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CSIRO Land and Water
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CONTENTS

PREFACE

The Edgeroi area, near Narrabri, is a typical part of the North-western Slopes and Plains of New South Wales, and was studied to provide detailed information on the regional soil pattern. The following information will help the reader understand the form of this report on the landscape, geology and soils.

The purpose and method of survey is outlined first, and is followed by a short description of the *geology* of the district. The *landscape* is then described.

The area resembles the Riverine Plains of southern New South Wales, and details of that area help one to understand the history of the Namoi landscape. Other data, from Victoria and elsewhere, give information on past climates and geological environments that relate to soil development.

Earlier studies of the *soils* are reviewed, and our laboratory data is summarised using *fuzzy* k-*means*. This method of analysis is not commonly used for soil information and for that reason the detailed output is presented. Each data set is discussed according to the following system:

First	the data are described (in the first Table, #.1)
Second	measures of performance for a series of fuzzy groups are given (Table #.2)
Third	the centroids of the groups that best describe the data set are set out (Table #.3)
Fourth	the relations of the centroids to field conditions, and the sites in the groups, are described (Table #.4 etc.).

The third and fourth tables for each data set will be of most use to the reader seeking information about the soils.

Soil types are defined in relation to the observed geological, geomorphic and geochemical information.

A glossary of unfamiliar terms is set out in an Appendix.

Soils and landscapes near Narrabri and Edgeroi, NSW, with data analysis using fuzzy *k*-means

W. T. Ward[1]

Summary

Narrabri lies by the Namoi River, near the Nandewar Range in north-west New South Wales, and Edgeroi rail siding, by the Newell Highway, is 24 km further north. The name Edgeroi is used also for the 1:50 000 topographic map that covers that district. The area is typical of the North-western Slopes and Plains of New South Wales and was studied to provide information on the regional soil pattern. It has a warm, dry subhumid climate with an annual rainfall near 700 mm, on the average, but with extreme variability. In this report the soils of the area are described, the soils at Edgeroi are mapped, and data are given for localities shown on the neighbouring Narrabri, Wee Waa, Bunna Bunna, and Pilliga topographic maps. Forests mostly occupy the hilly land and extend west into grassy plains, which once carried scattered wilga *(Geijera parviflora)* and myall *(Acacia pendula)*. Woodlands border the rivers, and brigalow *(Acacia harpophylla)* occurs south of the Namoi. Attention is concentrated on surface geology and on the natural landscape because the soils vary mainly according to parent sediment and landform. To emphasize features of agricultural significance, detailed laboratory data for the surface soil are summarised and included in the soil classification using a new method of data analysis, fuzzy k-means.

The basement rocks of the area include Pilliga Sandstone, Nandewar and Garrawilla basalts, and clayey sands of Purlawaugh Formation. They are overlain by the calcareous Rolling Downs Group, which is limited in its exposure, and by a soft Tertiary sandstone. Colluvium and alluvium derived from these rocks and sediments are common soil parent materials. The sandstone ridges east of the Newell Highway have gradients that decrease slowly downslope, to give concave cross-valley profiles. Unlike the steeper slopes near ridge crests, the footslopes are sites of sediment deposition or sediment transport to a stream.

In past ages, deposition of sediments has been episodic. The materials eroded from the hills were deposited first on the plains, and spread upstream from there to the lowest footslopes. The flattened surface gradients encouraged further sediment deposition. A buried soil in the colluvial mantle is formed on calcareous clays blown into the catchment but surface wash at the time of sediment deposition has obscured the aeolian origin. The same clays mantle vast areas of the plains where they form the Grey Clays and Brown Clay soils. Windblown dust is thus the parent sediment for the main soils used to grow cotton.

The landscape of the North-western Plains is composed of five terraced alluvial-fan units above the modern flood plain. The oldest are mantled with windblown dust but this is not found on the flood plain and the two youngest terraced fans. Where there is enough slope on the oldest parts of the plains, and on hillslopes, aeolian sediments are not usually found, having mostly been stripped away by rain wash during and after deposition.

The plains resemble the Riverine Plains of southern New South Wales, and a comparison gives an understanding of the history of the Namoi landscape. Data from other Australian states and elsewhere help to define past climatic conditions and the geological and soil environments. The landscape was formed episodically, probably during glacial ages when the forest cover was severely reduced, allowing the hillside catchments to be shaped by surface wash. The windblown dusts mark exceptionally dry periods coinciding with the peak glacial

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ages. Nevertheless, the dust storms of the 1920s and 1930s are a reminder that glacial ages (in this case perhaps a 'little glacial age') are, at least in these latitudes, merely the result of variations in common weather patterns. Droughts and dust storms continue as a threat to agriculture. The soil variation seen today is explained by the changes induced in the landscape in response to the climatic changes of the past half-million years, and by the transport of nutrient elements in the soil (by rainfall, surface wash and subsurface interflow) from high points and upland slopes to stream drainage lines and ultimately to floodwater soaks on the plains. The clay soils, for instance, are in this way related to dust storms of past ages, to the accession of cyclic salts, and to the pattern of rain water dispersal. Water-shedding sites are leached of the more soluble elements that arrived with the dust or were released subsequently by weathering, and those elements were transferred to areas of run-on on the plains where, in places, the resulting changes in exchangeable sodium percent have resulted in textural differentiation and collapse of topsoil structure.

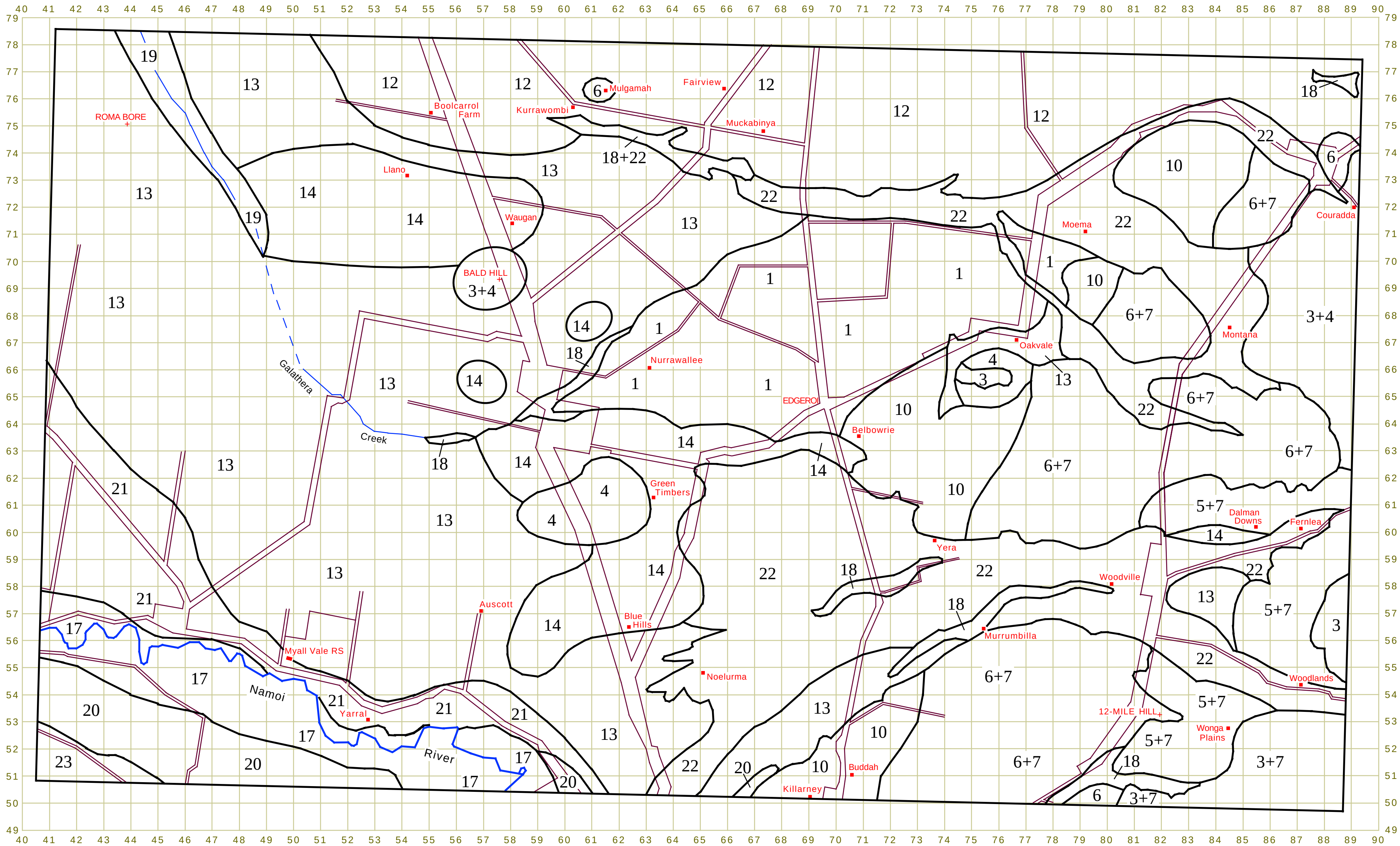
Aeolian sediments lying on the high plains at Bohena, south of Narrabri, still retain a vast quantity of salt which is leaking slowly through the neighbouring soil to intermittent drainages. Land use on these soils is restricted by surface microrelief and salt content, and on the adjoining texturally differentiated soils, by toxic levels of exchangeable aluminium. Surface water management is essential here for successful agriculture.

Data acquired by grid survey and laboratory analysis of soil samples were used to test new computer-based methods of soil classification using fuzzy *k*-means. Soil samples were taken mostly at six standard depths to 2.6 m. They were described by standard methods and analysed for fourteen attributes. Samples from 374 profiles were examined. In this report fuzzy analyses of the clay content and cation chemistry of the surface 0.2 m are given in detail. Numerical studies of the analyses agree with field perceptions of soil relationships. They identify significant attributes in profiles of deep clayey soils that show little morphological variation, and permit substantial improvements to field classification. A simple soil-landscape approach is combined with fuzzy analysis in order to balance the numerical analyses with conventional non-numeric earth-science data.

Forty soils are grouped in 22 soil series, and one soil association is recognized. Some important differences among the soils are related to soil drainage, and others to age of the alluvial ground surface; in the latter set the older soils usually have a differentiated texture-contrast profile. Texturally differentiated profiles are also found on landscapes formed by natural erosion. Most of the differences shown by the soils are due to differences in parent rock, however.

The contribution of the inorganic cycle to soil formation is well marked, for several soils are formed entirely on aeolian dusts or on water-sorted aeolian dusts, while many others have benefited from the addition of aeolian material.

The soils are described in relation to three landscape units: the eroded landscape; dust-mantled plains and lunettes; and alluvial plains. Gilgai with brigalow characterise the *in situ* dusts, while linear gilgai mark most areas of soil on weathered Garrawilla basalts.



MAP: Soils of the Edgeroi district, New South Wales, drawn on the Edgeroi map sheet (oblique rectangle). Grid is 1 km. Legend appears in Table 13.

Introduction

The cracking clay soils of northern New South Wales and southern Queensland have developed a high significance in the last thirty years as a consequence of the successful establishment of irrigated agriculture, especially cotton. Oilseeds, too, have become increasingly important. The rapid development of these enterprises alongside the wheat lands of the lower Namoi, Gwydir and Macintyre valleys has generated a desire for more soil information. Immediate concerns about sheet erosion and soil compaction are being met by appropriate conservation measures and by specific research. The desire for soil knowledge is not focused on particular needs but farm managers anticipate that future problems will need better background information than is presently available.

The rapid agricultural development has highlighted the general deficiencies of our present understanding of soil characters and the constraints on soil distribution in this region. The present study attempts to remedy these deficiencies.

As the lower Namoi Valley is too large for detailed study, the Edgeroi 1 : 50 000 map sheet was arbitrarily chosen from among similar areas with equal claims for systematic examination, with supplementary reconnaissance on neighbouring sheets (Figs. 1-2). The size of the area and its varied landscape allow different field situations to be examined, and the scale of mapping prevents overburdening with detail.

The investigation was not simply a soil survey. It tests current Australian field survey methods, joined with new skills inspired in recent years by the Rothamsted pedology laboratories in England, and tries new techniques recom-ended for soil survey by Butler (1980). His proposals to rectify defects in customary soil classifications depend on the use of unbiased soil samples and require the measurement both of useful and descriptive soil properties. It is not possible to eliminate bias entirely. The intent in this study is to limit it or else make it explicit.

The usual approach to soil survey involves field inspection of soil exposures and pits, with inference and generalization of the observed data by a soil scientist. The scientist becomes more expert as this work progresses and becomes, through this experience, the prime source of information. No individual today can acquire the wide experience of soils that is sought by today's farmer, however, and many scientists now favour the idea that soil knowledge should not be summarised categorically in the field but should be recorded instead in an electronic database where it can be accessed in its original form. Moreover, data interpretations do not have to be only those made by the field personnel. Users with other expertise and other points of view can make helpful insights.

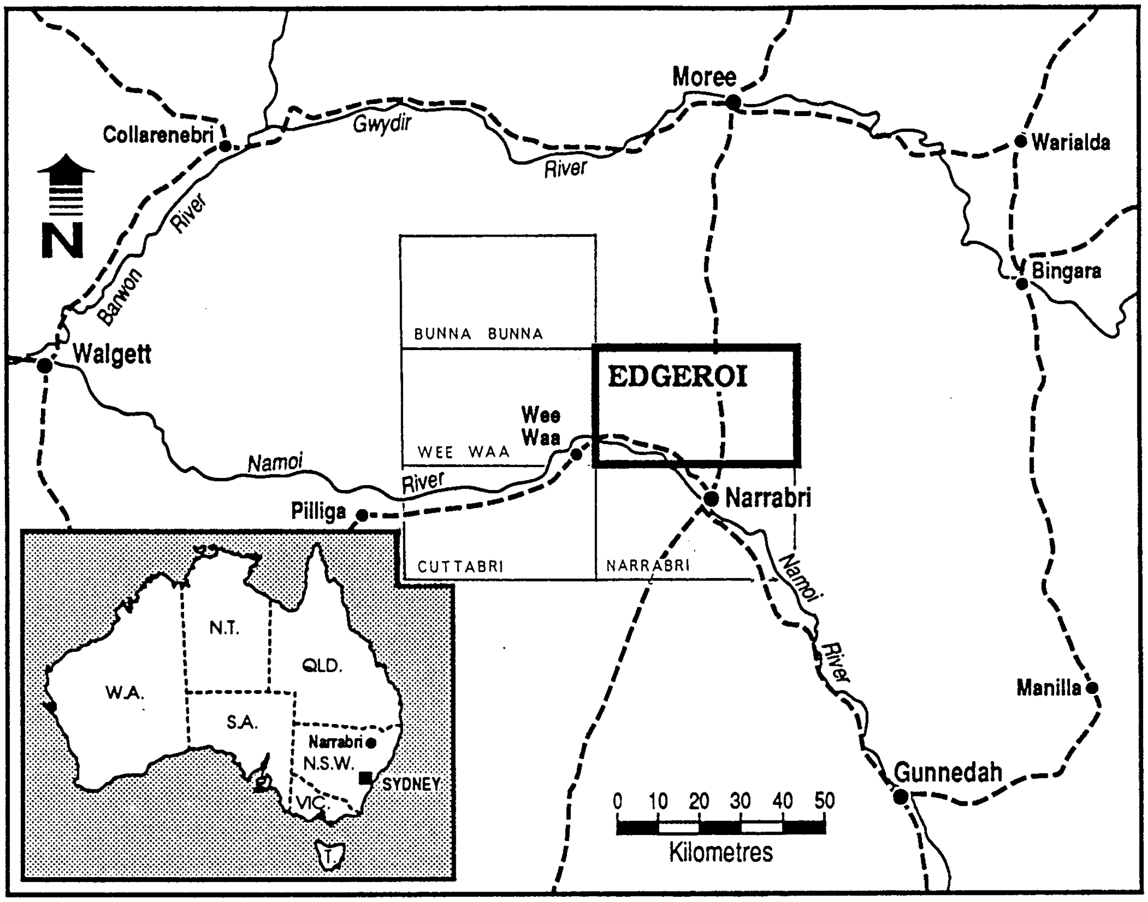


Figure 1. The study area in which the sites were located.

Purpose of study

The immediate objectives of the Edgeroi project are: (1) to relate the cracking clay soils to the landscape generally; (2) to test new concepts of soil classification for pedology and agriculture by using mathematical techniques to specify soil classes; (3) to relate the soils of the local research stations to the soils of the district.

The parent sediments, history of the landscape, geological controls of soil distribution, and a mathematical examination of the soil data are discussed in this report. The Myall Vale research station is described separately (Ward et al. 1999).

Method of study

Geological and geomorphic studies of the district were made using field methods and models detailed by Lahee (1961) and Cotton (1948). A database of morphological, chemical and physical information (McGarry et al. 1989) was also compiled, mostly using the conventions of McDonald et al. (1984). The primary observations in this database relate to 318 sampling sites on the Edgeroi sheet, with another 56 sites on adjoining sheets (Fig. 2). Site locations are given in Appendix 1. Of the Edgeroi sites, 210 form a systematic, equilateral grid, with approximately 2.8 km between sites (Fig. 3). This ensured that site placement on the sheet was random in regard to landscape and soil patterns; the procedure eliminates bias in site selection and simplifies interpolation of numerical results. The other sites relate to areas of landscape change missed by the grid and to landscape transects and areas of interest where additional detail was sought. Descriptive attributes included soil colour, texture, structure, consistence, salinity, pH, exchangeable bases, organic carbon (for methods see McGarry et al. 1989), and physical and biological attributes of the sites. These were recorded at several fixed depths and identified with horizon type.

In collecting these data, Butler's (1980) recommendations were not followed exactly. He suggested that a provisional soil classification should be developed first by free survey, which would involve interpretation of soil-landscape relations in the usual way, and then be tested by rigorous grid sampling. As this requires duplication of effort, it was decided to use the inspections made during soil sampling as the basis for provisional soil classification, and the data obtained later by detailed soil description and chemical analysis to test the classification. This variation can be accepted because field classification is usually based on perceived landscape structure as well as soil inspection; it uses only the gross morphology of the soil, and proceeds rapidly by induction. In making these observations a grid is unnecessary. The proposed tests require that a grid should be used, however. Testing must wait upon detailed soil description and laboratory analysis, and was done by pattern analysis. In adopting this different course it is necessary only to guard against the risk that the regular, mechanical grid sampling and detailed soil description might replace the soil scientist's primary function, to investigate observed changes in the soil landscape.

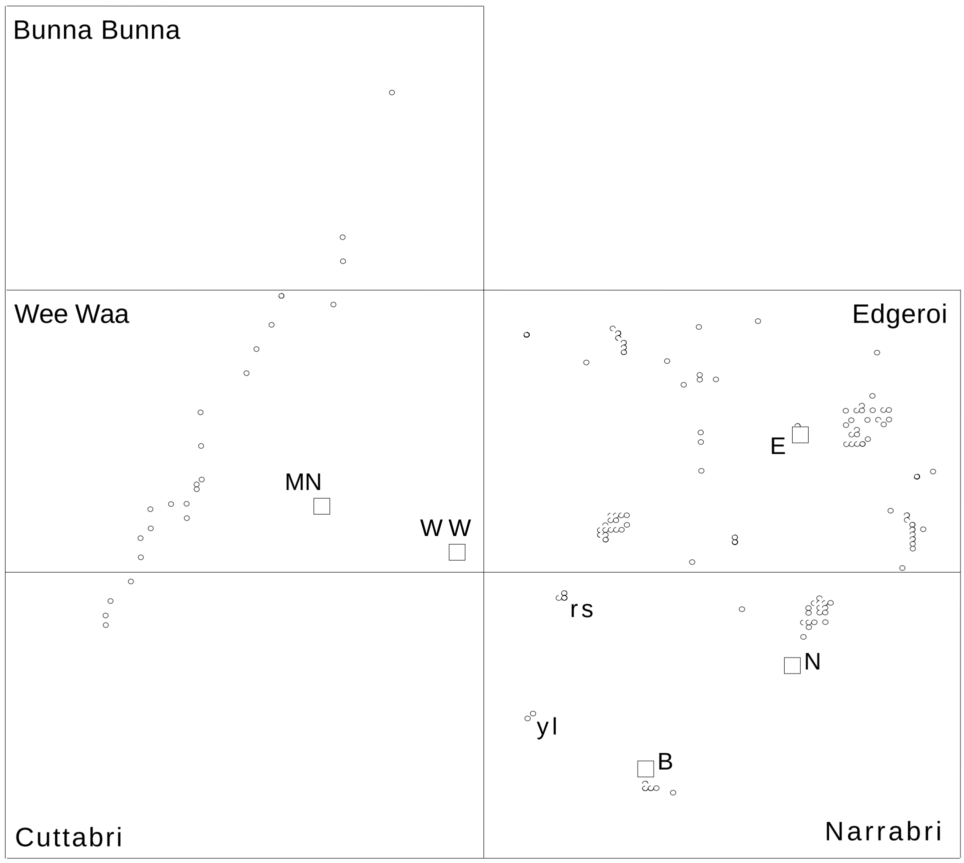


Figure 2. The Edgeroi data set, lower Namoi Valley: site locations on the Bunna Bunna, Wee Waa, Edgeroi, Cuttabri and Narrabri map sheets, excluding those on the regular Edgeroi grid. B, Bohena; E, Edgeroi; MN, Merah North; N, Narrabri; WW, Wee Waa; rs, Round Swamp; yl, Yarrie Lake.

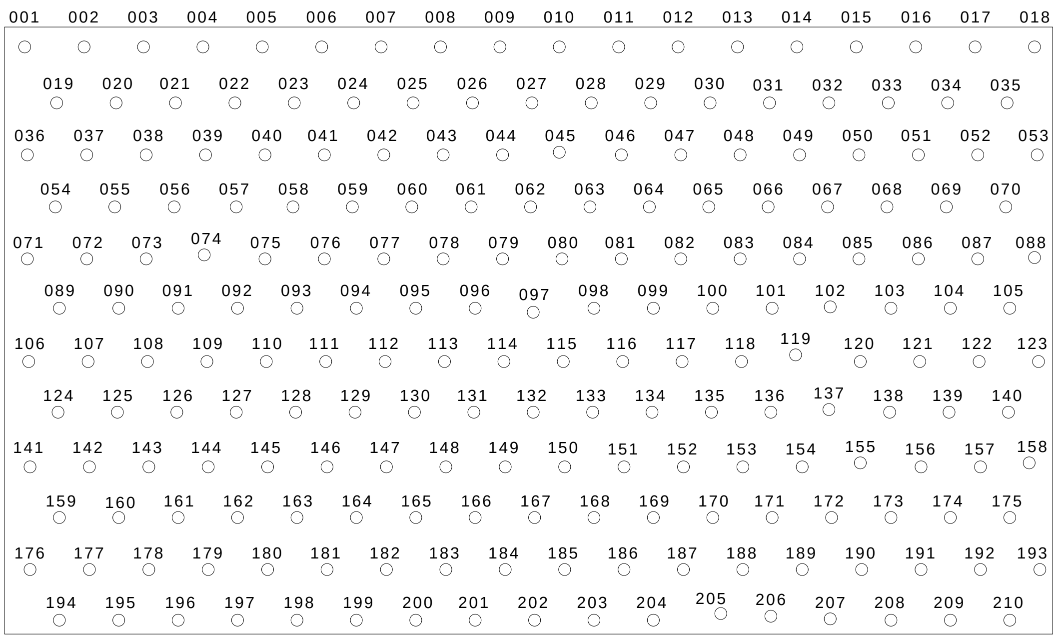


Figure 3. Locations of sampled sites. The rectangle marks the boundary of the Edgeroi map sheet.

Butler's proposals have a clear value but they are limited by local practices, whilst the numerical tests make no use of field skills. There is much that is arguable, and developments will not follow this particular direction. What is needed to test basic ideas and procedures is a body of data that matches Butler's requirements. Theoretical arguments are, after all, less important than observed facts.

Topography

The contours at 20 m intervals and spot heights on the Edgeroi map sheet are too widely spaced to show the landform shape well, especially on the plains.

Four 1 : 31680 maps (Waugan, Edgeroi, Galathera and Bobbiwaa, dated 1969), have contours at intervals of 25 ft (7.6 m), and spot heights that give more detail. These maps provided the elevations of the soil sampling sites and are also the basis for the topographic map (Fig. 4) that was compiled to aid geomorphic interpretation. The map was prepared by estimating elevations at the 1000 m metric grid intersections, using all map data. Heights were also estimated for summits on ridges. The contouring program (Anon, n.d.) showed irregularities in some places where smooth slopes were known. Inaccurate height estimates were highlighted, and some hill margins were poorly defined. These faults occurred mostly at Bald Hill and 'Green Timbers'. New contours were interpolated after re-examining the height data and adding estimated elevations at 500 m centres.

Climate

Temperatures in summer are very warm, the mean maximum reaching 30°C in November and then surpassing that value in each of the following four months (Table 1). Mean monthly minimum temperatures (19°C in January and February) decline to 3° in July.

Details of monthly precipitation for Narrabri West and Moree, the weather stations nearest the area examined, are shown in Table 1. The area is dry, the average rainfall at Narrabri West being 712 mm p.a., with a slight maximum in summer. Rainfalls from month to month are extremely variable, and it is not uncommon for there to be no rain at all. The rainfall also varies greatly from year to year. This is to be attributed partly to the inland location, midway between the distant tropical and temperate air masses: only the most vigorous fronts and tropical outbreaks reach this far. The rainfalls are mainly light, and ineffective owing to evaporation. Water that enters the soil is soon used up by plant growth with the result that there is little drainage except as surface runoff attending the infrequent heavy downpours.

The erratic rainfall limits the value of statistical averages taken over a lengthy period but a moisture balance calculated according to Thornthwaite's (1948) method (Fig. 5) permits a general comparison with other regions. The climate at

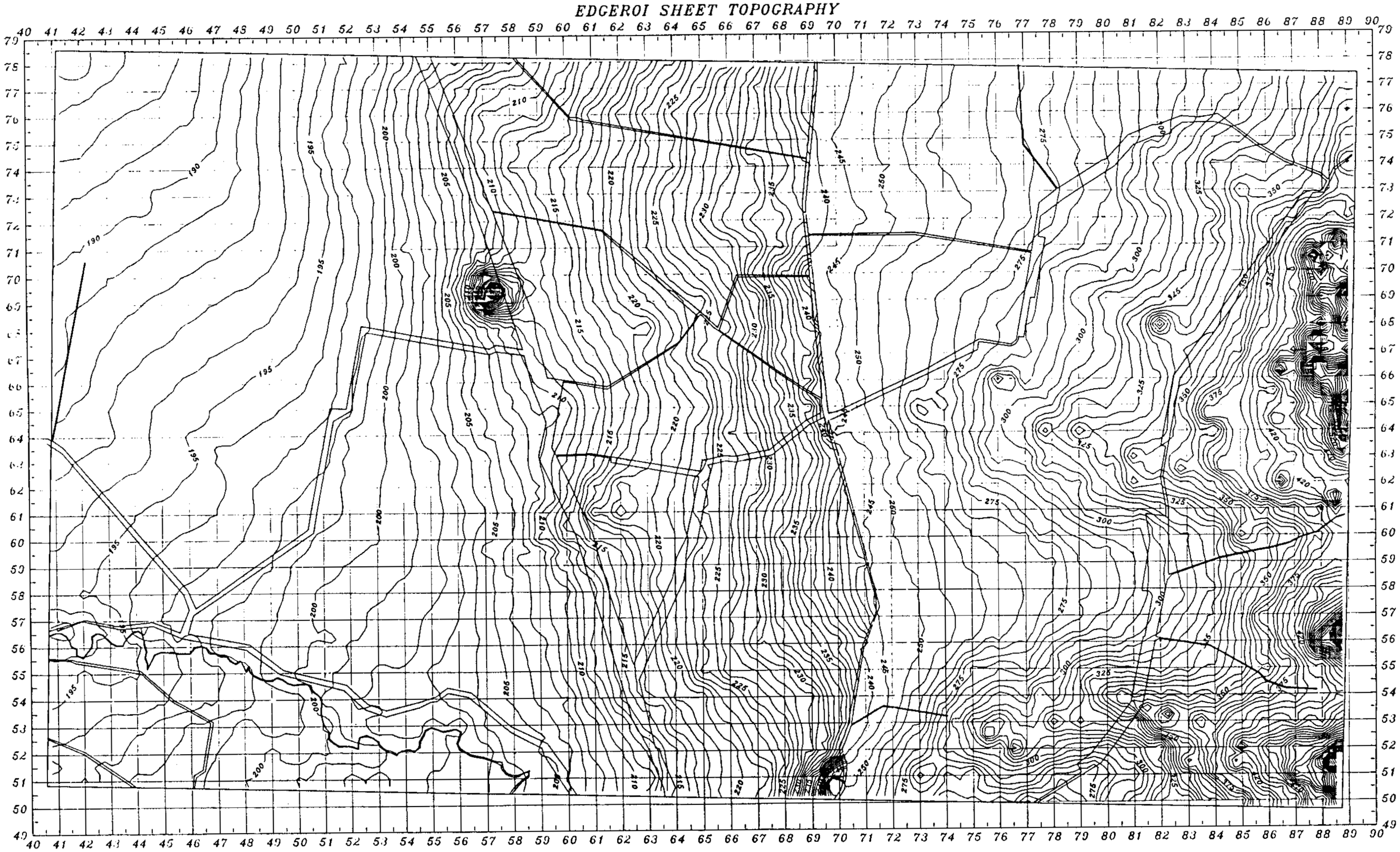


Figure 4. Topographic contours, Edgeroi map sheet, shown at 5 m intervals E of the Newell Highway and at 1 m intervals further W. The peak on the plains is Bald Hill, the irregularities 9 km SSE show the volcanic outlier at "Green Timbers". The contours reveal the low gradients of the Namoi alluvial plains and change direction at Galathera Creek, which gathers most of the drainage from the E, and is guided NW by the change of slope. Spring and Bobbiwaa creeks ccupy the deep, broad valley in the SE. Their combined alluvial fan is outined by the contours west of Newell Highway. The grid squares mark 1 km on a side.

Narrabri is identified by this method as dry subhumid with, on the average, no water surplus available for runoff.[2]

The reported rainfall and temperature data are for the years 1962 to 1986, for Narrabri West, and approximately the same period is recorded for Moree. A long rainfall record (from 1888) is available for 'Pendennis', 50 km WNW of Narrabri, near Merah North. This record is summarised in Table 1.

The irregular variations in the rainfall of the lower Namoi Valley are not random but, like those at Bourke (Nicholls, 1990), are to be attributed mostly to the effect of the Southern Oscillation, a meteorological phenomenon associated with the anticyclones that pass across Australia to the southern Pacific Ocean (Allan, 1988; Nicholls, 1990). The southeasterly trade winds produced by the anticyclones drive warm ocean water towards northern Australia where moisture given by evaporation is fed to the tropical atmosphere. The ocean water is mounded up in the Coral and Timor seas owing to the wind drag, and when the winds decrease the piled up warm water returns to the southeastern Pacific, with the result that less moisture is then transferred to the Australian tropical atmosphere. The strength of this basic action of the Southern Oscillation is indicated by the difference in atmospheric pressures measured at Tahiti, in the eastern Pacific, and at Darwin, in northern Australia. Widespread droughts occur when the Southern Oscillation index gives large negative values ('El Niño' years). High annual rainfalls and widespread flooding are associated with positive values of the index (La Niña, anti El Niño or anti-ENSO years). The relation of the Southern Oscillation index values to 'Pendennis' rainfall is shown in Fig. 6.

Nicholls (1990) compared rainfall data for two sets of years centred on El Niño and anti-ENSO events. He found that the high rainfalls which are associated with large positive values of the Southern Oscillation index begin around March or April and continue through the year to reach a high peak in summer. Ordinary values reappear about April of the following year. Thus a year, in climatic terms, can be defined as the twelve months extending from April to the following March. Study of the 'Pendennis' record from this standpoint[3] allows the recognition of three different April to March rainfall histories, which are exemplified by 1982/3, 1979/80, 1932/3, and 1928/9 - years which are dry throughout (group 3a); 1981/2, 1975/6, 1973/4, and 1963/4 - years that are dry in autumn and winter but have wet summers (group 3b); and 1985/6, 1962/3, 1947/8, and 1918/9 - years which have fair to good rainfalls except in autumn (group 3c). The averages for these sets of reference years are illustrated in Fig. 7. The rainfall history of the area is summarised in Fig. 8, where each year of the 'Pendennis' record is scored according to how well it relates to the reference group exemplars. The 'dust-bowl' years of the 1920s and '30s, and the droughts of the mid-1940s are well evidenced.

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[2] Fourth mesothermal, with a temperature-efficiency regime normal to megathermal. The climatic type is $C_1B'_4da'$. Similar calculations for Moree show its climate to be DB'_3da', that is, semiarid, with no water surplus, third mesothermal, and a temperature-efficiency regime normal to megathermal.

[3] Using the method of fuzzy *k*-means (see subsequent pages).

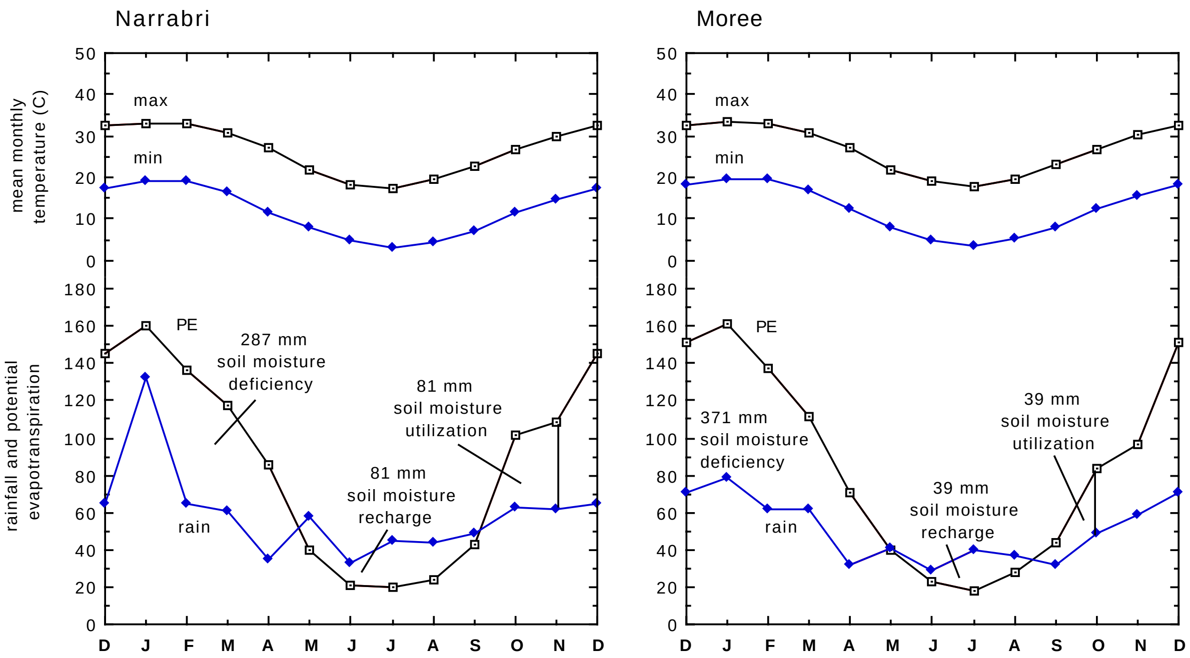

Figure 5. Mean monthly temperatures and relation through the year of average monthly rainfall and potential evapotranspiration calculated according to Thornthwaite's (1948) method for Narrabri West and Moree (composite data, post office and meteorological station). Extreme temperatures: maximum 43.4°C (Narrabri), 44.4°C (Moree); minimum -5.5°C (Narrabri), -5.3°C (Moree). Mean annual temperature: 18.7°C (Narrabri), 19.1°C (Moree). Total rainfall 712 mm (Narrabri), 590 mm (Moree). Total potential evapotranspiration: 1001 mm (Narrabri), 965 mm (Moree). Moisture index -17.2 (Narrabri), -23.1 (Moree); humidity index 0 (Narrabri), 0 (Moree); aridity index 28.7% (Narrabri), 38.5% (Moree).

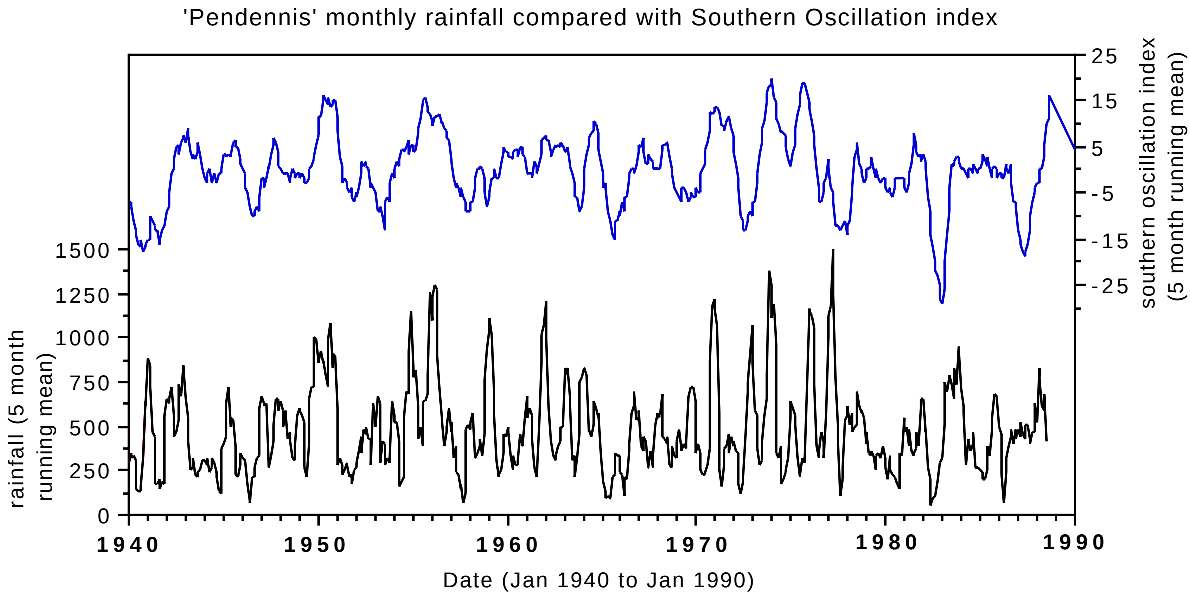

Figure 6. "Pendennis" monthly rainfall compared with Southern Oscillation index. Five-month running means since January, 1940. High positive values of the index tend to be associated with high rainfalls, and vice versa.

Station		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Rainfall														
Narrabri W.	mean	132	65	61	35	58	33	45	44	49	63	62	65	712
	maximum	307	219	203	137	189	92	160	111	115	211	128	184	
	minimum	2	5	0	0	0	2	1	0	0	6	6	3	
	raindays	8	6	5	4	5	6	6	7	6	8	7	8	76
Moree	mean	79	62	61	32	41	27	40	37	32	49	59	71	590
	maximum	218	249	225	133	164	95	189	159	114	113	170	199	
	minimum	5	3	0	0	0	0	0	1	0	8	2	4	
	raindays	8	6	6	4	5	5	6	5	6	7	7	8	73
'Pendennis'	mean	75	59	53	32	38	40	38	34	33	49	46	55	552
Merah N.	maximum	324	256	396	181	173	191	147	125	126	179	170	249	
	minimum	4	0	0	0	0	2	0	0	0	0	0	2	
Temperature														
Narrabri W.	maximum	33.2	33.1	30.9	27.2	22.0	18.4	17.5	19.5	22.9	26.6	29.9	32.7	26.1
	minimum	19.0	19.0	16.4	11.7	7.8	4.7	3.2	4.4	7.2	11.4	14.5	17.4	11.3
	mean	26.1	26.0	23.6	19.4	14.9	11.5	10.3	11.9	15.0	19.0	22.2	25.0	18.7
Moree	maximum	33.4	33.2	30.7	27.1	22.0	18.9	17.7	19.5	23.0	26.9	30.4	32.6	26.3
	minimum	19.5	19.5	16.9	12.5	8.1	4.9	3.6	5.1	7.9	12.2	15.4	18.0	12.0
	mean	26.4	26.3	23.8	19.8	15.0	11.9	10.6	12.3	15.4	19.5	22.9	25.3	19.1

Table 1. Mean monthly and annual rainfall (mm) and temperatures (^{o}C) at Narrabri, Moree and 'Pendennis'.

