General Report on the Lands of the Hunter Valley

Comprising papers by R. Story, R. W. Galloway,
R. H. M. van de Graaff, and A. D. Tweedie

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PART I. INTRODUCTION AND SUMMARY DESCRIPTION OF THE HUNTER VALLEY

I. General

(*a*) *Reasons for the Survey*

The survey was made at the request of the Hunter Valley Research Foundation, which has as its main object the conducting and fostering of research into all problems connected with the land and its use. The foundation was initiated by a group of private citizens after the heavy and destructive floods in the Hunter valley in 1955.

(*b*) *Location*

The location of the Hunter valley (lat. 31° 30′ – 33° 15′ S., long. 149° 30′ – 152° E.) is shown on the land system map which accompanies this report. It has a narrow outlet to the sea and is ringed by a loop in the Great Dividing Range, which forms a high and rugged boundary to the north and south but a low one to the west, with gentle slopes. It extends inland for 150 miles, with a width of between 60 and 100 miles. Including the Lake Macquarie catchment, which was surveyed also, the area is a little under 8500 sq. miles.

8200
2500

(*c*) *Records*

References to settlement, population, activities, and natural features in the valley are scattered through a number of publications and reports, including those of the Hunter Valley Research Foundation (Burley 1961*a*, 1961*b*; March 1960*a*, 1960*b*; Renwick 1960), the Soil Conservation Service of New South Wales (undated), Huddleston, Green, and Kaleski (1948), the Premier's Department, New South Wales (1954), the Upper Hunter Regional Development Committee (1954), Gray (1955, 1959), Tweedie (1956), and Fraser and Vickery (1937, 1938, 1939). They have been freely drawn upon in the compilation of this introduction.

(*d*) *Population and Activities*

The Hunter valley was first settled in 1817 and now supports about 350,000 people, of whom nearly 60% live in and around the port of Newcastle. From mines in the valley, Newcastle handles about half the black coal produced in Australia. A great deal is put to use in the city itself in the maintenance of factories for the production of steel (with ore from other parts of Australia), machinery, chemicals, cement and bricks, electricity, textiles, and clothing, and in the processing of building board and food. These various activities combine to put Newcastle among the major industrial cities of Australia. About 20 miles inland from Newcastle is a second densely populated industrial area dependent directly and indirectly upon the Cessnock coal-fields.

Only 7·5% of the total work force is engaged in rural pursuits, but this small proportion is nevertheless extremely important in its influence on vegetation and on run-off, and in feeding the population. Like the industrial population, it is concentrated in the lowlands, the mountainous country to the north and east being very thinly populated and that along the southern watershed virtually uninhabited. Most of the settled land is grazing land, in the west for sheep and in the east for cattle, and what arable land there is is mostly on alluvium and under supplementary fodder crops.

(*e*) *Communications*

The Hunter River is of importance as a waterway only in the lower reaches. The two railways and two highways which carry nearly all the traffic between Sydney and Queensland pass through the Hunter valley and provide for much of the internal traffic as well. In addition there is one major bituminized road out of the valley to the south from Singleton, and branch railway lines serving Merriwa and the Cessnock coal-fields.

II. Natural Features

(*a*) *Climate*

The mean annual rainfall is below 30 in. in about half of the valley and is about 20 in. in the driest parts. In the mountains it rises sharply with altitude, reaching a maximum of 60 in. in the Barrington Tops area 35 miles from the 22-in. isohyet. Winter and summer rainfall are about equal on the average, but erratic enough to cause serious intermittent losses through droughts or floods. Winter snowfalls occur along the watershed and frosts over practically the whole of the valley. In summer, maximum temperatures sometimes exceed 100°F.

(*b*) *Land Forms*

The land forms show a close relationship to the geology. In the south are rugged hills on resistant sandstone (southern mountains, Plate 1, Fig. 1). The central Goulburn valley (Plate 1, Fig. 2) is a complex of plateaux on resistant sandstone and open valleys on weaker shale and sandstone. Rolling to hilly country (Merriwa plateau, Plate 2, Fig. 1) and steep ranges with high summit plateaux (Liverpool Range, Mt. Royal Range, Barrington Tops) occur on basalt in the north. Rugged country occurs on hard lavas, sandstone, and conglomerate in the north-east (north-eastern mountains, Plate 2, Fig. 2). In the centre of the valley is a belt of lower country formed on softer sandstone and shale (central lowlands, Plate 3, Fig. 1). Near the coast are swamps and sand dunes developed on geologically young material (coastal zone).

The Hunter River drains the northern part of the valley and reaches the sea at Newcastle. Its main tributaries are the Wollombi from the south, the Goulburn from the west, and the Paterson and Williams from the north.

(*c*) *Soils*

Soil development is influenced by parent material, and also follows the trend of rainfall; in low-rainfall parts soils with alkaline horizons are common but in higher-rainfall parts the soils are characteristically more strongly leached, and are acid throughout the profile. Large areas with soils which are physically suitable for agriculture or improved pasture are only of low to fair fertility. A very small proportion of the soils is very fertile. Roughly two-fifths of the area has soils which are virtually useless agriculturally because of shallowness combined with infertility, coarse textures, and rugged relief.

(*d*) *Vegetation*

In the relatively inaccessible parts of the region the vegetation is mainly eucalypt woodland except for some rain forest in the high and wet Barrington Tops area. In the more accessible parts the vegetation has been changed greatly by the clearing of the original woodland and the destruction of many of its grasses through uncontrolled grazing (Plate 3, Fig. 2; Plate 4, Fig. 1). This process is now extending into the steeper parts of the valley as well (Plate 4, Fig. 2).

III. Methods Used

(*a*) *Survey Technique*

The technique used in the survey was that of Christian and Stewart (1953), whereby the land is classified, through a study of its natural features, into *land systems*, or areas each with its own characteristic combination of land forms, soils, and vegetation, and consequently its own potential and own reaction under any given set of conditions. Each usually has a characteristic pattern on the aerial photographs, which is a valuable aid in mapping.

It will be apparent that land systems may be related in various ways, and may be grouped together according to the interests of a particular worker.

Units may be similarly defined, but are classified as units rather than land systems when it is not possible to delineate them satisfactorily on the air photographs used as the basic document, or on the final map. The subdivision of land systems into units is largely determined by the scale of working. Some units are characteristically associated with one particular land system and are either scattered throughout its extent or occupy a significant portion of it, e.g. the sand plains in the Duck Hole land system. Other units are simply small outliers of different land systems, e.g. the small areas of undulating country (Bow land system) which occur in the valleys of the hilly basalt Ant Hill land system. Plateaux (Tubrabucca land system) have been split into units according to altitude, which affects the local climate and hence the vegetation and soil.

The detail of the survey was limited by the time available for field work (4 months), by the scale of mapping (4 miles to the inch), and by the space allotted for the text. Only land systems with a minimum width of a quarter of a mile could be mapped, and half a mile was the minimum generally aimed at.

The survey was done as a joint project by a team of workers. They conducted the study by means of traverses, sample areas, and aerial photographs, and from the pooled information thus gained they delimited and mapped the land systems, using their own discretion in deciding how much generalization was necessary. Field work was done throughout the four seasons in periods of about 2 weeks each, with traverses along almost all the public roads and some fire trails, and with sample areas as shown in Figure 1.

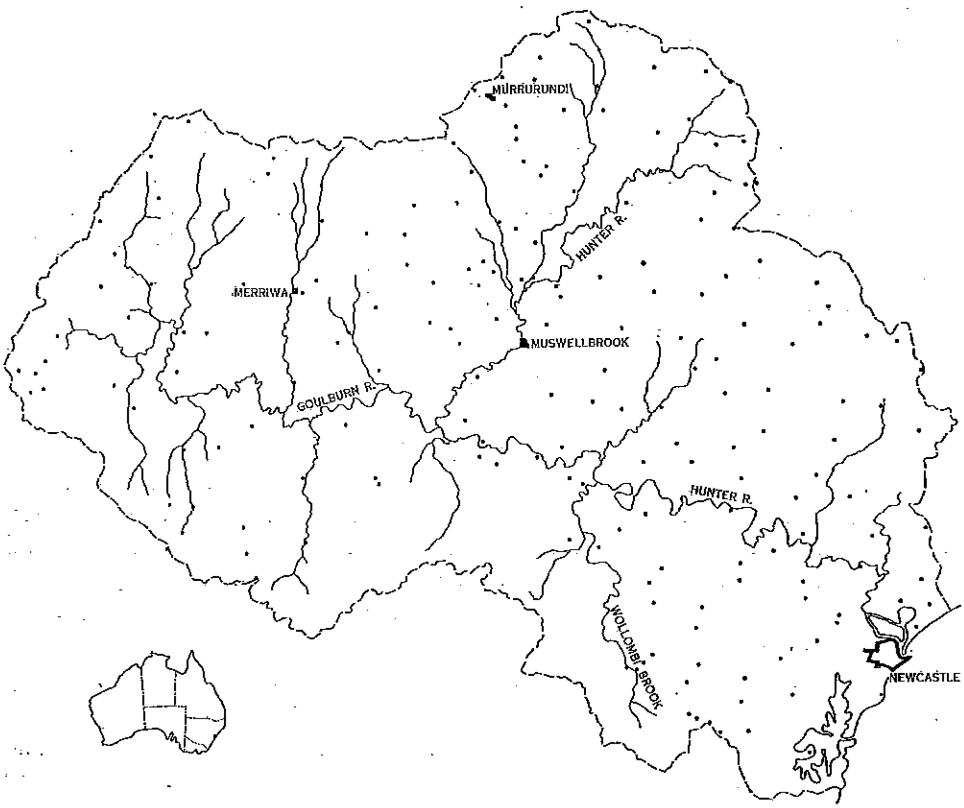

Fig. 1.—Map of Hunter valley showing sample areas.

This report has been written to conform to the standardized pattern of other regional reports produced by the Division of Land Research and Regional Survey, C.S.I.R.O.

(b) *Mapping*

Forty-three land systems have been mapped in the Hunter valley. As their boundaries commonly coincide with lithologic and physiographic boundaries, the land systems have been organized into groups accordingly, and the land system map can serve for maps of lithology and physiography. The distributions of soils and vegetation are shown on separate maps. Ideally the soil and vegetation mapping units should be groups of land systems and this is commonly so. However, the boundary between soil or vegetation units sometimes cannot be established from the air photos used for mapping land systems. An example is the boundary between solonetzic and podzolic soils, which has been established on the soils map approximately from field observation only. Therefore a number of land systems transgress this boundary.

IV. Acknowledgments

The assistance of the following institutions and people is acknowledged with many thanks: The Hunter Valley Research Foundation, for help and coöperation with administrative and scientific work (figures for cleared and wooded areas from Mr. T. Burley); the National Herbarium, Sydney, for the determinations of the botanical collections (Mr. L. A. S. Johnson for help in the field as well, and for pointing out the changes in eucalypt nomenclature which are listed in Part VII); Mr. R. Earp and Dr. Nancy T. Burbidge, for botanical help; officers of the New South Wales Soil Conservation Service, Department of Agriculture, and Forestry Commission; the Director and staff of the New South Wales Department of Mines for providing geological information, including the basis of the geology map, rock and soil analyses, and helpful criticism; the staff of the Geology Department, Newcastle University College; geologists of Broken Hill Pty. Ltd. and the Joint Coal Board; officers of the New South Wales Conservation and Irrigation Commission and the Department of Main Roads; Mr. C. Ivin of Murrurundi for geological information; Mr. R. Brewer, Division of Soils, C.S.I.R.O., for accompanying the soil scientist in the field to assist in identifying the soils and for additional chemical information; Dr. Odd Gjems, Norwegian Forestry Research Institute, for carrying out a number of X-ray analyses of clay minerals; the Meehan family and the Barrington Club for hospitality.

The Division of National Mapping, Department of National Development, compiled the base map of the area. The preparation of all the maps, diagrams, illustrations, and the manuscript was done by staff of the Division.

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PART II. LAND SYSTEMS OF THE HUNTER VALLEY

By R. STORY,* R. W. GALLOWAY,* and R. H. M. VAN DE GRAAFF*

The characteristics of the major parts of the 43 land systems (Christian and Stewart 1953†) are set out in Table 1 according to lithologic and topographic affinities. In the text which follows, the land systems are arranged in alphabetical order, each described in tabular form and illustrated with a diagram. The section above the block diagram lists the characters which apply to the land system as a whole, the section below the block diagram deals with the characters peculiar to each unit.

The areas of the land systems were determined with a dot grid (25 dots per sq. in.) on maps at a scale of 1 in. to 1 mile or (where maps were not available) on semi-controlled mosaics at approximately the same scale. The proportions of the land system occupied by the various units were subjectively estimated by the team from air photos and field experience.

More detailed information about geology, soils, and vegetation of the land systems can be obtained by referring to Parts IV, VI, and VII. The locality references are to the eight major types of country described in Part V. The geological ages, soil names, and vegetation communities are listed in the index.

*Division of Land Research and Regional Survey, C.S.I.R.O., Canberra, A.C.T.

†CHRISTIAN, C. S., and STEWART, G. A. (1953).—General report on survey of Katherine–Darwin region, 1946. C.S.I.R.O. Aust. Land Res. Ser. No. 1.

TABLE 1

CHARACTERISTICS OF THE MAJOR PARTS OF THE LAND SYSTEMS

(Land systems arranged according to lithologic and topographic affinities)

Land System	Geology	Topography	Rainfall (in.)	Soils	Vegetation
Rouse	Palaeozoic granite	Hilly	24	Skeletal soils and bare rock	Savannah woodland of box, gum, and ironbark, some thinned or cleared
Ulan	Palaeozoic granite	Undulating	24	Pale brown sandy and gritty earths, some outcrop	Savannah woodland of box, gum, and ironbark, mostly cleared
Alston	Devonian limestone	Rugged	28	Much outcrop with shallow cracking clays in pockets	Anomalous woodland of large-flowered bundy and grass-tree
Mt. Butterwicki	Carboniferous sediments and some lavas	Rugged	30–40	Mostly shallow brown podzolic soils, brown earths, and skeletal soils	Tall mixed woodland, mainly gums and stringybarks, or wet sclerophyll forest, mostly thinned or cleared
Benmore	Devonian and Carboniferous sediments	Rugged	26–30	Shallow brown earths, podzolic, solonetzic, and skeletal soils	Savannah woodland of box and gum, mostly thinned or cleared
Wallaroo	Carboniferous mudstone, tuff, and chert	Hilly	30–40	Mostly brown podzolic soils and some earths and skeletal soils	Tall mixed woodland, mostly thinned or cleared
Upper Rouchel	Devonian and Carboniferous tuffs, chert, mudstone, and minor lavas	Hilly	24–30	Brown solonetzic soils, skeletal soils, some podzolic soils and earths	Savannah woodland of box and gum, mostly thinned or cleared
Vacy	Carboniferous mudstone and chert, tuff	Undulating	28–40	Mostly deep brown podzolic soils	Tall mixed woodland, some thinned or cleared

Timor	Carboniferous sediments	Undulating	24	Mostly brown solonetzic soils, some degraded black earths	Savannah woodland of box and gum, mostly thinned or cleared
Rainforest	Carboniferous sediments capped by Tertiary basalt	Rugged	40–60	Mostly stony krasnozems, associated clayey humic skeletal soils, and some podzolic soils	Rain forest
Mt. Royal	Carboniferous sediments capped by Tertiary basalt	Rugged	40–50	Krasnozems, brown earths, and podzolic soils	Wet sclerophyll forest
Cranky Corner	Carboniferous lavas with some conglomerates and glacial beds	Rugged	30–40	Skeletal soils and rock outcrop with some shallow cracking clays, solonetzic soils, and podzolic soils	Tall mixed woodland, mainly gum, stringybark, and ironbark, some thinned or cleared
Colonel	Carboniferous and lower Permian lavas with some conglomerate and glacial beds	Rugged	26	Skeletal soils with some earths and solonetzic soils	Savannah woodland of box and gum, with ironbark in the south, some thinned or cleared
Barigan	Tertiary basic intrusives	Hilly to rugged	26	Bare rock, loamy skeletal soils, and shallow stony red earths	Anomalous woodland of white box over dense shrubs
Moonibung	Carboniferous lavas, tuffs, conglomerate, and glacial beds	Hilly	28–32	Shallow podzolic soils, skeletal soils, and some shallow cracking clays	Tall mixed woodland, mainly gum and ironbark, mostly thinned or cleared
Apis	Carboniferous, Permian, and Tertiary lavas and intrusives	Hilly	26	Clayey skeletal soils and often stony shallow cracking clays	Savannah woodland of box and gum, with ironbark in the south, mostly thinned or cleared
Parkville	Carboniferous and lower Permian lavas and glacials, Tertiary basic igneous intrusives	Undulating	26	Cracking clays with solonetzic soils and degraded black earths	Savannah woodland of box, gum, and ironbark, mostly cleared

TABLE 1 (*Continued*)

Land System	Geology	Topography	Rainfall (in.)	Soils	Vegetation
Ogilvie	Permian conglomerates, sandstone, and shale	Rugged	22–32	Skeletal soils, some shallow earths, solonetzic soils, and degraded black earths	Savannah woodland, denser than usual, of box, gum, and ironbark in the west; wet or dry sclerophyll forest in the east
Redhead	Permian sandstone	Hilly	40	Podzolic soils and coastal sands, bare rock on cliffs	Heath or dry sclerophyll forest
Elrington	Permian and Lower Triassic shale, sandstone, and conglomerate	Hilly	32–40	Podzolic soils with some skeletal soils and earths	Dry sclerophyll forest
Glendower	Permian shale, sandstone, and conglomerate	Hilly	22–30	Solonetzic and podzolic soils, earths, skeletal soils, some cracking clays and degraded black earths	Savannah woodland of box, gum, and ironbark, mostly thinned or cleared
Beresfield	Permian and Lower Triassic shale, sandstone, and conglomerate	Undulating	32–40	Podzolic soils	Dry sclerophyll forest, 50% cleared
Killarney	Permian shale, sandstone, and conglomerate	Undulating	22–30	Mostly podzolic and solonetzic soils, small patches of shallow earths, skeletal soils, cracking clays, and degraded black earths	Savannah woodland of box, gum, and ironbark, mostly thinned or cleared
Bray's Hill	Permian calcareous sandstone and shale	Hilly	22	Cracking clays with associated degraded black earths and solonetzic soils	Eucalypt tree savannah, mostly cleared, with plains grass

Blairgowrie	Mainly Permian calcareous sandstone and shale, also on Carboniferous lavas and glacials and Tertiary basic intrusives	Undulating	22–24	Cracking clays with associated degraded black earths, solonetzic soils, and some podzolic soils	Eucalypt tree savannah, mostly thinned or cleared, with plains grass
Watagan	Triassic sandstone and minor shale	Rugged	36–40	Predominantly sandy, humic, skeletal soils and shallow sandy earths, and some podzolic soils	Wet sclerophyll forest
Three Ways	Triassic sandstone with subordinate shale beds	Rugged	24–36	Sandy skeletal soils, sometimes humic, some earths	Dry sclerophyll forest
Lee's Pinch	Triassic sandstone and minor shale	Rugged	22–30	Bare rock and sandy, gritty, or gravelly skeletal soils, minor areas with podzolic soils and earths	Shrub woodland of ironbark and gum
Munghorn Gap	Triassic sandstone	Plateau	26–30	Fairly deep sandy earths and some skeletal soils	Dry sclerophyll forest or shrub woodland of ironbark and gum
Greenhills	Triassic and Jurassic sandstone and shale	Undulating	22	Shallow brown or yellow earths, skeletal soils, and some solonetzic soils	Savannah woodland of box, gum, and ironbark, mostly cleared
Roscommon	Jurassic shale, sandstone, and Tertiary basalt	Undulating	22	Deep krasnozems and shallow stony krasnozems	Eucalypt tree savannah, mostly cleared
Liverpool	Tertiary basalt	Rugged	30–40	Clayey humic skeletal soils, shallow cracking clays, and small areas with alpine humus soils	Savannah woodland of box and gum, some thinned or cleared
Ant Hill	Tertiary basalt	Hilly	22–30	Dark, rather shallow, stony cracking clays	Savannah woodland of box and gum, mostly thinned or cleared
Bow	Tertiary basalt	Undulating	22	Deep black and dark cracking clays, sometimes stony	Eucalypt tree savannah, mostly thinned or cleared, with plains grass

TABLE 1 (*Continued*)

Land System	Geology	Topography	Rainfall (in.)	Soils	Vegetation
Tubrabucca	Tertiary basalt	Plateau	30–60	Leached krasnozems and transitional alpine humus soils with or without basalt floaters, minor areas with alpine humus soils, skeletal soils, and sphagnum peats	Eucalypt subalpine woodland or wet sclerophyll forest
Avicennia	Estuarine alluvium	Flat	40	Waterlogged, saline, brown, heavy, clayey regosols	Scrub (mangroves) and open mud flats
Nesta	Estuarine alluvium	Flat	38–40	Permanently wet or moist peaty meadow soils	Fen (swamp) vegetation, mostly cleared
Hexham	Recent alluvium	Flat	40	Acid swamp soils and meadow soils and some clayey regosols	Fen (swamp) vegetation, mostly cleared
Hunter	Quaternary alluvium	Flat	24–40	Wide range of soils, cracking clays, chernozemic, solonetzic, podzolic soils, and regosols	Cleared and under cultivation or pioneer grasses
Yarramoor	Quaternary basaltic alluvium	Flat	22	Dark and black cracking clays and some alluvial regosols	Eucalypt tree savannah, mostly thinned or cleared
Sandy Hollow	Quaternary colluvium	Undulating	22–26	Mostly brown earths and solonetzic soils	Savannah woodland of box, gum, and ironbark, mostly cleared
Duck Hole	Aeolian sand	Undulating to hilly	38–40	Sandy aeolian regosols and humus–iron podzols, small areas with peaty meadow and acid swamp soils	Dry sclerophyll forest
Warkworth	Quaternary aeolian sand	Undulating	24–28	Brown, single-grained, sandy aeolian regosols	Anomalous woodland, mostly cleared, or heath

ALSTON LAND SYSTEM (4 SQ. MILES)

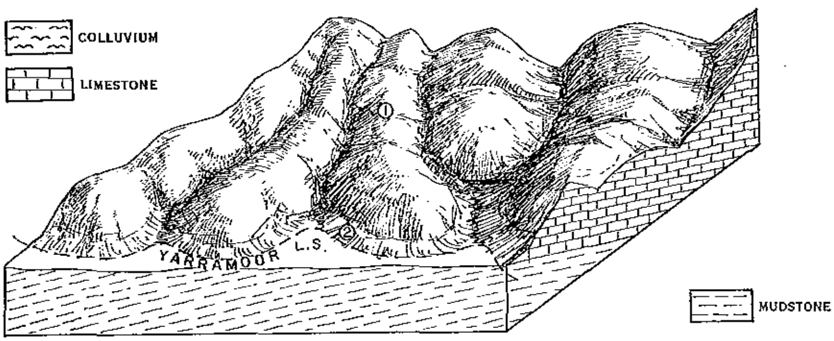
Geology.—Devonian limestone.

