STUDIES IN PEDOGENESIS IN NEW SOUTH WALES

V.* THE EUCHROZEMS†

By E. G. HALLSWORTH‡, J. D. COLWELL§, and F. R. GIBBONS‡

Summary

A study has been made of certain red soils overlying basalt around Inverell, N.S.W., that are distributed in a complex manner amongst the black soils of chernozemic character considered to be the climax soils from basalt under the present climate. The red soils are sufficiently distinct from related soils to merit separation as a new soil group—the euchrozems.

The euchrozems are shown to be affected by residual leached soils of a previous wetter climate, but are not merely relics. Laterite residuals, which are relics of a former period, are found in perched positions as a capping on most of the euchrozem catenas. The euchrozems are considered to be derived partly from basalt weathering under present-day conditions and partly from the relics of the former soils, the latter distributing sesquioxide by movement down the catena.

Evidence for the conversion of euchrozems to chernozemic soils is shown, and the term "reversion" applied to this process, since it constitutes a reversal of the weathering sequence. A series of stages from the euchrozem catena to the chocolate/chernozem catena is described, which together with the occurrence of two distinct basalt flows, the upper overlying laterite on both basalt and other rocks, affords an adequate explanation of the complex distribution of the soils.

I. INTRODUCTION

During an investigation of the fertility levels of the north-western wheat belt of New South Wales in 1948, a complex pattern of red and black soils on basalt was observed which could be interpreted neither by reference to the literature nor in terms of the sequence of soils forming on basalt recently described by the authors (Hallsworth *et al.* 1952). This sequence of krasnozems, chocolate, chernozemic, and sierozemic soils could be interpreted in terms of weathering as affected by the interaction of topography and the present climate, the krasnozems being the most strongly leached and the others progressively less so. Around the town of Inverell, however, black soils of chernozemic character and red soils showing superficial resemblance to krasnozems occur side by side in a fine

* Parts I-IV of this series have appeared as follows:

I. The influence of rice cultivation on the grey and brown "gilgai" soils of the Murrumbidgee Irrigation Areas. *J. Soil Sci.* 3(1): 89 (1952).

II. The chocolate soils. *J. Soil Sci.* 3(1): 103 (1952).

III. The alpine humus soils. *J. Soil Sci.* 3(2): 190 (1952).

IV. Ironstone soils. *J. Soil Sci.* 4(1): 24 (1953).

† Euchrozem = brightly coloured (Gk. *euchro* = brightly or strongly coloured).

‡ Formerly Agricultural Chemistry Laboratories, University of Sydney; now University of Nottingham.

§ Formerly Agricultural Chemistry Laboratories, University of Sydney; now Chemists' Branch, N.S.W. Department of Agriculture, Sydney, N.S.W.

mosaic, although underlain at comparable depth by basalt which is either identical or of very similar character. To these anomalous red soils the term "euchrozem" has been applied (Gibbons and Hallsworth 1952).

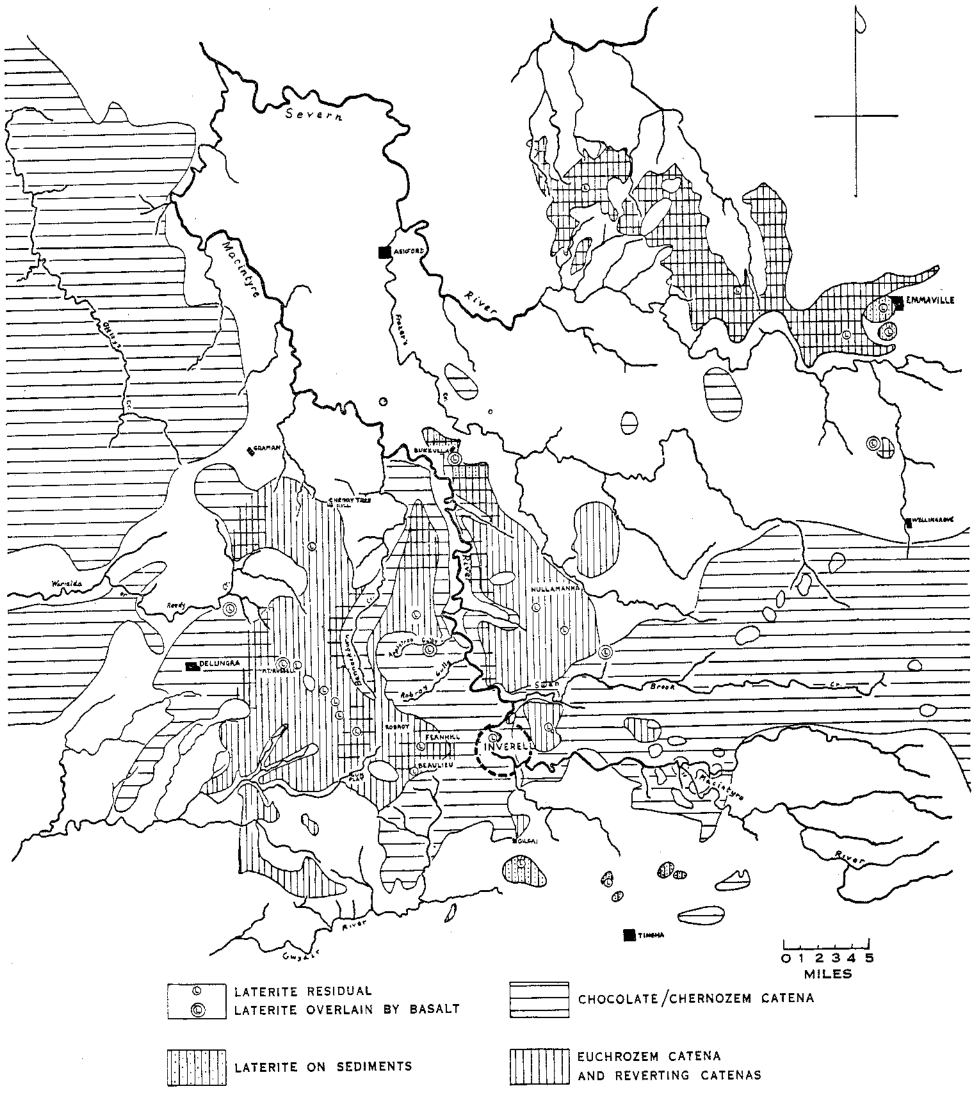


Fig. 1.—The distribution of euchrozem and laterite residuals in the Inverell district.

A typical profile would show a friable, dark brownish red clay loam at the surface, of crumb to loose medium nutty structure; this merges gradually into a harder, but still friable, crumb-structured brownish red clay, sometimes mottled with numerous rust, purple, or black fleckings due to irregular ferromanganiferous concretions which are most common between 3 ft and 4 ft deep. This horizon merges into a blocky-structured orange to yellow-orange clay which passes into the decomposing basalt at from 4 ft to 6 ft or at greater depths.

For the climatic data for Inverell, it would be expected that the catena of soils formed on basalt would be chernozemic in character (Hallsworth 1951; Hallsworth *et al.* 1952). This catena, which consists of reddish and normal chocolate soils on the upper slopes, brown chernozemic soils on the middle and lower slopes, and black chernozemic soils on the lower slopes and flats, occupies the greater proportion of the basalt area round Inverell.

