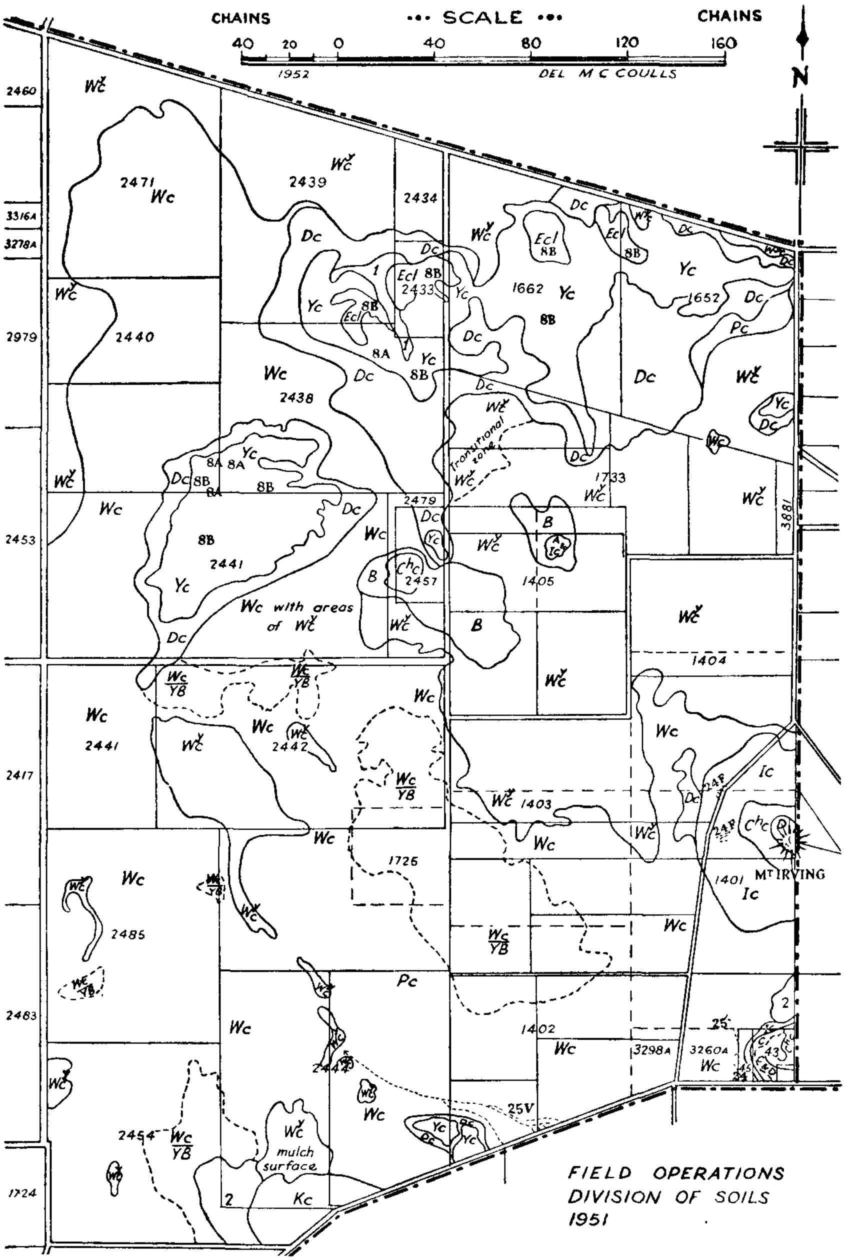


Fig. 2.—Soil map, part Parish of East Prairie, County of Aubigny, Queensland.

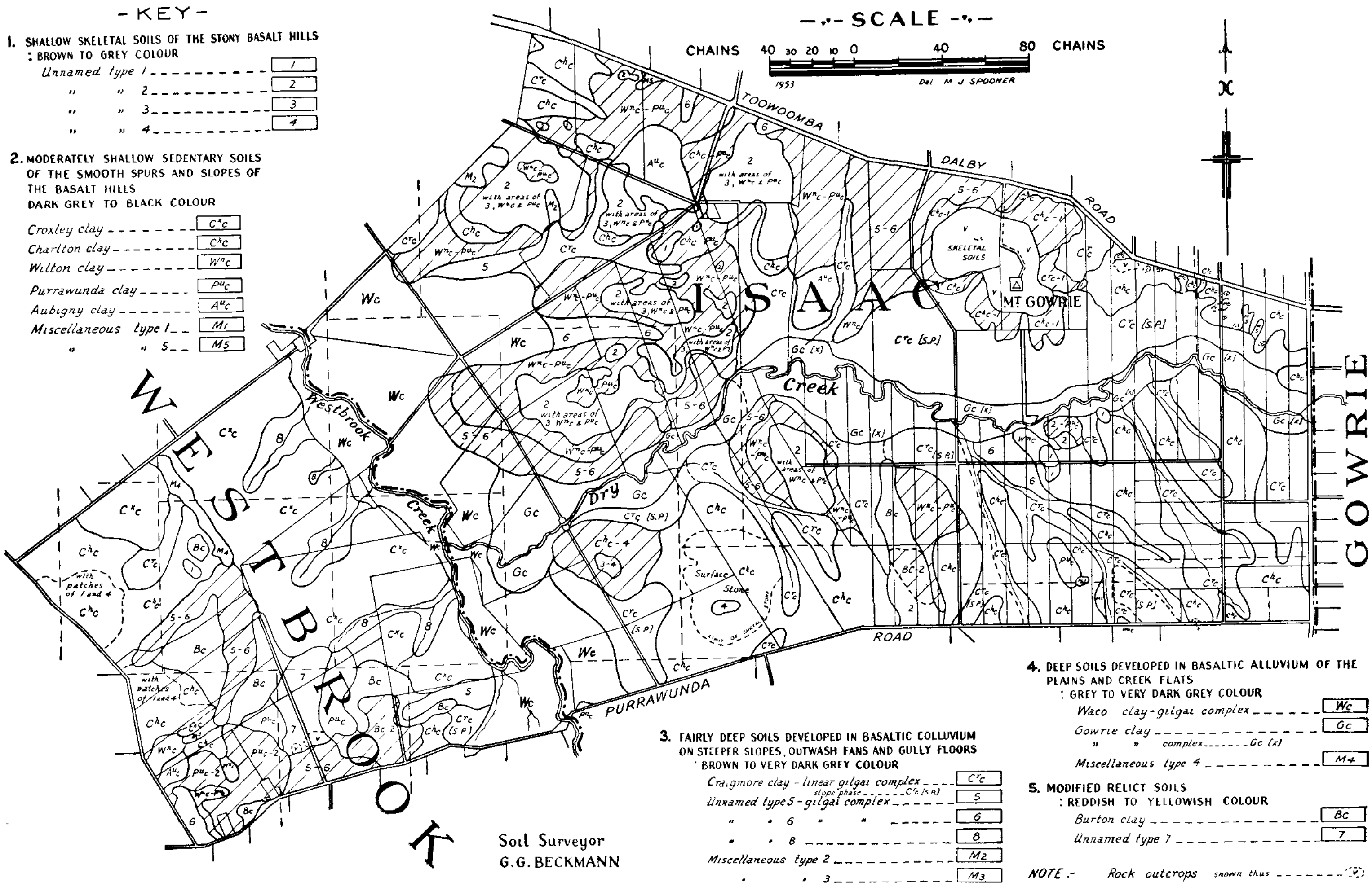


Fig. 3.—Soil map, Mt. Gowrie Area, part Parishes of Isaac and Westbrook, County of Aubigny, Queensland.

KEY TO SOILS

(*a*) *Skeletal Soils on Basalt*

$K^{e}scl$ ....Kenmuir stony clay loam	$T17$......Type 17
$K^{e}l$ ....Kenmuir loam (fine crumb variant)	

(*b*) *Moderately Deep Soils on Basalt*

Mcl ....Mallard clay loam	$T9$ ......Type 9
$T8$ ....Type 8	

(*c*) *Soils on Sandstone and its Derivatives*

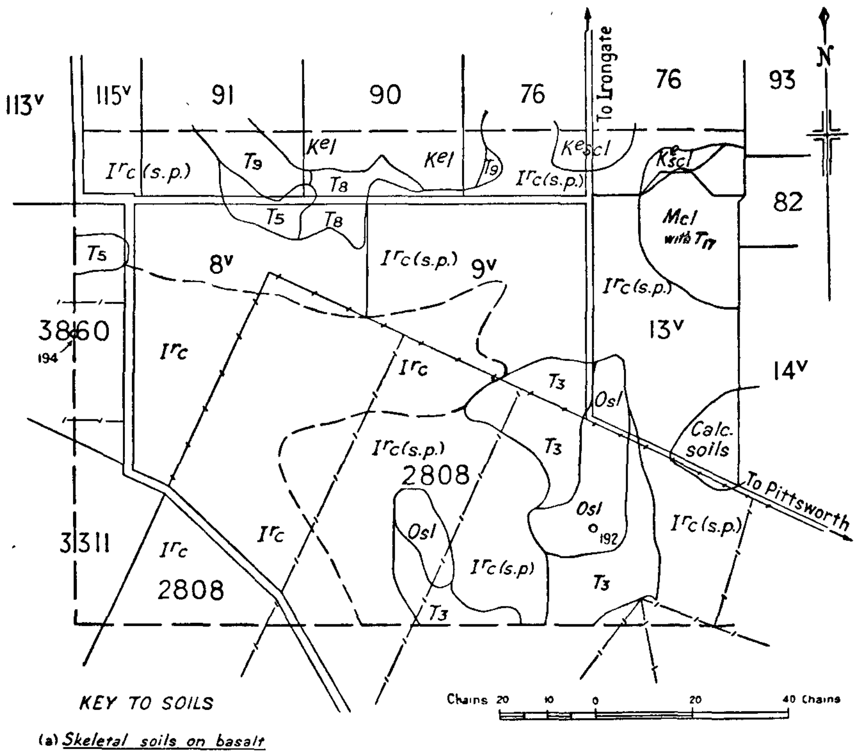
Osl..........Oakview sandy loam	$T3$ ......Type 3

(*d*) *Soils on Colluvium* (*mixed materials from basalt and sandstone*)

$I^{r}c$ ....Irongate clay	$T5$ ......Type 5
$I^{r}c(s.p.)$......Irongate clay, slope phase	

(*e*) *Calcareous Soils* ....*Calc. soils*

Sample sites shown thus...... ○ 194



SOIL SURVEYORS
G. G. BECKMANN

FIELD OPERATIONS
DIVISION OF SOILS 1953

Fig. 4.—Soil map, Irongate Area, Parish of Beauaraba, County of Aubigny, Darling Downs, Queensland.

LEGEND

I. GENERALLY WELL-DRAINED SOILS

Gabbinbar Loam, reddish brown earthy surface horizons grading into red well-structured clays, generally without laterite .... Gl

Ruthven Clay Loam, reddish brown clay loams overlying red well-structured clays generally without laterite .... Rcl

Ruthven Clay Loam, shallow solum phase, with thin red clay horizon .... Rcl (s)

Rangeville Loam, shallow earthy soil overlying massive laterite .... Ral

Middle Ridge Clay Loam, reddish brown clay loams over red well-structured clays with variable amounts of laterite nodules .... MRcl

Type 12, reddish brown clay loams over red well-structured clays with large amounts of laterite fragments grading into indurated "mottled" zone 12

II. IMPERFECTLY DRAINED SOILS

Nelson Clay Loam, dominantly yellow friable clay soil with nodules or cemented pisolitic masses of "black" laterite .... Ncl

Type 15, reddish yellow plastic clay soil overlying very weathered yellow-brown basalt 15

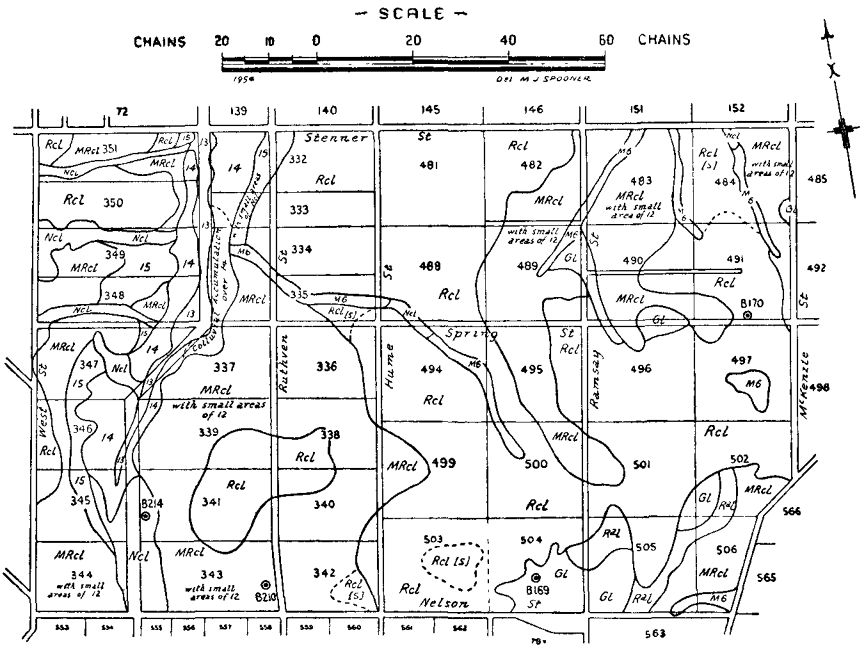
Miscellaneous Group 6, variable red to yellow-red soils with soft black concretions occupying the minor drainage lines M6

III. POORLY DRAINED SOILS

Type 14, mottled grey, wet plastic clays associated with the main drainage line 14

Type 13, mottled grey and yellow-grey wet plastic clays occupying the main drainage line 13

Note: Soil sample sites shown thus .... ⊙ B210



SOIL SURVEYORS *FIELD OPERATIONS*
C. H. THOMPSON, G. G. BECKMANN *DIVISION OF SOILS 1952*

Fig. 5.—Soil map, Middle Ridge Area, part Parish of Drayton, County of Aubigny, Queensland.

III. The Soils

(a) General

Most of the soils in the Toowoomba area have formed from basalt rock, either directly from the rock weathering in place, or from the products of rock weathering which have been transported to lower levels. Small areas of soils developed in sandstone and other parent materials also occur. The farmers of the area readily recognize two broad groups, the "red" soils and the "black" soils, which have both formed in basaltic materials. The black soils dominate the area. They are highly fertile clays, with a high water-storage capacity, are hard when dry and very sticky when wet, and can be cultivated satisfactorily only over a narrow moisture range. The red soils have lighter textures, are friable or crumbly when moist, and are easy to cultivate. They are only moderately fertile and have a lower water-storage capacity than the black soils.

Some of the soil associations mapped in this area have been more narrowly defined than usual, and in these as much as 80–90 per cent. of the pattern is composed of one soil type.

(i) *Survey Technique.*—As an initial step in the study of the soils of the area several small units were selected for detailed survey. These were used to provide information on the occurrence and the relationship of the soils in the larger patterns which were later delineated by ground reconnaissance assisted by aerial photographs. Field operations commenced during July 1951 with the detailed examination of the East Prairie and Mt. Gowrie areas, each of about 10,000 acres (Beckmann 1952; Thompson 1952). These were followed subsequently by the smaller (2000–5000 acre) areas of Middle Ridge, Aubigny, Cecilvale, Southbrook, and Irongate (Thompson 1954*a*, 1954*b*; Thompson, Hubble, and Beckmann, 1954; Beckmann 1956) (Figs. 2–7). During the 1953 season the whole area was mapped using the soil association as a mapping unit (see soil association map). This was done from the roads of the area as far as possible, with some cross-country traverses, giving a traverse cover at a 2-mile interval along which soil examinations were made about half a mile apart.

(ii) *Gilgai Microrelief.*—More or less regular patterns of small mounds—called puffs—and depressions are characteristic surface features of many of the virgin clay soils. These microrelief formations are known as *gilgai*. They develop as a result of seasonal moisture changes in these deep clay soils which expand and crack with wetting and drying.

Two main types of gilgai are recognized in the Toowoomba and Kurrawa areas, the "crabholey type" associated with the almost flat plains, and the "linear form" occurring on the lower hill slopes.

The crabholey type, known locally as "melonhole", consists of a pattern of crudely circular puffs and intervening depressions. Both the puffs and the depressions vary in size and in degree of development, as measured by the difference in level between the crest of the puff and the bottom of the depression. Although gilgai dimensions are not constant in any one soil, each type has a fairly characteristic range, and a set form of gilgai development, e.g. the typical gilgai of the Waco soil consists of rather small depressions set in a general level of puff soil, but in the Waverley soil both puffs and depressions are rounded and occupy approximately

LEGEND

A. SKELETAL SOILS: very shallow stony soils with little or no profile development associated with the flattish tops and steep slopes of the basalt hills; non-arable.

Kenmuir Stony Clay Loam, grey-brown to red-brown soil .... $K^{e}scl$

Majuba Clay, very dark grey to black granular soil .... $M^{a}c$

B. SEDENTARY SOILS: very shallow to moderately deep soils formed from weathered basalt on the gentle lower slopes of the hills, depth very variable; red-brown to black in colour; generally arable, some types barely so due to thinness and surface stone, but all types cultivated in some parts of the area.

(*a*) Very Dark Brown to Black Clay Soils: 6–42 in. deep, well-developed granular surface horizons.

Beauaraba Clay, very shallow dark brown to black soil .... $B^{e}c$

Purrawunda Clay, very dark greyish brown soil, generally shallow well-developed granular surface .... $P^{u}c$

Charlton Clay, shallow very dark grey soil with low structural development .... $C^{h}c$

Wilton Clay, shallow soil with very dark brown surface over red-brown clay subsoil .... $W^{n}c$

(*b*) Brown to Red-brown Soils: 12–70 in. deep, moderate structural development.

Southbrook Clay Loam, reddish brown surface soil with some stone overlying red-brown to red clay .... $S^{o}cl$

Type 7, brown to red-brown weakly structured clay soil 7

Aubigny Clay, reddish brown light clays overlying red-brown clays developed in basalt containing calcite and calcium carbonate .... $A^{u}c$

Burton Clay Loam, reddish brown surface over red-brown to red clay; moderate to deep soil .... Bcl

C. SEDENTARY-COLLUVIAL SOILS: moderately deep very dark brown to black clay soils, strong granular surface structure, linear gilgai microrelief. Occurs on gentle lower slopes.

Irving Clay Linear Gilgai Complex, a very dark grey-brown soil usually with moderate structure Ic

Knapdale Clay Linear Gilgai Complex, a very dark grey soil usually with low structural development .... Kc

D. SOILS DEVELOPED IN BASALTIC ALLUVIUM on the gently undulating plains. Very dark brown to black deep heavy clay soils with granular surfaces and low to moderate subsoil structure development, and slight to moderate crabholey microrelief development.