Rainfall.—28 in.

Locality.—North-eastern mountains.

Elevation.—2400–2800 ft. **Local Relief.**—200–400 ft.

Wooded Area.—40%.



Unit	Area (%)	Land Forms	Soils	Vegetation
1	80	Very rocky hills with slopes up to 50%	Shallow, much outcrop; dark reddish brown cracking clay (Krui), in isolated karstic pockets; neutral grading into mildly alkaline; phosphate rich	Anomalous savannah woodland, *E. nortonii* dominant, with *Angophora floribunda* and *Brachychiton populneum*; *Xanthorrhoea* sp. abundant on outcrops; fair grass cover of *Aristida* sp. and *Themeda australis*
2	20	Belt of stony colluvium up to 200 yd wide fringing the rocky hills of unit 1; slopes 5–10%	Dark reddish brown, slightly acid krasnozem (Torrielodge); solum free of stones	Savannah woodland of box and gum (*E. albens*, *E. blakelyi*, and *E. melliodora*), with fair grass cover of *Aristida* and *Dichanthium* spp.

Ant Hill Land System (567 sq. miles)

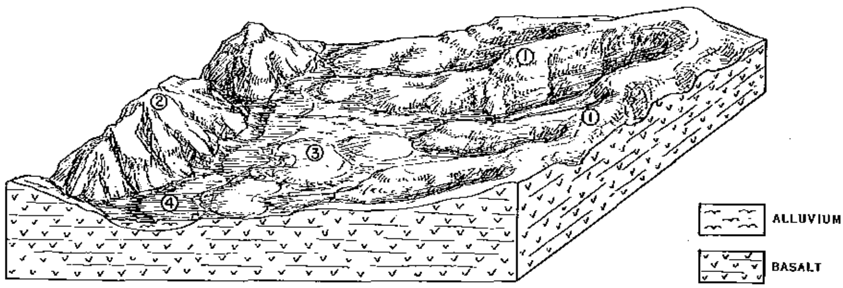
Geology.—Tertiary basalt.

Rainfall.—22–30 in.

Locality.—Merriwa plateau.

Elevation.—1200–2500 ft. **Local Relief.**—Up to 500 ft.

Wooded Area.—10%.



Unit	Area (%)	Land Forms	Soils	Vegetation
1	80	Basalt hills and lower mountain slopes; wide range of slopes (5–35%), frequent rocky bluffs 5–50 ft high and subhorizontal benches 10–100 yd wide; alluvial or colluvial fill up to 100 yd wide in valley bottoms, frequently gullied	Mainly shallow but also commonly deep, dark, cracking clays (Guan and Segenhoe), often stony; fine-textured non-humic skeletal soils; rare patches with "anomalous" krasnozems or reddish cracking clays	Savannah woodland of box and gum, mostly thinned or cleared, trees 30 ft, *E. albens*, *E. blakelyi*, *E. melliodora*, and *Angophora floribunda*; shrubs rare; fair ground cover of *Dichanthium*, *Medicago*, and *Trifolium* spp., and *Stipa setacea*, with lesser amounts of *Aristida* spp., *Danthonia linkii*, *Panicum queenslandicum*, and *Themeda australis*
2	5	Rugged hills and mountains (similar to Liverpool land system, unit 1)	As for unit 1, but much shallower and more stony, usually no marked accumulation of organic matter in topsoil	Savannah woodland of box and gum, some thinned or cleared, mainly *Angophora floribunda*, *E. albens*, *E. laevopinea*, *E. melliodora*, and *E. tereticornis*; shrubs rare; ground cover mainly a short grass turf with *Trifolium* and *Medicago* spp. (similar to the drier parts, below 30 in., of Liverpool land system)
3	10	Undulating valley floors; slopes 7–15%; few outcrops (similar to Bow land system, unit 1)	Deep black and dark cracking clays (Segenhoe) (similar to Bow land system, unit 1)	Eucalypt tree savannah (similar to Bow land system, unit 1)
4	<5	Terraced alluvium in valley floors; less than ¼ mile wide and 10 ft above stream bed; dominantly gravel in headwater areas, silt and clay, gravel elsewhere; whole surface liable to frequent flooding in headwater areas, elsewhere only lower terraces affected	Dark cracking clays (Segenhoe) (similar to Yarramoor land system, unit 1); in headwater areas often gravelly prairie soils	Cleared and under various grasses, clovers, medics, and weeds; or under crops; or eucalypt tree savannah (similar to Yarramoor land system, unit 1)

APIS LAND SYSTEM (86 SQ. MILES)

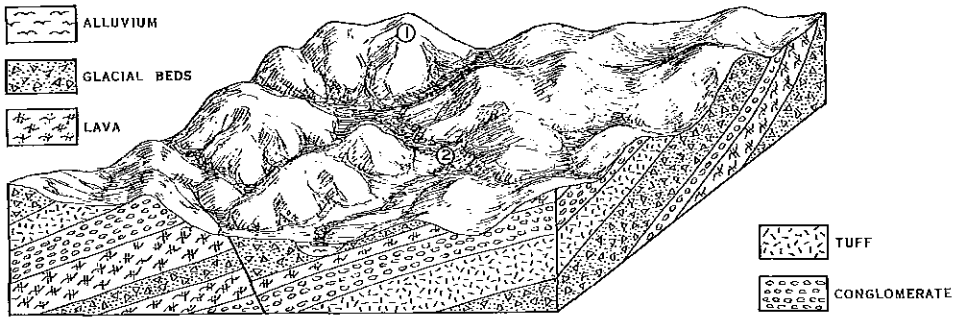
Geology.—Carboniferous, Permian, and Tertiary lavas and intrusives.

Rainfall.—26 in.

Locality.—Western and southern fringe of north-eastern mountains.

Elevation.—200–2800 ft. **Local Relief.**—Up to 500 ft.

Wooded Area.—20%.



Unit	Area (%)	Land Forms	Soils	Vegetation
1	95	Rocky hills up to 300 ft high; slopes generally 10–30%, locally steepening to cliffs up to 50 ft high; undulating low hills, broken by rocky strike ridges up to 50 ft high; broad stony ridge tops; liable to gullying and sheet wash where soil is present	Fine-textured non-humic skeletal soils; stony, mostly shallow dark cracking clays (Guan), but sometimes reddish brown (Krui) and deep (Springfield), linear gilgai common on gentle slopes; small areas with coarse-textured non-humic skeletal soils; some colluvial slopes with red podzolic soils (Pokolbin or Rosscole)	Savannah woodland of box and gum with ironbark in the south, mostly thinned or cleared, 40–50 ft high, commonly *E. moluccana* and *E. crebra;* in rocky places shrubs of many species; usually a good ground cover of *Dichanthium*, *Medicago*, and *Trifolium* spp.; *Aristida* spp. and *Stipa setacea* common with uncontrolled grazing
2	<5	Terraced clayey alluvium up to ¼ mile wide; liable to flooding on lower levels	Restricted observations; presumably cracking clays	Cleared, and under cultivation or pioneer grasses

AVICENNIA LAND SYSTEM (6 SQ. MILES)

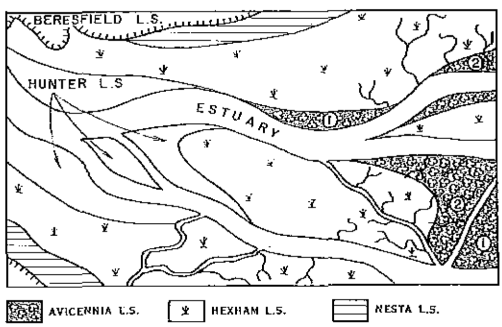
Geology.—Estuarine alluvium.

Rainfall.—40 in.

Locality.—Coastal zone.

Elevation.—0–10 ft. **Local Relief.**—5 ft.

Wooded Area.—50 %.



Unit	Area (%)	Land Forms	Soils	Vegetation
1	50	Tidal mud flats inundated at every high tide	Very dark grey-brown, strongly mottled, clayey alluvial regosols (Fullerton); numerous shell fragments, saline	Dense scrub of *Avicennia marina* 12 ft high
2	50	Tidal mud flats inundated only at high spring tides and crossed by winding tidal creeks	No records; presumably similar but not as saline, and possibly even with acid, peaty topsoils	Scrub of *Avicennia marina* patchy or fringing tidal creeks, elsewhere *Arthrocnemum* dominant, with *Sporobolus virginicus*, *Paspalum vaginatum*, and sedges

BARIGAN LAND SYSTEM (11 SQ. MILES)

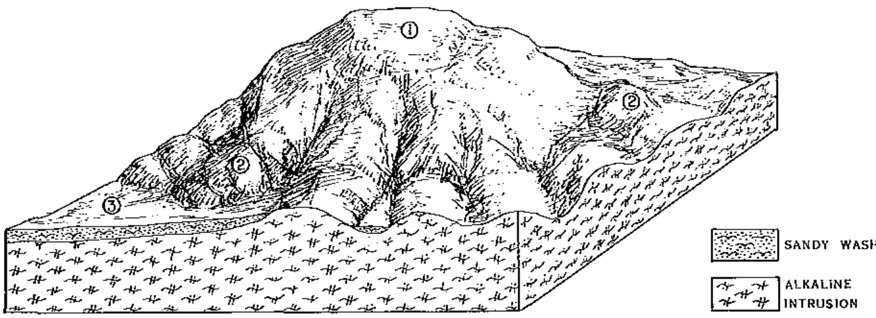
Geology.—Tertiary basic intrusives.

Rainfall.—26 in.

Locality.—Central Goulburn valley and western end of the southern mountains.

Elevation.—800–2800 ft. **Local Relief.**—Up to 1000 ft.

Wooded Area.—40%.



Unit	Area (%)	Land Forms	Soils	Vegetation
1	45	Extremely steep dome-shaped hills up to 1000 ft high with slopes up to 90% and much bare rock	Footslopes mantled by dark medium-textured skeletal soils with abundant angular rock fragments up to 10 in. in dia.; sometimes humic surface soils; steep upper slopes mainly bare rock	Bare rock, or anomalous woodland of *E. albens* with scattered *Brachychiton populneum*, *E. goniocalyx*, and *E. laevopinea*; dense 5 ft shrub layer of *Cassinia* spp.; grass cover of *Themeda australis* and *Aristida* spp.
2	45	Rocky hills with slopes 10–30% and stony rubble up to 5 ft thick in valleys	Much rubble; reddish moderately coarse-textured non-humic skeletal soils locally merging into shallow stony moderately coarse red earths (Cox's Gap)	As for unit 1, but with *Angophora floribunda* and *E. blakelyi*, and less *E. albens*
3	10	Sandy wash on gentle lower slopes below unit 2	Moderately coarse-textured red earths (Cox's Gap); probably shallow to moderately deep	Wiry pioneer grasses, or under cultivation

BENMORE LAND SYSTEM (323 SQ. MILES)

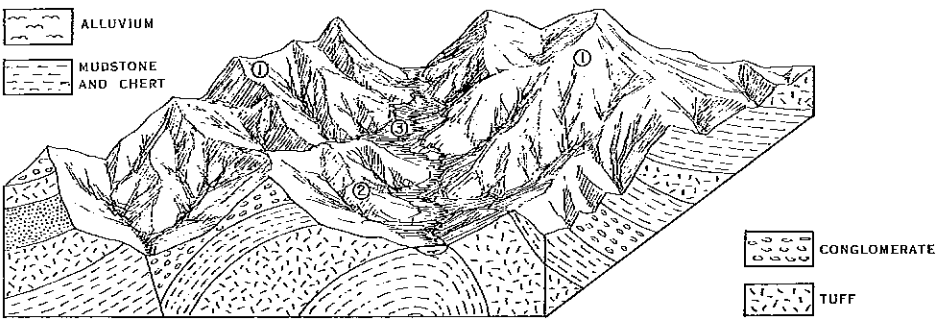
Geology.—Devonian and Carboniferous sediments.

Rainfall.—26–30 in.

Locality.—Northern part of north-eastern mountains.

Elevation.—700–2700 ft. **Local Relief.**—Up to 1500 ft.

Wooded Area.—30%.



Unit	Area (%)	Land Forms	Soils	Vegetation
1	85	Steep ridges usually with narrow crests; slopes exceeding 25%, dissected by closely-spaced ravines; local relief 300–1500 ft; outcrops, slumping, and gullying widespread	Shallow brown earths (Woolooma), locally stony; also brown podzolic soils (Binnie) and brown or red solonetzic soils (Clanricard or Overton); shallow, moderately coarse- to moderately fine-textured, non-humic skeletal soils	Savannah woodland of box and gum 30 ft high, mostly thinned or cleared, *E. albens* and *E. laevopinea* common at low and high altitudes respectively, with *E. melliodora* and *E. tereticornis* throughout; shrubs rare; grasses *Dichanthium* spp., giving good cover, less commonly *Aristida* spp., giving poor cover; *Medicago* and *Trifolium* spp. throughout
2	10	Undulating to moderately steep lower slopes with local relief less than 300 ft and only occasional outcrops (similar to Upper Rouchel land system, unit 1)	Mainly solonetzic soils (Clanricard and others) and earths (similar to Upper Rouchel land system, unit 1)	As for the lower slopes of unit 1
3	<5	Terraced sandy alluvium in valley bottoms less than ½ mile wide; lower terraces liable to flooding	One record of a chernozem (Abermusden) buried under 5 in. of sandy alluvial regosol (Rouchel)	Cleared and under pioneer grasses

BERESFIELD LAND SYSTEM (159 SQ. MILES)

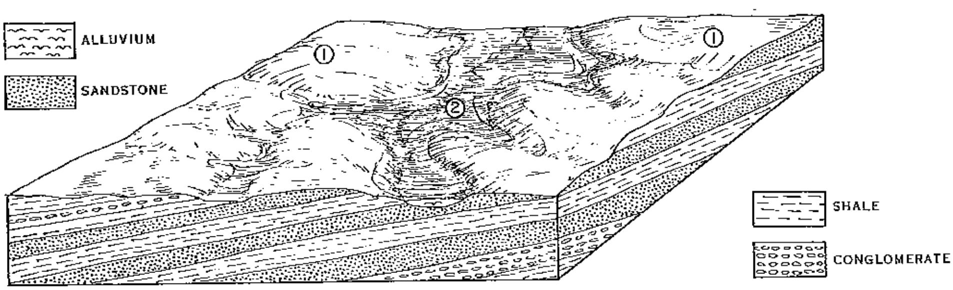
Geology.—Permian and lower Triassic shale, sandstone, and conglomerate.

Rainfall.—32–40 in.

Locality.—Seaward end of the central lowlands.

Elevation.—0–400 ft. **Local Relief.**—Less than 100 ft.

Wooded Area.—50%.



Unit	Area (%)	Land Forms	Soils	Vegetation
1	95	Undulating lowlands; slopes generally less than 10%, steepening locally to 25% at heads of widely-spaced shallow valleys; stony clay colluvial fill in hollows	Predominantly podzolic soils (mainly Binnie, also Vaux, Buttai, Singleton), often with medium to strongly acid subsoils	Dry sclerophyll forest of gums, ironbarks, and stringybarks, and including *Angophora costata*, *E. gummifera*, and *E. pilularis*; shrubs usually dense, Leguminosae common; usually good ground cover of *Imperata cylindrica*, *Themeda australis*, and non-grasses, where cleared *Paspalum dilatatum* dominant, with *Senecio lautus* and *Sporobolus* spp.
5	5	Terraced alluvium in valley floors; sand, silt, and clay; up to ¼ mile wide; subject to flooding on lower levels	Restricted observations; soils variable; podzolic soils, earths, meadow soils, and alluvial regosols	Cleared and under *Paspalum dilatatum*, *Senecio lautus*, and *Sporobolus* spp.

Blairgowrie Land System (71 sq. miles)

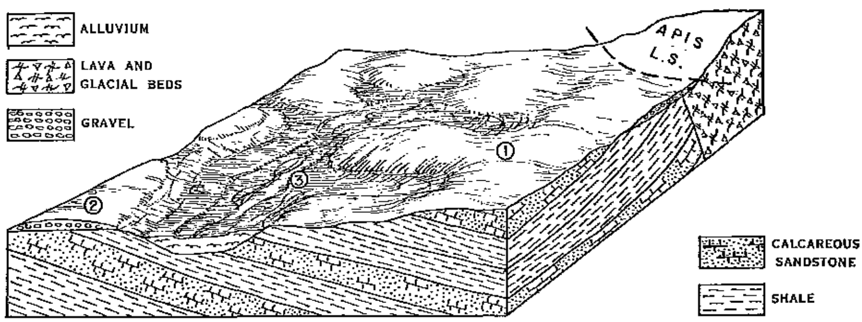
Geology.—Mainly Permian calcareous sandstone and shale, also Carboniferous lavas and glacials and Tertiary basic intrusives.

Rainfall.—22–24 in.

Locality.—Inland parts of central lowlands.

Elevation.—500–1000 ft. **Local Relief.**—100 ft.

Wooded Area.—10%.



Unit	Area (%)	Land Forms	Soils	Vegetation
1	85	Smooth, gently undulating lowlands with no outcrop; patches of gravelly surface wash on upper parts, derived from adjacent basic igneous hills; shallow minor valleys at ½–1 mile intervals with extensive alluvial or colluvial fill, partially dissected by gullies	Complex soil pattern; predominantly cracking clays (mainly Segenhoe, also Springfield), linear gilgai common; degraded black earths (Rowan, also Ellis) and solonetzic soils (Cropwell, Clanricard, Piercefield, Overton) co-dominant	Eucalypt tree savannah of *E. albens*, *E. melliodora*, and *E. blakelyi* about 30 ft high, mostly thinned or cleared; shrubs virtually absent; ground cover nearly all *Stipa aristiglumis* with less *Dichanthium* spp. and *Stipa setacea*, *Carthamus lanatus* and *Danthonia linkii* often abundant with uncontrolled grazing (similar to Bow land system, unit 1)
2	10	Old gravel terrace remnants 50–200 ft above the Hunter River	Red podzolic soils (Rosscole), solonetzic soils (Cropwell, Clanricard), and cracking clays (Segenhoe); soils often very gravelly	Cleared and under *Dichanthium* spp. or *Stipa setacea*, with *Aristida* and *Chloris* spp. and *Danthonia linkii*, shrubs rare; patches of savannah woodland of box, gum, and ironbark, 40 ft, with *Casuarina luehmannii*, *E. albens*, *E. melliodora*, and *E. tereticornis*
3	5	Sandy alluvium in major valleys, occasionally flooded	Restricted observations; cracking clays (Segenhoe), solonetzic soils (Clanricard, Piercefield), and chernozems (Abermusden)	Cleared and under cultivation or pioneer grasses

Bow Land System (294 sq. miles)

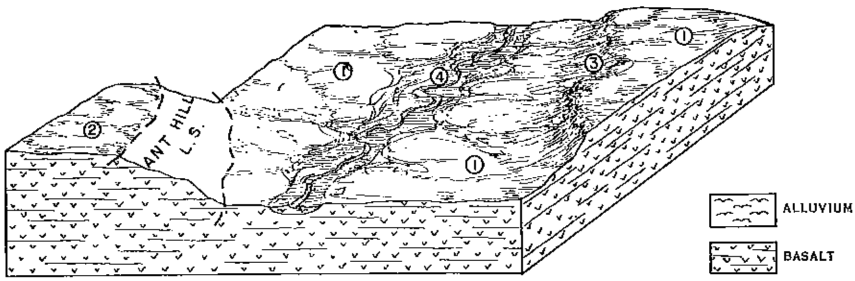
Geology.—Tertiary basalt.