The remainder of the basalt, however, exhibits either the euchrozem catena* or else a catena which is intermediate between the "chocolate-chernozem catena" and the euchrozem catena (Fig. 1).

Field investigation of the euchrozems has shown that they generally occur in association with residuals of laterized basalt in the eluvial position of the catena. This has been found in a sufficient number of cases for it to be postulated that in all cases such a residual has been present at some stage in their development, although now it may have been largely or entirely removed by erosion.

II. Environment

(*a*) *Climate*

The climate of Inverell (lat. 29° 47′, long. 151° 10′, altitude 1980 ft) is sub-humid and warm temperate. Average rainfall is 29.9 in., with a slight summer maximum. Temperatures range from a mean maximum of 86.4°F in January to a mean minimum of 31.9°F in July. Severe frosts are common in winter, but snow is virtually unknown. Average relative humidity is 65 per cent.

(*b*) *Topography*

The topography varies from undulating through rolling to hilly and is predominantly rolling.

(*c*) *Vegetation*

The chocolate-chernozem catena supports a savannah woodland of white box (*Eucalyptus albens*) usually in pure stand, although myall or boree (*Acacia pendula*), wilga (*Geijera parviflora*), and rosewood (*Heterodendron oleaefolium*) may occur in the west of the area; on the flattest portion in the lower parts of the catena a grassland association is found of plains grass (*Stipa aristiglumis*) and wallaby grass (*Danthonia linkii*). On the residual laterite a scrub formation is found of green wattle

* The authors propose to restrict the use of the term "catena" to situations where topography is the only variable factor of the soil-forming system. It may appear that it would not be in keeping with this principle to describe as a "catena" the sequence of euchrozems on a basalt hill capped with laterite, but in this case the parent material of the laterite itself was also basalt, albeit in a former and different climate.

(*A. mollissima*) and mallee red gum (*E. dealbata*), whilst the euchrozems carry a savannah woodland of white box (*E. albens*) as the dominant tree, rough-barked apple (*Angophora intermedia*), kurrajong (*Brachychiton populneum*), and red gum (*E. dealbata* = *E. blakelyi*).

(*d*) *Geology*

The geology of the Inverell area has been described by Andrews (1914), Voisey (1945), David (1950), and others, all of whom assume the basalts of the area to be essentially of one age and to have been erupted during the early Tertiary (Oligocene?) period. By contrast two major periods of extrusion for the basalts of the New England region had been suggested by David (1932) and three by Owen (1949).

Numerous exposures of the entire laterite profile developed on basalt can be seen at Inverell, Fernhill, Nullamanna, Mt. Russell, Cherry Tree Hill, Bauxite Hill, and Wellingrove. That this basalt itself overlies laterite is shown where the junction of the basalt and the underlying rock has been exposed by stream action (Appendix I). At certain points this underlying laterite has been derived from an earlier basalt (Owen 1949).

There seems no doubt that a younger and an older series of basalts are present. The accurate dating of these two periods is of little consequence in the genesis of the modern soils. At whatever stage of the Tertiary period laterization occurred, an extensive extrusion of basalt has undoubtedly taken place subsequently and has itself been laterized.

III. Field Description of the Soils

The catenas observed show variations depending on the extent to which the laterite has been removed by erosion and all stages may be found, varying from those with a cap of massive laterite on the crest through various degrees of breakdown of the cap to catenas showing no evidence of laterite (Table 1).

In all cases the soil developing from the decomposing indurated zone in the eluvial position on the crest of the hill is very finely aggregated and breaks easily to particles of very small dimensions. The term "snuffy" has been applied elsewhere to this particularly powdery structure. Soils of this type occupy only a very small proportion of the whole area of laterite-affected soils. The colluvial position of the laterite/euchrozem catena sometimes exhibits a scree formed from pieces of the indurated zone, and such soil as is present resembles that of the eluvial position.

In lower catenary positions euchrozems occur, and the soil becomes stiffer, developing a coherent surface layer which breaks easily into a hard crumb even when dry. The soils do not show the self-mulching structure or the wide-cracking and gilgai features of the soils in comparable positions on the chocolate/chernozem catena.

TABLE 1

FIELD DESCRIPTIONS OF THE SOILS FOUND ON SLOPES FROM WHICH THE LATERITE CAP HAS BEEN REMOVED TO VARYING DEGREES

Catena	Eluvial	Colluvial	Illuvial	Illuvial
Nullamanna	Profile 395. Slope 0°. Top of hill Reddish brown powdery loam; "snuffy" structure; containing large pieces of the bauxitic indurated horizon. This changes through brownish red loam between 1 ft 6 in. and 4 ft, giving way to brick-red clay with white mottlings between 4 ft and 6 ft. No fragments of the indurated zone below 6 in. Fossil laterite	Profile 396. Slope 3° 0′. 30 ft below 395 Brownish red powdery silty clay, poor fine crumb; no stones or concretions. This becomes more stony with depth and it was not possible to auger deeper than 2-3 ft. The pebbles are of rotten basalt	Profile 397. Slope 1° 15′. 46 ft below 395 Reddish brown light clay loam; fine crumb structure; merging into red light clay at 1 ft; compact crumb structure; friable; thence to 6 ft, colour lightens to yellowish orange, with texture and structure similar; dark-coloured ferromanganiferous concretions present from 6 in. to 6 ft. Euchrozem	Profile 398. Slope 0° 15′. 52 ft below 395 Brownish red clay loam; hard crumb structure; changing to red light clay at 12 in. which becomes yellow-red with depth. Ferromanganiferous concretions present from 6 in. becoming more frequent and larger to 6 ft. Some bauxite concretions present at 3 ft to 3 ft 6 in. Euchrozem
Beaulieu	Profile 365. Slope 0°. Top of hill Red-brown powdery sandy loam; "snuffy" structure. Changing to bright red gravelly loam at 1 ft 3 in. Gravel consists of bauxite concretions which increase to about 3 ft but diminish below, finally disappearing at about 6 ft. Colour remains bright red to 7 ft. Fossil laterite	Profile 366. Slope 5° 10′. 50 ft below 365 Brownish red powdery loam; "snuffy" structure; changing to red gravelly loam at 18 in. Remains bright red to 6 ft, containing a few bauxite concretions at all depths	Profile 367. Slope 2° 00′. 80 ft below 365 Brownish red friable clay loam; fine crumb structure; changing to a red light clay at 6 in. with coarse crumb structure becoming bright red and with a few ferromanganiferous concretions at 2-3 ft. Changing to orange light clay between 5 and 6 ft. Euchrozem	Profile 371. Slope 2° 00′. 147 ft below 365 Dark reddish brown compact clay, with harsh crumb structure, merging through a red blocky clay into a gravelly brick-red clay overlying rotten basalt at $5\frac{1}{2}$ ft. Ferromanganiferous concretions appear at 18 in., and calcium carbonate concretions appear below 3 ft. Transitional euchrozem-chernozem soil

TABLE 1 (*Continued*)