Waco Clay Gilgai Complex, very dark greyish brown soil with moderately structured subsoil .... Wc

Waco Clay Gilgai Complex (*yellow-brown subsoil phase*), as for Waco clay but with a yellow-brown subsoil below 18 in. .... Wc(YB)

Waco Clay Gilgai Complex (*weathered basalt substratum phase*), as for Waco clay but with weathering basalt below 48 in. .... Wc(wbp)

Waverley Clay Gilgai Complex, very dark grey to black poorly structured soil .... $W^{y}c$

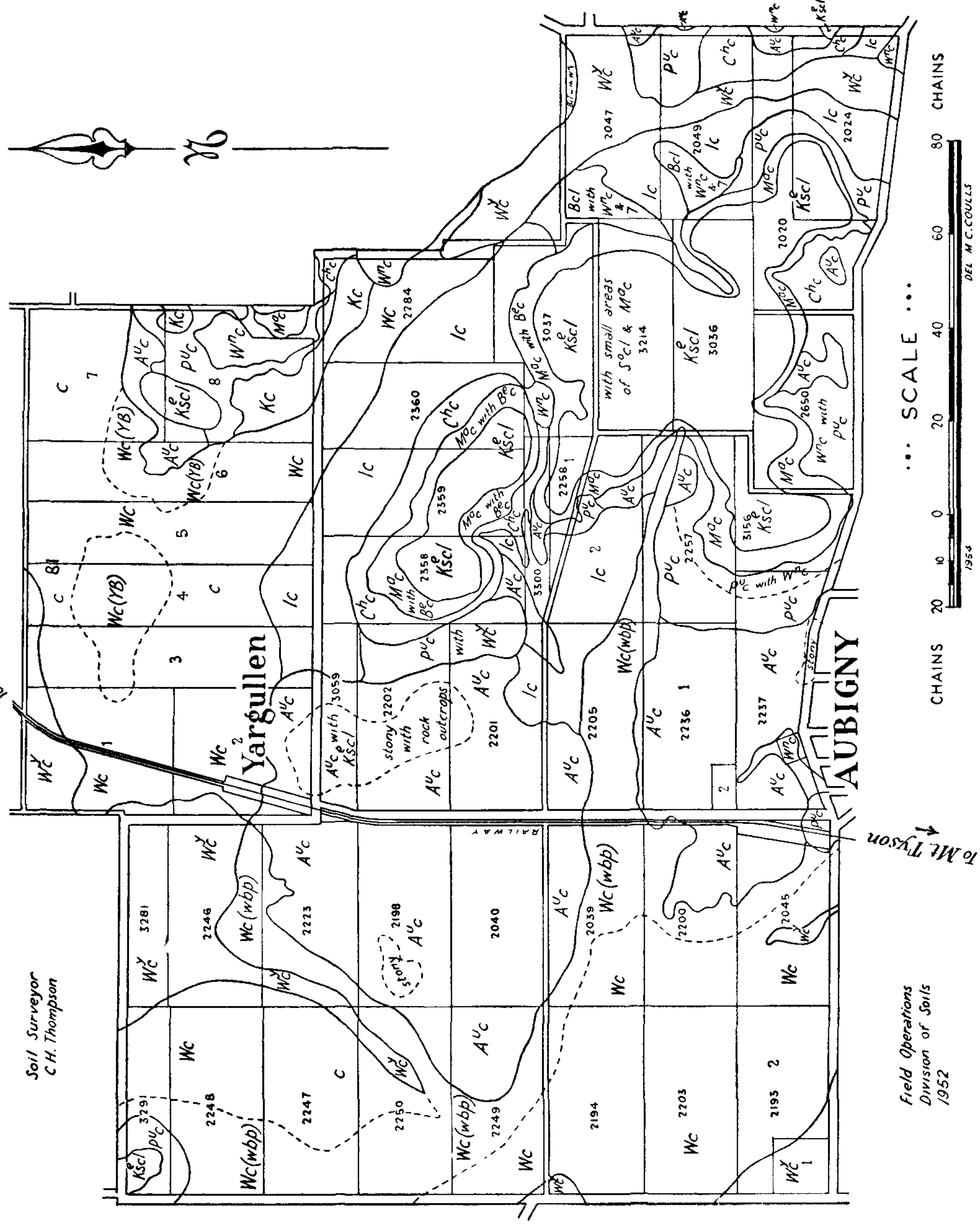


Fig. 6.—Soil map, Aubigny Area, part Parish of Westbrook, County of Aubigny, Queensland.

LEGEND

A. SKELETAL SOILS: very shallow stony soils showing little or no profile development associated with the flat tops and steep stony slopes of the basalt hills; non-arable.

Kenmuir Stony Clay Loam, greyish brown to reddish brown soil	$K^{e}scl$
Majuba Clay, very dark grey to black granular soil	$M^{a}c$

B. SEDENTARY SOILS: very shallow to moderately deep soils formed from weathered basalt on the gentle lower slopes of the hills, depth very variable, colour ranging from red-brown to black; generally arable, some types scarcely so due to thinness and surface stone but all types are cultivated in some part of the area.

(*a*) VERY DARK BROWN TO BLACK CLAY SOILS from 6 to 42 in. deep; well-developed granular surface horizons.

Beauaraba Clay, very shallow dark brown to black soil	$B^{e}c$
Type 16, shallow dark grey-brown clay soil	16
Purrawunda Clay, very dark greyish brown soil, generally shallow, well-developed granular surface	$P^{u}c$
Charlton Clay, shallow very dark grey soil, generally with low structural development	$C^{h}c$
Wilton Clay, shallow soil with very dark brown surface over red-brown clay subsoil	$W^{n}c$

(*b*) BROWN TO RED-BROWN SOILS (12–70 in. deep) moderate structural development.

Mallard Clay Loam, shallow brown soil with gravel throughout	Mcl
Southbrook Clay Loam, reddish brown surface soil with some stone overlying red-brown to red clay	$S^{o}cl$
Type 7, brown to red-brown weakly structured clay soil	7
Burton Clay Loam, reddish brown surface over red-brown to red clay; moderate to deep soil	Bcl
Burton Clay Loam, orange variant, reddish brown surface over reddish yellow-brown clay	Bcl(v)
Type 19, dark brown clay, surface over mottled yellow-grey and yellow-brown weakly structured clay	19

C. SEDENTARY-COLLUVIAL SOILS: moderately deep very dark grey-brown clay soils, strong granular surface structure, linear gilgai micro-relief, occurs on gentle lower slopes of the hills.

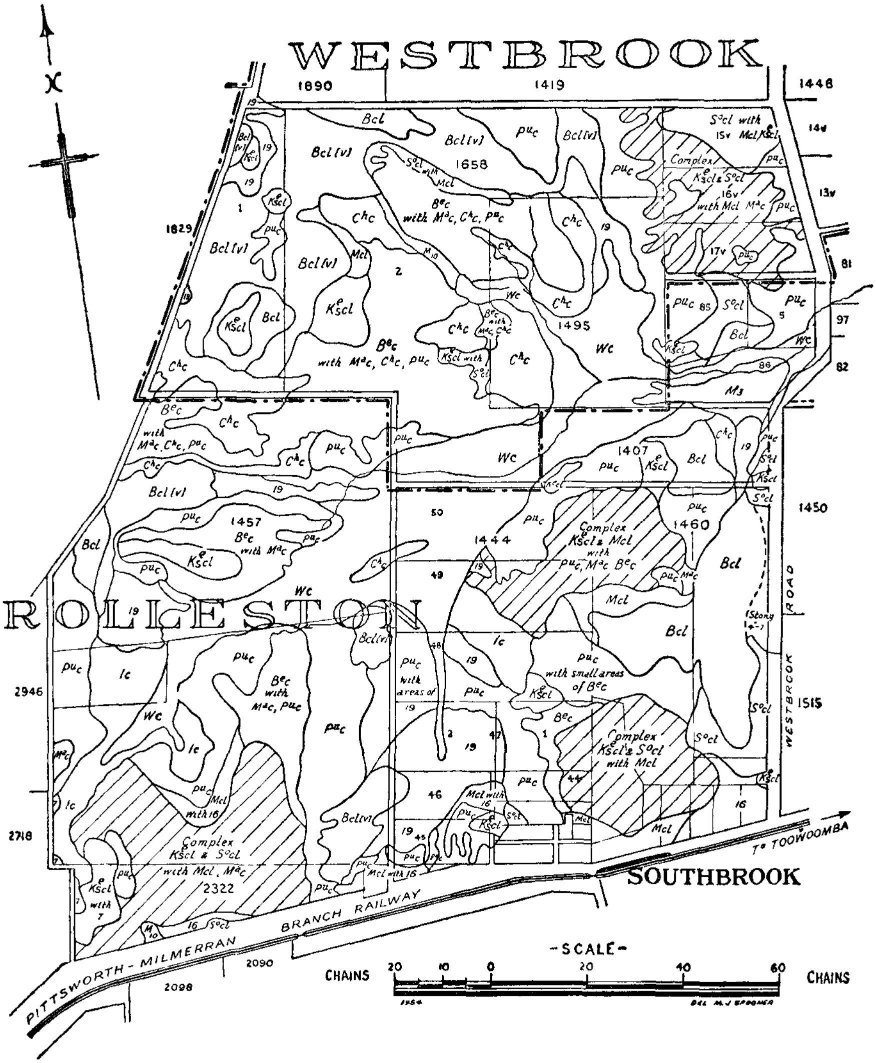
Irving Clay, linear gilgai complex	Ic

D. SOILS FORMED FROM BASALTIC ALLUVIUM: along minor drainage channels very dark brown to black heavy clay soils, coarse granular surface, low structural development in subsoil, slight to moderate gilgai.

Waco Clay, subdued gilgai complex	Wc

MISCELLANEOUS SOILS: groups of variable soils occupying small areas along minor drainage lines.

Group 3, very dark grey-brown clays with low to high accumulation of carbonates, moderate structure	M3
Group 10, very dark grey clays of variable depth overlying basalt boulders	M10



SOIL SURVEYOR
C.H. Thompson

Fig. 7.—Soil map, Southbrook Area, part Parishes of Westbrook and Rolleston, County of Aubigny, Queensland.

equal areas. The area occupied by the puff varies with the soil type, and in some soils is as low as 15 per cent. and in others as much as 70 per cent.

On the lower hill slopes the clay soils have linear gilgai consisting of continuous lines of puffs and depressions, like the crests and troughs of waves, running parallel to the maximum slope down to the valley floor. The puffs are usually about 4 or 5 yd apart and up to 5 yd across, and the difference in level ranges from 2 to 12 in.

Close examination of gilgai in these soils shows that the puff and depression profiles differ markedly from each other. They are in fact two different soils occupying small recurring areas, forming an intricate pattern or soil complex, referred to as a *gilgai complex.*

At the puff-crest or centre, a tongue of lighter-coloured deep subsoil containing soft or nodular carbonate or both rises to, or almost to, the surface. This differs markedly from the depression soil. The puff slope has a profile similar to that of the depression, but usually somewhat shallower to the deep subsoil. Although the raised puff area might form up to 70 per cent. of a gilgai complex, the distinct puff-crest soils usually occupy considerably less than 25 per cent. of the total puff area.

The depression soils of a gilgai complex are usually fairly deep, mostly having more than 3 ft of dark clay horizons above the lighter-coloured deep subsoil. Because of their relatively uniform characteristics, series names are applied to these depression soils, and the complex as a whole is referred to as, e.g. Waco clay, linear gilgai complex.

As the puff-crest soils in this area have only a few inches of dark granular clay grading into material very similar to the deep subsoil of the depression soil, it is possible to obtain an idea of the "puff" profile from the depression description. For this reason the depression soils only are described in the present report.

(*b*) *Descriptions of Soils*

In this subsection the soil types of each of the four physiographic divisions are briefly described under a simple grouping based on soil parent material, colour, etc. (cf. Table 4). Detailed type descriptions are not given in this report; the important soils will be more fully described in a later publication on the pedology of the area.

(i) *Soils of the Toowoomba Plateau*

Friable, highly permeable red soils, varying greatly in thickness but generally more than 6 ft deep, occupy the greater part of the plateau. Many of these soils are associated with lateritic materials—nodular or massive hardened red clays or ironstone materials—which are considered to be part of an ancient and very deep soil cover. The complete laterite profile, as known from other parts of Queensland, usually shows several well-defined zones (Whitehouse 1940). The important zones in the Toowoomba area in order of occurrence with depth are:

a *ferruginous zone* of friable red soil and laterite;

a *mottled zone* of mainly whitish clays coarsely mottled with red, some units of which have hardened; and

a *pallid zone* of whitish clay or soft altered rock.

Most of the soils of the plateau are believed to be the modified remains of these various parts of the old laterite profile that have been exposed by erosion and dissection. There are also smaller areas of moderately shallow red soils formed more recently from fresh basalt rock, and minor occurrences of indifferently to poorly drained soils formed on transported materials.

TABLE 4

SOILS OF THE TOOWOOMBA AREA

Soils of the Toowoomba plateau	(i) Red soils associated with lateritic materials		Gabbinbar, Ruthven, Rangeville, Toowoomba, Middle Ridge, Harristown, and Type 12 soils
	(ii) Yellow and grey soils associated with lateritic materials		Nelson, Type 11, and Type 10 soils
	(iii) Red basaltic soils		Drayton, Kynoch, and Type 15 soils
	(iv) Soils formed in transported materials		Type 13, Type 14, and Misc. Group 6 soils
Soils of the basaltic uplands	(i) Skeletal soils formed on basalt	Brown soils	Kenmuir and Type 6 soils
		Dark soils	Croxley, Majuba, and Types 4 and 17 soils
	(ii) Sedentary soils on basalt	Red soils	Mallard, Southbrook, Aubigny, Burton, and Types 19, 7, and 8 soils
		Dark soils	Beauaraba, Purrawunda, Wilton, Charlton, Types 16 and 9, and Misc. Group 1 soils
	(iii) Sedentary soils on sandstones and shales		Oakview, Yarranlea, and Types 3 and 18 soils
	(iv) Soils formed on colluvial materials	Basaltic origin	Irving, Craigmore, Knapdale, and Ramsay soils
		Mixed origin	Murlaggan, Irongate slope phase, and Types 2 and 5 soils
	(v) Soils formed in basaltic alluvium		Type 1, Gowrie, and Misc. Groups 3 and 4 soils
Soils of the alluvial plains	(i) Soils formed in alluvium	Basaltic origin	Waco and Waverley soils
		Mixed origin	Irongate, Cecilvale, and Misc. Group 7 soils
	(ii) Soils formed in calcareous materials		Edgecombe, Yargullen, and Dalkeith soils
Soils of the steep eastern slopes of the range	(i) Soils formed in basalt		Group D; Groups A, B, and C
	(ii) Soils formed in sandstone		Group H; Groups E, F, and G

(1) *Soil Type Descriptions.—(A) Red soils generally associated with laterite materials.*—Important characteristics of these soils are their red colour, high porosity and permeability, strong friability, and generally great depth, though two types are relatively thin, grading into laterite below. Their surface horizons are generally 6–8 in. thick, and under virgin conditions have moderate to high organic contents,

fairly dark reddish brown colour, and strongly developed crumb to fine blocky structures, grading into red clays of strongly developed fine blocky structure below.

These soils have been strongly weathered over a very long time and have rather low fertility. Contents of available phosphorus and exchangeable potassium are low. All of the soils are mildly acid in reaction, sometimes tending to be near neutral in their surface horizons.

Two types—the Gabbinbar loam and Ruthven clay loam—are virtually free of laterite; the other soils contain variable, low to high, amounts of lateritic gravel and larger lumps.

Gabbinbar loam.—The most striking features of this soil are the loamy texture and strong fine crumb structure of its surface horizon, the low plasticity of the soil material to a depth of 18–24 in., and its great depth. The surface soil is a dark reddish brown to brown strongly organic loam, which is very friable when moist but has a powdery to snuffy character when dry and is then hard to wet. It erodes rapidly from exposed sites when cultivated.

Below the surface the profile consists of light yellowish red-brown clay loam of very low plasticity but extreme friability, grading into many feet of low to moderately plastic friable red clay below about 24 in. A few hardened clay nodules up to $\frac{1}{2}$ in. size may occur in the profile, and in some areas massive laterite occurs below a depth of 8 ft.

Ruthven clay loam.—This soil has a higher clay content and stronger plasticity and other clayey properties in the upper parts of its profile than the Gabbinbar soil, and is essentially free of lateritic material. The surface horizon of dark reddish brown clay loam grades below into many feet of red moderately plastic clay with fine blocky structure. Generally there are no hardened clay nodules to a depth of 3 ft and few nodules below.

A *shallow phase* is recognized, being shallower to the underlying weathered basalt rock and generally a yellowish red colour below 36 in.

Rangeville loam.—This is a shallow red soil containing moderate to high amounts of fine lateritic gravel and some larger lumps of laterite and grading into or abruptly overlying massive laterite at depths ranging from 12 to 36 in. The greyish brown to dark reddish brown loam surface soil is very friable to "snuffy" and grades into light yellowish red-brown clay loam with much lateritic gravel. There is sometimes a thin horizon of red-brown clay below, but when the change to the underlying laterite is abrupt the soil above it is often more yellow-brown in colour and less clayey.

Toowoomba loam.—This is a deep friable red clay soil containing large amounts of lateritic gravel, particularly in the upper part of the profile. The surface loam horizon is similar to that of the Rangeville soil, and grades below through about 12 in. of light yellowish red-brown extremely friable loamy soil into very gravelly red clays. The gravel includes both hardened clay and ironstone nodules with some larger lumps up to several inches in size.

Middle Ridge clay loam.—This soil is more than 6 ft deep and has apparently developed in the lower part of the ferruginous zone of the old laterite profile. The main profile features are about 7 in. of dark reddish brown clay loam surface grading through a thin transitional horizon into red moderately plastic clay. There are small amounts of lateritic gravel in the top 18 in. and moderate to high amounts in the lower horizons.

Type 12 *clay loam*.—This type is closely associated with the Middle Ridge series but usually occupies a lower topographic position. It has a reddish brown clay loam surface grading into red moderately plastic clay, with variable amounts of laterite gravel and fragments overlying upper mottled zone materials in which the red parts of the mottle have hardened and form tubular structures 1–4 in. in diameter. Depth of soil to the hardened material varies from 2 to 4 ft.

Harristown loam.—The most striking feature of this soil is its high content of lateritic gravel consisting of irregular fragments of hardened red clay which become coarser and more angular in the subsoil. The surface soil, 6–8 in. thick, is a dark brown to reddish brown friable loam with moderate amounts of lateritic gravel grading below into red friable clay loam to clay with large amounts of coarser gravel and some patches of light grey clay. Below about 3 ft the laterite forms a cellular mass filled with mottled light grey and red clay. This is considered to be the upper mottled zone material of the old laterite profile.

(*B*) *Yellow and grey soils associated with lateritic materials*.—There are only small areas of these soils, all of which contain some lateritic materials and are apparently formed in the remnants of the old lateritic cover of the area. Their surface horizons are fairly thick and dark coloured, and contain moderate amounts of organic matter. Like the red soils they have a low content of available phosphorus and are generally slightly to moderately acid in reaction.

Type 10 *loam*.—This is a rather organic shallow soil overlying and formed from predominantly greyish mottled zone clays containing some laterite. The surface horizon, 8–11 in. thick, is a very dark grey-brown or brown friable organic loam with few laterite fragments. Below this the soil gradually becomes less organic and more clayey, grading into a mottled brown and dark reddish grey-brown friable clay with coarser laterite fragments below about 12 in. The mottled light pinkish grey-brown clay below 18–20 in. is little-altered parent material considered to be the lower mottled zone of the old laterite profile.

Type 11 *clay loam*.—The surface horizon of this soil is a dark brown friable clay loam with a few soft black nodules, grading through a yellowish transitional layer into a yellow-brown clay at about 9 in. depth, with large amounts of very soft nodules. This is underlain by a coarsely mottled blue-grey, red, and yellow, stiff-plastic heavy clay which grades into soft kaolinized basalt with depth. Soil depth is 3–4 ft and the presence of moderate amounts of soft black nodules is characteristic.