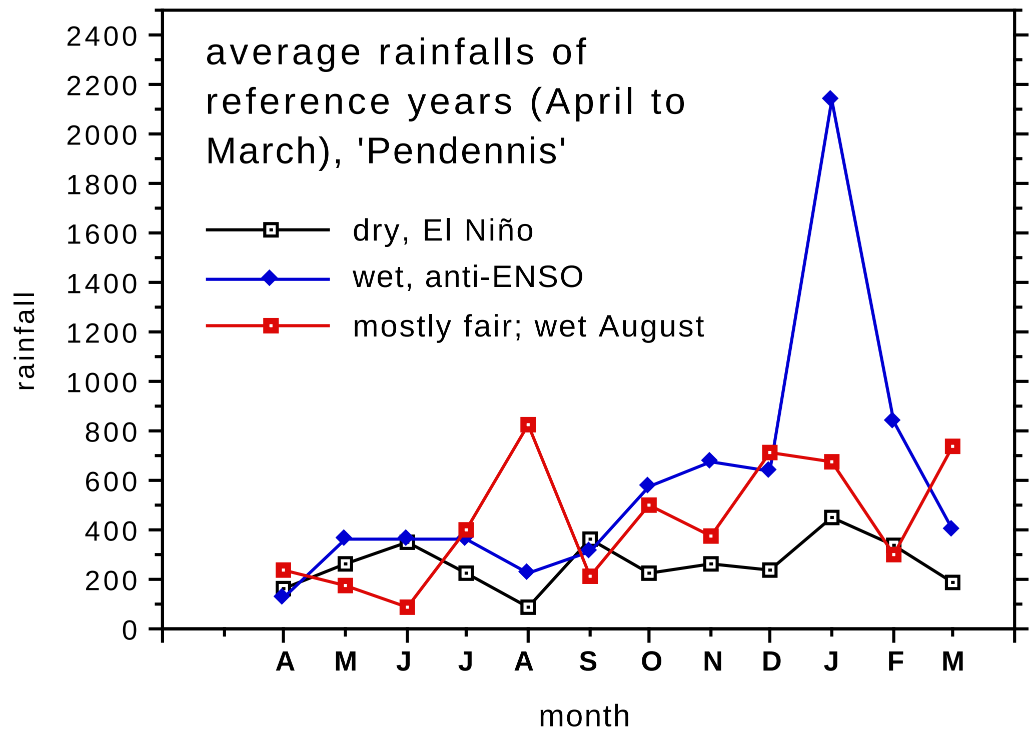

Figure 7. Average monthly rainfalls for three groups of reference years (April to March), "Pendennis". The averages are for 1982/3, 1979/80, 1932/3, and 1928/9 (dry, El Niño); 1981/2, 1975/6, 1973/4, and 1963/4 (wet, anti-ENSO) and 1985/6, 1962/3, 1947/8, and 1918/9 (mostly fair, wet August).

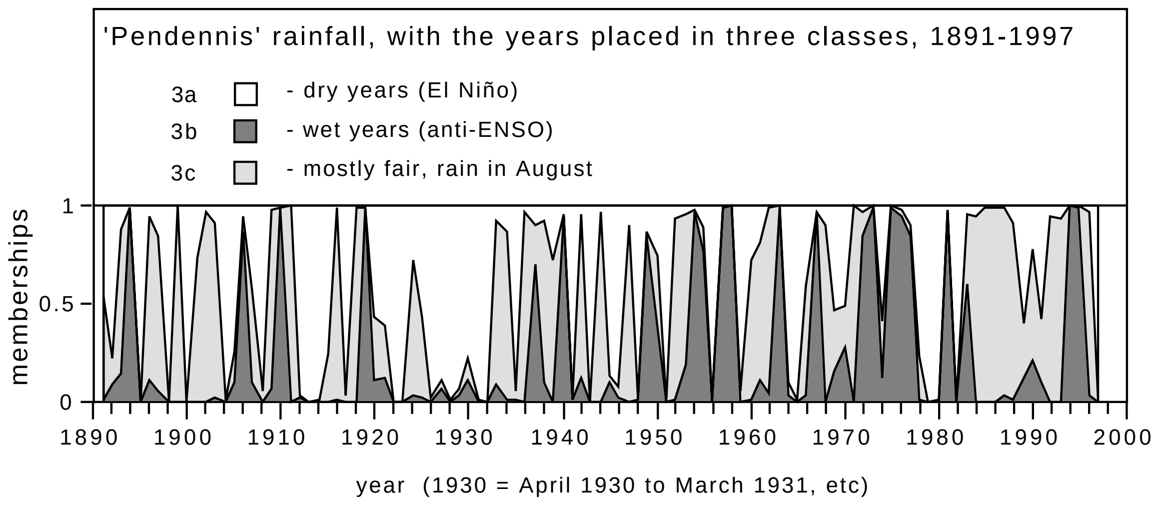

Figure 8. "Pendennis" rainfall, with the years scored by degree of membership in three classes exemplified by the reference years in Fig. 7.

Vegetation

The vegetation at the time of European settlement was partly dry sclerophyll forest and partly grassland, with patches of wilga and myall in places. The forest occupied the hilly land and followed sandstone ridges down to grassy plains. Woodlands occurred on the low ground near the Namoi River and scattered brigalow occurred further south. Records of vegetation made at each soil site allow a general description of the present cover. Trees within 100 m and identifiable shrubs and grasses at the drilled site were recorded. Plant distribution is related to rock type.

The vegetation on the basaltic lands has mostly been cleared. The scattered trees and shrubs include *Eucalyptus albens* (white box) and, less commonly, *E. crebra* (narrow-leaved ironbark). In several places *Callitris columellaris* (white cypress pine), *Geijera parviflora* (wilga), *Acacia salicina* (cooba) and *Elaedendron australe* (red-fruited olive plum) are present. The grasses are mostly *Stipa*, the main species being *S. scabra* (rough speargrass), *S. verticellata* (slender bamboo grass) and *S. setacea* (corkscrew grass). The weeds *Lepidium* (wild turnip), *Vicia sativa* (common vetch), *Lepidium bonariense*, (cut-leaf peppercress) and *Bassia quinquecuspis* var. *villosa*, (grey rolypoly) are prominent in cultivated places.

Ridges of Pilliga Sandstone carry dry sclerophyll forest. On uplands and especially on shallow sites *Eucalyptus populnea* (bimble box), *Acacia deanii* (Deane's wattle), *Acacia concurrens* (curracabah), *Callitris columellaris* (white cypress pine), *Geijera parviflora* (wilga) and *Cheilanthes tenuifolia* (rock fern) are prominent. Elsewhere *Eucalyptus blakelyi* (Blakely's red gum), *E. crebra* (narrow-leaved ironbark), *E. albens* (white box), *E. pilligaensis* (Pilliga grey box) and *Casuarina luehmannii* (bull oak) are present (Fig. 9). The wire grasses, especially *Aristida ramosa* (purple wiregrass) and *Aristida caput-medusae* (many-headed wiregrass) are dominant. They are usually associated with *Stipa scabra* (rough speargrass) and *S. verticellata* (slender bamboo grass). On cleared land where crops are occasionally taken, *Bassia quinquecuspis* var. *villosa* (grey rolypoly) is common.

Dry sclerophyll forests with *Casuarina cristata* (belah) originally occupied Tertiary sandstones and alluvial plains at Edgeroi. Much of this cover still remains. Belah remains prominent, and is associated with *Eucalyptus populnea* (bimble box), *E. melanophloia* (silver-leaved ironbark), and *Geijera parviflora* (wilga). *Callitris columellaris* (white cypress pine) and *Casuarina luehmannii* (bull oak) occur less frequently. Among the grasses, *Stipa scabra* and *Enteropogon acicularis* (curly windmill grass are common. *Chenopodium pseudomicrophyllum* (small-leaf goosefoot) was recorded in several places. *Bassia quinquecuspis,* (black rolypoly) and *Bassia quinquecuspis* var. *villosa* (grey rolypoly) occur on cleared ground.

The broad alluvial plains are dominated by grassland. *Stipa scabra* and *Stipa verticellata* occur, usually with *Enteropogon acicularis* (curly windmill grass). *Juncus usitatus* (common rush) and *Marsilea drummondii* (nardoo) occur in moist low-lying and slowly draining areas. *Bassia quinquecuspis* ssp. *semiglabra* (dark rolypoly), and especially *Bassia quinquecuspis* (black rolypoly), *Lepidium* (wild turnip) and in places

Silybum marianum (variegated thistle) and *Lepidium bonariense* (cut-leaf pepper-cress) infest cultivated land.

Lightly wooded lands occupy the flood plains and low alluvial plains except for the lowest reaches of Galathera Creek, where the cover is dominated by *Juncus usitatus* (common rush), with *Stipa scabra* and various Asteraceae. Marsilea *drummondii* (nardoo) was noted at one site. *Eucalyptus camaldulensis* (river red gum) is prominent near the Namoi River and *E. tessellaris* (carbeen) occurs on ground usually above the main flood plain. Several species of grass were recorded, among them *Stipa scabra, Paspalidium (? P. constrictum), Panicum decompositum* (native millet), and *Enteropogon acicularis* (curly windmill grass). *Bassia quinquecuspis* (black rolypoly) is again the common weed.

Figure 9. Site ed205, Killarney State Forest. Narrow-leaf ironbark (*Eucalyptus crebra*), *Acacia concurrens* and sparse *Aristida* on a slow-draining sandy soil of Killarney association, from Pilliga Sandstone. The four-legged pyramid is a camera tripod.

Geology

Local variation in soils is largely associated with the types of rocks and sediments on which the soils are formed. Thus it is necessary to identify the rocks that contribute to the soil pattern when studying the soils of a district. Two classes can be usefully separated: *basement rocks*, and *transported sediments*. Basement rocks form the ridges and high points in the landscape. Transported sediments are formed from them by weathering and by removal of the weathered product.

In the second class, *colluvium* is material that has been transported by rock falls and slumps or by intermittent surface runoff and rill erosion. It occurs on hill slopes, and is usually a mixture of sand, silt and clay, with angular gravels and poor bedding. *Alluvium* has been transported by flowing water in streams and rivers. It is better sorted than colluvium into beds of sand, silt and clay but although stones and gravels in alluvium are rounded by abrasion, the distinction is seldom clear-cut. *Aeolian sediments* are either wind drifted sands, or dust deposits from the atmosphere. Both are very well sorted. Drifted materials are moved short distances by the wind at ground level whereas dust and loess are carried a long way in the air.

The distinction between basement rocks and transported sediments is sensible only in relation to the modern landscape. A transported sediment in one age could be a basement rock at another time. This is the case at Edgeroi, where the Jurassic Pilliga Sandstone - originally a transported sediment - is now best considered as part of the basement.

It is difficult to show colluvium on geological maps because it is thin and superficial and obscures the rocks beneath. Alluvial deposits are commonly shown without much detail. Dusts can be overlooked because they are difficult to identify without laboratory study. To farmers these surface materials are important, for soils are often formed on them.

Basement rocks

The eastern margin of the Edgeroi sheet lies against the Nandewar Range, the eroded remnant of an enormous shield volcano, one of several that were built 13 to 14 million years ago, in the Tertiary Era (Dulhunty and McDougall 1966). Chemical analyses of some of the volcanic rocks are provided by Wilkinson (1969), and rock descriptions are given by Abbott (1969). The range is now much less than its original size, having been reduced to perhaps a quarter of its original mass by natural erosion. The rocks consist of alkali basalts and trachytes, and are named Nandewar Volcanics. The basalts at Bald Hill, 'Oakvale' and 'Green Timbers' are also believed to be part of this formation. Except for these outliers, the basalts do not extend very far into the area studied.

The main basement rocks in the Edgeroi district (Table 2) are Pilliga Sandstone, which forms prominent ridges, and Purlawaugh Formation, relatively soft clayey sands with mudstones, best seen beneath the sandstone beside the Bingara Road at the crest of the hill at the 12-mile (see map). Pilliga Sandstone is a coarse-textured and porous quartz sandstone, locally with interbedded claystones, pebble beds and conglomerates. Ironstones mark the contact with Purlawaugh Formation in the 12-mile road cut, and are seen as detached fragments in several places in adjoining fields.

Nandewar Volcanics
Tertiary alluvial sandstone and conglomerate
Rolling Downs Group
Pilliga Sandstone
Garrawilla Volcanics
Purlawaugh Formation

Table 2. Sequence of basement rocks.

Basaltic rocks occur in the Purlawaugh sediments near the contact with the Pilliga Sandstone. They are not seen in the exposure at the road cut but form rocky outcrops or lie close to the surface on the slopes above Bobbiwaa and Spring creeks mostly east of the Bingara Road. They occur opposite the entrance to 'Murrumbilla', and on 'Woodville', 'Dalman Downs' and 'Fernlea', and lie near the ground surface by Spring Creek, especially on 'Wonga Plains'.

The present-day outcrops of the Pilliga Sandstone are the eroded remnants of a single massive sheet tilted by earth movements gently to the west so that the base, which lies near 360 m elevation at the 12-mile, descends to 300 m south of 'Murrumbilla' homestead and passes below the 230 m level at the Newell Highway near 'Killarney'. On the north side of Bobbiwaa Creek the same contact descends from 400 m at 'Fernlea', through 300 m north of 'Woodville', to the level of the creek at the southern margin of the Bobbiwaa State Forest.

Below the Pilliga Sandstone the ground surface is formed on Purlawaugh Formation and across the basaltic rocks which occur in it. Outcropping ledges of these rocks are found in places on the slopes but commonly there is no outcrop and the ground surface is cut smoothly across deeply weathered reddish brown volcanic beds containing floaters of basalt. Some outcrops on 'Wonga Plains' and further south are mapped as Nandewar Volcanics by Dulhunty (1968) but he describes them as Garrawilla Volcanics in his text.

Nandewar Volcanics occur at the crest of the ridge at the 12-mile, and their occurrence there, and in a similar location on the same ridge further east, suggests that the ridge follows the line of an ancient valley that served as a channel for lava at the time of the volcanic eruption. It seems that the present-day landscape has thus been inverted: the ancient valley has become a ridge owing to the presence in it of hard volcanic rocks, and the ancient interfluves have become valleys.[4]

The valleys of Spring, Bobbiwaa and Mulgate creeks are the only ones cut deeply enough to expose the rocks beneath Pilliga Sandstone. The other valleys to the north are wholly contained in the formation.

Calcareous clays and marls which represent the Rolling Downs Group form gentle slopes on 'Killarney', 'Veone', 'Cooyong' and especially on the I.A. Watson Research Farm. The calcareous beds are particularly noticeable because the calcium carbonate has formed rounded nodules and cemented layers of rock-like calcrete in the soil. This, and the marls associated with it at the Bingara Road near 'Cooyong' (near grid reference Narrabri 712474), was once excavated for agricultural lime. Soft yellow Tertiary sandstones with rounded gravels occur above the Rolling Downs Group at 'Veone' and 'Killarney' and in other areas above Pilliga Sandstone at 'Buddah', 'Oakvale' and 'Moema'. At 'Oakvale' these Tertiary alluvial beds are capped by Nandewar Volcanics. In a small quarry nearby, at Edgeroi 750666, stone and gravel beds that lie beneath the basalt have provided a useful local source of road metal.

The soft Tertiary sandstones and the Rolling Downs beds must both have covered very large parts of the Edgeroi district at different times, perhaps all of it below the present day 300 m contour, to form extensive alluvial plains. The deposits are limited now to the residual interfluves west of the Killarney and Bobbiwaa State Forests. The basalt at 'Oakvale' and further north at Haystack Mountain has preserved some of these rocks and buries parts of the original alluvial landscape.

In spite of their prominence, most of the basement rocks do not give rise directly to soils. The present field study has shown that they contribute more usually to a superficial hillside veneer of colluvium.

Transported sediments

Colluvium. Colluvium is produced by weathering and natural erosion in the immediate catchment and as a consequence its composition varies according to the local rock type. In the Edgeroi district the deposits thicken downslope often to more than 4 m. They are poorly sorted but sands and detached fragments of rock are more common upslope and in the lower parts of thick deposits, where there are some signs of water-sorting. The contact with the rock beneath is sharp. This is the result of abrasion during sediment transport and it follows that the hillsides were originally subject to erosion by water before being covered with debris. The power required to abrade the rocks and transport the stones in the colluvium implies rushing water but the deposits are sheet-like and ill-sorted rather than channel fill. Thus the hillsides must once have lacked any obstruction to runoff during rain.

[4] For more information on inversion of relief see Hills (1939) and Cotton (1944).

Vegetation was necessarily sparse, even absent. These conditions must have occurred a long time ago, because forests occupied the hillslopes at settlement and the soils which occur now on the colluvium are well differentiated.

Alluvium. Widespread alluvial deposits extend from the Nandewar Range to the Namoi River. Streams that rise in the range bring basaltic debris mixed with sandstone to the plains. This is deposited as the gradients decrease to form broad valley plains and alluvial fans (Fig. 10) that flood around isolated high points such as the volcanic Bald Hill and the similar outlier at 'Green Timbers'. North of Bald Hill, at 'Mulgamah', a small knoll of Pilliga Sandstone is almost overtopped by the surrounding alluvium. The Namoi River brings alluvium of mixed composition and mostly fine size to the country northwest of Narrabri. Clays with interbedded sandy clays extend commonly to depths of at least 6 m, but drilling near Narrabri and Wee Waa has shown that extensive sandy strata are encountered in this area, from 9 to 15 m (Stannard and Kelly 1977). Near old river courses on the plains, sandy clays or sands are within 3 m of the surface in places.

Figure 10. Site ed050, "Moema North", Bobbiwaa clay loam, developed on the alluvial fan of Moema Creek. View south across new wheat towards Nandewar Range.

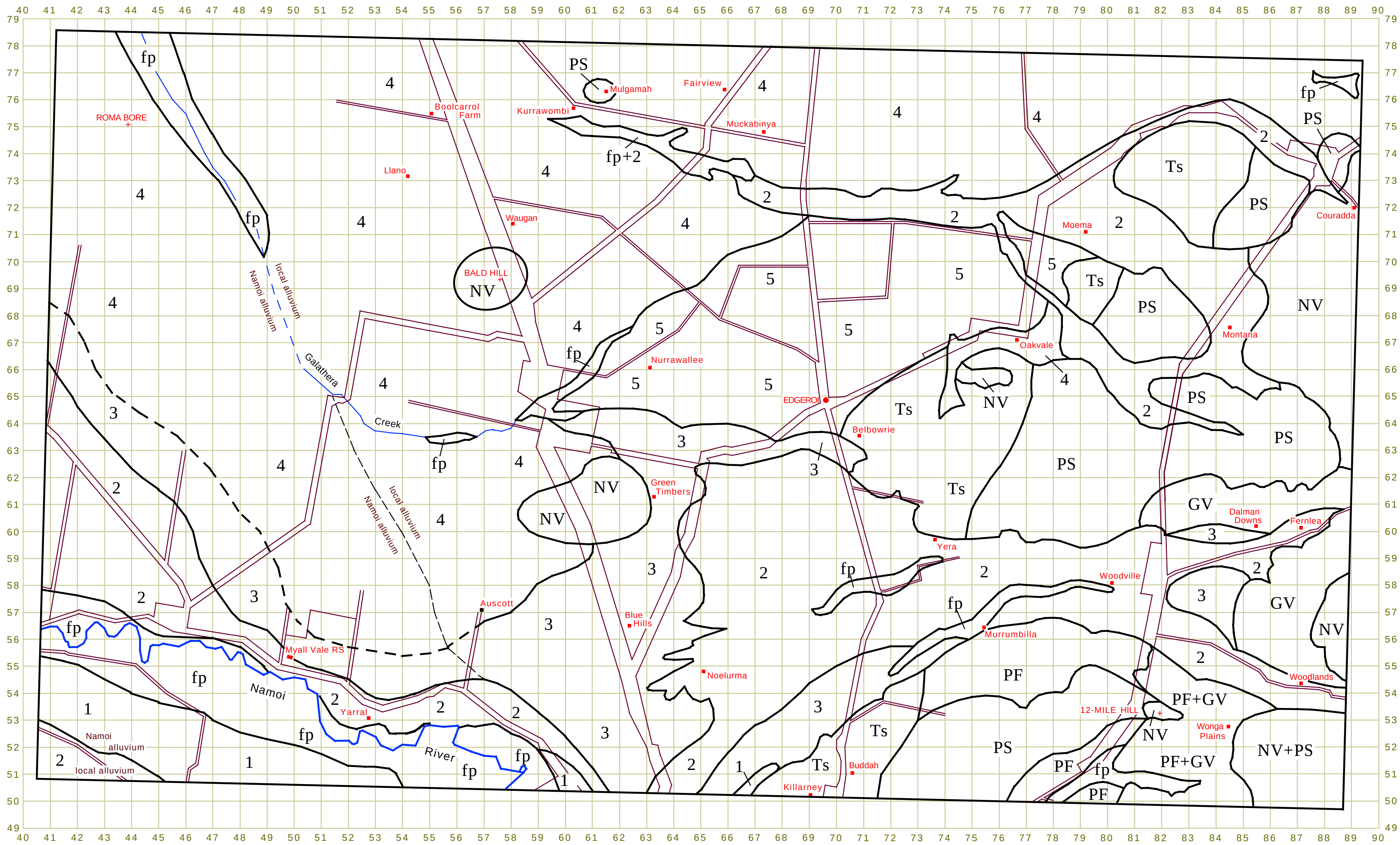

Figure 11. Parent rocks and sediments, Edgeroi sheet. PS, Pilliga Sandstone; PF, Purlawaugh Formation; GV, Garrawilla Volcanics; NV, Nandewar Volcanics; Ts, Tertiary sandstone; fp, flood plain; 1, 2, 3, 4, first, second, third and fourth terraced fans; 5, eroded (fifth) fan; colluvium, not shown. A mantle of water-washed aeolian clay rests on the third and fourth terraced fans. Rolling Downs Group does not occur in the area shown here. Grid is 1 km.

Landscape

> The country when seen from any eminence, appeared to be very generally wooded, but the lower grounds were perfectly clear, or thinly strewed with bushes, and slender trees, chiefly varieties of acacia. The principal wood consisted of *casuarinæ* which grew in thick clumps, or scrubs, and very much impeded ... our progress in any given direction. I found that these scrubs of casuarinæ grew mostly on rising grounds, and chiefly on their northern or eastern slopes. We saw little of the callitris tribe, after we had crossed the rising ground [probably at 'Killarney' (WTW)] near our last camp on the Nammoy. On the contrary, these casuarinæ scrubs, and grassy plains seemed to characterize the country to the westward and northward of the Nundewàr Range, as far, at least, as we had yet penetrated.
>
> – Major T.L. Mitchell, *Journal*, 7 Jan. 1832 [published 1838]

The Namoi River is a major tributary to the Barwon, part of the Darling river system. It drains the southern part of the New England Plateau and the Liverpool Plains, the main tributaries being the Manilla, Peel and Mooki rivers. In the study area it receives intermittent drainage from Mulgate and Spring creeks, which rise in the Nandewar Range and enter from the northeast, and from Bohena Creek which flows north from the sandstones of the Pilliga Scrub. Bobbiwaa Creek is ill-defined in its lower course and its waters mostly become dispersed on the plains before reaching the Namoi. Galathera, Ten-Mile and Boggy creeks are other important local drainages but after flowing west from the Nandewars towards the Namoi they turn to the northwest ultimately to enter Thalaba Creek, a tributary to the Barwon River.

At Wee Waa the Namoi flows, in flood time, into several distributaries, the best marked being Gunidgera and Pian creeks (Water Resources Commission of NSW 1980). Other distributaries leave the river further west, mostly to re-enter the Namoi further downstream.

The rainfall is well distributed but long droughts are common and there are occasional high-intensity, short-duration storms. Thus long periods of low river flow alternate with infrequent floods that extend on occasion far beyond the immediate flood plain as a consequence of the low relief. In major floods water from the Namoi commonly joins with the flooded Gwydir and Macintyre rivers to inundate immense areas, amounting to millions of hectares, of the western plains.[5]

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[5] Note on Terminology: A *flood plain* is the land over which a river spreads naturally in flood (Macquarie dictionary; OED) and thus the term can be applied to most of the lower Namoi Valley. However, flood plains are usually characterised by active surface erosion and sedimentation, which gives them distinctive sediments and distinctive soils. Thus a flood plain - to an earth scientist (Gunn et al., 1990; AGI 1976) - is that part of the river valley which is built of sediments deposited according to the river's present habit. Usually the different usages can be applied without confusion but not in the lower Namoi Valley. Owing to the low relief, major floods there cover areas that are not composed of sediments deposited in the present regimen. Whilst these areas receive some fresh sediment at times of high flood, the amount is too small to permanently change the appearance of the flooded soil profile. In the present report the term flood plain will be used in its restricted sense.

The vast extent of the alluvial plains, especially in relation to the ephemeral flow in the local streams and relatively small flow of the Namoi, shows that their formation must have involved a vast span of time.

1. Sandstone Foothills

Broad ridges of Pilliga Sandstone extend from the Nandewar Range towards the Newell Highway south of Edgeroi (Fig. 11), but as the highway is approached the Pilliga Sandstone gives way to a soft Tertiary sandstone. This last unit is not well exposed anywhere owing to a well developed soil cover.

The sandstone ridges are generally undulating to rolling. From their highest levels they fall to the valleys through broad slopes whose gradients decrease slowly towards the valley floor to give a cross-valley shape that is noticeably concave when viewed in profile. This shape is caused by surface runoff and reflects changes in the sediments on which the soils are formed.

On each ridge two hillslope elements can be easily recognized. Smooth, convex *uplands* can be identified above long concave slopes which form *pediments* veneered with colluvium that has been washed down from higher levels. In most cases the uplands grade smoothly to the pediments without an angular junction at the change in slope, except where massive sandstone beds, ironstone layers, or basalts crop out.

Pediment origin

It is commonly understood that pediments are formed as debris is washed from the sides of steeply incised valleys to a stream (Young 1972). The valley is supposed to widen without any change of slope, to produce the pediment form (Fig. 12). The absence of steep land, scarps and debris slopes above the pediments at Edgeroi makes this explanation unlikely.

To explain the landform in the Edgeroi district it is necessary only to consider how water moves across the land surface in this dry environment, where the vegetative cover is incomplete and rainfall intensity frequently exceeds the capacity of the parched ground to absorb the water.

When rainstorms occur in these conditions loose particles of soil are taken into suspension and material entrained by overland flow is carried downslope. Near ridges, the volumes of water are small and sediment is entrained mostly by droplet impact and rain splash. Downslope the flow steadily increases and erosion by the running water becomes important. Further down, no erosion can occur unless some of the material already in suspension is deposited, for the water by now is fully charged with sediment (Fig. 13). It follows that the watersheds are eroded by rainwash more slowly in comparison with the more inclined slopes

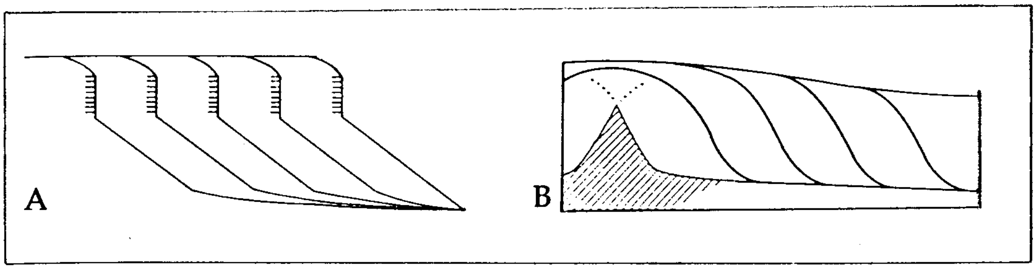


Figure 12. Two hypotheses of pediment development by parallel retreat of valley-side slopes: in A with a scarp and debris slope above the growing pediment; and in B without a scarp (After A. Young, 1972).

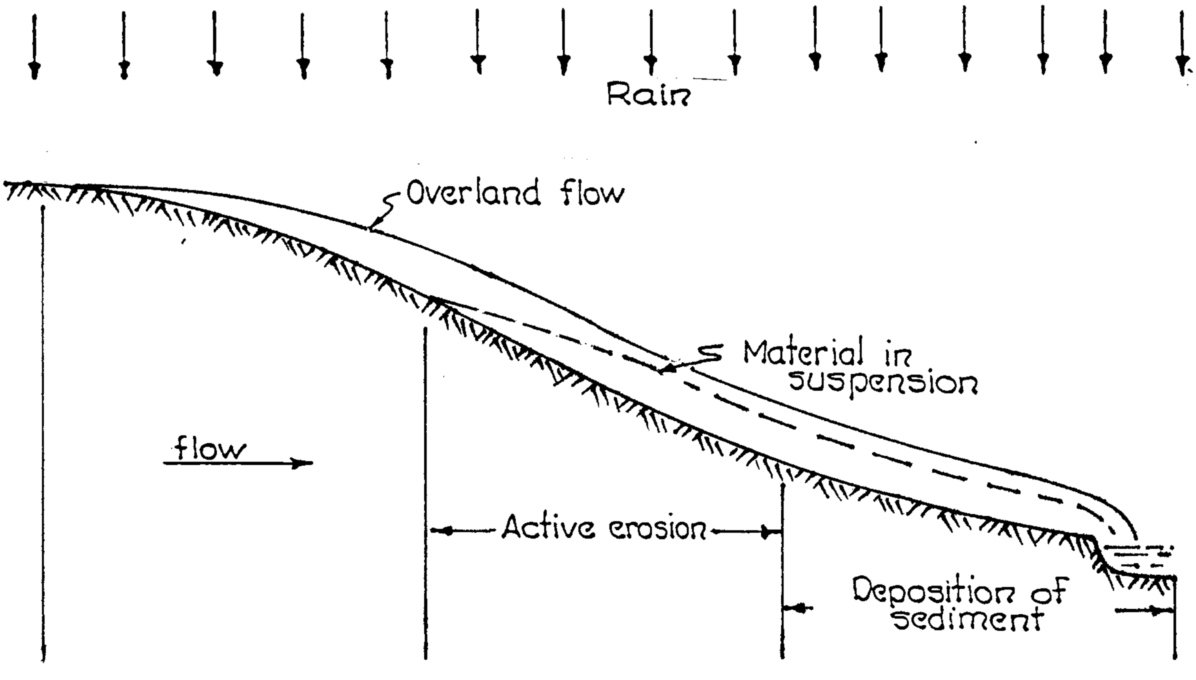


Figure 13. Profile of a valley-side illustrating sediment transport by overland flow (After R.E. Horton, 1945).

below a crest, and that the lowest slopes are sites of deposition or have become areas across which sediment is transported to a central stream. Continued rainwash, in conditions where the products of natural erosion are not carried out of the drainage system, will thus develop concave hillslopes.

Four different hillside zones (East 1987) can be recognized. At crests there is a residual zone where there is relatively little surface wash because the slope is gentle, and relatively high infiltration once the soils have become moist. As a consequence rock weathering dominates over surface wash. Further downslope where surface runoff is more rapid there is a greater opportunity for soil removal, but weathering is still important. The transported material is carried to the lower slopes where it begins to accumulate. Thus soil formation on the lower slopes (i.e., on the pediment) occurs mostly on material which has been eroded from the higher ground. In drainage lines on the hillsides where runoff is concentrated by surface depressions, and in the stream channel at the slope foot where the runoff water collects, the sediments are better sorted because of the greater concentration of water, and grade from colluvium to alluvium. However, bedding is usually poor because of variations in the size of rain showers and runoff events.

Erosion is most likely to occur on slopes that are poorly protected by vegetation, as agricultural experience confirms. It is limited in forested land where the impact of the rain is broken by the cover and where runoff is impeded by surface litter. Thus the occurrence of pediment slopes on a hillside implies an arid environment with a surface cover giving poor protection from rainstorms. As the sandstone ridges were forested at the time of European settlement, the landforms indicate that a more arid environment was once present here.

Drilling shows that the lower slopes of the present hillsides are thickly mantled with weathered colluvium, to a depth of several metres. This thickness is too great for the whole deposit to have been merely material that was temporarily left stranded between rainstorms. It must represent continued deposition over a considerable time. Sediment deposition would probably occur first along the main streams draining the hills, and would spread from there to the lowest pediment slopes, to raise the surface levels. This in its turn would further reduce the gradient and result inevitably in the deposition of more debris on the lowest slopes. Better vegetation growth on the finer and better-watered sediments near the drainage lines would also reduce the velocity of surface runoff and encourage further sedimentation.

With deposition spreading to the pediment the area subject to erosion becomes diminished. Material entrained by rainsplash and wash is soon deposited not far from its place of origin, and a more-or-less stable and graded land surface develops. Rapid unimpeded flows of surface water across the sloping pediments would end if forest became established, and ultimately the forest would protect the landform.

It follows that the Edgeroi landscape was formed in open, somewhat arid conditions. The hillslopes acquired their present form because alluvium was retained in the drainage system and colluvial wash was retained on the pediments. In later more humid conditions, they were stabilized by spreading forests and grassland. Clearing and cultivation of the pediments in modern times has reproduced a bare desert-like environment, and has restored the hazard of sheet erosion.

Transect at 'Murrumbilla'

The detailed structure of a pedimented slope is shown by drilling at 'Murrumbilla' near Spring Creek.

The transect (Fig. 14) shows that the ridge and its associated pediment is formed at this place on Pilliga Sandstone lying above Purlawaugh Formation (clay and clayey sand) and Garrawilla Volcanics (basalts and associated pyroclastic rocks). At the ridge crest the soils are formed directly in Pilliga Sandstone. Further down, near the contact with Purlawaugh Formation, they are developed partly in a shallow superficial layer of colluvium. This becomes thicker as the land falls towards Spring Creek and consists mostly of sand with clay. Small angular quartz gravels derived from coarse-textured beds in the alluvial Pilliga Sandstone, some plate-like pieces of iron-cemented sandstone from the base of that formation, and fragments of basalt eroded from the Garrawilla Volcanics occur mostly at the contact of the colluvium with the country rock, where the separation of coarse and fine fractions gives evidence of watersorting.

On the pediment slope a bed of grey calcareous clay lies beneath the superficial deposits and above the basal stony conglomerate. This subsurface clay has evident remnants of soil structure and (except for colour) the profile of a cracking clay soil, especially at site ed344 (Fig. 15), but in other drill-holes the contact between the superficial deposits and the calcareous clays is eroded. The lenses of gravel and stone and the buried soil show that this is part of an early colluvial mantle which covered the pediment before the development of the overlying colluvium and the modern soils.

Red colours are found in the soil at higher levels on the pediment, at sites ed337, 338 and 339. They are prominent at a depth of 1.5 m at ed337. The colours occupy the centres of soil aggregates and grade through yellowish brown, to grey at the surface of each soil fragment. This pattern indicates different degrees of hydration of iron oxides in the soil, the yellowish brown and grey zones being the most hydrated. Its relationship to the pattern of cracking and thus to the pattern of water entry into the soil implies that the soil was once drier than it is at present, and was red throughout. The colour has since been partly altered to yellowish brown and grey by water entering the cracks. Because these new colours are continuous with the present-day subsoil colours it is concluded that the change is associated with present-day soil formation; the red colours give evidence of a former weathered condition and were present before the modern duplex soil was

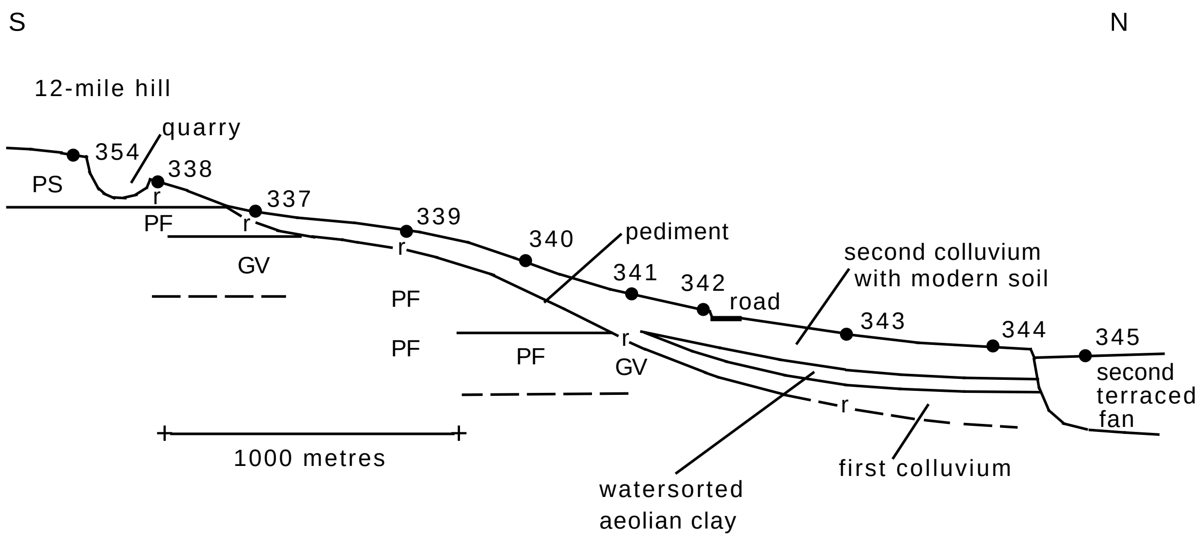


Figure 14. Section of hillside slope at "Murrumbilla", showing bedded colluvium on pediment and basement rocks. The transect is at an angle to the slope above ed340 and it approaches a spur in this area. This causes the irregularity in the profile here. PS, Pilliga Sandstone; PF, Purlawaugh Formation; GV, Garrawilla Volcanics. Red-weathering colours are indicated by the letter "r". Scale, vertical: horizontal 10:1. Depths are exaggerated 5 times for clarity.

Figure 15. Site ed344, "Murrumbilla". View north across the pediment footslope towards Spring Creek. The soil is Murrumbilla loamy sand, developed on colluvium mostly from Pilliga Sandstone and Purlawaugh Formation. Some windblown clay is included in the parent sediment.

formed. Thus, the present-day soil in situations where red colours occur in the subsoil is believed to have formed by the alteration of a prior soil.

The soils that are now developed on the pediments are mostly duplex soils, formed on sandstone or on sandy beds in Purlawaugh Formation, or on colluvium derived by erosion of the Pilliga Sandstone. Small areas of clay soil also occur, on clay beds in Purlawaugh Formation, on colluvium containing a significant contribution of clay from Purlawaugh Formation, and where Garrawilla Volcanics crop out, as in the valley of Spring Creek east of the Bingara road. The changes in the soil profile shown in the detailed transect reflect varying proportions of Garrawilla Volcanics in the colluvial debris.

The following sequence of events is revealed by the drilled section: 1, erosion to form the pediment; 2, progressive sedimentation on the pediment with development of a red-weathered profile on the basement rocks and upper slopes and cracking clay soil on lower slopes; 3, renewed sedimentation that buried the clay soil and resulted in its replacement, on the new sediment, by duplex soils; 4, stream incision at the foot of the slope; 5, back-filling of the stream channel with alluvium now weathered to form a reddish brown soil.

Transect at 'Oakvale'

The rolling landscape at 'Oakvale' is formed of soft Tertiary sandstones containing, in places, thin beds of well-rounded quartz gravels. One ridge is capped in part by basalt. This contributes debris to the adjoining colluvial slopes, where cracking clay soils are developed. Elsewhere, the pedimented hillsides rise smoothly to the ridge crests, without any marked change of slope where the ground surface passes from colluvium to rock *in situ*.

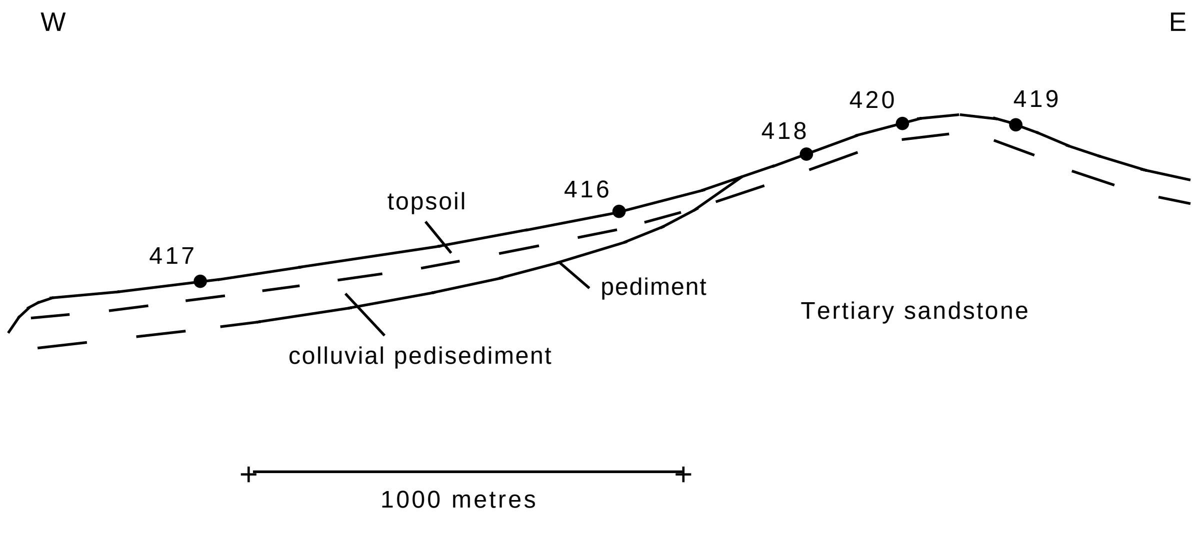


Figure 16. Drilled section at "Oakvale", showing relation of soil to parent sandstone and pedisediment. Scale, vertical: horizontal 10:1. Depths are exaggerated 5 times for clarity. W, West; E, East.