Rainfall.—22 in.

Locality.—Merriwa plateau.

Elevation.—800–2000 ft. **Local Relief.**—Less than 100 ft.

Wooded Area.—10%.



Unit	Area (%)	Land Forms	Soils	Vegetation
1	80	Gently undulating lowlands and broad valley-side benches; slopes generally 3–10%; small valleys 10–40 ft deep at ¼–½ mile intervals with colluvial and/or alluvial fill now being eroded by gullies; occasional low outcrops	Uniformly mantled with cracking clays (Segenhoe); sometimes stony, linear gilgai common; occasional small patches of red soils, krasnozems (Torrielodge) or cracking clays (Krui, probably Springfield)	Eucalypt tree savannah of *E. albens*, *E. blakelyi*, and *E. melliodora*, about 30 ft high, mostly thinned or cleared; shrubs virtually absent; ground cover nearly all *Stipa aristiglumis* with smaller amounts of *Dichanthium* spp. and *Stipa setacea*; *Carthamus lanatus* and *Danthonia linkii* often abundant with uncontrolled grazing
2	10	Plateaux of moderate altitude (less than 2500 ft) with undulating surface and widely-spaced, shallow, dry valleys; slopes less than 10%; few outcrops except towards steeper plateau margins	Cracking clays (Segenhoe), sometimes non-self-mulching, and degraded black earths (Rowan)	As for unit 1, but ground cover very variable, *Stipa aristiglumis* absent or rare, no *Carthamus lanatus* with uncontrolled grazing, many non-grasses, dominant grass *Danthonia linkii*, *Stipa setacea*, *Panicum queenslandicum*, *Dichanthium* spp., or *Cynodon incompletus*
3	5	Occasional small steep rocky areas (similar to Ant Hill land system, unit 1)	Mainly the shallower, less mature, stony cracking clays (Guan) (similar to Ant Hill land system, unit 1)	Scattered and patchy savannah woodland of box and gum with fair grassy ground cover (similar to Ant Hill land system, unit 1)
4	5	Terraced alluvial and colluvial fill in major valleys; less than ¼ mile wide; sand, silt, or clay overlying gravel; lower terraces subject to flooding (similar to Yarramoor land system, unit 1)	Deep black or dark cracking clays (Segenhoe), free of stones (similar to Yarramoor land system, unit 1)	Cleared and under cultivation or pioneer grasses (similar to Yarramoor land system, unit 1

Bray's Hill Land System (23 sq. miles)

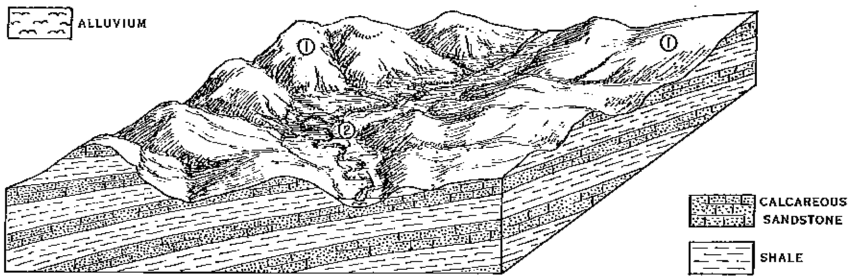
Geology.—Permian calcareous sandstone and shale.

Rainfall.—22 in.

Locality.—Inland part of central lowlands.

Elevation.—500–1300 ft. **Local Relief.**—50–300 ft.

Wooded Area.—10%.



Unit	Area (%)	Land Forms	Soils	Vegetation
1	95	Rounded hills and lower escarpment slopes; slopes generally 10–25%; occasional sandstone bluffs up to 10 ft high on upper slopes; smooth lower slopes with linear gilgai, sometimes gullied; shallow minor valleys with sand, silt, and clay colluvial and/or alluvial fill	Dark or reddish cracking clays (Segenhoe or Springfield), sometimes shallow, linear gilgai fairly common; associated dark or reddish degraded black earths (Rowan or Ellis) and brown or red solonetzic soils (Clanricard or Overton)	Eucalypt tree savannah largely cleared (mainly *E. albens* and *E. melliodora*) with *Brachychiton populneum*; grasses *Stipa aristiglumis*, *S. setacea*, *Aristida*, *Chloris*, *Danthonia*, *Dichanthium*, *Eragrostis*, and *Urochloa* spp.
2	5	Terraced sandy or gravelly alluvium in major valleys crossing the land system	Restricted observations; cracking clays and solonetzic soils	Cleared and under cultivation or pioneer grasses

Colonel Land System (81 sq. miles)

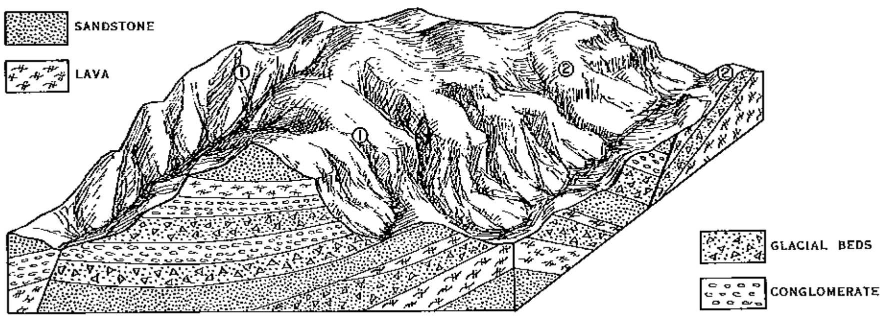
Geology.—Carboniferous and lower Permian lavas with some conglomerate and glacial beds.

Rainfall.—26 in.

Locality.—Western margin of the north-eastern mountains.

Elevation.—1000–3000 ft. **Local Relief.**—Up to 1500 ft.

Wooded Area.—80%.



Unit	Area (%)	Land Forms	Soils	Vegetation
1	80	Steep, massive mountains, hills, and escarpments > 300 ft high; cliffs up to 100 ft high frequent; occasional gently sloping benches with pockets of colluvium; locally subject to intense gullying where cleared of forest	Fine- to coarse-textured skeletal soils, with patches of earths and solonetzic soils; cooler, more humid sites often with humic surface soils; rock outcrop; rarely without soil cover (at Mt. Wallabedah)	Savannah woodland of box and gum, 60 ft, *E. albens* often dominant with lesser amounts of *Angophora floribunda*, *E. laevopinea*, *E. melliodora*, and *E. tereticornis*, and with ironbark in the south; a large variety of fairly dense shrubs where rocky; fair ground cover dominated by *Aristida* or *Dichanthium* spp. with a little *Themeda australis*, *Stipa setacea*, and *Chloris* spp.
2	20	More gently sloping hill tops and valley floors (similar to Apis land system, unit 1)	No records; presumably similar to Apis land system, unit 1	Savannah woodland of box and gum, with ironbark in the south (similar to Apis land system, unit 1)

Cranky Corner Land System (91 sq. miles)

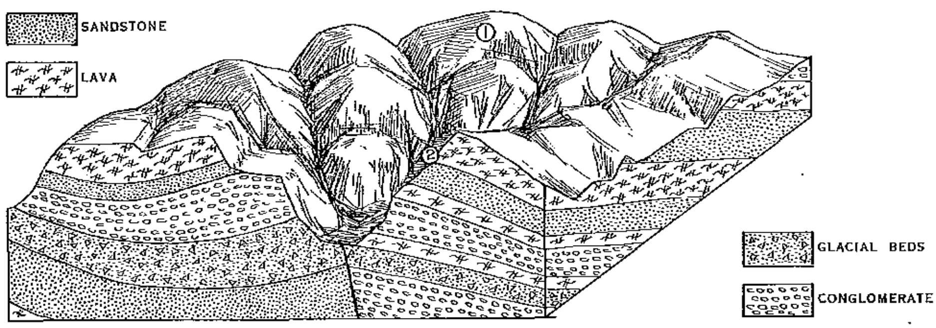
Geology.—Carboniferous lavas with some conglomerate and glacial beds.

Rainfall.—30–40 in.

Locality.—Southern margins of north-eastern mountains.

Elevation.—400–2000 ft. **Local Relief.**—300–1000 ft.

Wooded Area.—80%.



Unit	Area (%)	Land Forms	Soils	Vegetation
1	80	Extremely steep massive mountains, hills, and escarpments with rubbly slopes and cliffs, up to 200 ft high	Coarse- to fine-textured skeletal soils, with patches of shallow cracking clays (Guan) or solonetzic or podzolic soils (Pokolbin); cooler, more humid sites with humic surface soils; much rock outcrop	Tall mixed woodland, some thinned or cleared, usually 50 ft but up to 100 ft high, commonly *E. acmenioides*, *E. canaliculata*, *E. eugenioides*, *E. maculata*, *E. tereticornis*, and ironbarks, with medium dense shrubs below and rather sparse but leafy grasses
2	20	Deep ravines	Predominantly skeletal soils, often humic in the surface	Rain forest (similar to Rainforest land system, unit 1, but poorer in species and not as tall)

Duck Hole Land System (47 sq. miles)

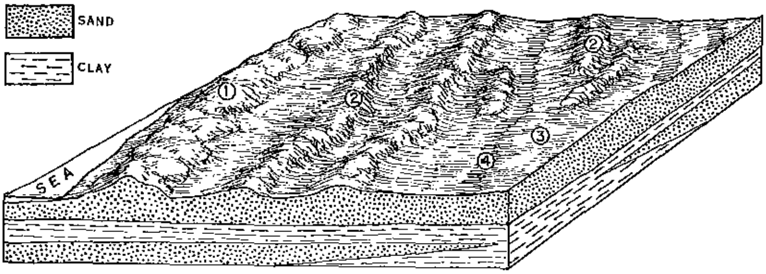
Geology.—Aeolian sand.

Rainfall.—38–40 in.

Locality.—Coastal zone.

Elevation.—0–150 ft. **Local Relief.**—10–100 ft.

Wooded Area.—90%.



Unit	Area (%)	Land Forms	Soils	Vegetation
1	10	Active dunes adjacent to the beach, tending to invade stable dunes of unit 2	Yellowish white single-grained sandy aeolian regosols (coastal sands); some lime present from fragmented sea shells	Scanty herbaceous vegetation, prostrate or stoloniferous
2	35	Steep, stable dunes, up to 100 ft high, forming continuous belt adjacent to unit 1, and scattered patches on unit 3	Sandy aeolian regosols (coastal sands) with decomposing litter or humus in the surface; humic surfaces coherent and very acid; no free lime in upper parts of solum; possibly also patches with humus–iron podzols on inland dunes	Dry sclerophyll forest, trees 60 ft *Angophora costata* or *E. pilularis* d minant, *E. gummifera* present, scattered trees up to 20 ft high of *Banksia serrata*, *Melaleuca quinquenervia*, and *Persoonia levis*; dense shrubs up to 5 ft high, rich in Leguminosae; sparse ground cover
3	40	Undulating sand plains, forming low ridge-and-swale topography	Humus–iron podzols medium to extremely acid	
4	15	Swampy hollows amongst dunes of unit 2, and between low ridges of unit 3	Black peaty meadow soils (Devon) and similar acid swamp soils with varying contents of mineral matter; possibly with iron hard-pans in subsoil	Fen (swamp) vegetation, dense shrubs, *Callistemon* spp. prominent; scattered or dense *Melaleuca* spp., *E. robusta*, or *Casuarina glauca*

Elrington Land System (156 sq. miles)

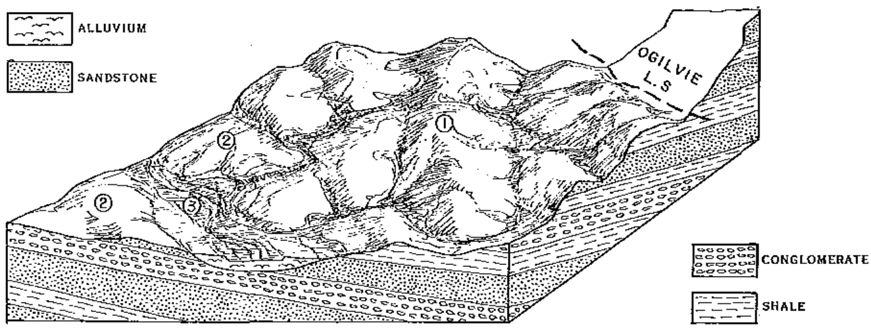
Geology.—Permian and lower Triassic shale, sandstone, and conglomerate.

Rainfall.—32–40 in.

Locality.—Seaward end of the central lowlands.

Elevation.—20–500 ft. **Local Relief.**—Up to 300 ft.

Wooded Area.—90%.



Unit	Area (%)	Land Forms	Soils	Vegetation
1	80	Rounded hills and lower slopes of escarpments; slopes generally 10–30% but locally steeper on occasional outcrops; some slumping particularly on shales; colluvial fill of stony clay in valley heads, partially dissected by gullies	Mainly podzolic soils (Binnie commonest); occasional earths likely; soils sometimes gravelly; also coarse-textured non-humic skeletal soils	Dry sclerophyll forest, 40 ft, of gums, ironbarks, and stringybarks, and including *Angophora costata*, *E. acmenioides*, *E. pilularis*, and a little *E. saligna* and *Syncarpia glomulifera*; Leguminosae and Proteaceae prominent in a fairly dense 6 ft shrub layer; good ground cover of herbs and leafy grasses (*Imperata cylindrica*, *Paspalum dilatatum*, *Sporobolus* spp., *Themeda australis*)
2	15	Undulating foot slopes; gradients less than 10%; no outcrop (similar to Beresfield land system, unit 1)	Predominantly podzolic soils, Binnie and possibly others (similar to Beresfield land system, unit 1); locally yellow earths (Growee) on colluvial aprons below steep sandstone slopes	Dry sclerophyll forest (similar to Beresfield land system, unit 1)
3	< 5	Terraced alluvium; sand and clay; less than ¼ mile wide; liable to flooding on lower terraces	Restricted observations; coarse- to fine-textured alluvial regosols (Rouchel, Maitland, Errington)	Dry sclerophyll forest with an admixture of non-eucalypt trees; shrubs and ground layer as for unit 1

GLENDOWER LAND SYSTEM (656 SQ. MILES)

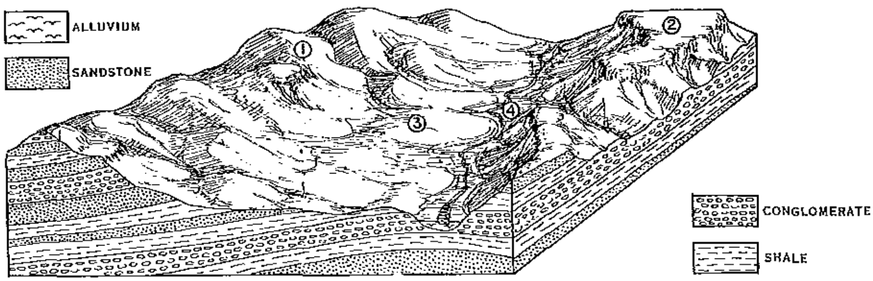
Geology.—Permian shale, sandstone, and conglomerate.

Rainfall.—22–30 in.

Locality.—Central lowlands and central Goulburn valley.

Elevation.—200–1700 ft. **Local Relief.**—Up to 300 ft.

Wooded Area.—20%.



Unit	Area (%)	Land Forms	Soils	Vegetation
1	65	Moderately steep rounded hills, outcrops of sandstone or conglomerate frequent, especially towards summits; slopes generally 10–25%; frequent gullying and sheet erosion	Wide range of soils; predominantly texture-contrast soils; solonetzic soils (Overton, Clanricard, Piercefield) in drier parts as well as podzolic soils (Binnie, Vaux, rarely Pokolbin) in wetter parts; brown earths (Cumbo, Woolooma) on certain sandstones, conglomerates, and sandy colluvium; cracking clays (Segenhoe, Guan, Krui) without stony rubble and frequently with linear gilgai, and degraded black earths (Rowan, Ellis) on lime-rich shales and sandstones; non-humic skeletal soils common	Savannah woodland of box, gum, and ironbarks, mostly thinned or cleared, trees 30–40 ft, ironbarks, *E. albens*, *E. moluccana*, *E. melliodora*, *E. tereticornis*, *E. maculata*, *E. dawsonii*, and *Angophora floribunda*; shrubs sparse; commonest grasses *Aristida*, *Chloris*, *Danthonia*, and *Dichanthium* spp. and *Stipa setacea*
2	20	Moderately steep hills up to 200 ft high, composed of lime-rich sandstones and shales, and either rounded with slopes 10–25% or tabular with undulating summits bounded by steep slopes including low sandstone cliffs; occasional linear gilgai on gentler foot slopes		Savannah woodland of box, gum, and ironbark, mostly thinned or cleared, often with *Brachychiton populneum* and *E. albens* on higher ground, *E. melliodora* below; ground cover *Stipa setacea* with scattered *Aristida* and *Medicago* spp. and *Stipa aristiglumis*
3	10	Undulating areas in major valleys with no outcrop (similar to Killarney land system, unit 1)	Predominantly podzolic and solonetzic soils; inclusions of cracking clays, degraded black earths and earths (similar to units 1 and 2 but slopes less steep, similar also to Killarney land system, unit 1)	Savannah woodland of box, gum, and ironbark mostly thinned or cleared (similar to Killarney land system, unit 1)
4	<5	Alluvium in valley bottoms; dominantly sandy but with some clay; terraced; subject to flooding on lower levels	Restricted observations; solonetzic soils (Clanricard, Piercefield, Togar) and podzolic soils (Pokolbin observed); cracking clays (Segenhoe); meadow soils (Eskdale); alluvial regosols (Maitland)	Cleared and under cultivation or pioneer grasses

GREENHILLS LAND SYSTEM (249 SQ. MILES)

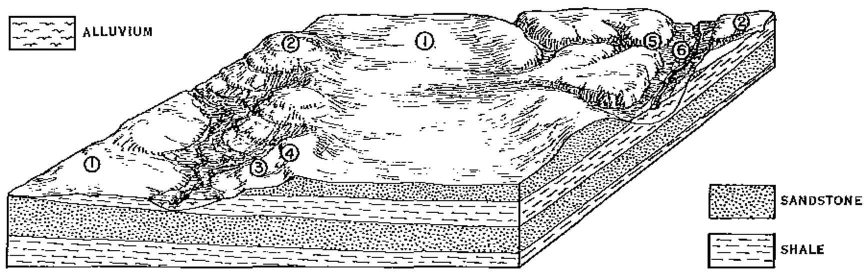
Geology.—Triassic and Jurassic sandstone and shale.

Rainfall.—22 in.

Locality.—Merriwa plateau.

Elevation.—1000–1800 ft. **Local Relief.**—Up to 300 ft.

Wooded Area.—40%.



Unit	Area (%)	Land Forms	Soils	Vegetation
1	60	Rolling lowlands with slopes less than 15%; very broad shallow valleys, with sandy floors and frequently without definite stream channels	Mainly shallow but sometimes deep brown earths (Cumbo) and some yellow and red earths (Dusodie and Baerami); occasional solonetzic soils (Clanricard) on interbedded shales	Savannah woodland of box, gum, and ironbark, 30 ft high, boxes patchy, mostly cleared, fair cover of *Aristida*, *Chloris*, *Danthonia*, and *Medicago* spp., *Stipa setacea*, and *Trifolium* spp.
2	15	Rocky sandstone knolls, hills, and cuestas, 50–150 ft high	Restricted observations; probably mainly coarse-textured non-humic skeletal soils and some shallow earths (Cumbo)	Shrub woodland of ironbark and gum, mainly ironbarks with less *Callitris endlicheri*, *E. tereticornis*, and *E. trachyphloia*; shrubs frequent, *Acacia* spp. prominent; fair grass cover of *Aristida*, *Danthonia*, and *Eragrostis* spp. and *Stipa setacea*
3	10	Smooth, straight slopes (0–10%), 50–500 yd long; no outcrop; covered with sandy wash a few inches deep on upper slopes thickening to 10 ft on lower slopes	Brown earths (Cumbo), shallow to very deep, sometimes gravelly; solonetzic soils (Clanricard, Piercefield, rarely Overton); occasional degraded black earths (Ellis) on interbedded shales	Savannah woodland of box, gum, and ironbark, mostly cleared (similar to Sandy Hollow land system, unit 1)
4	<5	Horizontal sandstone outcrops forming low bluffs up to 15 ft high or bevelled rock surfaces parallel to the general slope; interspersed with unit 3	Restricted observations; mainly coarse-textured non-humic skeletal soils; much bare rock	Practically bare
5	5	Narrow valleys 20–200 ft deep, with steep rocky walls often following dominant joint trends	No records; presumably like units 2 and 4—skeletal soils and bare rock	As for unit 2 but with denser shrubs
6	<5	Terraced alluvium in major valleys; generally sandy, but of finer texture where derived from basalt	Restricted observations; soils very variable owing to different sources of parent materials, frequently from outside this land system; earths (Cumbo, Mulbring, Baerami), cracking clays (Segenhoe), degraded black earths (Rowan), solonetzic soils (Strathearn), meadow soils (Eskdale), and alluvial regosols (Maitland)	Cleared and under pioneer grasses, sometimes under cultivation

HEXHAM LAND SYSTEM (62 SQ. MILES)

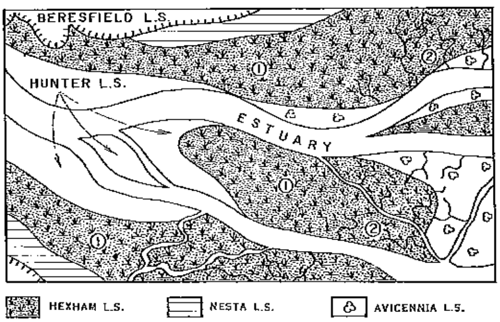
Geology.—Recent alluvium.