Catena	Eluvial	Colluvial	Illuvial	Illuvial
Cherry Tree Hill	Profile 402. Slope 0°. Top of hill Brownish red powdery gravelly silt loam, nutty structure. Pebbles of bauxite present, with maximum at 6-12 in. Giving way to a red light clay free from gravel at 18 in. Colour becomes lighter with depth. From 4 to 6 ft white fleckings are present. Fossil laterite	Profile 403. Slope 1° 00′. 20 ft below 402 Brownish red friable silty loam; nutty structure, with bauxitic gravel present between 6 and 18 in. Changes at 18 in. into red light clay with some ferromanganiferous concretions; compact crumb structure. Texture remains same but colour becomes somewhat lighter to 6 ft. Euchrozem	Profile 404. Slope 0° 40′. 30 ft below 402 Brownish red friable silty loam, nutty structure, giving way through brownish-red clay loam to red clay at 12 in.; friable crumb structure. This changes gradually into a greyish-red gritty clay from 3 to 6 ft containing small ferromanganiferous concretions. Euchrozem	Profile 405. Slope 0° 40′. 35 ft below 402 Brownish red silty clay loam; crumb structure; friable; merging gradually into red clay; compact crumb structure; this extends to 6 ft. A few ferromanganiferous concretions present. Euchrozem
Gum Flat	Profile 391. Slope 2° 15′. Near top of hill Reddish chocolate clay loam; large crumb to small nutty structure; friable; numerous basalt stones and floaters. This changes at 6 in. to a reddish brown friable clay free from stones which extends to 3 ft. Pieces of decomposing basalt occur at 3-4 ft	Profile 392. Slope 3° 15′. 20 ft below 391 Reddish brown clay loam; crumb to small nutty structure; friable; changing at 6 in. to a reddish brown light clay; compact crumb structure; friable; becoming yellow-brown at depth to 6 ft. Ferromanganiferous concretions begin at 1 ft and increase to 6 ft. Euchrozem	Profile 393. Slope 3° 25′. 61 ft below 391 Chocolate loam, fairly compact but breaking to nutty structure when handled. Changes through a chocolate clay loam to a chocolate clay with yellow flecks and black mottlings of ferromanganiferous concretions at 12 in. Changes to a yellow-brown clay with black mottlings and containing basalt pebbles at 6 ft. Transitional euchrozem-chernozem soil	Profile 394. Slope 1° 00′. 87 ft below 391 Dark chocolate brown clay loam; small nutty to very small cloddy structure; this overlies at 9-12 in. a chocolate heavy clay; semicolumnar to massive structure; hard and stiff. This changes through yellow-brown heavy clay to the decomposing basalt at 6 ft. Free carbonate concretions numerous. Brown chernozemic soil

TABLE 1 (*Continued*)

Catena	Eluvial	Colluvial	Illuvial	Illuvial
Beaulieu	Profile 361. Slope 0°. Top of hill Reddish chocolate friable clay loam; coarse crumb structure; very stony. Giving way to reddish chocolate stony clay at 6 in. which merges into broken basalt at about 2 ft. Reddish chocolate soil	Profile 362. Slope 3° 10′. 32 ft below 361 Chocolate friable clay; small crumb structure. Changing through a dark reddish brown clay at 6 in. to a bright red-brown clay at 2 ft which changes to brown, mottled with greys and yellows as it merges into decomposing basalt at about 3 ft. Normal chocolate soil	Profile 363. Slope 2° 15′. 61 ft below 361 Dark brown friable clay, hard crumb structure. Changes fairly sharply to dark brown tenacious clay with white flecks due to calcium carbonate concretions at 6-12 in. This merges into dark grey-brown clay containing carbonate concretions, giving way to decomposing basalt at about 3 ft. Brown chernozemic soil	Profile 364. Slope 2° 5′. 95 ft below 361 Black heavy clay; hard crumb structure, self-mulching surface, changing to blocky to semi-columnar subsoil with carbonate concretions. Decomposing basalt at about 3 ft. Black chernozemic soil

The catenas at Cherry Tree Hill or Beaulieu lack the massive remnant of the indurated horizon of the laterite, but still show the snuffy red soil at the top and the bauxitic pisolites. That at Gum Flat lacks both the massive remnants and the snuffy red soil, and euchrozems occupy the middle slopes but are replaced by chernozemic soils on the lowest positions. At Beaulieu a chocolate/chernozem catena exemplifying the climatic climax to be expected on basalt in that environment contrasts strikingly with a euchrozem catena on the adjacent hill. The junction between the red and black soils coincides with the centre of the valley between the hills, where recent erosion has widened the original creek to a gully which for most of its course has a red bank on one side and a black bank on the other.

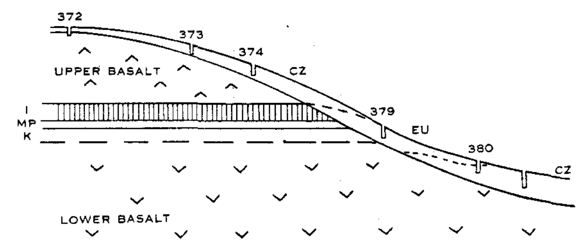


Fig. 2.—The occurrence of euchrozems at Mt. Russell where laterite outcrops from beneath the upper basalt flow. The numbers refer to profiles mentioned in the text. *I* = indurated zone; *MP* = mottled-pallid zone; *K* = kaolinized basalt; *CZ* = chernozemic soil; *EU* = euchrozem.

As would be expected from the more vigorous erosion, laterite residuals occur only rarely in hilly topography. Where they are found, as for example at Bauxite Hill and Fernhill, the lower parts of the slope below the laterite residual are cut up into an intricate series of ridges and valleys and the illuvial component of the euchrozem catena is hardly developed at all. The ridges themselves, particularly those well removed from the laterite residual, show a sub-catena similar to the catena already described for Gum Flat, whilst the soils of the inter-ridge valleys become more chernozemic in character. With the marked formation of ridges and steep-sided V-shaped valleys, the development of any but the eluvial and colluvial complex of the ridge catena is prevented.

Where erosion has cut through the two flows, the soil formation is more complex. Thus at Mt. Russell or at Prairie Vale, the upper flow shows no signs of laterite, and the soils developed are typical of the chocolate/chernozem catena, with wavy gilgai developing in the lower members. These are succeeded lower down the slope by euchrozems developed on the underlying laterite, which are commonly followed at lower levels by the chernozems of the valley. The pattern of bright red-brown soils sandwiched between the black soils of the upper flow and those of the valley is particularly striking (Fig. 2).

IV. Analytical Results

The soils were examined by a shallow pit dug to expose the surface horizons, and then by augering to the underlying rock or to 6 ft. As the horizons usually were not clearly differentiated, analyses were carried out at the standard depths of 0-3 in., 3-6 in., 6-9 in., 9-12 in., 12-18 in., 18-24 in., 2-3 ft, 3-4 ft, 4-5 ft, and 5-6 ft.

(a) *Mechanical Composition*

The soils formed on the fossil laterite residuals are very much lower in clay than their analogues of the chocolate/chernozem catena; the euchrozems show a lower clay content in the surface than do chernozemic soils from comparable catenary positions, although the clay content of the subsoil rises to comparable or higher levels (Table 2).

TABLE 2

MECHANICAL COMPOSITION: CLAY AS PER CENT. OF OVEN-DRY SOIL

Depth	Fossil Laterite (4 Profiles)			Euchrozem (12 Profiles)			Chernozem (6 Profiles)			Chocolate (4 Profiles)		
	Max.	Min.	Mean	Max.	Min.	Mean	Max.	Min.	Mean	Max.	Min.	Mean
0-3 in.	39	22	32	66	37	45	76	53	66	55	42	47
3-6 in.	44	26	36	73	40	53	77	51	68	48	38	43
12-18 in.	73	37	45	87	61	70	79	58	63	65	52	60
2-3 ft	83	58	67	88	58	75	77	57	63	—	—	—
5-6 ft	79	50	67	77	31	67	79	58	69	—	—	—

(b) *Composition of the Clay*

On a restricted number of samples the silica/sesquioxide ratio and the minerals of the clay were determined (Table 3).

