7. DISTRIBUTION, PROPERTIES AND ORIGIN OF SOILS ON THE ALLUVIUM

7.1. Previous surveys

Soils of the Lockyer Valley alluvial plains have generally been investigated at low intensity by previous workers (Bureau of Investigation 1949, Isbell *et al.* 1967, and Shaw 1979). The only detailed soil survey conducted in the study area has been a 1:5 000 survey of the Gatton Research Station (Powell 1982). This 50 ha area covered a toposequence from the southern bank of Lockyer Creek extending onto the alluvial plain. On the gentle levee of Lockyer Creek, prairie soils and chernozems with clay loam to light clay textures were present, while heavier dark cracking clays (black earths) were found on the alluvial plain.

7.2. Surveys in progress

More recently soil survey programs have been instigated by the CSIRO Division of Soils and by the Queensland Department of Primary Industries.

CSIRO Division of Soils (K.J. Smith personal communication) have conducted a 1:50 000 soil survey of soil landscapes from the Little Liverpool Range east of the study area to the eastern margin of Tenthill Creek. Soils have been mapped as soil landscape units comprising a number of identifiable soil classes.

The author, under the direction of the Department of Primary Industries, is currently mapping the soils of the Lockyer Valley alluvia at a scale of 1:50 000. Soils are being mapped as soil profile classes (refer to Section 5.1.1).

To date 43 separate soil profile classes have been identified on Lockyer Valley alluvia. Distribution appears to relate largely to the nature of source material (parent material), the past or present position of the watercourse, and distance that the alluvium has been deposited away from the streams. In addition, soils on older high lying alluvia are distinctly different from lower positioned soils of younger age. Laboratory analysis of representative profiles from this survey are

included in Appendix 6.

7.3. Soil map

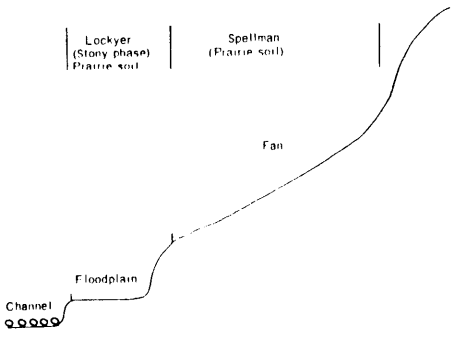
The 25 soil profile classes mapped on the alluvia in the study area fall into six distinct groups determined by landform and by the lithology of the source material (see Table 7.1 and legend of attached soil map).

Table 7.1. Lithology - landscape soil groups and associated source materials.

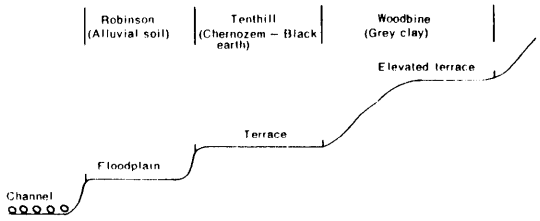
Lithology - landscape group	Source materials
Soils of the major stream flood plains and levees	General catchment, dominantly basalt
Soils of the major stream terraces and plains	General catchment, dominantly basalt
Soils of the major stream elevated terraces, fans and pediments	General catchment, dominantly basalt
Soil of the alluvial fans derived from basalt (upper reach tributaries)	Subcatchments, dominantly basalt
Soils of the alluvial fans and flats derived from upper Marburg beds (middle reach tributaries)	Subcatchments, dominantly Heifer Creek Sandstone and Ma Ma Creek Sandstone
Soils of the alluvial fans and flats derived from lower Marburg beds (lower reach tributaries)	Subcatchments, dominantly Winwill Conglomerate and Gatton Sandstone

The relationships of typical alluvial landscape elements and some of the soils within them are illustrated by four transects within the study area (Fig. 7.1). Along the reaches of major tributary streams (Tenthill Creek, Blackfellow Creek), soils are associated with easily distinguished alluvial terraces and fans (Fig. 7.1a, 7.1b, 7.1c). In contrast, the downstream valley floor of Lockyer Creek is an extensive alluvial plain with subtle surface features, and soil patterns were difficult to recognise (Fig. 7.1d).

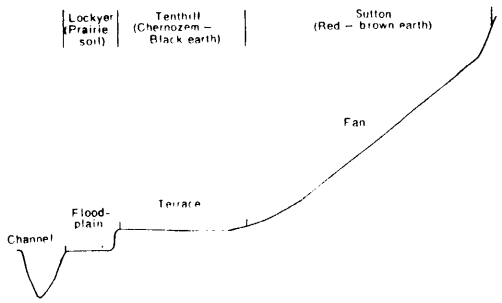
Several soil profile classes were found along both upstream and downstream reaches of major streams (e.g. Lockyer in Figs 7.1a and 7.1d and Tenthill in Figs 7.1b and 7.1d). Some soils that belonged to a particular terrace upstream were found on one of the components of the alluvial plain landscape downstream. For other soils distribution was restricted to either up- or downstream reaches of the major streams e.g. Spellmann in 7.1a and Blenheim in 7.1d.



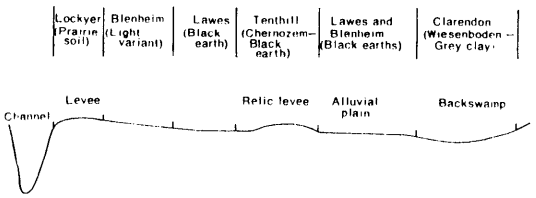
(a) Upstream reach - Blackfellow Creek (site 23*, Las Peidras)



(b) Midstream reach -Tenthill Creek (sites 13 to 16, Mt Sylvia)



(c) Downstream reach - Tenthill Creek (sites 4 to 7, Lower Tenthill)



(d) Downstream reach - Lockyer Creek (sites 1 to 3, Lawes)

* Site numbers on soil map indicate general location of transects.

Fig. 7.1. Cross section of four typical alluvial soil landscapes in the study area.

The soils occurring on the alluvial fans and flats associated with minor tributaries also separated into natural groupings on the basis of their source materials. Because the major streams progress through geological sequences of contrasting lithology, these soil groups were closely associated with local alluvial fans and flats along certain reaches of the streams. The landscape position of the less widely distributed soil profile classes is indicated in tables giving the main features of the component soils of each lithology - landscape group (Section 7.4).

7.4. Properties of soil profile classes

Soil profile classes are discussed under the headings of six major lithology - landscape groups. Component soil profile classes of each group are not discussed individually but their distinguishing features and landscape position are summarised in tables. Analytical data are also summarised in tabular form and for some groups it has been possible to discuss soils in terms of constituent sub-groups e.g. levee crests and floodplains and levee backslopes in Section 7.4.1. However, the analytical data of other groups may not be readily discussed this way and are discussed on a group basis only. Analytical data was drawn from the results of this study, from the results of the in progress survey by the author and other published data (Powell 1982, Schafer *et al.* 1984). More detailed information on individual soil profile classes is found in Appendix 6. This includes description of their modal range, observed variants, soil classification and laboratory data from representative profiles. More detailed results of mineralogical analysis are also presented in Appendix 7.

7.4.1. Soils of the major stream floodplains and levees

These soils border the channels of the major streams and their upper reach tributaries (Fig. 7.1). In upstream reaches they occur on flood plains below extensive terraces (Plate 7.1) where as down-stream they are found on levees that gradually merge with the alluvial plains.

Soils belong to either the mildly leached dark soils grouping or soils showing no profile development (Stace *et al.* 1968). The solum is generally 0.3-0.7 m thick, dark coloured, moderately structured and in the loam to light-medium clay texture range. Below the solum, buried soils, or bedload layers of gravel, cobble, sand or finer sediment are encountered. The soils have high overall fertility and are usually cultivated. On drying their surfaces either form a thin hard surface crust and appear cloddy if recently cultivated.

They may be distinguished from soils of the adjacent terraces and plains by the duller lustre of their smooth ped fabric (Northcote 1974) below cultivation depth and the absence or only trace presence of carbonate in the subsoil. Lower clay and higher silt contents are possibly responsible

for the dull appearance of these soils.

Essential features of component soils

The distinguishing features of soil profile classes occurring within this landscape group are summarised in Table 7.2.

Table 7.2. Morphology and landscape position of soils of the major stream floodplains and levees.

Soil profile class	Distinguishing features	Landscape position
Robinson	Dark or brown sandy loam to clay loam 0.1 to 0.4 m deep over layers of soil*, sediment or coarse bedload (gravel, cobble, stone)	Flood plains, flood plain splays, point bars, channel benches
Lockyer	Dark clay loam to light clay with dark or brown neutral to alkaline structured subsoil to 0.4 to 1.0 m deep, over dark or brown layers, palaeosols or coarse bedload	Flood plains, levees
Cavendish	Dark clay loam to light clay with calcareous structured light clay to medium clay subsoil containing traces of carbonate.	Levee banks and backslopes

* buried palaeosol

Analytical data

Analytical data are summarised in Table 7.3. Methods of analysis used for this and subsequent tables are described in Bruce and Rayment (1982). pH was measured in water, E.C. at 1:5 dilution and CEC using ammonium chloride at pH 8.5.

Table 7.3. Summary of analytical data for soils of the major stream floodplains and levees.

Horizon	pH 1:5	E.C. mS cm^{-1}	Silt %	Clay %	CEC $cmol(p^+)kg^{-1}$	Dominant cations	ESP	CEC/%clay
A	7.2-7.9	0.03-0.04	13-21	10-23	26-35	Ca^{++}, Mg^{++}	<1.3	>1
B	7.4-8.0	0.03-0.05	17-18	20-23	24-33	Ca^{++}, Mg^{++}	<2.2	≥1
Substrate	7.0-8.0	0.03-0.11	7-17	9-35	29-37	Ca^{++}, Mg^{++}	1-9	≥1

Soils associated with the levee crests and flood plains of major streams have neutral to slightly alkaline pH's in the solum (pH 7.2-8.0), low salinity and chloride levels, but variable organic carbon (0.9-4.2%) and total nitrogen levels (0.06-0.15%) in the surface 0-0.1 m. This variability is believed to be due to different land use histories. Clay contents vary from 10 -23% and silt from 13-21% in the solum but become either higher or lower below the solum. Cation

exchange capacities in the solum range from 24 to 35 cmol(p^+)kg^{-1} and the exchange complex is largely occupied by calcium and magnesium in about equal amounts. Exchangeable sodium percentages in the solum are less than 2.2 but may increase slightly in the subsolum. CEC/% clay ratios equal or exceed 1 through the profile to 1.5 m.

Soils of the levee backslopes are composite soils and were not included in the Table 7.2 summary. They have pH, salinity, organic carbon and total nitrogen levels similar to levee crests, but have higher clay contents (35-40%) and silt contents (26-31%) in the solum. Cation exchange capacities are correspondingly higher (36-47 cmol(p^+)kg^{-1}) and cation proportions are similar to the levee banks. Below the solum are buried soils with higher clay contents (40-53%), similar silt contents (24-35%) and higher sodicity (2.6-4.8 ESP). Soils of the levee backslopes have been called Blenheim - light textured variant. All soils analysed are at least 70% base saturated and soils on floodplains are commonly fully base saturated.

The clay contents of profile classes belonging to this soil group are much lower than for most of the other soil groups associated with the major streams (Tables 7.3, 7.7, 7.12). This suggests that these soils were derived from alluvia deposited by floodwaters with higher velocities in comparison to the other alluvial deposits.

Soil mineralogy

In the two profiles analysed for clay mineralogy from the floodplain (sites 8, 16), interlayered smectite was found to be dominant with minor kaolinite and a trace of illite (Table 7.4). The Lockyer profile from the levee of Lockyer Creek (site 1) in contrast was dominantly smectite. Nevertheless these results suggest that these soils are mainly basaltic in origin. These soils have consistently low light/heavy mineral ratios (<12), and generally high augite/opaque ratios (Table 7.5). In addition, the CaO content indicates that a significant amount of plagioclase is present in the light mineral fraction. The abundance of augite and high CaO content in the soil profiles samples also indicate that these soils are basaltic in origin. In addition soils have not been greatly weathered since deposition. A palaeosol buried 5.5 m below the levee component of this unit was radiocarbon dated at 10 240 $\pm$ 130 years b.p. Therefore soils must be younger than 10 240 years.

Table 7.4. Clay mineralogy of soils of the major stream floodplains and levees.

Site no.	Soil profile class	Depth m	S	SI	K	I
16	Robinson	0-0.20		++++	+	tr
		0.20-0.50		++++	+	tr
8	Lockyer	0-0.25		++++	++	tr
		0.25-0.40		++++	+	tr
		0.90-1.10		++++	+	tr
		1.70-1.80		++++	+	tr
1	Lockyer	0-0.25	+++		++	tr
		0.25-0.50	++++		++	tr
		1.20-1.50	++++		++	tr
		5.33-5.43	++++		+	tr
		7.00-7.10	++++		+	tr

Table 7.5. Fine sand mineralogy of soils of the major stream floodplains and levees.

Site no.	Soil profile class	Depth m	Light/heavy ratio	Light fraction CaO %	Heavy fraction Augite %	Opaques %	Augite/Opaques ratio
16	Robinson	0-0.20	2.9		47	35	1.34
		0.20-0.50	3.1		59	37	1.59
8	Lockyer	0.25-0.40	5.5		42	51	0.82
		0.65-0.90	3.5		39	42	0.92
		1.30-1.70	6.6		52	52	0.62
1	Lockyer	0-0.25	5.8	2.01	45	41	1.09
		0.70-0.90	8.9	1.17	21	59	0.36
		1.10-1.40	11.1	1.11	16	67	0.26
		5.43-5.53	3.3	3.26	38	55	0.70
		7.00-7.10	5.5	2.38	28	67	0.42

Origin of soils

Soils and substrate in this alluvia have

(i) high smectite/kaolinite ratios

(ii) high augite/opaque ratios

(iii) high calcium oxide values in the profile measured

(iv) illite in only trace amounts

These characteristics are also shown in the results of basaltic regolith which makes up 54%

of the catchment (Tables 6.3, 6.4). This fulfills all the criteria suggested in Section 6.2.3 as indictive of alluvia of mainly basaltic origin.

7.4.2. Soils of the major stream terraces and plains

These soils are associated with the wide alluvial plains of the downstream reaches and the terrace above the flood plain of tributary trunk streams (Plate 7.1). Most of the soils belong to the mildly leached dark soil grouping of Stace *et al.* 1968, probably due to the nature of their parent material, their low topographic position with moderate leaching, the semi-arid climatic conditions of soil formation and their relatively young age. Some of the better drained soils belong to the mildly leached brown soil grouping.

The solum is generally black to brown with clay loam to heavy clay surface textures becoming medium to heavy clay and alkaline in the subsoil. The subsoil contains carbonate and has a lenticular structure. The exception is Sippel profile class which has sandier surface soils, and angular blocky subsoils which may be carbonate free (Table 7.6). Below the solum of all profile classes, buried soils or brown loamy textured sediments are found (Plate 7.3).

Most soils on this landscape are cultivated apart from backswamp depressions. The heavier textured soils are self mulching and periodically crack, whereas the lighter textured surface soils are cloddy and crusting. In horizons below the depth of cultivation, soils of this group are distinguished by a highly lustrous (lac) smooth ped fabric.

Essential features of component soils

The essential features of the soils are summarised in Table 7.6.

Table 7.6. Morphology and landscape position of soils of the major stream terraces and plains.

Soil profile class	Distinguishing features	Landscape position
Lawes	Dark self-mulching, cracking medium clay with dark or brown calcareous subsoil to 1.0-1.4 m over brown friable lighter textured layers.	Alluvial plains adjacent to relict levees
Blenheim	Dark self mulching, cracking medium to heavy clay with dark, brown or grey calcareous subsoil to 1.5 m deep or over medium to heavy clay palaeosol.	Extensive back plains
	Light textured variant: light clay surface texture	Infilled channels of prior streams and levee backslopes
Clarendon	Humic mottled surface horizon over mottled dark or grey medium to heavy clay with grey calcareous subsoil to 1.5 m deep.	Backswamps
Flagstone	Grey self mulching, cracking clay with grey calcareous subsoil to 1.5 m deep or over brown fraible lighter textured layers.	Backplains
Sippel	Hardsetting texture contrast soil with dark fine sandy loam to fine sandy clay loam surface soil to 0.15 to 0.45 m over brown or grey brown neutral to alkaline clay subsoil.	Alluvial plains
Tenthill	Dark brown weakly self mulching cloddy light to light-medium clay with brown calcareous subsoil to 0.4 to 0.7 m over brown friable lighter textured layers.	Relict levees, terraced plains, prior streams
Hooper	Dark brown weakly self mulching cloddy light to light-medium clay with brown calcareous subsoil to 0.7 to 1.4 m over brown friable lighter textured layers.	Relict levees, prior streams

Soil analytical data

A summary of the soil analytical data in this lithological - landform group shows a wide range of values (Table 7.7). Generally, however, the vast majority of these soils are neutral to alkaline, have clay contents varying from 30-75%, and have calcium and magnesium dominant clays. Soil analysis values are discussed in terms of subgroups separated on the basis of landscape component.