A transect drilled in an undisturbed and vegetated headland at the southern farm boundary showed that the colluvial sediments on the pediment are thin and extend to within two or three hundred metres of the ridge crest (Fig. 16). The area able to supply fresh sediment to the pediment is thus restricted, and it follows that a reasonably stable slope had developed. This has been disturbed over a limited area only at site ed416, where the topmost 0.14 m is composed of young but probably prehistoric sediments, and at ed417, where fresh sediment washed from the adjoining cultivated field lies at the surface.

A well-differentiated sand-over-clay soil profile is developed on both the Tertiary sandstone and the transported colluvium. On the lower parts of the pediment mottles produced by slow soil drainage are evident in the subsoil, and there are a few scattered nodules of calcium carbonate. On the higher slopes lime is abundant. Red colours are also prominent there, and grey stains giving evidence of impeded soil drainage mark the external faces of the structural soil aggregates. The modern soil on the upper slopes, at least, has been formed, therefore, on a prior red soil. This condition gives further support to the inference that a stable situation had once developed and had endured for a significant period.

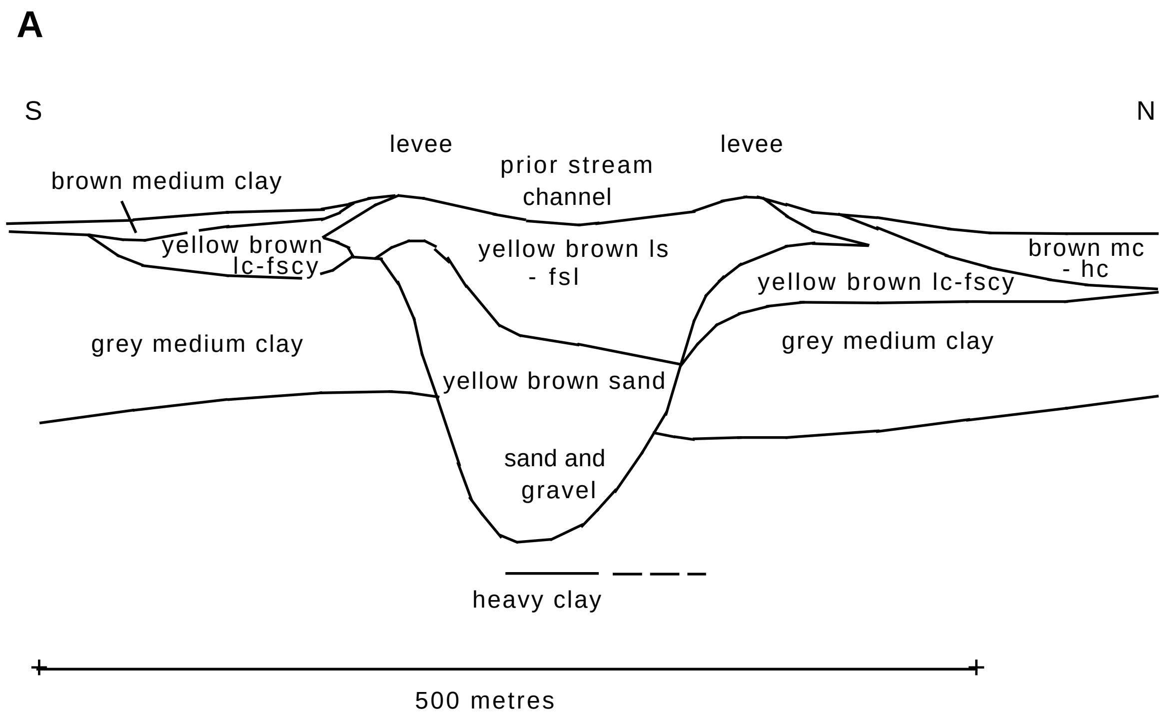
2. Alluvial Landscape

Previous Work

McGarity (1950), in a reconnaissance of the North-western Plains, separated brown, grey and black alluvia near Edgeroi. He accepted the then prevailing belief that our present age has followed a prior arid time and suggested that the brown soils had formed and persisted on high sites since then. He thought that the heavy grey clays had been deposited more recently, in swamps and standing flood water.

Hallsworth and Waring (1964) believed that the soil pattern on the plains south of the Namoi River reflected alluvial deposition. They supposed that the deep sands had been left as stream-channel fill, the clays were deposits left in quiet backwaters, and the soils showing sand-over-clay were formed on mixed sediments deposited between the streams and backwaters. The present-day sand-over-clay soils (i.e., the duplex soils) had been produced simply by percolating rainwater, which had washed the clay that had been at the surface into the subsoil. There was too little clay in the deep sands to produce a sand-over-clay profile, and too much in the clay soils to allow significant in-washing.

Stannard and Kelly (1977) recognized that the alluvial deposits of the lower Namoi plain were part of a typical riverine plain that had formed in an episodic fashion. They separated low flood plains, and other units, from prior stream formations which had meandered over and partly buried earlier clay plains. Drilled sections showed that major prior streams had been cut as narrow channels to depths about 8 m. These channels were later infilled (Fig. 17). Minor prior streams, before they had become choked with sediment, had occupied only shallow channels.



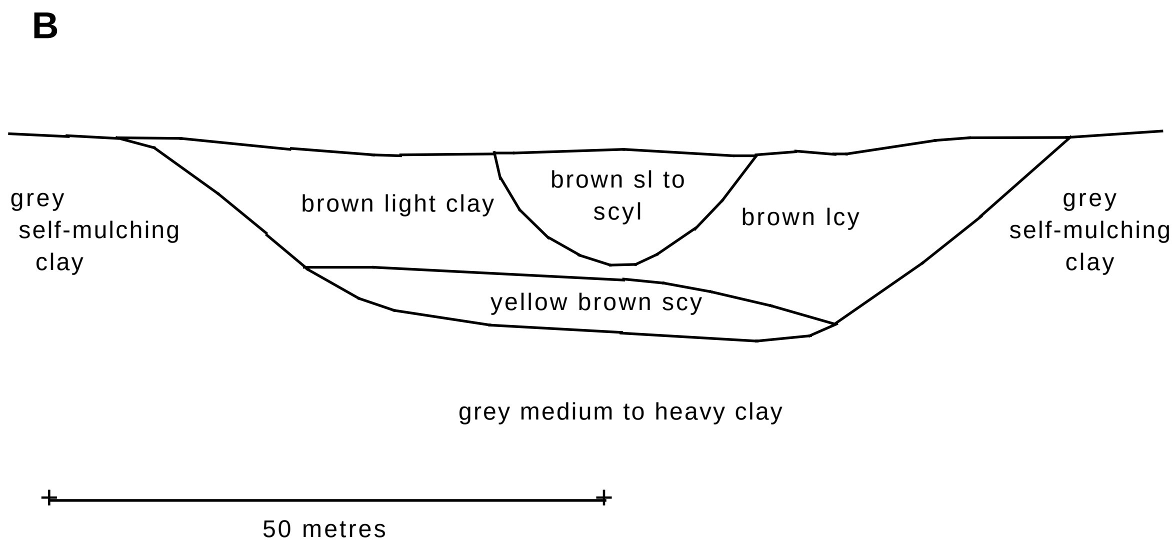


Figure 17. Cross-sections of a typical prior stream, A (scale, vertical: horizontal 20:1), and a terminal minor branch of a prior stream, B (vertical: horizontal 10:1). Both sections after Stannard and Kelly (1977). fscy, fine sandy clay; fsl, fine sandy loam; hc, heavy clay; lc, light clay;.ls, loamy sand; mc, medium clay; scy, sandy clay; scyl, sandy clay loam; N, North; S, South.

Riley and Taylor (1978) used the name 'western alluvial plain' only for the deposits of the Namoi and Gwydir rivers, noting that they formed two large, low-angle alluvial fans. Their examination of Landsat images suggested a possible subdivision of each fan into three parts, namely, most recent fan deposits, older(?) fan deposits, and an 'area of interaction' between the Namoi and Gwydir fans. The sand and gravel bedload was deposited mostly in the east, they reported, where the rivers were wide and shallow. For the most part, sediment deposition was localized, and occurred where distributary offtakes were most prevalent. Swamps on the Gwydir, like those on the Castlereagh and Macquarie rivers, trapped the bedload that reached them. Below the swamps the rivers occupied deep, muddy channels.

Butler and Hubble (1978) also separated the Namoi and Gwydir fans from the deposits of the trunk streams, but based their decision mostly on the different proportions of the solodised solonetz and grey clays developed on the fans as compared with those on the alluvium of the Barwon and Macintyre rivers. They attributed the observed soil variation to a prior stream pattern, variation in parent sediment, variation in catchment rock types, and local variations in drainage. They believed that the individual character of the alluvial fans denied the possibility of any general spread of wind blown deposits there.

Rust and Nanson (1989) reported that the Cooper and Diamantina rivers carried clay aggregated to the size of sand as bedload. This was deposited by overbank flow during floods and formed the bulk of the flood plains. They inferred that the aggregates had originated as granules in the cracking clay soils of the headwaters as a consequence of stresses during wetting and drying, and had been delivered to the rivers by surface runoff. After the clay aggregates had been deposited on the flood plains they were obscured by compaction and by clays lodged in pore spaces. Rivers that drained other areas of cracking clay soils were also likely to carry clay aggregates as bedload.

Namoi Landscape

Namoi flood plain. For the greater part of its traverse across the western plains the Namoi River occupies a single meandering channel with a deep trough-like cross section and nearly flat gradient. The river banks are steep, in places vertical, and the average depth and width is 3 m and 50 m, respectively. The river bed near Narrabri consists of muddy sand, pebbles and cobbles, and contains long deep pools and short muddy sections and sand or gravel bars. Levee banks are poorly defined. Where there is conspicuous surface relief near the main channel it is in the form of shallow secondary channels and scour holes modelled by flood. At greater distances from the river the ground surface is flat or slopes very gently to low backswamp areas diversified by shallow and meandering abandoned channels. Above Collins Bridge near Wee Waa the ground behind the backswamps rises rapidly for 1-3 m in most places to the level of a more extensive adjoining surface, the junction being clearly marked by a scarp eroded by the meandering river as it developed its flood plain.

Pits and holes drilled in the flood plain reveal fine sands and silty clays in poorly defined horizontal layers mostly without signs of bedding. Weakly developed buried soil layers are common, and near the river the surface of the ground is mostly formed of fresh sediment. The absence of point bar deposits giving evidence of lateral accretion and the common occurrence of organic residues indicate a flood plain gradually built by the deposition of relatively fine-grained alluvium on well vegetated ground. The incremental growth that builds up the flood plain in this way is overtopped only by increasingly larger floods. From Myall Vale downstream the river banks tend to be higher than the surrounding country and overbank flow in flood time is diverted into lower ground such as that adjoining the Spring Plains road.

At Wee Waa billabongs become prominent. Old channels leading from Collins Bridge towards 'Helebah' and 'Bellevue' and streams such as Pian and Gunidgera creeks provide alternative courses for flood waters. Below Wee Waa, from a point near 'Tulladunna' where the river breaks out to Pian and Gunidgera creeks, the Namoi is reduced in size and has intricately convoluted meanders.

Namoi terraces and fan. At Narrabri and along the north and south banks of the Namoi river to Myall Vale and Collins Bridge the flood plain is separated, by low scarps, from higher ground with soils that differ from the flood plain as a consequence of a greater degree of soil formation. This high ground is formed of weakly consolidated alluvial beds and the surface generally is flat, but in places small variations in level occur, such as immediately southeast of the Bald Hill turnoff, on the road from Narrabri to Wee Waa. Most of the small differences in level coincide with changes in the soil. Traced upstream, with the soil as a guide, the different levels separate into at least three and perhaps four distinct terraces or, going downstream, come together to form a smooth, uninterrupted surface. These changes in level are significant in spite of their small size, not only because they mark changes in soil but also because they indicate distinct stages in the history of the alluvial plains. Furthermore, they show that the Namoi has developed in the same way as its tributary streams.

The first (lowest) terrace is exposed beside Doctors Creek in Narrabri and in an eroded area 2-4 km northwest of the township, by the Narrabri-Wee Waa road. It also occurs around Pian Creek west of Wee Waa, where it retains its original water-moulded surface, including flood channels and low natural levees.

At the road turnoff to Bald Hill the ground is formed by the second terrace above the flood plain. Surface runoff shows that it falls very gradually to the north for perhaps 1 km, firstly towards Black Gully and then, further west, to Spring Creek. West of Spring Creek the first and second terraces lie south of the fourth, which is the highest and oldest. The ground surface is smooth, locally with barely evident surface traces of abandoned alluvial channels, and falls north away from the Namoi River for the full distance to Galathera Creek. The terraces are difficult to separate by eye in many places because they rise nearly to the same level, especially the third terrace, which is distinguished by a consistent and abrupt change in soil from red-brown earth or brown clay to a grey cracking clay. At Myall Vale the second terrace reaches a higher elevation than the third and as a consequence the third terrace is mostly concealed here by the younger deposits. It is difficult to recognize the extent of the terraces and show them accurately on a map because of the similarities in level. The reddish-brown colour of the soil on the second terrace is a useful guide but reddish colours also occur on the fourth terrace where there is good soil drainage.

From Spring Creek the second terrace follows the north bank of the Namoi more or less continuously to the research station at Myall Vale, where it spreads away from the river, following ancient stream lines, that is, prior streams, towards Spring Plains. In this area the terrace landform disappears entirely, to be replaced by wide-spreading alluvial fans. In several places large abandoned meanders preserve the original flood plain relief.

The third terrace is best seen beside the Newell Highway and Bingara Road at Mulgrave Creek but is mostly concealed beneath younger alluvium down to Collins Bridge. Beyond this point it is represented by a large alluvial fan which is developed very extensively as clay plains west of 'Boolcarrol'. Here its surface exposure is interrupted by younger, but now abandoned, prior stream courses containing deposits equivalent to those of the second terrace. Traces of the original riverine topography are evident in places but typically the surface of the ground is smooth.

South of the river, for a short distance, a remnant of the second terrace puts Narrabri West above flood level. Further west the terrace becomes sandy where Bohena Creek and others rising in areas of Pilliga Sandstone to the south bring in large quantities of quartz sand. At the Namoi River, however, the sandy sediment becomes mixed with the alluvium of the main river and its separate character is lost. For the most part, on the south side of the river, the Namoi flood plain lies against a relatively high plain with duplex soils.

The tributary streams

The streams that rise in the Nandewar Range flow to the western plains through hills formed mostly of sandstone. Viewed as landforms, the deposits of each tributary, like those of the Namoi and Gwydir except for the smaller scale, form enormous fan-shaped bodies of alluvium, each shaped like the convex segment of a cone. The heads of the cones are commonly channelled near the streams, so that successive alluvial infills appear as terraces where the streams emerge from the Nandewar Range, but at the foot of the landform - the furthest extremity of the cone - the channelled alluvial fan grades into a plains sector without channels. Gradients average 2-3 m per km. The same cone shape is also formed by the deposits of the Namoi River, except in this case the surface gradients of the flood plain are very low indeed, becoming about 0.6 m per km in the western part of the area examined.

At their headwaters the tributaries occupy small valleys drained by deep, fast flows over a boulder floor. Further down, where they enter the sandstone foothills, the watercourses have become entrenched in wide alluvium-filled valleys but the streams here are much shallower owing to sedimentation, and present an increasing flood risk as lower ground is approached. The channel deposits in this sector are separated in places by scarps beside the channels from older sediments which occur as terraces above the immediate flood plain. The terraces match one another in level and carry similar soils, but unmatched terrace levels also occur beside the narrow waterways. Floods are mostly confined by the high ground.

In the middle reaches of the streams the scarps, which usually separate different bodies of alluvium further upstream, are lacking and the alluvial plains have a uniform surface formed by coalescing deposits. The apparent uniformity is deceptive, however. The entrenched streams, the gradual diminution of terrace scarps downstream and the occurrence of soils buried by younger alluvium are evidence that the development of the alluvial landscape has been interrupted. The deposits of each stream have the character of a multi-storied fan rather than a single alluvial fan, each storey having a more gentle gradient than its predecessor. Where scarps are developed, the younger deposits are enclosed by the older; where they are absent in the middle and lower reaches of the streams, younger alluvial deposits overtop the older and spread widely so as to give the plains their uniform surface and appearance of continuous development.

The streams do not always reach the Namoi River or Galathera Creek because their flows are variable and intermittent. As a result, sediment is left stranded in the watercourses, which become choked; it then spreads by overflow onto the adjoining plains. Where this has occurred the stream beds are shallow and difficult to recognize. The watercourses are frequently abandoned as the ground surface is built up by the accumulating debris. The streams are mostly dry, or reduced to a series of ponds which, as a consequence of sediment deposition, lie on the highest ground. This circumstance was noted by Major Mitchell while traversing the fans of Mulgate, Spring and Bobbiwaa creeks:

> We found these ponds in situations which seemed rather elevated above the adjacent plains, at least their immediate banks were higher; hence we usually came upon them where we least expected to see water, before we became acquainted with this peculiarity of the country. [*Journal*, 3 Jan. 1832 (Mitchell 1838)]

He thought that the occurrences of water might be due to differences in permeability. The plains ...

> consist chiefly of a rich dark coloured earth ... so absorbent that water will not lie on the surface until the whole mass is saturated and in dry weather it opens everywhere in large deep cracks ready to receive much more than all the water which falls in ordinary seasons. The existence in high situations of the few ponds or currents of water to be found there may therefore depend more on the nature of the subsoil than on the direction of ... the natural drainage .. [*Field Journal*, 4 Jan. 1832]

Viewed from the air, the young stream deposits present a braided or intricately lobed appearance, and the sediments are spread widely by overbank flow as thin sheets over earlier deposits. The terrace scarps which were common upstream are not seen. They are replaced by shallow depressions and backplains that in some areas contain swamps. The ground surface is formed of broad undulations which follow the convex surface of each fan-shaped body of alluvium spilled from the watercourse. Streams arising on the plain begin in the depressions between adjoining fans or follow the low ground against the enclosing sandstone ridges. They provide alternate drainage lines which the main streams may occupy or migrate to in times of flood. At these times the floodways can become permanent changes in the main watercourse.

Where Spring Creek approaches the Namoi River its channel becomes well marked as it descends to the river flood plain. Bobbiwaa Creek is best defined by artificial levees in its lowest course; its floodwaters spread on to cultivated land and then drain to the Namoi River.

Different soils occur on each of the terraces found at the heads of the alluvial fans. These soils, in the same sequence, are also found on the flood deposits which spread from the drainageways further downstream. The similar soil profiles in the different sectors of an alluvial fan aid correlation of the successive deposits that comprise the plains sector with the successive channel fills near the fan head.

Although the western plains are at times flooded, they are mostly now mantled with well developed soils, and new sedimentation there is shown by drilling to be very limited or wanting. The rivers provide significant deposits, at the present time, only on the low ground near the watercourses and, in the case of Galathera Creek, mainly along its lowest reaches north of the Bald Hill-Myall Vale road crossing.

The alluvial terraces beside the waterways near the hills and by the Namoi River are readily separated as low, middle and high terraces but these adjectives are not appropriate for the equivalent deposits on the plains, for the terraces, when traced downstream, lose the height differences that enable easy separation and disappear at the point where the alluvium becomes high enough in the channels to match the level of the surfaces formed on the older sediments nearby. Further down from this point - termed the *intersection point* (Hooke 1967) - the younger sediments spill out of the channel to spread over older deposits. The separate deposits which form the land surface thus become difficult to distinguish without drilling. This general pattern is varied only between the Newell Highway and 'Boolcarrol Farm' where the wide-spreading conjoined fans of Ten-Mile and Bulldog creeks, east of the highway, are confined, to the west, for a few kilometres in narrow valleys cut into older alluvium.

The terrace sequence described for the Namoi River is matched by similar terraces and fan deposits on the eastern tributaries, except that sediments matching the first terrace at the Namoi were not confidently identified. Alluvium related to the second and third terraces forms prominent fans on the eastern creeks, especially Bobbiwaa Creek. A prior course of Bulldog Creek is shown by its abandoned levee banks where it crosses the highway at Trevena Lane south of Bellata. At 'Noelurma' the reddish brown Bobbiwaa fan reaches nearly to Bald Hill Road; further south it joins with similar alluvium deposited by the Namoi River. In the north the alluvium extends past 'Yera' and 'Tarlee' towards Tarlee Creek but in this direction the sediments reach only to 'Green Timbers'. Alluvium related to the older, third terrace is partly buried by the reddish brown alluvium near Bald Hill Road at 'Noelurma' and 'Blue Hills'. Here the western edge of the Bobbiwaa alluvial fan feathers out as brown strips and patches over darker (grey and yellowish grey) clays of the third unit. These dark sediments are also well developed beside Mulgate Creek and across the wheat fields of the I.A. Watson Research Farm. The oldest (fourth) terraced fan forms extensive plains north and south of Bald Hill. It has dark grey colours to some depth but on well-drained land as at 'Boolcarrol Farm', 'Mulgamah' and 'Fairview' reddish brown colours are common.

Transect at 'Noelurma'

At 'Noelurma', by Bald Hill Road, and on adjoining properties to the north, cultivated fields show a prominent colour pattern. Brown and dark brown soils occur commonly as strips among grey and greyish brown soils. The brown colours mark deposits of the second terraced fan from Bobbiwaa Creek and show where the deposits have spread over the grey soils of the third terraced fan. A transect close to Bald Hill Road showed three layers (Fig. 18). The dark soil seen in the fields continues beneath the brown sediments and soils as a buried layer in which the original topsoil and subsoil of the third terraced fan is clearly visible. The buried topsoil grades up in most places to a second layer which is dark brown in colour but has a somewhat less well developed structure. This in its turn gives way sharply to brown and yellowish brown deposits of the second terraced fan, the contact being marked in places by coarse sands and rock fragments. At one site, ed332, a fourth, very thin layer, is present at the ground surface. This is apparently a late alluvial addition to an area that had already received new sediment.

Small patches of brown sediment occur in cracks in the buried dark grey soil. Similar patches are found in the overlying layer. They are also found at depth nearby, in the dark soils that escaped burial. These patches are most likely to be alluvial sediments or surface soil washed by rain and floodwater into open cracks. In many places on the plains deposits like these were seen, and where the sediment was sandy thin layers of coarse and fine sand were observed. The brown soil forming the ground surface is slightly acid but pH values of 8 to 9 occur in the subsoil. These values continue into the buried layers beneath. Small nodules and diffuse patches of calcium carbonate occur sporadically both in the buried topsoils and nearby soils not covered by fresh sediment.

The following explanation of the features seen in the drilled section is suggested. It would appear that flood waters that first reached this area were mostly accepted by the cracks in the clay soils so that the small quantities of sediment they carried became trapped underground as inwashed sediment. As the volume of surface water or frequency of flooding increased, greater quantities of sediment

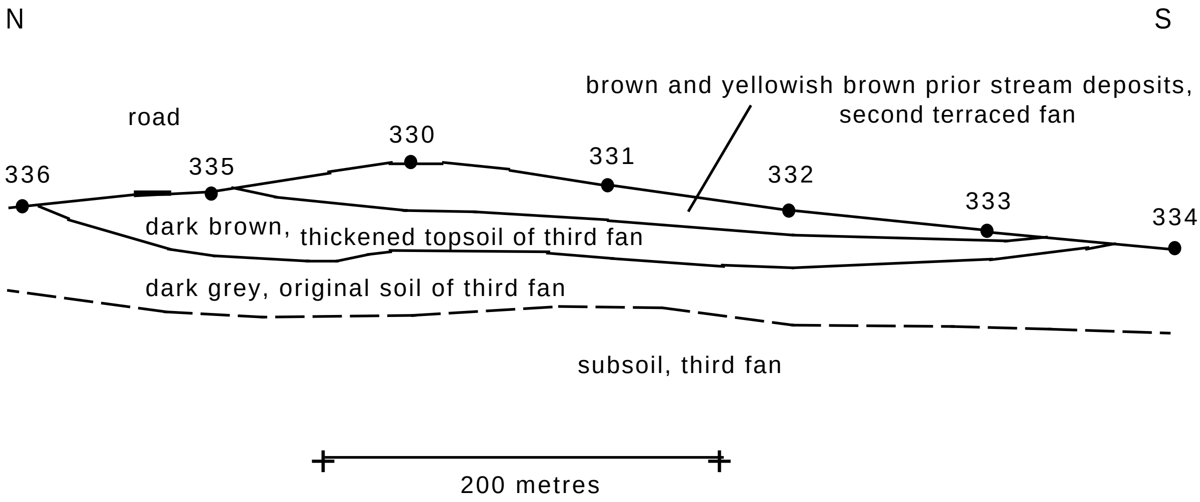


Figure 18. "Noelurma" transect, showing burial of the third terraced fan beneath prior-stream deposits. The original soil was at first thickened by the encroaching flood deposits and was finally overwhelmed as the quantities of sediment increase. Scale, vertical:horizontal 25:1.

became available. Wetting closed the cracks and sediment deposition began on the ground surface. At first, the vegetation was not seriously affected by the small quantities of new sediment. It survived, and each new increment increased the topsoil depth. But in time a flood came that brought enough sediment to overwhelm the vegetation, and buried the soil so deeply that a new soil began to form on the fresh material. Sediment was washed into cracks as they developed. Seepage of salts, and chemical changes that accompanied the weathering of the new sediment changed the pH of the buried topsoil. Small segregations of calcium carbonate formed in the adjacent soils.

Weakly eroded fan alluvium

An alluvial deposit with belah forest occupies high ground above younger terraces and alluvial fans in the area around Edgeroi siding. West of the Newell Highway its level steadily falls until finally, in this direction, it is overtopped by the younger beds. The landscape is very gently undulating in most places as a result of natural erosion over the long period it has been exposed to weathering, and the streams, Tarlee and Middle Galathera creeks, unlike those of the plains elsewhere, occupy broad, open depressions.

Terminology of the alluvial deposits

For convenience in the following pages the successive parts of the alluvial landscape are described in order of their age, from youngest to oldest: 'flood plain'; 'first terraced fan'; 'second terraced fan', etc.

3. Aeolian Landscape (by W.T. Ward and G.H. McTainsh[6])

Windblown sands have been found only at Yarrie Lake and Round Swamp, 27 km west of Narrabri, and at 'Bonny Hill' near Merah North.

At 'Bonny Hill' the homestead is built on a low sandhill that rises slightly above the surrounding alluvium. The sand is deeper than 10 m, however, showing that this is a larger dune that has been partly buried by sediment accumulation. The dune is associated with the first terraced alluvial fan and rests on the second one. The sands were probably blown from an old river bed, now concealed.

Yarrie Lake and Round Swamp lie on a relatively high, but slightly eroded alluvial plain, possibly equivalent to that at Edgeroi siding but in this case mostly composed of alluvium derived from sandstone. Wave action has provided the two water bodies with sandy beaches behind which, to the north-northeast, there are low ridges of blown sand, of crescentic outline, rising approximately 1 m above high water. Traces of the soil that was buried by the sand occur beneath the ridges (Fig. 19). The lake and swamp are both partly bordered now by low cliffed shore-lines. Sandy beach ridges occur especially on the southern shores. The shorelines were originally irregular but they are now circular as a result of shoreline erosion and the development of sand spits. Both water bodies are intermittently recharged from nearby drainage lines. Yarrie Lake is normally full of water but Round Swamp is often dry.

Dunes such as those on the north-northeast shores of Yarrie Lake and Round Swamp provide evidence of wind-blowing. Their crescent shape, in plan view, has provided the name 'lunettes', and their position on the lake shore indicates the direction from which the winds have come, for they must of course lie down-wind from the sediment source. Lunettes are formed usually of sand blown from a lake shore but in southwest New South Wales lunettes of clay are also known, the variation being due to different conditions at the time of lunette formation. Well-sorted sands imply high water, active shoreline erosion, longshore transport of sediment, and active beach building to provide a sand source. Clays indicate falling or low lake levels, with exposure of the fine sediment of the lake bed to drying conditions and wind transport. Thus a transition from quartz sand to clay in a lunette or sequence of lunettes is evidence of a change in the hydrology of a lake basin, and reflects a change in the climate (Bowler 1973).

The dense forest around Yarrie Lake and Round Swamp, and sheltering them from the wind today, must have been absent at the time the lunettes were formed for otherwise the wind could not blow the sediment from the lake shore and swamp beds.

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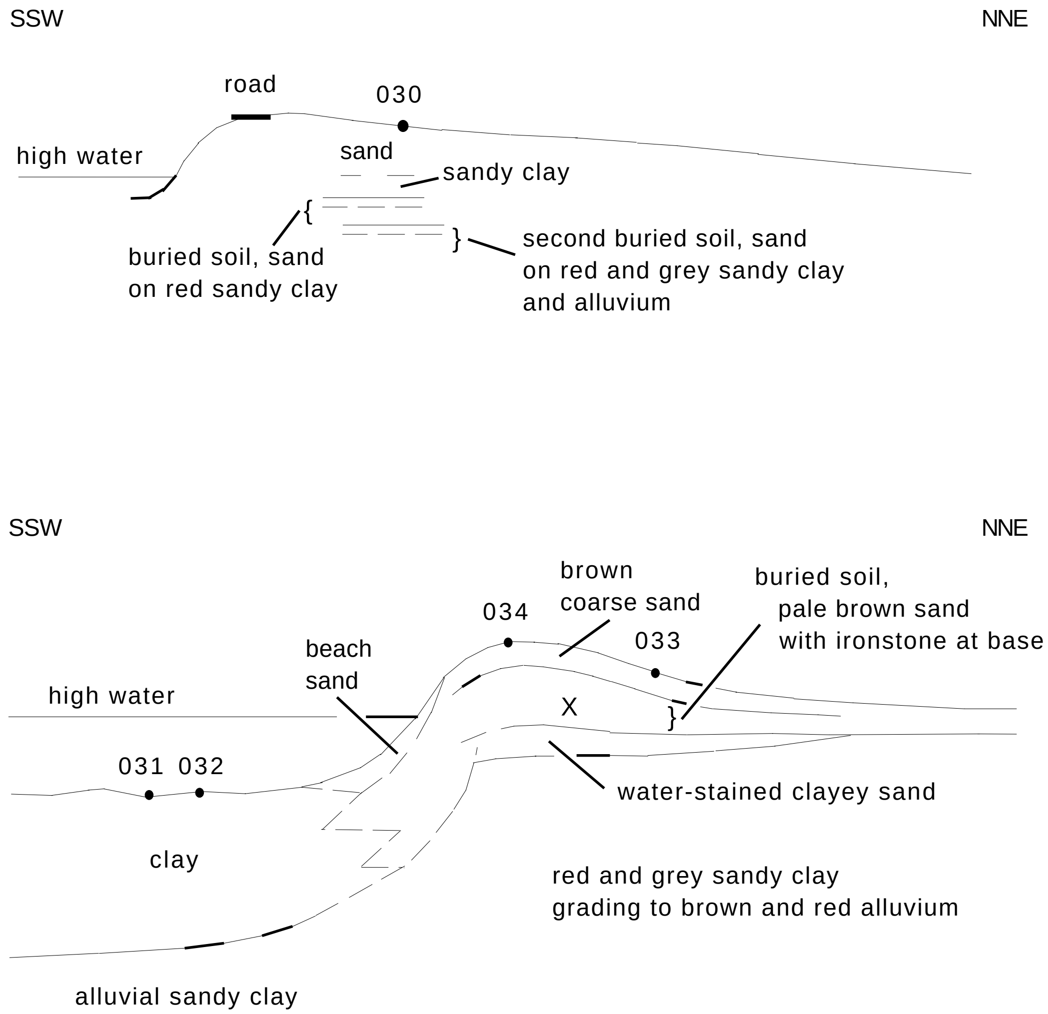

Figure 19. Lunettes at Yarrie Lake (top) and Round Swamp. A sand sample (×) gave an age of 13 000 - 13 400 years BP. Scale, vertical : horizontal 20 : 1.

Transects at Yarrie Lake and Round Swamp

A detailed study could not be made at Yarrie Lake because of the high water level. A levelled traverse (Fig. 19) was made of the lunette, and a soil core confirmed the sequence shown in a nearby quarry, where a duplex soil is developed in blown sand above a partly truncated prior duplex soil formed on alluvium.

The transect at Round Swamp begins in the swamp and bisects the lunette. The bed of the swamp is formed of dark grey clay and has a slightly gilgaied microrelief, with regularly distributed patches of sand on the clay. Soil horizons and sedimentary structures are not well enough developed to confirm active gilgai shrink-swell deformation. The clay is two metres thick, and lies on weathered alluvium containing patches of lime.

The lunette consists of deep sand over sandy clay, to form a duplex soil profile, and is two metres thick at the highest point. Coarse, irregularly-shaped ironstones rest on the sandy clay at the base of the deep surficial sands. Red-weathered alluvial beds lie beneath the sandy clay, close to the highest swamp-water level. At greater depth these beds are like those beneath the clays in the swamp. The sands at the ground surface of the lunette show traces of bedding possibly because of recent wind disturbance. The duplex soil profile developed on the lunette shows that the main episode of sand-blowing is of considerable age, however.

The drilled section shows that an alluvial landscape with red soils was subjected to wind erosion which produced a hollow - now occupied by the swamp - and a lunette in which a sand-on-clay soil has developed. Two metres of clay have since accumulated in the swamp. Particle-size analysis shows that these include a significant windblown component. The dark coloured organic matter in the clay indicates soil formation and implies that the swamp has often been dry. There were possibly two episodes of clay accumulation, and the thickness of the clay could have been augmented by sediments brought in by surface wash.

Aeolian dusts

Unlike windblown sands, aeolian dust deposits (i.e., clayey loess, or *parna*, Butler and Hutton 1956) are difficult to recognize because they do not produce distinctive landforms. A *prima facie* case for the presence of parna, however, is made by the occurrence in a landscape of a uniform calcareous clay layer above diverse substrates (Butler 1958). The common occurrence at the ground surface in the Edgeroi district of clay mostly lacking signs of textural variation or watersorting, lying above different rocks, thus suggests that it might have been transported there by the wind, but this is difficult to prove owing to the seeming lack of distinguishing criteria. A windblown origin could explain the uniform soils across Galathera Creek, where contrasting soils would be expected from the differences in the alluvium supplied on the west by the Namoi River and on the east by the tributaries of Galathera Creek.

Sediments that are deposited from the air fall equally on land and water, on hills and plains, and on rocks of all kinds. Unlike wind-drifted sands, which usually develop into dunes, air-borne dust is spread uniformly, and new landforms are not usually created. The rate of sediment deposition is mostly slow, allowing ample time for modification by rain splash and local runoff, and for the incorporation of the dust in soil by earthworms, ants and burrowing animals. Where rainwash is effective the wind-deposited sediment is soon transported to an alluvial situation. These circumstances - the lack of a characteristic landscape, rapid inclusion in soil, and susceptibility to surface wash and erosion - make it difficult to recognize the occurrence of significant dust deposits.

At first the dust is mixed with the original soil but as deposition proceeds the proportion of dust increases, and in time the original sediment and soil pattern is overwhelmed by the new contribution so that the final result is a landsurface mantled with windblown material.

The detection of windblown dust in a landscape relies firstly on the identification of a layer of sediment that is fine enough for transport as dust by the wind. This layer would occur on different rocks and landforms, and would be generally present, except where rainwash has removed it. The layer would not occur on landscapes formed since sediment deposition.

A second proof of an aeolian sediment is given by mineral peculiarities, for dusts carried by the wind might contain unusual minerals derived from the rocks exposed at a distant dust source. In the same way, the presence of an ordinary mineral assemblage over an uncommon rock, in places where other means of sediment transport can be ruled out, can show that dust is present in the target area. In soils developed on wind-borne material the original minerals are normally reduced by weathering to the resistant residual grains, e.g. quartz.

A third proof derives from the fact that large particles cannot be carried in suspension by the wind. Such transport is limited to grain sizes mostly smaller than 30-50 µm, i.e., fine sand, and air is rarely still enough to let the smallest particles of silt and clay settle to the ground, except as aggregated particles, as with parna. Thus an aeolian sediment is, in a fashion, 'finger-printed' by a size-frequency peak in the 30-50 µm (0.03-0.05mm) grain-size range (McTainsh et al. 1988). Smaller fractions are carried to great distances, finally to be washed from the air in rain. Dust movement within Australia on a continental scale is discussed by McTainsh (1989) in relation to climatic conditions; he shows that a major dust path passes over the Namoi area.

Historical evidence of wind erosion is available for the study area. Most residents have first-hand experience of dust storms which, at the very least, scatter debris, as well as cause a loss of soil from a district. One in 1923 was described by Mr S.A. Thompson of 'Pendennis', Merah North, as follows:

> Thursday the 20th September 1923 will long be remembered in these parts as 'Black Thursday' - a hurricane started about mid-day and continued till 6 pm. In parts the surface was swept of all vegetation and bore drains were filled up level with rubbish, dust etc. In places fences collapsed and others had dirt etc piled up against them over 3 feet deep. This was the worst dust storm I have seen for over 20 years.

And on Thursday on 13 September 1928:

> Terrible wind and dust-storm, at times couldn't see more than $^1/_4$ mile.

The 1920s and 1930s are remembered as years of drought and dust-storms in western New South Wales and South Australia. The dust-blowing is attributed not so much to hurricanes or terrible winds but to inappropriate farming systems or over-cultivation of land not suited to agriculture (Williams 1978), or to overgrazing by sheep and rabbits (Ratcliffe 1936, 1937, 1938). Others have said that clearing and agriculture had lowered water tables and allowed the soil to dry out, making it susceptible to wind erosion (Anon. 1936, 1937). It might be argued, therefore, that the dust storms described by Mr Thompson were due primarily to human interference with the natural landscape, and are thus not relevant to the present study, which is concerned with the possible occurrence in the Namoi Valley of windblown dust as the result of natural events. Other evidence, however, suggests that human activities were not entirely to blame.

Coastal sand movements in southeast Queensland, and changes in the shoreline there (Ward and Russell 1980; Ward 1984), give evidence of nation-wide changes in wind strength and frequency that built up through the first decades of the twentieth century to reach a peak in the 1930s. There were associated changes in rainfall. These changes are enough to explain the dust-blowing. Wind erosion in the 1930s, however, was seen to occur first on pastures weakened by grazing and on fallowed land, and it seemed to contemporary observers that the farmers had caused the erosion by clearing, over-stocking and cultivation, with the result that the farmers, and government farm policies, were held to be responsible. No doubt hard grazing and cultivation had contributed to the erosion problem, but the important changes in the wind were not noticed.

Field evidence of an early period of wind erosion is found in the section drilled at 'Murrumbilla', where a buried clay soil occurs between two beds of colluvium (Fig. 14). Both beds contain fragments of local rocks but the lower bed is rich in clay. The buried soil formed on it strongly resembles the Grey Clays of the western alluvial plains. It must once have formed the ground surface in the catchment. The overlying sediment is less clayey and has sand-over-clay soils that are typical of the modern slopes. Both colluvial beds terminate abruptly at the foot of the slope, at an old watercourse now filled with alluvium of the second terraced fan. The differences between the two colluvial beds and their soils show that they cannot both be derived equally from the limited hillside catchment in which they occur for the clays in the older bed have no obvious source there. They are best explained as dust introduced by wind-blowing before the younger colluvium and alluvium had appeared. Particle size analysis supports this view.

Soil samples were taken from several localities for detailed particle size analysis to find if a windblown fraction could be identified. Samples were taken from the section at 'Murrumbilla', from the plains, from residual rocks and elsewhere. Soil from the basalt crest of Bald Hill was examined, for any quartz there must have been blown there by the wind. Samples were also taken from a low (60 cm) mound of clay measuring 100 × 180 m on 'Waugan' near Bald Hill, on an otherwise perfectly flat plain. This unusual feature might be the remnant of an ancient clay dune.