Rainfall.—40 in.

Locality.—Coastal zone and seaward end of central lowlands.

Elevation.—0–50 ft. **Local Relief.**—5 ft.

Wooded Area.—10%.



Unit	Area (%)	Land Forms	Soils	Vegetation
1	80	Freshwater swamps on alluvial material near sea-level; ponds formed by subsidence of low-lying areas; occasional drier sites on old levees and patches of wind-blown or marine sand	Dark, acid swamp soils and meadow soils (Mangoola); surface soils usually peaty but with considerable content of mineral matter; no records for occasional drier sites	Fen (swamp) vegetation; open water with floating aquatics; wet areas with dense *Melaleuca quinquenervia*, fringed by *M. styphelioides*, *E. robusta*, *Casuarina glauca*, and *Livistona*; drier areas often cleared and under *Cynodon dactylon*, *Paspalum dilatatum*, and *Stenotaphrum secundatum*
2	20	Brackish swamps, occasionally covered by high spring tides and crossed by winding tidal creeks	Acid swamp soils and fine-textured alluvial regosols (Errington), in places saline (Fullerton), and some meadow soils; ground water brackish	Fen (swamp) vegetation; wet areas under *Arthrocnemum*, *Paspalum vaginatum*, sedges, and *Sporobolus virginicus*; drier areas under *Cynodon dactylon*, *Paspalum dilatatum*, and *Stenotaphrum secundatum*

Hunter Land System (330 sq. miles)

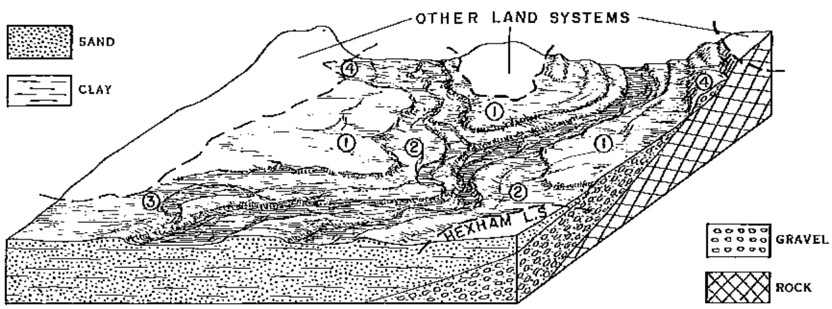
Geology.—Quaternary alluvium.

Rainfall.—24–40 in.

Locality.—Throughout the Hunter valley, but mainly in central lowlands.

Elevation.—0–2000 ft. **Local Relief.**—0–30 ft.

Wooded Area.—Negligible.



Unit	Area (%)	Land Forms	Soils	Vegetation
1	40	Higher alluvial terraces, generally sandy with underlying gravel, but underlain by clay in the major valleys of the sandstone country; height above stream bed 10–15 ft and width ¼ mile in upper valleys increasing downstream to 20–40 ft and ½–3 miles respectively along the middle Hunter; generally level surface with occasional low dunes or old levees; rarely flooded	Older terraces have cracking clays (Segenhoe) and solonetzic soils (Cropwell, sometimes Strathearn, possibly others) in drier areas, and some podzolic soils in wetter areas on alluvium derived from basalt or of mixed origin; earths (Cumbo, Woolooma) occur on well-drained siliceous coarse-textured alluvium	Mostly cleared and under cultivation or grassland of *Cynodon*, *Aristida*, *Eragrostis*, *Paspalum*, *Sporobolus*, and *Hordeum* spp.; weeds common; cover fairly good; shrubs rare; trees where present scattered, mainly *E. tereticornis*, *E. melliodora*, and *Angophora floribunda*, but other gums and non-eucalypts commoner where rainfall over 35 in.
2	35	Lower alluvial terraces composed of sand, silt, and clay; rarely more than 100 yd wide or more than 10 ft above stream bed, but locally occupying most of the valley floor in Wollombi, Baerami, Bylong, Growee, and Williams valleys; gently undulating surface with sandy levees and scoured flood channels 1–3 ft deep near the stream, and swampy hollows and abandoned channels away from the stream	Younger terraces (locally two terraces, or blanketing the older terraces) have well-developed soils, predominantly chernozems (Abermusden, Bylong) and some earths where alluvium was very sandy; also limited areas with prairie soils; minor recent terraces with immature alluvial regosols (mainly Rouchel, but Maitland or Errington on finer-textured deposits); depressions have meadow soils (Eskdale); in some localities a sterile sandy deposit is burying fertile alluvial soils	As for unit 1, but non-eucalypts commoner, *Casuarina cunninghamiana* and *C. glauca* frequent and widespread on river banks
3	20	Flood-plains of lower Hunter, Paterson, and Williams; silt or clay with some sand layers; 1–4 miles wide; gently undulating relief with levees, abandoned channels, and backswamps, occasionally flooded	Immature soils; mainly alluvial regosols of medium and fine textures (Maitland, Errington); swampy depression with meadow soils (Eskdale) and acid swamp soils	Cultivation
4	<5	Patches of boulders, gravel, and sand bordering units 1 and 2 and comprising fragments of older terraces, tributary fans, or colluvium derived from adjacent slopes	Soils of heterogeneous age and parent materials in widely differing climates; in drier areas solonetzic soils (Togar, Clanricard) and chernozems (Abermusden) along middle Hunter River, and in wetter areas podzolic soils (Rosscole, Binnie); also observed cracking clays (Segenhoe) and earths (Cumbo, Woolooma, Mulbring); soils sometimes gravelly	Cleared ground, good cover of *Paspalum*, *Imperata*, *Sporobolus*, *Cynodon*, and *Eragrostis* spp.

KILLARNEY LAND SYSTEM (539 SQ. MILES)

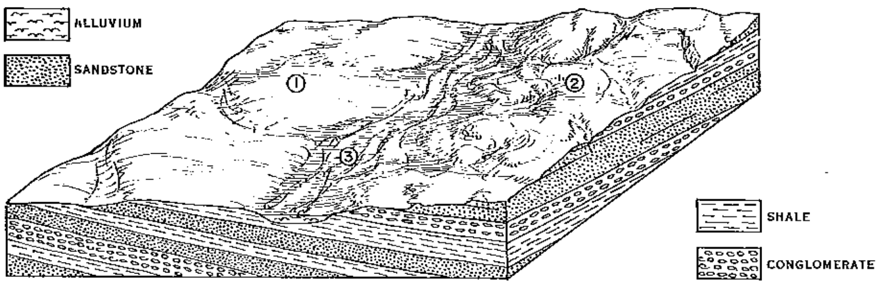
Geology.—Permian shale, sandstone, and conglomerate.

Rainfall.—22–30 in.

Locality.—Inland parts of the central lowlands; central Goulburn valley.

Elevation.—200–1700 ft. **Local Relief.**—Less than 100 ft.

Wooded Area.—20%.



Unit	Area (%)	Land Forms	Soils	Vegetation
1	75	Undulating lowlands with widely-spaced broad, shallow valleys; slopes generally less than 10%; local relief less than 100 ft; occasional outcrops near hill tops; up to 10 ft of stony colluvial fill in valley heads; gravelly surface wash in areas adjacent to steep hills; considerable sheet and gully erosion	Soils very variable; predominantly podzolic soils (Binnie, Vaux, sometimes Pokolbin and Rosscole) especially towards the wetter east; solonetzic soils (Overton, Strathearn, Clanricard, Piercefield, Togar, and possibly others) co-dominant and more extensive in drier centre and west; smaller patches with cracking clays (Segenhoe), degraded black earths (Rowan, Ellis), brown and yellow often shallow earths (Cumbo, Growee, especially near Wollar and Ulan); dominant soils different from area to area	Savannah woodland of box, gum, and ironbark, mostly thinned or cleared, trees 30 ft high, *E. albens*, *E. dawsonii*, *E. maculata*, *E. tereticornis*, and ironbarks; shrubs rare; ground cover of *Themeda australis* where protected, otherwise *Aristida*, *Chloris*, *Danthonia*, and *Dichanthium* spp., and *Stipa setacea*, with *Medicago* and *Trifolium* spp.
2	20	Undulating lowlands with closely-spaced, small shallow valleys; slopes less than 10%; local relief less than 50 ft; frequent outcrops and stony surfaces; little or no colluvial fill; very active sheet erosion	Similar range of soils to unit 1; more shallow coarse-textured earths; also skeletal soils; soil families observed include Cumbo, Clanricard, Piercefield, Overton, Binnie	
3	<5	Terraced alluvium in main valleys of unit 1; sand, silt, and clay, sometimes overlying coarse ironstone gravel; up to ¼ mile wide	Large range of soils due to widely differing ages, parent materials, and drainage status; chernozems, solonetzic soils, earths (Woolooma, Cumbo); solonchaks in valley bottoms patchy but common; salt encrustation common on creek banks	Cleared and under cultivation or pioneer grasses

Lee's Pinch Land System (1386 sq. miles)

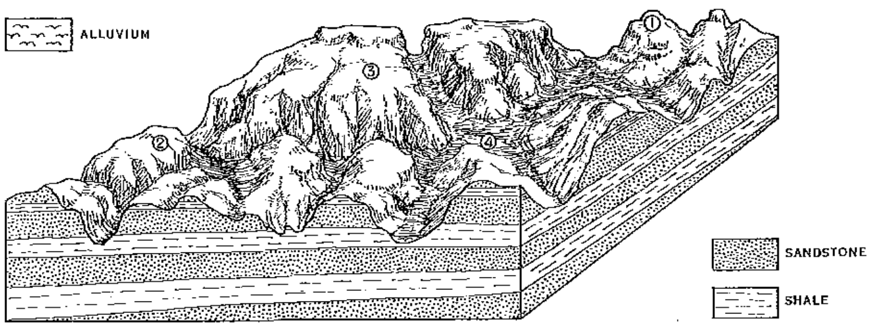
Geology.—Triassic sandstone and minor shale.

Rainfall.—22–30 in.

Locality.—Southern mountains.

Elevation.—500–3300 ft. **Local Relief.**—Up to 2500 ft.

Wooded Area.—100%.



Unit	Area (%)	Land Forms	Soils	Vegetation
1	30	Rugged hills with rounded summits; irregularly benched slopes often littered with boulders and with very frequent sandstone outcrops including low cliffs up to 30 ft high; fairly narrow flat-floored valleys 400–1000 ft deep	Mainly shallow coarse-textured skeletal soils and bare rock; in moist cool sites humic surface soils; infrequently on interbedded shales or arkosic sandstones shallow podzolic soils (Binnie, Pokolbin); in stable sites coarse-textured earths	Shrub woodland of ironbark and gum 40–80 ft high, ironbarks common, with *E. punctata*, *E. agglomerata*, and *E. oblonga*, and with scattered or dense *Callitris endlicheri*, *Casuarina torulosa*, and *Persoonia* spp. below; shrubs usually abundant and mixed, Leguminosae common; ground cover poor, of grasses and herbs
2	30	Rugged hills margined by sandstone cliffs 50–500 ft high usually overlooking steep shaly slopes littered with boulders; cavernous weathering of the cliffs; narrow inaccessible valleys 500–2500 ft deep	Similar to unit 1; predominantly coarse-textured non-humic skeletal soils; probably more bare rock	As for unit 1, but with more herbs, shrubs, and non-eucalypt trees in ravines and at bases of cliffs
3	35	Stony, hilly plateaux with ridges and escarpments up to 200 ft high; very steep margins including cliffs up to 100 ft high; narrow gorges along the major rivers	Restricted observations; similar to units 1 and 2; deep yellow earth (Mulbring) in level, stable site on plateau	Shrub woodland of ironbark and gum 30 ft high, including *E. punctata*, *E. trachyphloia*, and stringybarks; ground cover poor; many non-eucalypts in ravines and at bases of cliffs
4	<5	Sandy alluvium occupying valley floors in unit 1; liable to frequent flooding and deposition of sand in middle and upper reaches	Restricted observations; deep sandy stratified alluvial regosols (Rouchel); sedimentation in valley bottoms frequent and calamitous owing to low soil stability on sandstone hills	Shrub woodland of ironbark and gum with an admixture of non-eucalypt trees, sometimes cleared and under pioneer grasses

Liverpool Land System (450 sq. miles)

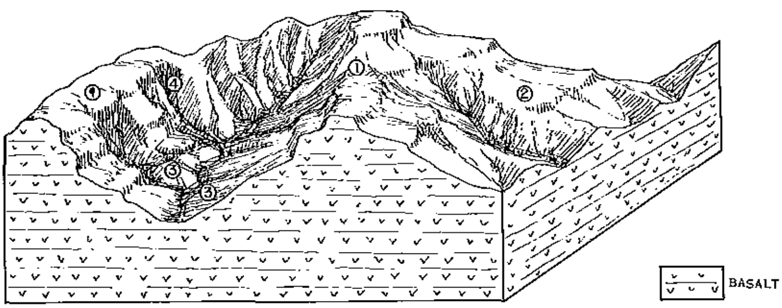
Geology.—Tertiary basalt.

Rainfall.—30–40 in.

Locality.—Liverpool and Mt. Royal Ranges.

Elevation.—1800–4000 ft. **Local Relief.**—Up to 1500 ft.

Wooded Area.—60%.



Unit	Area (%)	Land Forms	Soils	Vegetation
1	70	Rugged hills and ridge tops; frequent bluffs and cliffs up to 150 ft high; narrow valleys 300–1500 ft deep with very steep slopes (up to 90%) and restricted patches of water-worn boulders on floor; much surface rubble, active erosion by sheet wash and gullying, plus slumping where cleared	Mostly fine-textured humic skeletal soils, but non-humic at lower altitudes or on exposed drier and warmer slopes; merging into shallow cracking clays (Guan) in less steep and more stable sites and into alpine humus soils (Barrington) on minor gentle grassy slopes at high altitudes	Savannah woodland of box and gum, some thinned or cleared, trees up to 80 ft, *Angophora floribunda*, *E. albens*, *E. laevopinea*, *E. melliodora*, and *E. tereticornis* below 30 in. rainfall, grading into *Casuarina torulosa*, *E. laevopinea*, *E. mannifera*, *E. saligna*, and *E. viminalis* where wetter; shrubs scattered, ground cover mainly a short grass turf with tussocks of *Poa* sp. and *Themeda australis* but non-grasses abundant
2	10	Steep hills with marked benches, frequently ill-drained, up to 200 yd wide; weathered crumbly rock with occasional more resistant layers	Restricted observations; probably essentially similar to unit 1; soils possibly slightly more stable and mature; cool, moist, south-facing slopes with humic, friable, surface soils	Much cleared ground with good cover of *Poa* sp. and non-grasses; remainder 40 ft anomalous woodland, *E. nortonii* abundant on middle slopes, with *E. laevopinea* and *E. melliodora* below and *E. mannifera* above; shrubs uncommon
3	15	Hills less than 300 ft high and moderately sloping lower valley sides (similar to Ant Hill land system, unit 1)	Mainly brown stony immature cracking clays (Guan) (similar to Ant Hill land system, unit 1)	Savannah woodland of box and gum (similar to Ant Hill land system, unit 1)
4	<5	Rocky slopes usually facing south or south-east with much surface rubble (similar to Rainforest land system, unit 1)	No records; presumably fine-textured humic skeletal soils, with some krasnozems; high organic matter content in surface	Rain forest (similar to Rainforest land system, unit 1)

Moonibung Land System (61 sq. miles)

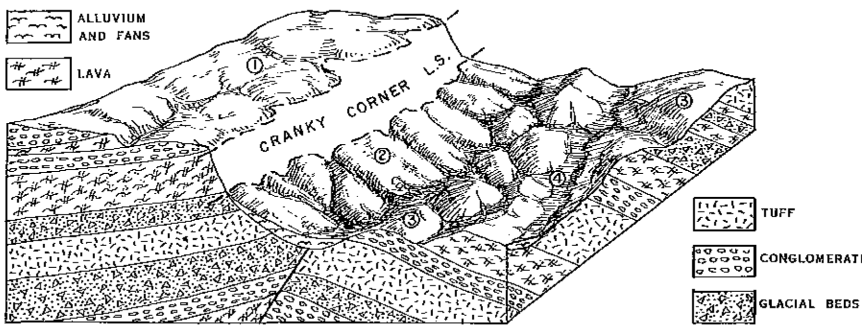
Geology.—Carboniferous lava, tuff, conglomerate, and glacial beds.

Rainfall.—28–32 in.

Locality.—Southern margin of north-eastern mountains.

Elevation.—400–1500 ft. **Local Relief.**—100–300 ft.

Wooded Area.—30%.



Unit	Area (%)	Land Forms	Soils	Vegetation
1	35	Rocky plateau summits with slopes generally 10–25%	Restricted observations; soils predominantly shallow; mainly podzolic soils (Binnie), probably also skeletal soils	Tall mixed woodland, 50 ft, mostly thinned or cleared, commonly *E. canaliculata*, *E. maculata*, *E. tereticornis*, and ironbarks; shrubs fairly common; usually good grass cover, mainly *Dichanthium* spp., *Paspalum dilatatum*, and *Themeda australis*
2	25	Moderately steep scarp-foot slopes with extensive fans of bouldery rubble	No records; probably podzolic soils, but deeper and stony	Mostly cleared, grasses as for unit 1
3	35	Rolling steep hills, up to 300 ft high; slopes 10–25%; frequent outcrops on higher areas; colluvial fill in hollows	Restricted observations; cracking clays (Guan) with some fine-textured skeletal soils in Mt. View area	As for unit 1
4	<5	Terraced gravelly and sandy alluvium of major valleys in unit 3; up to 200 yd wide; liable to flooding	Variable soils; alluvial regosols (Maitland), earths (Woolooma), cracking clays (Segenhoe), possibly also podzolic soils	Cleared and under pioneer grasses

MT. BUTTERWICKI LAND SYSTEM (479 SQ. MILES)

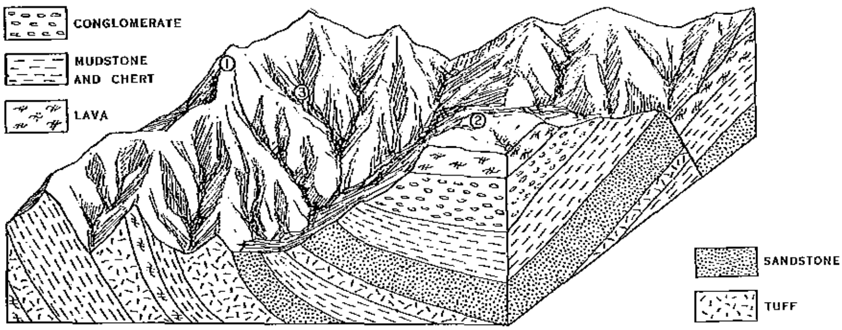
Geology.—Carboniferous sediments and some lavas.

Rainfall.—30–40 in.

Locality.—North-eastern mountains.

Elevation.—500–3000 ft. **Local Relief.**—300–2000 ft.

Wooded Area.—40%.