Table 7.7. Summary of analytical data for soils of the major stream terraces and plains.

Horizon	pH 1:5	E.C. mS cm^{-1}	Silt %	Clay %	CEC $cmol(p^+)kg^{-1}$	Dominant cations	ESP	CEC/%clay
A	7.0-8.3	0.03-0.24	16-29	31-62	21-65	Ca^{++}, Mg^{++}	1.5-5.9	0.63-1.1
B	7.0-9.3	0.09-0.94	11-35	40-74	37-71	Ca^{++}, Mg^{++}	1.2-26	0.67-1.2
Substrate	7.4-8.5	0.03-0.62	9-30	16-43	19-51	Ca^{++}, Mg^{++}	1.8-10	>1.2

Soils of the relict levees of prior streams and of upstream terraces

These soils have neutral to moderately alkaline soil pHs (7.0-8.3) in both the A and B horizons, low salinity levels (E.C. <0.35 mS cm^{-1}) and low chloride levels (<0.03%). These soils have variable surface clay contents (31-49%) but the silt contents are more uniform (16-23%). Subsolum layers, usually below about 0.7 m have lower clay contents (21-34%) with correspondingly higher fine sand contents (38-61%). CEC/% clay ratios are 0.7-1.0 in the solum, but subsolum layers have ratios >1.2. Similar high CEC/% clay ratios have been noted in subsolum layers on Warrill Creek floodplain soils (Powell 1979) and also at Gatton Research Station (Powell 1982). It is suggested that partially weathered pseudomorph minerals present in the fine sand fraction are responsible. Calcium is usually the dominant exchangeable cation with magnesium subdominant and sodium is a minor component (ESP <3).

Soils of the extensive terraced plain

These soils have neutral to weakly alkaline surfaces (pH 7.2-7.8) and moderately to strongly alkaline subsoils (pH 8.4-9.3). Subsoils accumulate low to high amounts of salts (0.25-1.0 $mScm^{-1}$) at 0.8-1.4 m depth, with high salinity occuring in soils with deep clay subsoils. Clay contents in the solum range from 40% to 70%, while subsolum layers, if present, have 27-36% clay. Silt usually ranges between 15% and 25% (rarely up to 35%) in both the solum and subsolum. The CEC's of both the solum and subsolum are in the 40-60 $cmol(p^+)kg^{-1}$ range despite a reduction in clay content in the subsolum. CEC/% clay ratios range from 0.7-0.99 in the solum but exceed 1.2 in the subsolum. This suggests that subsola of these soils also contain pseudomorph minerals in the fine sand fraction.

The exchange complex through the upper solum is usually 90-100% base saturated with calcium and magnesium the co-dominant cations or magnesium dominant. With increasing depth magnesium and sodium increase. Soils with shallower sola to about 1 m (e.g. Lawes) have low ESPs (<2.5) throughout but may have slightly more sodic subtrates (ESP's up to 4). Deeper clay soils (e.g. Blenheim) have low sodicity in the surface 0-0.1 m (ESP's <5) but subsoil ESP's range from 8 to 26.

Laboratory analysis of the Sippel profile class (Table 7.8) does not fit the summary data outlined above. Sippel is sandier than the other profile classes of this subgroup and occurs mainly on the alluvial plain of Deep Gully. It has lower clay, CEC and ESP values than the other profile classes; it also has lower pH and E.C. values and appears to have been more effectively leached.

Table 7.8. Summary of analytical data for Sippel profile class.

Horizon	pH 1:5	E.C. mS cm^{-1}	Silt %	Clay %	CEC $cmol(p^+)kg^{-1}$	Dominant cations	ESP	CEC/%clay
A_1	6.0	0.03	15	15	16	Ca^{++}, Mg^{++}	0.6	1.1
B	7.1-7.8	.02	10	27-33	23-24	Ca^{++}, Mg^{++}	0.9	0.7-0.9

Backswamp depression soils

These soils (e.g. Clarendon) show analytical values similar to the deeper clay soils of the adjacent plains except that surface pH is more acid (pH 5.4-5.8). Acidity may extend to 0.6 m in gilgai mound profiles. These acid horizons have lower base saturation (56-59%) probably reflecting leaching conditions caused by prolonged saturation, and acidification from accumulation of humic materials.

Soil mineralogy

Table 7.9 shows that soils on this landscape are composed mainly of interlayered smectite with subordinate kaolinite, and trace amounts of illite. Profiles show a tendency for progressively greater disorder in smectite in the horizons approaching the surface. Increasing hydroxy interlayering of smectites suggests increased stability (Weed and Nelson 1962). Thus the increasing breakdown of smectite clays in horizons and materials closer to the surface can be explained by

increased interlayering. This is evident for profiles from sites 2 and 3 (Table 7.9). In these profiles, interlayered smectite is dominant above 1.0 m but below this depth, clays are dominantly smectites with minimal interlayering. In contrast clays below 1.0 m from sites 7 and 15 (Table 7.9) are interlayered but are more crystalline with sharper diffraction peaks than the clays above 1.0 m. The reasons for differences between profiles are unknown but sites 2 and 3 are from the downstream alluvial plain landscape of Lockyer Creek whereas sites 7 and 15 are from the terrace of Tenthill Creek. It is suggested that smectite interlayering is occurring as a result of weathering since time of deposition, with weathering being most advanced in surface horizons.

Table 7.9. Clay mineralogy of soils of the major stream terraces and plains.

Site no.	Soil profile class	Depth	S	SI	K	I	C
15	Tenthill	0-0.20		++++	+	tr	tr
		0.20-0.40		++++	+	tr	
		0.54-0.70		++++	+	tr	
		0.70-0.87			+++	tr	+++
		1.70-1.80		++++	+	tr	
7	Tenthill	0-0.25		++++	+	tr	
		0.25-0.40		++++	+	tr	
		0.65-0.90		++++	+	tr	
		1.30-1.70		++++	+	tr	
2	Lawes	0.30-0.60		++++	++	tr	
		0.60-0.90		++++	++	tr	
		1.00-1.15	++++		+	tr	
		1.30-1.60	++++		+	tr	
3	Tenthill-	0.23-0.50		++++	++	tr	
	light textured variant	0.5-0.68		++++	++	tr	
		1.00-1.35	++++		++	tr	
		1.35-1.50	++++		++	tr	

Table 7.9 shows chlorite to occur in substantial amount at 0.70-0.87 m in a Tenthill profile (site 15) located at Mt Sylvia. In this profile, the sample was taken from what appears to be the darkened A horizon of a buried palaeosol. Chlorite and increased kaolin appear to be the product of former surface weathering, since the clay mineralogy of layers above and below this horizon are both dominated by interlayered smectite. It is suggested that this mineral is dioctohedral chlorite of pedogenic origin, which was formed in the past by surface weathering. A trace of chlorite was also noted in the

present A horizon and may indicate incipient formation of chlorite.

Catchment source rock composition (54% basalt) and soil properties such as high clay contents and dark soil colours suggest that these soils are derived from basaltic alluvium. The clay mineralogy results support this, as smectite and interlayered smectite clay minerals were also found to be dominant in basaltic regolith (Table 6.3).

Table 7.10. Fine sand mineralogy of soils of the major stream terraces and plains.

Site no.	Soil profile class	Depth	Light/heavy ratio	Light fraction CaO	Heavy fraction Augite	Heavy fraction Opaques	Heavy fraction Augite/Opaques ratio
		m		%	%	%	
15	Tenthill	0.20-0.40	333		13	82	0.16
		0.54-0.70	2.8		43	45	0.93
		1.70-1.80	69		35	48	0.74
7	Tenthill	0.25-0.40	42		17	77	0.23
		0.47-0.60	2582		34	52	0.65
		0.90-1.20	6.2		53	42	1.26
2	Lawes	0.30-0.60	11.8	0.49	11	85	0.12
		1.00-1.15	18.0	1.58	22	65	0.34
		1.30-1.60	8.8	1.75	18	65	0.27
3	Tenthill-	0.23-0.50	7.4	0.28	tr	85	<0.01
	light textured variant	1.00-1.35	5.9	1.84	16	65	0.26
		1.50-1.60	-	2.38	16	74	0.10
		4.45-4.65	25	2.76	41	57	0.72

The results of fine sand mineral analysis (Table 7.10) do not show any consistent trends for light/heavy mineral ratios. It is suggested that these values reflect ratios of mainly resistant minerals such as quartz (light) and the opaques (heavy) with differences down the profile reflecting differences in alluvial source materials and stream competence. However, there does seem to be a general trend towards increased augite and decreased opaques down the profile; light fraction CaO content also increases down the profile. These trends suggest progressive profile weathering toward the surface, which is compatible with the clay mineralogy results indicating breakdown of smectite. This differs from the results of the previous group of soils (Table 7.5) in which augite and %CaO decrease down the profile, suggesting minimal weathering.

Origin of soils

Soils and substrate in this alluvium have

(i) medium to high smectite/kaolinite ratios

(ii) low to high augite/opaque ratios

(iii) low to high CaO values in the two profiles measured

(iv) illite in only trace amounts.

Substrates have properties very similar to the basalt source materials (Table 6.3) whereas the sola differ in being lower in augite and %CaO in the fine sand fraction. This difference is believed to be due to weathering during the time since alluvial deposition (10 000-20 000 years b.p).

Radio carbon dates of buried palaeosol A horizons below two of these soil profiles (sites 2 and 3) suggest a maximum age of about 20 000 years b.p. (Appendix 5).

7.4.3. Soils of the major stream elevated terraces, fans and pediments

These soils occur in elevated positions above the terrace along the margins of the major stream valleys (Fig. 7.1b) or as isolated remnants unrelated to the present major streams (Plate 7.1). The elevated terrace is usually positioned on Ma Ma Creek Sandstone beds and is moderately dissected. Where it is isolated from the major streams, it is found on gently sloping ridges between first and second order streams (Plate 7.2).

They are generally grey or brown clays characterised by weakly crusting to moderately self mulching surfaces, which periodically crack when dry. Such soils belong to the group of soils showing minimal profile development (Stace *et al.* 1968). Along the mid and upper reaches of Tenthill Creek and its major tributary they are underlain by cobbly brown sediments. Subsoils are alkaline but may become neutral to weakly acid with depth. In this part of the catchment, soils of elevated alluvia are generally associated with brigalow-belah softwood scrub.

Dissected elevated terraces were observed only along upstream and middle reaches (Fig. 7.1b). Further downsteam, this soil group was found on pediments and in places along the

drainage lines of minor streams. Here they appear to be derived from the neighbouring upland sedimentary rocks bordering the extensive alluvial plains.

It was noted that buried palaeosols found beneath the wide alluvial plain (Plate 7.3) along Deep Gully and Lockyer Creek were of similar morphology to the grey clay profile classes (Woodbine and Leshke) of this soil group. Based on the similarity of stratigraphic age sequence and morphology, such palaeosols are believed to be equivalent to the surface soils of this group i.e. they represent a former alluvial plain surface along the major streams.



Plate 7.1. Middle reach of Tenthill Creek showing wide alluvial terrace (Tenthill profile class), narrow floodplain along creek (Lockyer profile class) and elevated abandoned terrace on first rise in background (Townson profile class).



Plate 7.2. Gently sloping rises of isolated dissected elevated terrace (cultivated).



Plate 7.3. Deep Gully stream bank (site 11) showing Tenthill profile class overlying buried grey clay.

Essential features of component soils

The main features of these soils are summarised in Table 7.11.

Table 7.11. Morphology and landscape position of major stream elevated terraces, fans and pediments.

Soil profile class	Distinguishing features	Landscape position
Leschke	Grey, hardsetting, crusting light to medium clay with grey subsoil to 1.5 m. Subsoils are alkaline but may become neutral with depth.	Elevated terraces, pediments, local alluvial plains
Woodbine	Grey or dark self-mulching, cracking medium clay with grey subsoil to 1.5 m. Subsoils are alkaline but may become neutral to acid with depth.	Elevated terraces, pediments, local alluvial plains
Thorton	Dark cobbly self-mulching cracking light to medium clay with dark or brown medium to heavy clay subsoil to 0.5 to 1.3 m over brown layers or coarse bedload.	Elevated terraces, alluvial fans, and adjacent pediments
Townson	Dark self-mulching cracking medium to heavy clay with dark, grey brown or brown subsoil to 1.5 m.	Elevated alluvial fans and adjacent pediments
Ryan	Brown hardsetting sandy loam with massive red brown neutral sandy clay subsoil.	Pediments

Analytical data

Table 7.12 shows that the soils of the elevated terraces have weakly acid to weakly alkaline surface soils (pH 6.2-8.2) but have moderately to strongly alkaline subsoils (pH 8.3-8.8) within 0.3 m. The pH decreases to neutrality by 0.6 m or continues unchanged to 1.2 m before becoming strongly acid (pH 5.5) by 1.5 m. Moderate to high salinity accumulates in the subsoils (0.5 to 1.5 mS cm^{-1}) at depths as shallow as 0.3 m or as deep as 0.8 m. Salinity reaches a maximum at 0.6 to 1.2 m.

Clay contents usually range from a depth of 40 to 60% while silts vary from 11 to 21%. CEC's are in the 21 to 49 $cmol(p^+)kg^{-1}$ range resulting in CEC/%clay ratios usually in the range of 0.6 to 0.8. Calcium and magnesium are the dominant exchangeable cations with calcium slightly dominant in the surface soil and magnesium becoming increasingly dominant with depth. As calcium decreases, sodium also increases with ESP values of 2.7 to 6.7 in the surface increasing

to values of 26 to 35 with depth.

These soils are also distinct from others in having lower surface phosphorus levels (31-32 ppm bicarbonate extractable P by Colwell's method) and lower copper (0.6-1.2 ppm) and zinc (0.3-0.8 ppm) as determined by DTPA extraction (Appendix 6).

Table 7.12. Summary of analytical data for soils of the major stream elevated terraces, fans and pediments (2 profiles).

Horizon	pH 1:5	E.C. mS cm^{-1}	Silt* %	Clay* %	CEC $cmol(p^+)kg^{-1}$	Dominant cations	ESP	CEC/%clay
A	6.2-8.2	0.1-0.24	15-21	32-48	21-38	Ca^{++}, Mg^{++}	2.5-10	0.63-0.79
B	5.5-8.8	0.13-2.2	11-18	40-62	25-49	Ca^{++}, Mg^{++}, Na^{+}	5.5-35	0.6-0.83

* range based on 6 profiles

Table 7.12 shows a wide range of values for pH and electrical conductivity. However there was a consistent trend towards acid to neutral pH's in the deep subsoil with maximum pH's in the upper metre of the profile. Sodicity is generally high and increases to very high levels in the subsoil where magnesium is the most abundant cation.

Soil mineralogy

Table 7.13 shows all soils to have consistently high smectite/kaolinite ratios, except for the Woodbine grey clay (site 22) which has somewhat lower smectite/kaolinite ratios. The buried palaeosol from site 3 and subsoil samples deeper than 1.5 m at site 14 differ from the other soils in being dominantly smectite with only weak interlayering.

Results of fine sand analysis (Table 7.14) show a high proportion of opaques in the heavy fraction. The high CaO value (2.06%) in the buried palaeosol is very likely due to contamination from brown basaltic alluvial deposits above (see Appendix 4 for description). These latter deposits are similar to substrate materials below the soils of the terraced alluvial plains (Table 7.10).

Table 7.13. Clay mineralogy of soils of the major stream elevated terraces, fans and pediments.

Site no.	Soil profile class	Depth	S	SI	K	I
22	Woodbine	0.05-0.30		++++	++	+
		0.30-0.80		++++	++	+
		1.60-1.80		++++	++	+
22	Unnamed brown cobbly soil	0-0.10		++++	+	+
14	Woodbine	0-0.10		++++	+	tr
		0.10-0.25		++++	+	tr
		0.70-1.10		++++	+	tr
		1.55-1.80	++++		+	tr
		3.00-3.25	++++		+	
3	Buried palaeosol under	5.85-5.95	++++		+	tr
	Tenthill	6.8-6.9	++++		+	tr
10	Thornton	0-0.12		++++	+	tr
		0.12-0.2		++++	+	tr
		0.7-0.8		++++	+	tr
11	Buried palaeosol under Tenthill (Plate 7.3)	5.7-5.8		++++	++	tr

Table 7.14. Fine sand mineralogy of soils of the major stream elevated terraces, fans and pediments.