The buried soil on the clayey colluvium at 'Murrumbilla' and the samples from Bald Hill, 'Waugan' and elsewhere were found to contain a high proportion of quartz sand peaking between 30 and 50 µm (see Fig. 20), indicating that aeolian dust is widespread and forms a veneer on the older plains (about 1 m on the third terraced fan, 3 to 4 m on the fourth, and variably on the weakly eroded alluvium of

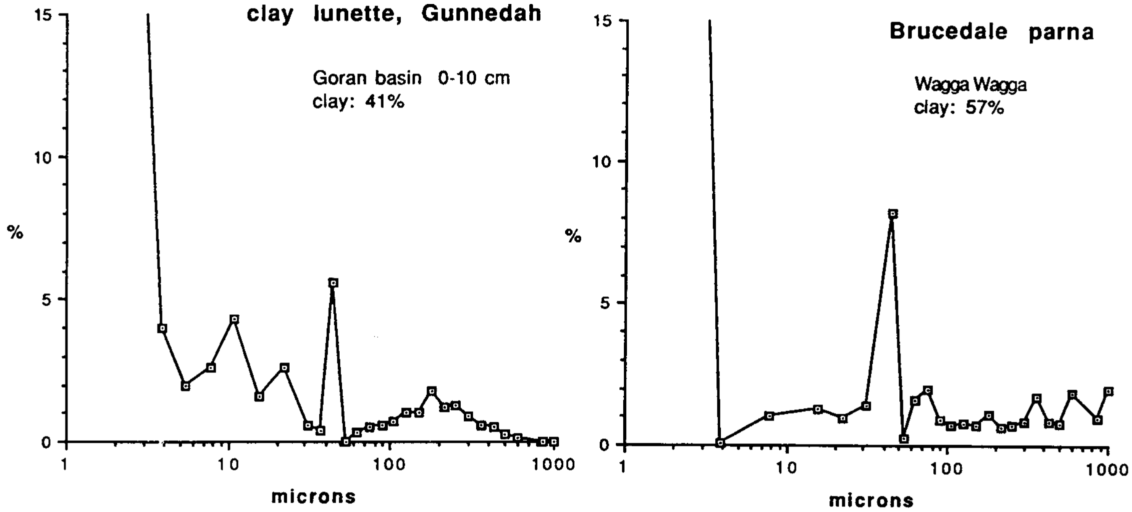

Figure 20 (parts 1, 2, and 3). Particle sizes of soils, some parent sediments, and dune sand, with percent plotted against size in µm. The analyses used pipette analysis at ½- and 1-ϕ intervals below 31 µm, wet-sieve analysis at ¼-ϕ intervals from 31 to 90 µm, and dry-sieve analysis at ¼-ϕ intervals above 90 µm (McTainsh et al. 1988).

Part 1 (above): Results, for reference, for a clay lunette and for Brucedale Parna (Beattie, 1972, sampled by W.T. Ward and A. Dare-Edwards). Note the relatively high proportion of sediment at 30-50 µm in these aeolian sediments. These are the largest sizes that are supported by the wind. Fractions above 60 µm are usually from local sources and travel by surface wash or by bouncing along the ground. The diagnostic peak at 30-50 µm is composed of minerals that resist weathering; other material originally in this range has certainly been broken down, to contribute to the smallest fractions. The peak's small size does not therefore mean a small content of windblown material.

The Pilliga and Tertiary sandstones (parts 2 and 3, following pages) are typical of sediments with no aeolian component. Note the lack of a 30-50 µm peak in these rocks and in old alluvium (ed236, na033). The peak is prominent in the gilgai at Bohena, in the knoll at "Waugan", in the residual soil at Bald Hill, in the soils on the older terraced fans (ed220, na017), and in the wind-drifted lunette sand. It can be detected in places in colluvium, e.g., ed187, and is present at "Murrumbilla" (ed344; the sample is from the buried soil found in the drilled pediment section).

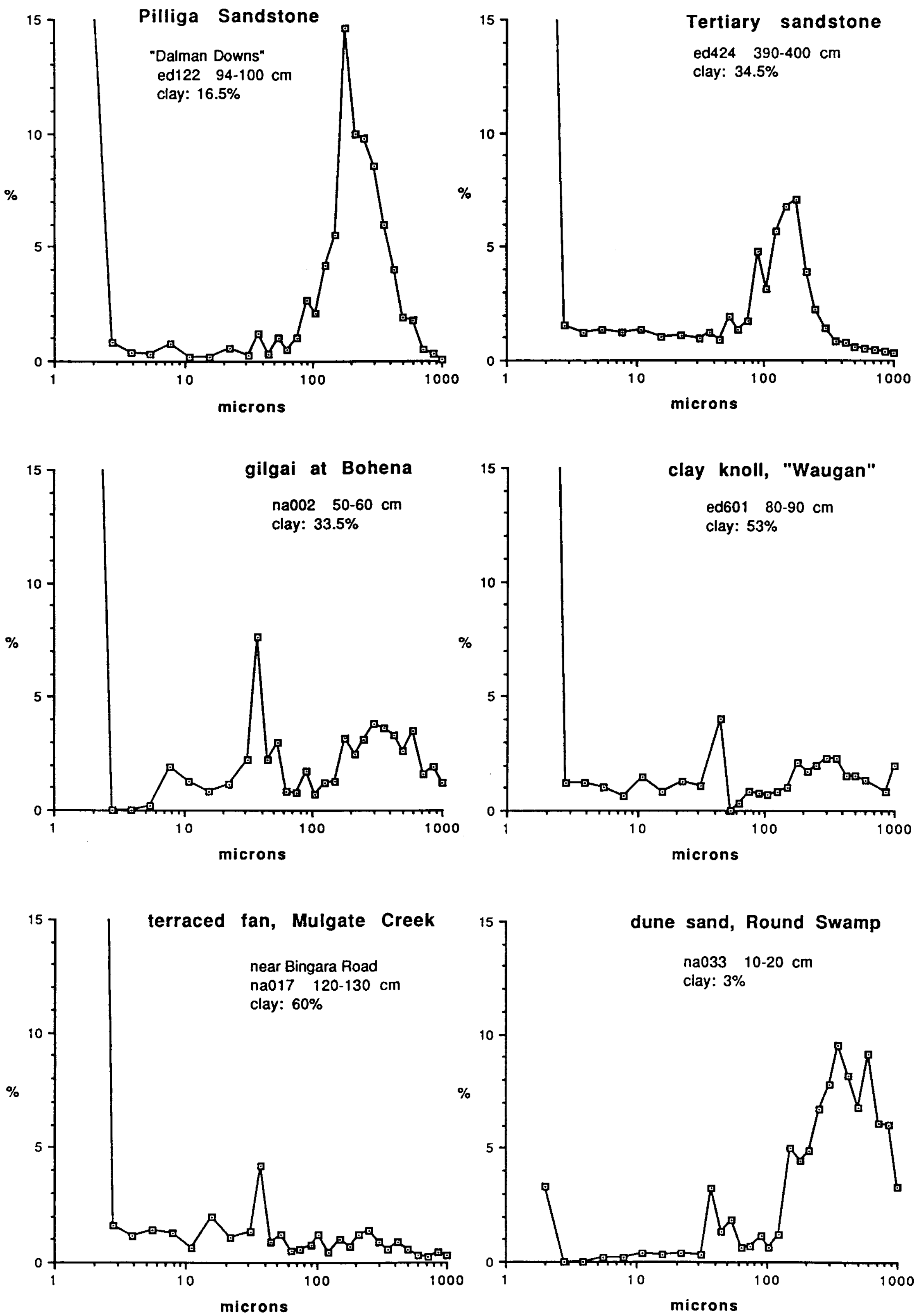

Figure 20 (part 2).

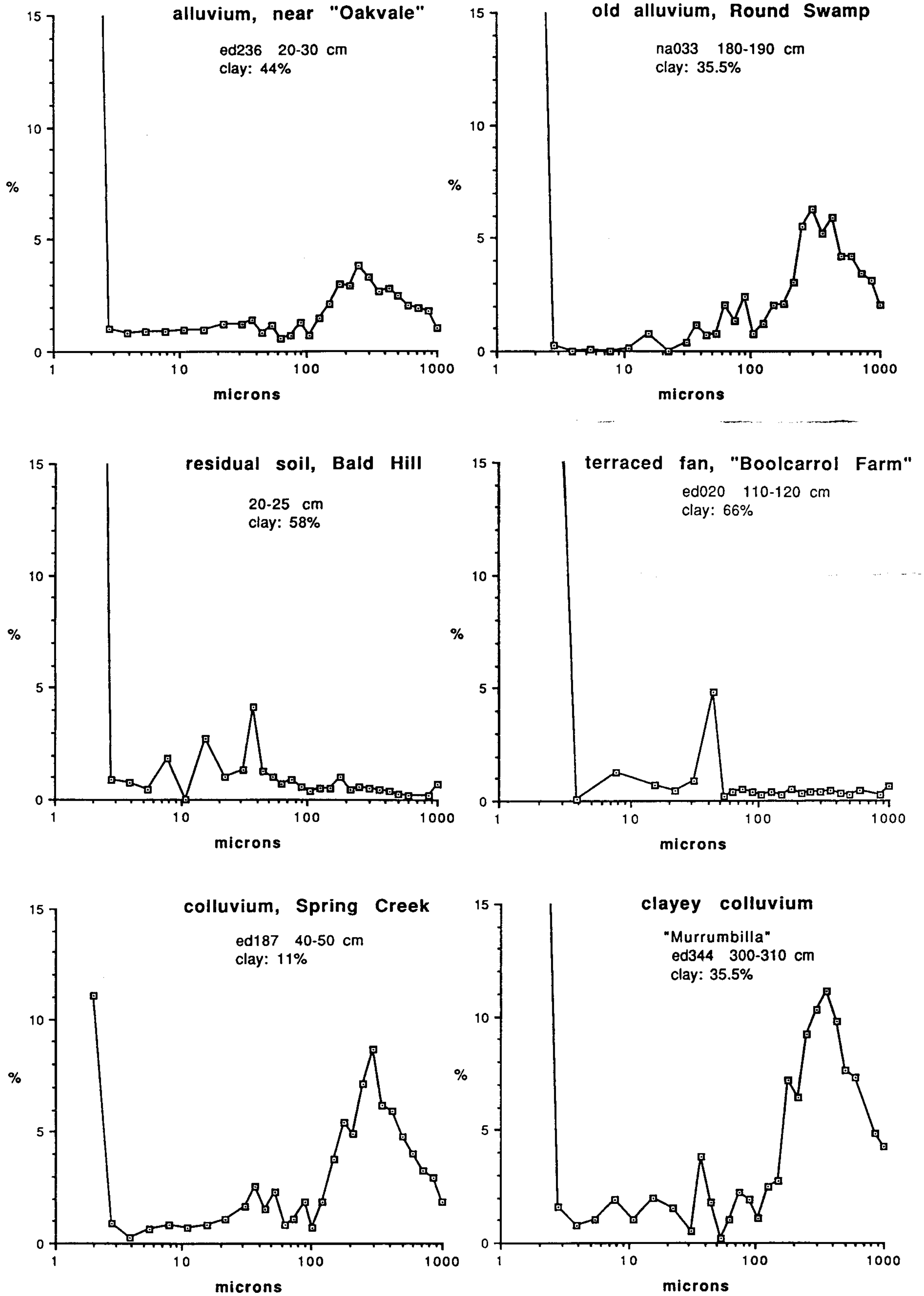

Figure 20 (part 3).

the old fan around Edgeroi). Small quantities of dust occur in some soils on residual rocks, and some is trapped in Round Swamp. The windblown sediment cannot be identified by eye, however, because it has been affected by rainwash and has acquired the appearance of alluvium. Moreover, its texture is fine and sediments of local origin are included.

It follows from the observed field relationships and particle-size data that the older wheat and cotton soils of the Edgeroi district are formed largely on wind-blown dust, deposited in an ancient semiarid period. The dust storms which occurred in historic times have not left a comparable record.

Transects of dust-mantled landscapes at Bohena, south of Narrabri, and at 'Llano', near Bald Hill, give details of soil variations in relation to surface stratigraphy.

Transect at Bohena

This transect was made to obtain information about the gilgai soils which occur in this locality. They carry brigalow *(Acacia harpophylla)* and reach an amplitude of 2 m. North of the Namoi River gilgai are rare and small.

The transect commences near Bohena Creek at grid reference Narrabri 598298 and follows the adjoining road west for a distance of 3 km. The first site is located on a terrace equivalent to the second terraced fan of the Namoi River but the remainder of the transect is on a single higher level at constant elevation. Yellow duplex soils occur on this level near Bohena Creek, and strongly gilgaied grey clays with brigalow further west. The yellow duplex soils are on sandy alluvium. Red colours are prominent at depth and their pattern and relation to natural partings give evidence of a prior soil condition.

To the west the duplex soil appears to grade laterally to grey clays with prominent gilgai but the drill cores show that the red-weathered material descends beneath the grey clay, with clear evidence in cores na007 and na008 of stratigraphic burial. The red alluvium is sandy at depth but near the top it consists mostly of clay occasionally with thin lenses of coarse sand. This alluvial clay is not easily separated from the overlying grey clay, for the red colours become intermingled with the grey and are less common higher in the section.

The beds are readily differentiated by particle-size analysis, however, for fine sand is abundant in the upper part but not in the red and grey-mottled clay. The fine sand is 30-50 µm in diameter, the characteristic size-frequency peak of wind-borne sand, and shows that the gilgaied clays are aeolian in origin. The wind-blown origin is consistent with the evidence of burial. Moreover, if aeolian sediments are present in the district it is likely that they should be here, because of the lack of surface drainage. To summarise, the transect reveals an early red-weathered surface, now partly remodelled by weathering to yellow duplex soil, and partly buried beneath grey aeolian clays that now support brigalow. The detailed core descriptions suggest that a break possibly occurs within the aeolian clays near 0.8 m.

Transect at 'Llano'

Although windblown clays rest without sign of watersorting on a prior alluvial soil at Bohena, on the plains north of the Namoi River they appear generally to be partly watersorted by surface wash, for there are thin lenses of laminated sand in some places and occasionally coarse sands and gravel, and the sediments pass at depth into alluvium. A series of cores was recovered from a line transect from site ed022 on 'Boolcarrol Farm' to site ed040 on 'Llano', drilled to identify the parent sediment and to obtain data that might explain an obvious trend in the surface soils, which are brown and well-structured in the north, and greyish brown and poorly structured in the south (Fig. 21). It was thought at first that these features might indicate that the soils in the north were those of the second terraced fan, and that the change towards the south might be due to these sediments thinning out over an older fan surface. This impression was not supported by the results of drilling.

The section revealed by the cores showed three main layers (Fig. 22). The first layer extends from the surface to a depth about 0.8 m and is thickest in the south. It is stained with organic matter and is brown to greyish brown in the south (layer 1A) and dark brown in the north (layer 1B); the change from A to B occurring at ed370. There is a progressive change in colour and structure from north to south and no convincing sign of a sedimentary break.

The second layer (2) extends to a depth of 3 to 4 m and has prominent carbonate concretions at the base. It is mottled dark brown and grey in the south (2A). In the north it is differentiated so that its upper part is dark brown to dark reddish grey (2B), with the lower part showing mottled dark grey and dark reddish grey colours. The mottling is due to slow drainage and the changes from site to site indicate worsening drainage from north to south.

The third and deepest layer begins with an ancient buried soil. This is best shown in core ed362 but the prominent carbonate concretions in the other cores at the base of the second layer seem to mark similar breaks. Beneath the buried soil and carbonate the sediments are dark, medium-textured and mottled in the north (3A) and browner and sandier, with some evidence of depositional banding (3B) in the south. The colour changes are due to differences in drainage, but in this case the better-drained material is in the south, in contrast to layers 1 and 2.

The colours of the second layer reveal an increasingly poor drainage with distance from north to south as the depression between the Ten-mile and Galathera Creek alluvial fans is approached. This worsening drainage is probably the cause of the change in topsoil colour and the trend in surface structure. A detailed study shows that the soil structure involves interactions of sodium, calcium, and clay

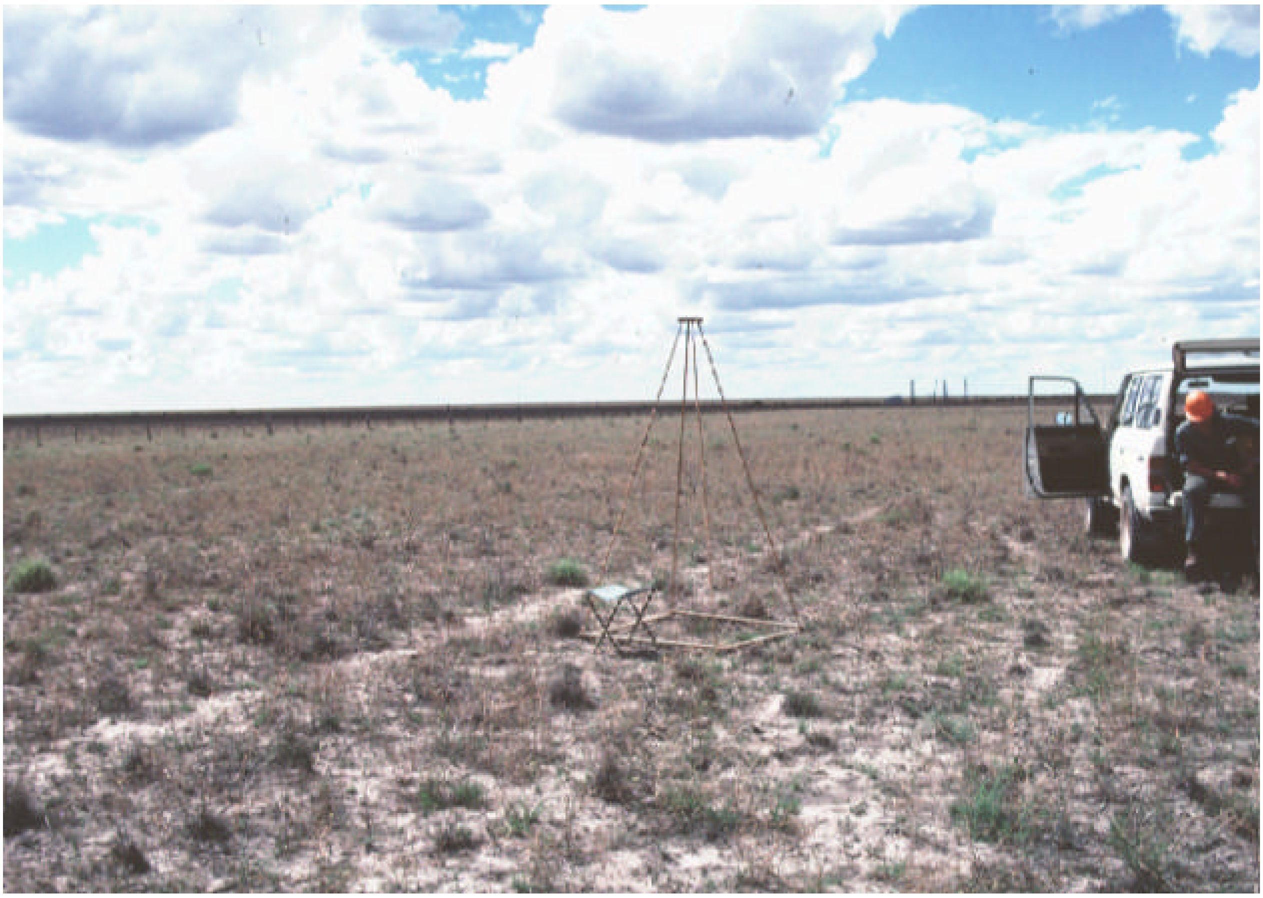

Figure 21. Site ed367, "Llano". View north, along the line of transect, showing Meriah medium clay, hardsetting phase, on water-sorted aeolian clays over prior alluvium. This is a site with poor drainage and high salt content (Group 3b, Tables 8.4, 8.5). This is sample site 3 of Little et al. (1992).

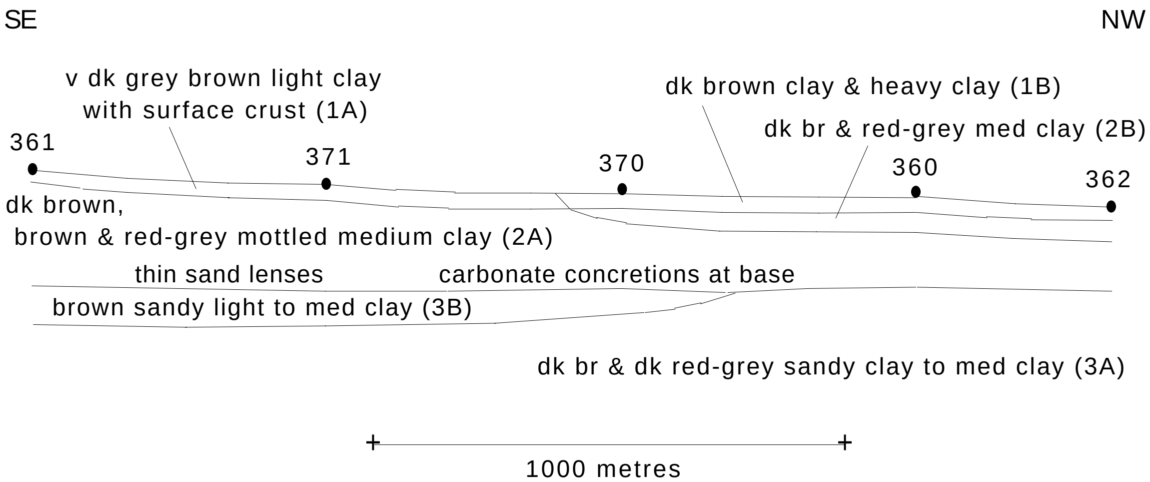

Figure 22. Drilled soil transect at "Llano", showing subsurface layers. Scale, vertical : horizontal 40:1. Site ed367 (see Fig. 21) is 200 m SE of ed371.

contents (Little et al. 1992). Particle-size analysis supports the view that the sediments above the buried soil are water-sorted aeolian clays. The buried soil marks an original alluvial surface spreading from Ten-mile Creek. The beds in the subsurface (layer 3), where the opposite drainage condition is observed, are possibly from Galathera Creek.

The sequence of transported sediments in the Edgeroi district is summarised in Table 3.

Terrace-sediment unit
flood plain
first terraced-fan (and "Bonny Hill" dune sand; lunettes at Yarrie Lake and Round Swamp)
second terraced-fan
third terraced-fan with aeolian clay veneer; younger "Murrumbilla" colluvium
fourth terraced-fan with aeolian clay mantle; older "Murrumbilla" colluvium and its buried soil; red palaeosol
eroded (fifth) fan

Table 3. Sequence of transported sediments near Narrabri and Edgeroi.

4. Red-weathered landscape

Highly coloured, partly red-weathered sediments are exposed in a few cuttings and pits, such as in the lower part of the road cut west of Bohena Creek at Cain's Crossing, south of Narrabri. They were also found at several places during field sampling, for example, in ed067 at 'Moema', ed242 at 'Woodville', ed337 at 'Murrumbilla' (see p. 22), at 'Oakvale' (pp. 24, 25), na033 at Round Swamp, na030 at Yarrie Lake, and in all sites drilled near Bohena. The red colour is a consequence of weathering, for it marks the sedimentary rocks irrespective of their original lamination and thus must have developed after the sediments were laid down. It occurs usually in patches that can be of several centimetres diameter, and was found in some cores over a depth of 3 to 4 m. The patches occur typically where the soil is dense, and are separated by zones of yellowish brown and grey which follow cracks and other voids. Where soil aggregates are well-formed, the centres are red and the external faces are yellowish brown or grey.

Although its restriction to the weathered zone shows that it was formed by subaerial processes, the red-weathered material is not closely related to the present groundsurface. It does not occur, for instance, on erosional slopes that are undercut by streams and thus made unstable; yellow and yellowish brown soils are typical of these situations. At 'Moema', for example, the red soil colours are found on slopes that terminate, not at a drainage line, but at the foot of a spur protected from stream erosion by terraced alluvium. This relation of the red colour to protected slopes indicates that the colour marks the landscape of a former time. At Cain's Crossing, the red-coloured beds are exposed beneath the sediments of a young terrace. At Round Swamp and Yarrie Lake, they occur in alluvium beneath the swamp and beneath the sand lunettes. At Bohena, they are associated with a ground surface partly buried by aeolian clays, and the aeolian clays are also partly stained with red. It is assumed that these occurrences are the records of a single episode of weathering for there are no observations that suggest that the red-weathering occurs at more than one level.

The different field occurrences show that the red colour is associated not with present-day conditions, but with a former groundsurface now reduced in area as a consequence of landscape development. From the patchwork of red, yellowish brown and grey in the soil, and the association of these colours with natural partings, it can be accepted that the red colour was once more extensive and is being modified by the entry of water and hydration of the red minerals.

It is inferred, therefore, that the red colour implies oxidation of soil minerals, whilst the enclosing yellowish brown and grey colours show greater degrees of hydration, induced subsequently by water percolating slowly through the soil in reducing conditions. It is likely that the red weathering required free drainage, seasonally dry conditions and a warm to possibly hot environment. In today's Edgeroi landscape bright red colours are developed on well-drained sands, as at ed193, and reddish-brown colours on well-drained clays, as at ed014, but red colours in clay as in the red-weathered material do not occur.

The red weathering has affected both hillslopes and plains, but was not seen on the alluvial fans and terraces north of the Namoi River. Its distribution on hillslopes is scattered owing to natural erosion of the hillslopes, and perhaps because of weathering in moist sites. The red weathering was frequently observed on the plains south of the Namoi River during drilling, in cuttings and in the spoil from earth tanks.

Because the identification of a 'red-weathered past landscape' is based simply on the colour of a relict weathered material and its pattern, and because red shades occur frequently in soils, Munsell colour notations are given here. The observed colours are: dusky red (10R3/4), dark red (10R3/6, 2.5YR3/6), weak red (10R4/4), red (2.5YR4/6, 4/8, 5/6), reddish brown (2.5YR4/4), and yellowish red (5YR4/6, 4/8, 5/6, 5/8). Inherited red soil colours which occur on alluvial terraces and stranded marine platforms in east Gippsland, Victoria (Ward 1977) are discussed later in relation to landscape chronology.

5. Comparison with Riverine Plain

The Riverine Plain, in southern New South Wales, strongly resembles the lower Namoi Valley in its landscape, has similar soils, and has been the subject of thorough study. Concepts derived there have been applied to the Namoi Valley (Stannard and Kelly 1977). Thus a comparison with the lower Namoi Valley is worthwhile. Five depositional units in the Riverine Plain are known to contribute to the modern landscape above the modern flood plain (Butler 1958; Table 4).

Unit
modern flood deposits
Coonambidgal terrace sediments and alluvial sheets - deposits of ancestral rivers. Source-bordering dunes are associated with old river channels. Some lunettes (Colongulac dune parna) are possibly of this age
Mayrung prior stream deposits - associated source-bordering sand dunes occur in places
Widgelli Parna - windblown clays spread uniformly as sheets over the contemporary landscape
Quiamong riverine sediments - found beneath Widgelli Parna
Katandra sediments - a riverine and aeolian complex separated from younger units by a deeply leached palaeosol and in places by other parna

Table 4. Sediments of the Riverine Plain (Butler, 1958).

Review

The alluvial beds of the Riverine Plain were deposited by the Murray and Murrumbidgee rivers and their tributaries as the plain developed. The oldest beds record abandoned river courses and the youngest (Coonambidgal and modern) occupy more recently developed channels. Low scarps set off the Coonambidgal sediments from the alluvial landscape generally, for these sediments only partly fill trenches cut by the rivers in the broad plains. In a similar fashion the Coonambidgal terraces are separated from the modern flood plain. The oldest stream deposits are not topographically distinct except in the upper reaches of the plains where the channel deposits are slightly above the general level. Here 'the Quiamong... occurs as separate ribbon-like lobes... and... out on the plain these lobes broaden and tend to become continuous laterally', like the Mayrung deposits

(Butler 1958). The alluvial beds therefore form fans like the alluvial terraced-fans of the Namoi River.

The ancient abandoned river courses vary in the appearance of their channels and the different kinds have been described as prior streams and ancestral rivers (Butler 1950; Pels 1964). The prior streams are believed to be the oldest. They have broad, shallow, relatively straight channels filled with sand, the bedload of the ancient river, and terminate on the plains. The ancestral rivers carried a greater proportion of silt and clay than the prior streams and are believed to be suspended-load streams, like the modern ones. They have a much larger meandering form, however, and a greater channel size. The modern rivers are sinuous, narrow and deep.

The environments associated with riverine sedimentation have been extensively debated. Butler (1958) associated the prior streams with climates that were more arid than the present one. He cited the brief lapse of time between the Mayrung alluvium and the Widgelli Parna, which was clearly the product of arid conditions, the lack of soil between the parna and the underlying Quiamong beds, and the fact that the prior stream pattern does not cross the Riverine Plain, whereas the present rivers do. He concluded that the Quiamong and Mayrung deposits were associated, respectively, with the climatic changes leading into and out of the arid period that provided the Widgelli Parna. The Coonambidgal system gave evidence of another perhaps less arid phase.

Langford-Smith (1959, 1960) disagreed with Butler: the widths of prior streams and meander-belts implied much larger river discharges and higher flood peaks than at present. Riverine deposition had taken place in humid, not arid, times. The channels had subsequently silted up. Butler considered that in humid ages the rivers had carried the sediment across the plain to be lost downstream. The higher rainfalls had enabled the ancestral rivers to drain to the Murray.

Butler (1959) used a nomenclature that related the mapped soils and sediments to time intervals named K-cycles. A K-cycle had an unstable phase, during which older soil landscapes were destroyed or buried, and a subsequent stable phase, when soil development occurred on the new *groundsurface,* that is, on the land surfaces of all kinds that formed in one K-cycle. Three groundsurfaces were recognized: the K_1 (Colongulac dune parna and Coonambidgal alluvium); the K_2 (Mayrung alluvium, Widgelli Parna, and Quiamong alluvium); and the K_3 (Katandra). Prior K-cycles (K_4, K_5) were found as subsurface burials elsewhere.

Infilled prior stream channels simply implied a migration of the locus of deposition, not historic change, according to Stannard (1962). Langford-Smith revised his earlier opinion and (Langford-Smith 1962) associated alluvial deposition with the change from humid to arid times. Dury (1963) recognized that larger discharges would lead to erosion and sedimentation; he was in favour of Langford-Smith's new position. The different viewpoints concerning the relation to arid and humid phases seemed now to be reconciled; theoretical arguments were less important than observed stratigraphy (Cotton 1964). Lawrence (1966, 1976) grouped Butler's sedimentary units together and gave them formal geological names. He defined two formations (Coonambidgal, Shepparton) and recognized five members in Shepparton Formation (Mayrung, Widgelli, Quiamong, Katandra and Kialla members). Pels (1966) divided and extended Butler's Coonambidgal unit.

Schumm (1968) made an exhaustive study of prior stream shapes and agreed with Butler: the prior streams had seasonally high flood peaks but low annual runoff. The climate was drier than today but whether cold or hot could not be distinguished. The ancestral rivers had the highest discharges and indicated a wetter climate, denser vegetation, and less sediment yield from the headwater basin. The modern highly meandering rivers reflected decreased runoff.

In southwest New South Wales glacial-age lake levels changed with the changing seasons (Bowler 1975). Hot and dry westerly winds prevailed and reduced the water levels in summer. Clayey pellets from the dried lake beds were swept onshore, in late summer and early autumn, to accumulate as lunettes. In South Australia (Williams 1973), vigorous sand-blowing was identified with the peak glacial age, from 24 000 to 16 000 years B.P., after prior alluvial deposition to 30 000 yr and brief soil formation.

Bowler (1978) found that Coonambidgal deposition, ancestral rivers and dunes were active at the time of the last glacial maximum. Ancient stream channel shapes were too diversified to enable the simple correlation with age that had been reported; prior stream forms were final phases that concealed earlier stages with different forms.

The climate during the last glacial-age was strongly seasonal (Bowler 1978). The winters in the highlands were cold and severe, with much snow. Late frosts, high winds and short growing seasons prevented afforestation of fragile catchments. High runoff in spring and summer carried sand and gravel to the plains where, in winter, low water levels allowed the sand to drift. As the glacial age ended, warmer summers permitted the plant cover in the catchments to improve. There was less runoff, slopes stabilised, and less sand reached the streams. Low temperatures in glacial ages explained the greater river volumes (Bowler et al. 1978); the absence of forest in the catchments explained the fast runoff and high flood peaks. Sands blown into the Darling anabranch might have enlarged its meanders. Bowler's later work (1980) on the Woorinen sediments near Mildura implies a limiting age of 0.4 m. yr for the deposits of the Riverine Plain.

Thermoluminescence datings by Page et al. (1989) place the last phase of prior stream activity and some ancestral rivers in the interval from around 90 000 yr (most datings) to 45 000 yr B.P. Other ancestral rivers by the Cadell Fault near Echuca provide dates of 30 000 yr.

Resume and application to Namoi Valley

To summarise the riverine sequence from southern New South Wales: early deposits of varied origin (Katandra sediments) are separated by a well-developed palaeosol (Katandra soil) from younger alluvium (Quiamong) which grades up, in most places, without much sign of weathering, to windblown clay (Widgelli Parna) that is followed in its turn by alluvium mostly with reddish brown soils (Mayrung) and by weakly weathered alluvium that forms low terraces (Coonambidgal) close to the modern flood plain.

This history equally describes the lower Namoi Valley, if the units identified in the present survey are substituted for the southern ones (Table 5).

Namoi Valley	*Riverine Plain*
modern flood plain	modern sediments
first terraced fan	Coonambidgal
second terraced fan	Mayrung
third terraced fan (aeolian veneer) fourth terraced fan (aeolian veneer)	Widgelli Parna
third terraced fan (alluvium), younger "Murrumbilla" colluvium, alluvium below watersorted parna at "Llano"	Quiamong
"Murrumbilla" buried soil, red palaeosol at "Murrumbilla", buried soil at "Llano"	Katandra soil
older Murrumbilla" colluvium fourth terraced-fan alluvium eroded (fifth) fan	Katandra sediments

Table 5. Apparent relation of Namoi Valley terrace-sediment units to Riverine Plain sediments.

Ancestral river channels have not been identified in association with the deposits of the first terraced-fan in the Namoi Valley. This is not a significant difference, however, for the ancestral river form is apparently associated with glacial-age maxima, and is concealed by, or degraded to, the prior stream form as sedimentation proceeds.

There is no obvious reason why the history of climatic change inferred for the Riverine Plain should not be extended to the Namoi Valley. The periglacial environment of the southern highlands would be more limited in the headwaters of this region, of course. It may be significant that in the Namoi Valley prior stream channels are associated with source-bordering dunes in only a few places. This could indicate a better vegetative cover by stream lines, less intense winds than in the Riverina, or possibly a less variable river flow.

The widespread introduction of parna, and interrupted alluvial deposition, are well explained by low rainfall and open desert conditions, for present-day dust-storms are frequent where the annual rainfall decreases to around 200 mm (McTainsh et al. 1989). Furthermore, alluvial deposition is limited when rainfalls decrease.

The common view that the last glacial age was arid, windy, and had marked seasons, encourages comparison with the 1920s and '30s when western New South Wales experienced hot summers and widespread droughts, wind and violent dust storms. There were irregular floods, low winter temperatures and heavy snowfalls in the highlands. These weather patterns imply a northward displacement of southern depressions and strengthened westerlies. Weaker incursions of tropical air reduced summer precipitation. Sprigg (1982) inferred similar conditions for glacial times. Cold fronts extended further north; strong northwesterlies beforehand sent dust to the southeast and southwesterlies after the front turned the dust to the north. The strong zonal circulation of the 1930s contrasts with later years when tropical air was brought more frequently to the south, giving better summer rains. Years like these were possibly less frequent in glacial times.

6. Chronology

The firm identification, by carbon dating, of the Coonambidgal deposits and their equivalents with the last glacial age implies that earlier deposits of a similar kind are similarly related to prior glacial ages. Thus the Mayrung/Queerbri alluvia could identify the last glacial age but one, and the Quiamong/third terraced-fan alluvia the preceding glacial. Such matches are purely speculative.

There is no good evidence for an exact chronology of the lower Namoi Valley. At present the only method of dating in years is by radiocarbon or by thermoluminescence. The latter method indicates an age of ca. 13 000 years B.P. for the sand at 70 cm depth in the Round Swamp lunette.[7] The aeolian clays of the Edgeroi district could have the same age, for one might infer that the wind erosion that produced the lunette was associated with the introduction of the parna. It is more probable, however, that the dated level in the lunette is for a recent episode of wind-blowing, because the degree of soil development on the terraced fan alluvium which post-dates dust deposition appears to be too great to fall in this brief time.

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[7] The ages provided by the analyses are 13 400 ± 2 500 yr (regenerative thermoluminescence test method) and 13 000 ± 2 300 yr (additive technique, D.M.Price, written communication, 23 Jan. 1990).

Data related to the age of the ancient red landscape

On the east Gippsland plains, in Victoria (Ward 1977), red-weathered soils occur on marine terraces 21 m above present sea level but not on the deposits related to two lower interglacial shorelines. Alluvial beds and windblown dune sands (Bundalaguah and Rotamah soil associations) mark the low sea level of the last glacial age; the soils are like others near Melbourne (Bowler 1970), on a terrace formed before 31 000 years B.P. Near Adelaide, alluvial sedimentation in late glacial ages (Ward 1966) followed deposition of aeolian sediments (Ngaltinga Clay) at a time of low sea level. Ngaltinga Clay includes alluvial beds (Phillips and Milnes 1988) and is perhaps divided by an alluvial horizon (Richard May, verbal report) but the ages are uncertain. Near Brisbane, red mottles in the Strathpine terrace (Mew 1978, soil unit 11) are evidence of red-weathering. This terrace appears to mark the highest elevation reached by the sea on this coast, and thus might be 0.43 to 0.48 m. yr old (Ward, 1985).

These fragmentary records suggest that the red weathering predated the last two interglacial ages but is younger than 0.43 m. yr.

Remnants of a red-weathered landscape near Wellington, New Zealand, are associated with periglacial deposits and weathered loess (Te Punga 1964), in a field relationship like that at Edgeroi. The red-weathering corresponds with interglacial conditions, identified with warm sea temperatures between <0.38 and 0.45 m. yr ago (Te Punga 1972; Vella et al. 1976). Warmth at this time is also evidenced by ocean sediments (Kennett 1969, 1970; Nelson et al. 1986; Jansen et al. 1986; Pisias and Rea 1988) and by terrestrial deposits (Brigham-Grette and Hopkins 1989; Huston et al. 1989). Aeolian dusts are found in quantity (Chuey et al. 1987).

In this report it is accepted that the events of the Riverina and Namoi Valley are related. The presence of parna at similar levels supports the idea that Ngaltinga Clay in South Australia is equivalent to Widgelli Parna in the Riverina. Soil similarities support the relation of the South Australian Christies Beach Formation (Ward 1966) to the Mayrung, Queerbri (i.e., second terraced fan) and Bundalaguah deposits. Red-weathered horizons define the oldest pairings (Table 6), and the similar estimated ages for warmth in the different localities suggest that climatic environments 0.35 to 0.45 m. yr ago were responsible for the development of the red-weathered landscape at Edgeroi.

Riverina	Adelaide	Gippsland	Edgeroi district		
			hills	fans and plains	dunes & parna
modern	modern			floodplain	
	Waldeila	Wuk Wuk			
Coolongulac (dune)	Ngankipari (dune)	11/7.5[1] Rotamah (dune)			Bonny Hill (dune) Yarrie (lunette)
Coonambidgal				1st terraced-fan	
Mayrung	Christies Beach[2]	11/7.5 Bundalaguah		2nd terraced-fan	
		26/11 Llowalong			
	Taringa	37/26 Bairnsdale			
Widgelli parna	35/26 Ngaltinga Clay			watersorted parna on earlier fans	upper part of Bohena parna
Quiamong	Kurrajong	65/37 alluvium not recognized	2nd colluvium, Murrumbilla	3rd terraced fan	
[older parnas, & alluvium]		70/65 Briagolong		watersorted parna on earlier fans	lower part of Bohena parna
Katandra		125/70 Moormurng	1st colluvium Murrumbilla	4th fan	
		160/125		eroded (fifth) fan	

[1] Numbers refer to former sea level elevations in feet above present sea levels (Ward, 1966). Two numbers separated by a slash indicate the interval between the levels.

[2] Williams (1969) dating is accepted.

Table 6. Suggested relationships of coastal and continental sediments.