Unit	Area (%)	Land Forms	Soils	Vegetation
1	75	Very steep ridges with narrow crests; slopes ranging from 25 to 100%, dissected by closely-spaced ravines giving extremely broken topography; much outcrop; liable to slumping	Dominantly shallow to deep podzolic soils (Binnie); with medium- to fine-textured often humic skeletal soils and brown earths (Woolooma, Cumbo) co-dominant; soil depth depends on slope and ease of weathering of parent rocks	Tall mixed woodland, mainly gums and stringybarks, or wet sclerophyll forest, mostly thinned or cleared, trees up to 100 ft high, commonly *Angophora floribunda*, *E. acmenioides*, *E. canaliculata*, *E. laevopinea*, and *E. microcorys*; few shrubs; good ground cover of *Imperata cylindrica*, *Paspalum dilatatum*, and *Poa* and *Sporobolus* spp. with *Pteridium aquilinum*, *Trifolium* spp., and many other non-grasses
2	20	Massive hills with extensive cliffs and much surface rubble (similar to Cranky Corner land system, unit 1)	No records; probably similar to Cranky Corner land system, unit 1 (often humic skeletal soils; some shallow podzolic soils)	Tall mixed woodland 50–100 ft high, with shrubs and sparse grasses (similar to Cranky Corner land system, unit 1)
3	5	Deep, narrow valley heads, generally facing south, bounded by cliffs or very steep slopes; much surface rubble	Restricted observations; probably similar to unit 1, with more skeletal soils; podzolic soils (Binnie)	Rain forest (similar to Rainforest land system, unit 1, but poorer in species and not as tall)

Mt. Royal Land System (142 sq. miles)

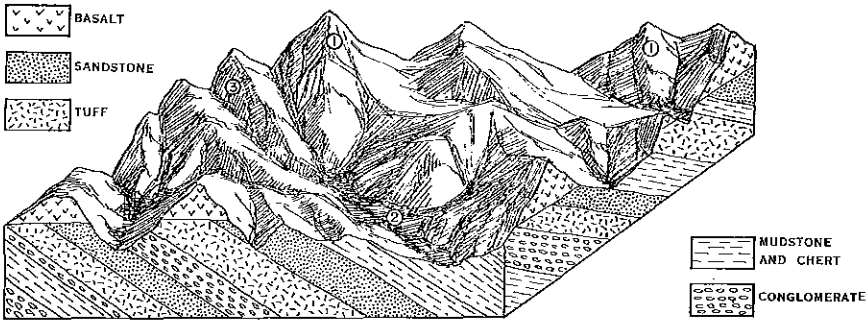
Geology.—Carboniferous sediments capped by Tertiary basalt.

Rainfall.—40–50 in.

Locality.—North-eastern mountains.

Elevation.—1000–4000 ft. **Local Relief.**—Generally exceeding 1000 ft.

Wooded Area.—90%.



Unit	Area (%)	Land Forms	Soils	Vegetation
1	85	Fairly steep to very steep ridges with broadly rounded summits or narrow crests; slopes dissected by closely-spaced ravines; numerous structural benches up to 300 yd wide alternating with steep slopes and bluffs 20–200 ft high; upper slopes usually covered with basalt rubble; gullying and slumping frequent where cleared	Variable soils; krasnozems (Torrielodge) on hill-tops and slopes below basalt uplands extending from the Barrington plateau; podzolic soils (Pokolbin, probably Binnie) on lower slopes; alpine humus soils (Barrington) and transitional alpine humus soils (Meehan) rare; shallow to moderately deep brown earths (Woolooma) on some sedimentary rocks	Wet sclerophyll forest up to 120 ft high, of *E. campanulata*, *E. microcorys*, and *E. saligna*, crowns usually touching without overlapping; lower tree layer of scattered *Angophora floribunda* and *Casuarina torulosa* 30–40 ft; shrubs uncommon except near rain forest, good 2 ft ground cover of *Poa* sp., *Themeda australis*, *Pteridium aquilinum*, and *Imperata cylindrica*
2	10	Wide major valleys with hilly floors	No records; probably predominantly podzolic soils, mainly Binnie, some Pokolbin (similar to Wallaroo land system, unit 1, but wetter)	As for unit 1, but mostly cleared, and with less *E. campanulata*
3	<5	As for unit 1, particularly on slopes facing south or south-east and in heads of ravines	Similar to unit 1; equivalent to Rainforest land system, unit 1; krasnozems, possibly with humic fine-textured skeletal soils	Rain forest (similar to Rainforest land system, unit 1)

MUNGHORN GAP LAND SYSTEM (12 SQ. MILES)

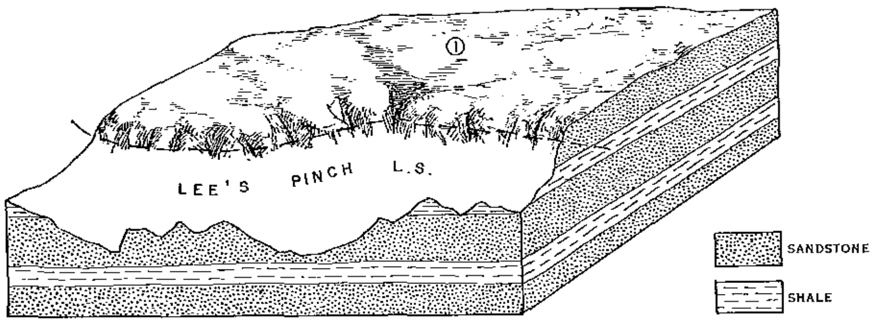
Geology.—Triassic sandstone with minor shale.

Rainfall.—26–30 in.

Locality.—Western end of southern mountains.

Elevation.—2400–2700 ft. **Local Relief.**—10–50 ft.

Wooded Area.—100%.



Unit	Area (%)	Land Forms	Soils	Vegetation
1	100	Gently undulating to level sandstone plateaux up to 2 miles wide; some outcrop at margins; gradients 0–5%	Soil cover uniform; moderately deep to deep, strongly acid, coarse-textured brown earths (mainly Growee), sometimes with mottled subsoils; shallow soils, skeletal soils, and outcrop near plateau margins	Dry sclerophyll forest or shrub woodland of ironbark and gum, 35 ft, commonly *E. mannifera* and *E. rossii*, with ironbarks, stringybarks, and *Callitris endlicheri*; shrubs 3 ft, fairly dense; ground cover mainly non-grasses, fairly dense

NESTA LAND SYSTEM (6 SQ. MILES)

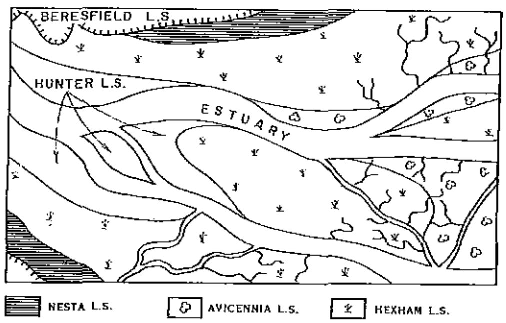
Geology.—Estuarine alluvium.

Rainfall.—38–40 in.

Locality.—Coastal zone.

Elevation.—0–10 ft. **Local Relief.**—0–10 ft.

Wooded Area.—Negligible.



Unit	Area (%)	Land Forms	Soils	Vegetation
1	100	Flats formed on recently emerged marine silt and clay, occasional patches of fine aeolian sand and coarse marine sand forming very low rises a few feet above the general level	Black meadow soils of moderately fine to fine texture (Eskdale, Mangoola) on marine sediments, and of coarse texture (Devon) on superficial windblown sands; soils are badly drained, peaty, mottled, leached, and acid	Fen (swamp) vegetation, mostly under cultivation; or old cultivation with *Cynodon dactylon* dominant and *Pennisetum clandestinum*, *Stenotaphrum secundatum*, *Sporobolus virginicus*, *Paspalum vaginatum*, *P. dilatatum*, sedges, and weeds; scattered *Casuarina glauca*, *Melaleuca* spp., and *Livistona australis*

OGILVIE LAND SYSTEM (233 SQ. MILES)

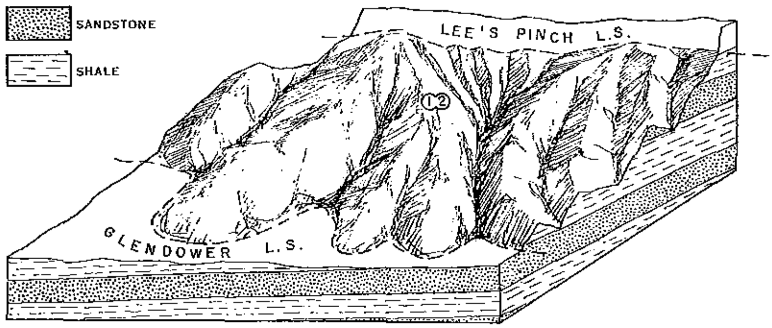
Geology.—Permian conglomerate, sandstone, and shale.

Rainfall.—22–32 in.

Locality.—Northern edge of southern mountains.

Elevation.—250–1500 ft. **Local Relief.**—300–700 ft.

Wooded Area.—100%.



Unit	Area (%)	Land Forms	Soils	Vegetation
1	85	Steep hills and escarpments several hundred feet high; frequent outcrops of sandstone and conglomerate forming cliffs up to 50 ft high and providing much blocky surface rubble; occasional benches up to 300 yd wide on thick, resistant sandstone or conglomerate beds; closely-spaced ravines on shales often partly choked with sandstone rubble; slumping, gullying, and sheet erosion active, especially where cleared	Skeletal soils of various textures; earths (Baerami observed); solonetzic soils (Overton, Clanricard); degraded black earths (Rowan, Ellis); soils often shallow, with fragments of sandstone or shale	Savannah woodland of box, gum, and ironbark, denser than usual and about 40 ft high; broad-leafed shrubs frequent on cool slopes, scanty otherwise; ground cover of grasses and non-grasses good on cool slopes, poor otherwise
2	15		Restricted observations; analogous to unit 1 but wetter; presumably coarse- to medium-textured skeletal soils, some humic; shallow earths and podzolic soils (Pokolbin seen)	Wet or dry sclerophyll forest, boxes absent, smaller non-eucalypt trees frequent where sheltered; fairly dense mixed shrubs; dense ground cover of grasses and non-grasses

PARKVILLE LAND SYSTEM (41 SQ. MILES)

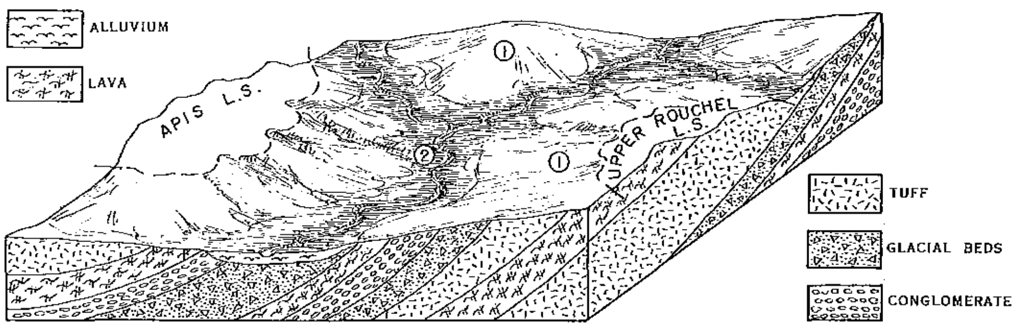
Geology.—Carboniferous and Lower Permian lavas and glacials, Tertiary basic igneous intrusives.

Rainfall.—26 in.

Locality.—North-eastern mountain belt and central lowlands.

Elevation.—200–2300 ft. **Local Relief.**—Up to 100 ft.

Wooded Area.—Negligible.



Unit	Area (%)	Land Forms	Soils	Vegetation
1	95	Undulating lowlands; slopes less than 10%; few outcrops; areas of gravelly wash derived from adjacent steep hills; widely spaced shallow valleys (¼–½ mile apart, 10–50 ft deep)	Complex soil pattern; predominantly cracking clays (Segenhoe, some Springfield); solonetzic soils (Clanricard, Cropwell, Glenbawn) and degraded black earths (Rowan) co-dominant; rarely podzolic soils (Pokolbin) (similar to Blairgowrie land system, unit 1)	Savannah woodland of box, gum, and ironbark, mostly cleared and under *Dichanthium* spp. and lesser amounts of *Medicago* spp. and xeromorphic grasses; shrubs rare; trees scattered, about 50 ft high, *E. albens* dominant, associated with *E. laevopinea*, *E. melliodora*, and *E. tereticornis*
2	5	Gravelly, sandy alluvium in the larger valleys partially dissected by recent gullies 5–15 ft deep	Restricted observations; brown earths (Cumbo, Wooloomа); alluvial regosols; presumably cracking clays and solonetzic soils	Cleared, and under cultivation or pioneer grasses

RAINFOREST LAND SYSTEM (156 SQ. MILES)

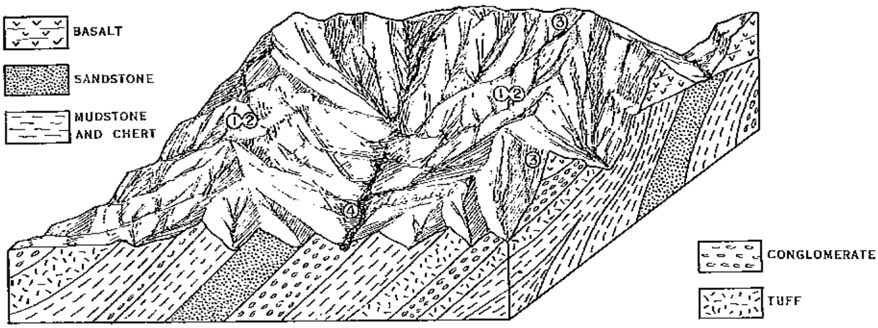
Geology.—Carboniferous sediments capped by Tertiary basalts.

Rainfall.—40–60 in.

Locality.—Southern margin of Barrington Tops.

Elevation.—1000–5000 ft. **Local Relief.**—Up to 2000 ft.

Wooded Area.—100%.



Unit	Area (%)	Land Forms	Soils	Vegetation
1	65	Steep ridges with narrow uneven crests; slopes generally about 80%, with closely-spaced deep ravines or with cliffs and bluffs 10–200 ft high	Restricted observations; deep krasnozems (Torrielodge), probably strongly acid, locally with stones or boulders	Subtropical rain forest, rich non-eucalypt flora, no dominant species, abundant lianes and epiphytes; upper layer of 100-ft trees, lower layer of 20-ft trees, both with unbroken canopy; dense shrubs; herbaceous ground cover of varying density, grasses rare
2	5		As for unit 1 (related to Mt. Royal land system, unit 1)	Wet sclerophyll forest up to 120 ft high with *Poa* sp. below (similar to Mt. Royal land system, unit 1)
3	20	Basalt screes and cliffs	Restricted observations; extremely stony, fine-textured, humic, skeletal soils of acid reaction; rock outcrop	Temperate rain forest of *Nothofagus moorei* 100 ft high and more; smaller trees and shrubs rare; epiphytes rare except for mosses and lichens; ground cover of mosses and ferns
4	10	Wide major valleys with moderate slopes; boulder terraces or narrow gorges 10–50 ft deep in valley floors	Restricted observations; red, strongly acid podzolic soils (Pokolbin); sometimes have waterworn pebbles; rock outcrop	As for unit 1

REDHEAD LAND SYSTEM (4 SQ. MILES)

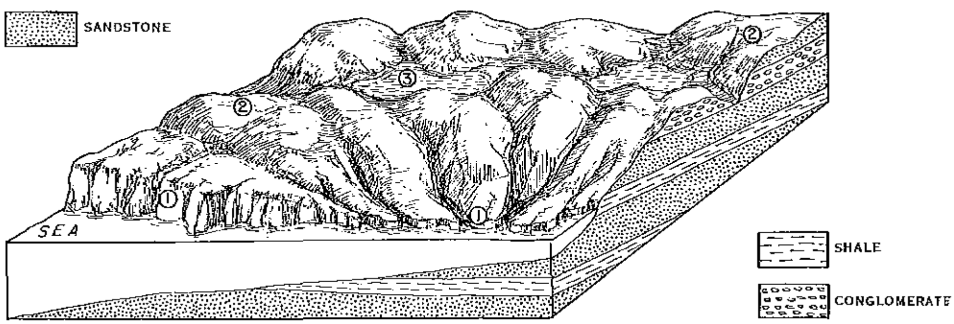
Geology.—Permian sandstone.

Rainfall.—40 in.

Locality.—Coastal zone.

Elevation.—0–300 ft. **Local Relief.**—Up to 300 ft.

Wooded Area.—85%.



Unit	Area (%)	Land Forms	Soils	Vegetation
1	15	Cliffs	Mainly bare rocks	Practically bare
2	50	Steep to rolling hills, partly overlain by wind-blown sands in thin patches or forming dunes up to 10 ft high	Podzolic soils (Vaux) and sandy aeolian regosols (coastal sands), often with extremely acid, humic, coherent topsoils	Dense heath of many species; sparse ground cover of *Pteridium aquilinum*, *Themeda australis*, and mixed herbs; scattered clumps of *E. gummifera*
3	35	Valleys up to 100 ft deep with slopes 10–25%; sometimes blocked by wind-blown sand to form swamps and lagoons	No records; presumably acid swamp soils in swamps, otherwise similar to unit 2	Dry sclerophyll forest, 40 ft, including *Angophora costata*, *E. gummifera*, and stringybarks, with scattered smaller trees of *Banksia integrifolia*, *Casuarina torulosa*, and *Persoonia lanceolata*; scattered mixed shrubs; fair grass cover of *Imperata cylindrica* and *Themeda australis*

ROSCOMMON LAND SYSTEM (36 SQ. MILES)

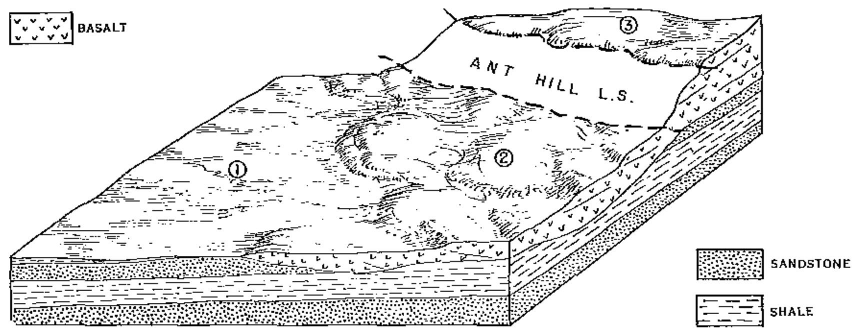
Geology.—Jurassic shale and sandstone, and Tertiary basalt.

Rainfall.—22 in.

Locality.—Southern margin of Merriwa plateau.

Elevation.—1000–1200 ft. **Local Relief.**—Less than 100 ft.

Wooded Area.—Negligible.



Unit	Area (%)	Land Forms	Soils	Vegetation
1	45	Almost level plains with maximum gradients less than 3% and no surface drainage	Mainly deep permeable krasnozems (Torrielodge); sometimes secondary lime at depth; rare patches with high content of ferruginous fragments (Roscommon); small unchannelled depressions with brown, mottled soils (Hook); minor inclusions of cracking clays (Segenhoe) and possibly degraded black earths	Eucalypt tree savannah, mostly cleared and under cultivation or *Stipa setacea*, with some *Aristida*, *Dichanthium*, and *Medicago* spp.; scattered 20–30 ft *E. albens* with some *Brachychiton populneum* and *E. melliodora*
2	50	Undulating basalt country with stony surface and occasional outcrops; slopes less than 8%	Restricted observations; mainly shallow stony krasnozems (Tunbridge); minor inclusions of cracking clays	Eucalypt tree savannah, mostly cleared, with pioneer grasses and *Medicago* spp.; scattered or patchy 20–30 ft *Angophora floribunda* or *E. albens*
3	5	Undulating basalt plateaux below 2000 ft; widely-spaced shallow valleys; no outcrop; slopes less than 10%	Krasnozems (Torrielodge, with minor areas of Hook)	Eucalypt tree savannah, mostly cleared, good cover of mixed grasses commonly *Danthonia racemosa*, *Chloris* spp., *Panicum queenslandicum*, and *Sporobolus* spp.; remainder tree savannah up to 80 ft high, *E. tereticornis* dominant, *E. melliodora* occasional

ROUSE LAND SYSTEM (13 SQ. MILES)

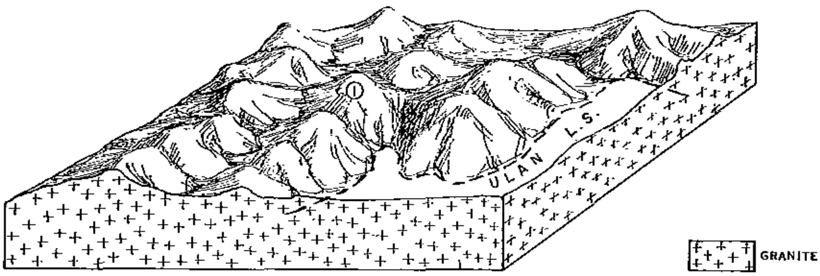
Geology.—Palaeozoic granite.

Rainfall.—24 in.

Locality.—Western end of central Goulburn valley.

Elevation.—1500–2000 ft. **Local Relief.**—30–300 ft.

Wooded Area.—80%.