Site no.	Soil profile class	Depth	Light/heavy ratio	Light fraction	Heavy fraction		
				CaO	Augite	Opaques	Augite/Opaques
		m		%	%	%	ratio
22	Woodbine	0.35-0.45	1621		6	84	0.07
		0.90-1.00	146		3	83	0.06
		1.60-1.70	10.3		9	76	0.12
14	Woodbine	0.10-0.25	84		10	80	0.13
		0.70-1.10	440				
		1.55-1.80	333		4	73	0.05
		2.00-2.05	470		8	84	0.09
		3.00-3.25	9.3		2	92	0.02
3	Buried palaeosol under	5.85-5.95	26		20	79	0.25
	Tenthill	8.20-8.30	59	0.50	3	87	0.03
10	Thornton	0-0.12	11.6		6	91	0.07
		0.12-0.20	17.6		6	90	0.07
		0.20-0.30	11.2		3	85	0.04
		0.70-0.90	22		5	80	0.06
2	Buried palaeosol under Lawes	6.33-6.4	46	2.06	23	71	0.32

In places, the soils have a cobble component similar in density to that found in the upper tributary terraces and fans of current streams. This suggests that these areas are former upper tributary deposits, possibly former channels.

The dominance of basalt cobbles over sandstone cobbles together with the dominance of interlayered smectite over kaolinite in the clay fraction (Table 7.13) suggest that this material is dominantly basaltic.

However, fine sand mineralogy (Table 7.14) in general did not show any great similarity with basaltic source material results (Table 6.4). The exception is the high %CaO values found for buried palaeosols, which could also be explained by contamination from less weathered material above moving down cracks in the clay rich palaeosols.

It is suggested that the low proportion of augite in these soils is due to weathering over time. These soils are known to be older than the two previous soil groups because upstream they occur on a higher terrace in an advanced state of dissection; in some locations, these terraces have been abandoned by the major streams.

Alternatively these soils could have a greater component of Jurassic sediment source materials in the parent alluvium. Until further research clarifies this matter, explanations will continue to be equivocal. Buried palaeosols believed to belong to this group of soils and period of alluvial deposition have been radio carbon dated at 19 360 $\pm$ 280 years b.p. (site 2) and 21 770 $\pm$ 280 years b.p. (site 3). This gives a minimum age of deposition but these dates do coincide fairly closely with the last glacial maximum, a period of extreme aridity and presumably sediment redistribution in Australia (Section 2.2).

7.4.4. Soils of alluvial fans derived from basalt (upper reach tributaries)

These soils occur on steep fans (5-15%) along the upper tributary trunk streams. The fans descend gradually onto the terraces and plains. Although Tertiary basalt is the major source material for these fans, Jurassic Walloon Coal Measures and Heifer Creek Sandstone may contribute in a minor way. Soils are characterised by the presence of stone and cobble on the surface and both

are commonly present in the profile. Profile colours vary from black to brown and soils are underlain by brown sediment or cobble.

Soils are loam to heavy clay in texture, moderately structured and may contain carbonate in alkaline subsoils. They belong to the mildly leached dark soils grouping (Stace *et al.* 1968).

Essential features of component soils

The main features of the two component soils are summarised in Table 7.15.

Table 7.15. Morphology and distinguishing features of soils of alluvial fans derived from basalt.

Soil profile class	Distinguishing features	Landscape position
Peacock	Dark stony loam to light clay with structured dark or brown neutral subsoil to 0.4 to 1 m over brown layers or coarse bedload.	Alluvial fans
Spellman	Dark or grey brown cobbly loam to light clay with dark or brown alkaline medium clay subsoil to 0.4 to 0.1 m over brown layers, palaeosols or coarse bedload.	Alluvial fans

Analytical data

A summary of data from two sites is shown in Table 7.16.

Table 7.16. Summary of analytical data for soils of alluvial fans derived from basalt (2 sites).

Horizon	pH 1:5	E.C. mS cm^{-1}	Silt %	Clay %	CEC $cmol(p^+)kg^{-1}$	Dominant cations	ESP	CEC/%clay
A	6.1-6.3	0.05	25-31	29-45	40-47	Ca^{++}, Mg^{++}	<1	1.0-1.2
B	6.9-8.4	0.02-0.42	13-25	32-60	51-60	Ca^{++}, Mg^{++}	1.5-6	0.87-1.4
Substrate	7.6-8.0	0.03-0.04	17-22	38/45	43-54	Ca^{++}, Mg^{++}	2.0-2.8	1.2-1.9

Soils are moderately acid in the surface becoming neutral to moderately alkaline at depth. Otherwise the solum has generally similar properties to the soils associated with relict levees and upstream terraces, except that subsoil sodicity may be slightly higher (ESP up to 6). Salt levels vary from low to moderate amounts. Silt contents are variable and clay contents increase with depth of solum but may decrease in the substrate. Calcium and magnesium are the dominant cations and ESP values are generally low (<6). CEC/%clay ratios are consistantly high (>0.8) suggesting smectite is the dominant clay mineral.

Soil mineralogy

Table 7.17. Clay minerals of soils of the alluvial fans derived from basalt.

Site no.	Soil profile class	Depth	SI	K	I
23	Spellman	0-0.13	++++	+	tr
		0.13-0.40	++++	+	tr
		0.40-0.75	++++	+	+
		0.75-0.88	++++	+	tr

X-ray diffraction traces confirm that interlayered smectites are the dominant clay mineral (Table 7.17). Like the soils of the major stream terraces and plains these soils also show increasing smectite interlayering in surface clay samples, presumably the result of increased weathering.

Origin of soils

Cobbles and stones present in these landscapes are mainly basalt. Tables 6.3 and 7.17 indicate that these soils have a clay mineral suite very similar to the basaltic source materials. These soils are therefore concluded to be mainly basaltic in origin. The common cobble component indicates deposition under high stream velocities whereas the mainly clay and silt deposits indicate slower stream velocities and colluviation.

It was also noted that the morphology, analytical data and clay mineralogy of these soils were similar to the soils of the relict levees of prior streams and upstream terraces (see Section 7.4.2) This supports the conclusion that these latter soils are largely basaltic in origin and are associated with parent alluvium deposited by high velocity streams.

Based on the principle of descendancy (Section 2.2.4), these soils are the same age as the soils of the major stream terraces and plains, i.e. between 10 000 and 20 000 years old.

7.4.5. Soils of alluvial fans and flats derived from upper Marburg beds (middle reach tributaries)

These soils occur in fans and narrow local alluvial plains (first or second order streams) draining Heifer Creek and Ma Ma Creek Sandstones. Generally they have affinities with the mildly leached brown soils grouping (Stace *et al.* 1968). Characteristically these soils are associated with softwood scrub, often dominated by brigalow and belah.

Soils on this landscape descend and merge gradually with the soils of the major stream terraces and plains. Based on the principle of descendancy these soils are also deduced to be of the same age as the terraces and plain soils (10 000-20 000 years b.p).

This soil landscape has been largely cleared and most soils are cultivated; the topsoil is hardsetting and becomes cloddy on tillage. The solum is generally grey brown, yellow brown or red brown in colour with a sandy clay loam to sandy clay surface texture and a gradual increase in clay with depth. This group may be distinguished from other sandstone derived soils by their more gradual texture increase down the profile. Buried soils and sedimentary layers are common below the solum at about 1 m depth.

Essential features of component soils

The main features of the component soils are summarised in Table 7.18.

Table 7.18. Morphology and landscape position of soils of alluvial fans and flats derived from upper Marburg beds.

Soil profile class	Distinguishing features	Landscape position
Sutton	Brown hardsetting sandy clay loam to sandy clay with neutral to alkaline red brown sandy clay to sandy medium clay subsoil to 0.7 to 1.0 m over brown to red brown layers.	Alluvial fans, local alluvial plains
Abell	Grey brown to brown hardsetting sandy clay with yellow or brown, neutral, sandy clay to sandy medium clay subsoil to 0.7 to 1.0 m over yellow to brown layers.	Alluvial fans, local alluvial plains, pediments
Geisemann	Brown hardsetting sandy clay loam with brown or yellow brown acid to neutral sandy clay loam to sandy clay subsoil to 0.7 to 1.0 m over seasonally saturated mottled grey, ferromanganiferous sandy clay and other layers	Mid and lower slopes of alluvial fans
Laidley	Grey brown hardsetting sandy clay loam to sandy medium clay with variable A_2 horizon development and yellow to brown sandy medium to heavy clay subsoils. Deep subsoils are alkaline and non-calcareous and overlie buried layers.	Lower slopes of alluvial fans and local allivial plains

Analytical data

Soils of fans and alluvial plains out of upper Marburg beds are medium acid to neutral in the surface soil (pH 5.9-7.0) and neutral to alkaline in the lower subsoil (pH 7.4-8.8). Below alkaline subsoils pH may decrease to neutral in substrate materials. Salinity levels of soils of neutral pH are very low (E.C. <0.07 mS cm^{-1}) whereas soils of alkaline pH have E.C. values up to 0.23 mS cm^{-1} at depth.

Table 7.19. Summary of soil analytical data for soils of alluvial fans and flats derived from upper Marburg beds.

Horizon	pH 1:5	E.C. mS cm^{-1}	Silt %	Clay %	CEC cmol(p^+)kg^{-1}	Dominant cations	ESP	CEC/%clay
A	5.9-7.0	<.07	11-23	26-39	22-32	Ca^{++}	<0.1	0.58-0.72
B	6.7-8.6	0.02-0.17	10-16	30-53	21-28	Ca^{++}	0.8-8.6	0.53-0.68
Substrate	7.2-8.4	0.03-0.23	7-17	23-37	15-25	Ca^{++}, Mg^{++}	1.1-10	0.53-0.78

Clay contents range from 26 to 39% in the surface and gradually increase down the solum to 30 to 53%. In the subsolum, clay contents decline to 23-30% but may increase again at a lower

depth. Silt contents vary from 11-23% in the solum.

CEC varies widely, corresponding to changes in clay content. The major cation on the exchange complex is calcium with magnesium subdominant. Levels of sodicity are very low in the neutral pH soils (ESP <1) but may be moderately high in alkaline soil profiles (ESP up to 10). These soils are different from the soils groups discussed so far in that they are low in salts, calcium is the dominant cation in the solum and CEC/%clay ratios never exceed 0.8. The last figure suggests that smectite is not so likely to be the dominant clay mineral.

Soil mineralogy

Table 7.20 shows that randomly interstratified minerals and kaolinite are co-dominant clays. In addition some substrate materials were found to have a significant interlayered smectite component instead or randomly interstratified mineral (Fig. 7.4).

Table 7.20. Clay mineralogy of soils of alluvial fans and flats derived from upper Marburg beds.

Site no.	Soil profile class	Depth	SI	RIM	K	I	C	Q
5	Sutton	0-0.30		+++	+++	+		
		0.56-0.80		+++	+++	+		tr
		0.80-0.97		+++	+++	++		
		1.60-1.70	+++		+++	++		tr
6	Unnamed	0-0.23		+++	+++	++	tr	tr
	transitional soil	0.43-0.63		+++	+++	++	tr	tr
		1.06-1.34	+++		++	+	tr	tr
		1.45-1.70		+++	+++	++	tr	tr

The clay mineral suite in the solum and upper layers of the substrate are very similar to that in the regolith samples derived from Walloon Coal Measures and Heifer Creek Sandstone (Table 6.3). In contrast the lower substrate samples (e.g. 1.6-1.7 m depth in site 5) contain interlayered smectite and kaolinite in proportions similar to the shale saprolite and landslide outwash source material results (Table 6.3).

Fine sands are virtually free of any weatherable minerals in the heavy fraction (Table 7.21) and are composed mainly of opaques. The CaO content of the fine sand light fraction is notably low at all sampled depths and even lower than the CaO content of Jurassic sediment source

materials (Table 6.4).

Table 7.21. Fine sand mineralogy of soils of alluvial fans and flats derived from upper Marburg beds.

Site no.	Soil profile class	Depth	Light/heavy	Light fraction	Heavy fraction		
				CaO	Augite	Opaques	Augite/Opaques
		m	ratio	%	%	%	ratio
5	Sutton	0-0.30	35	0.01	tr	86	0.01
		0.80-0.97	17	0.01	tr	92	0.01
		1.28-1.60	112	0.01	tr	83	0.01

Origin of soils

These soils are derived from the surrounding catchment rock materials of Heifer Creek Sandstone beds and Ma Ma Creek Sandstone beds. On the basis of clay mineralogy it is suggested that the solum above 1 m is derived from surface colluvium, whereas the substrate material is alluvial material derived from landslide debris. Low estimates of weatherable of fine sand minerals reflect the nature of the source rocks.

7.4.6. Soils of alluvial fans and flats derived from lower Marburg beds (lower reach tributaries)

These soils have developed along alluvium on narrow drainage lines derived largely from Winwill Conglomerate and Gatton Sandstone, the lower beds of the Marburg Formation (Fig. 6.1). They are found in minor tributaries along the lower reaches of the major streams. They belong to the mildly leached brown soils grouping (Stace *et al.* 1968) and are characterised by a texture contrast profile form and a coarsely structured impermeable subsoil, which distinguish them from other soil groups. Soils of this group have slow internal drainage and low available water capacity and have a lower land use potential than the other soil groups. They are mainly used for grazing of native pastures. Vegetation is typically an open forest of eucalypt species including narrow-leaved ironbark, bluegum, Moreton Bay ash and silver-leaved ironbark.

Main features of component soils are summarised in Table 7.22.

Table 7.22. Morphology and landscape position of soils of alluvial fans and flats derived from lower Marburg beds.

Soil profile class	Distinguishing features	Landscape position
Stockyard	Hardsetting texture contrast soil with dark to grey brown clay loam surface soil with variable A_2 horizon development to 0.15 to 0.35 m over grey brown, yellow brown or brown neutral to alkaline clay subsoil to 0.7 m. Gravel and sediment layers occur below 0.7 m.	Local alluvial plains
Hattonvale	Hardsetting texture contrast soil with grey brown or brown sandy loam to sandy clay loam surface soil with variable A_2 horizon development to 0.15 to 0.45 m over grey brown or yellow brown alkaline clay subsoil to 0.6 m. Layers common below 0.6 m.	Local alluvial plains
Glencairn	Loose or hardsetting texture contrast soil with dark or brown loamy sand to sandy loam surface soil with bleached A_2 horizon to 0.4 to 0.6 m over acid yellow and grey mottled sandy light to medium clay	Local alluvial plains, minor alluvial fans
Whiteway	Hardsetting texture contrast soil with dark loam to clay loam surface soil with sporadically bleached A_2 horizon to 0.1 to 0.3 m over dark light-medium to heavy clay subsoil, calcareous at depth.	Major stream terraced plains adjacent to local alluvial plains

Analytical data

This soil group is highly variable in some properties and the following comments apply to the soils with sandy surface textures. Soils are acid (pH 6.0-6.7) at the surface and neutral to alkaline at depth (maximum pH of 7.5 to 9.1). Salinity levels may be low throughout the 1.5 m profile (E.C. <0.4 mS cm^{-1}) or may be high and peak at 0.6 m (E.C. 1.2 mS cm^{-1}). Clay content varies from 12-15% in the sandy A horizon abruptly increasing to 29-33% in the subsoil. Subsolum layers have lower clay contents (19-29%). A shallow clay rich (>40% clay) alluvial deposit may sometimes be found overlying these soils. Silt contents are variable, ranging from 10 to 32% in the solum.

Table 7.23. Summary of analytical data for Stockyard profile class.

Horizon	pH 1:5	E.C. mS cm^{-1}	Silt %	Clay %	CEC cmol(p$^+$)kg^{-1}	Dominant cations	ESP	CEC/%clay
A	6.7	0.67	32	13	9	Ca^{++}, Mg^{++}	14	0.69
B	7.5	0.51	27	29	17	Mg^{++}, Na^+	40	0.58
Substrate	8.4-8.9	0.37-0.8	10-36	19-29	13-21	Mg^{++}, Na^+	38-42	0.68-0.72

CEC's range from 9 to 16 cmol(p$^+$)kg^{-1}meq 100 g^{-1} in the A1 horizon and from 17 to 23 cmol(p$^+$)kg^{-1}meq 100 g^{-1} in the subsoil. Layers below the solum have CEC's ranging from 13 to 24 cmol(p$^+$)kg^{-1}meq 100 g^{-1}.

CEC/% clay ratios varied from 0.58 to 0.75 in the solum except for one A1 horizon which was 1.02. Layers below the solum vary from 0.66 to 0.97. The exchange complex may be calcium dominant throughout with magnesium subdominant, or calcium and magnesium may be co-dominant in the surface soil with magnesium becoming dominant at depth. ESP varies from less than 1 in a calcium dominated profile to 42 in a magnesium rich profile.

The dominance of magnesium and sodium in the B horizon of these soils is believed to reflect a similar balance of cations in the source materials. Zahawi (1975) found sodium and magnesium to be the dominant cations in groundwater from lower beds of the Marburg Formation. Mineral composition was not investigated in these soils.

Origin of soils

The soils occur within catchments of lower Marburg beds. These soils therefore developed on alluvia derived from the lower beds of the Marburg Formation. They have lateral continuity with the soils of the major stream terraces and plains and are therefore considered to be of equivalent age i.e. 10 000 to 20 000 years old. The alluvial overburdon deposit may be of equivalent age to the soils of the major stream floodplains and levees.

7.5. Substrate materials

Substrate materials are the materials found below the soil profile (Speight and Isbell 1984) and their properties have been described in Section 7.4. Examination of substrate material by deep

cores (Appendix 4), gully exposures (Plate 7.3) and routine 1.5 m soil cores revealed evidence of post-burial alteration of alluvial strata and also buried palaeosols.