Soils

> We soon thereafter entered another extensive plain, on which the rich soil, when we had got half way across, changed to a stiff clay, the grass marking the change by a difference in colour, being red on the clay and quite green on the other soil. This clay occupied the highest part of the plain [Mitchell was passing from Gommel heavy clay to Bobbiwaa clay loam (WTW)]. Passing through another scrub of acacia pendula [myall], we reached a plain still more extensive [Here, near ed167, during a halt for repairs to a dray, Mitchell sketched the Nandewar Range and recorded the bearings of its principal summits1[8]]... A brush of acacia pendula also bounded this plain on the north, beyond it we entered a scrub of forest-oak (casuarina), which was so very thick that we were compelled .. to cut our way .. for upwards of 2 miles [Tarlee clay loam].
>
> - Major T.L. Mitchell, *Journal*, 3 Jan. 1832 [published 1838].

1. Review of Previous Work

Gibbons and Hallsworth (1950) mapped several soil associations near Narrabri. Grey clays (described as chernozem-like soils) and grey clays with gypsum (sierozem-like soils; these had lighter colour and better self-mulching character) were separated from complexes of red-brown earths and solodized-solonetz. Thin deposits of sand on grey clays between Narrabri and Wee Waa were regarded as alluvial wash. Gilgai were common on the heavy soils to the southwest; here the subsoil had been forced to the surface. Deep red sands associated with the solodized-solonetz soils were described as 'sand-monkeys', the name reportedly being derived from the Aboriginal 'moongie'.

McGarity (1950) attributed soil variation on the plains of the Namoi and Gwydir rivers mostly to climatic change, patterns of flood deposition, and variations in soil drainage. Wind had a major role only in the erosion of sandy duplex soils. He roughly mapped five soil groups near Edgeroi, basing his separations on the presence or absence of gypsum in the uppermost ~2 m, soil colour, and parent material. Basaltic soils were separated from brown, grey and black alluvia. Hallsworth et al. (1955) attributed gilgai development to seasonal wetting and drying, and to the transfer of topsoil to subsoil by its collapse into cracks.

Isbell (1957, 1962) and Hubble and Isbell (1958) reported that alkaline clay soils occurred in southern Queensland over acid materials. The soils were associated with brigalow, like those south-west of Narrabri. Huge areas of gilgai lacked surface drainage. Light grey and red mottles occurred at depth in some places. Isbell (1957) supposed that the abundant montmorillonite clay might have been derived from kaolin in lateritic soils (by erosion and later alteration in a swampy environment) but he, and Hubble and Isbell (1958), favoured the idea that the salts and carbonates and perhaps much of the clay had originated as windblown dust. Oertel and Giles

[8] The sketch of the Nandewar Range is in the published journal.

(1964) noted that the alkaline/acid boundary is movable and confirmed that it was not associated with any texture change.

Hallsworth and Waring (1964) believed that soil variation near Narrabri was due to the distribution of sediment by floods. The sand-over-clay profiles were formed by clay washed by rain from topsoil to subsoil. Northcote et al. (1965) and Northcote (1966, 1984) identified hard alkaline red and brown soils, seasonally cracking clays, and cracking clays with gilgai, and subdivided the clay soils according to colour and size of surface soil aggregates.

Veen (1973) argued that kaolin clay could not form today in the brigalow soils; it was probably inherited from ancient times. If the montmorillonite in the soil had been derived by alteration of the kaolin, as Isbell (1957) had suggested, the change in clay type would increase the volume of the soil. This would explain both the origin of the gilgai and the acidity of the subsoil. To produce this effect the soils would need to receive an influx of salts at a time of change from strongly leaching to non-leaching conditions.

Stannard and Kelly (1977) distinguished physiographic provinces (Pilliga Scrub, Alluvial Plain, etc.), and related the alluvial soils to flood plains and prior streams, grouping them by texture profile, soil colour and self-mulching character. van Dijk (1980, 1984) inferred that the sodium chloride in the soils had originated by deposition from the air or by weathering at depth, and stated that the cracking clays had developed on several ancient landscapes. Fifteen million years ago kaolin formed by weathering had been altered to montmorillonite, and extreme gilgai were developed; natural erosion had since changed alkali and carbonate patterns but otherwise the soils had remained unchanged. Beckmann et al. (1984) affirmed that gilgai were formed by the expansion of soil material on weathering. Seasonal changes in moisture would maintain the gilgai form.

An excellent review of the cracking clays by Hubble (1984) cannot be adequately summarised. The soils include truncated remnants of old deep-weathering profiles; their colour reflects rainfall, drainage and parent material. The clays were formed *in situ*, both in modern and ancient times. The world soil group - the *Vertisols* - to which the cracking clays belong was described by Probert et al. (1987). In the Narrabri district 13 soil groups, based on texture profile, subsoil morphology and soil reaction, were mapped as complex associations by the Soil Conservation Service of NSW (n. d.). Soil variation was attributed to variations in geology, relief, drainage and climate.

The above studies mostly point to special conditions of soil formation that might apply to the lower Namoi Valley, and indicate possible soil-forming processes. Relations of the soils to the landscape and signs of soil conditions inherited from former times were not investigated in detail.

In the present study the parent sediments and the history of the landscape were examined in order to provide an understanding of the background to soil development. It was shown that the clay soils, although contained in an alluvial landscape, are formed mostly on partly watersorted windblown dusts that mantle the alluvial sediments. In places on the hillsides and on the oldest alluvial plains the soil parent materials were prior soils developed during stabilization of a landscape that had formed probably in an arid environment without forest cover.

The observed soil variation cannot be explained in terms of modern conditions as Hallsworth and his colleagues (1950, 1955, 1964) attempted. The past climatic changes which McGarity (1950) had inferred, following Butler (1950), are also important. Nor can the variation be explained by restricting the study to arbitrarily selected parts of the soil landscape. Although Hubble and Isbell (1958) and Isbell (1957, 1962) identified the puzzling features of the clay soils, there was no way to examine possible explanations except by geological studies that were not done. Veen (1973) found that accession from the air was the only means of accounting for the clay minerals and, indeed, the gilgai. However, the time scale suggested by van Dijk (1980, 1984) is unnecessarily long. In the present report the intervals of dust accumulation are referred to past glacial ages, which in these latitudes differ from present-day conditions only in windiness, mean temperature and moisture balance. The droughts of the 1920s and '30s show that changes of this kind continue as a hazard to the present day.

Soil Development

Soils reflect their climatic environment and the materials on which they are formed. They also retain evidence of their past history, especially if they have been subjected to sediment deposition. This is recorded both passively, by the accumulation of surface sediment, and actively, by changes in cation chemistry. To take a broad view: as the soils of the uplands are traced downslope they are seen to change in depth, texture and nutrient content. Particles detached by weathering, surface wash and throughflow move inexorably to lower levels. Soluble elements leached from the crests and highest slopes are transported to the colluvium which lies on the hillsides, and then to the alluvial beds of the plains. From time to time this style of weathering, leaching and sediment transport is interrupted, as when dust is gathered from dried ponds, plains and river beds and is returned by the wind to topdress the upland catchments.

The drill cores have shown that the sandstone ridges and parts of the oldest alluvial landscape in the Edgeroi district once carried a deep red-weathered soil. Areas of this soil that remain have been remodelled to form the present-day soil in places but the present study is not sufficiently detailed enough to allow them to be mapped.

Where erosion has removed the ancient red-weathered zone, the soils have formed from the underlying rocks in conditions of changing vegetation and climate. The tendency everywhere has been to form cracking clays on mudstones and basalts, which readily weather to clay, and texture-contrast soils on moderately quartz-rich rocks. Cracking clays have formed on the windblown dusts and on the fine-grained alluvial beds of the Namoi and its tributaries. Alluvial soils as such are restricted to the flood plains. Owing to the moderately low rainfall the effects of leaching are restricted, with the result that high levels of sodium and magnesium remain to characterise the soils of the plains. High soluble salts and high sodium chloride in the cracking clays are also noteworthy.

Classification of the sampled sites

The 374 sampling sites in the Narrabri and Edgeroi districts were chosen mostly by means of a grid or by regular spacing on a transect, so that the information would not be biased by the observer's opinions or by conventional views of soil landscapes. The sampled sites, as a result, represent a range of soil conditions rather than kinds of soil. Where the grids missed obvious landform changes, where details of observed variations were sought, and on the research farms additional sites were selected by subdividing the main grid and by line transects. It is accepted here that the 374 sites adequately represent the soil population.

Soil classes are formed simply by grouping similar soil profiles. Of the features that are used to assess similarity, some are descriptive - such as degree of stoniness - whilst others reflect soil forming processes. When making a classification, untested opinions can introduce a bias, especially in relation to supposed genetic characters. This bias is limited where classifications favour plain description, but arbitrary rules cannot be avoided.

The properties of a soil result mostly from environmental effects, but soil scientists often confine their attention wholly to the features of the soil profile, on the grounds that the important environmental factors are reflected in the profile and thus a profile classification will automatically deal with them (Soil Survey Staff 1951). This assumption is not to be trusted in new studies, because the usual rules for classification might need modification in the light of new observations.

Soil classifications by profile have at times proved unsatisfactory as an instrument for mapping, and for this reason soil-landscape maps have been developed. With this approach local geomorphic evidence is taken into account along with the differences in soil profile. This approach has been extended at Edgeroi by including geological information in the classification. It is further developed below by systematic use of chemical observations.

Individual soils are recognized in a field survey when variations in soil texture, colour and structure are found to be correlated with changes in an observed soil-forming factor. For convenience, the soils can be grouped according to the landscape unit in which they occur and according to parent material. Differentiating characteristics will vary from group to group. In the Edgeroi district parent material, microrelief, and drainage condition (as indicated by colour) appear to be the main properties. In the texture contrast soils texture and thickness of the surface soils, parent material and subsoil reaction are important. In selecting soil type boundaries consideration has been given to the detection of natural groupings in relation to chemical measures by means of the technique of fuzzy *k*-means (Bezdek 1981).

Classification of the cracking clays according to great soil group (Stace et al. 1968) identifies *black earths*, on basalt; *brown clays*, on parna, on terraced alluvium and on Garrawilla Volcanics; and *grey clays*, on parna with gypsum [formerly termed sierozem] and without gypsum [chernozem], with and without self-mulching surfaces. Among the texture contrast (duplex) soils are *red brown earths*, *solodized solonetz* and *solodic soils*, many with light erodible topsoils. There are also *lithosols*, shallow soils mostly with common sandstone or basalt outcrops, *alluvial soils*, and *sandy red earths* beside streams draining the Pilliga Scrub.

A final detailed soil classification is not made before examination of the laboratory data.

2. Data analysis by fuzzy *k*-means

Data analysis by fuzzy *k*-means is a numerical means of detecting groups, i.e., clusters of similar individuals, in data sets. The individual members of the groups (e.g., soil samples) are described by numerical variates (e.g., clay content, pH, calcium percent, etc.). The analysis accepts that each individual has, in effect, a potential membership, to greater or less degree, in every group that is formed (Bezdek 1981). The extent of membership in any one group is allowed to range from zero, i.e., no membership, to one, i.e., membership in one group exclusively. The scores for group membership, and the averages for each group formed, are the outcome of the analysis.

In classification by this means various numbers of groups are tested for the same set of data, with the purpose of finding a best grouping. Mathematical tests of grouping performance identify the one that is most appropriate.

Because the number of groups that might exist in a data set is unknown, a series of fuzzy analyses using a variety of possible group numbers is first performed (Ward, A.W. et al. 1992). Each solution in this series is the best mathematical result for the given group number. Many tests have been suggested to find if one result is better than the others. Those used here are *objective function value, fuzziness performance index,* and *maximum partition entropy*. Objective function values decrease as group numbers increase, and a larger decrease than usual will indicate a more effective grouping. With fuzziness performance index, and maximum partition entropy the best group number is the one with the smallest score. The analyst can, if desired, choose another criterion, or use common sense, to decide the best group number.

The average values for the measured attributes describe the final groups. These are weighted averages, or centroids, that is, average values weighted by group membership scores. The centroids show the general features of a group. The soil properties at each site will differ, of course, according to the features and unique history of that sampling site.

In this analysis of the chemical data, the surface soil to 0.2 m depth was chosen for study because it carries the crop and is of most concern to the farmer. It is also the part that is most altered by weathering from the original parent sediment. Normally, in a field study, soil classification is based entirely on a rough classification of parent sediments combined in some degree with soil morphology to about one metre depth. Sediments and profiles are not always well associated with features of agricultural significance, however. By taking the chemistry of the topsoil into consideration it is hoped to orient the soil classification more effectively towards practical needs. For the most part, there are three samples at each site, at 0-2, 0-10, and 10-20 cm. As each sample is separately identified with a group, each site can be characterised by a three-letter group symbol.

This method of analysis has not previously been applied to soil information and because of its novelty the detailed output is presented in this report in full. Each data set is discussed according to the following system:

First — the data are described (in the first Table, #.1).
Second — the centroids of the groups that best describe the data set are shown (in Table #.2).
Third — the relations of the centroids to field conditions are described, and the sites in each group are listed (in Table #.3 etc.).

Measures of performance for the several series of fuzzy groups are given in Appendix 2. These results identify the best group number for the data set.

Soil cations and clay, 0 - 0.2 m

Clay content, cation exchange capacity (cec, as shown by the sum of the measured cations), eAlp (exchangeable aluminium percent), eKp, eNap, eMgp, and eCap were chosen as single data set on the grounds that *clay percent* is strongly related to physical soil characteristics and is the primary focus in regard to nutrient supply, that *cec* represents the nutrient reserve available for plant growth, and that *e(element)p* - exchangeable element percents - measure the proportions of the nutrient elements accessible to plant growth on the clay complex. Cation exchange properties do not allow for phosphorus, sulphur and trace element contents, but they are useful as a means of providing a broad overview.

It follows, for the purposes of this report, that similar clay percents, similar sums of cations, and similar exchangeable element percents describe similar soils.

The systematic field study has identified three kinds of country: the *erosional landscape* (i.e. the sandstone ridges, basalt hills and eroded alluvial plains); *dust-mantled alluvial lands;* and *alluvial plains.* These landscapes are obvious and dissimilar, and justify the division of the numerical data into three separate data sets that together include all of the surface soils analysed in the laboratory. Thus, in this report a conventional, but elementary, soil-landscape approach is combined with numerical classification. Although other approaches might be taken, the intention here is to allow the field study simply to guide the fuzzy analysis, and then only to a small extent.

Sandstone ridges, basalt hills and eroded alluvial plains

The soils are mostly *solodized solonetz* and *solodic soils*, but *lithosols*, *black earths* and *brown clays* occur on basalts and weathered basalts, and *grey clays* occur on the weakly dissected alluvial beds of the fifth fan and in some places on colluvial slopes. The chemical data set is described in Table 7.1. The results of tests made to find the best number of groups are set out in Appendix 2. This shows that the best results are provided by five groups.

The five centroids are given in Table 7.2. Only six of the 250 samples were not clearly identified with a group, and the three samples in each set to 20 cm belonged mostly to the same class. Leached surfaces occur with some sequences, however, and slightly higher clay percents occur at the ground surface in other cases.

A comparison with field data shows that the chemical pattern revealed by fuzzy analysis strongly reflects parent rock and site position on the hillslope, especially in the case of Pilliga Sandstone (Table 7.3). These relationships, which are sensible and agree with field experience, give confidence in the analytical method. The groups are most conveniently discussed in order of increasing clay content (Table 7.4).

Group 5b, with the least clay, consists of soils under forest at ridge crests and watersheds on Pilliga Sandstone. The group is associated downslope with Group 5d which becomes more common and replaces Group 5b in that direction. Group 5d includes soils under open grassy forests and pastures, and is typical (in association with Group 5e) of the soils of the Tertiary sandstone. On the lowest hillslopes surface soils of Group 5d pass at shallow depth to Group 5e. These distributions reflect the extensive leaching that the high points in the landscape have experienced, and demonstrate transfer of nutrient elements in soil drainage to lower levels and greater depths. The replacement of the leached elements at ridge crests with exchangeable aluminium is a noticeable feature.

Group 5e is comprised of nearly all soil samples from the fifth fan (except for three sites which at depth grade to 5c) but it also occurs on water-shedding clayey sites on other rocks, including both Pilliga Sandstone and Garrawilla Volcanics. These are all leached soils on nutrient-rich parent materials. Group 5a is found on slow draining sites on Purlawaugh and Rolling Downs formations, and in similar places on the texturally-differentiated soils formed on Tertiary sandstone. It differs from 5e mostly in the ratio of calcium to magnesium. Group 5c has the highest clay content, and characterises the basaltic rocks and their associated colluvial sediments. These distributions are summarised in Table 7.3, and the sites are listed according to fuzzy group in Table 7.5.

Attribute	Min	Max	Mean	St. dev.
clay %	2.5	66.8	26.5	17.46
cec	2.2	762.4	194.6	182.07
eAlp	0.01	95.79	9.00	22.03
eKp	0.02	38.36	8.74	7.13
eNap	0.01	42.58	2.12	4.86
eMgp	0.21	86.49	24.02	12.49
eCap	0.20	86.52	56.29	21.53

Table 7.1. Sandstone ridges, basalt hills and eroded alluvial plains. Summary statistics for data from all surface soils (0-20 cm). 250 samples × 7 attributes: clay, cec (cation exchange capacity), eAlp, (exchangeable aluminium percent), eKp, eNap, eMgp, and eCap. Soil reaction ranges down to pH 4.4.

Group	clay %	cec	eAlp	eKp	eNap	eMgp	eCap
5a	30.4	189.8	0.47	5.01	2.57	42.27	49.71
5b	8.8	17.7	65.50	12.69	2.55	10.32	9.61
5c	53.6	495.4	0.03	3.36	1.02	25.44	70.16
5d	10.5	44.4	4.89	18.55	1.88	20.69	54.31
5e	25.1	180.2	0.91	6.16	1.90	20.90	70.18

Table 7.2. Sandstone ridges, basalt hills and eroded alluvial plains. Weighted mean values (centroids) for fuzzy soil groups for clay, cec (cation exchange capacity), eAlp (exchangeable aluminium percent), eKp, eNap, eMgp, and eCap. 250 samples × 7 attributes.

	Rock					
	basalt	Pilliga sandstone		Tertiary sandstone	Purlawaugh Formation	fifth fan
Position on slope		Sand-stone	Silt-stone			
crests:	5e	5b	5e	5d	-	5e
flanks:	5c	5d	5a	5a	5a	5e
footslopes:	5c	5d	-	5e	-	5e, 5c

Table 7.3. Sandstone ridges, basalt hills and eroded alluvial plains. Fuzzy soil groups arranged in relation to parent rock and hillslope position.

Group	clay %	cec	eAlp	eKp	eNap	eMgp	eCap
5b	8.8	17.7	65.50	12.69	2.55	10.32	9.61
5d	10.5	44.4	4.89	18.55	1.88	20.69	54.31
5e	25.1	180.2	0.91	6.16	1.90	20.90	70.18
5a	30.4	189.8	0.47	5.01	2.57	42.27	49.71
5c	53.6	495.4	0.03	3.36	1.02	25.44	70.16

Table 7.4. Sandstone ridges, basalt hills and eroded alluvial plains. Centroids rearranged in order of clay content. 250 samples × 7 attributes.

	basalts			Pilliga Sandstone		Tertiary	Rolling	fifth
	shallow	deep soil		leached	flanks and	sandstone	Downs	fan
Group	soils	grey	brown	crests	colluvium		Group	
5b				ed052				
				ed086				
				ed102				
				ed104				
				ed120				
				ed121				
				ed122				
				ed189				
				ed190				
				ed205				
				ed206				
				ed354				
5d					ed033	ed067		
					ed051	ed100		
					ed068	ed118		
					ed085	ed187		
					ed171	ed416		
					ed172	ed418		
					ed173	ed422		
					ed188			
					ed338			
					ed344			
5e	ed070		ed175		ed105	ed034	na022	ed063
	ed208				ed137	ed117	na023	ed064
					ed207	ed417	na024	ed065
						ed419		ed066
						ed420		ed080
								ed081
								ed082
								ed083
								ed096
								ed097
								ed098
								ed099
								ed236
5a	ed158	ed239	ed242		ed119	ed033	na012	
					ed136	ed051	na015	
					ed191	ed135	na020	
					ed210	ed204	na025	
					ed337	na010	na026	
					ed341			
					ed342			
5c	ed059	ed053	ed123					
	ed087	ed101	ed157					
	ed088	ed130	ed241					
	ed192	ed131						
	ed193	ed212						
	ed209	ed424						
	ed425							

Table 7.5. Sandstone ridges, basalt hills and eroded alluvial plains. Soil sample sites arranged in relation to parent rock and five fuzzy groups in order of increasing clay content. The fuzzy groups clearly reflect parent rock and site.

Dust-mantled alluvial lands

The soil samples treated as separate entities

The data set is described in Table 8.1 and performance scores for fuzzy analysis in Appendix 2. Most of these soils are *grey clays*, but better-drained *brown clays* overlying alluvium in the northeastern part of the Edgeroi sheet are also included. The 392 samples × 7 attributes gave four centroids (Table 8.2). The more detailed groupings, for instance into 6 and 7 groups, appear to be dividing earlier groups on the basis of K and Na, reflecting perhaps cultivated sites versus those in pasture.

Attribute	Min	Max	Mean	St. dev.
clay %	20.9	74.7	52.0	10.52
cec	86.8	600.7	389.7	92.89
eAlp	0.01	0.74	0.02	0.05
eKp	0.01	16.24	4.04	2.09
eNap	0.02	21.39	4.34	3.06
eMgp	0.02	56.63	32.33	6.48
eCap	33.42	85.23	59.29	6.99

Table 8.1. Dust-mantled alluvial lands. Summary statistics for data matrix of 392 samples × 7 attributes, clay, cec, eAlp (exchangeable aluminium percent), eKp, eNap, eMgp, and eCap, for all samples from 0-20 cm.

Group	clay %	cec	eAlp	eKp	eNap	eMgp	eCap
4a	48.4	380.3	0.02	2.35	9.36	30.97	57.31
4b	37.9	240.7	0.03	7.10	3.75	35.78	53.36
4c	59.4	451.3	0.01	3.72	3.84	36.41	56.04
4d	49.8	372.4	0.02	4.16	2.81	27.01	66.01

Table 8.2. Dust-mantled alluvial lands. Centroids for fuzzy soil groups for clay, cec, eAlp (exchangeable aluminium percent), eKp, eNap, eMgp, and eCap. 392 samples × 7 attributes, diagonal metric, fuzzy exponent 1.3.

The individual samples mostly showed clear relationships with one of the four groups, with only fourteen equally divided memberships, i.e., borderline samples. The sample sets to 0.2 m were varied, but the three samples from each site score high memberships mostly as ccc (i.e., 0-2 cm, 4c; 0-10 cm, 4c; 10-20 cm, 4c), ddd, and baa or bba. The last two, the geochemically differentiated profiles, are common near Bald Hill, at 'Waugan' and 'Llano', and by the Bald Hill road crossing at Galathera Creek. They occur also further south, near 'Blue Hills'. These are mostly known to be localities where surface waters are concentrated by run-on. The area at 'Blue Hills' is a terminal soak of Bobbiwaa Creek. In contrast, the ddd sites lie mostly at high levels on the alluvial fans upstream, and are prominent where aeolian clays lie on the fans spreading from the Nandewars. The ccc sites are common on the fan of the Namoi River, where the gradient is very slight, and in the light of the other distributions this can be attributed to the slower runoff on the flatter slopes. It seems, therefore, that the cation distributions are associated with site drainage. The high Ca / Mg ratios (2.44, for group 4d) typify the watershedding ground above the more magnesian (Ca / Mg 1.54) group 4c, which is succeeded, where water runs on, by somewhat clay differentiated, sodic areas that have mostly been allowed to remain in native pasture (groups *b* on *a*, Ca / Mg 1.49, 1.85).

Detail is provided by the closer spacing of data at 'Myall Vale'. Nine sites are classed here as ddd (ed162, 215, 216, 219, 221, 222, 228, 229, 230), and five mostly as ccc (ed217, 220, 223, 226, 231). Except for ed231 these five lie in the northeast corner of the property. The sample from 0-2 cm at ed223 (the north-easternmost site) is group 4b. This pattern is consistent with a separate, more detailed study of the 'Myall Vale' data set (Ward et al. 1999), especially with the result for two-groups, even though the study of the 'Myall Vale' data included all topsoils. Compared to the Namoi plains in general, 'Myall Vale' contains more 4d than 4c, that is, its greater part has less clay and is more calcic than the land to the north. Its relatively good drainage could result from its situation close to the river.

The centroids as rearranged in Table 8.3 reflect a steady improvement in drainage condition. Groups 4d and 4c commonly form separate profile sequences with 4d in well drained sites. Where the soil receives surface water from the surrounding country Group 4b mostly lies on Group 4a. From the mapped distribution it seems that Group 4d lies more commonly over 4c in relatively well-drained sites high on the alluvial fans, but rests on the more sodic Group 4a at lower levels.

Group	clay %	cec	eAlp	eKp	eNap	eMgp	eCap
4d	49.8	372.4	0.02	4.16	2.81	27.01	66.01
4c	59.4	451.3	0.01	3.72	3.84	36.41	56.04
4b	37.9	240.7	0.03	7.10	3.75	35.78	53.36
4a	48.4	380.3	0.02	2.35	9.36	30.97	57.31

Table 8.3. Dust-mantled alluvial lands. The centroids rearranged according to drainage condition. Groups 4d and 4c commonly form separate profile sequences but samples of Group 4b mostly lie over samples of Group 4a.

The soil samples treated as site variables

The groupings of the data for each soil, sample by sample, reveal a sensible geographic pattern, as described, but it is difficult to describe each site simply when there are three samples to be classed at each site. It would be better, in practice, to classify the sites, rather than the samples. For this reason the data were re-examined, but in this analysis the attributes for the three soil-layers were not treated sample by sample, but as additional site variables. This analysis placed the 135 sites in three classes, shown in Tables 8.4 (centroids), and 8.5 in relation to profile colours and geographic setting. The three groups are related to the prior grouping as follows: Group 3a (Table 8.4) is mostly the prior grouping, 4ccc; group 3c is essentially 4ddd;

3b is mainly 4b on a. Some 4a's are placed in 3a (20 samples) and some 4b's in 3c (1 sample) and 3a (7 samples). The slight difference associated with the dust-mantled Namoi plains is not evident in this treatment, but otherwise the three site groups show, with little variation, the same map pattern as the four soil-sample groups.

Group[1]		clay %	cec	eAlp	eKp	eNap	eMgp	Ca
3a	00	59.1	438.2	0.01	4.83	3.23	33.50	58.44
	01	57.9	443.2	0.01	3.90	4.08	36.06	55.96
	02	58.9	459.5	0.01	2.76	5.69	36.11	55.44
3c	00	49.3	362.1	0.02	5.23	2.40	26.06	66.31
	01	47.8	357.7	0.02	4.10	3.49	27.67	64.73
	02	49.0	379.2	0.01	2.66	4.57	28.17	64.60
3b	00	35.8	223.0	0.04	6.90	4.90	34.03	54.16
	01	36.5	241.9	0.04	5.28	6.13	35.26	53.31
	02	41.1	295.0	0.02	3.13	8.07	33.45	55.36

[1] and layer identification.

Table 8.4. Dust-mantled alluvial lands, with the three surface samples treated as site variables. Centroids for analytical results from all surface soils. 3 soil layers $\times$ 7 attributes (clay, eAlp, (exchangeable aluminium percent), eKp, eNap, eMgp, and eCap), 135 soil profiles. Centroids in order of decreasing clay content.

Relation of fuzzy groups to landscape

Some relationships to landform that are not implied by the initial separation of the Edgeroi soil data set into three landscape subsets are discussed in this section.

The soil groups defined by fuzzy analysis define three zones for the soils formed in aeolian sediments. These are most clearly expressed on the Ten-Mile Creek alluvial fan, in the northern part of the Edgeroi district (Fig. 23). Group 3a occupies the more elevated ground and is succeeded downslope by 3c and then 3b. This sequence is also one of decreasing clay content in the surface soil. The central zone (3c) has least magnesium and the lowest zone has most sodium (Table 8.3). The same pattern might be present on the Namoi alluvial fan but only the highest part of this fan is covered by the Edgeroi sheet. Its soils are mostly 3a (Figs 24, 25). The better-drained ground near the river at 'Myall Vale' is mostly 3c, and this group occurs in some other places to the northwest, at lower elevations. Further west, in a limited study of the Namoi alluvial fan on the Wee Waa sheet, group 3b was found at only one site (we002).

The groupings suggest that cation distribution is governed by site drainage, with the more soluble elements being leached from higher sites and transferred to lower levels by surface wash and by runoff to drainageways further downstream. The geographic pattern of the three fuzzy groups and the continuation of group 3c upstream along the Bulldog Creek drainage line is consistent with this interpretation. However, it is surprising that the relatively high sites, group 3a, do not have the least sodium and magnesium.

	Dust-mantled alluvial fans					Dust-mantled Namoi plains		
	brown clays		grey clays			brown	grey clays	
Group	fm [1]	cm wc	fm lo	cm wc	hardset	cm wc	fm lo	cm wc
3a	ed009	ed005	ed003	ed004		ed107	ed001	ed019
	ed010	ed023	ed008	ed007			ed054	ed108
	ed011		ed016	ed166			ed055	ed109
	ed012		ed017	ed183			ed073	ed110
	ed013		ed092	ed186			ed090	ed125
	ed014		ed147	ed201			ed091	ed127
	ed015		ed167	ed336			ed141	ed128
	ed021		ed334	na018			ed144	ed143
	ed031		ed360	na019			ed145	ed164
	ed032		ed362	na021			ed146	ed217
	ed129		na013				ed163	ed220
			na014				ed223	ed226
			na016				bu002	ed231
			na017					we001
								we005
								we006
								we007
3c	ed006	ed024	ed062	ed022	ed094		ed037	ed036
	ed025	ed076	ed075	ed043			ed072	ed071
	ed027	ed079	ed084	ed044			ed089	ed126
	ed028		ed156	ed060				ed162
	ed029		ed423	ed061				ed215
	ed030		ed433	ed074				ed216
			na011	ed077				ed219
				ed093				ed221
				ed095				ed222
								ed228
								ed229
								ed230
								we011
3b		ed042	ed165	ed057	ed039			we002
		ed139	ed213	ed078	ed040			
		ed148		ed112	ed041			
		ed149		ed113	ed058			
				ed114	ed211			
				ed115	ed361			
				ed184	ed370			
					ed371			
					na031			
					na036			

[1] fm, fine self-mulching; cm, coarse self-mulching; lo, loose; wc, weak surface crust.

Table 8.5. Dust-mantled alluvial lands. Two-way table showing soil sample sites in relation to site and to three fuzzy groups (in which the sites have memberships greater than 0.499). Analytical results from all surface soils. 3 soil layers x 7 attributes (clay, eAlp, (exchangeable aluminium percent), eKp, eNap, eMgp, and eCap), 135 soil profiles. Fuzzy groups in order of decreasing clay content.

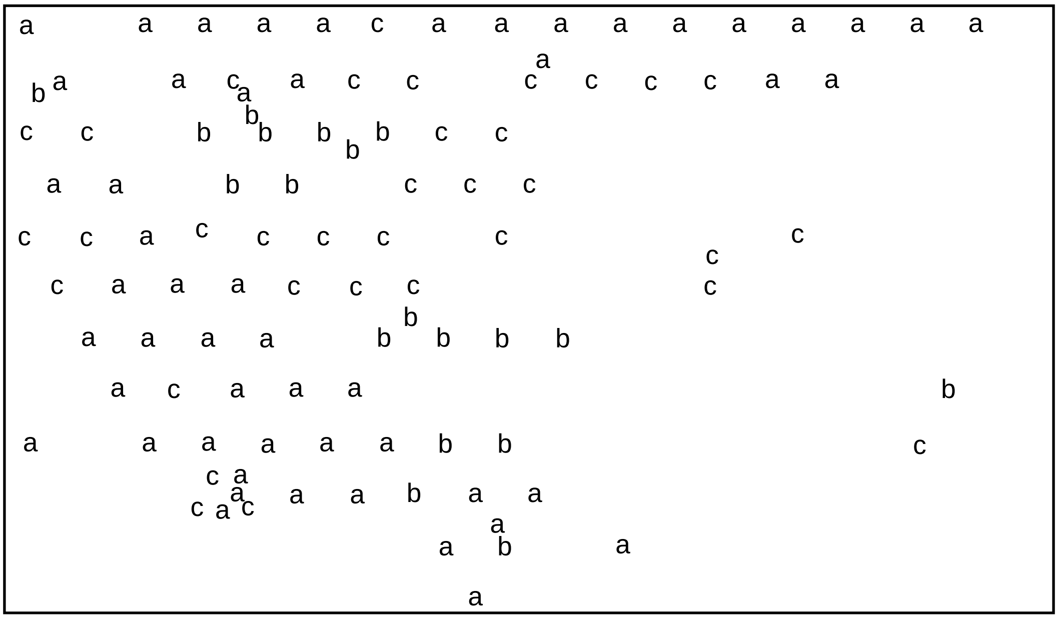

Figure 23. Dust-mantled alluvial lands, Edgeroi map sheet, showing three fuzzy groups (a, b, c). Group "a" occupies relatively high well-drained sites, "b" has poor drainage, and "c" occupies an intermediate position. Some off-grid sites omitted for clarity.

Although a geographic pattern is clearly evident, the chemical and clay data do not seem to show a strong relation with soil morphology. The obvious colour differences in 3a and 3c, the self-mulching versus weak crusting character, and the sporadic occurrence of fine calcium carbonate nodules in the surface horizons were not found in the fuzzy analysis. However, group 3b contains several soils with poor surface structure, and to investigate this a further study was made of this group using, firstly, all laboratory data. This divided the soils on clay content and calcium:magnesium ratios but did not separate the poorly structured soils.

When the known crusting and non-crusting soils were separated arbitrarily, aluminium, magnesium, calcium, pH and carbonate showed no significant difference. These attributes were therefore set aside and the analysis repeated using the remaining attributes. Four subgroups of group 3b were identified, and these reflected differences in the field (Table 9.1 and Appendix 2). Subgroup 4c contained only one soil, ed114, which had very large chloride and phosphate values. Subgroup 4a contained coarse self-mulching soils with signs of surface crusting in places, 4b was hardsetting but had light clay surface textures, and 4d was of sandy clay loams with hardsetting topsoils. High values for sodium mostly characterise the hardsetting soils of subgroups 4b and 4d (Table 9.2). The other elements, except perhaps for potassium and carbon, do not seem to be important. Subgroup 4d shows low clay activity ratios (i.e., cec/clay) but this is not the case with 4b, which also includes hardsetting soils. Group 4b is found only in three places, by Galathera Creek (one soil profile, ed213), on the southern section of the 'Llano' transect, and in a clay pan near Roma Bore (Edgeroi 423747).

The units shown by the condition of the soil surface and by fuzzy analysis of the numerical data are not well described by surface soil textures alone.

Figures 24. Site ed146, "Auscott". Cotton crop on Gommel heavy clay, on water-sorted aeolian clays.

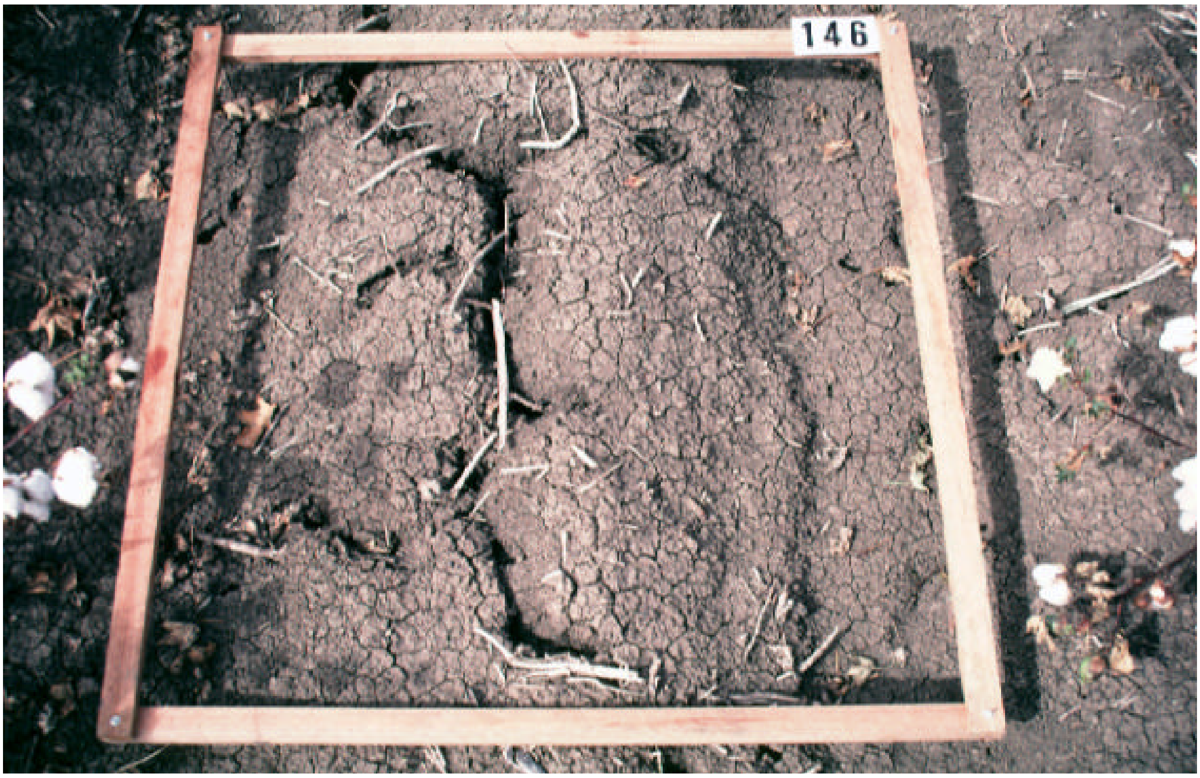

Figure 25. Typical desiccation cracks in Gommel heavy clay at site ed146. The wooden frame measures 1 m on a side. This is a well drained site with low salt content (Group 3a, Tables 8.4, 8.5).

Attribute	Min	Max	Mean	St. dev.
clay %	20.9	50.9	38.6	6.60
cec	112.4	382.2	268.9	60.60
eKp	1.02	14.51	4.22	2.48
eNap	0.02	17.35	6.35	3.88
cond	5.7	44.2	13.5	7.20
chlor	1	291	39.6	42.98
C	0.46	2.4	1.14	0.48
P	0	65.1	10.2	14.09

Table 9.1. Dust-mantled alluvial lands. Summary statistics for data matrix of group 3b (Tables 8.5, 8.6). 214 samples × 8 attributes: clay, cec, eKp, (exchangeable potassium percent), eNap, conductivity, chloride, carbon and phosphate for all samples from 0-20 cm.

Group [1]		clay %	cec	eKp	eNap	cond.	chloride	C	P
4c	00	47.2	284.8	8.10	1.41	27.6	22.3	2.40	0.0
	01	46.8	292.0	7.78	4.01	43.9	288.7	1.74	62.7
	02	50.8	362.8	3.43	4.22	18.6	123.2	0.94	13.6
4a	00	39.4	259.3	6.55	2.90	9.4	19.0	1.48	0.0
	01	40.1	292.2	4.64	3.54	13.3	35.5	1.40	29.8
	02	43.8	333.8	2.34	5.49	10.7	22.1	0.86	9.4
4b	00	38.4	276.1	3.88	8.95	15.0	56.6	1.11	0.0
	01	40.7	301.0	2.37	10.02	15.9	37.5	0.79	10.3
	02	43.5	356.9	1.27	13.83	19.0	76.7	0.66	3.4
4d	00	30.1	171.3	6.40	5.79	8.0	20.5	1.11	0.0
	01	29.8	172.8	4.90	7.20	15.2	36.4	1.36	17.6
	02	37.4	256.1	2.21	9.09	11.3	28.1	0.71	3.9

[1] and layer identification.

Table 9.2. Dust-mantled alluvial lands. Centroids for data matrix of group 3b (Tables 8.4, 8.5), with the three surface samples treated as site variables, in order of deteriorating surface soil condition. 22 sites × 8 attributes, diagonal metric, fuzzy exponent 1.3. Group 4c contains one site only (ed114). Three soils (ed361, ed370, ed371) had no 0-2 cm samples and to complete the analysis it was assumed that 0-2 cm samples had the same composition as 0-10 cm, except for phosphate which was not determined on samples at 0-2 cm.