Nelson clay loam.—The striking features of this soil are a brownish grey friable clay loam surface about 5 in. thick grading into several feet of predominantly yellow-brown friable clay, and the presence of moderate amounts of hard black lateritic nodules and some concretionary masses up to several feet in size. The friable yellow-brown subsoil is often finely mottled with reddish brown and yellow-grey, and the nodules and concretionary masses occur from the surface to depths of several feet. The soil is more than 6 ft deep, moderately acid, and situated marginal to the broad drainage lines where drainage is impeded and there is a seasonal water-table.

(*C*) *Red basaltic soils.*—In contrast to the red soils previously described, these soils have formed from relatively fresh basalt rock. Distinctive features are their shallower depth of soil (2–6 ft thick), moderate plasticity of the red clay subsoils, and the presence of weathered basalt parent material of mealy consistence passing into hard rock below. Some basalt stone and gravel are usually present.

Surface horizons are friable with well-developed crumb structure, and the red clay subsoils have strongly developed fine blocky structure, moderate plasticity, and high permeability. Soil reaction ranges from slightly acid in the surface soil to neutral or slightly alkaline in the deeper subsoil, and the soils are more fertile than the deep red soils associated with lateritic materials.

Drayton clay loam.—This soil is 18–36 in. deep to weathered basalt parent material. There may be some surface stone, but the profile is generally stone free. The surface, 7 in. thick, is a dark brown or reddish brown clay loam which grades into a red moderately plastic clay. In the deeper profiles there is generally a thin horizon of faintly mottled yellowish brown and red-brown, coarse-structured, stiff clay containing some black concretions and basalt gravel, immediately above the basalt parent material.

Kynoch clay loam.—This soil is 3–6 ft deep to the weathered mealy parent material. The surface horizon, of about 8 in., is a dark brown to reddish brown friable clay loam. Below this there may be a thin layer of clay with a strongly developed subangular blocky structure with conchoidal fracture and brittle to hard consistence when dry. Below about 12 in. this grades into several feet of red clay subsoil with fine irregular blocky structure. Generally only a few pieces of basalt stone or gravel occur, but in some places considerable amounts of stone and boulders, a foot or two in diameter, are present on the surface and in the subsoil.

Type 15 *clay loam.*—Type 15 has about 5 in. of grey-brown or dark reddish brown clay loam surface soil, grading through about 10 in. of light reddish brown clay into bright yellow-brown plastic clay, which overlies soft very weathered basalt. The soil is 4–6 ft thick and may have some iron-stained gravel in the lower horizons.

(*D*) *Soils developed in transported materials.*—These soils occur in the drainage lines of the area and have impeded drainage with seasonal or permanent water-tables close to the surface.

Type 13 *clay.*—This type occupies the wet floors of the main drainage lines. Its main features are about 4 in. of rusty flecked brownish grey light clay surface soil with organic matter, about 20 in. of dark grey and bluish grey heavy clay subsoil with rusty yellow inclusions, and a deep subsoil of mottled light grey, bluish grey, and yellow-grey clay with rusty flecks and nodules grading into weathered basalt below a depth of 7 ft. The water-table is generally encountered between 12 and 24 in.

Type 14 *clay.*—Type 14 is closely associated with Type 13 and found on the narrow flats marginal to the major drainage lines. It has 3 in. of dark brownish grey light clay surface grading through about 6 in. of dark yellowish grey heavy clay into mottled yellow-grey clay overlying soft weathered basalt below 5 ft. Soft black nodules occur through the clay layers, and weathered basalt gravel and some carbonate nodules are found in the lower part of the profile.

Miscellaneous Group 6.—Somewhat variable red soils of the minor drainage lines form this group. The main profile features are dark brown or dark reddish brown light clay surface soils overlying more than 6 ft of red, grading to brownish yellow, clay with low to moderate amounts of soft black nodules and iron-stained gravel.

(2) *The Soil Associations of the Toowoomba Plateau.*—Three associations have been recognized and mapped in the plateau area, separating (*a*) the lateritic soils with deep "earthy" surface horizons, (*b*) soils with clay loam surface horizons and containing variable amounts of laterite, and (*c*) the shallower red soils developed in relatively fresh weathered basalt.

Toowoomba-Gabbinbar association.—This is a small unit found only on the eastern edge of the Toowoomba plateau immediately above the steep scarp of the range. It occupies the ridge crests and the long 2–7° slopes down to the drainage lines. Soils of variable depth with "earthy" surface horizons make up most of the association. Toowoomba and Gabbinbar soils are the dominants. Rangeville and Harristown soils occupy smaller areas as associate types, and Ruthven, Kynoch, Drayton, and Middle Ridge soils have minor occurrence. Remnants of the native vegetation suggest that this unit once carried a eucalypt forest cover.

Ruthven-Middle Ridge association.—This association occupies the low ridges, long slopes, and drainage lines of a large part of the dissected Toowoomba plateau. The soils are dominantly clay loam types containing variable amounts of laterite. The Ruthven and Middle Ridge soils on the ridges and slopes are strongly dominant, and small areas of most of the soils found on the plateau are included in the unit as minor components of the pattern. The virgin vegetation appears to have been a eucalypt forest.

Drayton-Kynoch association.—In a narrow and discontinuous belt of country along the western edge of the plateau, soils of the Drayton and Kynoch series are dominant and have been mapped as a separate association. Small areas of Ruthven and Types 11 and 4 soils occur as minors in the pattern. Much of this unit, which occupies broad ridge-crests and gentle slopes, lies at a lower level than the two associations of lateritic soils, but above the dark clay soils of the more strongly dissected uplands which lie immediately to the west.

(ii) *Soils of the Basaltic Uplands*

Very shallow stony soils and shallow to moderately deep stone-free types developed from basalt dominate the upland area and occupy the highest part of the landscape. Very dark clay soils contribute a high proportion of the pattern with moderate areas of brown and smaller areas of red basaltic soils. On the long gentle slopes there are important areas of dark, deep clay soils developed in colluvium, and smaller areas of similar soils formed in alluvium along the drainage lines (Fig. 8).

(1) *Soil Type Descriptions.*—(*A*) *Skeletal soils developed from basalt.*—These are very shallow, stony soils 8–10 in. deep to hard basalt rock and are generally without horizon differentiation. Brown and dark-coloured subgroups are recognized.

Brown subgroup

Friable loam and clay loam types with a crumb to fine blocky structure are included in this group. They have a neutral reaction and are generally highly fertile soils, but owing to their shallow depth and stoniness are mostly non-arable.

Kenmuir stony clay loam.—This brown to grey-brown clay loam soil ranges from 2 to 8 in. deep to hard basalt and has much basalt stone through the profile. Some veins of red clay may occur between the rock fragments below a depth of 6 in.

Kenmuir gravelly clay loam.—Soils generally similar to the Kenmuir stony clay loam but with very small amounts of stone and with large quantities of basalt gravel of 2 in. or smaller size form this type. Soil depth ranges from 6 to 12 in. The underlying basalt is very weathered, and horizontally jointed, and breaks into 2-in. flakes when disturbed. This soil occurs on the extensive flat-tops and is cultivated in some areas for forage crops.

Kenmuir loam, fine-structured variant.—Soils similar to the Kenmuir series, but with a very strongly developed fine crumb structure and powdery consistence when dry, form this variant. It is 2–6 in. deep and has basalt gravel and small stone through the profile.

Fig. 8.—A section of the basaltic uplands showing the flat-topped hill crests with skeletal soils in the distance, and the cultivated slopes of sedentary and colluvial soils extending to the narrow drainage line in the middle distance.

Type 6 loam.—This soil is generally stone free and is a brown friable loam 4–6 in. deep to soft, very weathered parent material of mealy consistence. It occurs on hill crests and slopes under softwood scrub and cypress pine.

Dark-coloured subgroup

This is a grouping of dark brownish grey to very dark brown soils with granular to fine blocky structure, a neutral reaction, and a texture range of loams to heavy clays. These are shallow, stony, non-arable soils with a high fertility level.

Type 17 loam.—There is only a limited occurrence of this soil under softwood scrub on the steep slopes and some of the hill crests. It is a very dark brown to black loam with moderate organic accumulation and a strong medium granular structure. Soil depth is generally less than 6 in. and there is much large basalt stone on the surface and through the soil.

Type 4 clay loam.—Type 4 is a very dark brownish grey clay loam or light clay soil with a fine blocky structure. Depth of soil to weathered basalt is 4–6 in. and basalt gravel occurs through the profile. Small areas of this soil occur on the hill crests throughout the area.

Majuba clay.—This very dark grey heavy clay soil occurs on moderate to steep (10–20°) hill slopes. The structure is coarse granular on the surface, grading into blocky units with depth. There are some rock outcrops, and large amounts of stone on the surface and through the profile. Soil depth to hard basalt is generally less than 12 in.

Croxley clay.—This is a shallow type with slight profile differentiation and is really intermediate between the skeletal and sedentary groups. The surface is a dark brownish grey to dark brown medium clay with some stone, overlying a dark grey-brown heavy clay (sometimes weakly mottled with reddish brown) with moderate amounts of basalt gravel about 1 in. size and a little stone. The soil depth ranges from 6 to 16 in. to yellowish grey weathered basalt.

(B) Sedentary soils developed in basalt.—These are generally stone-free shallow to moderately deep soils which have formed from weathering basalt in place. Red and dark-coloured subgroups are recognized.

Red subgroup

The soils of this group have a brown clay loam or light clay surface and generally red clay subsoils with a fine blocky structure. Depth to parent weathered basalt is variable and some types have visible carbonate nodules in the lower horizons. Soil reaction is slightly acid to neutral in the surface and neutral to moderately alkaline below. In the virgin state these soils are moderately fertile. They have moderate amounts of organic matter and a moderate to high available phosphorus content.

Mallard clay loam.—The main features of this soil are a brown to grey-brown clay loam surface horizon, 2–7 in. thick, overlying a brown clay subsoil mottled with some red-brown and yellow-brown, and passing into soft weathered basaltic parent material at depths of from 10 to 18 in. Some small basalt stones and gravel occur on the surface, and gravel occurs through the profile. Soil reaction is slightly acid becoming neutral with depth.

Southbrook clay loam.—This moderately shallow soil is 15–33 in. deep, and has much surface stone, but, generally, a stone-free clay subsoil. The main profile features are about 6 in. of brown or reddish brown clay loam, overlying about 12 in. of red plastic clay with a strong fine blocky structure, which grades through mottled clay into soft weathered basalt. The soil has a neutral reaction throughout.

An *orange variant* is recognized with predominantly orange-coloured clay subsoils and a slightly acid to neutral reaction.

Aubigny clay.—This soil closely resembles the Southbrook soil and is found on long gentle slopes of generally less than 2°. Important features by which it is recognized are: a light clay surface merging below through brown medium clay to red-brown or yellowish red clay subsoil; slight amounts of carbonate nodules in the lower clay horizon and moderate amounts with some calcite crystals in the underlying "mealy" weathered basalt; small amounts of surface stone and large amounts of $\frac{1}{2}$-in. basalt gravel in the lower clay horizon; and a neutral surface reaction changing to moderately alkaline in the deeper subsoil.

Burton clay loam.—This deeper red soil is of special interest because it has formed largely from old red soil materials or strongly weathered basalts that were buried by younger lava flows and later re-exposed by erosion. Some less weathered materials have also been incorporated in the soil during its development.

Important profile features are about 6 in. of dark reddish brown clay loam overlying red or red-brown clays, with a strong, fine, blocky structure grading into weathered parent material below 3–6 ft. The soil is free of stone and gravel but a few pieces of hardened sesquioxidic clay have been recorded in some profiles. Soil reaction is neutral or slightly acid in the surface and changes to slightly alkaline in the deeper subsoil. A few pieces of nodular carbonate have been found in the lower clay horizons in some places.

The type occurs on gentle middle or lower slope sites in the dissected upland area in close association with dark clay soils which may occur in both higher and lower slope positions.

An *orange variant* is recognized, occupying slightly lower topographic positions and generally having a few pieces of nodular carbonate in the lower part of the profile. Surface colour and texture are as for the type, but the clay subsoil is dominantly yellow-brown or yellow-red.

Type 19 *clay.*—This type appears to be limited to the Southbrook district where it is found in transitional areas between the Burton soil and the dark, heavy clay soils at lower levels. The surface 3 in. is a dark brown medium clay, and the subsoil is a brownish yellow heavy clay, with a medium to coarse blocky structure and some carbonate nodules. Depth of soil to weathered basalt ranges from 3 to 5 ft.

Type 7 *clay.*—Small areas of this type are distributed through the area on medium to gentle slopes and saddles. Distinctive characteristics are a strong clay texture, stiff plastic consistence when moist, and predominantly reddish brown colour. It has about 2 in. of dark brown or dark reddish brown, coarse, granular clay surface, overlying 12–24 in. of reddish or red-brown coarse, blocky, heavy clay which grades into strongly weathered basalt, and hardened clays. Soft and nodular carbonate content is variable, always being present in the deeper subsoil, and often through all of the subsoil. The soil reaction is neutral at the surface and moderately alkaline in the lower horizons.

Type 8 *clay loam.*—Type 8 has about 3 in. of dark greyish brown, friable clay loam surface grading through dark brown or brownish grey clay into red-brown clay becoming yellow-red with depth. There are small amounts of basalt gravel through the profile and some carbonate in the lower horizons. Depth of soil to weathering basalt ranges from 2 to 3 ft. The type occurs on slopes of about 5° or less, below pronounced scarps in the upland area.

Dark-coloured subgroup

Striking features of these soils are their dark colours, their strongly plastic to very sticky consistence when moist to wet, and their shallow to moderate depth—ranging from 6 to 36 in. to the weathered basaltic parent material. High clay contents are characteristic and they have a distinctive granular structure in the surface 2 in. grading into medium to coarse blocky structural aggregates, which have visible fine ($\frac{1}{16}$ in.) units tightly interlocked to form the larger aggregates.

Soil reaction is neutral, changing to moderately alkaline with depth, and the fertility level is generally high. These soils contain moderate amounts of organic matter, high contents of available phosphorus, and, in most cases, an adequate potassium status. Extreme swelling and shrinking with changing moisture content is a feature of these soils. When dry they crack appreciably, but not as much as the deeper dark clays on the plains. They have a high water-storage capacity and a fairly wide range of available moisture.

Beauaraba clay.—This is dark brownish grey or very dark brown clay soil only 4–12 in. deep to weathering basalt. Some basalt gravel occurs throughout the profile and soil reaction is neutral.

Type 16 *clay*.—The main feature of this type is a thin, dark grey-brown, weakly granular clay surface 1 or 2 in. thick, grading into coarse blocky, yellow-grey-brown clay subsoil overlying soft weathered parent material. The soil depth varies from 10 to 18 in. and the reaction is neutral throughout.

Purrawunda clay.—Large areas of the moderately shallow soils of the uplands are of this type which consists of very dark brown or very dark grey-brown clays 15 to 36 in. deep to soft weathered basalt. The colour becomes browner with depth, and a few small carbonate nodules may be present in the lower clay horizon or in the weathered parent material at some sites. The soil reaction is neutral, becoming moderately alkaline with depth.

Wilton clay.—This type occupies similar positions to, and the surface closely resembles, the Purrawunda soil with which it is usually associated, often forming a soil complex. It can be distinguished from the Purrawunda by a subsoil horizon of red-brown clay of irregular blocky to prismatic structure below 8–14 in. Depth of soil to soft weathered basalt varies from 15 to 33 in.

Charlton clay.—Like the Purrawunda clay, which it resembles closely, this soil occupies large areas of the moderate slopes of the uplands. It differs from the Purrawunda soil in being very dark grey and in having coarse granular structure in the surface and coarse blocky structure in the subsoils. In depth, soil reaction, and the presence of carbonate, it is similar to Purrawunda. Some profiles show a mottled dark brown and reddish brown transitional clay horizon immediately above the weathered basalt. A *shallow phase*, 10–15 in. deep to parent material, has been recognized, usually occurring as small patches within the type area.

Type 9 *clay*.—Only small areas of this soil have been observed; their distribution seems to be restricted to the Irongate district. The type has about 2 in. of very dark brown, granular, medium clay surface, grading into dark brown to dull yellowish brown heavy clay. Soft and nodular carbonate occurs throughout the profile below a depth of 2 in., and the soil ranges in depth from 2 to 4 ft to hard basalt.

Miscellaneous Group 1.—Soils of rather variable characteristics comprise this group. In general, they are very dark brown and dark brownish grey heavy clays, which grade through a mottled brown clay horizon into a band of red, hard to brittle clay with a conchoidal fracture ("baked clay"). They are underlain by weathered basalt at depths of less than 4 ft.

(*C*) *Sedentary soils on sandstones*.—Of the four soil types recognized, three show pronounced texture contrast in their profiles with loamy sand to loam surface soils overlying clay subsoils at relatively shallow depth. The fourth type has clay texture throughout.

In general these are soils of low to moderate fertility with fair potassium and available phosphorus contents. Soil reaction and depth vary greatly.

Oakview sandy loam.—This soil occupies the crests and moderate slopes of the sandstone rises in the south-western part of the area, mainly south of Irongate. Important profile features are a brownish grey to grey-brown sandy loam surface, grading through a brown or light reddish brown sandy clay loam transitional horizon into red or yellow-red sandy medium to heavy clays below 6–9 in. There is some soft and nodular carbonate in the lower horizons. Depth of soil to carbonate-enriched parent material ranges from 18 to 26 in. The reaction of the surface soil is slightly alkaline becoming moderately alkaline with depth.

An *acid variant* is recognized on the highest part of some of the rises. It has a moderately to slightly acid reaction throughout the soil, although the underlying weathered sandstone contains carbonates.

Type 18 *sandy loam*.—Small areas of this soil occur immediately downslope from the Oakview series soils on some of the sandstone rises. Its distinctive profile features are about 5 in. of darkish grey-brown sandy loam surface followed by a whitish loamy sand subsurface and a tough clay subsoil. There is an abrupt change to the clay subsoil which has a coarse columnar structure with dark staining on the outside of the columns and is generally a mottled greyish, yellowish, and reddish brown colour. This is followed by yellow-grey-brown blocky clay with accumulations of nodular carbonate. Some iron-stained gravel occurs through this profile. Depth of soil to weathered parent material is 39–72 in., and the reaction is slightly acid in the surface, neutral in the top of the clay, and strongly alkaline below.

Yarranlea clay loam, gilgai complex.—The soils of this complex are 4–6 ft deep to parent material, much of which may have formed from shales. They occupy gently sloping areas below Type 18. The gilgai microrelief consists of puff and shelf development with an average difference in level of 2 in. The shelf profiles occupy the larger areas and have about 3 in. of darkish grey-brown clay loam surface over a thin, ashy-grey light clay subsurface. The mottled dark grey and brown clay subsoil below 4–6 in. has a prismatic structure and rapidly grades into a yellow-grey and yellow-brown clay deep subsoil. Soft and nodular carbonate occurs below a depth of 12 in. and some crystalline gypsum is found in the lower horizons.

The puff profile has about 2 in. of dark brownish grey granular clay surface grading into yellow-grey-brown, coarse blocky heavy clay. Carbonate nodules and iron-stained gravel occur throughout the profile with some gypsum in the lower horizons.

Type 3 *clay*.—Small areas of this soil occur in the Irongate district and occupy the slopes of low spurs below the sites of Oakview series soils. The profile is greater than 4 ft deep to underlying sandstone and has apparently formed in materials weathered from this rock, though there may have been additions of basaltic materials in places.

The surface horizon is a dark brown, granular medium clay about 3 in. thick passing into yellowish and olive-grey heavy clay, which becomes mottled yellow-grey and light grey below 24 in. Soft carbonate occurs in slight to low amounts below 9 in. and increases with depth. Soil reaction ranges from neutral to moderately alkaline, and the soil is moderately fertile.