The clay of the topsoil of the laterite contains abundant haematite; that of the euchrozems contains abundant kaolinite and a little haematite, but montmorillonite is lacking; that of the chernozems is very largely montmorillonite, with a silica-sesquioxide ratio distinctly higher than that of the euchrozems. The transitional soil 169.1 is intermediate between euchrozem and chernozem for both clay composition and silica-sesquioxide ratio.

(c) *Organic Matter*

The mean figures for the organic matter of cultivated soils of both euchrozems and chernozems are similar, ranging from 3.3 to 4.6 per cent.

(d) *Soil Reaction and Exchange Complex*

The average pH values are given in Table 4 and the exchange complex figures for some individual profiles in Table 5.

TABLE 3

MINERALOGY OF THE CLAY FRACTION

Profile and Sample No.	Description of Site, Etc.	Catenary Position	Depth	Clay Composition*			
				Montmorillonite	Kaolinite	Haematite	$\frac{SiO_2}{R_2O_3}$
348.1	Byron. Chocolate soil	Eluvial	0-3 in.	++	–	–	2.6
352.7	Byron. Chernozem	Colluvial	3-4 ft	++	++	–	3.3
354*a*.7	Byron. Chernozem	Illuvial	3-4 ft	+++	+	–	3.2
187.6	Warialda. Chernozem	Illuvial	2-3 ft	++++	+	–	2.4
361.3	Beaulieu. Chocolate soil	Eluvial	6-12 in.	++	++	–	1.9
362.1	Beaulieu. Prairie soil	Colluvial	0-3 in.	++	+	–	2.5
364.1	Beaulieu. Chernozem	Illuvial	0-3 in.	++	–	–	2.2
395.1	Nullamanna. Fossil laterite	Eluvial	0-3 in.	–	–	+++	1.6
341.1	Fernhill. Fossil laterite	Eluvial	0-3 in.	–	+	+++	0.2
392.3	Gum Flat. Euchrozem	Colluvial	6-12 in.	–	+++	++	1.5
386.3	Rob Roy. Euchrozem	Eluvial	6-12 in.	–	+++	+	1.3
389.4	Rob Roy. Euchrozem	Colluvial	12-18 in.	–	+++	–	2.1
169.1	Inverell. Transitional between euchrozem and chernozem	Illuvial	0-3 in.	++	+++	+	1.7
176.4	Oakwood. Chernozem in euchrozem catena	Illuvial	1-2 ft	++	+++	–	1.8
176.6	Oakwood. Chernozem	Illuvial	3-4 ft	+++	++	–	n.d.
174.1	Oakwood. Chernozem in euchrozem catena	Illuvial	0-3 in.	+++	+	–	2.0

* By method of MacEwen (1949). + = present; — = absent; n.d. = not determined.

The pH profiles of the euchrozems approach those of the chernozems but whereas chernozem profiles on basalt in the Inverell district show a steep rise in pH into the subsoil, this is not necessarily the case with the euchrozems, as in about half the cases examined the pH falls again in the deep subsoil. The relatively high pH of the upper horizons of the fossil laterite profiles is interesting, since these soils would be expected to be strongly leached and acid, the low silica/sesquioxide ratio and absence of primary minerals (Carroll and Woof 1951) emphasizing the vigorous rock breakdown that had taken place during their formation. The pH of the fossil laterites at Inverell represents a reversion of the soil characters from those in a more humid environment, and the formerly strongly acid laterites have now been so enriched with bases that the pH values of their surface soils are almost comparable with those of the chernozems, although in many the pH falls in the subsoil. The high figures for exchangeable potassium and calcium of the surface soils suggest that this reversion has resulted from the accretion of relatively base-rich leaf litter, the bases having been absorbed by the deep roots of trees penetrating to the decomposing rock below. The quantities involved are not large. For example, at Beaulieu, assuming that the exchangeable calcium of the original laterite was approximately that of the deepest horizon of the fossil laterite analysed (sample 365.9), it can be calculated from the data in Table 5 that the soil of the horizons above this has gained 7200 lb of calcium per acre. This only amounts to an accretion of 1.8 lb per annum over the 4000 years commonly assigned to the Recent Period. This represents only a fraction of the 28 lb per annum per acre returned by the leaf fall from jarrah growing on fossil laterite on granite in Western Australia (A. Hatch, private communication 1952) and would be expected to be an even smaller fraction of that returned in the leaf litter of the acacia scrub growing on the laterite residuals of the Inverell district.

TABLE 4

MEAN pH VALUES

Depth	Fossil Laterite (Mean of 4 Profiles)	Euchrozem: No. of Profiles	Euchrozem: Max.	Euchrozem: Min.	Euchrozem: Mean	Chocolate Soil (Mean of 3 or 4 Profiles)	Chernozem Soil (Mean of 3 or 4 Profiles)
0-3 in.	6.8	26	7.4	5.3	6.4	6.2	7.0
3-6 in.	6.9	25	7.4	5.3	6.4	6.4	7.1
6-12 in.	7.0	14	7.7	6.0	6.9	6.7	—
12-18 in.	6.8	21	8.1	6.0	6.9	6.6	7.4
2-3 ft	6.3	19	7.4	5.9	6.8	6.8	8.8
5-6 ft	6.6	14	8.1	5.3	6.9	—	8.8

TABLE 5

EXCHANGEABLE CATIONS AND EXCHANGE CAPACITY

Catena	Group	Soil No.	Depth	Exchange Capacity	Exchangeable Cations* (m.e.%)					Exchangeable Cations (% exchange capacity)				
					H	Ca	Mg	K	Na	H	Ca*	Mg	K	Na
Beaulieu	Fossil laterite	365.1	0-3 in.	17.27	6.3	9.5	0.8	0.5	0.2	36	55	5	3	1
		365.3	6-12 in.	11.85	n.d.	5.0	n.d.	0.1	0.2	n.d.	36	n.d.	1	2
		365.9	5-6 ft	5.35	3.1	1.4	0.6	0.1	0.2	57	26	11	2	4
	Euchrozem	369.1	0-3 in.	37.14	0	30.6	5.2	1.0	0.3	0	82	14	3	1
		369.3	6-12 in.	28.96	0	14.4	13.9	0.4	0.3	0	50	48	1	1
		369.8	4-5 ft	48.73	2.2	29.4	16.4	tr.	0.7	5	60	33	0	2
Nullamanna	Fossil laterite	395.1	0-3 in.	37.11	9.5	20.4	6.2	0.8	0.2	26	55	17	2	1
		395.3	6-12 in.	17.86	0	12.9	4.8	tr.	0.2	0	72	26	0	2
		395.8	4-5 ft	8.89	0	4.4	4.0	tr.	0.5	0	50	45	0	5
	Euchrozem	396.1	0-3 in.	30.89	0	24.0	4.5	1.7	0.7	0	78	15	5	2
		397.1	0-3 in.	22.84	1.7	17.1	2.9	0.9	0.2	8	75	13	4	1
		397.3	6-12 in.	22.04	6.7	21.4	2.3	0.4	0.2	30	56	10	2	2
		397.8	4-5 ft	15.74	2.4	7.2	5.5	0.1	0.5	15	46	35	1	4
Cherry Tree Hill	Fossil laterite	402.1	0-3 in.	28.14	0	21.2	6.1	0.5	0.4	0	75	22	2	1
		402.9	5-6 ft	12.62	0	5.4	6.6	tr.	0.6	0	43	52	0	5
	Euchrozem	403.1	0-3 in.	26.36	1.4	19.0	5.4	0.4	0.2	5	72	21	2	1
		404.1	0-3 in.	25.85	1.4	19.9	3.6	0.8	0.2	5	77	14	3	1
		404.3	6-12 in.	18.28	n.d.	13.6	n.d.	0.2	0.2	n.d.	74	n.d.	1	1
		404.8	4-5 ft	16.72	4.3	7.7	4.6	tr.	0.1	26	46	27	0	1