Alluvial plains

The soil samples treated as separate entities

The soils of the alluvial plains occur mainly on terraced fans. They are mostly *brown clays* and *grey clays*, but several *alluvial soils* have been described from the flood plain of the Namoi River. Some profiles among the brown clays resemble *red brown earths*. Sandy alluvium from the Pilliga district gives rise to *sandy red earths*. Cations and clay contents are summarised in Table 10.1 and group performance scores are given in Appendix 2. Weathering has affected soil profiles on the low terraces near the flood plain, and in some cases the samples include buried soils. The soils are relatively young and retain features inherited from the original sediment.

Attribute	Min	Max	Mean	St. dev.
clay %	6.7	73.2	44.35	13.70
cec	18.2	677.6	319.9	115.20
eAlp	0.01	3.76	0.07	0.40
eKp	1.01	21.81	5.44	3.64
eNap	0.02	33.76	3.28	3.75
eMgp	17.88	59.64	33.22	7.60
eCap	31.23	76.83	58.01	9.02

Table 10.1. Alluvial plains. Summary statistics for data matrix of 214 samples × 7 attributes: clay, cec, eAlp, (exchangeable aluminium percent), eKp, eNap, eMgp, and eCap for all samples from 0-20 cm.

Fuzzy analysis favoured three groups (Table 10.2). Three of the 214 samples were not clearly grouped, and the samples in most sets to 0.2 m belonged mostly to the same class. Profile group ccc is more common upstream, and bbb downstream, but the detailed pattern is erratic, and appears to be associated with random variations in clay percent. There are no significant differences among the soils in clay activity (i.e., cec/clay percent). A second analysis without the clay data gave a similar result, but the profile sequences were clarified. Three groups like the first set were again favoured (Table 10.3, Fig. 26). Cation assemblages and clay percent are linked, perhaps because of the connection between soil texture and site drainage.

Group	clay %	cec	eAlp	eKp	eNap	eMgp	eCap
3a	43.4	299.9	0.07	4.42	6.07	42.54	46.92
3b	31.2	205.0	0.11	9.33	1.19	30.00	59.41
3c	52.5	395.9	0.03	3.74	3.01	30.50	62.74

Table 10.2. Alluvial plains. Group centroids. 214 samples × 7 attributes, diagonal metric, fuzzy exponent 1.3.

Group	clay %	cec	eAlp	eKp	eNap	eMgp	eCap
3a	-	-	0.0573	4.3234	6.0909	42.3023	47.2446
3b	-	-	0.1438	10.6710	1.0450	31.2684	56.9217
3c	-	-	0.0305	3.9492	2.7371	29.5998	63.6984

Table 10.3. Alluvial plains. Group centroids for cations only. The assemblages are essentially the same as the groups in Table 10.3. 214 samples × 5 attributes.

The sample sets to 0.2 m were mostly ccc (on well drained clayey sites), bbb (on well drained loamy sites with pasture), and aaa (on sites with relatively high sodium and magnesium, in soaks, swamps and distributary channels). Contrasts between samples from the ground surface and those beneath (i.e., changes from 3b to 3c, and from 3c to 3a at some sites) are probably due to leaching of the surface soil by rainfall. Calcium dominates cation assemblages upstream and magnesium and sodium are dominant downstream. High values of potassium occur under well-drained pastures and where there is more sand.

The soil samples treated as site variables

The groupings of the data for each soil, sample by sample, reveal a sensible pattern, as described, but it is difficult to describe each site simply when there are three samples to be classed at each site. Moreover, a single class for each site would be more useful for mapping purposes. A third analysis of the cation plus clay data by fuzzy *k*-means, with the attributes treated as site variables, provides a simple overview. The 75 sites were placed in three classes (Tables 10.4, 10.5) in relation to sediment source, flood plain and terraced-fan landform. The changes from the sample- to site-classification were minor, and allow the same lettering system to be used as in the prior grouping.

Group[1]		clay %	cec	eAlp	eKp	eNap	eMgp	Ca
3c	00	53.6	397.5	0.04	5.04	2.30	30.15	62.47
	01	52.4	389.5	0.03	3.82	2.97	32.92	60.27
	02	54.1	406.4	0.02	2.50	4.10	33.07	60.31
3a	00	32.8	224.3	0.09	10.65	1.11	28.57	59.61
	01	32.0	212.6	0.09	9.06	1.56	29.84	59.49
	02	35.8	248.9	0.09	4.84	2.17	30.45	62.50
3b	00	35.1	225.6	0.06	7.11	5.45	41.60	45.82
	01	33.9	219.7	0.10	5.95	6.85	42.98	44.15
	02	44.8	332.0	0.09	2.84	7.42	43.86	45.80

[1] and layer identification.

Table 10.4. Alluvial plains, with the three surface samples treated as site variables. Centroids, for 3 soil layers × 7 attributes (clay, eAlp, (exchangeable aluminium percent), eKp, eNap, eMgp, and eCap), 75 soil sites (214 samples).

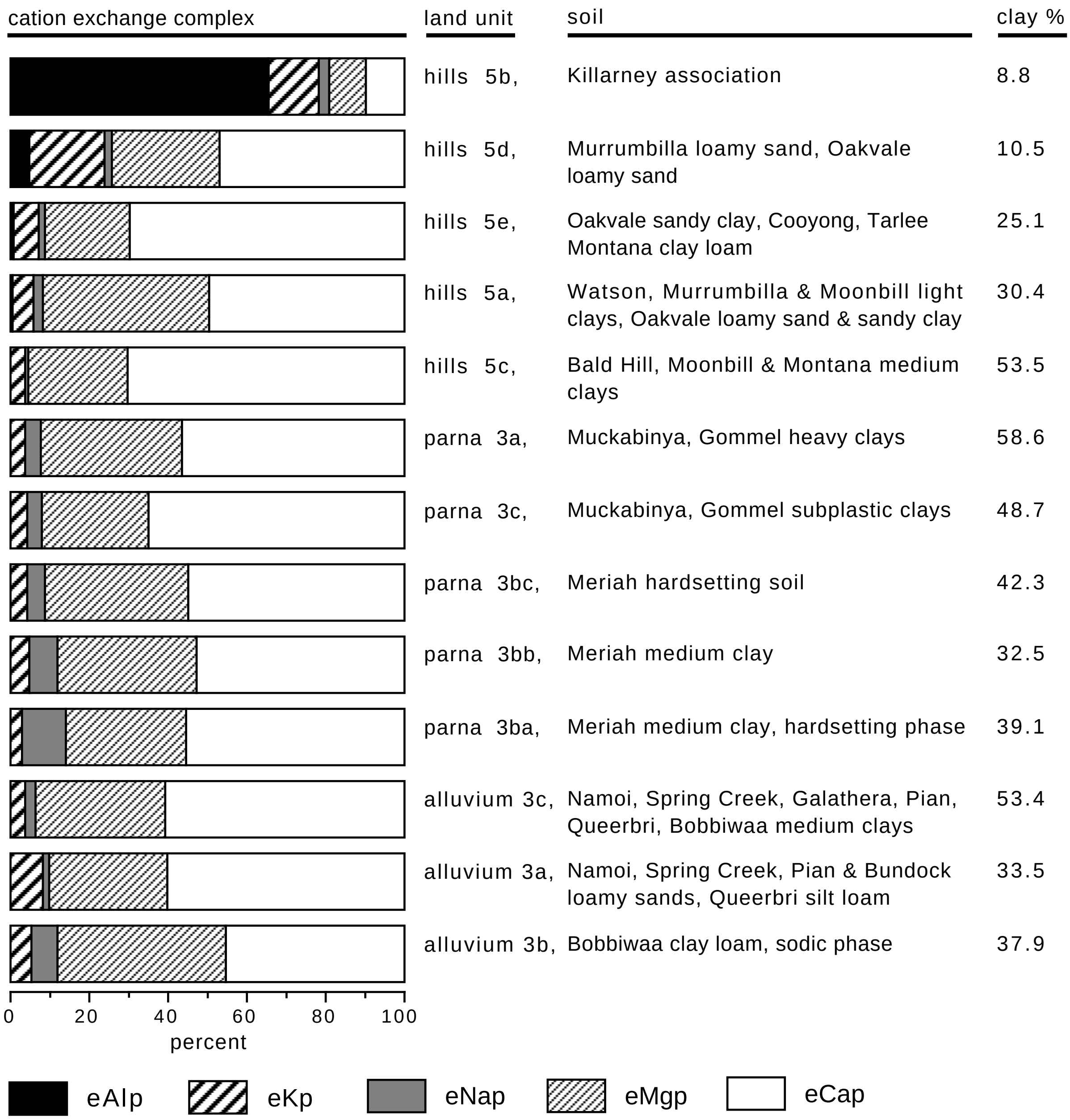

Figure 26. Cations in the fuzzy soil groups. The figure shows the proportions of each cation in the exchange complex of the surface soils in each of the best-fitting fuzzy groups for hill, aeolian clay mantle (= parna), and alluvial plains in the Edgeroi district. The figures shown beside each diagram are average clay contents, and the soils in the groups are also given. The subdivision in parna 3b shows averages for the different soils in 3b that form this group.

	Alluvial lands ...						
	... from Nandewars[1]			... from	... from Namoi River		
Group	flood plain	first terraced fan	second terraced fan	Pilliga Scrub	flood plain	first terraced fan	second terraced fan
3c	ed002		ed035		ed177	ed142	ed106
	ed020		ed045		ed178	ed196	ed161
	ed038		ed046		ed179	ed197	ed181
	ed056		ed047		ed198		ed182
	ed111		ed048		we009		ed218
	ed170		ed049				ed233
	ed227		ed050				ed234
			ed069				
			ed103				
			ed140				
			ed150				
			ed174				
			ed202				
			ed237				
3a	ed018	ed203	ed116	ed194	ed159	ed195	ed124
	ed152		ed134		ed160	we008	ed176
	ed154		ed138		ed199	we010	ed232
	ed155		ed151			we013	ed244
	ed214		ed238				ed180
							ed232
3b	ed235		ed132		ed200		ed224
			ed133				
			ed153				
			ed168				
			ed169				
			ed185				
			ed330				
			ed331				
			ed332				
			ed333				
			ed335				

[1] and Galathera Creek.

Table 10.5. Alluvial plains, with the three surface samples treated as site variables. Two-way table showing soil sample sites in relation to site and three fuzzy groups (in which the sites have memberships greater than 0.499). 3 soil layers × 7 attributes (clay, eAlp, (exchangeable aluminium percent), eKp, eNap, eMgp, and eCap), 75 soil sites (214 samples).

Soils lacking clay percent data

Clay percent data for soil samples from Bohena, south of Narrabri, and Round Swamp, near Culgoora, are not available. The strong relation of clay percent to sum of cations, however, allows the substitution of the cation data for the clay. To help interpretation, some soils with clay data and already examined are included.

The data set (Table 11.1) consists of cation analyses from *all* sampled depths on eroded, dust-mantled, alluvial, and dune landscapes on the Narrabri sheet.

Attribute	**Min**	**Max**	**Mean**	**St. dev.**
cec	0.9	576.5	238.6	156.51
eAlp	0.01	79.39	2.15	8.56
eKp	0.03	36.84	5.98	6.28
eNap	0.02	59.26	14.85	15.04
eMgp	3.47	84.78	40.30	13.81
eCap	0.02	90.28	36.97	22.74

Table 11.1. All Narrabri samples, all depths. Summary statistics for data matrix of 234 samples × 6 attributes: cec, eAlp, (exchangeable aluminium percent), eKp, eNap, eMgp, and eCap.

The soils are mostly *grey clays*, some with prominent gilgai, but *solodized solonetz* and *solodic soils*, *lithosols*, *rendzinas* and *red brown earths* occur on erosional landscapes, and on alluvial lands associated with the ancient formerly red-weathered landscape south of the Namoi River, and on sand dunes at Yarrie Lake and Round Swamp. Performance scores for fuzzy analysis are given in Appendix 2. The scores favour five centroids (Table 11.2). Seven of the 234 samples were not clearly allocated to a single group.

Group	**cec**	**eAlp**	**eKp**	**eNap**	**eMgp**	**eCap**
5c	440.6	0.36	2.67	11.92	40.05	45.03
5e	250.3	3.07	3.01	39.38	45.77	8.81
5d	199.4	1.48	3.07	12.28	56.30	26.99
5b	146.7	0.91	6.50	2.69	21.10	69.10
5a	114.5	3.14	15.48	4.45	33.94	43.34

Table 11.2. All Narrabri samples, all depths. Centroids arranged according to sum of exchangeable cations. 214 samples × 6 attributes, diagonal metric, fuzzy exponent 1.3.

The results emphasize the relation between cation chemistry and parent rock and confirm the prior results given for the surface soils with clay data (Table 10.3). In the analysis of eroded landscapes (Table 7.4), the soils on the Rolling Downs clay and on Tertiary alluvium were classed as fuzzy group 5a, and on the Rolling Downs marls as 5e (except for na003 which was not examined). The soils of the dust-mantled landscape (Table 8.2) were group 3a, except for na011 (3c), na031 and na036 (3b, floor of Round Swamp). These findings and the groupings shown in Table 10.3 suggest that na003 can be regarded as a member of fuzzy group 5e (Table 7.5); and that na032 and na035 are members of group 3b (Table 8.2).

The fuzzy analysis of all profile samples shows up the high sodium contents of groups 5c, 5d, and 5e (Table 11.3), especially 5e, which has a mean exchangeable sodium content near 40%. Values like this are common at Bohena, and in the Rolling Downs marls. Site na025, at the base of the Tertiary sandstone, also has high sodium values, suggesting that groundwater might be bringing sodium to the soil at this location. The higher-than-normal sodium values in na021, and sodium and calcium values in na011, sites that are near Rolling Downs and Tertiary beds, also suggest the entry of groundwater containing these elements.

Bohena						I. A. Watson Research Farm								Round Swamp			
terrace		**red plain**		*gilgai*		**Rolling Downs** marl		**Rolling Downs** sodic clay		**Tertiary**		*Fourth fan*		dune sand		*lake bed*	
na00401	a	na00501	a	na00701	b	na00301	b	na01201	d	na01001	d	na01101	b	na03001	b	na03102	a
na00402	~	na00502	a	na00702	c	na00302	b	na01202	d	na01002	c	na01102	b	na03002	b	na03103	a
na00403	~	na00503	~a	na00703	c	na00303	b	na01203	d	na01003	c	na01103	b	na03003	b	na03104	a
na00404	d	na00504	~a	na00704	c	na00304	b	na01204	d	na01004	d	na01104	c	na03004	b	na03105	a
na00405	d	na00505	e	na00705	e	na00305	b	na01205	d	na01005	d	na01105	d	na03005	a	na03106	a
na00406	d	na00506	e	na00706	e	na00306	e	na01206	d	na01006	d	na01106	e	na03006	a	na03107	a
na00407	d	na00507	e	na00707	e	na00307	e					na01107	e			na03108	a
na00408	d	na00508	e	na00708	e	na00308	e	na02000	~c	na01501	~			na03301	a	na03109	a
				na00709	e			na02001	b	na01502	d	na01301	c	na03302	a		
		na00601	a	na00710	e	na02200	b	na02002	b	na01503	d	na01302	c	na03303	a	na03201	a
		na00602	a	na00711	e	na02201	b	na02003	c	na01504	d	na01303	c	na03304	a	na03202	a
		na00603	~	na00712	e	na02202	b	na02004	c	na01505	e	na01304	c	na03305	a	na03203	a
		na00604	e			na02203	b	na02005	d	na01506	e	na01305	c	na03306	a	na03204	a
		na00605	e	na00801	d	na02204	b	na02006	d			na01306	c	na03307	d		
		na00606	e	na00802	d	na02205	c			na02500	a			na03308	d	na03501	a
		na00607	e	na00803	d	na02206	d			na02501	e	na01401	c	na03309	d	na03502	a
		na00608	e	na00804	e	na02207	d			na02502	ea	na01402	c			na03503	a
				na00805	e	na02208	d			na02503	e	na01403	c	na03401	b	na03504	a
				na00806	e	na02209	d			na02504	d	na01404	c	na03402	b	na03505	a
				na00807	e	na02210	d			na02505	d	na01405	c	na03403	b	na03506	a
				na00808	e					na02506	e	na01406	d	na03404	b		
				na00809	e	na02300	b			na02507	b			na03405	d	na03601	a
				na00810	e	na02301	b					na01600	c	na03406	d	na03602	a
				na00811	e	na02302	b			na02600	b	na01601	c	na03407	d	na03603	a
				na00812	e	na02303	b			na02601	b	na01602	c			na03604	a
						na02304	d			na02602	c	na01603	c			na03605	a
				na00901	b	na02305	d			na02603	d	na01604	c			na03606	a
				na00902	c	na02306	d			na02604	d	na01605	c			na03607	a
				na00903	d					na02605	e	na01606	c			na03608	a
				na00904	d	na02400	b			na02606	e						
				na00905	e	na02401	b					na01700	c				
				na00906	e	na02402	b					na01701	c				
				na00907	e	na02403	b					na01702	c				
				na00908	e	na02404	b					na01703	c				
				na00909	e	na02405	b					na01704	c				
						na02406	d					na01705	c				
						na02407	d					na01706	c				
												na01800	b				
												na01801	c				
												na01802	c				
												na01803	c				
												na01804	c				
												na01805	c				
												na01806	d				
												na01900	c				
												na01901	c				
												na01902	c				
												na01903	c				
												na01904	c				
												na01905	c				
												na01906	c				
												na02100	c				
												na02101	c				
												na02102	c				
												na02103	c				
												na02104	e				
												na02105	e				
												na02106	e				
												na02107	e				

Table 11.3. All Narrabri samples (na...), from all sampled depths (...01, ...02, etc): Two-way table showing soil sample sites in relation to site and five fuzzy groups (a-e) in which the sites have memberships greater than 0.499. Eroded landscapes are shown as bold, dust-mantled landscapes as italics. The sample identification numbers increase according to depth.

Subset of Narrabri clay soils

The high sodium percentages at depth in the Bohena soils, and the strong developent of gilgai, distinguish that area from other occurrences of cracking clay. To examine the differences between these clays and those elsewhere, for instance near Mulgate Creek, a further analysis was done of the cation data plus pH, electrical conductivity, chloride and calcium carbonate contents. Electrical conductivity is a measure of salt in the soil.

The transect at Bohena begins (site na004) on a terrace equivalent to the second terraced fan of the Namoi River. It then crosses a high level plain. Sites na005 and na006 were sampled here, and also the strongly gilgaied grey clays with brigalow (na007, na008, and na009). The drilling showed that this high ground was formed as an alluvial plain and had a soil that was originally red. The surface sloped at that time very gently to the west but deposits of aeolian clays have filled in the lowest sites and now make the high plain perfectly level. Bohena, Mollee and Bundock creeks occupy broad and very shallow depressions in the plain, and on the slopes leading to the streams aeolian sediments are absent. This suggests that dust falling on these gentle slopes has most probably been washed away by rainfall. Sites na031, na032, na035 and na036 are aeolian clays that have been trapped in Round Swamp near Bundock Creek at Culgoora. Sites na013, 014, 016-019 and na021 are from the I.A. Watson farm and are included for comparison.

The results of fuzzy analysis of this data set are given in Tables 12.1 and 12.2 and Appendix 2. Groups 6c and 6f are alike, except that the soils in 6f are not as salty. Both groups resemble 6d, which forms the subsoil at Mulgate Creek, but 6d is more calcic, less sodic, and evidently better drained.

Attribute	**Min**	**Max**	**Mean**	**St. dev.**
pH	4.32	9.62	7.29	1.65
EC	1.1	323	45.7	49.82
chloride	0.5	2258	325.2	520.2
$CaCO_3$	0.05	9.9	0.70	1.37
cec	0.9	576.5	294.2	165.3
eAlp	0.01	79.39	3.53	11.20
eKp	0.55	35.00	5.80	6.21
eNap	0.13	59.26	18.20	16.08
eMgp	9.85	84.78	41.10	9.82
eCap	0.04	66.90	31.53	20.29

Table 12.1. Subset of 17 Narrabri clay soils, all layers. Summary statistics for data matrix of 131 samples × 10 attributes: pH, electrical conductivity, chloride, calcium carbonate, cec, eAlp, (exchangeable aluminium percent), eKp, eNap, eMgp, and eCap.

Group	pH	EC	chloride	$CaCO_3$	cec	eAlp	eKp	eNap	eMgp	eCap
6a	5.34	3.1	20.4	0.10	14.2	49.62	19.42	4.97	25.72	2.54
6b	8.41	22.1	61.5	0.52	433.1	0.04	3.23	7.43	35.94	53.38
6c	5.26	155.2	1615.6	0.20	346.6	2.11	2.97	38.67	45.08	11.17
6d	9.00	59.2	247.0	2.25	453.7	0.04	2.14	23.47	47.20	27.18
6e	7.11	13.0	25.9	0.28	151.1	1.25	13.11	3.84	35.56	46.30
6f	5.76	47.8	457.5	0.08	168.2	4.60	1.75	37.40	48.39	7.94

Table 12.2. Seventeen Narrabri clay soils, all layers. Centroids.

There is a great amount of soluble salt at depth in the Bohena soils. The clays at these depths are highly dispersed, and the subsoils are very dense. If this salt was to move and become concentrated elsewhere in the landscape the consequences for land users could be disastrous. The cracking clays at Mulgate Creek, in contrast, are rich in calcium and relatively leached of sodium and salts. At Round Swamp the clay sediments have the highest calcium values and a very low salt content. Sites na004 to na006, on the eastern margin of the Bohena gilgaied clays, show high salt and sodium levels in the subsoils and potentially toxic exchangeable aluminium values at the ground surface.

Explanation of soil salt contents

The aeolian sediments at Bohena lie at the highest part of the landscape and thus experience no run-on, all surface water coming from rainfall. The presence of salt in such a situation is surprising. The clayey beds are thick, however, and because of the impermeable subsoil, absence of an effective regional slope and gilgaied relief there is no runoff. The red colours and sandy alluvial beds at depth show that the soil originally drained freely but the present condition is one of no through drainage, which would suggest that the accumulating dusts at some point interfered with soil drainage, ultimately to establish the present ponded condition. It is inferred that the lack of drainage has allowed further retention of dusts and their included cyclic salts. Nevertheless a small loss by seepage is shown by the elevated salt and sodium levels in the subsoils at sites na004 to na006, on the eastern margin of the gilgai. These values indicate that salts from the gilgaied area are dispersing slowly towards the drainage lines.

At Mulgate Creek the aeolian sediments are watersorted and lie on relatively free-draining alluvium. Much of the original salt has been able to escape.

At Round Swamp the aeolian sediments have most likely lost their original salt to the surface runoff that periodically flushes through the area.

Other evidence of the movement of cation-charged soil solutions is provided by na011. This site lies on a dust-mantled alluvial plain close to calcareous sediments of Rolling Downs Group. It has high calcium values in comparison with the usual soils of the plain. Na021, which lies below sodic clays of Rolling Downs

Group, is high in sodium. Salts in the soils near the Galathera Tank might, in a similar way, be coming from Tarlee Creek, which receives much of its flow by drainage from the Bobbiwaa Creek alluvial fan.

soil series	*soil type and number*		*parent material*	*great soil group*
eroded landscape				
Tarlee	clay loam	1	eroded (fifth) fan	grey clay
Clarendon	sandy loam	2	red-weathered plain	solodic soil
Montana	clay loam	3a	basalt	lithosol
	medium clay	3b		
Bald Hill	medium clay	4	basalt	black earth
Moonbill	light clay	5a	basalt	euchrozem
	medium clay	5b		
Killarney	association	6	Pilliga Sandstone	yellow podzolic
Murrumbilla	loamy sand	7a	Pilliga Sandstone	yellow podzolic soil
	light clay	7b		
Cooyong	loam	8	Rolling Downs Group	rendzina
Watson	clay loam	9a	Rolling Downs Group	grey clay
	clayey sand	9b		
Oakvale	loamy sand	10a	Tertiary sandstone	solodic soil
	sandy clay	10b		
dust-mantled plains and lunettes				
Yarrie	sand	11	lunette sand	siliceous sand
Muckabinya	subplastic clay	12a	parna, watersorted	brown clay
	heavy clay	12b		
Gommel	subplastic clay	13a	parna, watersorted	grey clay
	heavy clay	13b		
Meriah	medium clay	14a	parna, watersorted	grey clay
	medium clay,hard-setting phase	14b		
	hardsetting soil	14c		
Round Swamp	clay loam	15	parna, watersorted	grey clay
Bohena	medium clay	16	parna	grey clay
alluvial plains				
Namoi	clay loam	17a	alluvium, Namoi	alluvial soil
	medium clay	17b		
Spring Creek	clay loam	18a	alluvium, Nandewar	alluvial soil
	medium clay	18b		
Galathera	medium clay	19	alluvium, Nandewar	humic gley soil
Pian	loamy sand	20a	alluvium, Spring Ck	alluvial soil
	clay loam	20b	alluvium, Namoi	
	medium clay	20c	alluvium, Namoi	
Queerbri	silt loam	21a	alluvium, Namoi	brown clay
	silt loam, bohena variant	21b	alluvium, Bohena	red brown earth
	clay loam	21c	alluvium, Namoi	brown clay
	medium clay	21d		brown clay
Bobbiwaa	clay loam	22a	alluvium, Nandewar	brown clay
	clay loam, sodic phase	22b		
	medium clay	22c		
Bundock	loamy sand	23	alluvium, Bundock Ck	red earth

Table 13. Soil legend. Soil types 2, 8, 9, 11, 15, and 16 appear on map sheets adjoining the Edgeroi soil map.

Description of soil units

> ... nitrates are not the land, nor phosphates; and the length of fibre in the cotton is not the land. Carbon is not a man, nor salt nor water nor calcium. He is all of these, but he is much more, much more; and the land is so much more than its analysis.
>
> - John Steinbeck, *Grapes of Wrath*, 1937

In this section soil series and soil types are described. The full list of soils is set out in Table 13, in relation to landform and parent material.

The *soil series* are identified by proper names (e.g., Namoi, Muckabinya) and are based on differences in parent material, taken together with soil profile form. The *soil types* are subsets of the soil series and are named according to the texture of the surface soil (as determined by its feel). The general correspondence between soil texture and cation assemblage in the landscape groups described above, however, allows the use of texture names that best describe the groups defined by fuzzy analysis. In order to keep the fuzzy groups intact, a small degree of soil texture variation has been allowed in several soil types. *Thus the concept of 'soil type' as used here varies slightly from the usual practice* (Soil Survey Staff, 1951). The departures are mostly trivial, however. Flexibility is needed when adapting old methods to new technology. Detailed descriptions of soil profiles, and analyses of soil samples for grid sites ed001 to ed210 are provided in McGarry et al. (1989).

There is considerable soil profile variation in the soils developed on Pilliga Sandstone, and for this reason that unit is identified as a *soil association*.

Centroids for soil fuzzy groups with similar chemistry are shown in Tables 7.2 (eroded landscape), 8.2, 8.4 and 9.2 (dust-mantled plains), 10.2, 10.3 and 10.4 (alluvial landscape), 11.2 (all Narrabri sites), and 12.2 (subset of 17 Narrabri clay soils). Some soil profiles that are not summarised in these tables are included with the soil types; these profiles were classed using available laboratory and field data. The general character of the cation assemblage for each soil type can be identified from the tables but, for convenience, the average values for each type are listed in Table 14 and in diagrammatic form, as stacked columns in Fig. 26. Brief soil descriptions are given in the text.

The observations are too widely spaced to permit the mapping of separate soil types.

soil	number[1]	clay %	cec	eAlp	eKp	eNap	eMgp	eCap
Tarlee cl	43	32.2	276.2	0.01	3.85	2.35	19.37	72.09
Clarendon sl	4	nd	20.6	12.48	17.81	0.41	35.76	34.18
Montana cl	9	28.4	193.9	0.45	7.80	0.38	28.13	63.26
Montana mc	20	53.6	519.3	0.01	3.99	0.54	28.57	66.88
Bald Hill mc	20	51.5	463.9	0.01	3.37	0.93	23.74	71.94
Moonbill lc	5	31.6	271.5	0.01	7.38	0.67	27.96	63.97
Moonbill mc	20	57.4	397.8	0.01	3.37	1.72	40.18	54.70
Killarney: sl	4	15.1	25.5	48.31	20.21	1.54	15.18	14.79
Killarney: s well	9	5.2	9.2	40.54	14.40	1.78	11.03	33.53
Killarney: s slow	21	8.9	20.0	63.00	12.59	4.02	12.26	8.48
Murrumbilla ls	43	8.9	30.9	5.64	14.81	2.62	23.87	53.41
Murrumbilla lcy	20	26.9	157.7	0.16	5.21	2.05	39.00	48.60
Cooyong l	11	22.9	146.7	0.04	6.61	3.64	20.96	68.76
Watson cl	10	28.4	173.5	0.07	4.13	2.00	40.97	52.85
Watson ls	3	4.4	18.0	0.48	15.41	27.04	29.55	27.65
Oakvale ls	24	10.9	57.8	6.28	14.47	0.94	22.19	56.29
Oakvale scy	24	23.1	143.9	0.17	8.54	1.22	28.71	61.37
Yarrie s [3]	6	4.3	16.7	0.44	15.93	0.40	17.15	66.84
Muckabinya spc	27	46.9	386.0	0.01	3.66	4.17	26.88	65.27
Muckabinya hc	39	58.3	486.8	0.01	3.79	4.33	32.90	58.96
Gommel spc [4]	100	46.6	355.4	0.01	4.12	3.30	26.91	65.65
Gommel hc	156	58.9	435.9	0.01	3.79	4.29	35.32	55.30
Meriah mc	21	32.5	201.0	0.05	4.69	7.03	34.95	53.28
Meriah mc, hs phase	10	39.1	299.9	0.01	2.71	11.42	30.18	55.67
Meriah hs	32	42.3	303.7	0.03	4.37	4.31	35.80	55.48
Round Swamp cl [5]	7	33.6	128.4	0.05	14.38	4.36	33.67	47.54
Bohena mc	6	nd	336.4	0.02	4.19	9.47	35.84	50.46
Namoi cl	12	40.5	250.7	0.02	5.68	2.55	35.46	56.30
Namoi mc	14	56.6	378.8	0.02	3.40	1.57	36.24	58.79
Spring Creek cl	15	27.6	269.4	0.02	7.51	1.27	25.26	65.96
Spring Creek mc	9	47.0	385.6	0.01	4.02	3.03	28.40	64.45
Galathera mc	15	60.4	398.1	0.01	4.18	6.41	37.00	52.41
Pian ls	3	9.5	40.8	2.46	17.43	8.16	33.83	38.11
Pian cl	9	37.2	243.3	0.02	7.38	1.11	28.31	63.19
Pian mc	9	64.6	406.9	0.01	3.60	4.30	32.72	59.36
Queerbri sil	2	26.6	137.3	0.03	4.87	5.46	34.25	55.39
do, Bohena variant	2	nd	26.7	46.86	16.38	1.03	21.43	14.43
Queerbri cl	15	40.1	217.0	0.02	9.81	1.75	32.79	55.62
Queerbri mc	21	52.7	362.3	0.01	4.09	2.58	31.07	62.24
Bobbiwaa cl	15	33.6	216.3	0.20	7.30	1.77	32.05	58.67
Bobbiwaa cl, sodic	28	38.6	279.5	0.01	5.10	6.37	45.08	43.44
Bobbiwaa mc	41	48.8	414.1	0.01	3.78	2.73	29.98	63.50
Bundock ls	3	7.7	28.0	0.19	12.39	0.19	21.80	65.80

[1] number of samples examined.
[2] number of samples for which phosphate values are available.
[3] Yarrie sand: clay content is mean of 4 values.
[4] Gommel spc, clay is mean of 96 values.
[5] Round Swamp: clay is mean of 3 values.

Table 14. Attribute means for Edgeroi soil types (clay, cec and percent exchangeable cations). cl - clay loam; hc - heavy clay; l - loam; lc - light clay.

soil	number[1]	pH	cond.	chloride	$CaCO_3$	carbon	phosphate	no[2]
Tarlee cl	43	7.6	12.2	23.1	0.22	1.60	14.7	29
Clarendon sl	4	5.3	9.8	24.0	0.05	0.98	8.1	4
Montana cl	9	6.7	12.6	11.4	0.05	2.26	62.4	6
Montana mc	20	7.5	13.8	19.0	0.57	2.52	49.9	14
Bald Hill mc	20	7.8	13.2	15.0	0.34	1.76	12.7	14
Moonbill lc	5	7.4	15.1	10.4	0.06	2.69	61.1	4
Moonbill mc	20	7.4	12.7	9.1	0.23	1.90	68.3	18
Killarney: sl	4	5.2	2.8	14.0	0.05	2.09	5.7	4
Killarney: s well	9	5.6	4.1	12.2	0.05	0.84	4.8	5
Killarney: s slow	21	5.0	5.9	19.7	0.05	2.01	5.5	14
Murrumbilla ls	43	5.9	5.8	10.3	0.05	1.28	18.4	31
Murrumbilla scy	20	6.7	9.8	24.1	0.05	2.02	24.0	16
Cooyong l	11	7.8	12.7	3.0	1.70	1.28	7.9	8
Watson cl	10	6.9	10.4	116.8	0.06	0.95	16.2	8
Watson ls	3	6.3	4.5	1.5	0.05	0.43	11.8	2
Oakvale lc	24	6.5	8.4	13.3	0.05	1.23	26.3	17
Oakvale scy	24	6.8	11.9	18.1	0.05	1.77	24.2	20
Yarrie s	6	6.2	4.1	6.3	0.05	0.43	35.4	6
Muckabinya spc	27	8.3	13.3	17.0	0.24	0.87	14.8	18
Muckabinya hc	39	8.4	16.2	26.2	0.46	1.04	21.3	26
Gommel spc	100	8.4	14.8	30.4	0.25	1.11	27.5	72
Gommel hc	156	8.3	16.2	32.5	0.26	1.09	28.1	109
Meriah mc	21	7.3	11.7	28.1	0.11	1.08	10.9	14
Meriah mc hs phase	10	8.0	19.2	69.2	0.19	0.94	5.1	8
Meriah hs	32	7.5	12.9	37.8	0.18	1.23	20.5	22
Round Swamp cl	7	6.5	20.9	40.0	0.07	1.14	19.5	7
Bohena mc	6	7.2	43.0	332.3	0.25	2.23	7.8	6
Namoi cl	12	7.1	11.3	17.9	0.05	1.87	91.9	8
Namoi mc	14	7.5	13.0	28.8	0.06	1.73	75.9	10
Spring Creek cl	15	7.5	18.2	24.3	0.28	2.44	44.3	10
Spring Creek mc	9	8.0	16.4	14.0	0.30	1.40	38.9	6
Galathera mc	15	7.7	12.0	38.9	0.06	1.12	27.7	10
Pian ls	3	6.1	23.3	287.0	0.05	1.07	84.3	3
Pian cl	9	7.0	14.0	20.0	0.10	1.57	54.4	8
Pian mc	9	7.4	16.0	57.0	0.21	1.02	27.8	9
Queerbri sil	2	6.7	6.9	12.5	0.05	1.51	57.8	2
do, Bohena variant	2	4.8	6.8	24.0	0.05	1.33	5.7	2
Queerbri cl	15	6.9	12.6	27.3	0.05	2.25	110.7	10
Queerbri mc	21	8.3	16.3	25.2	0.82	1.38	33.4	14
Bobbiwaa cl	15	7.2	9.9	15.7	0.06	1.82	43.9	10
Bobbiwaa cl, sodic	28	7.1	10.8	52.1	0.07	1.31	20.1	22
Bobbiwaa mc	41	8.1	15.1	18.51	0.63	1.47	26.6	28
Bundock ls	3	6.8	4.2	11.3	0.05	0.80	14.9	2

Table 14 (continued). lcl - light clay loam; ls - loamy sand; mc - medium clay; s - sand; scy - sandy clay; sil - silt loam; sl - sandy loam; spc - subplastic clay; hs - hard-setting; slow - slow draining; well - well draining.

Eroded landscape

The soils of this landscape are all exposed to erosion by surface rainwater runoff and to loss of nutrient elements through leaching. The soils occur on the sandstone ridges, basalt hills and eroded alluvial plains.

1... Tarlee clay loam

Tarlee and Galathera creeks have their headwaters in the flat to very gently undulating country surrounding Edgeroi township. This land is formed of ancient alluvial beds of the eroded fifth fan. It is partly mantled with wind-deposited sediments, and carries dark slow-draining *grey clays* beneath belah forest. Water-worn gravels, including basalt, are seen at the surface in several places and are reported at depth in several drill cores. A gravel quarry at 'Nurrawallee' (Edgeroi 630658) is surrounded by Tarlee soils but the exposure at the quarry shows 4 m of waterworn stones and 1 to 3 m of very firm puggy clay, and is most likely an isolated part of Pilliga Sandstone. The differentiated stony soil on clayey subsoil that is developed at the quarry lies at the same level as the Tarlee soils. In general Tarlee clay loam shows a varied surface condition ranging from granular, self mulching, to weakly developed surface crust. At several places gypsum was observed at depth, below carbonates.

Tarlee soils are neutral to weakly alkaline (Table 14), and have a low magnesium to calcium ratio (Ca:Mg = 3.7). Salt contents and sodium values are also low.

Tarlee clay loam: ed063, ed064, ed065, ed066, ed080, ed081, ed082, ed083, ed096, ed097, ed098, ed099 ed236, ed243, ed410, ed412

Tarlee clay loam where it is developed near 'Oakvale' (ed236) shows:

27 cm	black grading to very dark grey light to medium clay, moderate subangular blocky and granular structures, few very fine roots, pH 7.0 grading to 8.5, diffuse change to
78 cm	very dark grey medium clay, weak prismatic structure breaking to subangular blocky in the upper part, moderate slickensides, few rounded quartz gravels, common calcareous nodules, pH 8.5, diffuse change to
55 cm	dark brown light to medium clay, massive, with prominent calcareous nodules and few rounded quartz fragments,pH 7.0, gradual tongued change
on	brown sand with dark brown patches of clayey soil in fissures, weak horizontal fracture, prominent clay veins and fine manganese stains, pH 7.0, continuing to 2.70 m.

2… Clarendon sandy loam

'Clarendon' Homestead is situated at Narrabri 554295, close to the drilled transect at Bohena. The name is used here for sand-on-clay *solodic soils* that have formed in the modern landscape on red-weathered prior soils developed on the extensive and slightly eroded alluvial plains of this district. The Clarendon soil was examined in only a few localities by means of exposures in surface water storage tanks, roadside drains and hand augering. Two sites drilled on the Bohena transect were sampled for chemical analysis.

The topsoil of Clarendon sandy loam is acid (Table 14), with high values for aluminium and potassium, and very low phosphate. An unusual feature, for the soils examined in this study, is the magnesium dominance of the clay exchange complex. Topsoils are light (sandy loam, with sand at the ground surface in some places) and are susceptible to sheet wash and wind erosion when cultivated. Drainage through the soil is strongly impeded by the clayey subsoil. The data show high subsoil values for sodium (Tables 11.2, 11.3). Sodium contents increase towards the adjoining aeolian clays at Bohena, and are possibly derived from those sediments by leaching. Near the aeolian clays the Clarendon subsoils are alkaline.

Clarendon sandy loam: na005, na006

Clarendon sandy loam (na005) shows:

25 cm	dark greyish brown to pale brown sand, weak platy and granular structures, few very fine roots, pH 5.5, diffuse change to
28 cm	light grey sand with conspicuous white bleach in the lower part, structureless, pH 6.0 to 7.0, abrupt, wavy change to
72 cm	pale brown passing at depth to red sandy clay, with strong brown mottles and cracks containing patches of light grey sand from above, weak coarse columnar structure breaking to thick horizontal plates, few roots,pH 5.0 to 5.5, very diffuse change
on	yellow clayey sand with prominent very coarse white stains inherited from the prior soil on the parent alluvium, pH 6.5, continuing to 4.78 m.

3a… Montana clay loam

3b… Montana medium clay

'Montana' Homestead lies near the Narrabri-Courrada Road at Edgeroi 845675. The name is used for stony, and associated shallow basaltic soils (*lithosols* and shallow *black earths*) that occur commonly on this holding and at several other places in the foothills of the Nandewar Range. The soils are developed on colluvium and bouldery alluvium derived from Nandewar and Garrawilla volcanic rocks. They are well structured but are mostly too stony to cultivate, and contain rocky outliers that must be avoided. The land surface is gently sloping and undulating.

The surface soils are near neutral, with low conductivity and chloride, and high phosphate owing to the contribution from weathering basalt (Table 14). The high clay activity ratios for Montana medium clay (giving a mean of 9.7) imply a high proportion of smectite clay minerals. The two profiles of Montana clay loam have smaller ratios (6.8) perhaps because of the higher acidity and slower drainage at these sites.