(D) Soils developed in colluvium.—Colluvium comprises soil material and rock fragments that have been moved downslope by gravity, soil creep, and local wash to form accumulations several feet deep. These materials occupy long slopes, commonly of 3–4° but ranging from 2 to 8°. In the Toowoomba area the soils formed in these materials are dark heavy clays more than 4 ft deep. Linear gilgai of varying magnitude are common features with 2–8 in. differences in level between puffs and depressions. The depressions are up to 7 yd wide and the puffs are usually narrower, between 2 and 7 yd across. The soils are considered in two groups according to the origin of the colluvium.

Soils formed in basaltic colluvium

The soils of this group have, on the average, about 36 in. of very dark brown to black heavy clay overlying lighter-coloured materials—generally yellowish, reddish, or greyish brown—of lower clay content and tending to friable consistence when moist. The surface layer, 1–3 in. thick, is strongly granular in structure and is underlain by irregular blocky-structured clays grading into more or less massive material below 12–20 in. Soil reaction is alkaline throughout, with carbonate nodules present on the surface of the puffs and below depths of 20–24 in. in the depression profiles. They are highly fertile types and contain moderate amounts of organic matter, adequate contents of potassium, and often very high amounts of available phosphorus.

Irving clay, linear gilgai complex.—Distinguishing features of the depression soil of this complex are its very dark brownish colour and fine granular surface structure. The very dark grey-brown clay surface, about 2 in. thick, changes to very dark brown clay of medium blocky structure composed of fine aggregates tightly interlocked. The lighter, faintly mottled reddish and greyish brown deep subsoil is found below 33 in. Soft and nodular carbonates occur below about 20 in. and there may be a few pieces of basalt gravel and stone in the profile.

At the surface on the crest of the puff, a narrow band, 8–12 in. wide, of reddish grey-brown deep subsoil material is characteristic. The depth of soil material to underlying weathered basalt rock varies from about 40 in. to considerably more than 7 ft in lower positions.

Craigmore clay, linear gilgai complex.—Important features of the depression soil are generally coarser structure throughout, very dark brownish grey colour of the surface soil, and the yellowish to greyish brown friable clay deep subsoil below about 36 in. Apart from colour and the coarser structure, this soil is much the same as the Irving clay and the ranges of depths to free carbonates and the underlying weathered basalt rock are also similar.

Knapdale clay, linear gilgai complex.—Very dark grey to black surface colours distinguish this soil from the closely related Irving and Craigmore complexes. Characteristically, the fine granular surface layer is only about 1 in. thick, passing quickly into coarse blocky material below, and gradually becoming very dark brownish grey. The lighter-textured, more friable clay deep subsoil is yellow-brown to yellow-grey. Low amounts of small carbonate nodules occur below about 24 in. in the depression soil, and moderate amounts of large nodules (1–2 in. size) occur in the upper part of the lighter deep subsoil.

Ramsay clay, linear gilgai complex.—Features of this complex are incipient to slight linear gilgai development and a moderate angular blocky surface with little coarse granular material, grading rapidly into weak coarse blocky units. It is tougher when slightly moist and more plastic when moist than other soils of this group. The depression profile is dark grey-brown and becomes faintly mottled with yellow-grey-brown below 8 in. Below this it passes into mottled yellow-grey-brown, light brown, and yellowish brown heavy clay with weak blocky structure. Slight carbonate nodules occur below 18 in. The deep subsoil below 36–40 in. is predominantly yellowish brown and weakly friable when moist.

Miscellaneous Group 2.—This group covers rather variable soils developed in colluvium in the Mt. Gowrie area. Distinguishing features are approximately 2 ft of very dark brownish grey heavy clay, followed by a brownish yellow heavy clay horizon grading into red-brown heavy clay with soft and nodular carbonate. The soil is more than 5 ft deep.

Soils formed in mixed colluvium

The parent material is mixed colluvium of materials derived from basalt and the sandstone and shales of the Walloon series, found mainly in the south-western portion of the survey area. The soils are dark clay types with yellow-grey-brown deep subsoils underlain by sandstone and shales at depths of more than 4 ft. They are moderately to highly fertile and have a slightly alkaline reaction which becomes strongly alkaline with depth.

Murlaggan clay, linear gilgai complex.—The depression soil of the complex has a thin, very dark brownish grey, fine granular clay surface grading into very dark grey coarse blocky clay. Below about 2 ft there is a gradual change to a mottled brownish yellow-grey and light grey stiff clay which overlies weathered sandstone at about 4 ft. There is some nodular carbonate below 12 in., and crystalline gypsum in the lower horizons. The linear gilgai development is low. Tough to stiff plastic consistence when moist and a predominantly yellow-grey deep subsoil are features of this soil.

Irongate clay (slope phase).—The slope phase of the Irongate clay has incipient to slight linear gilgai development in some places. It is formed in mixed colluvium and differs from the type in topographic position. The type is described with the soils of the alluvial plains.

Type 2 clay.—This type is of minor importance but has a rather distinctive profile and occupies wide, gently sloping platforms immediately below the scarp of the flat-topped basalt ridges in the Irongate district. The surface is a dark grey-brown, granular to blocky clay, about 3 in. thick, which grades into a greyish brown to yellow-grey clay subsoil. Some profiles have a layer of hard, white, siliceous material below 24 in.; others grade into a light brown clay subsoil with moderate amounts of carbonate. Carbonates may occur as shallow as 6 in.

Type 5 *clay*.—This type is easily distinguished as a fairly deep, reddish brown clay soil with a light clay surface, 2–3 in. thick, over an angular blocky heavy clay subsoil. There are low amounts of carbonates below 2 ft and some large nodules up to 2 in. in diameter in the deep subsoil. This type is found in the Irongate district on slopes of 1–4° and is somewhat similar to the Oakview series, but is a deeper soil with clay surface texture and higher clay content in the lower part of the profile.

(*E*) *Soils developed in alluvium*.—These soils are formed in deposits of alluvium more than 6 ft thick associated with minor drainage lines and small valley floors. They are highly fertile and consist of at least 3–4 ft of dark heavy clay with granular surface structure. Gilgai development is generally absent.

The Waco clay, an important soil of this area, and the less extensive Yargullen and Edgecombe types occur to a larger extent on the plains and will be described in the section dealing with the soils of that area (Section 3(*b*) (iii)). The soils described next all cover small areas.

Gowrie clay.—This unit consists of variable dark brownish grey heavy clay soils with rather featureless profile. The surface soil is granular and the subsoil coarsely blocky to massive. Below about 48 in. the colour is predominantly yellowish grey, and some thin bands of sandy or fine gravelly material, often rather wet, may occur at these depths. Carbonates occur throughout, mainly as small nodules in very small amounts in the top 2 ft and as large soft patches in the deeper soil. Gilgai development is generally absent.

Type 1 *clay*.—This type has about 3 ft of very dark clay overlying a grey to brownish grey deep subsoil. The surface 1–2 in. has a fine granular structure which grades into medium blocky units with depth. Small amounts of carbonate nodules occur in the deep subsoil. The soil is of minor importance and its distribution is limited to the eastern half of the area.

Miscellaneous Group 3.—The most uniform feature of this group of very variable soils is their moderate to high content of carbonates associated with mottled yellow-grey, yellow-brown, and white clay subsoils, usually below about 12 in. depth. The soil above is dark brownish grey heavy clay with typical granular to coarse blocky structure.

Miscellaneous Group 4.—These soils are dark brownish grey heavy clays occupying the higher parts of drainage lines and are composed of recent alluvium eroded from the upland soils. They vary in depth from 2 to more than 6 ft to basalt stones below.

(2) *Soil Associations*.—The soils of this physiographic division have been grouped and mapped into 16 associations in each of which one or two soil series are strongly dominant. Where the dominant series includes more than one type the map symbol indicates which is dominant, e.g. Kenmuir stony clay loam–Mallard (K_g^e–M).

Kenmuir association.—This association occupies the crests of the flat-topped and rounded hills with slopes of generally less than 2°, but includes the steep slopes (10–25°) of short scarps and small areas of gently sloping land below. *Kenmuir stony clay loam* is very strongly dominant and many of the skeletal and shallow sedentary soils occur as minor components in the association. In some areas there may be an intimate mixing of Kenmuir, Mallard, and Southbrook soils forming soil complexes.

This association has a wide distribution and carries a grassy eucalpyt forest to tall woodland with some softwood species in the understorey. In the Irongate district small areas of this association are dominated by the *Kenmuir loam, fine-structured variant* (map symbol K^e *var.*), under fairly dense softwood scrub.

Kenmuir-Mallard association.—In this association the Kenmuir and Mallard soils are strongly dominant. Again, many of the skeletal and shallow sedentary types are minor components. Where the association includes large areas of low, gently sloping, flat-topped rises *Kenmuir gravelly clay loam* (map symbol K^e_g) is usually the co-dominant soil and there may be associate areas of Croxley clay. *Kenmuir stony clay loam* (map symbol K^e) is co-dominant in the higher areas which include flattish and rounded hills with steep slopes. The associated vegetation ranges from grassy eucalypt forest to tall woodland with some softwood species.

Kenmuir-Southbrook association.—The Kenmuir and Southbrook soils are strongly dominant in this unit. There are smaller areas of the Mallard soil and minor occurrences of many of the shallow sedentary and skeletal soils. The association includes the higher flat-topped hills and steep slopes and in such positions the *Kenmuir stony clay loam* (map symbol K^e) is the co-dominant soil. Where the unit occupies low extensive flat-topped rises north of Umbiram, *Kenmuir gravelly clay loam* (map symbol K^e_g) becomes co-dominant and the Southbrook soil is mostly represented by the *orange variant*. In some parts the dominant soils occur in an intricate pattern forming a soil complex, e.g. in the Southbrook area (Thompson 1954*b*). The associated vegetation varies from grassy eucalypt forest to tall woodland with some softwood species as an understorey.

Kenmuir-Beauaraba association.—In this association the thin dark clay soils of the Beauaraba series are co-dominant with the brown skeletal Kenmuir stony clay loam. Many of the other skeletal and shallow sedentary soils occur as minor types occupying small areas only. The topography is one mainly of low hills with rounded crests and moderate to steep slopes stepped with gently sloping areas. The associated vegetation is grassy eucalypt forest and tall woodland with an understorey of softwood species in dense thickets in some places.

Majuba-Charlton association.—Only two small areas of this association have been mapped, one near Linthorpe and the other south of Cambooya. It is restricted to flat-topped hills with slopes of less than 1° and the associated steep stony slopes from 12 to 25°. The unit is characterized by dark-coloured skeletal and sedentary clay soils of the Majuba and Charlton types. Small areas of Kenmuir, Beauaraba, and Purrawunda soils also occur. Mountain coolibah dominates the associated tall woodland vegetation.

Charlton-Beauaraba association.—This is an association of shal ately deep, sedentary dark clay soils. It is widely distributed throu on the flat-topped and rounded hills with associated steep but "s The range of slope within the association varies greatly, but the d Charlton and Beauaraba—usually occupy slopes of less than 5°. T clay occurs as an associate soil in some parts and many of the ske and colluvial soils have minor occurrence. The vegetation cover ran eucalypt forest to tall woodland with occasional softwood species.

Beauaraba-Purrawunda association.—This unit occupies simi positions to the Charlton-Beauaraba association and carries the san tation. The stone-free Beauaraba and Purrawunda soils are domi are associate areas of Charlton clay. Small areas of a number of the tary, and colluvial soils also occur.

Aubigny association.—A red sedentary soil, the Aubigny clay, ates this association. Small areas of Wilton, Kenmuir, Purrawun soils are included as minor soils. The aggregate area of the unit occurrence is limited to the north-western portion of the survey. gentle lower slopes of less than 2° between the flat-topped hills and The native vegetation has been largely removed and was probably c land type.

Burton association.—The Burton association also occupies lon slopes of 1–3° extending towards the valley bottoms. Its aggrega and the unit has been mapped only in the eastern part of the survey. I is strongly dominant, and there are minor areas of many of the sede a few of the skeletal soils. The native vegetation has been largely r remnants indicate that it was formerly grassy eucalypt forest.

Yarranlea-Oakview association.—There is a varying dominance series across the areas mapped, and Type 18 and Murlaggan clay o soils in the pattern. The landscape is one of low, smooth, rounded sloping crests (slopes of about 1°) and long intermediate slopes o Some very gently sloping to flat country is also included. This unit is low sandstone rises in the south-west portion of the survey. The as tation is grassy euclaypt forest to tall woodland, with some bela species.

Irving-Purrawunda association.—This association is widesprea area and occupies extensive areas of the long gentle slopes, rangir topographic positions to the Irving-Purrawunda association, but is a considerably smaller unit. With the dominant Charlton and Craigmore series there are smaller areas of Purrawunda clay, and most of the skeletal and sedentary types and many of the colluvial soils occur as minor types. The vegetation is as for the previous association.

Knapdale association.—The Knapdale clay is strongly dominant in this association of dark, stone-free clay soils. The Charlton clay occurs as an associate type with minor occurrences of Purrawunda, Wilton, Kenmuir, and Mallard soils. Distribution of the association is restricted to the north-western portion of the area on topographic positions similar to those of the Irving-Purrawunda association. The associated vegetation is grassland with scattered mountain coolibah on the higher slopes.

Fig. 9.—Hilly country west of Toowoomba with the Charlton-Craigmore association on gentle slopes. Note the gully erosion in the field beyond the drainage line. The Charlton-Beauaraba association is found on the flat crests and steep upper slopes.

Murlaggan association.—This is an association of dark clay soils developed in mixed parent material overlying sandstones and shales. It occupies the long lower slopes of the hills extending to the valley floor, and is found only in the south-western part of the area. Murlaggan clay is strongly dominant with small areas of Purrawunda, Cecilvale, Yarranlea, and Type 18 soils as minor types in the pattern. The vegetation has apparently been a tall woodland dominated by poplar box.

Ramsay association.—The topography of the Ramsay association is similar to that of the Murlaggan association but also includes some steep hill slopes and small areas of flats along the minor drainage lines. Its occurrence is restricted to the Ramsay district. Ramsay clay is strongly dominant. Small areas of Burton, Purrawunda, Kenmuir, and Type 1 soils are minor types in the pattern. The native vegetation is grassy eucalypt forest to tall woodland.

Irongate association.—This association is found in the Irongate district on long 2–6° colluvial slopes extending to the margin of the alluvial plains. Irongate clay is the dominant soil with areas of Types 2, 3, and 5, and Oakview and Purrawunda soils as minor types. Locally, Oakview and Type 2 sometimes reach associate status. The native vegetation on these soils is a brigalow and belah forest with some softwood species.

(iii) *Soils of the Alluvial Plains*

Deep, dark clay soils developed in basaltic alluvium dominate the alluvial plains with smaller areas of deep, grey, slightly sandy-surfaced clay soils formed in mixed alluvium and minor occurrences of shallow, dark soils derived from highly calcareous parent materials.

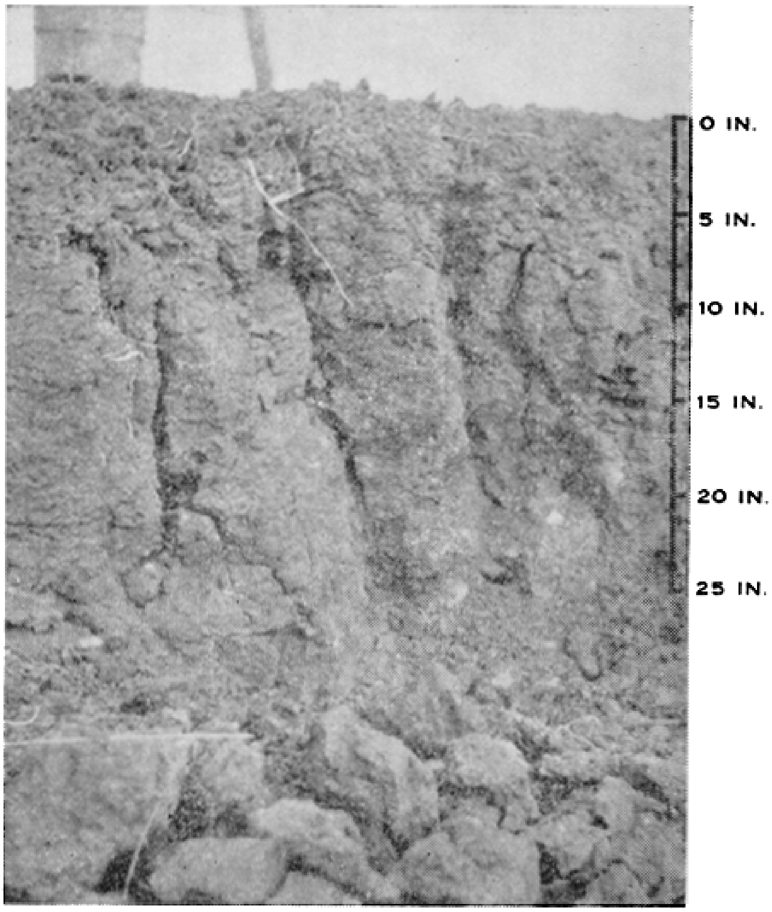


Fig. 10.—A black self-mulching clay soil formed in basaltic alluvium on the open plains. This shows the granular surface structure and extensive cracking characteristic of these soils in the dry condition.

(1) *Soil Type Descriptions.*—(*A*) *Soils developed in basaltic alluvium.*—The depth of the parent clay alluvium of these soils normally greatly exceeds the maximum depth of soil examinations, and may extend to tens of feet. The thickness of very dark brown to almost black clay soil averages about 42 in. and overlies many feet of lighter-coloured soil—brown, yellow-brown, or light brownish grey—of lower clay content and tending to be somewhat friable. The surface 1–3 in. of clay normally has moderate fine to coarse granular structure and grades below into medium to coarse irregular angular blocky clay in which the structure becomes coarser and more weakly developed with increasing depth. A typical black clay soil is shown in Figure 10.

The clays swell and shrink greatly with wetting and drying and in virgin areas gilgai microrelief of the crabhole type is generally moderately developed. The consistence of the dark clays is very hard to extremely hard when dry, strongly plastic when moist, and extremely sticky when wet. Their capacity to store "available" water for plant growth is high.

Soil reaction is neutral to slightly alkaline at the surface and becomes moderately alkaline in the subsoils in which carbonates are present in small amounts, mainly as small hard concretionary nodules but also as some soft patches. The soils are generally highly fertile and have particularly high contents of available phosphorus.

Waco clay, gilgai complex.*—Waco clay is a very dark grey-brown to very dark brown soil, becoming browner with depth and grading into mottled grey-brown and yellowish brown deep subsoil below 3 ft. It has a high clay content throughout and contains soft and nodular carbonate below 18 in.

The Waco clay gilgai complex has formed in alluvium derived from the nearby basaltic hills and occupies the extensive, very gently sloping alluvial fans, with falls of up to 20 ft to the mile, extending some 4–5 miles westward from the margin of the hills. The typical gilgai formation of virgin areas is one of rather small depressions set in a general level of extensive puff soils. The puffs occupy up to 70 per cent. of the area, and the depressions are about 2–5 yd across and 4–6 yd apart, with an average difference in level of 6 in.

Three phases are recognized: *a yellow-brown subsoil phase* with yellow-brown subsoil colours, a thinner solum, and more pronounced puff development than the type; *a weathered-basalt substratum phase* which is essentially the same as the type to a depth of 3–4 ft but is then underlain by weathered basalt; and *a subdued microrelief phase*† which has incipient to slight gilgai development and is restricted to the drainage lines through the upland area.