Unit	Area (%)	Land Forms	Soils	Vegetation
1	100	Rolling to rugged hills with rock outcropping over about half the area; gradients 10–35%; shallow, stony colluvial fill in valleys; strong control of relief by jointing	No records; presumably mainly coarse-textured, gritty, non-humic skeletal soils; much rock outcrop	Savannah woodland of box, gum, and ironbark, some thinned or cleared, 30 ft high; common additional trees *Acacia* spp., *Angophora floribunda, Callitris endlicheri, Casuarina stricta, E. macrorrhyncha, Ficus rubiginosa*; ericoid shrubs occasional; poor ground cover of *Aristida* and *Dichanthium* spp. and *Stipa setacea*

Sandy Hollow Land System (106 sq. miles)

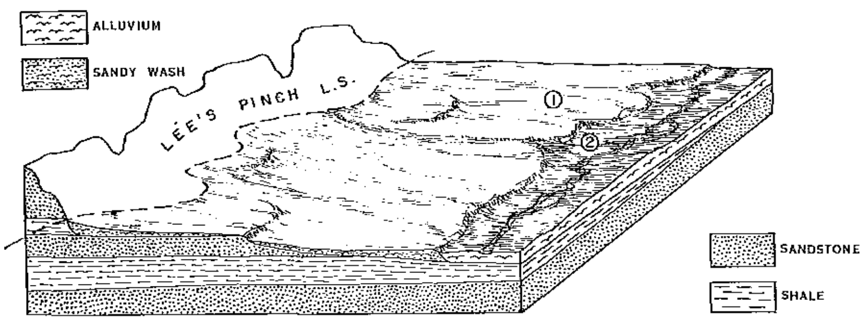
Geology.—Quaternary colluvium.

Rainfall.—22–26 in.

Locality.—Central Goulburn valley, south-eastern part of Merriwa plateau, and northern margin of southern mountains.

Elevation.—400–1000 ft. **Local Relief.**—Up to 100 ft.

Wooded Area.—10%.



Unit	Area (%)	Land Forms	Soils	Vegetation
1	95	Smooth slopes with gradients less than 10% covered by wash from adjacent rugged sandstone hills, gravelly at head of slope and finer downslope; rarely, an admixture of fine-grained basaltic material derived from dykes; occasional outcrops of sandstone in upper parts; generally dissected by shallow valleys (10–30 ft deep) issuing from adjacent hills	Upper slopes, sometimes also lower slopes, mainly deep coarse-textured brown and red earths (Cumbo, Baerami); may contain gravel; lower slopes usually with solonetzic soils (Piercefield, Strathearn) or more rarely podzolic soils (Vaux)	Savannah woodland of box, gum, and ironbark, mostly cleared and under *Aristida* spp., *Danthonia linkii*, *Eragrostis* spp., and *Stipa setacea*; shrubs rare; trees usually ironbarks with *E. melliodora* and *E. tereticornis*, up to 50 ft high
2	5	Terraced sandy or gravelly alluvium in major valleys fringing lower edge of unit 1; less than ¼ mile wide; liable to flooding and deposition of sand	Alluvium mainly belonging to through-going drainage; chernozemic soils (Bylong, Abermusden), meadow podzolic soil (Fal Brook), prairie soil observed	Cleared and under cultivation or pioneer grasses

Three Ways Land System (567 sq. miles)

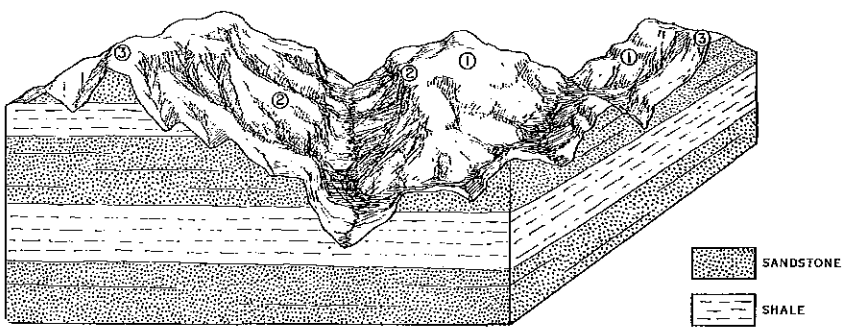
Geology.—Triassic sandstone with subordinate shale.

Rainfall.—24–36 in.

Locality.—Southern mountains.

Elevation.—500–3500 ft. **Local Relief.**—400–2500 ft.

Wooded Area.—100%.



Unit	Area (%)	Land Forms	Soils	Vegetation
1	50	Rugged hills with rounded summits; irregularly benched slopes often littered with boulders and with very frequent sandstone outcrops; narrow ridges with subhorizontal crests; narrow valleys 400–1000 ft deep (similar to Lee's Pinch land system, unit 1, but valleys narrower)	Restricted observations; mainly shallow coarse-textured skeletal soils, sometimes humic; some coarse-textured brown earths (Cumbo); much outcrop (similar to Lee's Pinch land system, unit 1)	Dry sclerophyll forest of *Angophora* spp., *E. eximia*, *E. trachyphloia*, and stringybarks with a rich flora of dense 4-ft shrubs and herbs; patches of non-eucalypt trees and shrubs in sheltered places; grasses uncommon
2	30	Rugged hills margined by sandstone cliffs 50–500 ft high, usually overlooking steep shaly slopes littered with boulders; narrow, inaccessible valleys 500–2500 ft deep (similar to Lee's Pinch land system, unit 2)	No records; presumably similar to unit 1	As for unit 1, but with more herbs, shrubs, and non-eucalypt trees
3	20	Moderately sloping (25% or less) ridge tops and upper hill slopes, only occasional outcrops	Restricted observations; similar to units 1 and 2 but soils somewhat deeper and earths more common	Anomalous woodland usually 50 ft high, of *E. crebra* with poor cover of shrubs and herbs below

TIMOR LAND SYSTEM (51 SQ. MILES)

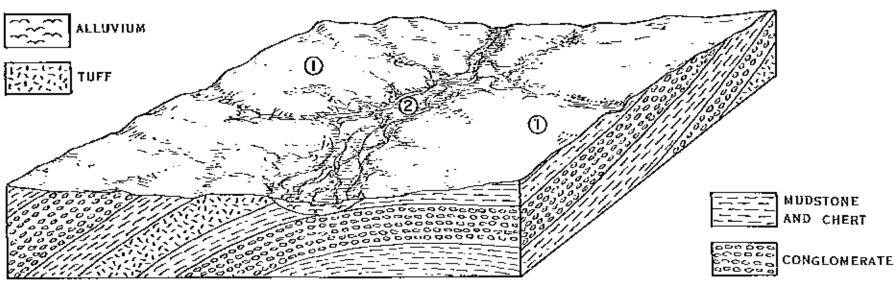
Geology.—Carboniferous sediments.

Rainfall.—24 in.

Locality.—Major valleys of the north-eastern mountains.

Elevation.—300–2000 ft. **Local Relief.**—Less than 100 ft.

Wooded Area.—10%.



Unit	Area (%)	Land Forms	Soils	Vegetation
1	90	Undulating country with slopes less than 10%; few outcrops; widely-spaced shallow valleys; sandy, gravelly surface wash around foot of steep hills adjacent to this land system; some sheet and gully erosion	Mainly texture-contrast soils, predominantly solonetzic (Clanricard, possibly others), rarely podzolic (Singleton) in easternmost more humid parts; small areas with degraded black earths (Rowan), brown earths (Woolooma) especially on fans	Savannah woodland of box and gum, 30 ft high, mostly thinned or cleared, commonly *Angophora floribunda*, *E. albens*, *E. melliodora*, and *E. tereticornis*; shrubs rare; ground cover usually *Aristida* spp. dominant, less commonly *Dichanthium* spp.
2	10	Alluvium in valley bottom; less than ¼ mile wide; terraced; generally sandy, but of finer texture where derived from base-rich rocks; liable to flooding on lower levels	Soils variable; chernozems (Abermusden), alluvial regosols (Rouchel), cracking clays (Segenhoe); also a podzolic soil (Binnie) and a brown earth (Cumbo)	Cleared and under cultivation or pioneer grasses

Tubrabucca Land System (62 sq. miles)

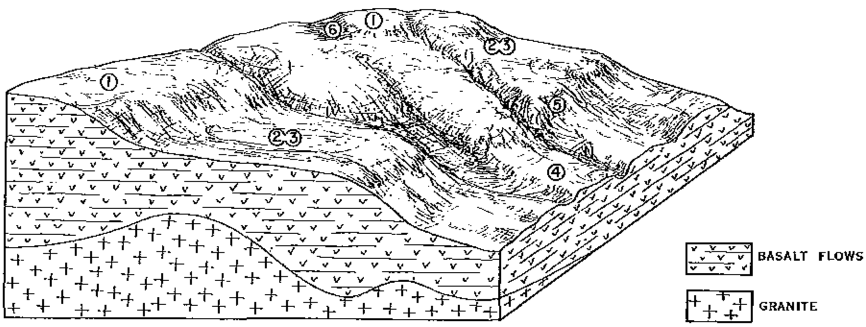
Geology.—Tertiary basalt on granite or sandstone.

Rainfall.—30–60 in.

Locality.—Mainly Barrington Tops, also Liverpool Range and southern mountains.

Elevation.—3000–5400 ft. **Local Relief.**—Less than 150 ft.

Wooded Area.—90%.



Unit	Area (%)	Land Forms	Soils	Vegetation
1	25	Gently undulating plateaux ½–3 miles wide, over 4500 ft above sea-level; occasional low rocky knolls and escarpments; gradients 0–5% increasing somewhat towards plateau margins and at breaks of slope between adjoining plateaux; shallow widely-spaced valleys; coarse surface rubble frequent	Mainly strongly leached, deep, permeable transitional alpine humus soils (Meehan), often with many angular basalt floaters throughout and on surface; grading into krasnozems of unit 2 at lower altitudes; minor areas of *Nothofagus* have similar soils but with thick humic surfaces	Eucalypt subalpine woodland, 50 ft, *E. dalrympleana* and *E. pauciflora* co-dominant, *E. stellulata* present; dense *Poa* sp. below, or patches of dense *Acacia* shrubs with sparse herbs and grasses; minor communities of *Nothofagus moorei*
2	50	As for unit 1, but 3500 to 4500 ft with less surface rubble	Strongly acid krasnozems (Torrielodge); deep, generally free of stones	Wet sclerophyll forest partly cleared, up to 100 ft, *E. dalrympleana*, *E. fastigata*, *E. laevopinea*, *E. pauciflora*, *E. stellulata*, and *E. viminalis*; fairly dense 15-ft *Acacia* shrubs; good ground cover, *Poa* sp. dominant, with *Festuca* and *Danthonia* spp. and *Pteridium aquilinum* and other non-grasses
3	20		Restricted observations; similar to unit 2; basalt floaters once observed	Wet sclerophyll forest, 50 ft, of *E. bicostata*, *E. blaxlandii*, and *E. laevopinea* with a few *Acacia* shrubs, two-thirds cleared and under grass turf with *Pteridium aquilinum* and tussocks of *Themeda australis*, *Poa* sp., and Cyperaceae
4	< 5	As for unit 1, but below 3500 ft and with no surface rubble	Restricted observations; soils probably variable owing to thinness of basalt capping and influence of underlying sandstone; krasnozems (Hook, probably Torrielodge); possibly also brown and red earths	Trees in a scattered or patchy anomalous woodland, 30 ft, *E. laevopinea* dominant, *E. mannifera* present; shrubs rare; mostly cleared and under grassland of *Sporobolus*, *Eragrostis*, and *Poa* spp. and *Themeda australis*, with localized infestations of *Hypericum perforatum*
5	< 5	Plateau margins with steep slopes (14–50%), rocky benches up to 50 yd wide and frequent gullies and slumps; much bouldery rubble on steep slopes (similar to Liverpool land system, unit 1)	On basalt equivalent to parts of Liverpool land system, unit 1, mainly fine-textured humic and non-humic skeletal soils; on sandstone mainly as for Three Ways land system, earths or podzolic soils (Vaux)	Savannah woodland of box and gum up to 80 ft, with *Poa* sp. and *Themeda australis* below (similar to Liverpool land system, unit 1)
6	Very small	Shallow swampy basins in unit 1	Grassy upper basin slopes with alpine humus soils (Barrington) with much basaltic rubble; swamps with black sphagnum moor peats, in places overlying lake sediment	Dense climax grassland, mainly *Poa* sp., with *Plantago* sp., Cyperaceae, Restionaceae, and ericoid shrubs; trees absent but *E. stellulata* present in shrub form

ULAN LAND SYSTEM (14 SQ. MILES)

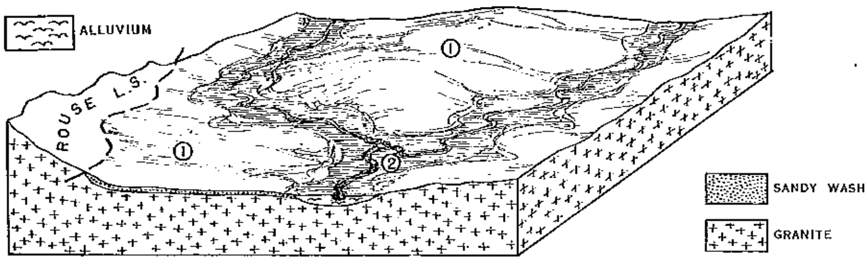
Geology.—Palaeozoic granite.

Rainfall.—24 in.

Locality.—Western end of central Goulburn valley.

Elevation.—1400–1600 ft. **Local Relief.**—Less than 100 ft.

Wooded Area.—20%.



Unit	Area (%)	Land Forms	Soils	Vegetation
1	80	Smooth, gently undulating slopes, 3–7%, up to ½ mile long and covered by gritty wash derived from adjacent steeper granite country; wash thin on upper parts of the unit, but thickening to more than 10 ft on lower parts; occasional slabby granite outcrops	Mainly pale brown sandy and gritty earths (Ulan); sometimes gradual texture increase to moderately fine in subsoil; some low rock outcrop	Savannah woodland of box, gum, and ironbark, mostly thinned or cleared, 30 ft high, ironbarks commonest, with scattered *Angophora floribunda*, *E. macrorrhyncha*, *E. melliodora*, and *E. tereticornis* and other non-eucalypts, dense 4 ft ericoid shrubs; poor ground cover of *Aristida* and *Danthonia* spp. and *Stipa setacea*
2	20	Gritty sand and clay in valley bottoms forming alluvial belt up to ¼ mile wide, resting on weathered granite; no terraces; extensive recent gullying	Restricted observations; presumably mainly solonetzic soils; near gully heads or along gullies patches of grey cracking clays (Moolarban) strongly alkaline throughout or in subsoil, possibly on truncated solonetzic soils	Cleared and under pioneer grasses

UPPER ROUCHEL LAND SYSTEM (293 SQ. MILES)

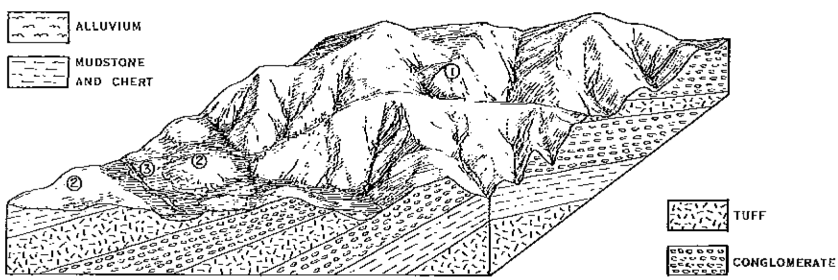
Geology.—Devonian and Carboniferous mudstone, tuff, and chert, and minor lavas.

Rainfall.—24–30 in.

Locality.—North-eastern mountains.

Elevation.—500–2700 ft. **Local Relief.**—50–500 ft.

Wooded Area.—10%.



Unit	Area (%)	Land Forms	Soils	Vegetation
1	80	Moderately steep (10–30%), rounded hills, and lower slopes, spurs, and major valley floors in more rugged areas; broken topography with close drainage pattern; sheet erosion and outcrops frequent	Predominantly solonetzic soils (Clanricard, also Overton, Strathearn, Piercefield); non-humic skeletal soils, mostly fine-textured, co-dominant; small areas with podzolic soils (Binnie, Pokolbin) in eastern wetter parts; some brown or red earths (Moonan) especially on fans	Savannah woodland of box and gum 30 ft high, mostly thinned or cleared, mainly *E. albens* where warm, *E. laevopinea* where cooler, with *E. melliodora* and *E. tereticornis* throughout and ironbarks confined to the southern areas; shrubs rare; good grass cover of *Dichanthium* spp. or poor grass cover of *Aristida* and *Hordeum* spp. and *Stipa setacea*; *Medicago* and *Trifolium* spp. present
2	15	Undulating areas with few outcrops, and slopes less than 15% (similar to Timor land system, unit 1)	Predominantly solonetzic soils (Clanricard) (similar to Timor land system, unit 1)	Savannah woodland of box and gum 30 ft high, with *Aristida* and *Dichanthium* spp. (similar to Timor land system, unit 1)
3	< 5	Alluvium in valley bottoms, less than ¼ mile wide; terraced; liable to flooding in lower parts	Restricted observations; cracking clays (Segenhoe) and solonetzic soils (Clanricard); possibly also chernozems	Cleared and under cultivation or pioneer grasses

VACY LAND SYSTEM (112 SQ. MILES)

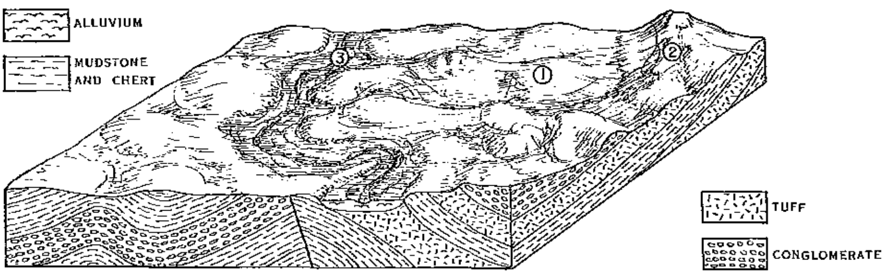
Geology.—Carboniferous mudstone, tuff, and chert.

Rainfall.—28–40 in.

Locality.—North-eastern mountains.

Elevation.—100–700 ft. **Local Relief.**—Less than 100 ft.

Wooded Area.—10%.



Unit	Area (%)	Land Forms	Soils	Vegetation
1	85	Undulating country with slopes less than 12% and occasional outcrops, particularly on rises; sandy or gravelly fans and surface wash in vicinity of steep hills in adjacent land systems; shallow valleys at ¼–½ mile intervals with up to 10 ft of colluvial and/or alluvial fill	Predominantly deep podzolic soils (mainly Binnie, rarely Pokolbin); possibly also earths on fans or colluvium	Tall mixed woodland, mostly cleared and under a good cover of *Dichanthium* spp., *Paspalum dilatatum*, or *Sporobolus* spp., with *Themeda australis* where protected; otherwise poor grass cover under 50 ft *E. amplifolia*, *E. maculata*, *E. moluccana*, *E. tereticornis*, and ironbarks; scanty to dense shrubs
2	10	Rolling hills with frequent outcrops (similar to Wallaroo land system, unit 1)	No records; probably similar to unit 1 but shallower (similar to Wallaroo land system, unit 1)	Tall mixed woodlands, dense leafy grasses where cleared (similar to Wallaroo land system, unit 1)
3	10	Sandy alluvium in valley bottoms; less than ¼ mile wide; terraced; liable to flooding at lower levels	No records; probably not dissimilar to Hunter land system, units 3 and 4 with alluvial regosols, earths, meadow soils; some prairie soils	Cleared and under cultivation or pioneer grasses

WALLAROO LAND SYSTEM (358 SQ. MILES)

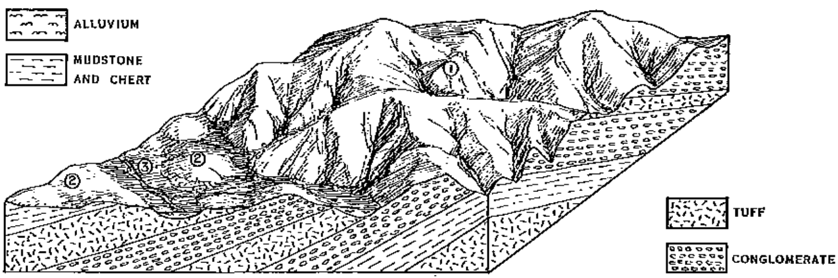
Geology.—Carboniferous mudstone, tuff, and chert.

Rainfall.—30–40 in.

Locality.—North-eastern mountains.

Elevation.—100–1000 ft. **Local Relief.**—100–400 ft.

Wooded Area.—20%.