Post-burial alteration was suggested by the absence of apparent bedding structures and the development of a smooth ped or earthy fabric (Northcote 1974) in medium textured beds and sandy fabric (Northcote 1974) in coarse textured beds. In fine textured deposits moderate to strong pedality has developed together with accumulations of carbonate.

Palaeosols were identified using the criteria suggested by Wyroll (1984):

(i) Texture and colour characteristics;

(ii) boundary relations between soil horizons and substrate material. An AC or BC horizon transition should be gradual whereas with underlying alluvial sediment there should be a sharp boundary;

(iii) lateral continuity of the soil stratigraphic unit; and

(iv) pedogenetic features such as pedality, fabric, organic matter darkening, increasing abundance with depth of carbonate segregations, and the presence of manganese segregations.

Some buried palaeosols have been linked with surface soils on the basis of their similar morphology, particle size, clay mineralogy, fine sand mineralogy and also their stratigraphic position (e.g. Section 7.4.3). In Section 9, buried palaeosols and surface soils have been grouped into soil stratigraphic units to develop a soil-geomorphic framework explaining alluvial soil landscape development in the study area.

8. NUMERICAL ANALYSIS OF DETAILED TRANSECT

8.1. Introduction

The widest extent of alluvia in the study area is located along Lockyer Creek near the Queensland Agricultural College, Lawes. Although the alluvial plain along this reach of Lockyer Creek is relatively featureless, soil patterns are commonly complex. Soils belonging to three of the lithology-landscape groups described in Section 7 are found in the area. These are:

(i) soils of the major stream floodplains and levees;

(ii) soils of the major stream terraces and plains; and

(iii) soils of alluvial fans and flats derived from lower Marburg beds (lower reach tributaries).

Most of the area is composed of soils from the second group which is the most widespread lithology-landscape group in the study area.

Distribution and variability of profile classes in this landscape were analysed in more detail than that available from the 1:50 000 map. Soil profiles were inspected on a 25 m interval line transect, to more accurately delineate soil boundaries and identify soil-landform relationships.

Line transects may show both local and general soil variation, but the nature of the variation may depend on transect direction (McBratney and Webster 1981). The line transect was located to reflect the presumed maximum soil variation and extended from the levee of Lockyer Creek at Gatton Research Station, south through the Queensland Agricultural College to the edge of the sandstone uplands, a distance of 3.4 km (see soil map).

At each site, the variables listed in Table 8.1 were measured. Because pH changes down the profiles are often independant of horizon, pH was measured at standard depths. Elevation was also obtained at each site using a Zeiss Elta 3/20 electronic tacheometer/theodolite.

Numerical analysis was used to evaluate the classification of profile classes and justify the position of soil boundaries and provide any new information.

Where necessary variants were quantified and transformed to reduce variance (Table 8.1),

prior to statistical analyses to estimate soil profile and soil horizon variability and continuity across the alluvial plain. Data patterns were compared with soil profile classes and map boundaries between classes subjectively assessed from field data.

Table 8.1. The variates and transformations to stabilise variances.

Variate	Unit	Transformation
field pH (0.05 m)†	pH	none
field pH (0.3 m)	pH	none
field pH (0.6 m)	pH	none
field pH (0.9 m)	pH	none
field pH (1.2 m)	pH	none
field pH (1.5 m)	pH	none
main colour‡ L*	%	square root
main colour u*	%	square root
main colour v*	%	square root
abundance of grey mottle	%	none
abundance of yellow mottle	%	none
texture-ribbon length	mm	none
texture-roughness	ratings 0-4	none
pedality - grade	ratings 0-3	none
pedality - horizontality	binary	none
pedality - verticality	binary	none
pedality - flatness	binary	none
soft carbonate abundance	ratings 0-4	none
hard carbonate abundance	ratings 0-4	none
soft manganese abundance	ratings 0-4	none
hard manganese abundance	ratings 0-4	none

† CSIRO indicator method (Raupach and Tucker 1959)

‡ Munsell colour scales were transformed to CIE (Commission Internationale d'Eclairage) co-ordinates L*, u*, v* (CIE 1978). The quantity L is the lightness of colour, similar to Munsell value. The other two co-ordinates are related to chroma as $(u^{*2} + v^{*2})^{0.5}$ i.e. a distance in a plane of fixed L*, and here in terms of the ratio v*/u*.

Texture was quantified by ribbon length and a roughness rating from 0 to 4. Grade of pedality as defined by Northcote (1974) was rated from 0 to 3 and form of pedality was assessed in terms of horizontality, verticality and flatness of peds (see Appendix 8 for details of ratings).

8.2. Soils and landform

Soil distribution and relief along the transect starting from the levee bank of Lockyer Creek are presented in Fig. 8.1. This shows that the alluvial landscape gently grades downslope, away from

the levee bank of Lockyer Creek. Over a distance of 2 500 m, there is a fall of about 5 m resulting in a very low average slope of 0.2%.

Although the landscape appears uniform on the ground, Fig. 8.1 shows the presence of relict levees and a channel belonging to a prior stream about 1 000 m along the transect. The low point of the transect is centred at about 2 500 m in a broad open depression 800 m wide. Further along the transect the alluvial landscape rises and flattens out where a local alluvial plain meets the major alluvial plain of Lockyer Creek (see soils map). Soil boundaries not apparent from surface features were readily discernible after inspection of soil profiles along the transect (Fig. 8.1). Distinguishing features of soil profile classes identified along the transect are shown in Table 8.2.

Fig. 8.1 shows the Lockyer soil profile class (a prairie soil, Plate 8a) on the levee bank of Lockyer Creek (0-300 m) with the light textured variant of the Blenheim profile class (a weakly cracking black earth) on the levee backslopes (300-575 m). Further along the transect (575 to 2000 m), Blenheim (Plate 8b) and Lawes (Plate 8c) soil profile classes (deep and shallow black earths respectively) occur together, usually as mappable soil bodies. However they also occur as a complex, notably on and adjacent to the prior stream channel at 1 000 m. On the relict levee at 1 100 to 1 400 m, Lawes contains or is underlain by gravel, indicating a former stream channel. At 1 600 m a complex of Lawes-depression phase and Blenheim was found, which included some Clarendon (a wiesenboden - grey clay) and typical Lawes. At 2 900 to 3 250 m, Clarendon was the only soil profile class. Beyond 3 250 m, a transition occurred from Blenheim, to an unnamed layered soil to a Stockyard soil profile class (a solodic soil).

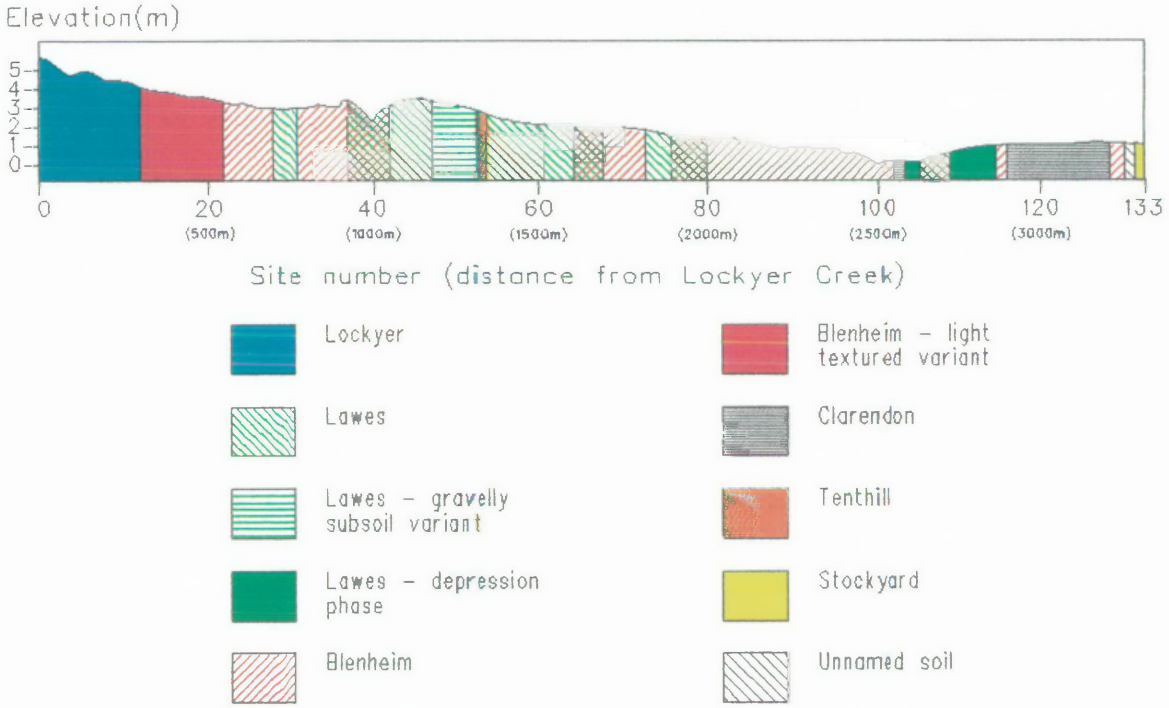


Fig. 8.1. Soil distribution and relief on detailed transect.

Table 8.2. Brief description of soil profile classes on detailed transect.

Soil profile class	Brief description
Lockyer	Dark clay loam to light clay with dark or brown neutral to alkaline structured subsoils to 0.4 to 1.0 m deep over dark or brown layers, palaeosols or coarse bedload.
Lawes	Dark self-mulching, cracking medium to heavy clay with dark, or brown calcareous subsoils to 0.7 - 1.4 m over brown friable lighter textured layers.
Lawes - gravelly subsoil variant	As for Lawes but overlying dense gravels.
Lawes - depression phase	As for Lawes but occurs in a depression; may contain grey subsoil horizons
Blenheim	Dark self-mulching, cracking medium to heavy clay with dark, grey or brown calcareous subsoil to 1.5 m deep or over medium to heavy clay palaeosol.
Blenheim - light textured variant	Dark weakly self-mulching, cracking light to light-medium clay to 0.3 to 0.7 m overlying dark medium to heavy clay palaeosol.
Clarendon	Humic mottled surface horizon over mottled dark or grey medium to heavy clay with grey calcareous subsoil to 1.5 m deep.
Tenthill	Dark brown weakly self-mulching cloddy light to light-medium clay with brown calcareous subsoil to 0.4 to 0.7 m over brown friable lighter textured layers.
Stockyard	Hardsetting texture contrast soil with dark to grey brown clayloam surface soil with variable A_2 horizon development to 0.15 to 0.35 m over grey brown, yellow brown or brown neutral to alkaline clay subsoil.
Unnamed soil	Mottled greybrown clayloam to 0.1 m over mottled dark light-medium clay over mottled grey brown light medium clay over calcareous yellow brown medium clay.

The detailed transect showed that Lawes is more widespread and variable than was suggested by the 1:50 000 map. The Lawes - gravelly subsoil variant was only revealed by the detailed transect as was the presence of Lawes in the depression at 2 500 m.

Although the sequence of profile classes found on the detailed transect is generally in accordance with the 1:50 000 soil map, the map boundaries were often in error by hundreds of metres. This is not surprising considering the low relief of the landscape and the absence of native vegetation as indicators of changing soils.

The detailed transect revealed the continuity of buried palaeosols in certain sections e.g. Blenheim - light textured variant occurs on the levee backslope where an alluvial deposit overlies a buried black earth. Where Blenheim occurs on the alluvial backplains near the depression at 2 500 m, it is underlain by buried grey clays with strong lenticular structure from sites 96 to 101.

Detailed field examination of this transect has shown that the relief and soil patterns of the alluvial landscape to be more complex than was apparent from field mapping at 1:50 000. Soil complexity was further examined using selected numerical techniques. The results of these analyses are discussed in the following sections.



Plate 8.1. Lockyer soil profile class.



Plate 8.2. Blenheim soil profile class.



Plate 8.3. Lawes soil profile class.

8.3. Fuzzy classification of pH profiles

8.3.1. Method

Most numerical classification methods are inappropriate for soil mapping because they impose class boundaries on properties that in reality vary continuously. To overcome this limitation, a fuzzy classification technique was used, which has the advantage of allowing continuous membership in classes and can also cope with extragrading or 'unusual' soil individuals (McBratney and de Gruijter 1987).

pH profiles were classified using the fuzzy c means method as described by McBratney and Moore (1985) and modified to deal with outliers or extragrades (McBratney and de Gruijter 1987).

In this method, n soil individuals with p soil attributes are used to find c centroids described in terms of p attributes and each individual is described in terms of its degree of belongingness or membership m to each of the c classes. Memberships are partial and take any value between and including 0 and 1.

The pH for each of the six depths was considered as independent and pH differences considered of equal importance at all depths, hence a Euclidean norm-including metric was used. Fuzziness exponents*, m, of 1.5 and 2.0 were tried for a series of 2 to 8 groups for each.

* Fuzziness exponent (m) is a measure of the fuzziness of a classification system. When m equals 1, classification of individuals is mutually exclusive, and membership allows for only one class i.e. it is non-fuzzy. If m $>$ 1, the classification allows multiple membership of individuals to a number of classes i.e. the classification of individuals is fuzzy (after McBratney and Moore 1985).

The result for m equal to 2.0 were found to be too fuzzy for this particular data set to be useful, so discussion is restricted to the results for m equal to 1.5.

Using the approach of McBratney and Moore (1985) the number of groups (classes) for fuzzy classification was decided after plotting fuzziness performance index (FPI) and normalised partition entropy (NPE) against number of groups (Fig. 8.2). These two measures of validity estimate the degree of fuzziness and degree of disorganisation respectively. The optimum number of groups was judged on the basis of minimising these two measures.

In Fig. 8.2 NPE does not show a minimum, whereas the FPI shows a definite minimum when the number of groups (c) equals five. Thus five was chosen as the most useful number of groups.

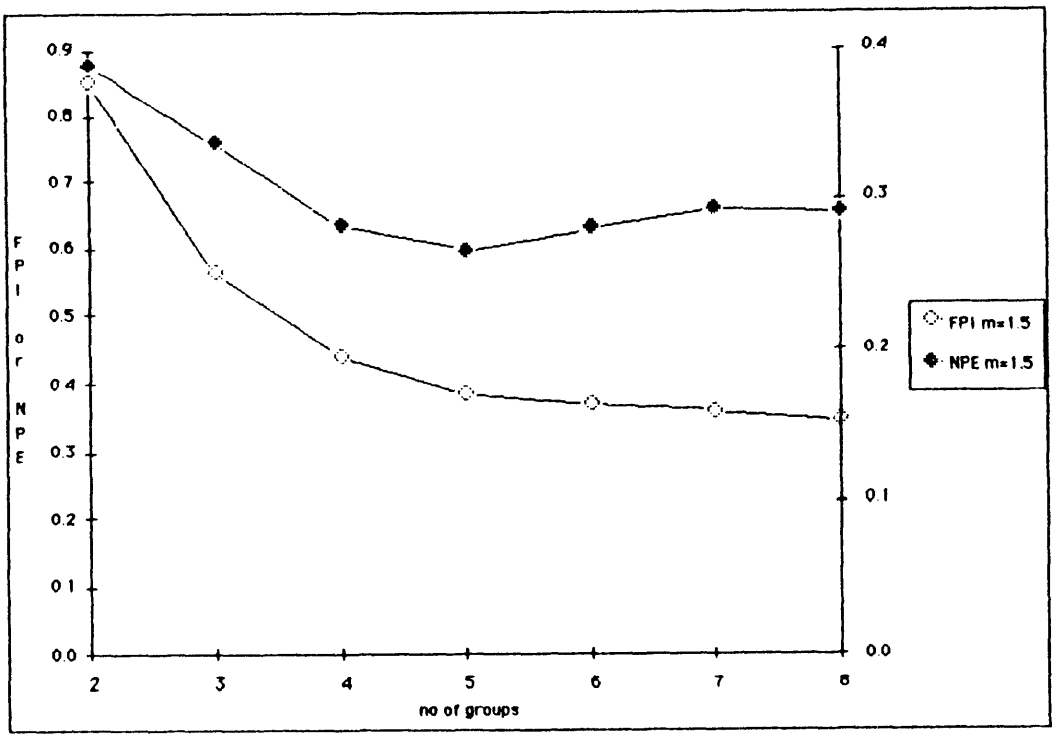


Fig. 8.2. FPI and NPE against number of groups using pH data.

Centroids for each of the five groups were calculated using the fuzzy c means method. Membership or degree of belongingness to the five fuzzy centroids was then calculated for all 133 soil pH profiles along the transect. The rate of change of membership between sites on the transect or digital gradient was also calculated to indicate the presence of soil boundaries or erratic local variation.