Montana clay loam: ed070, ed208
Montana medium clay: ed059, ed087, ed088, ed192, ed193, ed209, ed425

A description of Montana clay loam (ed070) shows:

50 cm dark reddish brown clay loam grading with depth to light clay, granular structure, common fine roots, few basalt fragments, pH 5.8 to 6.5,
130 cm dark reddish brown light to medium clay, weak prismatic structure breaking to moderate angular blocky structure, common to few very fine roots, pH 6.7 to 7.0, clear stratigraphic break
on basalt in situ, with manganese stains, continuing to 2.38 m.

Montana medium clay (ed192) shows:

55 cm dark brown to dark reddish brown light and medium clay, moderate lenticular structure breaking to angular blocky structure, weak slickensides at base, many very fine roots, pH 7.0 to 7.5, clear change to
11 cm reddish brown medium clay with dark patches of soil filling cracks, strong lenticular structure with slickensides breaking to angular blocky structure, common basalt fragments, common very fine roots, pH 7.5 abrupt change
on white clay loam with dark brown patches of soil filling cracks in basalt, with soft segregations of carbonate at 120 cm, massive, few roots pH 7.7 to 8.0.

4... Bald Hill medium clay

Deep *black earths* and similar dark grey soils are common on basaltic rocks in the foothills of the Nandewar Range, on Bald Hill (Edgeroi 576693) and at 'Green Timbers' (Edgeroi 633613). The soils are fertile, with excellent self-mulching structure, and are highly regarded for cropping. In most places they are developed on colluvial deposits derived from Nandewar Volcanics, with local contributions from Pilliga Sandstone on undulating and easy rolling slopes. Deep profiles dominate and in several places the presence of quartz sands in soil horizons above basalt indicates the presence of aeolian material. Rock crops out on some of the higher slopes.

The surface soils are near neutral, with low conductivity and chloride and high calcium values. They are like the Montana soils, except for lower phosphate levels (Table 14). Clay activity ratios (cec/percent clay) are high, giving a mean of 9.0, and imply a high proportion of smectite clay.

Bald Hill medium clay: ed053, ed101, ed130, ed131, ed212, ed239, ed424, ed427, ed428

Bald Hill medium clay (ed130) shows:

60 cm very dark grey medium clay, moderately developed subangular blocky structure, few fine calcareous nodules, few subrounded quartz fragments and fine patches of sediment filling cracks, few very fine roots, pH 7.5 to 8.7,

70 cm dark brown medium clay, strong wedge structure, moderate slickensides, few calcareous nodules becoming more abundant with depth, few quartz fragments, few very fine roots, pH 9.0, clear change

on brown sandy light clay, massive, with prominent soft calcareous segregations and abundant angular basalt fragments, pH 9.0, continuing in decomposing rock to 2.04 m.

5a… Moonbill light clay

5b… Moonbill medium clay

Deeply weathered and in places stony brown soils occur on Garrawilla Volcanics on gently sloping land below outcrops of Pilliga Sandstone near Spring, Bobbiwaa and Moonbill creeks east of 'Woodville' Homestead (Edgeroi 810581). In several places the soils show surface gilgai. These appear as parallel rises and depressions of low amplitude, spaced at 2-3 m, and mostly with a vertical interval less than 0.1 m. The gilgai are directed downslope, forming a linear pattern as described for other localities by Beckmann et al. (1973, 1984). Variations in the pasture are apparent and the gilgai can also be noticed because of their effect on vehicles travelling across them. Hallsworth et al. (1955) thought that gilgai like these developed their form partly by erosion by water channelled downslope but it is now generally accepted that they are formed simply by expansion of weathering soil materials on sloping ground. Several closely spaced drill holes showed no morphological variation across the gilgai except for a tendency to greater cracking and slightly deeper granular structure on the puffs. The surface in general is mostly firm to hardsetting.

Surface wash from the sandstone slopes is incorporated in the topsoil and may appear as sandy rises that conceal the weathered basalt.

The surface soils are neutral to slightly alkaline, with low conductivity, exchangeable sodium percent and chlorides, and high calcium and phosphate (Table 14). Calcium carbonate was frequently observed in the drill cores.

Moonbill light clay: ed158, ed175, ed242
Moonbill medium clay: ed123, ed157, ed241, ed347, ed348, ed349, ed350, ed351, ed352

Moonbill light clay (ed242) shows:

25 cm dark brown light clay, strongly developed subangular and angular blocky structures, common very fine roots, pH 7.5 to 8.0, gradual change to

110 cm dark brown to reddish brown light clay, weak coarse prismatic structure breaking to platy, few soft calcareous segregations becoming prominent with depth, pH 8.8, diffuse change to

55 cm light yellowish brown medium clay, weak angular blocky structure, with very few calcareous nodules and manganese concretions, pH 8.8, diffuse change

on pale grey and white decomposing rock with yellowish brown weathering stains in fissures, pH 8.5, continuing to 3.50 m.

Moonbill medium clay (ed157) shows:

20 cm dark reddish brown medium to heavy clay, moderately developed subangular blocky and granular structures, few angular basalt fragments, common very fine roots, pH 7.5, smooth change to

40 cm dark reddish brown medium to heavy clay, strong prismatic and angular blocky structures, common basalt fragments, few fine roots, pH 8.5, clear change

on dark red gravelly medium clay, massive and weak blocky structure, with prominent calcareous nodules and abundant angular basalt fragments, pH 8.5, continuing in decomposing rock to 1.93 m.

6… Killarney association

Killarney State Forest is mostly established on shallow *lithosols*, sand-on-clay *solodic soils* and *yellow podzolic soils* but *siliceous sands* are also common. Because of this variety of soils on Pilliga Sandstone and the relatively few site examinations, soil types on this sloping and undulating country are not defined. The soils are grouped instead according to surface texture and drainage (as indicated by subsoil colour) and are summarised on this basis. Ferruginous concretions are seen in places in the soil. The large plates of ironstone found at the ground surface and at shallow depth are derived from the sandstone. The ironstone is common at the base of the formation, where groundwater is held up at the contact with Purlawaugh Formation. Surface washes are a hazard on cultivated ground and where water is diverted from roadworks. Shallow rills were frequently seen.

The soils are mostly acid (Table 14), with aluminium the dominant cation and high levels of exchangeable potassium. Conductivity, chlorides and phosphate contents are low. Exchangeable calcium is relatively high in the well-drained sands.

Killarney association, sandy loams: ed104, ed354
Killarney association, well-drained sands: ed086, ed121, ed190
Killarney association, slow draining sands: ed052, ed102, ed120, ed122, ed189, ed205, ed206

A profile of a sandy loam (ed354, a solodic soil) shows:

22 cm dark brown sandy loam with sporadic bleach, weakly developed subangular blocky structure together with massive material, few subangular sandstone fragments, few very fine roots, pH 5.5, abrupt change to

33 cm yellowish red light to medium clay with few dark reddish brown organic stains, strong subangular blocky structure, abundant angular sandstone fragments, few fine roots, pH 5,8, diffuse change

on reddish brown rock with clay with prominent very coarse white mottles possibly due to intermittent waterlogging, massive, with abundant angular sandstone fragments, pH 8. 0 to 8.5, continuing in decomposing rock to 1.52 m.

The well-drained sands (ed190) show:

12 cm dark brown coarse loamy sand with slight bleach at the surface, weakly developed subangular blocky structure, few very fine roots, pH 7.0, gradual change to
63 cm brown to light yellowish brown coarse sand with common brown organic stains, single-grained, few fine roots, few subrounded quartz fragments, pH 7.5, diffuse change to
70 cm red clayey coarse sand to sandy light clay with brownish grey and reddish yellow mottles, coarse prismatic and subangular blocky structure, pH 7.0, abrupt irregular change
on yellowish red coarse sand with few coarse white mottles, massive with marked horizontal fracture, continuing to 2.54 m.

A representative profile of the slow draining sands (ed122) shows:

28 cm very dark brown sand with prominent thin pale brown bleached surface crust, massive, weak, few very fine roots, pH 4.0 rising to 5.5, gradual change to
22 cm yellowish brown sand, with charcoal fragments, single-grained, few very fine roots, pH 5.5, diffuse change to
67 cm red sand with prominent very coarse light grey mottles following roots and fissures, massive, with weak cast granular structure, pH 5.5, clear change
on yellow loamy sand with prominent very coarse white mottles, massive, few roots, pH 5.5, continuing to 1.93 m.

7a… Murrumbilla loamy sand

7b… Murrumbilla light clay

'Murrumbilla' Homestead is beside Spring Creek. The name is used for soils developed mostly on colluvial slopes below ridges of Pilliga Sandstone and on prior red-weathered soils on the sandstone. The landscape is pedimented and is most extensive in the east, where Pilliga Sandstone lies above the softer and less resistant Purlawaugh Formation. Clay beds in Pilliga Sandstone, aeolian clays washed from the hills, and Garrawilla Volcanics contribute in part to Murrumbilla light clay.

Murrumbilla loamy sand is a very light, loose sandy soil with clayey subsoil. It is formed mostly on colluvium and on the red-weathered prior soil and occupies broad, gentle slopes that descend gradually to the streamlines. The soil is susceptible to drought and sheet wash, and is more suited to pasture than crops. The ground is soon saturated in wet weather. The surface soil is acid, with low cation exchange capacity (Table 14). Calcium is the dominant cation. Exchangeable aluminium and potassium are relatively high. Chlorides, salts and phosphate contents are low.

Murrumbilla light clay is a more attractive soil owing to its heavier texture and larger nutrient supply. In places it includes clays from Purlawaugh Formation and weathered material from Garrawilla Volcanics. The effect of the volcanic contribution is seen in greater fertility and improved structure but the topsoil is thin, and soon affected by drought. Broad, gentle slopes are developed.

Murrumbilla light clay is neutral to slightly acid at the ground surface, with low to moderate cation content (Table 14). Calcium is the dominant cation and exchangeable aluminium and potassium are at low and very low levels. Chlorides, salts and phosphate contents are mostly low.

Murrumbilla loamy sand: ed068, ed085, ed105, ed137, ed171, ed172, ed173, ed188, ed207, ed338, ed339, ed344, ed346, ed353, ed355, ed429, ed430, ed431
Murrumbilla light clay: ed119, ed136, ed191, ed210, ed337, ed340, ed341, ed342, ed343

Murrumbilla loamy sand (ed068) shows:

20 cm	dark brown to brown loamy sand, weak subangular blocky structure, few black iron-manganese nodules, few very fine roots, pH 6.0 to 6.5, clear change to
40 cm	very pale brown and light grey loamy sand, weak subangular blocky structure, few fine roots, few subrounded quartz fragments, common prominent dark brown iron-manganese nodules, few very fine roots, pH 6.5 sharp change to
70 cm	strong brown and dark red loamy sand with prominent light grey mottles, medium prismatic structure, few roots pH 7.0 to 8.0, diffuse change
on	dark red light sandy clay loam with prominent strong brown and grey mottles, moderate prismatic and weak angular blocky structures, few fine calcareous veins at 240 cm, pH 8.5, continuing to 2.73 m.

Murrumbilla light clay (ed341) shows:

20 cm	dark brown light to medium clay, moderate angular blocky structure, few fine quartz gravels, few very fine roots, pH 6.2 to 6.5, gradual change to
150 cm	reddish brown and dark reddish brown light to medium clay with dark brown organic stains, strong wedge and angular blocky structure with weak slickensides, few calcareous nodules in lower part, few very fine roots, pH 8.5 to 9.0, diffuse change to
40 cm	yellowish red sandy to gravelly light clay with prominent brownish grey mottles, common calcareous soft segregations, weak subangular blocky structure, pH 9.0,
on	strong brown mottled light clay, lying on Garrawilla basalt at 2.64 m.

8… Cooyong loam

The name is from 'Cooyong' Homestead (Narrabri 720475), which lies near the soils that take this name. They are formed above marls that occur in Rolling Downs Group. They do not occur in the area covered by the Edgeroi map sheet but are developed on the I.A. Watson Wheat Research Farm of the University of Sydney and extend across the Narrabri-Bingara Road into 'Cooyong'.

The soil is very shallow over a hard lime cement *(calcrete)*, formed near the surface by the solution and redeposition of calcium carbonate in the upper part of the weathering profile. Calcareous nodules are abundant below the cemented lime band, and the deposit was once used as a source of agricultural lime, the diggings being in the road reserve adjoining 'Cooyong'. Detached pieces of the calcrete are common in the cultivated area. The soil effervesces with dilute hydrochloric acid, showing that the carbonates are present in the fine earth. There are scattered quartz pebbles in the parent sediments and pieces of angular red sandstone at depth above siltstone.

The soil has a thin surface crust but beneath this the topsoil is loose and powdery. Cooyong loam is alkaline, with very high levels of calcium (Table 14). Sodium, conductivity, chlorides and phosphate are low at the surface, but show higher values at depth (Tables 11.1, 11.2).

Cooyong loam: na003, na022, na023, na024

A description at the old lime pit (na003) shows:

2 cm	greyish brown loam to fine sandy loam, weak angular blocky structure, very few fine quartz gravels, common very fine roots, pH 8.5, gradual change to
18 cm	greyish brown fine sandy loam with black organic stains, moderately developed fine columnar structure, common coarse calcareous nodules, pH 8.5, sharp irregular change to
220 cm	white calcareous light clay and calcrete with prominent dark brown patches of soil in cracks, common calcareous soft segregations, few fine black manganese nodules at top, massive, grading with depth to weak lenticular structures, pH 8.5 to 8.8, smooth stratigraphic boundary
on	light grey and brownish grey silty loam, massive, with pieces of charcoal, fine manganese stains and veins of calcium carbonate and with pieces of ironstone and sandstone at 400 cm, continuing to 4.09 m.

9a… Watson clay loam

9b… Watson clayey sand

Clay beds of Rolling Downs Group lie at the ground surface at the entrance to the I.A. Watson Wheat Research Farm north of Narrabri and are thinly mantled with Tertiary alluvium on gentle slopes in other places on the northern part of the property. The two soils to which the name is applied are found only in this area.

Watson clay loam is a *grey clay* and has a very slightly gilgaied surface, with washes of sand and thin areas of a sandy bleached surface crust. The dark clays grade at depth to soft yellow sandstone. At one site soil drainage was impeded by a bed of clay which showed evidence of prior red-weathering. Gypsum was prominent in the soil above this bed. The topsoils are near neutral, with high chlorides and relatively high magnesium.

Watson clayey sand resembles a solodic soil and is developed both on a thin veneer of Tertiary sediments, and on surface wash from Tertiary alluvium, lying at shallow depth mostly on the marls of Rolling Downs Group. The surface soil is slightly acid.

Watson clay loam: na012, na015, na020, na026
Watson clayey sand: na025

Watson clay loam (na015) shows:

50 cm dark brown light clay grading to sandy clay, weak subangular blocky structure, few very fine roots, pH 5.5, diffuse change to
110 cm brown sandy clay with dark brown patches of sediment filling cracks and dark brown organic stains, moderate prismatic and subangular blocky structure, few calcareous nodules becoming common in lower part, pH 8.5, diffuse change
on light grey sandy clay with few dark reddish brown ferruginous stains and manganese stains, massive, pH 9.0, continuing to 2.75 m.

Watson clayey sand (na025) shows:

17 cm brown clayey sand, massive, grading to platy structure, few very fine roots, pH 6.0, passing to
19 cm light brownish grey clayey sand, weak angular blocky structure, few very fine roots, pH 6.5, abrupt change to
44 cm pinkish grey medium to heavy clay with common distinct yellowish brown and yellowish red mottles, weak angular blocky structure, common manganese nodules in lower part, pH 7.0 to 8.5, gradual change to
80 cm greyish brown carbonate rock with clay, prominent white calcareous nodules and few manganese nodules, pH 8.5, clear change
on very pale brown carbonate rock with clay, continuing to Garrawilla basalt at 2.53 m.

10a… Oakvale loamy sand

10b… Oakvale sandy clay

Solodic soils, with sand-on-clay profiles, are formed on soft Tertiary sandstones and associated colluvial sediments that form rolling and strongly rolling slopes at 'Oakvale' (Edgeroi 764671), near the head of Galathera Creek, and at several other places mostly at the western extremities of the ridges descending from the Nandewar foothills to the plains.

The soils consist of loamy sands and hardsetting sandy clays above compact yellowish brown sandy clay and clayey subsoils which in many places have carbonate and show traces of former red-weathering. As the parent sandstones at depth are non-calcareous, it is believed that the carbonates seen in the soil are derived by leaching from calcareous aeolian dusts. The landscape is pedimented, but the mantle of colluvium is thin in comparison with the landscape on Pilliga Sandstone. Unlike the soils on Pilliga Sandstone, these soils are favoured by belah *(Casuarina cristata).*

Oakvale loamy sand has a very light and loose topsoil and is formed mostly on colluvium on broad, gentle slopes. However, it can have a thin crust at the surface and in places is hardsetting. The soil is susceptible to drought and sheet wash, and is prone to gullying under cultivation. The lower slopes soon become saturated in wet weather. The topsoil is weakly acid to neutral, with a low cation content (Table 14). Calcium is dominant and exchangeable aluminium and potassium reach significant levels. Chlorides and salts are low.

Oakvale sandy clay, in places a clay loam, is mostly hardsetting because of its heavier texture. It is a more attractive soil than the loamy sand but the topsoil is thin and the soil droughty. The topsoil is neutral, with low conductivity and low chlorides, and has a moderate cation content (Table 14). Calcium is the principal cation.

Oakvale loamy sand: ed033, ed051, ed067, ed100, ed118, ed187, ed416, ed418, ed421
Oakvale sandy clay: ed034, ed117, ed135, ed204, ed415, ed417, ed419, ed420, ed422, na010

Oakvale loamy sand (ed418) shows:

30 cm	dark brown loamy fine sand to clayey sand, weak angular blocky structure, few very fine roots, pH 7.0, clear change to
20 cm	light brownish grey clayey sand with brown organic stains, weak angular blocky structure, few subrounded rock fragments, few very fine roots, pH 7.5, sharp change to
45 cm	red and yellowish red medium clay with prominent grey mottles, moderate to strong prismatic and angular blocky structure, few manganese nodules and subrounded quartz fragments, pH 8.5, diffuse change to
55 cm	yellowish red light to medium clay with prominent coarse brown mottles, strong prismatic and angular blocky structures, common soft calcareous segregations, pH 8.5, diffuse change
on	white sandy clay with brown soil in cracks, massive, continuing to 3.74 m.

Oakvale sandy clay (ed415) shows:

10 cm	very dark brown clay loam, moderately developed granular structure, few very fine roots, pH 7.5, abrupt change to
35 cm	very dark brown clay loam, with moderate platy and angular blocky structure, few soft calcareous segregations in lower part, few very fine roots, pH 7.5, abrupt change to
85 cm	dark reddish grey grading to yellowish brown silty clay, strong subangular blocky and weak prismatic structures, few calcareous soft segregations, pH 8.5, clear change
on	light yellowish sand, massive, common calcareous nodules, pH 8.0, continuing to 3.20 m.

Dust-mantled Plains, and Lunettes

11… Yarrie sand

Yarrie sand has developed on windblown sands forming small lunettes at the north-north-eastern margins of Yarrie Lake and Round Swamp. The unit has not been used for agriculture and carries mostly sclerophyll forest with *Callitris* pine. At Yarrie Lake a borrow pit provides a useful exposure. Weathered alluvium beneath the lunette was dug here for road base but the pit is now disused except for rubbish disposal. Yarrie sand gives at first an impression of weak profile development but a clayey subsoil is present at depth. This horizon was possibly an early deposit of loamy material.

The sand at 75 cm depth at Round Swamp is possibly ca. 13 000 yr old (see above, p. 51). At Round Swamp the sand at the surface (from 0-20 cm) is pale in colour and clearly separated by a stratigraphic break, showing it to be a relatively recent addition. The field records do not show if this has also occurred at Yarrie Lake.

Yarrie sand: na030, na033, na034

The soil (Table 14) is acid to near neutral, with calcium the dominant cation and high levels of exchangeable aluminium. Conductivity and chlorides are low. Phosphate values are higher than would be expected for this parent sediment, and may reflect human occupation of these attractive camp sites.

At times of high water, overflow from the impounded water occurs through the soil. This episodic lateral drainage has led to the development of ironstones at the base of the sand at Round Swamp. A similar process might occur at Yarrie Lake, for ironstone concretions are exposed in the borrow pit there.

A soil profile of Yarrie sand from Yarrie Lake (na030) shows:

40 cm	brown sand, single-grained and weak granular structure, common very fine roots, pH 6.0 to 6.5, diffuse change to
25 cm	light grey sand, conspicuously bleached, single-grained, with few very fine roots, pH 6.5, clear change to
19 cm	white coherent sand with prominent very coarse reddish brown ferruginous mottles,single-grained, becoming massive with depth, pH 7.2, clear, smooth change to
34 cm	strong brown sandy clay with prominent very coarse light grey mottles and dark brown organic stains, brittle, a single rounded quartz pebble at 98 cm depth, very few roots, pH 8.0.

This soil lies over buried soils:

10 cm	pale yellow sand with coarse white mottles, massive, brittle, pH 8.0, abrupt change to the former subsoil
40 cm	red sandy clay with abundant yellowish red and light grey mottles, weak blocky structure and brittle fracture, pH 8.5, diffuse change to a second buried soil:
25 cm	pale brown sand with common dark reddish brown ferruginous nodules, weak angular blocky structure and brittle fracture, pH 8.5, abrupt change to former subsoil
135 cm	greyish brown sandy clay passing to red sand with brown stains and prominent light grey mottles, weak blocky structure and brittle fracture, pH 9.0, clear stratigraphic break
on	light brownish grey cemented alluvium with clay, pH 9.0, continuing to 3.53 m.

12a… Muckabinya subplastic clay

12b… Muckabinya heavy clay

'Muckabinya' homestead is situated at grid reference Edgeroi 677748 near the Newell Highway north of Edgeroi. The name is taken here for fertile well drained and moderately well drained cracking *brown clays* developed on water-sorted aeolian sediments that overlie alluvial fans in the northern part of the Edgeroi district. The two soils have similar surface textures but differ in plasticity:

in spite of its high clay content, Muckabinya subplastic clay consistently behaves as a light to medium, or medium clay.

The soils look very like the Queerbri soils of the alluvial lands and are easily confused with them, especially where sediments from the local catchments are included and where the aeolian sediments lie above ancient alluvial channels, as at Boggy Creek near its intersection with the Newell Highway. However, the parent sediments do not display the changes in grain-size that characterise river channels and levees and they lie on surfaces older than the second terraced fan. Their aeolian origin is also shown by the presence of an aeolian 'fingerprint' in particle size analyses. A further point of difference is that the soils are easier to cultivate, being less prone to set hard in the topsoil.

In one place, at Edgeroi 599703 on 'Waugan', a low mound occurs on the flat clay-mantled landscape. The mound is shaped as a very smooth, low, elongated dome 100 by 180 m in extent and 0.6 m elevation. Its friable surface and self-mulching character further distinguishes it from the neighbouring country. Particle size analyses support the inference that this mound is the remnant of a clay dune. Phosphate and nitrate-nitrogen values are very high (site ed601) and difficult to explain, although at the present time the mound is favoured by foxes. Mr Arthur Lindsay-Smith writes: 'There has been no fertilizer of any kind used ... since my father started on the property. As there was no farming [beforehand], I would doubt that any fertilizer was used before 1948.' In these circumstances it would seem that the P and N values are possibly to be attributed to prehistoric human occupation.

Muckabinya soils are friable, mostly fine self-mulching soils, with a weak crust in a few places, and with thick brownish topsoils over reddish brown well structured clayey subsoils. The soils are alkaline (Table 14), with calcium the dominant cation. Chloride and phosphate contents are low except for ed601 and ed602 (because of their extreme values the data for these soils are not included in the tabled averages).

Muckabinya subplastic clay: ed006, ed024, ed025, ed026, ed027, ed028, ed029, ed030, ed076, ed079, ed601

Muckabinya heavy clay: ed005, ed009, ed010, ed011, ed012, ed013, ed014, ed015, ed021, ed023 ed031, ed032, ed129, ed245, ed602

A profile of Muckabinya subplastic clay near 'Fairview' (ed245) shows:

45 cm	dark brown light to medium subplastic clay, moderate subangular blocky and granular structures, few very fine roots, pH 7.5 grading to 8.8, gradual change to
50 cm	dark brown light to medium clay with pale brown patches of sediment filling cracks, moderate subangular blocky and weak lenticular structures, with few calcareous nodules, few very fine roots, pH 8.8, gradual change to
75 cm	reddish brown light to medium clay, moderate subangular blocky and weak wedge structures, few calcareous nodules and gypsum crystals, diffuse change
on	reddish brown medium clay with strongly developed wedge and moderately developed subangular blocky structures, polished slickensides, faint fine manganese stains, pH 8.8, continuing to 2.85 m.

A description of Muckabinya heavy clay (ed011) shows:

20 cm dark brown medium to heavy clay, moderately developed granular and subangular blocky structures, few very fine roots, pH 7.0, abrupt change to
50 cm dark brown heavy clay, weakly developed subangular blocky structure, with few calcareous nodules, few roots, pH 8.5, clear change
on dark brown medium to heavy clay, moderate grading to weak subangular blocky structure, with moderate wedge structure and slickensides, common distinct calcareous nodules and fine manganese stains, continuing to 2.60 m.

13a… Gommel subplastic clay

13b… Gommel heavy clay

The parish of Gommel includes Myall Vale Research Station. The name is used here for grey, slow-draining soils, mostly with loose, self-mulching surfaces, formed on watersorted aeolian clays. These sediments rest on Namoi alluvium in the western part of the Edgeroi map sheet and occur beside watercourses draining the Nandewar Range, for instance on the terraced-fan of Mulgate Creek where it is traversed by the Narrabri to Bingara Road. The soils are essentially *grey clays* but in a few places with slightly better drainage *brown clays* have been recognized. Where the surface structure is strongly developed, basalt has contributed to the parent sediment and *black earths* occur. The two soils have similar surface textures but differ in plasticity, that is, Gommel subplastic clay does not feel as heavy as its clay content would imply. Very slightly gilgaied areas can occur at the lowest sites.

Dull soil colours caused by poor internal soil drainage are common and the soils become heavy and untrafficable with heavy rain. The topsoil has been compacted in several places probably by early cultivation in wet conditions. After rain very thin deposits of sand may show at the ground surface. Some of this sand is washed into cracks and is probably the source of the small pockets of sand seen at depth. Soil textures tend to be subplastic.

Gommel subplastic clay: cu001, cu002, cu003, ed022, ed036, ed037, ed043, ed044, ed060, ed061, ed062, ed071, ed072, ed074, ed075, ed077, ed084, ed089, ed093, ed095, ed126, ed156, ed162, ed215, ed216, ed219, ed221, ed222, ed228, ed229, ed230, ed411, ed414, ed423, ed426, ed432, ed433, na011, we002, we011, we018
Gommel heavy clay: bu001, bu002, ed001, ed003, ed004, ed007, ed008, ed016, ed017, ed019, ed054, ed055, ed073, ed090, ed091, ed092, ed107, ed108, ed109, ed110, ed125, ed127, ed128, ed141, ed143, ed144, ed145, ed146, ed147, ed163, ed164, ed166, ed167, ed183, ed186, ed201, ed217, ed220, ed223, ed226, ed231, ed334, ed336, ed360, ed362, ed363, ed364, ed401, ed407, ed408, ed409, na013, na014, na016, na017, na018, na019, na021, we001, we004, we005, we006, we007

Gommel soils are alkaline (Table 14), with calcium the dominant cation. They have low sodium, low conductivity and low chlorides.

Gommel subplastic clay is well developed on the dust-mantled alluvial fans of the Edgeroi map sheet, and was found less commonly on aeolian sediments overlying Namoi alluvium, where Gommel heavy clay is the most frequent. This difference could be associated with the difference in gradient: where there is more slope, Gommel subplastic clay is favoured, perhaps as a result of the better surface runoff.

A profile of Gommel subplastic clay (ed043) shows:

7 cm	dark greyish brown light to medium subplastic clay, moderate platy and subangular blocky structures, few very fine roots, pH 7.0, sharp plough sole to
78 cm	very dark greyish brown medium to heavy clay with fine pale brown patches of sediment filling cracks, weak lenticular and moderate subangular blocky structures, with few calcareous nodules below 30 cm depth, very few roots, pH 7.0 grading to 8.5, gradual change
65 cm	dark brown medium clay, weak subangular blocky structure,
on	dark brown heavy clay with strong wedge structure and polished slickensides, few calcareous nodules and fine manganese stains, pH 8.0, continuing to 2.87 m.

A description of Gommel heavy clay (ed143) shows:

110 cm	very dark greyish brown medium to heavy clay, moderately developed angular blocky structure, few fine calcareous nodules, becoming common at depth, very few fine roots, pH 9.0, diffuse change
on	dark brown medium to heavy clay, strongly developed wedge structure breaking to weak angular blocky structure, with common calcareous nodules and soft limy segregations, few roots, pH 9.0 to 9.5, continuing to 2.82 m.

14a… Meriah medium clay

14b… Meriah medium clay, hardsetting phase

14c… Meriah hardsetting soil

The parish of Meriah includes a large area of grey, slow-draining sodic clays developed on watersorted aeolian sediments. These *soloths* and *grey clays*[9] are not well suited to agriculture and provide poor grazing. The better parts have a coarse mulching to weak crusting surface but mostly the topsoil is massive; in these areas the topsoil has a relatively pale colour and passes through a darker zone to the sub-soil below. The parent sediments are almost entirely confined to the alluvial fans but are wind-deposited clays that were probably only partly sorted by surface run-off at the time of deposition. The alluvial sediments lie at depths of 3-4 m and above this level there is commonly evidence of more than one buried soil. The Meriah soils occupy areas taking runoff, or receiving water from a larger catchment.

The field and laboratory observations made of the Meriah soils show that the texture of the surface soil is not strongly associated with the behaviour of the soil

[9] As Australian Great Soil Groups (Stace et al., 1968) refer to soil morphology, and not to soil genesis (as the names in some cases would seem to imply), the different soils of a soil series can fall in different Great Soil Groups

when cultivated or trampled by stock, or with the subgroups shown by fuzzy analysis (pages 63-69; Tables 8.4 and 9.1-2). As a consequence, it is not possible to identify constituent soil types wholly by means of their field texture. To resolve this problem the term 'hardsetting', because its over-riding significance to land use, is made part of the soil name, either as a substitute for a texture name or as a qualifying adjective.

Meriah medium clay: ed042, ed057, ed078, ed094, ed113, ed114, ed115, ed139, ed149, ed184, ed365, ed368, ed369, ed370
Meriah medium clay, hard setting phase : ed040, ed213, ed361, ed366, ed367, ed371, ed400, ed402, ed403, ed404, ed405, ed406
Meriah hard setting soil: ed039, ed041, ed058, ed112, ed148, ed165, ed211

Meriah medium clay contains coarse self-mulching soils but the surface frequently shows thin dispersed crusts, and is in places hardsetting and platy. It has relatively low exchangeable sodium percentages (Table 14) and relatively low chloride except for ed114, which has both excessively high chloride and phosphate, probably from animal wastes. Gypsum has been used by some farmers to improve the surface structure. Gypsum also occurs naturally in the Meriah soils, being frequently seen at depths below one metre.

Meriah medium clay (ed078) shows:

5 cm	very dark grey light to medium clay, moderate granular to subangular blocky coarse self-mulching structure, few very fine roots, pH 7.5, abrupt change to
60 cm	very dark grey light to medium clay, moderate angular blocky structure, with distinct calcareous nodules below 30 cm, few very fine roots, pH 7.5 to 8.0 , diffuse change to
167 cm	dark brown medium and heavy clay, moderate angular blocky structure, very few calcareous nodules, pH 8.5, clear stratigraphic break
on	dark reddish grey heavy clay, moderate wedge and blocky structures, pH 8.5, continuing to 2.82 m.

Meriah medium clay, hard setting phase, is an intractable soil with high sodium and high chloride values (Table 14). It was found only at three localities, by Galathera Creek (one profile, ed213), on the southern section of the 'Llano' transect, and in a clay pan at a scald near Roma Bore (Edgeroi 424748).

A profile of the soil (ed361) shows:

55 cm	very dark brown light to medium clay with prominent light brownish grey surface crust, moderate platy and angular blocky structures, few very fine roots, pH 6.5 rising at base to 8.5, diffuse change to
415 cm	brown medium clay with dark grey organic stains in the upper part, moderately developed wedge structure with slickensides breaking to angular blocky structure, distinct to prominent calcareous nodules, pH 9.0 gradual change
on	brown sandy light clay, massive, with horizontal fracture, prominent manganese stains and fine calcareous nodules pH 9.0.

Meriah hard setting soil has a poor surface structure, being mainly massive or platy, and in many places has a trampled appearance or is pockmarked with cattle hoofprints. Values for sodium are moderate, conductivity is low and the subsoil is dense as a consequence of slaking. The hard setting soil also differs from Meriah medium clay in having low clay activity ratios (i.e., cec / clay) in the topsoil.

A description of Meriah hard setting soil at Waugan Tank (ed211) shows:

6 cm very dark coarse sandy clay, massive structure, common very fine roots, pH 6.2, abrupt change to
111 cm very dark grey medium clay, weak angular blocky to subangular blocky structure, with few distinct calcareous nodules below 30 cm and manganese stains and gypsum crystals at depth, common to few roots, pH 7.0 to 8.2, smooth change to
57 cm greyish brown medium clay, moderate lenticular and angular blocky structures with slickensides, manganese stains, calcareous nodules and gypsum crystals, pH 8.7, clear change
on dark reddish brown medium clay with strong blocky structure, fine manganese stains and white calcareous nodules, pH 8.2, continuing to 2.63 m.

15… Round Swamp clay loam

Several dry and intermittently dry swamps and lagoons occur near Culgoora, west of Narrabri. Round Swamp and Yarrie Lake are the best examples.

Round Swamp is a shallow, circular rush-covered depression which is occupied at times by shallow water. When the swamp is dry its bed is seen to have a very slightly gilgaied microrelief, with thin patches of sand on the clayey surface and as inwashed coatings to fissures at depths to 0.9 m. Thus the swamp floor is considered to be a soil, a *gleyed grey clay***.** The parent sediments are shown by particle size analysis to be aeolian dusts that have become trapped in these sites.

The clays of Round Swamp are 2 m thick and lie on weathered alluvium with pockets of lime. The adjoining ground has yellowish brown sand-on-clay soils that grade to red-weathered alluvial sediments which begin about the same level as the high water mark in the swamp. These sediments, level for level, resemble those beneath the swamp.

The soil is near neutral to acid (Table 14), with calcium the dominant cation and relatively high levels of potassium. Phosphate, nitrate-nitrogen and chlorides are high at the ground surface and reflect cycling organic matter in the paludal environment. Clay activities are also low throughout the depth examined and indicate a difference in the clay from that of the plains generally, as a consequence of the difference in environment.

Round Swamp clay loam: na031, na032, na035, na036

A description of Round Swamp medium clay (na035) shows:

15 cm very dark greyish brown light to medium clay with few fine white powdery efflorescences, strongly developed angular blocky structure, few very fine roots, pH 5.5, clear stratigraphic change to

185 cm dark grey light to medium clay, mostly massive with weakly developed blocky structure, common ferruginous stains and tubules, few roots, pH 6.5 rising to 8.0, smooth stratigraphic break

on pale grey light clay, structureless, with prominent coarse strong brown ferruginous stains and few calcareous nodules continuing to 2.92 m.

16… Bohena medium clay

Bohena parish is west of the Newell Highway south of Narrabri. Several areas of heavily gilgaied grey clays occur there, the puffs and depressions of the gilgai giving a local relief of 2 m. The soils are developed on sediments shown to be aeolian by their particle size distribution. The sediments are believed to lie in their original site of deposition because there is no surface drainage (except from puff to depression) and no run-on from higher areas. The soils remain in part under their natural cover of brigalow *(Acacia harpophylla)* with belah *(Casuarina cristata)*, but most areas have been partly cleared and several are affected by regrowth. They were examined mostly in a small area (Narrabri 536302) adjoining 'Marooma', near Bohena telephone exchange.

The clays are dense, several metres thick, and show a uniform grey colour as a consequence of the lack of internal drainage. Flecks of yellowish brown and then red colours appear with increasing depth. These bright colours are attributed to better drainage during a former episode of weathering. At depth the soil becomes sandy and passes into weathered alluvium. It is thought that the wind-blown clays began to accumulate on a well drained red soil and were affected at the start by red-weathering but as deposition continued the drainage became impeded by the added clay, and the impounded water induced gley colours in the soil. Signs of episodic deposition were seen in some cores at depths of 0.7-0.8 m.

Bohena medium clay is alkaline to near neutral at the surface (Table 14), with calcium the dominant cation. There are significantly high levels of exchangeable sodium. Conductivity and chlorides are high. The relatively high phosphate and nitrate-nitrogen values at the ground surface reflect cycling organic matter.

The data set for the Bohena profiles, summarised in Tables 11.1 and 11.2, shows that the surface 0.25 to 0.4 m are relatively leached (note the low values of soluble cations), as one would expect, with an alkaline topsoil (pH 7.6) lying above acid subsoils (pH 5.1). The topsoil has high phosphate and exchangeable aluminium. It grades through a calcium- and magnesium-enriched zone to subsoils with very high conductivity, chlorides and sodium. The high values for sodium continue into the alluvium at depth. It would follow that highly saline clay will be exposed if the gilgaied surface is levelled.

Bohena medium clay: na001, na002, na007, na008, na009

Bohena medium clay (na007) shows:

18 cm very dark greyish brown light clay, moderate angular blocky structure, few fine roots, pH 6.5 grading to 8.0, gradual change to
52 cm dark grey medium clay, weakly developed angular blocky structure, very firm and strong, with few distinct soft calcareous segregations and gypsum crystals, few very fine roots, pH 8.5, abrupt stratigraphic change, possibly to a former soil
20 cm greyish brown medium clay, few charcoal fragments and weak subangular blocky structure, few gypsum crystals, pH 7.0, very diffuse change to
210 cm brown and greyish brown medium and heavy clay, weakly developed wedge structure with slickensides, very strong, pH 5.5 grading with depth to 4.0, diffuse boundary, continuing to 3.00 m.

The above horizons lie on thick grey and mottled grey and red clays which rest in turn on dusky red alluvial sandy clays at 6.2 m.

Alluvial Plains

17a… Namoi clay loam

17b… Namoi medium clay

The *alluvial soils* of the Namoi flood plain are mostly dark in colour and undifferentiated. Layers of sand, in places showing bedding because of their deposition in rapidly moving water, occur in several places, with intervening loamy sediments with granular structures that give signs of some weathering and accumulation of organic matter between floods. Better developed soil structures are seen in the cohesive alluvial clays. Fragments of charcoal are common, and small waterwashed carbonate concretions derived from eroded soils in the catchment are seen in several places, locally with small gravels. Floods are frequent on the lower parts of the flood plain and often cover most of the surface. They are recorded by shallow deposits of alluvium which rest on buried soil horizons, and by stranded timber and other debris. Watermarks on trees indicate that the depths of water are commonly as great as 3 m. The river near Narrabri occupies several channels, and elsewhere there are partly infilled billabongs and abandoned meanders, some with shallow lagoons and backswamps. Some sand carried by floodwater is trapped in cracks and fissures in the soils.

Namoi clay loam: ed159, ed160, ed199, ed200
Namoi medium clay: cu004, ed177, ed178, ed179, ed198, we009

The average values for clay and cations over the three surface soil samples for each soil are set out in Table 14.

The soils are slightly acid to neutral at the surface, with calcium the dominant cation. They have a relatively high phosphate contents (Table 15), and low conductivity and chloride values.

A brief description of Namoi clay loam (ed200) is:

50 cm dark greyish brown silty clay loam grading below to medium clay, weak to moderate blocky structure, with few roots, pH 7.2 to 8.7, clear change to
20 cm dark brown medium to heavy clay, moderate subangular blocky structure and few roots, pH 8.7, stratigraphic boundary to a former soil horizon:
20 cm dark brown silty clay loam, weak subangular blocky structure with very few small calcareous nodules, pH 8.7, gradual change
on dark brown medium and medium to heavy clay, weak subangular blocky structure with very few small calcareous nodules, pH 8.7, continues to 2.73 m.

Namoi medium clay (ed178) shows:

95 cm very dark grey light to medium clay, moderate subangular blocky structure in the upper part and grading below to weak prismatic and wedge structures, very few roots, pH 7.0 to 8.5, gradual change to
55 cm dark greyish brown light clay, weak to moderate prismatic and blocky structures, very few roots, pH 9.0, stratigraphic boundary to a sandy alluvial lens
on brown fine sandy clay, weak coarse prismatic structure with few fragments of indurated clay, pH 8.0, continues to 2.78 m.