Unit	Area (%)	Land Forms	Soils	Vegetation
1	80	Moderately steep rounded hills 50–300 ft high, with slopes 10–30%; lower slopes of major valleys in more rugged areas; broad structural benches and plateaux with slopes around 10% fringed by cliffs and bluffs up to 50 ft high	Predominantly podzolic soils (mainly Binnie, also Vaux, Pokolbin); earths (Cumbo, Woolooma, Dusodie) and skeletal soils co-dominant; rare patches of krasnozems (Torrielodge) on some hill crests	Tall mixed woodland, mostly thinned or cleared, 60 ft high, of *E. maculata, E. acmenioides, E. canaliculata, E. eugenioides, E. globoidea, E. propinqua, E. tereticornis*, with scattered smaller trees of *Casuarina torulosa*; shrubs and grasses sparse to dense; cleared ground under dense cover of *Imperata cylindrica, Medicago* spp., *Paspalum dilatatum, Pteridium aquilinum, Sporobolus* and *Trifolium* spp.
2	15	Undulating lowland areas with few outcrops (similar to Vacy land system, unit 1)	Similar to unit 1, but without krasnozems (similar to Vacy land system, unit 1)	Tall mixed woodland mostly cleared (similar to Vacy land system, unit 1)
3	<5	Sandy alluvium in valley bottoms; terraced and liable to flooding at lower levels; less than ¼ mile wide	Older terraces with podzolic soils (Binnie, Vaux, Rosscole); rarely solonetzic soils (Clanricard) or cracking clays (Segenhoe); also meadow podzolic soils (Fal Brook), earths (Dusodie); young terraces with alluvial regosols (Rouchel, Maitland); may be stony	Cleared and under pioneer grasses

WARKWORTH LAND SYSTEM (31 SQ. MILES)

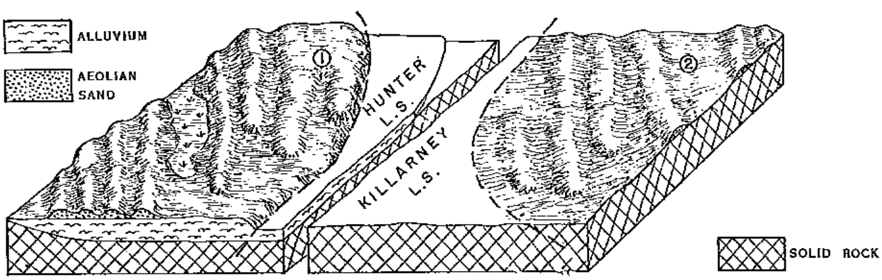
Geology.—Quaternary aeolian sand.

Rainfall.—24–28 in.

Locality.—Central lowlands.

Elevation.—100–300 ft. **Local Relief.**—Up to 25 ft.

Wooded Area.—50%.



Unit	Area (%)	Land Forms	Soils	Vegetation
1	75	Linear sand dunes 3–20 ft high, resting on high river terrace; aligned NW.–SE.; generally stable but subject to blow-outs; swampy seepage zones at margins	Sandy aeolian regosols (Warkworth) of single grain structure; very little organic matter in surface	Anomalous woodland, trees usually scattered, 12–40 ft high, *Banksia integrifolia*, *Angophora floribunda*, *E. tereticornis*, *Callitris endlicheri*, much cleared and under grassland of *Aristida* and *Eragrostis* spp., with *Imperata cylindrica*, *Pteridium aquilinum*, and *Stenotaphrum secundatum* where damp; shrubs uncommon
2	25	Long, low, linear dunes; less than 3 ft high, 100–200 yd apart, and up to ½ mile long, aligned NW.–SE.; thin sand sheets with gentle undulations reflecting the underlying rock surface	Sandy aeolian regosols (Warkworth) over mottled clay at shallow to moderate depth	Dense heath 5 ft high, of many species; scanty grasses; trees scattered, up to 40 ft high, *E. agglomerata*, *E. crebra*, *E. tereticornis*

WATAGAN LAND SYSTEM (58 SQ. MILES)

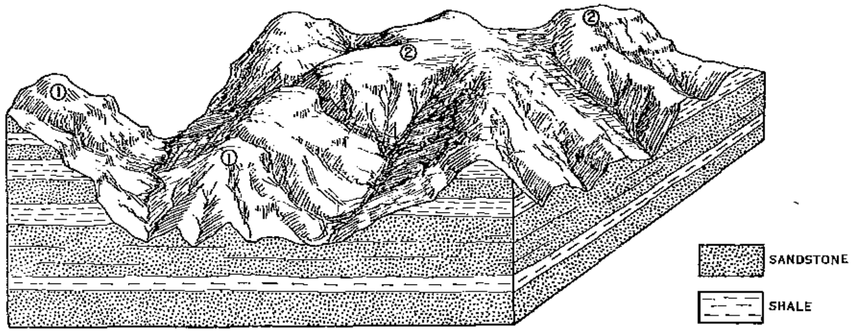
Geology.—Triassic sandstone and minor shale.

Rainfall.—36–40 in.

Locality.—Eastern end of southern mountains.

Elevation.—500–1800 ft. **Local Relief.**—Up to 1000 ft.

Wooded Area.—100%.



Unit	Area (%)	Land Forms	Soils	Vegetation
1	95	Steep ridges; slopes 25–40% with boulder-strewn, narrow, sloping benches below sandstone or conglomerate bluffs and cliffs up to 50 ft high; rounded crests up to 100 yd wide; deep, narrow valleys	Predominantly shallow coarse-textured, humic, skeletal soils, occasionally fine-textured; also earths (Woolooma, Cumbo), and podzolic soils (Pokolbin, Vaux) on shaly sandstones in stable sites	Wet sclerophyll forest, 100 ft, *E. saligna* dominant over most, with *E. acmenioides*, *E. agglomerata*, *E. pilularis*, and *Syncarpia glomulifera*; discontinuous lower layer of *Casuarina torulosa*, *Acacia* spp., and regrowth trees; dense 6 ft shrub layer; non-eucalypt trees and shrubs where sheltered; scanty grasses in sparse herbaceous ground layer
2	<5	Rolling plateau and broader ridge tops; slopes 0–15%; outcrops rare except where shallow valleys steepen abruptly at outer margins of the unit	Predominantly earths (Growee, Woolooma, Baerami) of mostly moderate depth; possibly podzolic soils	10% as for unit 1, remainder pine plantations or eucalypt regrowth

YARRAMOOR LAND SYSTEM (38 SQ. MILES)

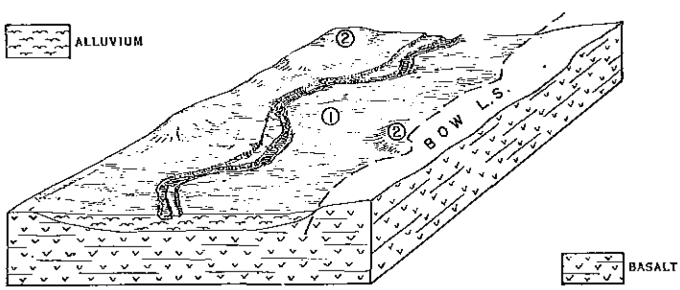
Geology.—Quaternary basaltic alluvium.

Rainfall.—22 in.

Locality.—Merriwa plateau.

Elevation.—600–1500 ft. **Local Relief.**—Up to 30 ft.

Wooded Area.—Negligible.



Unit	Area (%)	Land Forms	Soils	Vegetation
1	90	Alluvium derived from basalt; main terrace with level surface, rarely flooded, 10–30 ft above stream bed and $\frac{1}{4}$–$\frac{1}{2}$ mile wide, and of silt and clay, with subsidiary sand, overlying gravel; lower sandy, silty terraces of minor extent with undulating surface liable to frequent flooding	Mainly deep dark or black cracking clays (Segenhoe); lime nodules usually throughout, sometimes only in subsoil; sometimes with thin eluvial A horizons, grading into degraded black earths (Rowan); rarely grey coloured (Moolarban) around saline depressions; younger terraces with alluvial regosols of various textures	Cleared and under various grasses, clovers, medics, and weeds; or under crops; or eucalypt tree savannah of *Angophora floribunda* associated with *Eucalyptus melliodora* and lesser amounts of *E. tereticornis* and *E. albens*; *Casuarina cunninghamiana* along river banks; shrubs rare
2	10	Patches of undulating basalt lowlands (similar to Bow land system, unit 1)	Predominantly cracking clays (Segenhoe) (similar to Bow land system, unit 1)	Eucalypt tree savannah (similar to Bow land system, unit 1)

PART III. CLIMATE OF THE HUNTER VALLEY

By A. D. TWEEDIE*

I. GENERAL CLIMATIC CHARACTERISTICS

Weather sequences underlying the climatic character of the Hunter valley in the main relate to six air masses and the pressure patterns that stimulate their movement. In detail, in a region of strong relief contrasts, topography and aspect will also influence the climatic pattern.

Winter climates are strongly influenced by southern maritime air masses whose source region lies to the south of the continent. Cool to cold temperatures are characteristic, but the moisture condition of the air mass depends in large measure on its trajectory before reaching the Hunter valley, and in particular the track in relation to the trend of the New South Wales coast south of Newcastle. Onshore streams of southern maritime air in winter months are usually conditionally unstable and bring instability rains to localized areas of the coast and adjacent highlands. Southern maritime air streams that cross the coast before reaching the Hunter valley, however, are more or less dehydrated, the drying out reaching a climax in the modified southern maritime air mass which, in response to pressure patterns created by wave depressions south of Victoria, moves into the valley from the west. Light rain in the far west of the valley near Dalkeith and snowfalls on the western slopes of the Barrington plateau and Mt. Royal Range may result, but for most of the Hunter valley the outcome is clear, sparkling, and dry weather, with cold westerly winds and a high risk of frost. In contrast, wave depressions forming off the New South Wales coast stimulate the inflow of tropical Tasman air masses of moderate temperature, high moisture content, and high conditional instability. The outcome is widespread and frequently heavy rain in the lower Hunter.

In the summer, weather sequences normally progress from a cool and relatively stable southern air mass, through indifferent air masses of light airs, cool nights, and the possibility of afternoon thunderstorms to the inflow of moist warm air from the north-east with increased prospect of thunderstorm rain. The new cycle commences with squall line conditions as the southerly air replaces the northerly flow. A check to the eastward migration of anticyclones, and a more than normal east–west orientation of the intervening trough will introduce a strong flow of hot dry blustery air of tropical continental origin. Heatwave conditions obtain, with day temperatures in excess of 95 °F and usually little relief at night, though the change to southerly air with the onset of the "southerly buster" can produce a fall of 20 °F in as many minutes. Still less frequently, moving through western New South Wales in the trough between two successive anticyclones, warm saturated air of equatorial origin clashing with adjacent air masses will produce widespread flood rains which can register heavy falls in stations of the upper Hunter.

*Department of Geography, Newcastle University College.

The region, then, is one that is centrally located in relation to the weather sequences of eastern Australia. In average years its pattern of rainfall and temperature reflects this intermediate location, but unusual years can produce climatic conditions more characteristic of the winter rain–summer drought of southern Australia or of the summer rain–winter drought of the north.

The greater part of the region is a subhumid zone which becomes more humid in a thin coastal strip in the east and the higher country in the south and, even more so, in the north-east. There is no marked seasonality in the distribution of measured precipitation, though coastal stations have a maximum in the late autumn–early winter, with a secondary maximum in December. Inland stations, in contrast, have a maximum in the summer months with a secondary maximum in July. Most of the precipitation occurs as rain, though the high country of the Mt. Royal Range and the Barrington plateau experience at least one snowfall each year.

In summer throughout the valley high daytime temperatures occur. Only on the coast are they tempered by sea breezes which rarely reach more than 20 miles inland. There is no frost on the coast itself, but frosts are experienced in winter in all other locations, the season of frost risk extending from 2 months at Maitland to 5 months at Dalkeith and Murrurundi. High summer temperatures and associated water need together with the moderate rainfall bring a seasonal moisture stress for plant life in summer at all but the highest parts of the region, and frost hazards and low temperature restrict the growing season in winter in all but a very narrow coastal strip of the Hunter valley.

(*a*) *Precipitation*

In many of its important features (annual total, seasonal distribution, intensity, and variability) measured precipitation shows broadly similar characteristics over much of the valley. A general relation to relief and distance from the sea is evident throughout, but only on the thin coastal strips downstream from Maitland and on the steep slopes of Barrington plateau do the values change rapidly. The data for seven stations are summarized in Table 2.

Over half the valley (Fig. 2) measured precipitation totals between 22 and 30 in. a year, but on the coast the total rises to 40 in. and in the higher part of the Barrington plateau to more than 60 in. Lowest annual totals (less than 20 in. a year) are recorded in the middle valley near the confluence of the Hunter and Goulburn Rivers, and from this semi-arid core, rainfall totals increase steadily in all directions except westward until the gradients steepen in the high country of the north-east or on the coastal fringe.

The number of rain days per year shows a similar pattern. Coastal stations (Newcastle, 128) and south- and east-facing slopes of the north-east highland areas record more than 100 rain days per year. Elsewhere 80 to 90 rain days are typical. Intensities of rainfall per rain day, however, are highest at the subcoastal stations of Maitland and Cessnock, the values of 0·37 in. for these stations falling to 0·32 in. at Newcastle and to 0·26 in. at Dalkeith. In the north-west, at Murrurundi, intensities rise again to a yearly average of 0·35 in. for each rain day. Throughout the valley intensities are higher in the summer 6 months, a reflection of the increased

TABLE 2
SUMMARY OF RAINFALL CHARACTERISTICS FOR SEVEN CLIMATOLOGICAL STATIONS

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
Newcastle													
Rainfall (in.)	3·01	2·96	3·84	5·33	4·64	3·66	4·44	2·34	2·97	2·51	2·21	3·45	41·36
Variability (%)	53	65	54	60	61	71	51	45	54	65	57	56	16
Number of wet days	12	11	11	13	12	12	11	10	7	8	10	11	128
Rain per wet day (in.)	0·25	0·27	0·35	0·41	0·39	0·31	0·40	0·23	0·42	0·31	0·22	0·31	0·32
Maitland													
Rainfall (in.)	3·00	2·83	3·28	4·06	2·66	2·66	2·85	1·36	2·64	2·15	2·23	3·63	33·35
Variability (%)	58	57	54	66	80	73	75	59	64	66	63	53	21
Number of wet days	8	8	8	8	7	9	8	7	7	7	7	7	91
Rain per wet day (in.)	0·38	0·35	0·41	0·51	0·38	0·29	0·36	0·19	0·38	0·31	0·32	0·52	0·37
Cessnock													
Rainfall (in.)	2·53	2·57	2·57	3·19	2·33	1·75	2·39	1·18	1·82	1·96	2·17	3·20	27·66
Variability (%)	59	79	59	61	94	80	77	61	69	71	69	58	21
Number of wet days	7	7	7	6	6	6	6	6	5	6	6	7	75
Rain per wet day (in.)	0·36	0·37	0·37	0·53	0·39	0·29	0·40	0·20	0·36	0·33	0·36	0·46	0·37
Jerry's Plains													
Rainfall (in.)	2·78	2·05	2·16	2·19	1·56	1 73	2·11	1·17	1·67	1·85	2·59	2·98	24·84
Variability (%)	45	65	65	63	87	78	60	53	59	53	68	52	24
Number of wet days	8	7	7	7	6	7	7	7	7	8	7	7	85
Rain per wet day (in.)	0·35	0·29	0·31	0·31	0 26	0·25	0·30	0·17	0·24	0·23	0·37	0·42	0·30

Scone													
Rainfall (in.)	2·82	2·06	2·19	1·92	1·39	1·79	2·04	1·22	1·75	1·60	2·25	3·00	24·03
Variability (%)	42	67	80	59	78	77	59	46	60	47	61	46	24
Number of wet days	8	7	6	7	7	9	9	8	6	8	7	8	90
Rain per wet day (in.)	0·35	0·29	0·36	0·27	0·20	0·20	0·23	0·15	0·29	0·20	0·32	0·38	0·27
Murrurundi													
Rainfall (in.)	3·08	2·17	2·41	2·19	1·45	2·58	2·79	2·01	2·05	2·17	2·57	3·55	29·02
Variability (%)	35	55	72	62	73	65	47	59	54	52	55	45	21
Number of wet days	7	7	5	6	6	9	8	8	7	8	6	7	84
Rain per wet day (in.)	0·44	0·31	0·48	0·36	0·24	0·29	0·35	0·25	0·29	0·27	0·43	0·51	0·35
Dalkeith													
Rainfall (in.)	2·29	2·04	2·06	1·86	1·28	1·66	1·98	1·40	1·55	1·71	2·17	2·42	22·42
Variability (%)	43	72	76	61	85	71	58	46	59	49	68	51	24
Number of wet days	7	7	5	6	7	9	9	9	6	8	7	7	87
Rain per wet day (in.)	0·33	0·29	0·41	0·31	0·18	0·18	0·22	0·14	0·26	0·21	0·31	0·35	0·26

TABLE 3

SUMMARY OF TEMPERATURE AND HUMIDITY DATA FOR SEVEN CLIMATOLOGICAL STATIONS*

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year	Range
Newcastle (altitude 112 ft)														
Maximum temperature (°F)	77·7	77·7	76·1	72·1	67·1	62·9	61·4	64·1	68·2	71·3	73·9	75·9	70·7	16·3
Minimum temperature (°F)	66·6	67·1	64·7	59·5	53·7	49·5	47·7	48·8	52·6	57·2	61·3	64·3	57·7	19·4
Mean temperature (°F)	72·1	72·4	70·1	65·8	60·4	56·2	54·7	56·4	60·4	64·2	67·6	70·1	64·2	17·4
Heat-wave days (> 95°F)	1·0	0·7	0·1	0	0	0	0	0	0	0	0·7	0·8	3·3	
Frost days (< 32°F)	0	0	0	0	0	0	0	0	0	0	0	0	0	
Mean relative humidity (%)	74	76	76	74	74	71	70	68	67	69	71	75	73	
Maitland (altitude 19 ft)														
Maximum temperature (°F)	87·3	86·5	83·0	76·6	69·7	64·4	63·6	67·5	73·5	79·2	83·6	85·8	76·7	23·7
Minimum temperature (°F)	63·7	63·4	60·0	54·6	48·4	44·8	42·9	44·1	48·2	53·0	57·9	61·4	53·5	20·8
Mean temperature (°F)	75·5	74·9	71·5	65·6	59·1	54·6	53·2	55·7	60·8	66·1	70·8	73·6	65·1	22·3
Heat-wave days (> 95°F)	5·4	3·5	1·4	0	0	0	0	0	0	1·0	3·7	4·5	19·5	
Frost days (< 32°F)	0	0	0	0	0·3	1·4	2·7	1·9	0·2	0	0	0	6·5	
Mean relative humidity (%)	68	69	74	75	75	76	73	72	70	68	67	68	71	
Cessnock (altitude 40 ft)														
Maximum temperature (°F)	86·9	86·0	83·0	75·7	70·1	64·2	63·5	66·5	72·9	77·5	82·0	85·5	76·1	23·4
Minimum temperature (°F)	62·7	62·0	58·8	52·4	45·1	40·3	38·5	40·8	45·0	50·8	56·5	59·7	51·0	24·2
Mean temperature (°F)	74·8	74·0	70·9	64·1	57·6	52·3	51·0	53·7	58·9	64·1	69·3	72·6	63·6	23·8
Heat-wave days (> 95°F)	5·2	3·9	1·9	0	0	0	0	0	0	0	4·5	5·0	20·5	
Frost days (< 32°F)	0	0	0	0·1	0·5	4·4	6·8	2·1	0·1	0	0	0	14·0	
Jerry's Plains (altitude 150 ft)														
Maximum temperature (°F)	90·9	90·1	85·7	77·8	70·7	64·6	63·6	67·8	74·7	81·7	87·6	90·6	78·8	27·3
Minimum temperature (°F)	62·1	61·6	58·5	51·1	44·2	40·2	38·5	39·4	43·8	49·5	55·1	59·5	50·3	23·6
Mean temperature (°F)	76·5	75·9	72·1	64·5	57·4	52·4	51·0	53·6	59·3	65·6	71·4	75·1	64·6	25·5
Heat-wave days (> 95°F)	7·3	6·1	4·1	0·4	0	0	0	0	0	2·4	5·2	7·4	32·9	
Frost days (< 32°F)	0	0	0	0·4	1·8	4·5	6·8	4·0	1·0	0	0	0	18·5	

Scone (altitude 680 ft)														
Maximum temperature (°F)	91·0	88·6	84·6	76·4	69·1	62·7	61·7	65·8	72·8	79·7	85·4	88·8	77·2	29·3
Minimum temperature (°F)	61·5	60·7	56·5	49·1	42·6	38·9	37·0	38·5	42·4	49·1	54·2	58·1	49·0	24·5
Mean temperature (°F)	76·3	74·7	70·5	62·7	55·9	50·8	49·3	52·1	57·6	64·4	69·8	73·5	63·1	27·0
Heat-wave days (> 95°F)	8·6	5·8	2·8	0·4	0	0	0	0	0	0·9	3·4	7·9	29·8	
Frost days (< 32°F)	0	0	0	0·2	0·5	5·2	6·8	4·9	1·2	0	0	0	18·8	
Murrurundi (altitude 1548 ft)														
Maximum temperature (°F)	88·8	86·3	82·7	73·9	66·0	59·4	58·7	62·4	69·6	76·2	81·9	86·4	74·4	30·1
Minimum temperature (°F)	60·8	58·8	55·2	48·5	41·9	37·9	36·1	37·1	42·2	48·5	53·1	57·1	48·1	24·7
Mean temperature (°F)	74·8	72·5	68·9	61·2	53·9	48·7	47·4	49·7	55·9	62·3	67·5	71·7	61·2	27·4
Heat-wave days (> 95°F)	5·3	3·2	1·3	0	0	0	0	0	0	0	1·2	3·3	14·3	
Frost days (< 32°F)	0	0	0	0·3	2·0	7·2	10·4	7·1	2·4	0·1	0	0	29·5	
Dalkeith (altitude 800 ft)														
Maximum temperature (°F)	85·7	84·2	79·5	71·5	64·3	58·5	57·4	60·8	67·7	74·6	80·1	83·8	72·3	28·3
Minimum temperature (°F)	60·9	60·3	56·1	48·7	41·7	37·4	35·7	36·9	41·1	47·7	53·8	58·6	48·2	25·2
Mean temperature (°F)	73·3	72·2	67·8	60·1	53·0	47·9	46·5	48·9	54·4	61·1	66·9	71·2	60·3	26·8
Heat-wave days (> 95°F)	3·8	2·0	0·6	0	0	0	0	0	0	0	0·7	2·2	9·3	
Frost days (< 32°F)	0	0	0	0·4	4·0	9·9	12·0	8·9	4·7	0·8	0	0	40·7	
Mean relative humidity (%)	58	61	66	72	76	78	75	72	67	62	58	59	65	

* Sources of data: Bureau of Meteorology (1956) and Foley (1945).

incidence of thunderstorm rain in that season. For the middle and lower valley, however, the highest recorded daily fall was in June 1930. Dalkeith and Murrurundi, in contrast, recorded their highest daily total in February 1955.