The digital gradient is the normalised root mean square difference in memberships of all groups for all pairs of sites one sampling interval apart. The digital gradient g on the transect between sites k and $k+1$ is thus defined as:

$$g_{k+0.5} = \left\{ \frac{\sum_{i=1}^{c} \left(u_{i,k} - u_{i,k+1} \right)^2}{2} \right\}^{0.5}$$

where $u_{i,k}$ is the membership of group i at site k (A. B. McBratney, personal communication). It is an extension of the digital gradient described by Rosenfeld and Kak (1980). Small values of the digital gradient suggest points of stasis and large values suggest sharp changes i.e. soil boundaries.

8.3.2. Results and discussion

Centroids

Centroids for all five fuzzy groups (named 5a ... to 5e) are shown as pH profiles in Fig. 8.3. Four group centroids show an alkaline soil reaction trend with groups 5a, 5b and 5e not being greatly different. Groups 5c and 5d are the extremes of the range, with 5c becoming rapidly alkaline with depth, while 5d is alkaline at the surface and slightly less alkaline with depth.

The alkaline soil reaction in the subsoils is due to the base rich nature of the alluvial parent sediment, and the accumulation of bases in the subsoil. Swelling by smectite clays in these soils retards leaching and, under the climatic conditions prevailing since deposition, bases released by weathering have been leached into the suboil, as evidenced by the common presence of subsoil carbonate.

Swelling of smectite clays may also be a factor affecting pH profiles as a result of upward movement of base rich subsoils which lead to gilgai formation (Hallsworth *et al.* 1955). Where this occurs, as in gilgai mounds, high pH's can be expected close to the surface.

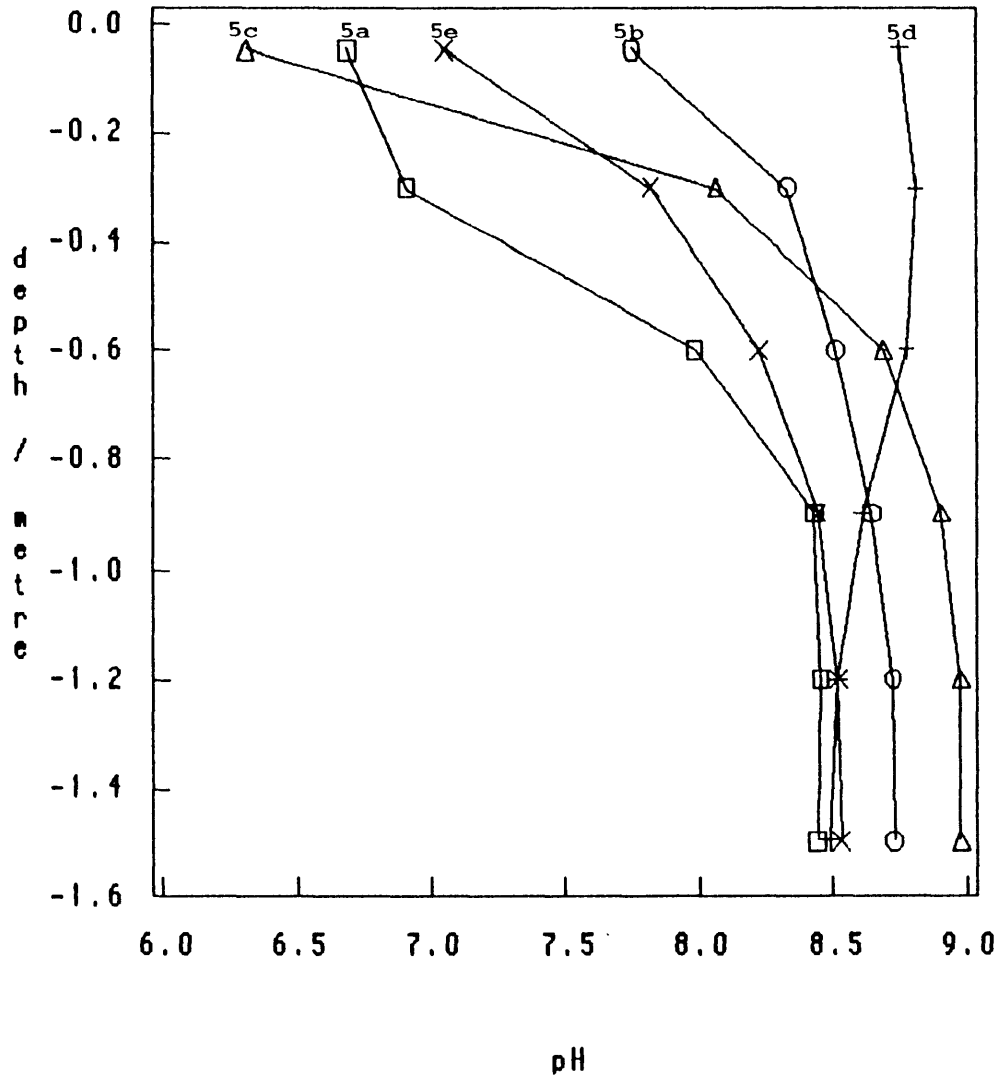


Fig. 8.3. Detailed transect pH centroids (m = 1.5).

Distribution of fuzzy groups on transect

Each profile on the transect was scored in terms of its membership to each of the five fuzzy groups plus an extragrade group. Profiles with high extragrade membership (> 0.5) were difficult to interpret in terms of centroidal groups because of their small membership. To improve interpretation, memberships of the five groups were recomputed to form a composition (sum of

unity) after excluding the extragrade membership. These memberships of the five fuzzy groups were then plotted on the transect to illustrate their distribution (Fig. 8.4). Unchanged extragrade memberships were also plotted.

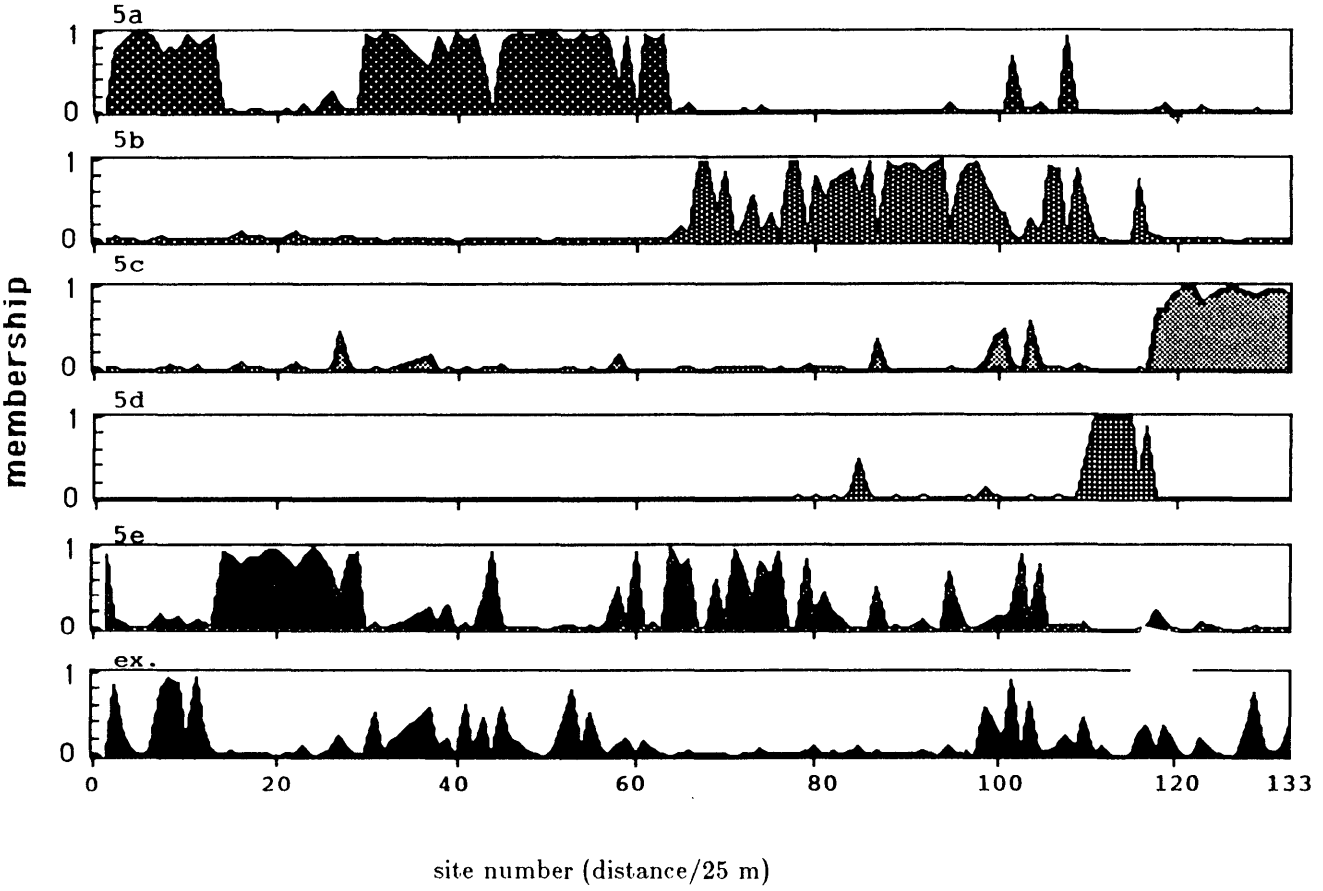


Fig. 8.4. Membership of detailed transect pH centroids (sum of unity) plus original extragrades fuzzy membership.

Fig. 8.4 shows that extragrades occur within the clusters of dominantly 5a profiles associated with present and relict levees. Extragrades are found to a lesser extent near 5c profiles around site 128. Extragrading occurs most strongly with these two groups because they form the most extreme profiles of all groups (Fig. 8.2). i.e. 5a is alkaline in the upper profile while 5c shows a rapid increase in alkalinity with depth; the other groups are in between.

Fuzzy groups were found to be associated with particular profile classes and landscape positions (Table 8.3); when referring to any fuzzy groups on the transect, it means profiles with high

membership to a particular group. Group 5a occurs in Lockyer and Lawes profiles on the elevated levees, both current and relict. Here drainage has been more effective, and bases have been leached from the upper profile, resulting in comparatively lower pH's at 0.5 m, 0.3 m and 0.6 m (Fig. 8.2). Group 5b and 5e have similar pH profile centroids, and both occur on the extensive alluvial backplains in Lawes and Blenheim profiles. Slower drainage conditions and reduced leaching have kept pH's higher in the upper profile of these groups. Distribution of group 5c is restricted to the backplain margins where Clarendon and Stockyard profile classes occur. The nature of group 5c (see Fig. 8.2) is related to the type of parent alluvium, which includes material of local sandstone origin, and the absence of irrigation water high in dissolved salts. In contrast, profiles of group 5d were found to be irrigated with bore water high in pH resulting in an alkaline pH throughout the profile (Fig. 8.2).

Table 8.3. Dominant soil profile classes and landscape position of fuzzy pH groupings on detailed transect.

Fuzzy group	Dominant soil profile class	Landscape position
5a	Lockyer Lawes	levee of Lockyer Creek relict levees of prior stream
5b	Blenheim and Lawes	extensive alluvial backplain including depression margin
5c	Clarendon, Stockyard	backplain margins
5d	Lawes-depression phase, Blenheim	margin of backplain depression
5e	Blenheim, Blenheim-light textured variant, Lawes	narrow levee backplain of Lockyer Creek; extensive alluvial backplain

To estimate boundary positions between fuzzy groups along the transect, the digital gradient (d.g.) or degree of change between adjacent profiles was plotted (Fig. 8.5). The diagram highlights high rates of change (d.g. $>$ 0.5) in black and does not take into account extragrades, which would increase the number of boundaries. High d.g. values can be explained in terms of changing soil properties or land management.

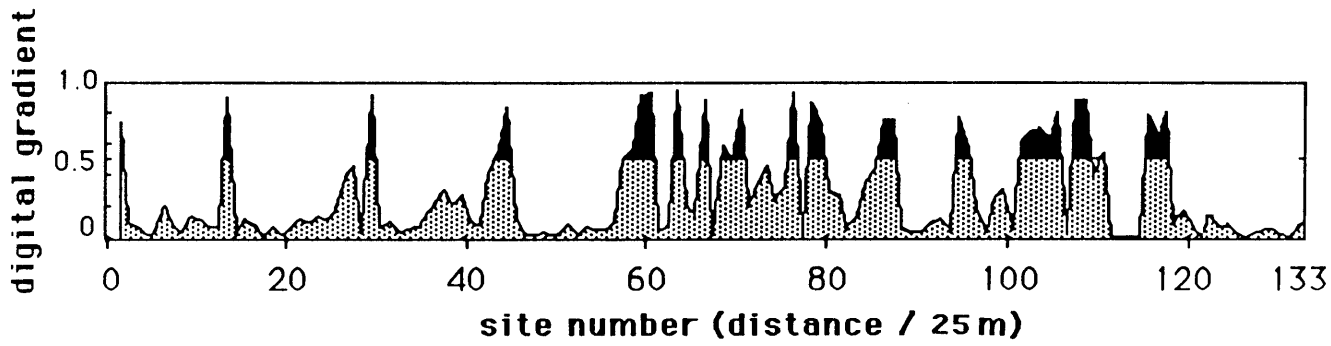


Fig. 8.5. Digital gradient of detailed transect pH profiles (excluding extragrades).

In Fig. 8.5 the rapid change at sites 1 to 3 is probably due to presence/absence of applied irrigation water. At about site 12 the transect first encounters carbonate and hence a high pH at depth and high d.g. The high d.g. at site 28 is caused by the presence of carbonate and high pH at shallow depth.

At site 43, Lawes profiles become underlain by gravel substrates instead of brown clayloams. High d.g. values are observed from site 58 to 116 where site membership alternates rapidly between 5b and 5e. This is the zone where gilgai formation has been noted. It is also the section in which a complex pattern of Lawes and Blenheim black earth profiles occur but these patterns are not associated with gilgai microrelief. At site 118 there is a change to the strongly alkaline group 5c where the transect passes through a block irrigated with water high in pH . This explains the anomalous pH values for Clarendon profile class which is characteristically acid in the surface (see Section 7.4.2).

Thus, changes in pH profiles along the transect are explained in terms of differences caused by irrigation water, internal drainage and swelling/shrinkage properties which control the position of carbonate and soluble salts in the profile.

This analysis has been useful in showing the relationship between pH profiles to landscape position; it has also demonstrated the effects of irrigation and parent material on pH profiles.

8.4. Fuzzy classification and ordination of morphological profiles

8.4.1. Method

For profile classification and ordination, attributes at fixed depths were preferred to attributes by horizon for several reasons:

(i) it avoided bias in delineation of horizon boundaries;

(ii) horizon sequences differ between profiles; and

(iii) it reduced the size of the data set, making computation more manageable.

Ten attributes from 0.05 m, 0.30 m, 0.60 m, 0.90 m, 1.20 m and 1.50 m deep were used for numerical analysis. All variables listed in Table 8.1 were used except for abundance of mottles and segregations. These were om itted because mottles affect very few profiles and segregations correlate with field pH values.

Ordination and fuzzy classification was carried out using these attributes. Fuzziness exponent (m) of 1.25 was tried for a series of 2 to 12 groups and FPI and NPE plotted against number of groups (Fig. 8.6). Fig. 8.6 shows FPI to be low for all groups from eight to 12 and NPE is lowest for group 8 and group 10. For this study, eight was chosen as the most useful number of groups as additional groups did not greatly reduce FPI and NPE.

The technique employed in the ordination of this data was multivariate planing (Friedman and Rafksy 1979). In this technique a two dimensional point plot is developed, such that a set of multivariate points which are close in multidimensional space are plotted close to the planar representation, i.e. distances between points reflect distances in multidimensional space. The axes are not made up of weighted averages of variables as in principal component analysis and are therefore more difficult to interpret. This method was used because it was suspected that variables were not simply linearly related to one another.