Waverley clay, gilgai complex.—The depression soil is a very dark brownish grey clay which grades into yellow-grey-brown and grey-brown deep subsoil below 3 ft. Soft and nodular carbonate occurs in the soil below a depth of 24 in. The main features of difference from the Waco soil are slightly darker surface colour, duller deep subsoil colours, and slightly coarser structural units particularly in the surface 6 in. The Waverley soil also has a different microrelief pattern, and occupies lower topographic positions resulting in slow surface drainage.

Like the Waco soil it is formed in basaltic alluvium, but occupies shallow depression lines through the alluvial fans and in the adjacent slightly lower plains. The microrelief of virgin areas is characterized by about equal areas of rounded puffs and depressions 3–7 yd in diameter with an average difference in level of 6–9 in.

(B) Soils developed in mixed alluvium.—The parent alluvium of these soils is mixed material derived from sandstone and basalt. These are grey to very dark grey soils with slight to low gilgai and fair to high fertility.

*This type, previously named Prairie clay (Thompson 1952), has been renamed to avoid possible confusion with the American great soil group of prairie soils.

†This phase also has a slightly coarser structure and was previously designated Westbrook clay during the Southbrook detailed survey (Thompson 1954*b*). Further examination during the association mapping has shown that it is best considered as a phase of the Waco type.

Irongate clay.—This soil has a very subdued microrelief of scattered shallow depressions with no obvious puff development. The surface dark brownish grey heavy clay has granular to fine blocky structure to a depth of about 1 in. and grades into a very dark brownish grey, coarse blocky clay with soft and nodular carbonate and some crystalline gypsum. Below 30 in. there is a gradual change to the light yellow-grey-brown deep subsoil with carbonate and gypsum. The soil reaction is slightly alkaline, changing quickly to strongly alkaline with depth.

A *slope phase* with linear gilgai development is recognized. This phase has developed in colluvium and has been mentioned in the discussion of the soils of the uplands.

Cecilvale clay, gilgai complex.—The main profile features of the Cecilvale clay are: about 1 in. of light brownish grey surface soil with a somewhat sandy light clay texture and a massive structure, about 3 ft of grey to dark brownish grey heavy clay with very coarse blocky or massive structure, and a faintly mottled light brownish grey deep subsoil which continues below 6 ft. There are a few black concretions in the first 30 in., and carbonate nodules and a little fine water-worn gravel below this depth. Soil reaction is slightly acid at the surface and changes to moderately alkaline in the subsoil. After rain a thin, whitish, fine sandy skin forms on the surface of exposed and cultivated areas.

The associated gilgai has a slight to low development and consists of puffs about 3–4 yd across and up to 8 yd apart, raised about 3 in. above the general level. There are also slight depressions or pans set in the general level in some places. The vegetation varies from woodland to grassy forest with poplar box as the dominant tree.

Miscellaneous Soils Group 7.—This is a group of miscellaneous soils formed in mixed alluvial parent materials occupying the depressions draining the Cecilvale clay area. These soils are dark brownish grey to black and more than 4 ft deep to the faintly mottled light brownish grey deep subsoil. They have heavy clay textures throughout and crack extensively during dry weather. The surface inch has a very coarse granular structure and overlies very coarse blocky units grading into massive soil below. A few black nodules occur throughout the profile, and there are carbonate nodules and water-worn gravel in the deep subsoil. These soils have variable gilgai development ranging from incipient in some places to a low development in others.

(*C*) *Soils formed in calcareous materials.*—These are dark, thin soils developed in strongly calcareous materials, and occupy scarcely perceptible rises in the eastern section of the open plains. Their very fine-structured surface consists of granular aggregates 1/64–1/16 in. in size and is subject to wind erosion during periods of bare fallow. Drifts of very fine granular clay, 18–24 in. deep, accumulate along fence lines on the lee side of cultivated fields and are a feature of these areas. The soils of this group are highly fertile but have a lower water-storage capacity than the deeper plain soils, and crops tend to burn off during dry periods. Losses of this nature are more often experienced on the shallow Edgecombe soil than on the other types.

Edgecombe clay loam.—This soil is a dark brownish grey, friable clay loam to light clay with strong fine crumb to granular structure, and contains small limestone fragments throughout. It is 13–24 in. deep to the hard limestone parent rock. Edgecombe clay loam occurs in association with the Yargullen soil but may be absent from some areas of the association.

Yargullen clay.—This type is a very dark brownish grey or black clay soil with about 6 in. of very fine granular surface soil grading into strongly developed fine blocky clay below. The dark-coloured soil ranges from 14 to 24 in. in thickness and grades below into a dominantly off-white and light yellowish grey marly clay, containing about 60 per cent. of carbonate. This marly clay continues to depths of more than 10 ft without apparent change, and is considered to be the parent material of the soil.

Dalkeith clay, gilgai complex.—The distinguishing features of the depression soil are: thin dark clay horizons, very fine structure units, particularly in the surface 6 in., and large amounts of soft and nodular carbonates in the deep subsoil. It consists of 15–20 in. of very dark brownish grey going to dark grey-brown clay, overlying mottled yellow-grey-brown and yellow-brown clay subsoil with large amounts of carbonate.

Slight gilgai development with puffs and depressions each about 6–7 ft across, and a difference in level of less than 3 in., is a feature of this complex. It occupies a position between the Yargullen and Waco soils and was first recognized in the East Prairie detailed survey, but has been found to have only a small occurrence outside that area.

(2) *Soil Associations.*—The soils of the open plains have been grouped and mapped in the four units described below.

Waco association.—The Waco association occupies the alluvial fans along the eastern margin of the open plains and extends up the broader valley bottoms into the upland area. It forms gently sloping plains, with falls of 20 ft to the mile, crossed by ill-defined drainage lines. Waco clay is very strongly dominant and occupies about 90 per cent. of the mapping unit. In the Toowoomba area minor areas of Waverley, Yargullen, and Dalkeith soils have been included.

Along the upper part of the drainge lines the *subdued gilgai phase* of the Waco clay becomes dominant, with associate areas of Type 1, and minor areas of Gowrie clay and the soils of Miscellaneous Groups 3 and 4. On the association map these areas are separated from the main Waco association by a broken line and designated as Waco with Type 1.

Waverley association.—The slightly lower areas of plain marginal to, or lying between, units of the Waco association are occupied by the Waverley association. Waverley clay makes up about 90 per cent. of the unit, with minor occurrences of the Waco soil on slightly higher areas. In the Toowoomba area this association has a limited occurrence in the north-western portion, but appears to be more extensive further north.

Cecilvale association.—This mapping unit covers the soils of the box country around Brookstead and extends into the Toowoomba area only in the south-western corner. It occupies a gently sloping plain crossed by shallow depressions. Cecilvale *clay and its phases (Beckmann and Thompson, unpublished data)* occupy almost all of the unit, but there are minor areas of Miscellaneous Group 7 and Mywybilla soils.

Yargullen-Edgecombe association.—The soils of the very low rises associated with areas of highly calcareous parent materials on the plains have been mapped as a unit forming the Yargullen-Edgecombe association. The Yargullen clay which occupies the very gentle slopes of these rises covers slightly larger areas than the shallow Edgecombe clay of the crests. The Dalkeith clay occurs as a transitional soil at the margins of the rises grading into those of the plains and, with small areas of Waco clay, is a minor soil in this association. The Edgecombe clay is absent from some small areas of the association. Surface drainage is generally good, and the original vegetation was grassland.

(iv) *Soils of the Steep Eastern Slopes of the Range*

Shallow and moderately deep soils formed from basalt dominate this unit, but there are significant areas of shallow soils formed from sandstones exposed on the lower slopes below the basalt. Miscellaneous soils formed from re-exposed laterite have a minor occurrence about half-way down the slope. Owing to the rugged nature and general inaccessibility of this area, normal traversing was impossible and the soils have been examined only at rather widely separated sites. No soil types or series are defined. The soil groups described below are based on close similarity of profiles and are approximately equivalent to soil series.

(1) *Soil Groups.*—(*A*) *Soils developed from basaltic materials.*—These are highly fertile, stony skeletal, and stone-free moderately deep soils. They have approximately twice the organic contents of the black clay soils to the west and contain high amounts of available phosphorus. The soil reaction is slightly acid changing to neutral with depth, and carbonates are absent from the solum.

Group A.—The soils of this group are 10–21 in. deep to soft, weathered basalt of mealy consistence and have about 3 in. of light greyish brown or brownish grey light clay surface of weak fine blocky structure overlying 8–17 in. of dark brown heavy clay mottled with brown and yellow-brown at depth. Pockets of weathered basalt are common in the lower clay horizon.

Group B.—These are moderately deep (30–45 in.) stone-free soils overlying soft weathered basalt. They have 4–8 in. of dark brownish grey or very dark brown clay loam to light clay surface with a strong medium crumb to granular structure, overlying 2–3 ft of dark brown heavy clay becoming mottled yellow-grey and yellow-brown with depth. Some black nodules and a little basalt gravel and stone occur in the lower horizons.

Group C.—These soils are shallow, 6–12 in. deep to soft weathered basalt. They have about 3 in. of yellowish or brownish grey clay loam surface of moderate fine crumb structure, overlying 5–7 in. of yellowish grey medium clay subsoil of moderate blocky structure with some soft weathered basalt gravel.

Group D.—These are shallow, stony skeletal soils less than 8 in. deep consisting of grey to very dark grey light clay with strong granular surface structure. Stone occurs on the surface and through the profile, but the underlying basalt is usually soft and very weathered.

(*B*) *Soils formed from sandstone*.—The soils developed from sandstone are shallow, moderately deep, and deep soils of low fertility. In the virgin condition they have low to moderate amounts of organic matter and a low content of available phosphorus in the surface horizons. Strong texture contrast from light surface horizons to clay subsoils is a feature of all but the soils of Group H.

Group E.—These soils are 27–45 in. deep to weathered parent material. Their main profile features are: about 3 in. of light brownish grey sandy loam surface, 4–10 in. of mottled very light brownish grey loamy sand, and a red-brown clay subsoil which becomes strongly mottled with yellow-brown and yellow-grey below and grades into weathered sandstone. The soil reaction is slightly acid on the surface and becomes moderately acid with depth. The structure of the surface soil tends toward weak crumb and that of the clay subsoil is weak prismatic to angular blocky.

Group F.—The soils of this group occupy slightly lower topographic positions than those of the Group E and are of about the same depth to parent material. They have a similar arrangement of horizons, but are distinguished by their predominantly yellow-grey and yellow-brown clay subsoils.

Group G.—These soils occur on the lower slopes of some of the rounded hills at the foot of the steep scarp. They are more than 5 ft deep to parent sandstone and have an abrupt boundary between the light-textured surface horizons and the clay subsoil. The surface soil of about 3 in. of dark grey-brown loamy sand grades into about 5 in. of very light brownish grey loamy sand, below which there is an abrupt change to a brownish grey clay of coarse columnar structure with some dark surface staining. The deeper subsoil has sandy clay texture with pockets of sand, is somewhat mottled with yellow-brown, and may contain some carbonate.

Group H.—Very shallow soils 6–9 in. deep to weathered sandstone form this group. They are coarse sands throughout, are dark brown on the surface, and become light orange-brown below.

(2) *Soil Associations*.—The two associations mapped on the scarp of the range are separated on the basis of different parent rocks.

Unnamed association A.—This association occupies the larger part of the range scarp in this area and includes the steep slopes of 15–25°, rocky knolls, narrow ridges, and spurs between the range crest (about 2000 ft M.S.L.) and the 1300-ft contour. The soils of Groups A and B are dominant, but there are associate areas of Group C and Group D soils, and minor occurrences of miscellaneous soils formed from laterite.

Grassy eucalypt forest covers most of the unit, with smaller areas of eucalypt forest on the higher slopes and minor areas of rain-forest in some of the deep gullies.

Unnamed association B.—This unit is made up of soils formed from weathered sandstone. It occupies the lower slopes of the scarp below the 1300-ft level and includes some rounded hills with slopes of 5–12° at the foot of the scarp. Groups E and F soils are dominant and soils of Groups G and H may occur as associates. Minor occurrences of dark alluvial soils along the drainage lines are included. The associated vegetation is dominated by eucalypts and varies from grassy forest to tall woodland.

IV. Land Use

(a) *Brief History of Early Settlement and Subsequent Changes in Land Use**

The first settlers came to the Darling Downs in 1840, and utilizing the lightly wooded natural grassland as pasturage for sheep established large pastoral holdings over the area. The first allocation of land for agricultural use was made by the Government of New South Wales, when some areas around Toowoomba were alienated for this purpose. Following the separation of Queensland from New South Wales in 1859, efforts were made to encourage land settlement in the new State and, during the 1860–1870 period, land acts were passed aimed at the subdivision of larger pastoral holdings for agricultural use. These, coupled with an influx of migrants, initiated a trend towards closer settlement. During this period a number of German settlers occupied small holdings of 10–20 acres in area in the Drayton-Middle Ridge locality. These people grew horticultural crops and small areas of wheat and kept a few dairy animals. They are credited by some authorities with the commencement of agriculture on the Darling Downs. Further land acts aimed at closer settlement were passed during the next 20 years, but, until the end of the century, the Toowoomba area was devoted largely to pastoral pursuits. From then onwards dairying and agriculture gained momentum and have continued to expand.

Some settlers were dairying as early as 1870, but the industry was of minor importance until the State Government took an active interest in it after 1890. The industry then expanded rapidly. The first butter factory was opened in Warwick in 1903 and another at Toowoomba in 1905. By 1937 there were 6413 dairy farms on the Darling Downs supplying 14 butter factories and 51 cheese factories. The number of farmers engaged in the industry has since declined and there has also been a centralization of factories.

Early records show that wheat was first grown near Warwick in 1843 and in the Toowoomba area in 1859. Closer settlement resulted in an expansion of wheat-growing and for the 1897–98 season some 300,000 bushels were harvested from the Toowoomba district. During the 1952–53 season 1,727,000† bushels of wheat were harvested in the Pittsworth Shire alone. With the expansion of the wheat and dairying industries, other crops, mostly winter and summer cereals, were introduced and now form an important part of the agricultural production of the area.

(b) *Present Land Use*

Dairying with subsidiary grain cropping and pig raising is the chief rural industry of the Toowoomba area. A smaller number of farms are used for cereal cropping with some livestock, while a few small properties are used solely for horse breeding, horticultural cropping, or poultry farming.

The Cambooya Shire occupies a typical section of the basaltic uplands and the agricultural production figures for this Shire are set out in Tables 5 and 6 to illustrate the land use trends since 1940.

*Dates of settlement and the early records of the darying and wheat industries are from the "Darling Downs Centenary Souvenir 1840–1940".

†Wheat production figures (1952–53 season) were made available by courtesy of the Queensland Government Statistician's Office.

TABLE 5

AGRICULTURAL PRODUCTION FIGURES* FOR THE CAMBOOYA SHIRE

All yields given in bushels

Year	Wheat		Barley		Oats			Grain Sorghum		Millet and Panic		Linseed		Maize	
	Acres	Yield*	Acres	Yield	Acres Fodder	Acres Grain	Yield	Acres	Yield	Acres	Yield	Acres	Yield	Acres	Yield
1940–41	13,533	211,358	1206	18,750	8,433	215	2,489	188	1,898	347	1,220	—	—	3767	64,331
1944–45	13,031	248,709	1705	40,719	10,652	897	17,421	1265	22,317	1787	16,356	—	—	2842	71,382
1948–49	22,016	470,415	2701	66,228	9,104	856	16,770	880	17,991	1974	20,802	149	1251	1237	21,870
1952–53	19,866	470,478	6438	187,491	12,097	1836	30,165	1168	30,165	1028	11,775	304	3207	1060	23,712

* Agricultural statistics kindly made available by the Queensland Government Statistician's Office.

TABLE 7

AVERAGE, HIGHEST-RECORDED, AND DRY-YEAR YIELDS IN BUSHELS FROM SELECTED SOILS*

Soil Type	Wheat			Barley			Grain Sorghum			Panic and Millet		
	Average	Highest	Dry Year	Average	Highest	Dry Year	Average	Highest	Dry Year	Average	Highest	Dry Year
Black Soils												
Waco	30	60	9–24	33	66	6–20	39	117	Crop Failure	18	21	—
Irving	27	51	8–18		No record		24	99		18	36	0–12
Purrawunda	25	39	8–18	33	60	6–20	20	60		18	36	0–10
Red Soils												
Aubigny	18	33	2–6	15	30	—	15	30		12	27	0–6
Burton	18	30	2–6	23	36	3–12	—	42		—	18	—

* Compiled from records of six selected farmers for each soil type covering periods of from 8 to 30 years.

(i) *The Dairying Industry*.—Dairying is now mainly for whole milk and cheese production. The farms supply nine cheese factories spaced through the area, and two pasteurized milk plants and a butter factory at Toowoomba. A number of cheese factories also serve as whole milk depots from which supplies are drawn to meet Brisbane requirements. Farm size varies with locality, ranging from 60 to 700 acres with an average size of 200–300 acres. Round (1953) states that there were 748 dairy farms in the Pittsworth and Cambooya Shires during 1950 and that these carried an average of 40 cattle per farm with 26 cows in production. He gives the average yearly milk production per cow of between 435 and 456 gal.

Although most of the farms in the Toowoomba area at one time were engaged in dairying, the industry today is confined to the basaltic uplands. There are two reasons for this. Firstly, the open plains were somewhat unsuitable, owing to lack of tree cover, absence of high ground, and the boggy nature of the soils during wet weather, and secondly, the high grain prices during the post-war period induced many farmers with a sufficiently large area of arable land to change to cereal cropping. So the industry today occupies the area dominated by shallow stony soils. These

TABLE 6

LIVESTOCK NUMBERS AND DAIRY PRODUCTION FOR THE CAMBOOYA SHIRE*

Year	Sheep	Pigs	Beef Cattle	Dairy Cattle	Milk Sold to Cheese Factories (gal)	Milk Sold to Other Factories (gal)	Cream Sold (lb)
1945–46	6749	4843	4746	12,402	—	2,405,506	1,321,512
1952–53	6055	2969	6055	15,823	1,800,914	1,503,259	1,047,116

*Stock numbers and production figures made available by the Queensland Government Statistician's Office.

areas are interspersed by numerous small areas of deeper soils which cannot be worked economically by the larger wheat machinery, but which can be satisfactorily managed with smaller equipment and are used extensively for growing fodder crops.

Owing to heavy grazing, the native pasture has been largely replaced by inferior species, and as yet no improved pasture of introduced species is in general use in the area although recently grass-legume mixtures have been recommended for this area by the Queensland Department of Agriculture (Wilson 1956). The dairying industry is at present largely dependent on forage crops. Oats, wheat, and barley are grown as winter feed, each farm carrying about 2 acres of fodder crop per cow. During the summer period forage crops of Sudan grass, sweet sorghums, and millet are grown, sometimes with an over-sowing of Poona pea. Some areas are sown to lucerne, but the climatic conditions are not entirely suited to this crop. In a few places, where grown under irrigation on the deeper valley-bottom soils, it does well, and this practice could be extended where water supplies are available. Reasonable production should also be possible by the row cultivation technique (Paltridge 1955) under dry-farming conditions.

Most of the arable areas on the dairy farms are used for forage crops. In good seasons some grain may be harvested from these sowings, and where the soils are suitable some areas are usually sown for grain production. The non-arable skeletal soils are mostly timbered and carry a sparse native pasture which affords only relief grazing, except in wet winters when these areas often produce a good growth of burr medics.

Pig-raising, utilizing skim milk and whey as a part of the feed, affords a lucrative sideline to the dairy farmers in the area.