TABLE 5 (*Continued*)

Catena	Group	Soil No.	Depth	Exchange Capacity	Exchangeable Cations* (m.e.%)					Exchangeable Cations (% exchange capacity)				
					H	Ca	Mg	K	Na	H	Ca*	Mg	K	Na
Bukkulla	Fossil laterite on sediments	399.1	0-3 in.	19.34	4.0	10.2	4.0	1.1	0.2	20	53	20	6	1
		399.4	1-2 ft	12.77	5.2	3.6	3.8	0.0	0.1	41	28	30	0	1
Beaulieu	Chocolate soil	361.1	0-3 in.	39.80	7.1	25.0	6.2	0.9	0.6	18	63	16	2	1
		361.3	6-12 in.	41.20	0	23.3	17.6	tr.	0.3	0	56	43	0	1
	Chernozem	364.1	0-3 in.	45.75	0.5	29.4	15.6	0.0	0.2	1	64	34	0	1
		364.3	6-12 in.	58.01	2.8	35.8	19.0	tr.	0.4	5	62	32	0	1
Gwydir Highway	Chocolate	422.1	0-3 in.	44.97	10.5	25.1	7.7	1.3	0.3	23	56	17	3	1
		422.3	6-9 in.	40.54	3.7	23.6	11.5	1.5	0.3	9	58	28	4	1
		422.5	12-18 in.	40.48	1.5	22.8	15.1	0.6	0.3	4	56	37	2	1
	Chernozem	424.1	0-3 in.	54.30	0.4	38.6	14.5	0.5	0.2	1	71	27	1	0
		424.4	12-18 in.	49.60	0	36.7	12.3	tr.	0.6	0	74	25	0	1
Dorrigo	Krasnozem	412.1	0-3 in.	13.23	8.8	2.2	2.0	0	0.2	66	17	15	0	2
		412.3	6-12 in.	11.09	10.0	0.9	0.1	0	0.1	90	8	1	0	1
		412.5	2-3 in.	4.03	3.4	0.6	0	0	0.1	84	14	0	0	2
		412.8	5-6 ft	6.59	6.0	0.4	0	0	0.2	91	6	0	0	3

* Where the sum of the exchangeable cations determined separately exceeded appreciably the exchange capacity, the amount of exchangeable calcium has been obtained by subtracting the sum of Mg, K, and Na from the exchange capacity.

The figures for the exchange complex show that although the soils on fossil laterite are generally base unsaturated, they are still in marked contrast to the modern krasnozems as found under 70-in. rainfalls at Dorrigo* which are base unsaturated to the extent of about 90 per cent.; this supports the pH figures. The euchrozems are slightly unsaturated, with calcium as the dominant ion, magnesium increasing in the subsoil; the exchange capacity is not high for either the fossil laterite or the euchrozem, and contrasts with the figures for chocolate and chernozem soils.

(*e*) *Free Ferric Oxide*

The free ferric oxide content (Deb 1950) was determined on the surface soil itself, instead of the clay fraction, since a considerable proportion of the particles of the sand fraction were aggregates of sesquioxides.

TABLE 6

FREE FERRIC OXIDE PER CENT. CONTENT OF EUCHROZEM AND RELATED SOILS

	Euchrozem Catenas				Chernozem Catenas			
	Nullamanna				Beaulieu			
Soil No.	395.1	396.1	397.1	398.1	361.1	362.1	363.1	364.1
% Free Fe_2O_3	14.9	10.7	9.7	6.2	7.3	5.0	3.8	2.4
	Cherry Tree Hill				Byron			
Soil No.	402.1	403.1	404.1	405.1	348.1	350.1	352.1	354a.1
% Free Fe_2O_3	10.1	9.2	8.8	8.4	5.6	2.3	2.4	2.2
	Beaulieu				Mt. Russell			
Soil No.	365.1	367.1	368.1	370	372.1	373.1	374.1	375.1
% Free Fe_2O_3	18.8	12.6	6.7	5.0	6.4	5.2	3.3	2.4
	Rob Roy				Mt. Russell (Effect of laterite outcrop)			
Soil No.	386.1	387.1	388.1	389.1	378.1	379.1	380.1	—
% Free Fe_2O_3	12.2	9.4	8.6	5.4	5.6	12.7	9.2	—
	Gum Flat							
Soil No.	391.1	392.1	393.1	394.1				
% Free Fe_2O_3	10.9	12.0	10.6	9.4				

These results (Table 6) show that the free ferric oxide is high (15-19 per cent.) in the soils on the fossil laterites (profiles 395, 365) and falls steadily into the euchrozem soils of the lower catenary positions. At Cherry Tree Hill, where the laterite cap has almost completely gone, the figure is distinctly lower. On the chocolate/chernozem catenas the reddish chocolate soil of the crest contains a fairly high proportion (5-7 per cent.) of free ferric oxide, as might be expected from its colour, but this quickly falls to quite low values (2.2-2.4 per cent.) in the lower catenary positions.

* On the eastern edge of the Northern Tableland.

The effect of the exposure of the laterite under the basalt cap is shown by the figures for Mt. Russell (profiles 378, 379, 380). The first samples below the cap are not so high in free ferric oxide as those a little lower downhill, because of the effect of surface creep from the overlying basalt, whilst the profiles from below the exposed laterite fall again in the same manner as the other euchrozem catenas.

V. Discussion

Associations of red and black soils developed on material of volcanic origin have been described from a number of localities. Stephens (1937) has described basaltic soils in Tasmania that show all gradations between a red "snuffy" soil and a heavy black clay. Desai (1939) has described the close association of the red earths and black cotton soils in Hyderabad and considered it to be the result of differences in topography, since the red earths occupy the higher, more freely drained positions and the black earths the lower positions. This differs from the soil pattern described above.

Bryan and Teakle (1949), referring to eastern Australia, have proposed a concept of "pedogenic inertia", whereby a process of soil formation, once established, tends to perpetuate itself regardless of changes in the environment to conditions unfavourable to the process. Their hypothesis that the red soils were developed under an earlier, wetter climate offers a partial explanation and is supported by the occurrence of numerous lateritic residuals, many of which show the almost complete fossil profile. The very much larger area of euchrozems found around Inverell in comparison with the restricted area of the residuals themselves, together with the different character of the euchrozems, requires a modification of the hypothesis that they are merely fossil soils from a former climate.