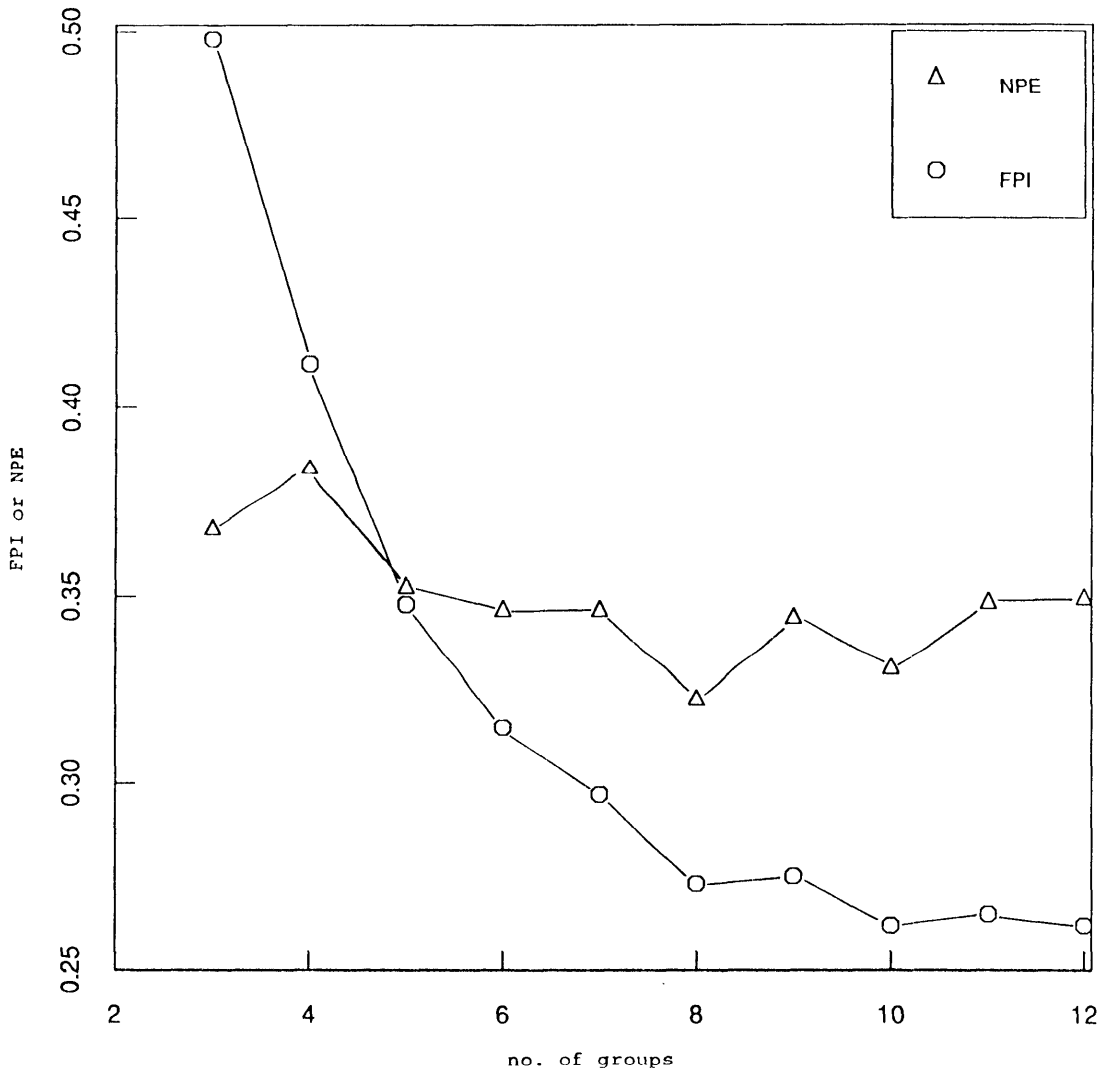


Fig. 8.6. FPI and NPE against number of groups using morphological profile data for m = 1.25.

8.4.2. Results and discussion

Fuzzy classification

The centroids of eight fuzzy groups are described in Table 8.4. Descriptions of fuzzy groups were found to agree with most field generated profile classes and are associated with landscape position and other geomorphic features (Table 8.5). Distribution of fuzzy groups is shown in Fig. 8.7. Extragrade profiles occurred as several categories:

(i) as multilayered profiles on the levee of Lockyer Creek (Lockyer profile class);

(ii) profiles which contained fine sandy loam to fine sandy clayloam textures at depth (some Lawes profiles);

(iii) Lawes profiles with either gravel in the B horizon or with shallow sola ($\leq$0.8 m);

(iv) an unnamed soil profile and a Stockyard profile derived from alluvium with a greater sandstone component compared to other soils on the transect; and

(v) Clarendon profiles with grey subsoils.

The fuzzy classification clearly separated profiles of the Lockyer Creek levee (8c and 8f) which reasonably equate to Lockyer and Blenheim-light textured variant respectively. It also highlighted the Lawes-gravelly subsoil variant (8a) and Clarendon profiles (8b). The group was probably exaggerated by the effect of irrigation water on soil pH. However such a feature has obvious land use significance and the separation is considered to be useful. 8g is a morphologically distinct category (dark Blenheim) but is not able to be mapped separately at 1:50 000 from the other Blenheim - Lawes category with brown subsoil (8e). 8h tends to occur around the open depression (Fig. 8.7) but is very similar in description and occurs in close vicinity to 8e. Field separation and mapping of groups 8e, 8g and 8h at 1: 50 000 does not appear to be feasible. Differences in subsoil colour are believed to be associated with gilgai horizon patterns as gilgai microrelief was observed close to the transect. Gilgai depression soils have dark subsoils where as mound profiles have brown subsoils close to the surface.

Group 8d is associated with relict streams and is a Lawes profile distinguished by its angular blocky primary ped structure. This group appears to be mappable at 1:50 000 scale (Fig. 8.7), but its distinguishing features were not realised during field work. This is because the secondary lenticular structure is very prominent in these profiles and land use differences were not apparent between these and other Lawes profiles. Thus fuzzy classification has usefully identified a group of soil profiles which may have pedogenetic and possibly land use differences from other similar soils.

Table 8.4. Description of centroids of eight fuzzy morphological profile groups on the detailed transect.

Fuzzy group	Depth (m)	Colour	Texture	Structure	Gravel	pH
8a	0.05	7.5YR2/2	medium clay	granular	-	6.4
	0.30	7.5YR3/2	heavy clay	angular blocky	small	6.5
	0.60	7.5YR3/2	heavy clay	angular blocky	small	8.2
	0.90	7.5YR4/3	medium clay	angular blocky	small	8.4
	1.20	7.5YR4/3	-	structureless	large	8.4
	1.50	7.5YR4/3	-	structureless	large	8.2
8b	0.05	10YR4/2	medium clay	angular blocky	-	6.4
	0.30	10YR3/1	heavy clay	angular blocky	-	8.1
	0.60	10YR3/1	heavy clay	angular blocky	-	8.6
	0.90	10YR3/2	heavy clay	angular blocky	-	8.9
	1.20	10YR3/2	heavy clay	angular blocky	-	9.0
	1.50	10YR3/2	heavy clay	lenticular	-	9.0
8c	0.05	10YR3/1	light-medium clay	angular blocky	-	7.0
	0.30	10YR3/2	medium clay	angular blocky	-	7.6
	0.60	10YR3/1	heavy clay	angular blocky	-	8.1
	0.90	10YR3/2	medium clay	angular blocky	-	8.4
	1.20	7.5YR3/3	medium clay	angular blocky	-	8.5
	1.50	7.5YR3/3	light-medium clay	prismatic	-	8.6
8d	0.05	10YR3/1	medium clay	angular blocky	-	6.7
	0.30	7.5YR3/2	heavy clay	angular blocky	-	7.3
	0.60	7.5YR3/2	heavy clay	subangular blocky	-	8.1
	0.90	7.5YR3/3	medium clay	angular blocky	-	8.4
	1.20	7.5YR4/3	silty clay	prismatic	-	8.5
	1.50	7.5YR4/3	silty clay loam	prismatic	-	8.4
8e	0.05	10YR2/2	medium clay	angular blocky	-	7.5
	0.30	10YR3/2	medium clay	angular blocky	-	8.1
	0.60	10YR3/2	heavy clay	subangular blocky	-	8.4
	0.90	10YR2/2	heavy clay	lenticular	-	8.6
	1.20	YR3/3	medium clay	angular blocky	-	8.6
	1.50	YR3/3	light-medium clay	angular blocky	-	8.6
8f	0.05	7.5YR3/1	clayloam	subangular blocky	-	6.6
	0.30	7.5YR3/2	clayloam	angular blocky	-	6.9
	0.60	7.5YR3/2	light clay	angular blocky	-	7.4
	0.90	7.5YR3/1	medium clay	angular blocky	-	8.3
	1.20	7.5YR3/2	medium clay	subangular blocky	-	8.4
	1.50	7.5YR3/2	light-medium clay	prismatic	-	8.4
8g	0.05	10YR2/2	medium clay	angular blocky	-	7.5
	0.30	10YR3/2	medium clay	angular blocky	-	8.1
	0.60	10YR3/2	medium clay	lenticular	-	8.4
	0.90	7.5YR3/2	medium clay	lenticular	-	8.6
	1.20	7.5YR3/2	medium clay	lenticular	-	8.7
	1.50	7.5YR3/2	medium clay	lenticular	-	8.7

Table 8.4 (continued). Description of centroids of eight fuzzy morphological profile groups on the detailed transect.

Fuzzy group	Depth (m)	Colour	Texture	Structure	Gravel	pH
8h	0.05	10YR3/1	heavy clay	angular blocky	-	8.0
	0.30	10YR3/1	heavy clay	lenticular	-	8.7
	0.60	10YR3/1	heavy clay	lenticular	-	8.7
	0.90	10YR3/2	heavy clay	lenticular	-	8.7
	1.20	7.5YR4/3	medium clay	subangular blocky	-	8.7
	1.50	7.5YR4/4	clayloam	prismatic	-	8.6

Note: decoding of centroid structure resulted in some depths recording subangular blocky. Howerver this is an error in the method as no such structures were recorded and the centroid value resulted from computation of the attributes of different structures.

Table 8.5. Description of eight fuzzy profile groups using soil profile classes.

Group	Soil profile class and site numbers	Comment
8a	Lawes - gravelly subsoil variant (sites 51-53)	infilled stream channel; located on relict levee of infilled prior stream
8b	Clarendon (sites 118-119, 120-124, 126-131)	poorly drained soil irrigated with water high in dissolved salts
8c	Blenheim - light textured variant (sites 13, 17-18, 22-27, 29, 72, 82, 102, 108)	Lockyer Creek levee backslopes. Some minor presence on extensive backplain
8d	Lawes with angular blocky primary subsoil structure* (sites 33, 37-39, 41-42, 44-48, 56, 58-61, 107)	On or adjacent to relict levees of the prior streams
8e	Blenheim with brown subsoil and deep Lawes with lenticular subsoil structure (sites 62, 66, 75-76, 78, 80-81, 84-85, 93-94, 106, 113-114)	sporadically distributed on extensive backplains; minor expression on Lockyer Creek levee backslopes. Possibly a gilgai mound profile.
8f	Lockyer (sites 3, 6, 8-12)	Levee deposits of Lockyer Creek overlie earlier floodplain deposits
8g	Blenheim dark throughout (sites 40, 69-71, 77, 86-89, 92, 95-97)	sporadically distributed on extensive backplains; minor expression on Lockyer Creek levee backslope. Possibly a gilgai depression profile.
8h	Deep Lawes, including Lawes wet variant (sites 67-68, 100, 104, 110-112, 115-117)	Distribution concentrated around open depression and surrounding margins.

* secondary structure was coarse lenticular (slickensides)

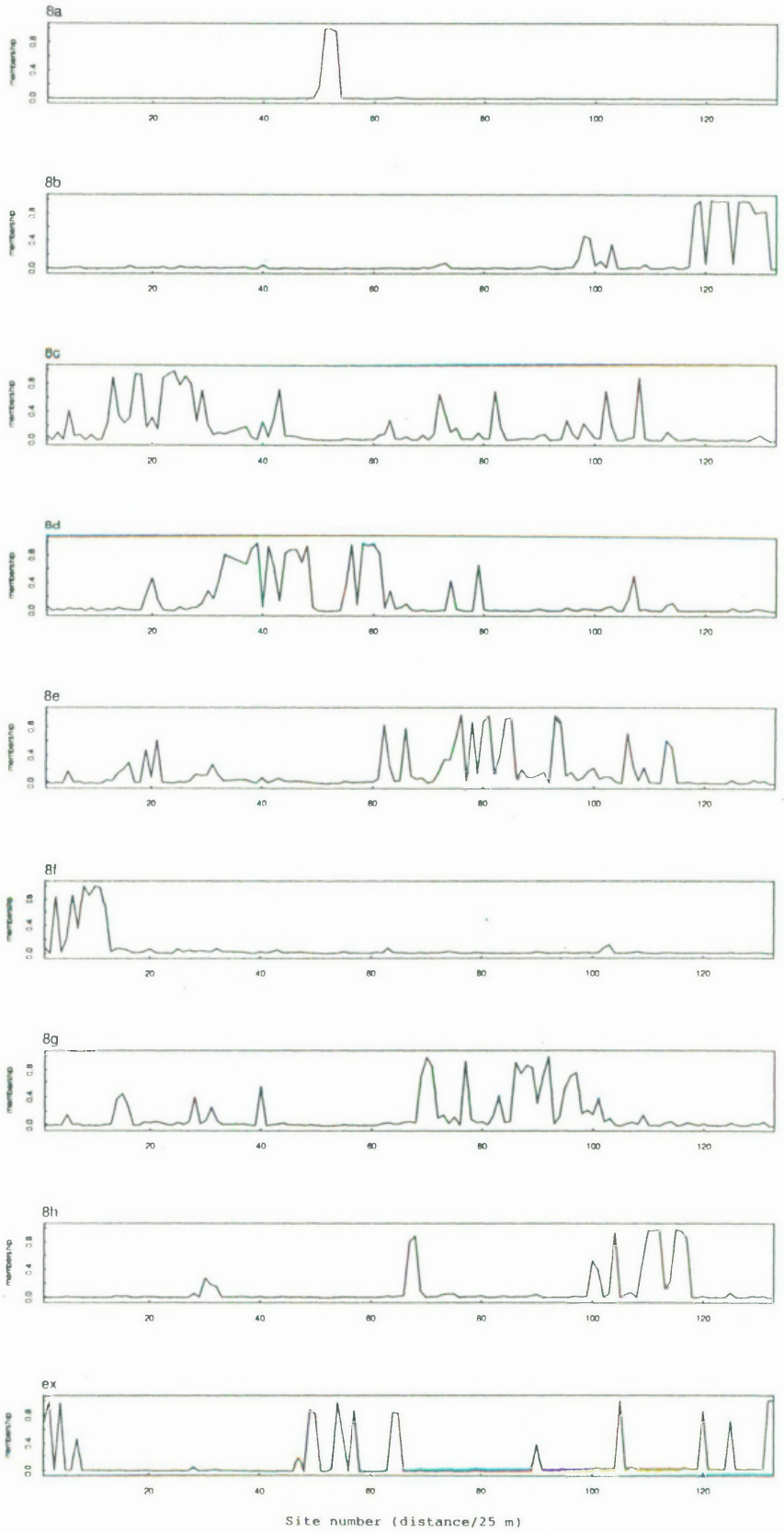


Fig. 8.7. Fuzzy membership of morphological profile centroids (including extragrades).

Ordination

Multivariate planing of morphological profiles shows a wide scatter of individuals with no apparent clusters (Fig. 8.8). When the eight fuzzy centroids are plotted on the same multivariate planing axes, a cluster and a linear relationship become apparent (Fig. 8.9).

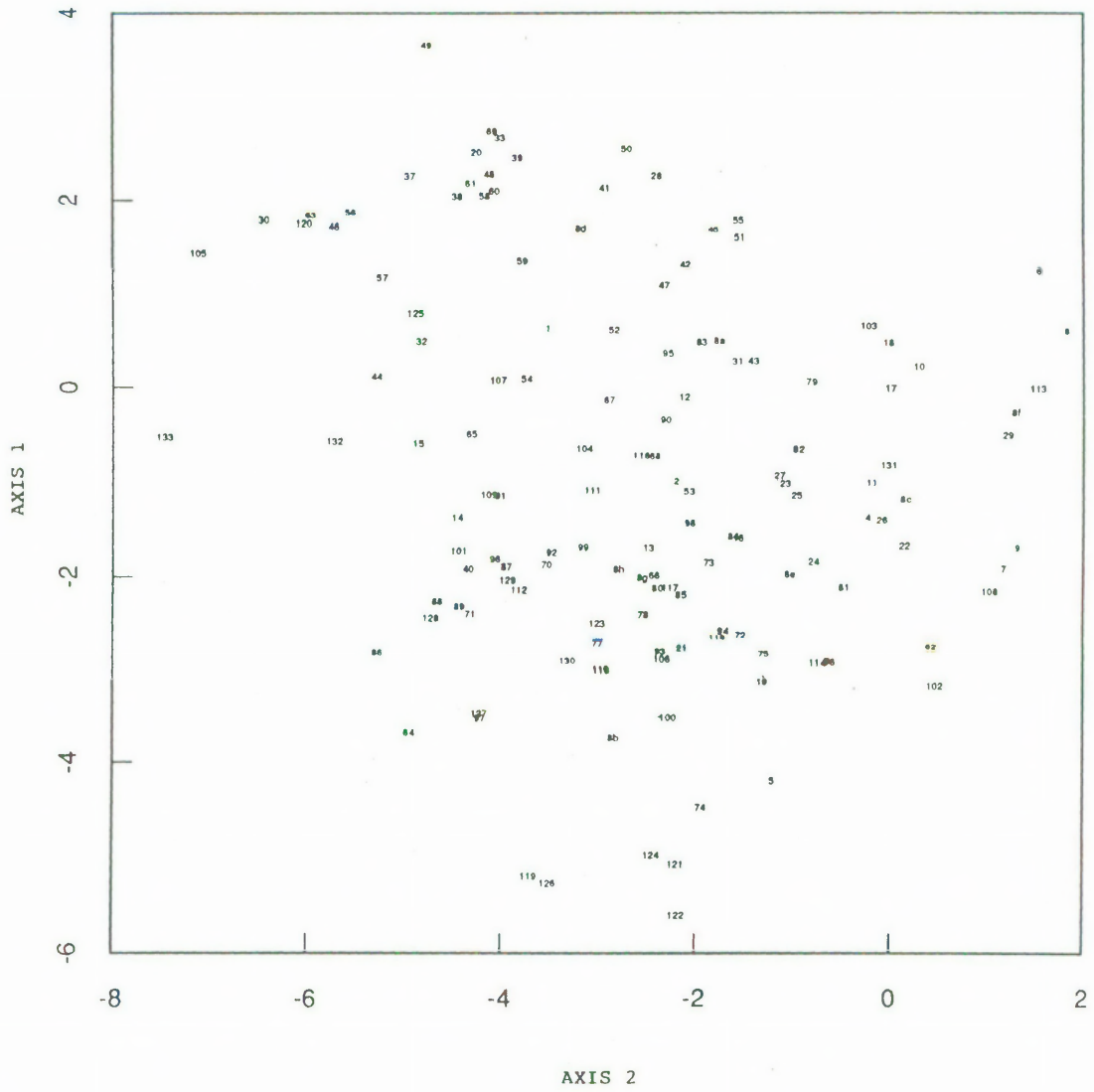


Fig. 8.8. Multivariate planing of morphological profiles on detailed transect.