(ii) *Cereal Cropping.*—The deep black soils of the open plains and broad valley bottoms are ideally suited to cereal cropping, and farmers of these lands concentrate on winter and summer grain crops. The grain-producing properties in the uplands also utilize the deep colluvial and shallower stone-free sedentary soils, and are usually situated adjacent to the larger valleys. Farm size ranges from 360 to 1000 acres.

Wheat is the main winter grain crop but smaller areas of barley, oats, linseed, and canary seed are grown. Grain sorghum dominates the summer cropping, and some panic and millet are also sown. Maize was once grown extensively in the area but has been largely replaced by grain sorghum in recent years.

Since the rainfall of the area is somewhat unreliable and of marked summer incidence, winter cropping is in most years dependent on moisture conserved by fallowing during the summer months. The normal practice is a short-term fallow—December to April inclusive—between successive winter crops, and a long fallow of approximately 12 months on the change from winter to summer cropping and *vice versa*. A broad rotation of three winter crops to one summer crop is generally followed, although some farms have grown wheat annually for longer periods. It is only rarely that two successive summer crops are grown in one field, and grain sorghum rarely succeeds immediately following a good crop of this grain.

Because of their higher general fertility and greater water storage capacity, the black soils are more satisfactory for grain production than the red soils, although the latter are more easily cultivated, give higher grain germination, and are able to utilize lighter rains. The red soils give a consistently lower yield, about one-third less than that obtained from the black soils (Table 7). Prior to the war most of the grain properties carried some sheep or beef cattle, but the high grain prices following the war induced many farmers to concentrate solely on grain production. In the past few years, however, there has been a gradual return of livestock and the trend is undoubtedly towards a more stable agriculture of grain production and stock fattening.

(iii) *Other Types of Land Use.*—With dairying and cereal cropping dominating the land use of the area, other rural activities are of minor importance and are mostly determined by proximity to market, type of soil, or local topography. On the plateau there are a few studs breeding race horses, and a number of small farms on the deep red soils growing horticultural crops for local consumption. In addition, there are a few poultry farms in the city environs.

The steep eastern slopes of the range are of little agricultural value and afford only relief grazing for beef and dairy animals from properties situated below the range. A portion of the steep scarp including some rain-forest pockets has been reserved as a bird sanctury—Redwood Park.

(c) *Principal Factors Affecting Crop Production*

Rainfall is the principal factor limiting crop production in the Toowoomba area, low yields being most often due to dry conditions. Most of the soils have high nutrient status, and their physical properties generally favour high productivity under dry farming when there is good management.

Soil erosion is severe. Though its effects on *productivity* may not have been really serious in the past, they are rapidly becoming so over increasing areas. The high nutrient status, high available water capacity, and generally moderate depth of the cultivated dark clays have lessened the effect on productivity of the severe losses that have occurred. Drainage problems and gilgai microrelief are of comparatively minor importance.

(i) *Rainfall.*—The earlier discussion of climate in relation to cropping indicated that winter rainfall in this area is generally inadequate for the production of winter grain crops. However, such cropping is an important agricultural pursuit made possible by storage under fallow of moisture from the preceding summer rains. While sufficient moisture may be stored in this manner in thoroughly moistened deep soils to produce a fair crop, winter rains provide moisture for planting and additional moisture during the growing period in most years. The latter is especially important on the shallower upland soils which have lower moisture storage capacities.

From data presented by Waring (1954) it has been calculated that $8\frac{1}{2}$ in. of rain must actually enter and be stored in these soils during the normal fallow period to raise their moisture contents (to a depth of 4 ft) from the low values at the end of a cereal crop to the high values of a moist fallow soil at planting. Allowance must also be made for moisture lost by evaporation from the bare surface soil after rain—say arbitrarily about $\frac{1}{2}$ in. at the end of each of about five effective rain periods during the summer months or a total of $2\frac{1}{2}$ in. On this basis about 11 in. of rain in falls of about 0·7 in. or more (lighter falls on the bare dry surface soils would almost all be lost by evaporation) is necessary during the fallow period following a cereal crop to replenish the moisture storage of the soil to a depth of 4 ft for the next crop. This is an average and rather idealized requirement; it makes no allowance for loss by run-off during rains of high intensity, nor for losses through weed growth if the farmer is unable to cultivate his fallow, when necessary, to keep it clean. Though the storage of the shallower sedentary soils is much lower, run-off losses are often high and probably almost as much rainfall would be required to replenish their moisture storage.

Daily rainfall records have been examined over the 40-year period 1911–1950 inclusive, to assess the "effective" rainfall of each summer fallow period (December 1 to April 30 inclusive) for the replenishment of soil moisture storage. All daily rainfalls of less than 0·50 in. were ignored if they were separated from higher falls by more than 3 days. At the same time winter rainfall during the normal growing period of the crop (May 1 to September 30 inclusive) for each year was determined and combined with the "effective" rainfall of the preceding summer to provide a measure of the total rainfall that may influence moisture supply to the winter crop. A crude estimate has also been made from the rainfall records of the suitability of weather conditions between November 1 and mid December for harvest. All of these estimates are summarized in Table 8 as percentage frequency of occurrence of conditions rated good, fair, or poor during the period examined.

Thus on these average estimates poor summer rainfall for the replenishment of soil moisture under fallow has occurred about 1 year in 7, the total summer and winter rainfall affecting the crop has been poor about 1 year in 4, and poor harvest conditions have occurred about 1 year in every 3.

Rainfall is also especially important for winter cereal crops during the period normally considered suitable for planting, i.e. May 1 to July 31 inclusive. When rains fail during this period, as in the year 1954, a large area prepared for winter crops may not be sown. Daily rainfall records have been examined to assess the time and frequency of occurrence of suitable planting rains during the 40-year period 1911–1950. Two slightly different sets of criteria have been used for this assessment. In the first of these (*A*), based on the physical properties of the soils, the minimum requirements are considered to be 0·80 in. in 1 day, 1·00 in. in a 2-day period, or 1·50 in. in a 5-day period. In the second (*B*), based on observation of current practices, 0·70 in. in a 2-day period, 1·00 in. in a 3-day period, or 1·25 in. in a 5-day period are considered sufficient.

Table 8

Percentage Frequency of Occurrence of Good, Fair, and Poor Rainfall Conditions Affecting Winter Cereal Cropping

Rainfall Conditions	Percentage Frequency of Occurrence of				Rainfall Conditions during Harvest Period
	"Effective" Summer Rainfall for Replenishment of Soil Moisture Storage under Fallow		Total Summer and Winter Rainfall Affecting Growth of Winter Cereal Drops		
	(in.)	(%)	(in.)	(%)	
Good	>12	57½	>20	52½	32½
Fair	8–12	27½	12–20	22½	37½
Poor	<8	15	<12	25	30

The results of these assessments set out in Table 9 show that by the criteria used, suitable planting rains have occurred most frequently in the first fortnight of this potential planting period and that the frequency decreases with time after mid May. Complete failure of planting rains during this period has occurred on the average 1 year in 5, according to criteria (*A*), and about 1 year in 7 according to criteria (*B*). In these circumstances the fallow period is usually extended to the early summer months when the land is sown to summer crops—usually grain sorghum. Occasionally, plantings are made outside the potential planting period considered here, but other hazards of winter cereal cropping are thereby usually increased.

(ii) *Nutrient Status of the Soils*.—As evidence of their high nutrient status many of the fertile black clay soils have been cropped more or less annually for periods exceeding 50 years without fertilization and without decline in yields. However, yield increases due to improved methods of management, new varieties of cereals, etc. have probably masked any actual decline that has occurred. On the red soils of the plateau area and parts of the uplands which have variable low to moderate nutrient status, yields have generally declined and crop responses to applied fertilizers are now common. Some of the lateritic red soils, particularly, and smaller areas of other types, have very low fertility.

Table 10 shows the contents of major nutrients in the surface horizons of the more important soils. The following discussion is based on laboratory data and field observations.

TABLE 9

OCCURRENCE OF PLANTING RAINS IN THE PERIOD MAY 1 TO JULY 31, INCLUSIVE

Period of Occurrence of Suitable Planting Rains	Percentage Frequency of Occurrence Based on	
	Criteria *A*	Criteria *B*
May 1–15 inclusive	22½	32½
May 16–31 inclusive	20	20
June 1–15 inclusive	15	17½
June 16–30 inclusive	12½	7½
July 1–31 inclusive	10	7½
Failure of planting rains (i.e. no planting rain in the 3-month period)	20	15

(1) *Nitrogen*.—The total nitrogen content of the Toowoomba soils ranges from low to high (1300–6400 p.p.m.) but the greater number of soils contain moderate amounts (1600–3400 p.p.m.). This is the nitrogen reserve of the soil and is slowly converted by soil microorganisms into the soluble ammonium and nitrate forms (available nitrogen) which can be used by the plant. The rate at which available nitrogen is formed and the quantity in the soil at any one time varies with the seasons, depending upon moisture, temperature, and plant growth. Waring (1952, 1953), Cox (1954), and Martin and Cox (1956*a*, 1956*b*) have shown that within these soils the nitrifying activity is very low during the winter period and that the greatest development of available nitrogen is during the summer months.

The black soils have a neutral to alkaline reaction, a high water-storage capacity with a wide range of available moisture, and generally good aeration in the surface 6 in. for most of the year. These characteristics favour the nitrifying microorganisms, so these soils should have a good nitrifying capacity, and, given favourable conditions, should build up accumulations of available nitrogen during the summer

TABLE 10

MAJOR PLANT NUTRIENTS (IN P.P.M.) IN THE SURFACE HORIZONS OF THE MORE IMPORTANT SOILS*
(Pounds of nutrient per acre surface 6 in. is approximately 1·5 times the nutrient p.p.m. figure)

Soil Series	Total Nitrogen	Phosphorus		Exchangeable Potassium	
		Available	Total	(p.p.m.)	(%)†
Soils associated with lateritic materials					
Gabbinbar	6420‡	16§	1076	132	1·5§
Ruthven	5020	14–91§	780	265	2·1
Rangeville	5070	18§	1046	—	—
Toowoomba	6400	25	1354	—	—
Middle Ridge	1700‖	39	1076	51	0·6
Skeletal soils developed in basalt					
Kenmuir	1760–5800	510–1283	2164–2657	585–1092	4·1–7·7
Majuba	4000	1068	2241	741	3·6
Soils formed in mixed material from basalt and sandstone					
Murlaggan	4300	11–45§	223–347	936	8·5
Irongate	3700	128	480	624	2·9
Cecilvale	1300	8–25§	184–240	140	1·6§
Soils developed in sandstone					
Oakview	1500	28–65	330–394	343	8·5
Group E	2060	21	321	238	4·8
Yarranlea	2700–3600	41	467	390	3·6
Soils formed in calcareous materials					
Yargullen	2470‖	534	917	2730	9·3
Edgecombe	3820	250	583	1287	6·7
Red soils developed in basalt					
Drayton	3140–3400	31–41	1247–1688	663	5·2
Kynoch	2600	45	1753	624	5·6
Mallard	2300	302–422	—	429	3·7
Southbrook	1700–3300	77–233	853–1586	468–546	5·0–5·2
Aubigny	1620‖	100	947	546	3·8
Burton	1870–2310	12–64§	823–1440	125–164	2·1–8·8
Dark clay soils derived from basalt					
(*a*) *Developed in basalt*					
Beauaraba	2200	629–1028	1701	327	1·8§
Purrawunda	1800–3070	135–1099	926–2001	1092	4·7
Charlton	1620–2500	107–221	656–943	429	1·9§
(*b*) *Developed in basaltic colluvium*					
Irving	1400–2580	281–1140	1226–1401	702–741	2·9–3·1
Craigmore	1700–2250	37–59	300–553	288	1·7
Knapdale	2600	953–1145	1238–1646	—	—
(*c*) *Developed in basaltic alluvium*					
Waco	950–2650‖	915–1380	634–1611	780–1092	3·5–3·9
Waverley	2280	713	1161	1711	6·5

*Sample depths of surface horizons range from 0–3 to 0–8 in.

†Per cent. total exchangeable metal cations.

‡Indicates a nutrient level below that generally accepted as necessary for plant growth. Where a range is given, this usually applies to the lower value only.

§Determinations from single samples unless range is given.

‖Indicates samples from cultivated fields; all others are from virgin sites.

fallow. Judging by the high yields of grain of good protein content and quality, there is no severe deficiency of nitrogen for crops grown on fallow though mild deficiencies may occur at times. This means that these otherwise highly fertile soils may give improved yields and a higher protein content of the grain if the supply of available nitrogen is increased during certain stages of plant growth. In fact Waring (1953) reports increased yields, higher protein content, and a reduction of mottled grain following urea sprays applied to wheat during the flowering period. This is supported by Bissett and Andrew (1953) in an experiment on the Purrawunda soil at Pittsworth where higher yields, increased protein content, and improved baking quality resulted from applications of nitrogenous fertilizers before planting.

All of the red soils formed on basalt are expected to respond to applications of nitrogenous fertilizer, and substantial yield increases have followed applications of farmyard manure or blood and bone fertilizer or both to the Burton soil. A marked improvement in the growth of oats has been observed on the Southbrook soil following a summer forage crop of Poona pea.

Martin and Cox (1956*a*, 1956*b*) have shown that there is a constant, slow decline of total nitrogen from the Waco clay with continuous cultivation and, since responses have been obtained to applied nitrogenous fertilizer to some soils (see foregoing), some effort should be made to maintain, if not improve, the nitrogen content of these soils. The economics of applying nitrogenous fertilizer to wheat lands is debatable, but it seems that experiments aimed at maintaining the nitrogen level of these soils by oversowing forage crops with legumes (e.g. Poona pea during the summer months and vetches or field peas during the winter period) would be well worth while. The red soils would give the greatest response to such treatment, but a significant improvement might also be obtained from the black soils.

(2) *Phosphorus*.—The soils of the Toowoomba area have high total phosphorus contents of from 193 to 2657 p.p.m. Available phosphorus, as determined by the dilute acid extraction method (von Stieglitz 1953), ranges from 8 to 1283 p.p.m. in these soils. Accepting the standard of 21 p.p.m. available phosphorus (50 p.p.m. P_2O_5) as a critical value for soils below which general crops usually respond to applied phosphate fertilizer, there are a few soils in this area which should benefit from phosphatic fertilizer.

The soils associated with lateritic materials contain low to adequate amounts of available phosphorus (14–39 p.p.m.) and many of these should respond to applications of phosphatic fertilizers. These soils are highly ferruginous and have somewhat acid reactions. Responses to applied phosphorus may therefore be limited by its conversion to insoluble forms, and light applications with each crop are expected to give better results than less frequent heavier applications.

The amounts of available phosphorus in the soils formed from mixed basaltic and sandstone parent materials vary from very low to high (8–128 p.p.m.). Of these, the Irongate soil has an adequate supply, the Murlaggan soil has low to adequate amounts, and Cecilvale clay has a very low to low content (18–22 p.p.m.). Crops grown on the Cecilvale soil and some areas of Murlaggan clay should respond to phosphatic fertilizers.

Of the soils developed from sandstone, Oakview, Yarranlea, and Type 18 have fair to adequate available phosphorus contents in virgin fields, but may benefit from fertilizer applications after prolonged cropping. The Group E soils on the range scarp also have low amounts of available phosphorus and may respond to treatment.

There are adequate amounts of available phosphorus in the virgin areas of the shallower red soils formed in fresh basalt, and these are not expected to respond to fertilizer treatment except perhaps in some fields which have been cultivated for a long period. All of the other soils in the area contain adequate to extremely high amounts of available phosphorus, and it is unlikely that any of these will require phosphate fertilizers for many years. In fact the average available phosphorus content of an acre of Waco clay soil to a depth of 1 ft is equivalent to the phosphorus removed from the soil by more than 700 wheat crops of 10 bags per acre each, assuming the phosphorus content of the grain to be 0·24 per cent. P.

(3) *Potassium*.—The standards used by the Queensland Department of Agriculture (von Stieglitz 1953) are applied here to assess the adequacy of the potassium supply in these soils. Soils with less than 78 p.p.m. (0·2 m-equiv.) of exchangeable potassium are generally expected to respond to applied potash; while soils with more than 78 p.p.m. may still give responses if their exchangeable potassium content is less than 2 per cent. of the total exchangeable metal cations.

The Middle Ridge soil has a low amount of exchangeable potassium (51 p.p.m.) and should respond to treatment. This is supported by observation of potassium deficiency symptoms in lucerne growing in this soil. All of the other soils contain more than 78 p.p.m. exchangeable potassium, but in five of the types, the Gabbinbar, Cecilvale, Beauaraba, Charlton, and Craigmore soils, the amount is less than 2 per cent. of the total exchangeable metal cations. However, of these only the Gabbinbar type is considered likely to respond to potassium fertilizers. With prolonged cultivation, especially if the nitrogen and phosphorus levels were improved, a response to applied potash might be expected from any of the soils associated with lateritic materials and perhaps some areas of the Burton soil.

(4) *Other nutrients*.—Sulphur deficiency has been suspected in some parts of the Toowoomba area but no case of it has been established. The likelihood of sulphur deficiency developing is considered to be greatest on the strongly leached red lateritic soils and very slight on some of the shallow sedentary soils. It is unlikely on the deep dark clay soils formed from alluvium and colluvium, most of which contain moderate amounts of soluble salts and sometimes gypsum (calcium sulphate) in their lower horizons.

In view of the concentration of molybdenum found in ironstone nodules from southern Australia (Oertel and Prescott 1944) and the now widespread association of molybdenum deficiency with lateritic soils, the possibility of its occurrence in the lateritic red soils of this area might be kept in mind.

Andrew, Kipps, and Barford (1952) report the correction of a chlorotic condition in young paspalum plants by foliage sprays and soil applications of zinc sulphate. The paspalum was grown in the Anchorfield clay (Kurrawa area) and the chlorotic condition is believed to have been due to the unavailability of zinc in this moderately alkaline soil. The surface of the puff profiles of all of the gilgai complex soils has a moderately alkaline reaction, and the poorer growth of wheat at these sites may be partly due to the unavailability of zinc.

(iii) *Physical Properties of the Soils.*—Owing to the dominance of soils containing very high contents of montmorillonitic clays—highly active types that swell and shrink greatly—extreme physical properties are characteristic of most of the arable soils. Many of these properties favour high productivity, e.g. the high water-holding capacity which makes possible the storage in the soils of large amounts of summer rainfall for the production of winter cereal crops. Others tend to limit productivity and constitute problems in farm management requiring special farming practices for best results. Among these may be mentioned the granular structure of the surface soils which favours fairly rapid drying out and tends to limit contact between soil and seeds; thus germination is reduced.

The physical properties of the more important soils of the area are summarized, with comments on their significance to farm practices and productivity, in Table 11.

(iv) *Soil Erosion.*—Soil erosion is severe in the uplands of the eastern Darling Downs, most of the cultivated lands of the Toowoomba area being affected to greater or less degree. Without doubt, it is the most serious agricultural problem of this area. Water is the important eroding agent and the soils most seriously affected are the dark clay soils of the sloping lands—the shallow to moderately deep sedentary types and the deeper colluvial types—which are especially liable to erosion. The more permeable and stable red soils of the uplands are much less affected, though less spectacular but important erosion has occurred on the deep red soils of the plateau area.

Some blowing of the cultivated red soils of the uplands, e.g. Burton and Southbrook soils, occurs but is of negligible proportion, and dark clay soils of this area are unaffected. Wind erosion is an interesting phenomenon associated with the small areas of fine-structured dark clay soils formed on highly calcareous parent materials but is of little practical importance.