The effect of laterite residuals on the soils forming around them has been noted by Bryan (1939), and Whitehouse (1940) has described soils similar to euchrozems in south-west Queensland, but no comparable soils were described by Stephens (1946). This appears to be due to the variation in the laterite profile associated with differences in parent material (Hallsworth and Costin 1953). The laterites associated with the euchrozems of the Inverell district are all bauxitic laterites, as are those of south-west Queensland, whilst those described by Stephens are entirely ferruginous, from which the pisolites are extremely hard, resistant to decomposition, and could possibly persist unchanged by abrasion although transported over long distances.

Stephens has rightly emphasized the horizontal zonation of the soil types derived from each successive exposed horizon of dissected laterite; the indurated and pallid zones each give rise to characteristic soils, but the soils developed on the rock beneath the laterite do not show the features of the laterite-derived soils except occasionally where contaminated by gravel from the indurated zone.

Some explanation of the soil distribution observed here is obtained from Stephens's approach, but some further extension of it is necessary, since the soil distribution does not accord with the measured thicknesses of the horizons.

In the records of test bores obtained by Owen (1949) the maximum thickness of the indurated bauxitic zone is 40 ft (even where protected from erosion by the later basalt flows). The deepest section measured of the kaolinized basalt was 29 ft. The mottled-pallid zone is only about $3\frac{1}{2}$ ft thick. The thickness of the entire profile consequently would amount to about 75 ft, of which the top 40 ft would be sesquioxide and the lower 35 ft largely kaolinitic, with a sharp transition zone between the two.

Thus at Fernhill the snuffy soils described above are clearly those developing on the former indurated zone or such superior horizons as still persist. The euchrozems commence below this and could be derived largely by further weathering of the underlying kaolinized basalt, which analyses show still to contain some 42 per cent. of Al_2O_3 and 20 per cent. of Fe_2O_3 (Carroll and Woof 1951). At this site erosion has cut through the kaolinized basalt into the unweathered basalt beneath, which at the present time is giving rise to chernozemic soils. This apparent agreement with Stephens's concept breaks down when the vertical distribution of the soils is measured. Here, where the quarry allows definite placing of the horizons of the laterite, euchrozems are encountered 140 ft below the top of the kaolinized basalt.

Detailed examination of other catenas confirms this. The vertical distances of the lowest euchrozems below the bauxitic horizons or below the crest of the hill where no bauxitic horizon is present are as follows:

Mt. Russell	42 ft	Gum Flat	95 ft	Beaulieu	120 ft
Nullamanna	46 ft	Rob Roy	125 ft	Cherry Tree Hill	33 ft

It follows that only at Cherry Tree Hill could the lowest members of the euchrozems have been formed as sedentary soils on the kaolinized basalt.

This implies either that the basalt has been kaolinized to much greater depths than 35 ft or that considerable migration of the soil has taken place down the slope. That the former alternative cannot hold is shown by the occurrence in the Gum Flat and Rob Roy catenas of relatively freshly weathered basalt and unweathered floaters in the profiles of top catena members, whilst euchrozems extend down the slopes to 90 and 120 ft respectively below the top of the hill.

The snuffy red soil of the crest and the upper euchrozems of all those catenas of which this snuffy soil is the top component (e.g. Fernhill, Mt. Russell, Nullamanna, and Beaulieu) could be derived directly from an exposed horizon of the laterite profile, as can the entire catena at Cherry Tree Hill. The lower euchrozem profiles at Fernhill, Mt. Russell, Nullamanna, and Beaulieu cannot be so regarded, nor can any of those of the Gum Flat and Rob Roy catenas.

Detailed consideration of the situation at Beaulieu confirms this. Here, as shown in Plate 2, are two adjacent low hills, one carrying the laterite/euchrozem catena (profiles 365-371) and the other the chocolate/chernozem catena (profiles 360-364). Comparison of the heights of the two hills shows that the laterite-capped hill is 80 ft above the level of the other one. The laterite on the western hill appears to have weathered through almost to the base of the pisolitic zone (profile 365), whilst the basalt stones and boulders on the top of the eastern hill show no signs of alteration, and hence this difference in height is in accordance with the thickness of laterized basalt postulated earlier.

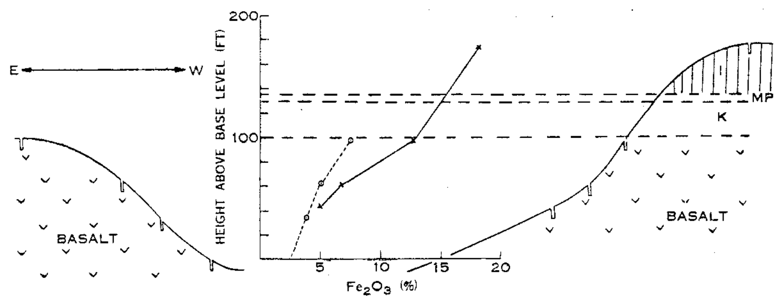


Fig. 3.—Beaulieu situation, showing the free ferric oxide content of the topsoil in relation to the position of the profile on the catena from an arbitrarily selected base level. The solid line represents the free Fe_2O_3 of the western catena, the dotted line that of the eastern catena. *I* = indurated zone; *MP* = mottled-pallid zone; *K* = kaolinized basalt.

Since the height of the basalt hill is still below the maximum depth to which the kaolinized basalt zone could extend in the laterite-capped hill, the soils at comparative heights on the two catenas should be the same on Stephens's hypothesis. That this is not so can be seen by comparing the profile descriptions, whilst marked discrepancy exists between the analytical figures for silica/sesquioxide ratio and free iron oxide. The figures for free iron oxide of the two catenas have been plotted against the heights of the profiles above an arbitrary base level (Fig. 3).

It can be seen at once that the free iron oxide content of the laterite-capped catena is considerably higher than that of the chocolate/chernozem catena at comparative levels, even beneath the lowest possible position of kaolinization. This can have been caused only by migration of iron oxide from the laterite into the lower catenary positions.

Since it has previously been demonstrated that catenary concentration of soil bases may take place (Hallsworth *et al.* 1952), it is evident that where two parent materials are exposed on one catena, the soil directly overlying the lower must be derived from both parent materials to varying degrees. Thus a comparison of the free ferric oxide figures for the catenas (Table 6) shows that the laterite has contributed free ferric oxide and presumably free aluminium oxide to the euchrozem. The clay of the euchrozems (Table 3) has been derived mainly from the kaolinized basalt, since in the chocolate/chernozem catena the basalt is weathering largely to montmorillonitic clay; nevertheless, it is possible that a proportion of the kaolin of the euchrozem is formed *in situ* from fresh basalt. This would be expected from the low silica/sesquioxide ratio of the system as a whole due to the input of sesquioxides, and the poor calcium input in the ground waters from the laterite as compared with those reaching the lower sites of the chocolate/chernozem catena.

For the euchrozems in the upper positions, and in all positions on the more gentle laterite-capped catenas, the kaolinized basalt or the pallid zone would probably contribute the bulk of the clay and the bases, whilst the bauxitic zone of the laterite would contribute free sesquioxide by migration down the slope.

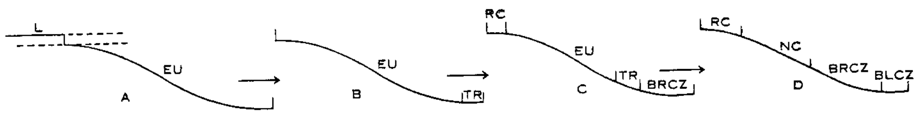


Fig. 4.—Diagrammatic representation of the sequence of catenas encountered with progressive erosion of the laterite. *L* = laterite; *EU* = euchrozem; *TR* = transitional; *RC* = reddish chocolate soil; *NC* = normal chocolate soil; *BRCZ* = brown chernozemic soil; *BLCZ* = black chernozemic soil.