In Fig. 8.9 the cluster including the centroids 8g and 8h appears to have a characteristic profile to 0.90 m. However below this depth colour and structure differs between centroids which were identified as separate profile classes (Table 8.5). It was also noted that these groups are spa-

tially separate on the transect although they both occur in close vicinity to one another (Fig. 8.7).

The apparent linear sequence of groups 8f, 8c, 8e and 8b seems to relate to distance and site number along the transect (Fig. 8.7). Morphologically, groups in this sequence become progressively more clayey in texture, more strongly alkaline and darker at depth. Such sequences are believed to relate to the particle size of alluvium deposited under flood conditions, as velocity declines away from the stream (see Section 1.4.4).

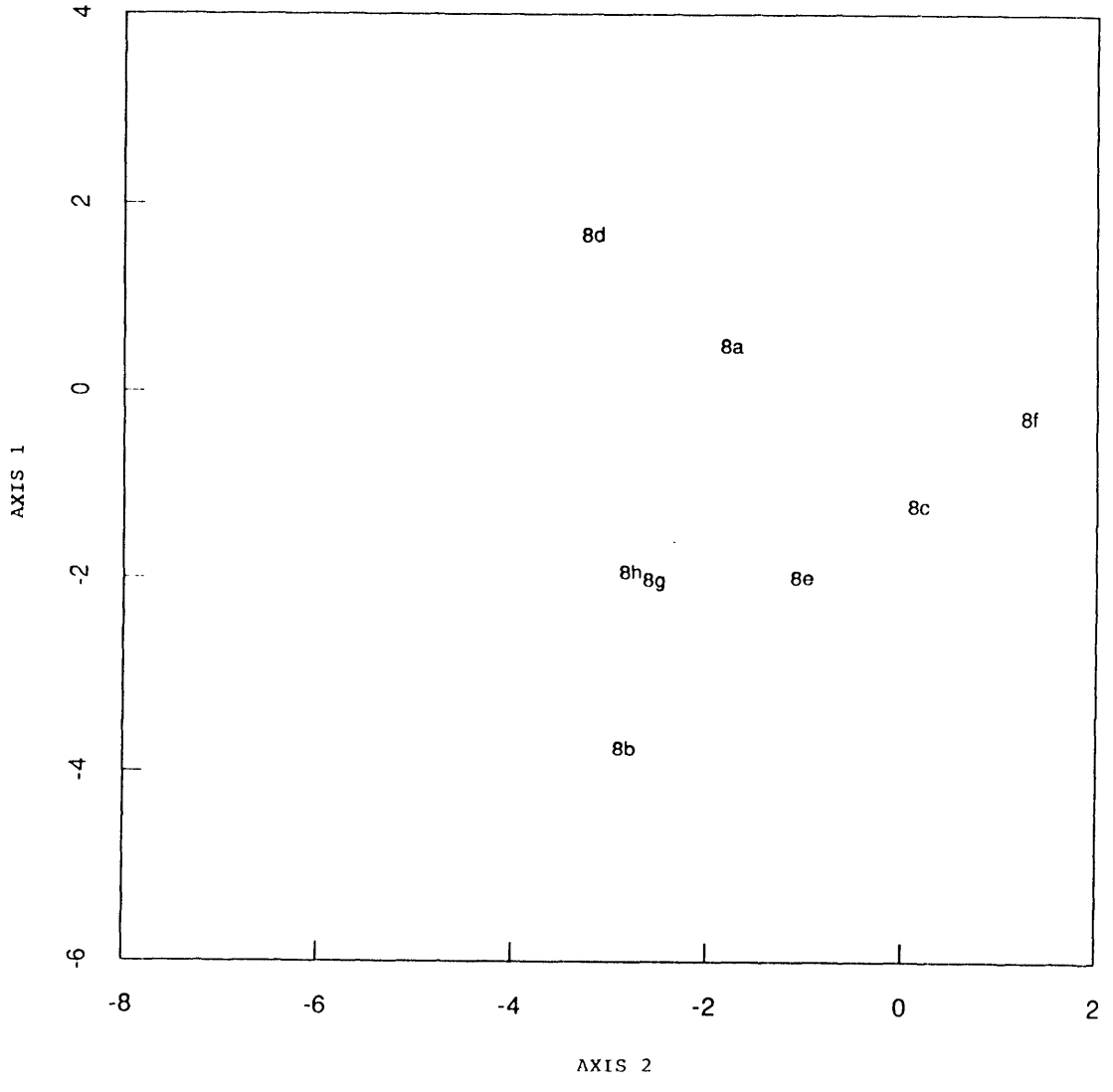


Fig. 8.9. Multivariate planing of 8 fuzzy centroid morphological profiles on detailed transect.

Outlying groups 8a and 8d are both associated with the relict levees or their margins (Fig. 8.7). Both group centroids have features of the Lawes profile class with 8a being the gravelly subsoil variant. Fig. 8.9 demonstrates the difference between Lawes profiles with 8d distinguishing features (angular blocky primary peds in the subsoil) and other Lawes profiles with lenticular primary peds in the subsoil (8a, 8e and 8h).

Numerical analysis of profiles has been useful in highlighting the relationships between profile morphology, landscape position and distance from Lockyer Creek. Such relationships reflect floodplain geomorphic processes.

Fuzzy soil profile groups were found to match most of the field generated profile classes of the alluvial plain. Fuzzy classification also showed that Lawes profile class could have been usefully split and there is a need for its relationship to Blenheim profile class to be examined more closely in the future.

8.5. Fuzzy classification and ordination of morphological horizons

8.5.1. Method

All the variables listed in Table 8.1 were used except for field pH's. Morphological horizons were classified using these variables by the fuzzy c means method described for pH profiles (Section 8.3.1). Using FPI and NPE as measures of validity, the optimum number of fuzzy groups was estimated to be 12. The centroids of the 12 groups were then computed together with the membership composition of each individual horizon in the transect.

The horizons were also subjected to ordination using principal component analysis and multivariate planing. These analyses aim to assess how similar or separate horizons are regardless of their position in the profile or along the transect.

8.5.2. Results and discussion

Fuzzy classification

The essential features of the centroids of the 12 horizon fuzzy groups are described in Table 8.6 together with the types of horizons with high group membership and their occurrence on the transect.

Distribution of horizon fuzzy groups along the transect and their position in the profile are shown in Fig. 8.10. Fig. 8.10 shows that surface horizons 12b and 12e occur throughout most of the transect, but are absent from the surface at the beginning (sites 1 to 15) and at the end (sites 127-133). These two horizons also occur at depth as buried palaeosols or as subsoils of most profile classes. These are rarely found deeper than 1 m. Horizons 12b and 12e appear to relate to the fine textured basaltic alluvium whereas it is absent where sandy parent alluvium is evident.

The presence of heavy clay horizons 12c, 12f, 12h and 12k from site 85 onwards may be the result of different conditions of alluvial deposition. Horizon 12h is considered to be equivalent to a buried grey clay palaeosol from 5 m below the Tenthill-light textured variant at site 3 on the soils map. This palaeosol was dated at 19 360 ± 280 years b.p.

Horizons 12a and 12l occur irregularly throughout the transect with 12l often overlying 12a. In the vicinity of the current levee (sites 1 to 20) and the relict levee (sites 60 to 75) the 12l horizons commonly occur twice in the same profile. Such profiles have gradual boundaries between horizons and only one or two attributes change e.g. colour might become browner but structure, texture and segregations remains the same.

Horizons 12d and 12j are the more porous brown substrate horizons found under the better drained soils of the transect. They are lighter textured than other horizons and are derived from coarser alluvium.

Horizon 12g is unusual in being associated with contrasting landform elements. It occurs in and around the elevated relict levees and also in the depression. It is similar to 12e but is slightly browner. This is to be expected in the elevated relict levee situation which promotes drainage and

an oxidising environment but not in a depression situation. The more slowly drained depression is an open one and although flooding occurs irregularly, water does not remain there permanently.

Table 8.6. Main features of horizon centroids.

Centroid	Main features
12a centroid	Horizon: B horizon mostly at 0.7-1.4 m Morphology: dark brown (7.5YR 3/3), light-medium clay, moderate angular blocky, small amount of concretionary carbonate Occurrence: occurs irregularly throughout transect but absent from sites 116-133 (2900-3325 m) where Clarendon profile class is extensive Comment: conditions of deposition and factors of horizon formation are similar throughout transect to site 116. Time is not significant factor in horizon morphology formation. Associated with soils younger than 20 000 years b.p. and also soils younger than 10 000 years b.p.
12b centroid	Horizon: A horizon, 2Ab, 2Bb Morphology: brownish black (7.5YR 3/1), medium clay, moderate angular blocky Occurrence: occurs regularly throughout transect except for sites 76-102 (1900-2550 m) and sites 124-133 (3100-3325 m). Seems to be less common in zones with evidence of former gilgai patterns. Comment: associated with upper profile of most soil profile classes.
12c centroid	Horizon: upper B horizon Morphology: brownish black (10YR 3/2), heavy clay, moderate angular blocky, occasional trace of concretionary carbonate, trace of concretionary manganese Occurrence: occurs irregularly from site 74-132 (1850-3300 m) and is associated with gilgai and heavy soil depression and adjacent back plains Comment: associated with heavy textured soils such as Blenheim, Lawes and Clarendon
12d centroid	Horizon: A, 2Ab, B21 horizons Morphology: brownish (10YR 3.5/3) light clay, strongly prismatic occasional trace of concretionary carbonate Occurrence: occurs regularly throughout transect except for 2 zones - sites 89 to 108 (2225-2700 m) and sites 118 to 133 (2950-3325 m) Comment: mostly associated with better drained zones of soils younger than 20 000 years such as Lawes and Lockyer
12e centroid	Horizon: A, 2Ab, B21 horizons Morphology: brownish black (7.5YR 2/2) medium clay, moderate angular blocky Occurrence: occur regularly through transect to site 109. Comment: horizon of slightly elevated alluvial plain surface of Lawes and Blenheim black earths and some buried palaeosols below the Lockyer prairie soil
12f centroid	Horizon: Palaeosol horizons 2Ab and 2Bb Morphology: brownish black (10YR 2/2), medium clay to heavy clay, moderate lenticular, trace of concretionary manganese Occurrence: occurs in zone from site 85-121 (2125-3025 m) which is where the back plain grades to an open depression and conditions are wetter Comment: horizon perceived as belonging to a buried grey clay palaeosol

Table 8.6. (continued). Main features of centroids.

Centroid	Main features
12g centroid	Horizon: A1, Ap, B2 Morphology: brownish black (7.5YR 3/2), medium clay, moderate angular blocky Occurrence: occurs in two situations. Firstly as an horizon of the upper profile which occurs in a zone from site 99 to 116 (2475-2900 m). This is the lowest wettest area on the transect i.e. an open depression. Secondly as an upper B horizon of the relict levees and adjacent plains. Comment: horizon occurs in Blenheim and Lawes black earths. Very similar to 12e centroid.
12h centroid	Horizon: 2Bb, 3Bb, some 2Ab Morphology: greyish brown (7.5YR 4/2), medium clay, strong lenticular, small concretionary carbonate, trace of concretionary manganese Occurrence: zone from site 87-132 (2175-3300 m) associated with back plains and depression Comment: commonly in same profile as horizon 12f and is part of buried grey clay palaeosol
12i centroid	Horizon: A, 2Ab, some 2Bb associated with levee backslope Morphology: brownish black (10YR 2/2), light medium clay, strong angular blocky Occurrence: in 2 zones from sites 3-40 (75-1000 m) and from sites 63-95 (1575-2375 m). Associated with southern levee backslopes of current and prior stream channel Comment: differences in age not a major factor in horizon formation. Associated with Lockyer prairie soil (younger than 10 000 years) and Lawes and Blenheim black earths which are 10 000 to 20 000 years old.
12j centroid	Horizon: 2B2, 2B3, D, some 3B Morphology: brown (7.5YR 4/4) silty clay loam, strong prismatic Occurrence: 2 zones from sites 2-10 (50-250 m) and 39-114 (975-2850 m). Occurs on current levee soils and extensive backplains, relict levees and depression. Not present where on levee backslope. Comment: absent where Lockyer prairie soils and Blenheim black earths overlap, horizon probably occurs below depth of sampling
12k centroid	Horizon: 2B2k, some 3B Morphology: brown (7.5YR 4/3) medium clay -, moderate angular blocky, small soft carbonate, trace concretionary manganese Occurrence: in wet depression and adjacent plain from sites 84-110 (2100-2750 m) Comment: colour is a relict feature of deposited material and poor drainage has not affected it due to impermeable horizon above. Found in Blenheim black earths and deeper Lawes black earths.
12l centroid	Horizon: 2A1b, 2B2b, some B2, 3B2b Morphology: brownish black (7.5YR 2/3), medium clay, moderate lenticular, occasional trace of concretionary carbonate Occurrence: regularly occurs in zone from sites 4 to 102 (100-2550 m) Comment: found in heavier textured soils such as Lawes, Blenheim and Clarendon. Regular occurrence could be related to gilgai patterns.
Extragrades	Horizon: D, 2B, 3B, C, last two profiles (sandstone derived) Comment: often the deepest horizons in the profile.

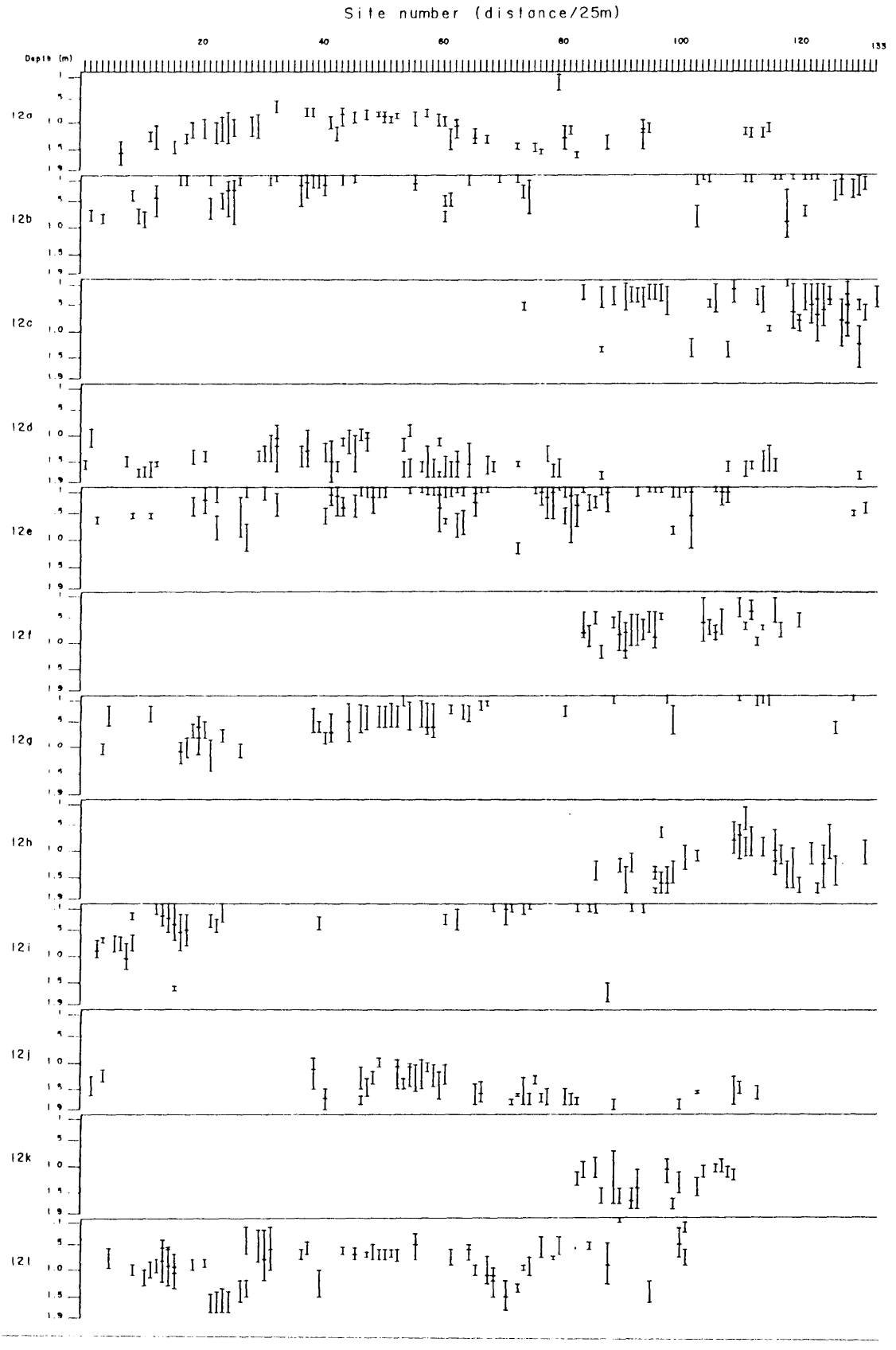


Fig. 8.10. Horizon membership (m>0.4) for 12 morphological centroids on detailed transect.