Gullying is the most spectacular form of erosion on the dark clay soils of the uplands. Sheet erosion, while less obvious due to the uniform nature of these soils and their variable depths to parent material, is at least equally important and perhaps more so. Because the soil materials are rather uniform, and subsoil materials when exposed are fairly quickly reduced to the granular condition of the surface materials, it is not easy to estimate how much soil has been lost by sheet erosion. This type of removal is greatest marginal to the frequent smaller gullies which characterize the erosion of the shallow sedentary soils, and is increased by the practice of cultivating across these gullies where they are still small enough to be crossed by agricultural implements. In this manner material is transported toward and into the gullies only to be lost with later heavy run-offs. In several areas of the shallow sedentary soils on higher slopes, weathered parent material is exposed in and marginal to these gullies.

Steep-sided, wide, and deep gullies (5–8 ft deep) are characteristic of the erosion of the deep colluvial soils but are much less frequent than the shallow gullies. Such gullies often extend several chains by headward erosion during the run-off following a single heavy rain.

Table 11

PHYSICAL PROPERTIES OF THE MORE IMPORTANT SOILS

Soil Type	Texture	Consistence		Structure		Available Moisture Capacity	Comments
		Dry	Moist to wet	Surface or 0–4 in.	Subsoil		
Red soils formed in basalt							
Drayton Kynoch Burton Southbrook Aubigny Mallard	Clay loam surface over heavy clays	Slightly hard	Friable to plastic	*Virgin*: Moderately developed crumb to fine blocky aggregates with low stability when saturated *Cultivated*: Fine blocky aggregates. Surface somewhat platy	Strongly developed fine blocky aggregates ($\frac{1}{8}$–$\frac{3}{8}$ in. size) which are generally closely interlocked in the deeper horizons. Good aeration and free drainage in the clay horizons	Generally a wide range in the surface and a moderate range in the clay horizons	These soils are very easy to cultivate and maintain in seed-bed condition. Grain germination is very good. The water holding capacity is lower than the following group; although these soils require more frequent falls of rain during the growing season, crops growing in them can benefit from light rains. There appears to be a slight structural deterioration in the surface horizons with prolonged cultivation
Dark clay soils developed in basalt or basaltic material							
Beauaraba Charlton Purrawunda Irving Craigmore Knapdale Waco Waverley	Heavy clays	Very hard	Plastic to very sticky	*Virgin*: Very fine granular grading into fine to medium blocky units *Cultivated*: Strong fine granular to cultivation depth	Medium to coarse blocky units (6–10 in. size) with visible $\frac{1}{16}$–$\frac{1}{4}$ in. aggregates tightly interlocked but which separate into discrete units on drying if brought to the surface during cultivation	Generally wide range in the surface and subsurface horizon	These soils cultivate freely and are easily maintained in a fine seed-bed condition which aids good grain germination. The high water-storage capacity of these soils is favourable for dry farming involving summer water storage under fallow conditions. Depth of soil influences the amount of water which can be stored in this way, and the shallower soils will require more frequent rainfalls. There is no apparent structure deterioration with cultivation under present management

TABLE 11 (*Continued*)

Soil Type	Texture	Consistence		Structure		Available Moisture Capacity	Comments
		Dry	Moist to wet	Surface or 0–4 in.	Subsoil		
Soils formed in mixed material derived from basalt and sandstone							
Irongate Murlaggan	Heavy clay	Very hard	Plastic to very sticky	As above	As above	As above	As above
Cecilvale	One inch of slightly sandy clay over heavy clay	Hard	Sticky	*Virgin*: Compact slightly platy surface grading into very coarse blocky units *Cultivated*: Mixed fine and blocky units to cultivation depth	Very coarse blocky rapidly becoming massive with no apparent visible fine aggregation	Fairly wide in the thin surface horizon but a narrow range in the clay subsoil	The cultivated surface of this soil puddles badly following rain and forms hard crusts or caps; it is therefore difficult to maintain in fine seed-bed condition. If seed bed is maintained grain germination is good. More frequent rains are necessary for crop production in the Cecilvale soil than on the black clay soils
Soils formed in sandstone							
Oakview	Sandy loam over heavy clay	Slightly hard	Friable	*Virgin*: Variable from loose single grain to weak fine blocky units *Cultivated*: Single grain or fine blocky units	Massive to weakly developed. Medium-sized prismatic to blocky aggregates	Low to fair range	A free-working soil cultivating to a fine seed bed in which grain germinates freely. The water-storage capacity of this soil is low and frequent falls of rain are necessary to maintain plant growth. Very light falls of rain on this soil can be utilized by the crop
Red soils associated with lateritic materials							
Ruthven Middle Ridge	Clay loam over clay	Slightly hard	Friable to plastic	*Virgin*: Moderately developed fine blocky	Strong development of fine blocky units	Good in the surface, fair below	Free-working soils, well drained and with good aeration. Soil germination good. Requires more frequent rains in the growing season than the black soils

The non-arable stony skeletal soils of the higher slopes and hill crests in the uplands are little affected by erosion, as they are protected by their moderate grass cover and surface stone. Only during heavy rain following extended dry periods, during which these areas are often overgrazed, is there any significant loss of soil material from them.

As a concomitant of the erosion of the dark clay soils of the sloping lands, deposition of eroded materials on lower slopes and some deposition and flooding on valley bottoms is common after heavy run-offs. Deposition also occurs in small areas on the lower parts of fields on slopes, especially where trapped by vegetation along fence lines. At several such sites examined, fences have been almost completely buried. which indicates deposition of up to 3 ft of soil material.

The severe erosion of the dark clay soils of the uplands is due to a combination of many factors, chief among which are the physical properties of the soils themselves, the sloping topography, the high intensity of many of the rainfalls (particularly during summer months), and farming practices which expose the soils in the bare cultivated state at times when heavy rainfalls occur. Their high clay contents, rather unstable structure, low infiltration capacity, and sloping sites predispose these soils to erosion, and the high-intensity storm rains provide a very potent erosive force. However, under the moderate to heavy grass cover of the virgin vegetation no significant erosion occurred, and the existing seriously eroded condition of these lands is undeniable evidence of unwise land use.

In the first place the pattern of subdivision and road development bears little sensible relationship to the soils and topography. Too many roads and fences run directly downslope, and their side drains have rapidly become actively eroding gullies which have often been diverted into adjacent farmlands. But more important has been the development of a farming system and practices that have taken no account of erosion risks. Soils are exposed in the cultivated bare fallow condition for lengthy periods when the erosion risk is high. Furthermore, the practice of working the land parallel to all fence lines instead of on the contour has the effect of providing furrows in the direction of maximum slope over approximately 40 per cent. of the area of cultivated fields.

Among the serious effects of erosion on these soils the following may be listed:

(1) Loss of plant nutrients in soil removed.—Ladewig and Skinner (1950, 1951) have estimated that with each acre-inch of soil eroded from a typical Darling Downs site, the loss of plant nutrients would be equivalent to "34 cwt of lime, 19 cwt of superphosphate, 17·5 cwt of muriate of potash, and 18 cwt of sulphate of ammonia". Soil analyses from the Toowoomba area suggest that these figures would represent the lower limit of nutrient loss from the upland black soils.

(2) Loss of moisture storage through thinning of the soil.—A loss of a 6-in. depth of soil represents a loss of moisture storage capacity equivalent to 1 in. of rain. This is important, as successful grain cropping is dependent on moisture storage by fallowing.

(3) Accentuation of run-off due to loss of the better-structured surface soil.

(4) Loss of water in the run-off which might otherwise be stored in the soil or move slowly through deeper soil horizons to maintain intermittent flow in the creeks.

(5) Loss of agricultural land, due to the impossibility of cultivating gullied areas, and from the isolation of portions of arable fields by large gullies.

It is unfortunate that the most erosion-liable soils of the cultivated slopes—the shallow sedentary soils—are also the types on which soil loss has the most serious effects; they are at the best thin soils, and large areas of them are under cultivation.

Steady progress in the control of erosion in this area has been made in recent years through the work of the Soil Conservation Service of the Department of Agriculture and Stock, and numerous projects have been established to demonstrate erosion control measures. On badly eroded lands engineering structures are necessary and pondage banks, graded banks, and grassed water-ways are used (Ladewig and Skinner 1950, 1951; Roche 1955). The extension of this work in relation to the large area of eroded land is necessarily slow. Effective control also requires changes in farm management and practices, and in these directions much can be done by farmers themselves, especially on the less affected lands. Some badly eroded areas may best be put under pasture more or less permanently. In other areas rearrangement of fields to facilitate contour cultivation, stubble mulching, changes in rotation and land use, contour strip cropping, etc. may effect satisfactory control without expensive engineering structures. The most important single factor in control is the protection of the soil surface by pasture or crop cover or by stubble mulching.

Erosion of the permeable red soils of the Toowoomba plateau, though important, is much less obvious than on the dark clay soils and consists mainly of sheet removal with deposition on the lower sides of fields. Most of this land is now under pasture of some sort. Contour furrows have been used on some of these steeper pasture lands (5–15 per cent. slope) and have proved highly effective in limiting run-off even after intense storm rains (Kelsey 1955). With their more stable structure the infiltration of water into these permeable soils is rapid. As a result there is less surface flow and, under pasture cover, no erosion problem exists.

The only significant wind erosion in the Toowoomba area occurs on the Yargullen and Edgecombe soils near the eastern margin of the plains. Under cultivation these fine-structured soils work down to a very fine and uniform tilth of clay aggregates about the size of sand grains which are then moved by strong south-west winds. The eroded materials accumulate as loose drifts up to 2 ft deep along fence lines on the lee sides of fields. Although interesting, this erosion is of little agricultural importance and could probably be controlled or at least much reduced by stubble mulching.

(v) *Lowland Flooding*.—As a direct result of the erosion and accelerated run-off from the uplands, short-term flooding of parts of the valley bottoms and margins of the plains is a recurring problem. Damage to crops varies with the severity and time of flooding, being most severe near harvest when crops may be flattened and ruined, and least severe in the early stages of crop growth. In the latter cases recovery is rapid if the crop has not been washed out and the water does not lie for long periods.

The duration of flooding in the valley areas—mostly on Waco soils—is generally no more than 24 hr but the waters move fairly rapidly and may cause some scouring. On the Waco soils of the edge of the plains, floods are shallower and slower moving, and may last 2–3 days, while the Waverley soils may be inundated for a longer period. Most farms of the lower areas have suffered some damage on occasions and all are affected by weed infestation from seed distributed by the waters. Some are troubled by deposition on local areas.

The amelioration of these problems is dependent on the wider use of better farming methods in the uplands, with emphasis on water and soil conservation.

(vi) *Effect of Gilgai Microrelief on Cropping*.—Areas with gilgai microrelief are essentially a complex of different soil types, and, in the virgin stage, puff and depression sites are easily recognizable by these soil differences as well as by differences of level. While in extreme cases puffs may occupy up to 70 per cent. of a virgin area, only the puff centre or crest, usually 3–6 ft across and occupying considerably less than 20 per cent. of the total area, differs markedly from the rest of the soil.

TABLE 12

WHEAT GROWTH DIFFERENCES ASSOCIATED WITH GILGAI SOILS

Growth Stage	Depression Site	Puff Crest Site
Young plants 4–6 in. high	Dark green healthy plants 1–2 in. taller than puff wheat	Yellowish green lower leaves. Smaller plants
Flowering period	Robust plants strongly tillered, good flag development, plants 2–6 in. taller than puff wheat	Spindly almost untillered plants with light or yellowish green leaf colour, and small ears
Ripening period	In good seasons large, high-yielding ears of plump grain	Ripens first up to 10 days before depression wheat. Ears small and often not completely filled with grain

With cultivation the differences in level are gradually reduced and are usually eliminated after about 5 years. However, soil differences persist and are reflected in plant growth for a much longer period. The irregularity in crops is very obvious during the first 4–5 years but becomes less marked thereafter, and a fairly even crop is usually obtained after about 10 years. This is probably due to the mixing of the surface soil with cultivation but some crop differences still remain, and in practice it is possible to locate puff soils by the poorer wheat growth, even after 30 years of farming.

During the first 10 years of cropping uneven growth associated with puff and depression soils is most noticeable during three growth stages as indicated in Table 12. After this period the differences become less evident, but are still noticeable during the flowering and ripening periods. Physical determinations have shown that the soil of the puff crest has a finer structure and a more favourable available moisture capacity than the depression soil, and in these respects should be more suitable for plant growth. During the early years of cultivation, however, the depression soil may be wet to greater depth in years of average or lower rainfall owing to some water shedding from the elevated puff sites.

At present it seems more likely that differences in wheat growth are due to different nutrient levels of the puff and depression soils. Exploratory analyses of adjacent virgin puff and depression soils of the Waverley clay complex tend to support this (Table 13), and show that, while both have high contents of phosphorus and potassium, the depression soil has a moderate total nitrogen content, but the puff soil below 3 in. has only low amounts. The puff profile also has a fairly high carbonate content and is strongly alkaline below 3 in.

Allowing for some movement of soil from puff to depression during cultivation, the analyses in Table 13 suggest that unevenness of growth may be due to the difference in nitrogen status. This is supported by the nitrogen content of wheat plants grown on adjacent puffs and depressions of Waverley clay complex following 3 years' cultivation. Analyses of two sets of plants showed that those grown on the puffs had only about 70 per cent. of the total nitrogen content of those from depression sites.

TABLE 13

SOIL ANALYSIS* OF ADJACENT PUFFS AND DEPRESSIONS FROM VIRGIN WAVERLEY CLAY GILGAI COMPLEX

	Depth (in.)	pH	Calcium Carbonate	Total Nitrogen	Total Phosphorus	Exchangeable Potassium
Puff	0–3	8·3	26,900	2130	1080	1365
	3–16	9·0	83,000	640	1041	507
Depression	0–3	7·4	—	2280	1161	1911
	3–16	8·4	1,200	1320	1046	1209

*Nutrients shown as parts per million.

This may not be the full explanation of the differences. As already mentioned, the puff soils have high carbonate contents and strongly alkaline reactions, and are fully saturated with exchangeable cations, so the availability of other nutrient elements, e.g. zinc and potassium, may be reduced. Though the uneven growth of crops on soil gilgai complexes is an interesting phenomenon, it is of little practical importance after the early years of cropping.

(vii) *Saline Seepage Areas.*—In the north-western section of the Toowoomba area several saline seepage areas form interesting features though they are of little agricultural importance and the aggregate area is small. They occur most commonly on the lower slopes close to the junction with the valley floors on to which their effects extend.

Although a few of these seepages have been active for many years, the majority developed after the wet 1950 season and have increased in activity in the sequence of relatively wet years since then. The seepage waters are believed to come from Walloon sandstones and shales which are generally both calcareous and somewhat saline, and affected areas are most prevalent where these rocks have only a thin covering of basalt or alluvium. The waters are often strongly saline; one surface-water sample collected from a property in the Mt. Tyson district had a total soluble salt content of 3290 p.p.m. of which 2200 p.p.m. was common salt. Salt incrustation on areas marginal to the seepage is common, and the associated soils are often highly calcareous. The latter material is probably derived both from the weathered basalt and the Walloon sediments, and the high concentrations evident suggest accumulation over a long period.

Following the 1950 season many small areas had to be left out of cultivation owing to seepage. In some of these, seepage has since decreased and the areas have been reclaimed for cultivation. Other seepages have continued and some are said to be increasing both in flow and in area affected. Where increasing salinity of the soil has resulted in the death of the ground cover, surface concentration of salt is rapid and subsequent reclamation is difficult. Such an area is illustrated in Figure 11.

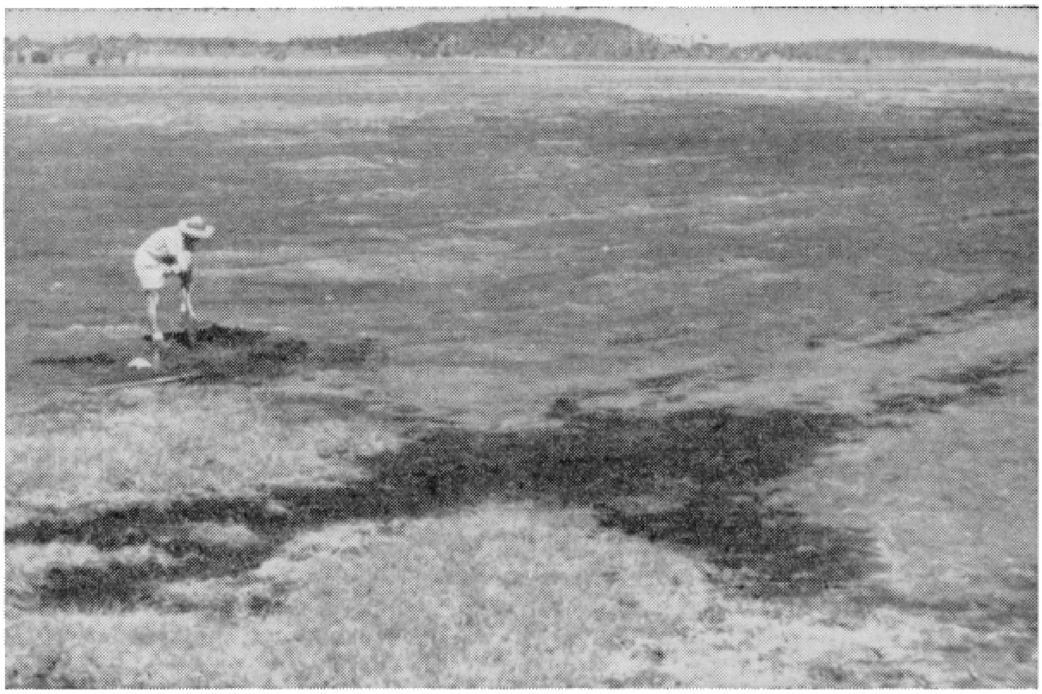


Fig. 11.—A field in the north-western Toowoomba area, showing the effects of saline seepage. Note the absence of vegetation from most of the area and the salt-tolerant grasses in the foreground.

In the early stages of development, the prevention of spread and the removal of the seepage waters through suitably placed surface drains should control the problem. Where the vegetation has been destroyed and the soil has become highly saline, reclamation involves in addition to drainage a reduction of the salt content of the surface soil by the leaching action of rainfall and the establishment of a cover of salt-tolerant plants to prevent further surface concentration of salt. When the salt content of the soil has been further reduced by natural leaching these moist areas may best be sown with some such plant as lucerne and left permanently covered.

(d) *General Conclusions on Land Use*

While dairying dominates the land use in the uplands, any further subdivision of farm size is unlikely. In fact, in areas with a low percentage of arable land the original subdivisions have proved too small and some farms today utilize two or more of these as the farm unit. Practically all the arable land is cultivated, but in recent years, under the stimulation of higher prices, cultivation has been extended on to some of the shallow, very stony soils of the near-level, elevated areas which would generally be considered as non-arable. There is some evidence that similar developments have been made previously and later returned to pasture, probably because cropping proved unreliable. It seems likely that the more recent expansion on these soils might also be uneconomic because of their shallow depth and stony nature. Development costs are high, involving not only clearing and stumping but also considerable "stone-picking", and the return from these soils, even in good seasons, is comparatively low.