For the euchrozems in the lower positions of the laterite-capped catenas of more rolling country and for all euchrozems in catenas without laterite, the parent material would be threefold, as the underlying basalt would also contribute in progressively greater proportions to the lower catenary members. The relative contributions of laterite and basalt to the euchrozems would be a function of the proportion of the local catchment area occupied by each and the slope of the catena, the latter determining the ease of input of ground waters from the freshly weathering basalt.

Once the laterite had been stripped from the top of the hill, its contribution to the complex would cease and in the course of time the catena would change to one for which the parent material would be basalt alone. A sequence of stages in time in the conversion of the euchrozem catena to the chocolate/chernozem catena would be characterized by a sequence of catenas. These stages, in fact, are represented by the catenas already described for the pre-laterite basalt, and can be illustrated diagrammatically (Fig. 4).

The laterite-capped euchrozem catena is changed, by the gradual stripping of the laterite capping, to the euchrozem catena (Fig. 4*B*, Rob

Roy). The Nullamanna, Cherry Tree Hill, and Beaulieu catenas (Table 1) represent intermediate stages. Thus at Nullamanna lumps of the indurated zone still persist at the top of the hill, at Cherry Tree Hill the laterite is represented only by bauxitic pisolites in the top five feet of soil, and at Beaulieu the greater slope has allowed the ground waters to become sufficiently basic for calcium carbonate concretions to appear at the lowest site.

A further increase in the contribution of basalt to the weathering material of the catena produces the third stage (Fig. 4*C*, Gum Flat), where the soils of the lower catenary positions are beginning to show the features of chernozemic soils, with a transitional band of euchrozems containing concretions of calcium carbonate. The soil at the top of the catena has lost sufficient of the sesquioxide material and gained sufficient from the freshly weathered basalt to acquire the characteristics of a reddish chocolate soil.

The final stage is reached (Fig. 4*D*, Beaulieu) when the continuing input of fresh weathering products from basalt completely dominates the kaolin and sesquioxides of the former laterite and induces the characteristics of the climatic climax for basalt, namely, the chocolate/chernozem catena.

Throughout this sequence of catenas, there is a progressive alteration in the properties of the soils, the exchangeable base figures increase in the lower catenary members, carbonate concretions appear, the silica/sesquioxide ratio of the clay fraction increases, and the red colour darkens and eventually changes to black. This change of properties is a reversal of the normal weathering processes; the process, therefore, has been described as "reversion" and the catenas in the intermediate stages termed "reversion catenas".

In the normal sequence of weathering, the monovalent and divalent cations are removed in that order with increased rate of leaching, leaving the trivalent cations behind, and so give rise to soils dominated by, respectively, Na-Ca, Ca, Ca-H, H-(Fe, Al); such a climatic sequence, in fact, is observed in comparable catenary positions in northern New South Wales (Hallsworth *et al.* 1952) with the chernozemic soil, chocolate soil, and krasnozem respectively.

It is apparent, however, that under the unusual conditions of a large input of sesquioxide on to an otherwise calcium-dominated soil, the soil formed would be dominated by Ca-(Fe, Al), and would show some of the properties of the sesquioxide-dominated soils, without the high acidity that usually accompanies the presence of the trivalent cations. Such a soil is the euchrozem, the large input of sesquioxides being derived either by movement downhill from the higher catenary positions or because the parent rock was not basalt but kaolinized basalt which had been partly weathered under a previous wetter climate. On the basis of the analytical data the euchrozems are Ca-(Fe, Al)-dominated kaolinitic clays, the reddish chocolate soils are Ca-H-dominated mixed montmorillonite and kaolin clays, and the krasnozems are H-(Fe, Al)-dominated kaolin clays. This is in accordance with their respective positions in the weathering sequence as described above.

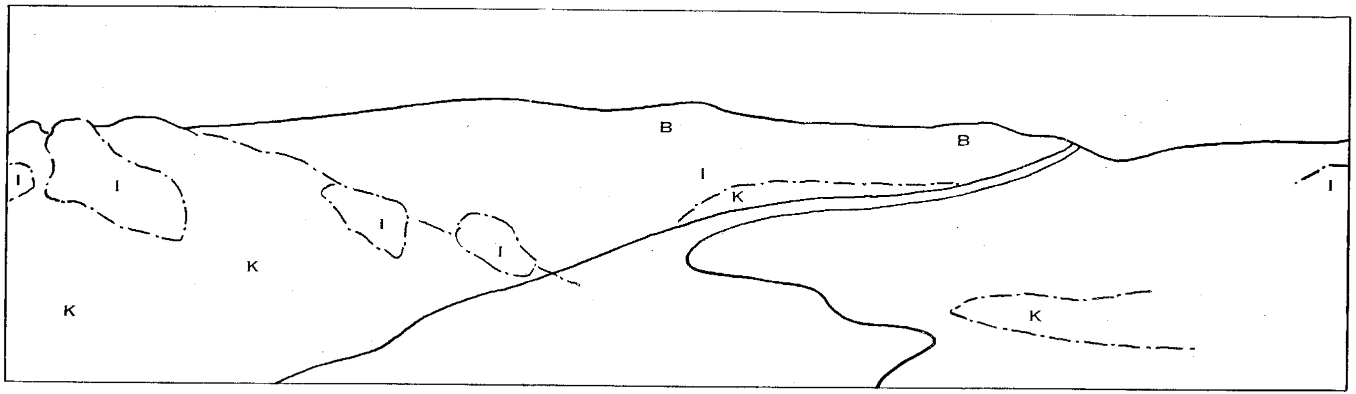
TABLE 7

COMPARISON OF PROPERTIES OF RELATED SOIL GROUPS

Properties	Horizon	Euchrozem	Chernozem	Reddish-Chocolate	Krasnozem
Colour	A_1	Dark brownish red	Black or dark brown	Reddish chocolate	Red
	B	Red	Black or dark brown	Reddish brown	Red
Visible porosity	A_1	Somewhat porous	Porous dry Closed wet	Porous dry Closed wet	Porous
	B	Somewhat porous	Closed	Closed	Porous
Handling consistency	A_1	Friable	Compact to tenacious	Compact to tenacious	Very friable
	B	Friable but hard	Compact to tenacious	Compact to tenacious	Very friable
Structure	A_1	Good crumb to loose medium nutty	Self-mulching to small cloddy	Crumb to small cloddy	Fine crumb
	B	Compact crumb	Semi-columnar to massive	Massive	Fine crumb
Calcium carbonate	A_1	Absent	Absent	Absent	Absent
	B	Occasionally in lowest members	Present	Absent	Absent
Total exchange capacity (m.e. %)	A_1	20-25	45-55	30-45	10-35
	B	15-20	45-55	30-45	10-35
Dominant cations (as % of t.e. capacity)	A_1	Ca 80% Mg 15%	Ca 70% Mg 30%	Ca 50% H 25%	H 65% Ca 15%
	B	Ca 60% Mg 35%	Ca 70% Mg 30%	Ca 50% Mg 40%	H 90% Ca 6%
Clay minerals		Kaolinite and sesquioxides	Mainly montmorillonite	Montmorillonite and kaolinite	Kaolinite and sesquioxides

The differences which warrant the separation of the euchrozems as a distinct soil group arise from the nature of the exchange complex and the balance of the saturating cations referred to above, which are reflected in their visible porosity, handling consistency, and structure. These structural differences themselves are reflected in the greater variety of tree species growing on the euchrozems than on the chocolate/chernozem association, and also in response of the soils to different cultivation and management practices. The differences are summarized in Table 7.