18a… Spring Creek clay loam

18b… Spring Creek medium clay

Spring Creek soils are developed in relatively well-drained places on the narrow flood plains of the streams which drain from the Nandewar Range. They are *alluvial soils*, like those of the Namoi flood plain, but there is more variety in grain size as the beds are poorly sorted. Buried soils are seen at many places in the exposed creek banks and in drilled cores, and layers of bedded sand, angular gravels, and occasionally calcareous concretions are common, the latter having been derived by erosion of prior soils. In the highest reaches where boulders are prominent cultivation is not possible. In the middle reaches the streams occupy channels cut deeply in the flood plain, and bear witness to the significant erosion hazard associated with flash floods and rapid runoff. Charcoal is frequently seen at buried soil horizons.

Spring Creek clay loam: ed018, ed152, ed154, ed155, ed214, ed240
Spring Creek medium clay: ed111, ed170, ed227

Table 14 lists the average values for clay, cations and other data over the three surface soil samples from each site. The soils are slightly acid to neutral, with calcium the dominant cation. They have relatively high phosphate contents, and low conductivity and chloride values.

Spring Creek clay loam (ed154) near Spring Creek shows:

45 cm dark brown silty clay loam grading below to clay loam, moderate subangular blocky and cast granular structures, with few roots, pH 7.0 to 8.0, gradual change to
55 cm brown clay loam, weak prismatic structure, few roots, pH 8.0, stratigraphic boundary to a former soil:

100 cm dark brown light to medium clay, strong subangular blocky structure, pH 8.5, diffuse change (to a former subsoil)
on dark reddish grey medium clay with pink inwashed clay skins, weak angular blocky structure to massive, with few small calcareous nodules, pH 8.5, continues to 2.75 m.

A brief description of Spring Creek medium clay (ed170) is:

32 cm dark brown light to medium clay, strong angular blocky structure with brown patches of sediment filling cracks, common fine roots, pH 7.5 to 8.0, abrupt change to
8 cm dark brown light to medium clay, moderate angular blocky structure with yellowish brown sediment in cracks, common roots, pH 8.5, sharp break to a former soil:
160 cm very dark grey light clay, weak prismatic and blocky structures and brown patches of sediment in cracks, pH 8.5 grading to 8.3, clear change (to a former subsoil)
on dark greyish brown medium clay, weak structure, with few black manganese nodules and small calcareous concretions, pH 8.8, continuing to 2.87 m.

19… Galathera medium clay

Galathera medium clay is a *humic gley soil***.** It is developed on swampy and poorly-drained alluvial beds adjoining Galathera Creek. The landscape is broad and featureless, with rushes and sedges especially in the northern part. Owing to frequent floods the main use is for grazing cattle. Matted roots occur at the surface above soft grey clays but in the higher places the soil dries out, forming a strong surface crust heavily and deeply marked by cattle footprints. In dry weather very deep wide cracks appear. Snail shells were seen in several places at the ground surface and in drill cores.

Galathera medium clay: ed002, ed020, ed038, ed056, ed235

The surface soils (Table 14) are neutral to slightly alkaline, with calcium the dominant cation. They have relatively low phosphate contents, and low conductivity and relatively low chloride values.

Galathera medium clay (ed020) shows:

105 cm very dark and dark grey medium to heavy clay, moderately strong angular blocky structure, few roots, pH 7.5 to 8.0, diffuse change
on dark grey light to medium clay, moderate angular blocky structure with prominent coarse organic stains, moderate wedge structure, few calcareous segregations, pH 8.0, becoming lighter in colour with depth, pH 8.0, and passing to clayey alluvium from 2.60 to 3.29 m.

20a… Pian loamy sand

20b… Pian clay loam

20c… Pian medium clay

Pian clay loam and medium clay are *alluvial soils* with weak profile development shown as a differentiation of a yellowish grey or, in places, yellowish brown subsoil. They are widespread in the vicinity of Pian Creek, an off-take of the Namoi

River near Wee Waa. The name was first applied to these soils by Flint and Hawkins (1958). Near Narrabri the soils occupy a terrace slightly above the level of the river flats, and they are well developed by the north bank of Narrabri Creek, north of the township. Because of morphological similarities a similar but coarse-textured soil beside the lower reaches of Spring Creek is also included with Pian series for convenience, as *Pian loamy sand.* However, its parent sediments are from a different source and it has a high sodium content as a consequence of its position in a natural soak.

Pian loamy sand: ed203
Pian clay loam: ed195, we008, we010, we012, we013
Pian medium clay: ed142, ed196, ed197

Table 14 lists the average values for clay, cations and other data over the three surface soil samples for each soil. The soils are slightly acid to neutral, with calcium the dominant cation in Pian clay loam and Pian medium clay. These soil types have low conductivity and chloride values. The profile of Pian loamy sand on scalded land near Spring Creek is both sodic and saline.

A brief description of Pian loamy sand (ed203) is:

10 cm dark brown to dark greyish brown loamy and clayey sand, weak subangular blocky structure, few very fine roots, pH 6.5, clear change to
20 cm greyish brown loamy sand, loose, single-grained few roots, pH 7.0, sharp wavy break to
25cm dark brown loamy coarse sand with prominent yellowish red rinds on soil aggregates, strong angular blocky structure and dark greyish brown organic stains, pH 8.0, gradual change to a former subsoil:
125 cm dark brown to brown sandy medium clay, moderate prismatic and subangular blocky structures, with prominent coarse calcareous segregations, pH 8.8, very diffuse change
on pale olive sandy medium clay with pockets of sand, common calcareous segregations, pH 8.8, continuing to 2.63 m.

Pian clay loam (ed195) shows:

40 cm very dark greyish brown sandy clay loam, moderate to weak subangular blocky structure grading through sandy loam to sandy clay loam, few fine roots, pH 6.5 to 8.0, gradual boundary to
140 cm dark yellowish brown to brown sandy clay loam, moderate prismatic and angular blocky structures, with yellowish brown patches of soil in cracks, pH 9.0 to 8.5, very diffuse boundary
on brown sandy clay loam with charcoal fragments, weak prismatic structure and brown patches of soil in cracks, pH 8.5, continuing to 2.79 m.

The soil textures imply episodic sediment accumulation but the profile shows no sign of interrupted soil development. Slow drainage is shown in the lower part of the core by gleyed grey colours in the yellowish brown groundmass.

A brief description of Pian medium clay (ed197) is:

30 cm very dark grey medium to heavy clay, moderate subangular and angular blocky structure, very firm, very few roots, pH 8.5 to 9.0, passing to

90 cm very dark grey medium to heavy clay, moderate to strong angular blocky and wedge structures structure with few distinct fine white calcareous nodules, few roots, pH 8.8 to 9.0,

on yellowish brown medium to heavy clay with few prominent yellowish red mottles, moderate angular blocky and wedge structures, pH 8.8, continuing to 2.86 m.

21a… Queerbri silt loam

21b… Queerbri silt loam, Bohena variant

21c… Queerbri clay loam

21d… Queerbri medium clay

Queerbri soils are typically developed on low terraces of the Namoi River not usually reached by floods, and on young alluvial fans and prior stream deposits that may take water at times of severe flooding. The input of new sediment is very low. This has allowed distinct soil profile development but the original sedimentary bedding is frequently observed and it can be difficult to separate soil horizons due to weathering from those due to alluvial deposition. Soft carbonate concretions and efflorescences occur in the subsoil, and in a few places carbonates can be detected in the topsoil. The name, Queerbri, was proposed by Flint and Hawkins (1958). Where the soils are relatively coarse-textured they grade to *red brown earths*, but they mostly lack the strong prismatic subsoil and well developed clay differentiation of that group. These soils are friable to weakly crusting, with brownish topsoils over reddish brown clayey subsoils. Most of the Queerbri soils are alkaline *brown clays*, with a relatively poor surface structure and tendency to hard-setting. On these soils scalds can be a hazard, and give a difficult surface for cultivation.

One soil profile examined near Bohena Creek resembles Queerbri silt loam but is developed on quartz-rich alluvium with clays mostly from a catchment formed by Pilliga Sandstone, and includes high levels of salts and sodium apparently from nearby aeolian clays. This soil was not mapped, but for convenience in classification it is accepted as a variant of Queerbri silt loam.

Queerbri silt loam: ed244, we016, we017
Queerbri silt loam, Bohena variant: na004
Queerbri clay loam: bu004, ed124, ed176, ed180, ed224, ed232, na027
Queerbri medium clay: ed106, ed161, ed181, ed182, ed218, ed233, ed234

The Queerbri soils (Table 14) are slightly acid, in the main, with calcium the dominant cation except in Queerbri sandy loam, Bohena variant. The soils have low conductivity and chloride values. Phosphate values are low, as would be expected, in the Bohena variant of Queerbri silt loam.

Queerbri silt loam (ed244) shows:

8 cm dark brown silt loam, moderate subangular blocky structure, very few fine roots, pH 6.5, abrupt change to

47 cm dark reddish brown silty clay loam, moderate subangular blocky structure, with very few roots, pH 7.5 to 8.0, gradual boundary to
95 cm dark reddish brown silt loam grading with depth to light clay, moderate prismatic and angular blocky structures, weak slickensides, and prominent calcareous nodules, pH 9.0, stratigraphic break to
150cm+ strong brown light fine sandy clay loam, massive, pH 8.5, continuing to 3.29 m.

In other places fine sandy topsoil textures occur.

Queerbri silt loam, Bohena variant (na004) shows:

20 cm reddish brown fine sandy loam, weak subangular blocky structure, few very fine roots, pH 4.5 to 4.0, gradual boundary to
20 cm yellowish red fine sandy clay loam with distinct sporadic bleach, massive and weak subangular blocky structure, pH 4.0, abrupt change to
30 cm dusky red light medium clay, weak lenticular and angular blocky structure, pH 5.0, diffuse change to
70 cm dark red grading to yellowish red clay, weak platy and moderate angular blocky structure with prominent coarse calcareous nodules, pH 8.5, diffuse change to
125 cm yellowish red sandy clay with light yellowish brown mottles, moderately developed platy and weak angular blocky structures, few calcareous nodules and manganese stains, pH 8.0, sharp stratigaphic break
on strong brown sand, pH 7.5, continuing to 2.88 m.

Queerbri clay loam (ed176) shows:

30 cm dark brown clay loam grading to sandy clay loam with depth, weak subangular to moderate angular blocky structure, few fine roots, pH 6.0 to 7.5,
80 cm dark reddish brown to yellowish red medium heavy clay , moderate to strong angular blocky structure, with slickensides, pH 8.0 to 9.0,
on yellowish red sandy clay loam with organic stains, weak prismatic and blocky structures, few pale brown calcareous nodules, pH 8.5 to 9.0, continuing to 2.81 m.

Queerbri medium clay (ed218) shows:

70 cm very dark greyish brown to dark brown medium to heavy clay, moderately strong subangular blocky structure with very few faint white calcareous nodules, with slickensides in lower part, few very fine roots, pH 7.8 to 8.5, gradual boundary to
36 cm dark brown medium clay, weak subangular blocky structure, with very few yellowish brown calcareous nodules, pH 8.3, gradual change
on dark brown light to medium clay loam, weak subangular blocky structure becoming stronger with depth, very few brown calcareous nodules, pH 8.5, continuing to 3.20 m.

22a… Bobbiwaa clay loam

22b… Bobbiwaa clay loam, sodic phase

22c… Bobbiwaa medium clay

The Bobbiwaa soils are developed on the extensive alluvial fan of Bobbiwaa Creek and occur elsewhere on similar deposits of fan alluvium with basaltic detritus spread below the Nandewar Range. The soils are not usually susceptible to floods, but may take water during prolonged rain. The lack of new sediment has permitted some soil profile development but the original sedimentary bedding is commonly shown by beds of sand and angular gravels. Coarse gravels and cobblestones are common upstream, and the groundsurface there is broken by old stream channels. Carbonate concretions are abundant in the subsoil, and small flecks of carbonate may occur in the topsoil. Much of the stream flow filters into the alluvial deposits and the water does not often reach major drainage lines, dispersing instead, with its contained salts, into the sediments and soils at the foot of the fans. Chloride, sodium and magnesium levels are higher in these positions, and the soils here are distinguished as a sodic phase.

Like the Queerbri soils the Bobbiwaa soils grade to *red brown earths*, but they do not usually have prismatic subsoils or strong clay differentiation. They range from friable and self-mulching to weakly crusting, with brownish topsoils over reddish brown clayey subsoils. Mostly the soils are best described as *brown clays*, with a relatively poor surface structure and tendency to hard-setting except in the upper reaches where there is a greater content of basalt. The hard-setting surfaces can become difficult to cultivate. Mean topsoil (0-20 cm) clay percent vales are: Bobbiwaa clay loam, ca. 33; Bobbiwaa clay loam, sodic phase, ca. 36; Bobbiwaa medium clay, ca. 53.

Bobbiwaa clay loam: ed116, ed134, ed138, ed151, ed238, ed345
Bobbiwaa clay loam, sodic phase: ed132, ed133, ed153, ed168, ed169, ed185, ed330, ed331, ed332, ed333, ed335
Bobbiwaa medium clay: ed035, ed045, ed046, ed047, ed048, ed049, ed050, ed069, ed103, ed140, ed150, ed174, ed202, ed237

Bobbiwaa surface soils (Table 14) are neutral to slightly alkaline, with calcium the dominant cation in Bobbiwaa clay loam and Bobbiwaa medium clay; in Bobbiwaa clay loam, sodic phase, the ratio of Ca to Mg is 1:1. The soils have low conductivity and slightly elevated chloride values in the sodic phase.

Bobbiwaa clay loam (ed134) shows:

42 cm	very dark grey sandy clay loam, weak to moderate subangular blocky structure, few very fine roots, pH 6.0 rising at base to 8.3, abrupt change to
72 cm	dark brown medium to heavy clay, moderate prismatic and angular blocky structures, prominent calcareous nodules, with few roots, pH 8.4, smooth change to
65 cm	brown medium to heavy clay, moderate prismatic and angular blocky structures, pH 8.0, clear change
on	dark brown light clay with rounded basalt gravels, weak prismatic and blocky structure, pH 7.8, continuing to 2.69 m.

Bobbiwaa clay loam, sodic phase (ed168) shows:

90 cm	dark brown light clay grading down to light to medium clay, moderate angular blocky structure, common very fine roots, pH 6.5, diffuse change to
130 cm	reddish brown and pinkish white medium clay, moderate angular blocky structure, with few calcareous nodules, pH 7.5 to 8.0, very diffuse change
on	reddish brown medium clay, weak angular blocky structure, weak slickensides, and few calcareous nodules, pH 8.8, continuing to 2.75 m.

Bobbiwaa medium clay (ed103) shows:

110 cm dark brown medium to heavy clay grading to light to medium clay, moderate angular blocky structure, few very fine roots, pH 7.3 to 8.0, diffuse change to
100 cm dark brown light clay, weak angular blocky structure, weak slickensides, few calcareous nodules, pH 9.0, clear stratigraphic change
on dark reddish grey loamy sand, massive, with rock fragments, pH 7.8, continuing to 3.53 m.

23... Bundock loamy sand

Bundock Creek is a major drainage line near Yarrie Lake and Round Swamp. Bundock loamy sand is a loose, very weakly structured soil, a *sandy red earth*, developed on alluvial sands forming part of a terraced fan of Bundock Creek as it approaches the Namoi River. The landscape is broad and flat to very gently undulating, with pine forest in the part covered by the Edgeroi sheet, but the soil is also used for wheat. There are several quarries, for the deeper weathered soil materials are used as road base and to form rafts for buildings.

Bundock loamy sand: ed194

The surface soil (Table 14) is slightly acid to near neutral, with calcium the dominant cation. Chloride and phosphate contents are low.

25 cm dark reddish brown loamy sand, single-grained to weak platy structure, few very fine roots, pH 6.5, gradual change to
25 cm dark red clayey sand, weak platy and angular blocky structures, with few very fine roots, pH 6.5, gradual change
on dark red sandy clay grading to red sandy clay, weak prismatic and platy structures becoming massive with depth, faint red clay skins, pH 5.5 to 6.0, continuing to 2.55 m.

Development of the soil landscape: an overview

The development of the Edgeroi soil pattern is intimately bound with the development of the Edgeroi landscape.

For this district, the present-day soil pattern began to form perhaps 500 000 years ago. The landscape which existed then looked rather like the present one except that it was covered with a red soil, which soon began to receive windblown dust and salts. Later, the climate became somewhat more humid, like today's, although still subject to change because of the global effects of past ice ages.

The soil mantle became differentiated by weathering and by redistribution of the weathered products. The high points in the landscape became leached of weatherable minerals, in the same way as topsoils are leached of nutrients by percolating water, to leave a residual mantle of fragmented rock or quartz [e.g., as in the soils of the Killarney association]. The small quantities of clay that remained retained aluminium and potassium by adsorption, and iron was left in places in the soil as ironstone concretions. Elements lost with the drainage water moved downslope and into the deep subsoil [e.g., Murrumbilla soil series].

In this generally semiarid environment calcium was incompletely leached from the developing soil, being retained preferentially among the exchangeable cations, and being held at depth and on the lower slopes as calcium carbonate [e.g., Muckabinya soil series] and, in more slowly draining and lower situations, as gypsum. Magnesium accompanied the calcium but was transported further [Gommel series], and to greater depths in the ground. Sodium and the associated chlorides were carried to the lowest and worst drained sites, where the topsoil became dispersed and the soil structure degraded [Meriah series].

Together with this geochemical differentiation of the landscape, there was a physical separation of the products of weathering: clays were carried downslope, from the soil surface to the streams and plains.

This continual transport through soil drainage and stream flow was augmented by episodic erosion associated with the natural development of the valley landscapes. Because of the succession of global glacial to interglacial ages (or, for Edgeroi, the succession of changing desert to subhumid phases induced by these events), periods without much change alternated with periods of enhanced sediment transport when debris was stripped from the hills to build the terraced fans of the plains [e.g., Bobbiwaa, Queerbri, Pian series]. In arid times the wind, carrying dust from the plains, returned large quantities of this sediment to the headwater catchments.

Blown sand has accumulated recently on the Round Swamp and perhaps the Yarrie Lake lunettes but historic records of dust-blowing are not matched by recognizable dust deposits on recent ground surfaces. Nevertheless, present-day conditions favour agriculture more than the conditions of the 1920s and 1930s. The geological evidence is that there were several times, in the past, when the climate was more arid than now. Droughts and dust storms will continue to threaten agriculture.

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Glossary*

cation	The positively charged ion of an element in solution.
cec	Acronym for cation-exchange capacity: the sum of exchangeable cations adsorbed by a soil, expressed in millequivalents per 100 grams of soil.
centroid	In fuzzy analysis, the group mean for all attributes weighted by membership values.
clay dune	An aeolian accumulation composed of clay originally aggregated as sand-sized particles.
colluvium	A poorly sorted unconsolidated deposit of rock fragments, sand, silt and clay that has accumulated below steep slopes by land-sliding and soil creep, and on gentle slopes mostly through inter-mittent surface wash and sheet flood.
duplex soil	A soil with a clear difference in texture (i.e., particle size) between topsoil and subsoil, so that two contrasting layers are formed.
floater	A piece of basement rock, detached by weathering, in a mass of weathered material; a core-stone.
geomorphology	The science dealing with the origin and development of landscapes; the scientific study and explanatory description of landforms.
gilgai	A succession of small basins and knolls in nearly level areas, or of slight depressions and rises that run with the slope, caused by expansion and contraction of the soil through changes in moisture content, or hypothetically (Veen 1973) through changes due to weathering.
glacial age	An episode in the history of the earth characterised by the presence of continental and extended polar ice sheets. Glacial ages are accompanied by changed climates and lowered sea levels.

*Based in part on:

Dudal, R. (1968). Definitions of soil units for the soil map of the world. World Soil Resources Reports No. 33. FAO, Rome.
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gley — A soil condition that arises from permanent or frequent wet conditions and poor aeration. A gleyed soil has grey, green, or blue-grey colours that become brown in the air. Reddish mottles are common beside root channels.

hardsetting — A topsoil that becomes compact, hard, and apparently massive as the soil dries out.

hydration — The absorption or combination of water with another substance.

interflow — That part of rainfall that is discharged as subsurface flow into a stream channel.

interglacial age — An episode in the history of the earth characterised by the absence or reduced extent of ice sheets. Interglacial ages have climates like the present, and high sea levels like the present one.

calcrete — Cemented calcareous deposits near the ground surface in the zone affected by weathering. The deposits are frequently layered, and are formed by the solution and re-deposition of carbonates especially in limy parent sediments. They are formed in the soil but limit soil depth as they develop.

lithosol — Soils with no clearly expressed zonation into topsoil and subsoil and consisting of imperfectly weathered rock fragments; a soil with hard rock at shallow depth.

lunette — A source-bordering crescent-shaped dune ridge or mound on the lee side of a lake.

microrelief — Small-scale differences in relief including mounds and swales a few metres across and with an amplitude from a few centimetres to 2 m.

montmorillonite — A clay mineral which swells in water and has a high capacity for cation exchange. An aluminosilicate, basically $Al_2O_3 \cdot 4SiO_2 \cdot H_2O$, with many variations in composition.

munsell colour — A brief description that specifies the three attributes of colour: hue, value and chroma, as numbers combined in an alphanumeric code.

natural erosion — Erosion of the natural landscape by the forces of nature undisturbed by human activity or domestic animals.

outlier — An isolated mass of rock or detached remnant separated from the parent rock mass by erosion. An outlier is surrounded by older rocks.

palaeosol — An ancient soil, i.e., a buried soil or a soil remaining from a past age in which conditions of weathering were unlike today's.

paludal — Pertaining to marshes.

parna — A wind transported material consisting of clay particles aggregated to the size of fine sand; similar coarser material that has been blown along the ground; clayey loess.

pediment	A slightly inclined planar rock surface which flanks higher ground and is thinly veneered with ill-sorted fluvial and colluvial sediments; the landform is apparently developed by sheet wash and desert floods.
pedology	The science dealing with explanations of soil origins and distribution; processes and factors of soil formation; and methods of classification and mapping. A pedologist uses the environmental sciences, especially the earth sciences - geology, geomorphology, and geochemistry - to further understanding of soil properties and relationships.
periglacial	Deposits and processes of cold environments like those near the margin of a glacier.
pH	The degree of acidity (or alkalinity) of a soil scaled 1-14 in terms of hydrogen-ion activity, with neutral being indicated by pH 7.
pyroclastic	A general term for fragmented material erupted from a volcano.
Quaternary	The division of geological time following the Tertiary era and characterised by the presence of abundant modern species and major glacial deposits; the last 1.69 million years. The Quaternary is conventionally divided into the Pleistocene and Holocene, the Holocene being the last 10 000 years.
rendzina	Soils with dark surface horizons underlain by hard calcareous material such as calcrete.
scald	A patch of ground injured by wind erosion, and so stripped to a hard subsoil layer or one made hard by dessication; a similar patch lacking vegetation, usually as a result of salt injury.
slickensides	Smooth, polished or striated surfaces produced by friction.
smectite	A group of clay minerals that includes montmorillonite.
solodic	Having a grey leached layer over a somewhat leached non-prismatic subsoil.
solodised	Having a grey leached layer over a solonetzic subsoil.
solonetz	A soil with a variable surface over a darker soil layer usually markedly alkaline and prismatic.
subplastic	A condition of some surface soils that makes them behave and feel as if they have less clay than continued manipulation or a particle size analysis will show.
Tertiary era	A major division of geological time, the third since the first appearance of abundant organic life.
thermoluminescence	The emission of light from certain substances, e.g., quartz, when heated slowly to temperatures below incandescence.
trachyte	A volcanic rock of less basic composition than basalt and lighter in colour.
transect	A measured traverse displaying sediments in cross-section.
vertisol	A soil group of self-mulching soils with a surface that turns over (L. *verto*, turn [FAO]). A clayey soil with deep wide cracks at some time of the year and high bulk density (Soil Survey Staff 1975).

Appendix 1

Site locations

Australian Map Grid references and soil type for the 374 sites are given below. The sites lie in Zone 55, 100 000 m grid square GG (prefix 7 for full east coordinates), except for cu001, cu002 and cu004, which lie in grid square FG (prefix 6). A key to soil numbers is shown at the foot of the table.

site	east	north	soil
bu001	2930	9860	13b
bu002	2380	8450	13b
bu004	2360	8240	21c
cu001	9860	4725	13a
cu002	9855	4820	13a
cu003	0110	5150	13a
cu004	9890	4960	17b
ed001	4180	7790	13b
ed002	4455	7780	19
ed003	4730	7775	13b
ed004	5010	7775	13b
ed005	5280	7770	12b
ed006	5560	7770	12a
ed007	5840	7760	13b
ed008	6120	7750	13b
ed009	6390	7740	12b
ed010	6670	7730	12b
ed011	6950	7720	12b
ed012	7220	7710	12b
ed013	7490	7705	12b
ed014	7770	7690	12b
ed015	8050	7680	12b
ed016	8330	7670	13b
ed017	8610	7670	13b
ed018	8880	7660	18a
ed019	4320	7550	13b
ed020	4590	7540	19
ed021	4870	7540	12b
ed022	5140	7530	13a
ed023	5420	7520	12b
ed024	5690	7520	12a
ed025	5970	7510	12a
ed026	6250	7510	12a
ed027	6530	7500	12a
ed028	6800	7490	12a
ed029	7080	7480	12a
ed030	7350	7470	12a
ed031	7630	7460	12b
ed032	7910	7455	12b
ed033	8180	7440	10a
ed034	8460	7440	10b
ed035	8730	7420	22c
ed036	4170	7310	13a
ed037	4480	7310	13a
ed038	4730	7300	19
ed039	5000	7290	14c
ed040	5275	7290	14b
ed041	5550	7280	14c
ed042	5830	7275	14a
ed043	6100	7270	13a
ed044	6380	7260	13a
ed045	6660	7260	22c
ed046	6930	7250	22c
ed047	7200	7210	22c
ed048	7480	7230	22c
ed049	7760	7220	22c
ed050	8030	7210	22c
ed051	8310	7200	10a
ed052	8580	7190	6c
ed053	8860	7180	4
ed054	4310	7070	13b
ed055	4580	7070	13b
ed056	4850	7060	19
ed057	5140	7050	14a
ed058	5410	7050	14c
ed059	5680	7040	3b
ed060	5960	7040	13a
ed061	6240	7030	13a
ed062	6510	7020	13a
ed063	6790	7010	1
ed064	7070	7010	1
ed065	7340	6990	1

site	east	north	soil no.
ed066	7610	6980	1
ed067	7890	6980	10a
ed068	8165	6970	7a
ed069	8440	6960	22c
ed070	8720	6950	3a
ed071	4170	6830	13a
ed072	4430	6830	13a
ed073	4710	6820	13b
ed074	4980	6850	13a
ed075	5270	6810	13a
ed076	5540	6800	12a
ed077	5820	6800	13a
ed078	6090	6790	14a
ed079	6370	6780	12a
ed080	6645	6780	1
ed081	6920	6770	1
ed082	7190	6770	1
ed083	7470	6760	1
ed084	7740	6740	13a
ed085	8020	6730	7a
ed086	8290	6720	6b
ed087	8570	6710	3b
ed088	8830	6710	3b
ed089	4310	6610	13a
ed090	4570	6590	13b
ed091	4850	6580	13b
ed092	5120	6580	13b
ed093	5400	6570	13a
ed094	5670	6560	14a
ed095	5950	6560	13a
ed096	6230	6550	1
ed097	6490	6500	1
ed098	6770	6530	1
ed099	7050	6510	1
ed100	7320	6520	10a
ed101	7600	6510	4
ed102	7870	6510	6c
ed103	8150	6490	22c
ed104	8420	6475	6a
ed105	8685	6470	7a
ed106	4160	6360	21d
ed107	4430	6350	13b
ed108	4710	6350	13b
ed109	4980	6340	13b
ed110	5260	6340	13b
ed111	5530	6320	18b
ed112	5810	6320	14c

site	east	north	soil no.
ed113	6080	6310	14a
ed114	6360	6320	14a
ed115	6630	6300	14a
ed116	6900	6290	22b
ed117	7180	6290	10b
ed118	7460	6280	10a
ed119	7700	6300	7b
ed120	8020	6260	6c
ed121	8280	6250	6b
ed122	8560	6245	6c
ed123	8830	6210	5b
ed124	4290	6130	21c
ed125	4560	6120	13b
ed126	4840	6110	13a
ed127	5120	6100	13b
ed128	5390	6090	13b
ed129	5670	6090	12b
ed130	5940	6080	4
ed131	6210	6080	4
ed132	6480	6070	22b
ed133	6760	6060	22b
ed134	7040	6050	22b
ed135	7310	6040	10b
ed136	7580	6030	7b
ed137	7850	6030	7a
ed138	8130	6020	22b
ed139	8410	6010	14a
ed140	8680	6000	22c
ed141	4140	5880	13b
ed142	4430	5880	20c
ed143	4700	5870	13b
ed144	4970	5870	13b
ed145	5250	5860	13b
ed146	5530	5850	13b
ed147	5800	5850	13b
ed148	6070	5840	14c
ed149	6355	5835	14a
ed150	6620	5830	22c
ed151	6890	5820	22b
ed152	7170	5810	18a
ed153	7440	5800	22b
ed154	7720	5790	18a
ed155	7990	5790	18a
ed156	8270	5770	13a
ed157	8540	5765	5b
ed158	8770	5760	5a
ed159	4280	5650	17a

site	east	north	soil no.	site	east	north	soil no.
ed160	4550	5640	17a	ed207	7830	5070	7a
ed161	4830	5640	21d	ed208	8100	5060	3a
ed162	5103	5620	13a	ed209	8380	5060	3b
ed163	5380	5620	13b	ed210	8650	5040	7b
ed164	5660	5610	13b	ed211	5680	7200	14c
ed165	5930	5610	14c	ed212	5820	6960	4
ed166	6210	5600	13b	ed213	5950	6400	14b
ed167	6480	5590	13b	ed214	5950	6480	18a
ed168	6750	5580	22b	ed215	5027	5568	13a
ed169	7020	5580	22b	ed216	4963	5568	13a
ed170	7290	5570	18b	ed217	5103	5685	13b
ed171	7570	5560	7a	ed218	4991	5513	21d
ed172	7840	5550	7a	ed219	5071	5626	13a
ed173	8130	5540	7a	ed220	5207	5623	13b
ed174	8390	5530	22c	ed221	4991	5620	13a
ed175	8670	5520	5a	ed222	5042	5684	13a
ed176	4130	5410	21c	ed223	5237	5678	13b
ed177	4405	5400	17b	ed224	4930	5507	21c
ed178	4680	5390	17b	ed226	5170	5683	13b
ed179	4960	5390	17b	ed227	6000	7530	18b
ed180	5230	5380	21c	ed228	5140	5630	13a
ed181	5520	5375	21d	ed229	5160	5560	13a
ed182	5780	5370	21d	ed230	5106	5568	13a
ed183	6070	5370	13b	ed231	5060	5530	13b
ed184	6340	5360	14a	ed232	5025	5470	21c
ed185	6600	5350	22b	ed233	4990	5470	21d
ed186	6880	5340	13b	ed234	4960	5490	21d
ed187	7140	5350	10a	ed235	4860	7210	19
ed188	7430	5320	7a	ed236	7700	6840	1
ed189	7700	5320	6c	ed237	7757	7228	22c
ed190	7970	5310	6b	ed238	7850	5700	22b
ed191	8240	5300	7b	ed239	5985	6115	4
ed192	8520	5290	3b	ed240	7950	5120	18a
ed193	8790	5280	3b	ed241	8160	5490	5b
ed194	4260	5160	23	ed242	8270	6080	5a
ed195	4540	5160	20b	ed243	6925	6545	1
ed196	4820	5150	20c	ed244	5880	5230	21a
ed197	5095	5150	20c	ed245	6580	7575	12b
ed198	5370	5135	17b	ed330	6320	5430	22b
ed199	5640	5140	17a	ed331	6320	5420	22b
ed200	5920	5125	17a	ed332	6320	5410	22b
ed201	6200	5120	13b	ed333	6320	5400	22b
ed202	6460	5120	22c	ed334	6320	5390	13b
ed203	6730	5110	20a	ed335	6320	5440	22b
ed204	7010	5100	10b	ed336	6320	5450	13b
ed205	7340	5120	6c	ed337	8080	5430	7b
ed206	7560	5080	6c	ed338	8085	5400	7a

site	east	north	soil no.	site	east	north	soil no.
ed339	8070	5460	7a	ed418	7540	6350	10a
ed340	8065	5490	7b	ed419	7590	6350	10b
ed341	8060	5525	7b	ed420	7570	6350	10b
ed342	8050	5560	7b	ed421	7640	6420	10a
ed343	8040	5590	7b	ed422	7460	6430	10b
ed344	8035	5625	7a	ed423	7420	6520	13a
ed345	8030	5645	22a	ed424	7510	6510	4
ed346	8080	5560	7a	ed425	7460	6590	3b
ed347	8130	6035	5b	ed426	7510	6670	13a
ed348	8130	6035	5b	ed427	7600	6660	4
ed349	8130	6035	5b	ed428	7650	6590	4
ed350	8129	6035	5b	ed429	7830	6580	7a
ed351	8129	6035	5b	ed430	7740	6590	7a
ed352	8129	6035	5b	ed431	7780	6530	7a
ed353	8125	6040	7a	ed432	7690	6670	13a
ed354	8090	5370	6a	ed433	7420	6670	13a
ed355	8070	5340	7a	ed601	5993	7032	12a
ed360	5175	7481	13b	ed602	5994	7037	12b
ed361	5240	7295	14b	na001	5320	3040	16
ed362	5125	7510	13b	na002	5320	3040	16
ed363	5168	7502	13b	na003	7123	4750	8
ed364	5180	7461	13b	na004	5585	2985	21b
ed365	5205	7400	14a	na005	5465	3000	2
ed366	5233	7315	14b	na006	5395	3015	2
ed367	5225	7338	14b	na007	5335	3020	16
ed368	5190	7441	14a	na008	5310	3030	16
ed369	5210	7380	14a	na009	5360	3020	16
ed370	5195	7420	14a	na010	7176	4778	10b
ed371	5218	7358	14b	na011	7129	4700	13a
ed400	4238	7474	14b	na012	6950	4745	9a
ed401	4236	7481	13b	na013	6895	4472	13b
ed402	4237	7477	14b	na014	7080	4623	13b
ed403	4238	7475	14b	na015	7000	4793	9a
ed404	4238	7476	14b	na016	6940	4550	13b
ed405	4237	7476	14b	na017	6966	4590	13b
ed406	4237	7478	14b	na018	6910	4630	13b
ed407	4237	7479	13b	na019	6990	4625	13b
ed408	4237	7480	13b	na020	6945	4708	9a
ed409	4236	7480	13b	na021	7040	4705	13b
ed410	6920	6550	1	na022	7061	4740	8
ed411	6110	7030	13a	na023	7086	4782	8
ed412	7560	6750	1	na024	7040	4812	8
ed413	7880	6670	22c	na025	7108	4802	9b
ed414	7790	6670	13a	na026	7042	4857	9a
ed415	7550	6430	10b	na027	6310	4740	21c
ed416	7500	6350	10a	na030	4260	3790	11
ed417	7410	6350	10b	na031	4570	4915	15

site	east	north	soil no.	site	east	north	soil no.
na032	4571	4917	15	we007	0880	6430	13b
na033	4577	4924	11	we008	0870	6130	20b
na034	4580	4930	11	we009	0840	6070	17b
na035	4560	4900	15	we010	0820	6040	20b
na036	4560	4900	15	we011	0730	5880	13a
we001	2280	7800	13b	we012	0710	5730	20b
we002	1760	7890	13a	we013	0550	5900	20b
we004	1620	7610	13b	we016	0335	5640	21a
we005	1450	7370	13b	we017	0220	5380	21a
we006	1340	7140	13b	we018	0860	6770	13a

soil	soil type [1]	soil	soil type
1	Tarlee clay loam	14a	Meriah medium clay
2	Clarendon sandy loam	14b	Meriah mc, hardsetting
3a	Montana clay loam	14c	Meriah hardsetting soil
3b	Montana medium clay	15	Round Swamp clay loam
4	Bald Hill medium clay	16	Bohena medium clay
5a	Moonbill light clay	17a	Namoi clay loam
5b	Moonbill medium clay	17b	Namoi medium clay
6a	Killarney Ass. (sl)	18a	Spring Creek clay loam
6b	Killarney Ass. (wds)	18b	Spring Creek medium clay
6c	Killarney Ass. (sds)	19	Galathera medium clay
7a	Murrumbilla loamy sand	20a	Pian loamy sand
7b	Murrumbilla light clay	20b	Pian clay loam
8	Cooyong loam	20c	Pian medium clay
9a	Watson clay loam	21a	Queerbri silt loam
9b	Watson clayey sand	21b	Queerbri sil, Bohena var
10a	Oakvale loamy sand	21c	Queerbri clay loam
10b	Oakvale sandy clay	21d	Queerbri medium clay
11	Yarrie sand	22a	Bobbiwaa clay loam
12a	Muckabinya subplastic clay	22b	Bobbiwaa cl, sodic phase
12b	Muckabinya heavy clay	22c	Bobbiwaa medium clay
13a	Gommel subplastic clay	23	Bundock loamy sand
13b	Gommel heavy clay		

[1]Ass, association; cl, clay loam; mc, medium clay; sds, slow draining sands; sil, silt loam; sl, sandy loams; var, variant; wds, well-drained sands.

Appendix 2

Performance scores, fuzzy analyses

When a data set is first examined, the number of groups that it might contain is unknown. For this reason, the analysis is run for a range of possible groups and the results are then compared with existing knowledge of the data or by means of mathematical tests.

The following table shows the results of the three tests used in the present analysis of the Edgeroi data set. With these tests the measure of the most efficient grouping is given, in the case of the *objective function value,* by a larger decrease than usual when successive results are compared. In the cases of the *fuzziness performance index*, and *maximum partition entropy*, the best group is the one with the smallest score. The results are sometimes best examined as graphs of the test scores against group number.

All analyses were run using the fuzzy *k*-means algorithm, diagonal metric, and the standard default setting, 1.30, for the fuzzy parameter (Ward, A.W. et al. 1992). In cases 1 to 4 the data are for clay percent, cation exchange capacity, and exchangeable element, as percent of total cations (Al, K, Na, Mg, Ca), for all soil samples at 0-2, 0-10 and 10-20 cm depth. In the Narrabri data set, case 5, the clay percent values are excluded and the cec and exchangeable element data are from all sampled depths. In the subset of 17 Narrabri clay soils, case 6, the data are for pH, electrical conductivity, chloride, calcium carbonate, and the five cations as before.

Groups in each analysis:	2	3	4	5	6	7
1. Sandstone ridges, basalt hills and eroded alluvial plains						
objective function value	1118	805	657	551	496	379
fuzziness performance index	0.073	0.074	0.078	0.074	0.085	0.077
maximum partition entropy	0.218	0.185	0.178	0.159	0.170	0.146
				✓		
2. Dust-mantled alluvial lands						
objective function value	2017	1640	1416	1273	1166	1079
fuzziness performance index	0.135	0.116	0.110	0.128	0.130	0.123
maximum partition entropy	0.387	0.292	0.255	0.274	0.263	0.239
			✓			
3. Dust-mantled alluvial lands. Data for 3b (soil samples treated as site variables).						
objective function value	356	269	209	180		
fuzziness performance index	0.121	0.086	0.070	0.084		
maximum partition entropy	0.357	0.230	0.165	0.185		
			✓			
4. Alluvial plains						
objective function value	1054	824	717	648	587	545
fuzziness performance index	0.105	0.092	0.109	0.115	0.107	0.111
maximum partition entropy	0.304	0.234	0.249	0.247	0.218	0.218
		✓				
5. All Narrabri samples, all depths						
objective function value	900	705	599	502	459	426
fuzziness performance index	0.086	0.087	0.083	0.075	0.079	0.083
maximum partition entropy	0.250	0.218	0.192	0.162	0.160	0.161
				✓		
6. 17 Narrabri clay soils, all layers						
objective function value	874	655	556	462	354	317
fuzziness performance index	0.090	0.077	0.081	0.072	0.058	0.055
maximum partition entropy	0.262	0.196	0.190	0.157	0.119	0.109
					✓	

Table Performance scores for 2 - 7 fuzzy groups. 1, Sandstone ridges, basalt hills and eroded alluvial plains. 2, Dust-mantled alluvial lands. 3, Dust-mantled alluvial lands, data for group 3b, with the data for the three surface samples treated as site variables. 4, Alluvial plains. 5, All Narrabri samples, all sampled layers. 6, 17 Narrabri clay soils, all layers. Best results are indicated by check marks (✓).