Group 12i surface occurs either as a surface horizon on the alluvial plain or as a palaeosol horizon buried by more recent levee deposits. This suggests that composition of parent alluvium for the 12i surface horizons and the 12i palaeosol horizons are similar and differences due to age are not apparent from morphology.

Fuzzy classification separated 12 horizons, several of which would not be considered different enough for field separation between profiles. However, such horizons may be obviously different within the one profile where subtle changes may be more obvious. Some horizons consistently related to landscape position (e.g. 12c, 12f, 12h, 12k), while others occur largely throughout the transect (e.g. 12b and 12e); others were characteristically deep horizons (e.g. 12d, 12j) buried palaeosols (e.g. 12h, 12i) or surface horizons (12b, 12e, 12g). Extragrades are concentrated at each end of the transect and around the gravel substrate horizon of the Lawes variant.

Ordination

Using all the variates listed in Table 8.1 except for field pH's, data from all horizons within profiles along the transect were subjected to principal component analysis. However, principle components 1 to 3 accounted for low amounts of variance:

principal component 1	14.0% of variance
principal component 2	11.7% of variance
principal component 3	8.5% of variance

This was caused by a low degree of covariance between variables. Correlation coefficients between principal component 1 and all 15 variables were all less than 0.5. Principal component 2 was positively correlated with ped verticality and flatness (r of 0.55 and 0.52 respectively). Principal component 3 was negatively correlated to abundance of soft manganese ($r = -0.54$) and positively correlated to abundance of hard manganese ($r = 0.50$).

Scores for components 1 and 2 were plotted for all horizons on the transect (Fig. 8.11) but showed no meaningful patterns.

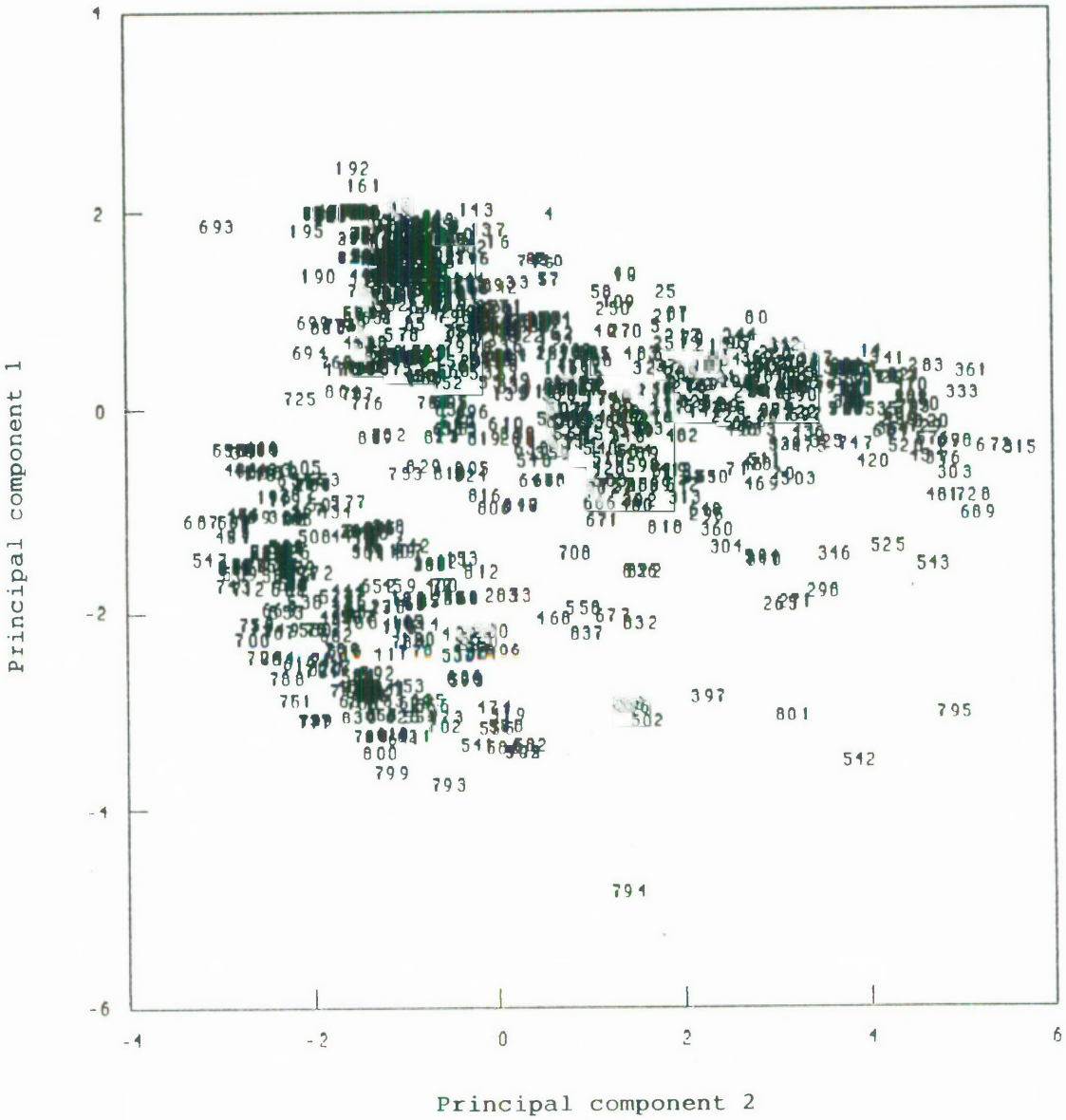


Fig. 8.11. Principal components 1 and 2 of detailed transect morphological horizons (numbered).

Multivariate planing was also carried out and this showed more useful trends but no clear clusters (Fig. 8.12).

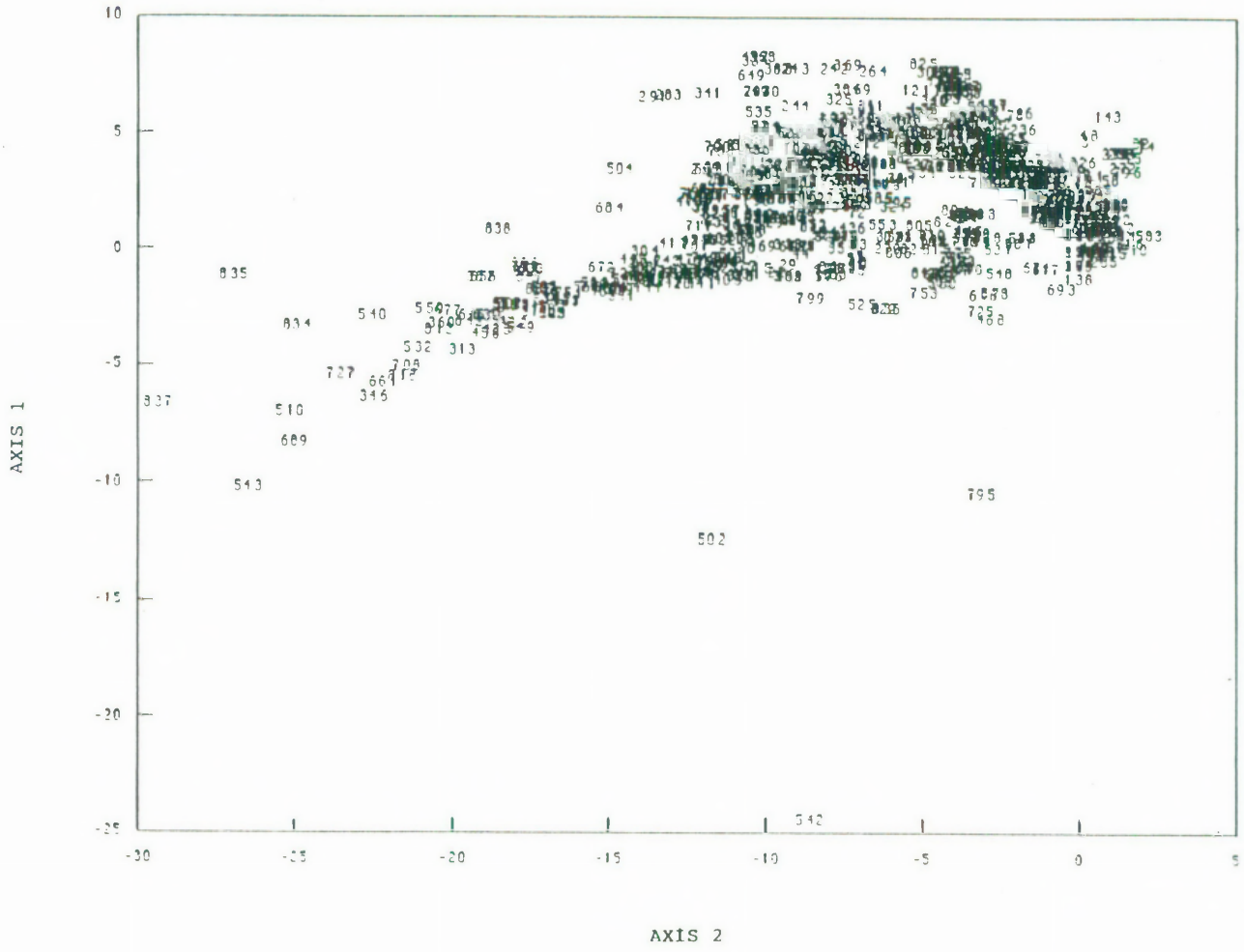


Fig. 8.12. Multivariate planing of detailed transect morphological horizons.

The main cluster of horizons located in the top right hand corner of Fig. 8.12 were mainly dark coloured A and B horizons. The 'tail' of horizons trailing off towards the left of the plot are mostly brown B horizons which occur widely throughout the transect. These are horizons not greatly affected by organic matter darkening and are well enough drained to maintain oxidised forms of iron. The outliers were either mottled or lighter textured horizons.

The presence of trends rather than clear clusters is not surprising considering that the soils are derived from similar parent sediment largely of basaltic origin. Examination of individual hor-

izons along the tail and the main cluster suggest that trends are due to differences in texture and colour. Texture is mainly controlled by particle size composition of the parent alluvium.

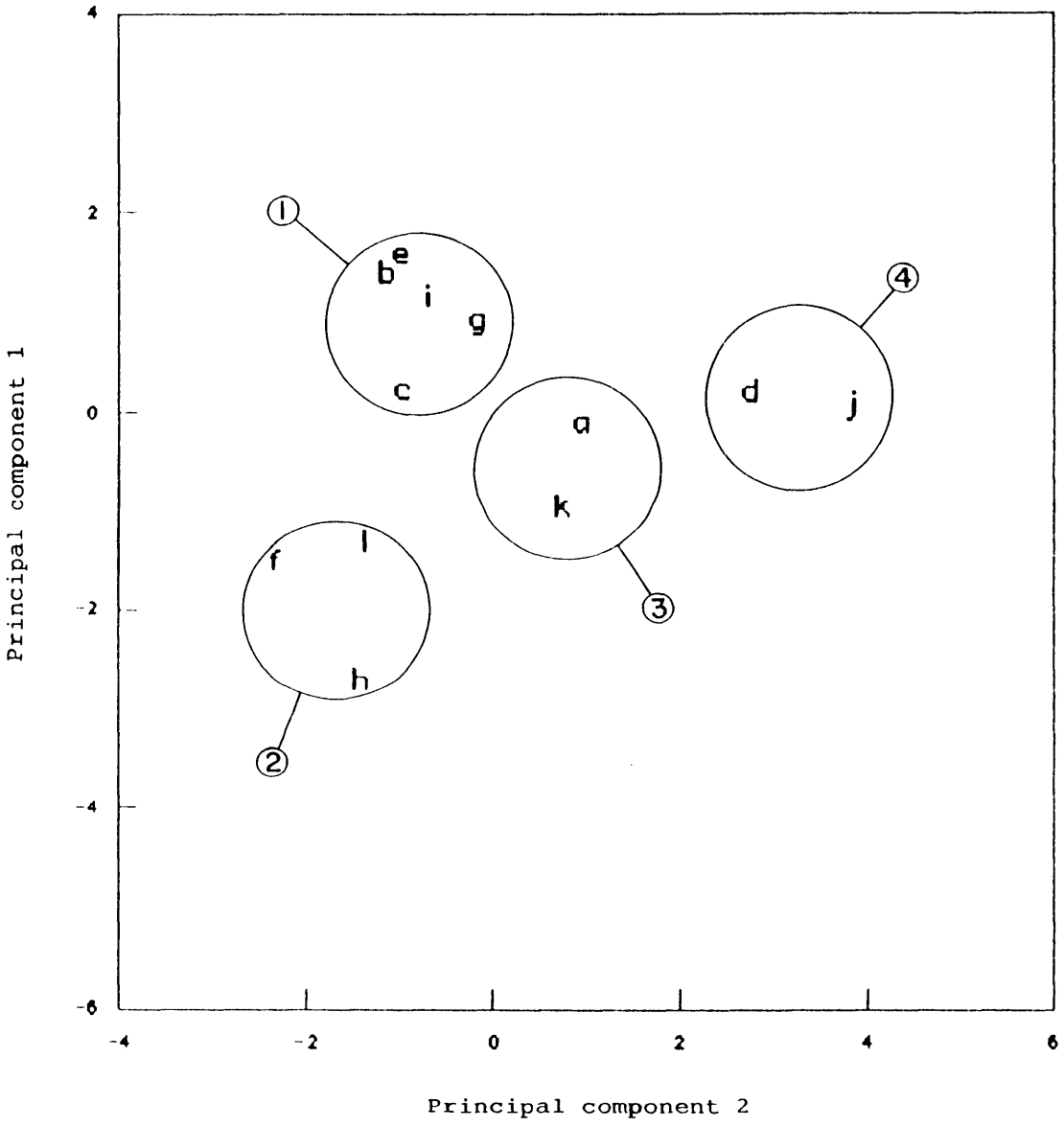


Fig. 8.13. Centroids of the 12 fuzzy horizon groups on first two principal components showing four clusters.

Numerical analyses of horizons were combined by plotting fuzzy group centroids on the first

two principal components (Fig. 8.13). Four clusters became apparent and fuzzy groups with similar morphology were found to cluster on this plot (Table 8.7).

Table 8.7. Summary of Fuzzy centroid clusters on principal components 1 and 2.

Cluster	Fuzzy groups	Properties in common
1	12b, 12c, 12e, 12g, 12i	dark, angular blocky, tend to be A and upper B horizons
2	12f, 12h, 12l	dark brown or grey brown medium clay to heavy clay, lenticular B horizons
3	12a, 12k	brown, light-medium to medium clay, angular blocky, carbonate accummulations
4	12d, 12j	brown, silty clay loam to light clay, prismatic, carbonate absent.

Cluster 1 is associated with dark upper profile horizons with angular blocky structure where as cluster 2 is a lenticular structured lower B horizon of variable colour. Clusters 3 and 4 occur progressively deeper in the profile and have progressively coarser texture. There appears to be linear trend with fuzzy groups associated with clusters 2, 3 and 4; this seems to be related to changes in depth and texture of horizons. The pedological significance of these data patterns need more investigation. Cluster 1 horizons appear to have surface related origins, while the trend of cluster 1, 2 and 3 may have a number of explanations e.g. horizon trends relate to (i) gradually changing depositional environment for parent alluvium, or (ii) supplementary pedogenisis of contrasting alluvial deposits. Detailed pedogenetic studies of individual profiles are required to further examine theories of pedogenesis.

Ordination and fuzzy classification have shown data patterns of horizons which can be related to landscape position and conditions of profile drainage. Horizon occurrence was found to also relate to buried palaeosols and gilgai incidence but not to age differences between soils younger than 20 000 years b.p.