The sedentary soils have been extensively cultivated in this area, and under the past farm management practices have been severely eroded; this has reduced the depth to parent rock and consequently the water storage capacity. These soils have a high nutrient level but their shallow depth and sloping position necessitate careful management if their productivity is to be maintained into the future. Soil and water conservation measures are very necessary, and many of the severely eroded fields will have to be returned to permanent pasture. Agricultural cropping is possible on the almost flat areas, but on sloping fields a system involving strip-cropping or temporary leys should give the best return with a minimum loss of soil. Grass-legume mixtures and seeding rates suitable for both summer and winter pastures for the Darling Downs have been determined by the Department of Agriculture and Stock (Wilson 1955, 1956). Difficulties have frequently been experienced in the establishment of sown pastures on the dark clay soils. Some are due to poor contact between the small pasture seeds and the granular surface soil, and to rapid drying out of the surface with resulting poor germination. Best establishment and management practices, including seed-bed preparation, time and depth of sowing, covering the seed, and rolling on the basis of present knowledge, are discussed in detail by Wilson (1956). Generally good results should follow the use of these practices on all of the dark clay soils.

The deep colluvial and alluvial soils on the lower hill slopes and valley bottoms are well suited to intensive agricultural cropping. These soils are highly fertile, have a high water-storage capacity, and, with good management, can be expected to maintain their high productivity under extensive cropping. An important point in relation to the continued cropping of these lands is the need to maintain the levels of organic matter and soil nitrogen. Stubble mulching, temporary leys, and the use of leguminous crops where possible should do much to reduce the depletion of the total soil nitrogen and organic matter reserves. Management practices should also include erosion control measures where necessary, particularly on the sloping colluvial lands.

All of the dark clay soils have a high nutrient level, but responses to applied fertilizer are expected on many of the red soils, particularly those associated with lateritic materials. Martin and Cox (1956*a*) have shown that there is a gradual depletion of the total soil nitrogen content under present land use with prolonged cropping, and this could probably be arrested by the use of rotations including leguminous crops where possible. Following these, a definite improvement in succeeding crops

TABLE 14

SUMMARY OF SIGNIFICANT AGRICULTURAL CHARACTERISTICS, PRESENT LAND USE, AND SOME COMMENTS ON THE MORE IMPORTANT SOILS

Soil Type	General Soil Features	Depth of Solum (in.)	Slope (degrees)	Drainage		Available Moisture Storage	Present Use	Comments
				Internal	External			
Soils Generally Associated with Lateritic Materials								
Ruthven	Clay loams over red fine blocky-structured clays	Greater than 84	1–5	Free	Free	Moderate in the subsoil	Urban agriculture	Very good physical conditions suitable for irrigation of horticultural crops. Plant nutrient supply poor to fair; low available phosphate and low total nitrogen; will respond to nitrogenous and farmyard manures, and should respond to applied phosphate and potash
Middle Ridge	As above with moderate amounts of laterite gravel		2–5					
Gabbinbar	Deep organic loams with red fine blocky-structured clay subsoils	Greater than 84	Generally 1–2	Free	Free	Moderate in the subsoil	Virgin forest and urban area	Earthy surface erodes rapidly when cultivated. Plant nutrient supply poor. Garden crops may respond to applied phosphate and potash
Toowoomba	Deep organic loams over clayey laterite gravel		1–5					
Rangeville	Deep organic loams over massive laterite	12–39	Generally less than 1	Impeded on massive laterite		Surface generally good but dries out fairly rapidly		Unsuitable for cropping

TABLE 14 (*Continued*)

Soil Type	General Soil Features	Depth of Solum (in.)	Slope (degrees)	Drainage		Available Moisture Storage	Present Use	Comments
				Internal	External			
Red Soils Developed on Basalt								
Drayton	Clay loams over red fine blocky-structured clay subsoils	18–36	1–8	Free	Free	Moderate in the clay subsoils	Urban agriculture	Moderately fertile soils with good physical properties, suitable for horticultural crops. Will probably respond to nitrogenous fertilizers
Kynoch		Greater than 44	2–7					
Mallard	Clay loams over gravelly clays mottled brown and red	13–20	Generally between 1 and 5				Fodder crops for dairy cattle and some grain crops	Moderately fertile soils with generally good physical properties. Will respond to nitrogenous and farmyard fertilizers. Use of Poona pea or other legumes with fodder crops will give a significant response in the succeeding crop
Southbrook	Clay loams over red fine blocky clay subsoils	15–27						
Aubigny	As above with carbonate and calcite in the lower horizon	15–27						
Burton	Clay loams over red blocky-structured clay subsoils	36–72						
Skeletal Soils Formed on Basalt								
Croxley	Light clays over gravelly heavy clays	6–13	1–2	Free	Free	Poor owing mainly to shallow depth of soil	Native pasture for relief grazing	Fertile soils, but generally non-arable owing to their shallow depth. Use of a suitable improved pasture would raise the carrying capacity
Kenmuir	Clay loams very stony	2–7	From less than 1 to 14					
Majuba	Very dark-grey heavy clays very stony	2–12	2–18					

TABLE 14 (*Continued*)

Soil Type	General Soil Features	Depth of Solum (in.)	Slope (degrees)	Drainage: Internal	Drainage: External	Available Moisture Storage	Present Use	Comments
Dark-coloured Soils Developed in Basalt or from Basaltic Materials								
Beauaraba	Very dark brown to very dark grey heavy clay soils with granular self-mulching surfaces and blocky subsoils overlying basalt	4–9	2–7	Slow after initial wetting	Free	The water storage capacity of these soils is high to very high, and amount stored in any type is governed by soil depth	Fodder and grain cropping	These soils are generally highly fertile with very good supplies of phosphate and adequate potash level. Total nitrogen content is low to moderate and gradually declining with prolonged cropping. A planned rotation utilizing leguminous crops, coupled with stubble mulching and deep working (of the deeper soils) with tyne implements, 1 year in 4 on the long fallow change of summer to winter crop, may increase yields from these soils
Type 16		9–15						
Purrawunda, Charlton		13–33						
Irving, Craigmore, Knapdale, Ramsay	As above, but developed in basaltic colluvium	Generally greater than 48	2–7				Grain cropping with some fodder crops	
Prairie, Waverley, Westbrook	As above, but formed in basaltic alluvium		Generally less than 1		Fair to slow			
Soils Formed in Highly Calcareous Materials								
Yargullen	Very dark clays; granular surface and blocky subsoil	14–24	Generally less than 1	Slow after initial wetting	Free	High	Grain with some fodder crops	These soils are highly fertile, but their available moisture capacity is limited by their shallow depth (particularly Edgecombe), and lower yields can be expected in dry years
Edgecombe	Grey strong fine granular-structured clay loams to clay	13–24		Free		Moderate		

TABLE 14 (*Continued*)

Soil Type	General Soil Features	Depth of Solum (in.)	Slope (degrees)	Drainage		Available Moisture Storage	Present Use	Comments
				Internal	External			
Soils Formed in Mixed Materials Derived from Basalts and Sandstones								
Irongate Murlaggan	Dark grey clay soils with granular surface horizons and blocky structured subsoils	Greater than 48	From less than 1 to 5	Slow after initial wetting	Generally free	High	Grain with some fodder cropping	Generally fairly fertile soils although some areas of the Murlaggan soil may respond to applied phosphate
Cecilvale	Grey to dark grey heavy clay soils with weakly developed coarse structure	Greater than 48	Less than 1	Slow	Slow	Low to moderate		A soil of low fertility which is expected to respond to phosphorus fertilizer. The total nitrogen content is low and could be improved by the use of legumes
Soils Formed in Sandstone								
Oakview	Loamy sands to sandy loams over red-brown blocky to prismatic-structured clays	15–30		Free		Moderate in the subsoil	Grain and fodder cropping	A moderately fertile soil which has given good yields over a period of years
Yarranlea	Light grey-brown sandy clay loams over grey-brown clay subsoils	Greater than 60	From less than 1 to 2	Slow	Free	Moderate	Mostly native pasture—some fodder cropping	A moderately fertile soil which should give fairly good grain yields with careful management

on most of the red soils can be expected. Crops on the black soils should also show some improvement in yield as well as quality.

Increased production in this area, and the stability of present land use, depends on better farm management involving, particularly, soil and water conservation measures. The introduction of improved pasture species suited to this environment, the use of temporary leys or permanent improved pastures (particularly on the sloping sedentary soils), greater use of leguminous crops where possible, and the protection of cultivated land by stubble mulching are the more important measures that should be used to this end.

The agricultural and related characteristics of the soils affecting land use have been summarized in Table 14.

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Appendix I

BOTANICAL NAMES OF COMMON PLANTS IN THE TOOWOOMBA AREA

Botanical Name	Common Name
TREES AND SHRUBS	
Acacia harpophylla	Brigalow
Angophora costata	Smooth-barked apple
Alphitonia excelsa	Red ash
Brachychiton populneum	Kurrajong
Callitris calcarata	Cypress pine (black)
C. glauca	Cypress pine (white)
Canthium buxifolium / *C. odoratum*	Softwood species without a common name
Capparis mitchellii	Bumble tree or wild orange or native pomegranate
Carissa ovata	Currant bush
Casuarina cristata	Belah
Dodonaea viscosa	Hop-bush
Eucalyptus crebra	Narrow-leaved ironbark
E. hemiphloia	Gum-topped box
E. intermedia	Red bloodwood
E. melanophloia	Silver-leaved ironbark
E. melliodora	Yellow box
E. orgadophila	Mountain coolibah
E. polycarpa	Bloodwood
E. populnea	Poplar box
E. tereticornis	Queensland blue gum
E. tesselaris	Carbeen
E. sp. aff. *wilkinsoniana*	Small-leaved stringybark
Flindersia collina	Leopard ash
Geijera parviflora	Wilga
G. salicifolia	Scrub wilga
Heterodendron diversifolium	A softwood species
Pittosporum phillyraeoides	Meemeei or cattle bush
Tristania conferta	Brush box
HERBACEOUS PLANTS AND GRASSES	
Agropyron scabrum	Common wheat grass
Aristida spp. (not identified)	Wire grasses
Bothriochloa bilboa	No common name
B. decipiens	Pitted blue grass
B. erianthoides	Satin-top grass
Dichanthium humilius	A blue grass
D. sericeum	Queensland blue grass
Marsilia sp.	Nardoo
Medicago denticulata	Burr medic
M. minima	Small woolly burr medic
Panicum effusum	Hairy panic
P. queenslandicum	Yabila grass
Sporobolus elongatus	Slender rats'-tail grass
Stipa aristiglumis	Plains grass
Themeda australis	Kangaroo grass
T. avenacea	Native oat grass

CLASSIFICATION AND CHARACTERISTICS OF DOMINANT SOIL SERIES

Great Soil Group (after Stephens 1956)	Series	Parent Material	Some Characteristics of the Soils	Depth to Parent Rock (in.)
(1) *Steep Eastern Slopes of the Range*				
Prairie—shallow black earth intergrade	Group A	Deeply weathered basalt	Brownish grey clay loams; mottled dark brown clay subsoils, weak blocky structure; some basalt gravel	10–21
	Group B		Dark brownish grey clay loams; mottled dark brown and yellow-grey-brown heavy clay subsoils; coarse blocky structure	30–42
Red podzolic	Group E	Weathering sandstone	Brownish grey grading to light grey loamy sands over mottled red-brown heavy clays; weak prismatic structure	30–45
Yellow podzolic	Group F		Brownish grey grading to light grey loamy sands over mottled yellow-brown clay subsoils; weak prismatic structure	27–42
(2) *The Toowoomba Plateau*				
Red earth	Toowoomba	Laterite (developed in basaltic materials)	Dark reddish brown loams grading through clay loams to red medium clays with much nodular laterite; acid reaction throughout	Greater than 72
	Gabbinbar	Lateritized basalt	Dark reddish brown loams grading through orange clay loams to red clays with strong fine blocky structure; acid reaction throughout	Greater than 72
Lateritic krasnozem	Middle Ridge	Upper mottled zone of laterite profile	Dark reddish brown clay loams; red fine blocky subsoil clays; large amounts of nodular laterite; acid reaction throughout	Greater than 72

Great Soil Group (after Stephens 1956)	Series	Parent Material	Some Characteristics of the Soils	Depth to Parent Rock (in.)
(2) *The Toowoomba Plateau* (*Continued*)				
Krasnozem	Ruthven	Lateritized basalt	Dark reddish brown clay loams, red fine blocky to visibly granular clay subsoils; trace of lateritic gravel; acid reaction throughout	Greater than 72
	Drayton	Basalt	Dark reddish brown clay loams; red visibly granular to fine blocky structured clays; neutral to alkaline reaction with depth	19–36
	Kynoch		Dark reddish brown clay loams; red clay subsoils, strong fine blocky structure; neutral to alkaline reaction with depth	44–72
(3) *The Basaltic Uplands*				
Skeletal soils	Kenmuir	Basalt	Brown to grey-brown loams to clay loams with much stone and gravel	2–7
	Majuba		Very dark grey granular heavy clays; very stony and some boulders	2–12
Krasnozem	Mallard	Basalt	Brown clay loams; mottled red-brown and brown clay subsoils with gravel; neutral to alkaline reaction	13–20
	Southbrook		Brown clay loams; red or orange clay subsoils; strong fine blocky structure; neutral to alkaline reaction	15–27
	Burton	Basalt and red clays derived from basalt	Brown clay loams; red clay subsoils with strong fine blocky structure; subsoil reaction alkaline	36–72

CLASSIFICATION AND CHARACTERISTICS OF DOMINANT SOIL SERIES (*Continued*)

Great Soil Group (after Stephens 1956)	Series	Parent Material	Some Characteristics of the Soils	Depth to Parent Rock (*in.*)
(3) *The Basaltic Uplands* (*Continued*)				
Krasnozem—red-brown earth intergrade	Aubigny	Basalt (highly calcareous)	Brown light clay surface; red clay subsoils; strong fine blocky structure; carbonate concretions and calcite in lower subsoil; alkaline reaction	15–27
Red-brown earth	Oakview	Sandstone (calcareous)	Brownish grey to grey brown loamy sands and loams, grading through very light grey and grey-brown sandy loams to mottled red-brown heavy clays; alkaline subsoil reaction	18–30
Black earth (shallow)	Beauaraba	Basalt	Very dark grey, granular to blocky structured heavy clays, neutral reaction	4–9
	Charlton		Very dark grey heavy clays; thin granular surface; coarse blocky subsoils; alkaline reaction	13–30
	Purrawunda		Very dark greyish brown heavy clays; thin granular surface, medium blocky subsoils; alkaline reaction	13–33
Black earth	Irving (linear gilgai complex)*	Basaltic colluvium and basalt	Very dark greyish brown heavy clays; granular surface; blocky subsoils; reddish grey-brown deep subsoils; alkaline reaction throughout	37–72
	Craigmore (linear gilgai complex)		Very dark brownish grey heavy clays; granular surface; coarse blocky subsoils; brown to grey-brown deep subsoils; alkaline reaction throughout	42–72

*In gilgai complexes important characteristics of the depression soil only are given.

CLASSIFICATION AND CHARACTERISTICS OF DOMINANT SOIL SERIES (*Continued*)

Great Soil Group (after Stephens 1956)	Series	Parent Material	Some Characteristics of the Soils	Depth to Parent Rock (in.)
(3) *The Basaltic Uplands* (*Continued*)				
Black Earth—*continued*	Knapdale (linear gilgai complex)		Very dark grey heavy clays; very thin fine granular surface; coarse blocky subsoils; yellow-grey-brown deep subsoils; alkaline reaction throughout	37–72
	Ramsay (linear gilgai complex)		Dark grey-brown heavy clays mottled with yellowish colours; coarse blocky subsoils	39–84
	Murlaggan (linear gilgai complex)	Mixed basaltic and sandy colluvium overlying sandstones and shales	Very dark grey heavy clays; thin fine granular surface; coarse blocky subsoils; yellow-grey deep subsoils grading into sandstones and shales; alkaline reaction throughout	54–72
	Irongate (linear gilgai complex)	Mixed basaltic and sandy colluvium	Very dark grey heavy clays; thin granular surface; coarse blocky subsoils; yellowish grey deep subsoils; alkaline reaction throughout	Greater than 72
Solodized solonetz	Yarranlea (gilgai complex)	Sandstones and shales	Light grey-brown sandy clay loams with ashy subsurface overlying mottled very dark brownish grey and brown heavy clays with coarse structure	48–72
(4) *The Alluvial Plains*				
Black earth	Waco (gilgai complex)	Fine basaltic alluvium	Very dark greyish brown heavy clays; granular surface and medium to coarse blocky subsoils; brown to grey-brown deep subsoils; alkaline reaction throughout	33–48

CLASSIFICATION AND CHARACTERISTICS OF DOMINANT SOIL SERIES (*Continued*)

Great Soil Group (after Stephens 1956)	Series	Parent Material	Some Characteristics of the Soils	Depth to Parent Rock (in.)
(4) *The Alluvial Plains* (*Continued*)				
Black earth—*continued*	Waverley (gilgai complex)		Very dark brownish grey heavy clays; thin granular surface; coarse blocky subsoils; grey-brown and yellow-grey-brown deep subsoils; alkaline reaction throughout	33–48
Grey soil of heavy texture	Cecilvale (gilgai complex)	Mixed basaltic and sandy alluvium	Thin grey sandy clay surface; coarse blocky dark grey heavy clay subsoils; grey and yellowish grey deep subsoils; alkaline reaction	33–54
Rendzina	Yargullen	Marly clay	Very dark grey heavy clays; strong granular grading to fine blocky structure	15–27
	Edgecombe	Limestone	Dark brownish grey strong fine granular clay loams and light clays	13–24

KEY TO SOIL SAMPLE SITES

Symbol	*Soil Type*	*Symbol*	*Soil Type*
B153	Waco Clay (gilgai complex) Depression Profile	B199	Oakview Sandy Loam
B156	Craigmore Clay (linear gilgai complex) Depression Profile	B200	Knapdale Clay (linear gilgai complex) Puff Profile
B157	Charlton Clay	B202	Purrawunda Clay
B158	Irving Clay (linear gilgai complex) Depression Profile	B203	Southbrook Clay Loam (Orange Variant)
B159	Irving Clay (linear gilgai complex) Puff Profile	B204	Waco Clay (gilgai complex) Subdued Microrelief Phase Depression Profile
B160	Waco Clay (gilgai complex) Depression Profile	B205	Irving Clay (linear gilgai complex) Depression Profile
B161	Croxley Clay	B206	Irving Clay (linear gilgai complex) Puff Profile
B162	Burton Clay Loam	B207	Mallard Clay Loam
B163	Charlton Clay	B208	Beauaraba Clay
B164	Purrawunda Clay	B209	Irving Clay (linear gilgai complex) Depression Profile
B165	Gowrie Clay		
B169	Gabbinbar Loam	B210	Middle Ridge Clay Loam
B170	Ruthven Clay	B211	Type 7
B171	Aubigny Light Clay	B212	Burton Clay Loam
B175	Type 16	B213	Toowoomba Loam
B177	Burton Clay Loam	B214	Nelson Clay Loam
B185	Drayton Clay Loam	B215	Harristown Loam
B189	Southbrook Clay Loam	B216	Kynoch Clay Loam
B190	Knapdale Clay (linear gilgai complex) Depression Profile	B217	Rangeville Loam
		B218	Purrawunda Clay
B191	Murlaggan Clay (linear gilgai complex) Depression Profile	B219	Kenmuir Gravelly Clay Loam
		B220	Majuba Clay
B192	Oakview Loamy Sand	B221	Southbrook Clay Loam
B193	Southbrook Clay Loam	B222	Shallow Red Soil on Basalt
B195	Yarranlea Sandy Clay Loam (gilgai complex) Shelf Profile	B223	Kenmuir Stony Clay Loam
B196	Yarranlea Sandy Clay Loam (gilgai complex) Puff Profile	B224	Type 18
		B225	Group E
B197	Kenmuir Stony Clay Loam	B226	Group A
B198	Murlaggan Clay (linear gilgai complex) Puff Profile	B227	Ramsay Clay (gilgai complex) Depression Profile

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