(*Photo*: J. D. Colwell



The Pindaroi road, east of Bukkulla. Boulders of basalt cap the hill on the right, overlying laterized sediments. The white kaolinized material is exposed in the centre and on either side of the road in the foreground. Massive lumps of the bauxitic indurated zone are exposed on the left, in the centre, above the kaolin, and on a small patch under the trees at the extreme right. I = indurated zone, K = kaolinized and mottled zones, B = Pliocene basalt over Miocene laterite.

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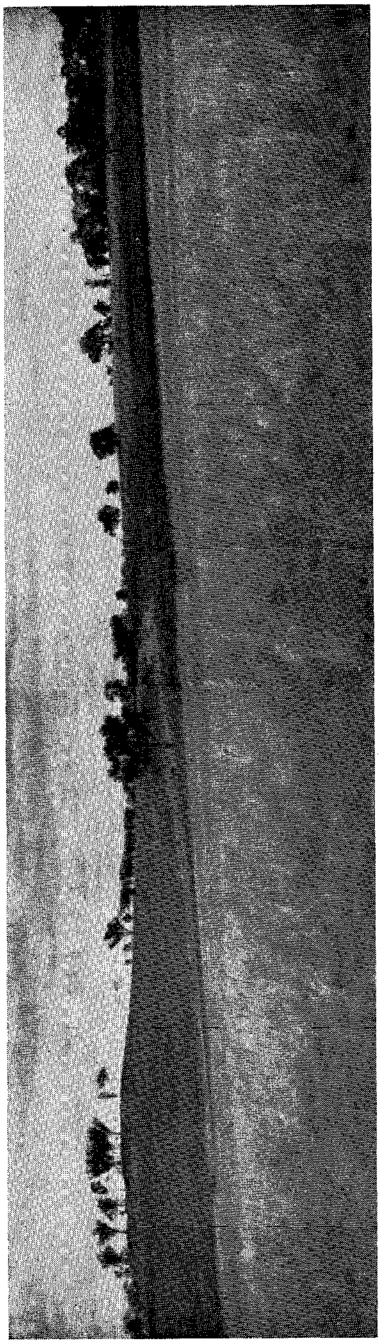

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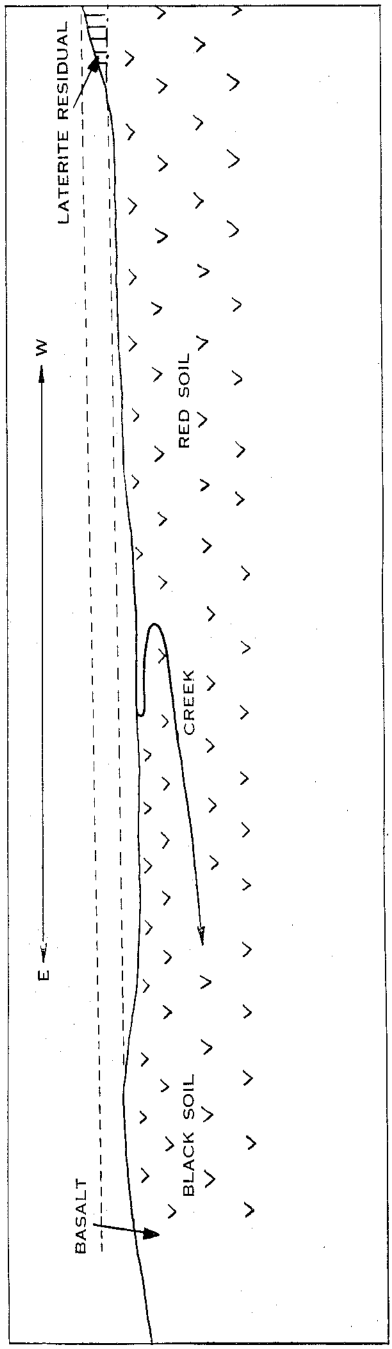
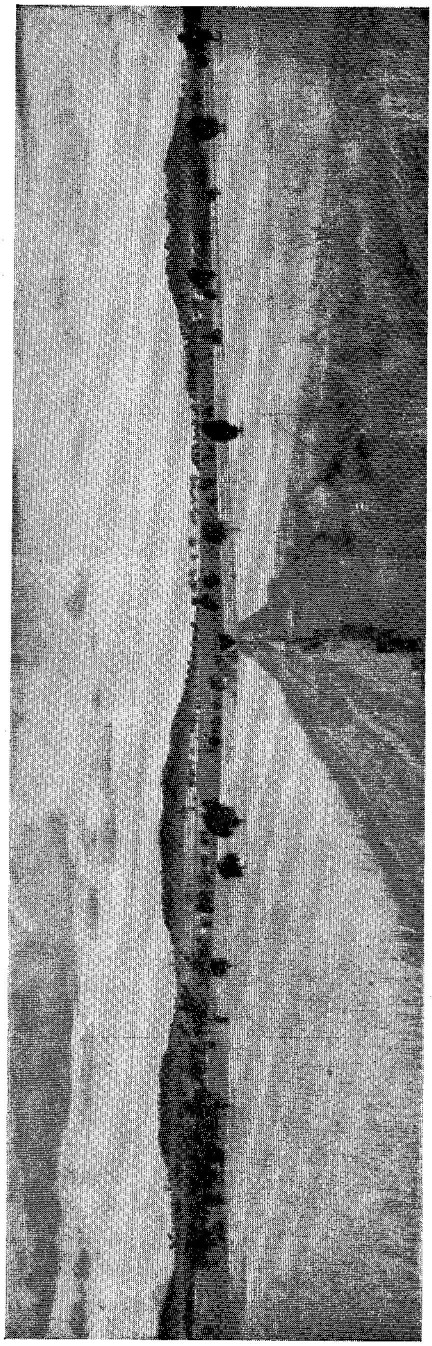


Beaulieu. The western hill is capped with a laterite residual, whilst boulders of basalt outcrop on top of the eastern hill.



(*Photo*: J. D. Colwell)

Euchrozem landscape between Mt. Russell and Oakwood. The flat-topped hills are dissected residuals of Oligocene (?) basalt. The kurrajongs (*Brachychiton populneum*), preserved because of their value as reserve fodder, form a distinctive feature of the vegetation.

VI. Acknowledgments

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Appendix I

Locations where Laterite is exposed beneath Basalt

(*a*) Bukkulla	½ mile E. on the Pindaroi road.
(*b*) Rob-Roy Gully	2 miles N. of Fernhill.
(*c*) Apple-tree Gully	"Parish's" bauxite deposit, 10 miles N. of Inverell on the Yetman road.
(*d*) Wellingrove	6 miles N. of Wellingrove on the Strathbogie road.
(*e*) Swanbrook	Portion 160, Parish of Campbell, County Gough, 10 miles NE. of Inverell.
(*f*) Mt. Russell	On the shoulder of Mt. Russell, 15 miles W. of Inverell.