The variability of the mean annual rainfall, expressed as a mean deviation from the mean, again shows a contrast between the coastal fringe and the remainder of the lowland sections of the valley. At Newcastle average annual variability is 16%; at Maitland and Cessnock it is 21%; at Jerry's Plains, Scone, and Dalkeith it increases to 24% and it falls again to 21% at Murrurundi. Throughout the valley monthly variability values are highest in late autumn–early winter.

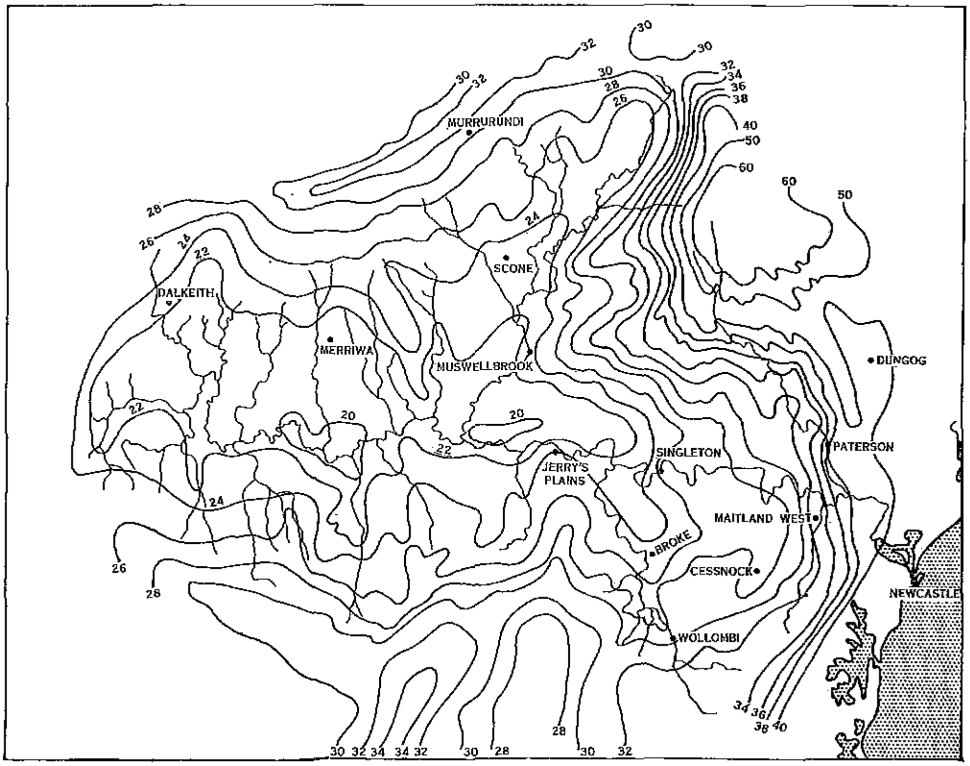


Fig. 2.—Isohyets of annual rainfall distribution (in.).

(*b*) *Temperature and Humidity*

Temperature records are available for the seven stations of Newcastle, Maitland, Cessnock, Jerry's Plains, Scone, Murrurundi, and Dalkeith (Table 3). Each of the inland stations is in a lowland location near mountainous country and the records may be less representative than they should, because of air drainage and local radiation effects.

Differences in monthly temperature data show some correlation with distance from the coast though, as with rainfall, the maritime influence diminishes most rapidly in the lower valley between Newcastle and Maitland. Daily mean temperatures show a regular progression from month to month with a slightly asymmetric curve. Minimum values for all stations are in July and maxima in January, except for Newcastle where maximum mean temperatures occur in February. This suggests that maritime influences are felt throughout the valley, but that in Newcastle the maritime influence is most evident in summer. Mean daily temperatures in the 3 summer months, December, January, and February, exceed 70°F for all stations, and in the

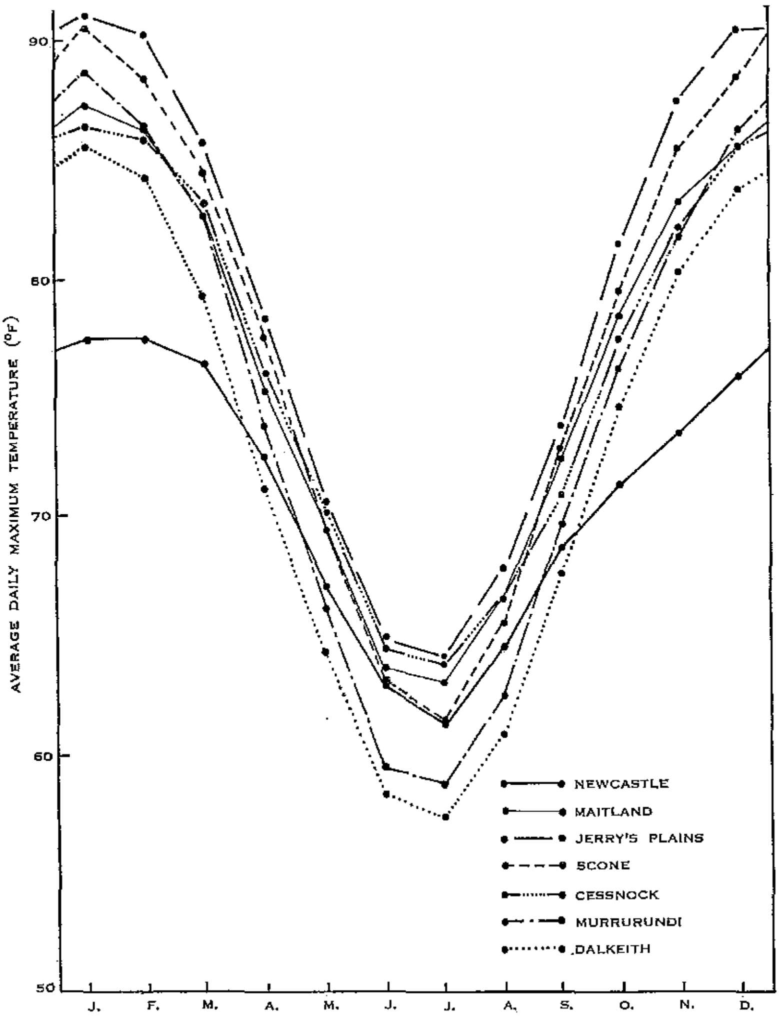


Fig. 3.—Mean maximum temperature at seven stations.

3 winter months are less than 56°F. Annual mean temperature ranges exceed 20°F for all stations except Newcastle, and the distance from the sea is again reflected in the increase of ranges from 22·3°F at Maitland to 27·4°F at Murrurundi.

Continentality with distance from the sea is better illustrated with mean monthly values of daily maximum and minimum temperatures (Figs. 3 and 4), and again the distinction between Newcastle and the remainder of the valley upstream from Newcastle is apparent. The mean minimum temperature for Newcastle in July is 47·7°F. Mid-valley and upper-valley stations record July minima below 39°F, Newcastle's minimum being 11°F higher than that of Murrurundi. In summer, mean minimum temperatures show a closer homogeneity for the valley, Newcastle's figure of 67°F

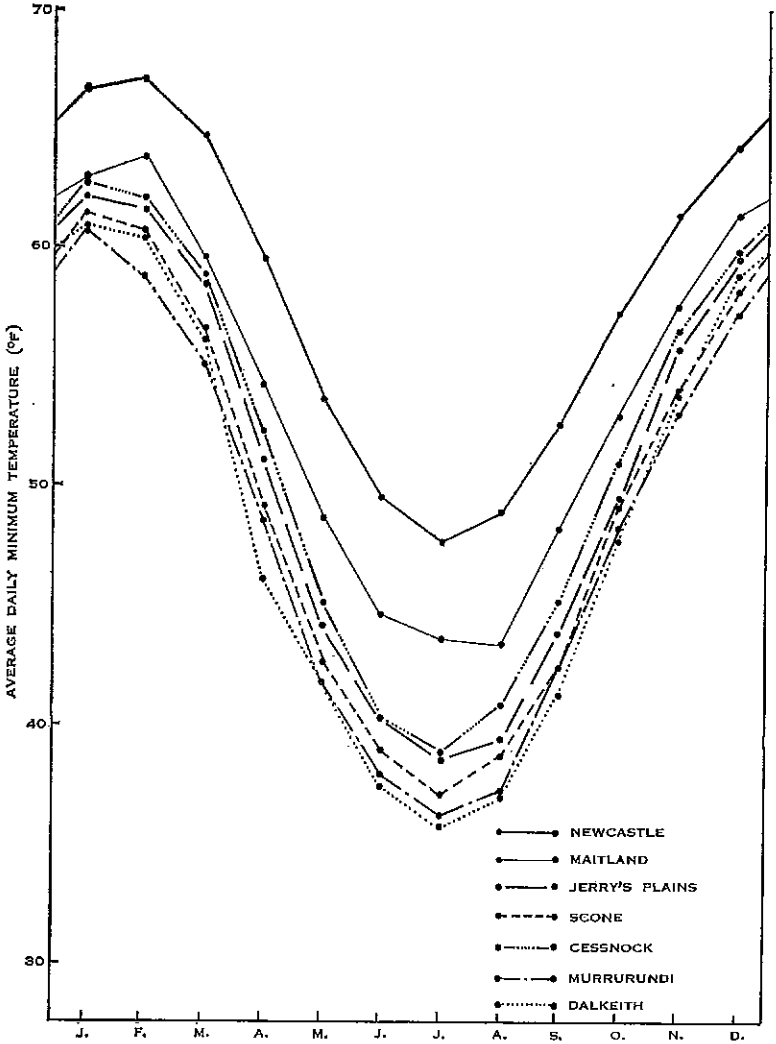


Fig. 4.—Mean minimum temperature at seven stations.

being only 6°F higher than the corresponding reading for Murrurundi. Mean maximum temperatures show a similar effect of distance from the sea. Values in summer at Newcastle are 77·7°F whereas mean maximum temperatures of over 85°F are recorded at all other Hunter valley stations in the warmest summer month, with Jerry's Plains recording maximum temperatures over 90°F for all 3 summer months. In winter mean maximum temperatures are more uniform, Newcastle's 61·4°F for July being only 2·4°F lower than Jerry's Plains and 4°F higher than Dalkeith in that month.

Altitude and location in relation to the sea and local relief features are reflected in the recorded incidence of frost at Hunter valley stations (Table 4). Severe frosts with screen temperatures below 32°F are not recorded at Newcastle in the average year, but 1·2 such days occur at Maitland, and Jerry's Plains records 18·5 days. Heavy frost incidence is highest at Dalkeith (40·7 days) despite an elevation of only 800 ft, but at Scone and Murrurundi local air drainage conditions have reduced this figure to 18·8 and 29·5 days respectively. The period of frost risk, however, shows a closer correlation with distance from the sea. The average incidence of light

TABLE 4

FROST INCIDENCE AT SEVEN CLIMATOLOGICAL STATIONS*

	Average Date of First Record of		Average Date of Last Record of		Average Frost-free Period (days)
	36°F	32°F	32°F	36°F	
Newcastle	—	—	—	—	365
Maitland	June 13	July 1	July 12	Aug. 16	300
Cessnock	May 17	June 5	Aug. 13	Sept. 10	248
Jerry's Plains	May 8	May 26	Aug. 28	Sept. 26	223
Scone	May 4	June 3	Sept. 3	Oct. 2	213
Murrurundi	Apr. 24	May 17	Aug. 20	Oct. 5	200
Dalkeith	Apr. 21	May 9	Sept. 30	Oct. 9	193

* Source of data: Foley (1945).

frosts (screen temperatures less than 36°F) begins in late April in the inland stations of Murrurundi and Dalkeith and lasts till early October. At central valley stations (Scone and Jerry's Plains) early May till the end of September is a frost risk period, and at Maitland light frosts can be expected between mid June and mid August. Growing seasons unrestricted by frost are thus reduced from 365 days at Newcastle to 193 days at Dalkeith with the figure for intervening stations reflecting their distance from the sea.

Although the higher elevations of the inland locations have a modifying effect, heatwaves in summer increase in frequency with distance from the sea. Maximum temperatures exceeding 95°F are recorded on 3·3 days in the average year at Newcastle, on 32·9 days at Jerry's Plains, 9·3 days at Dalkeith, and 14·3 at Murrurundi.

Relative humidity is recorded at three stations only—Newcastle, Maitland, and Dalkeith (Fig. 5). At Newcastle values are highest (76%) in late summer with lowest values (67%) in September. Maitland, only 20 miles away, almost reverses this pattern with a maximum (76%) in August and a minimum (68%) in January—emphasizing again the strong climate gradient, particularly in regard to moisture, in this area for the lower Hunter. Dalkeith, with a seasonal range double that of the other stations, has a maximum (78%) in June and a minimum (58%) in November, a rhythm more in harmony with the temperature values for that station.

II. Climate in Relation to Plant Growth

Significant aspects of climate affecting the plant growth of a region are the seasonal values and critical limits of heat and moisture which determine the length and characteristics of the growing season. In this region both factors are operative, both summer moisture stress and low winter temperatures placing limitations on the period of active plant growth. Occurring separately in different seasons, these limitations reduce the period of unrestricted plant growth for most of the Hunter valley to the intervening seasons of spring and autumn.

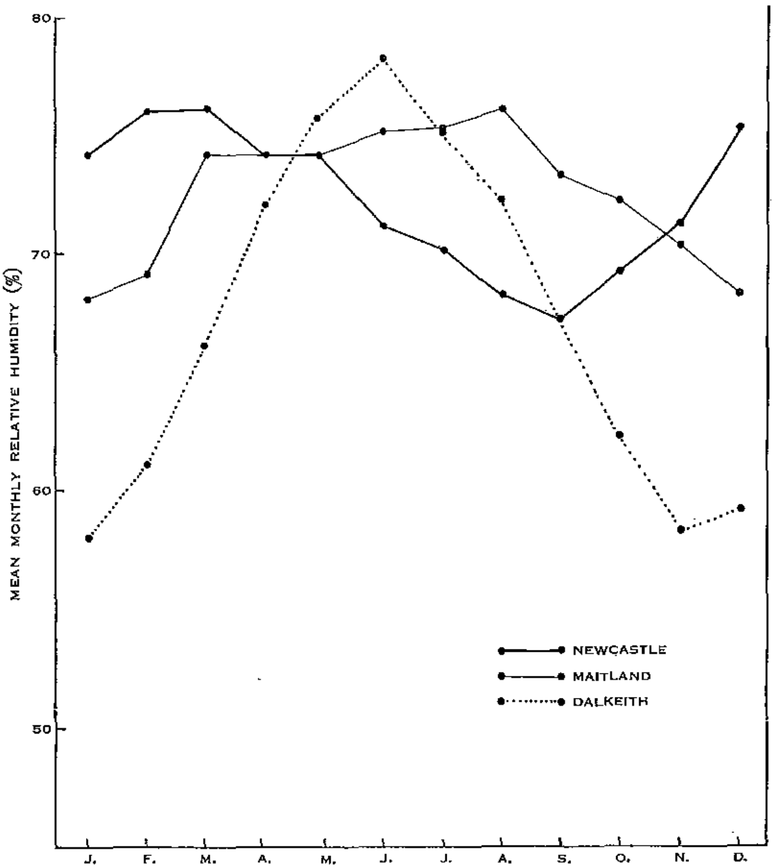


Fig. 5.—Mean monthly relative humidity at three stations.

A full assessment of the moisture factor as a limitation to the growing season demands a knowledge of soil moisture above wilting point. In the absence of the direct measurement of this feature, methods have been suggested for its computation from existing climatic data by the compilation of a moisture balance between the income of water as indicated by measured precipitation and the outflow of water as drainage and evapotranspiration. Of the methods put forward to compute evapotranspiration, those suggested by Penman (1948) and Prescott, Collins, and Shirpurkar (1952) were precluded by lack of adequate data in a region where local relief reduces the representativeness of the available records for the values specified. Mean temperature values, however, are more readily available, eight stations in the valley recording this feature, so that the formula put forward by Thornthwaite (1948) and the refined application of this suggested by Thornthwaite and Mather (1957) can be more widely applied.

Field experience in Canterbury, New Zealand, a region of comparable moisture status, suggests little practical difference between results computed from Thornthwaite's method and those obtained from Penman's (Fitzgerald and Rickard 1960).

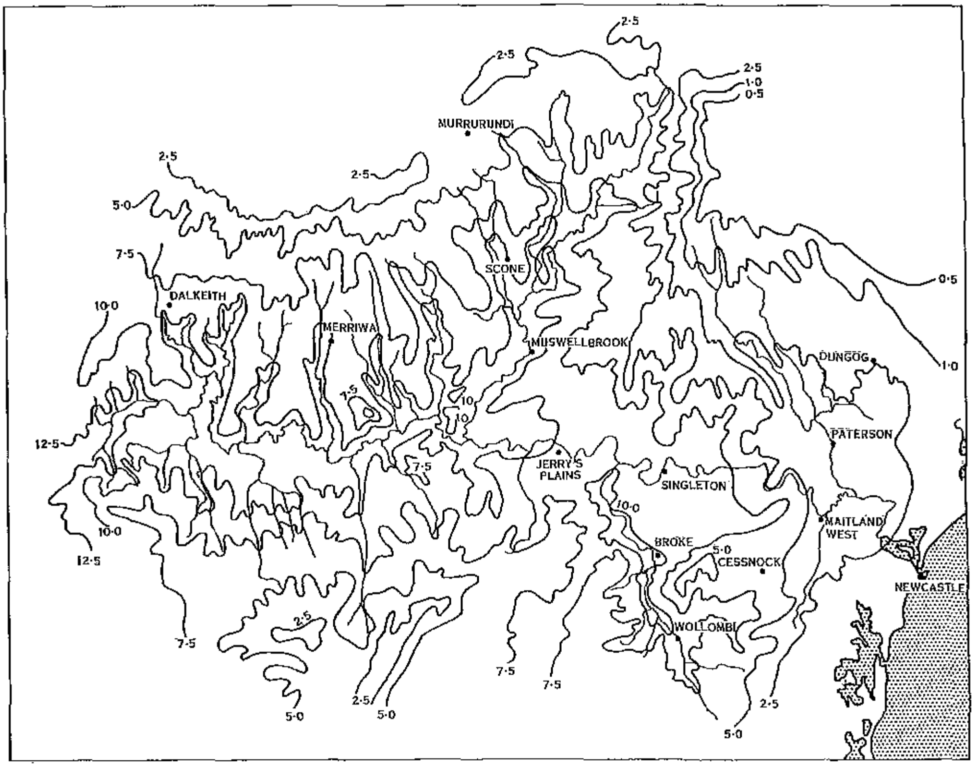


Fig. 6.—Annual moisture deficit (in.).

Moreover, by applying a standard lapse rate of 1 °F per 300 ft of altitude to recorded mean temperature data, this procedure can be extended to embrace a larger network of rainfall recording stations to obtain a more realistic picture of the moisture status of a hilly region than would otherwise be possible. Thornthwaite's method has accordingly been used throughout this paper.

In the computation of the water balance by this method three assumptions are made. First, that surface run-off is negligible until soil storage reaches 4 in.; and all measured rainfall enters the soil at the point of impact to add to the reservoir of soil moisture or to subsoil drainage. Secondly, that the soil moisture reservoir (i.e. water available for plant use between wilting point and field capacity) is 4·00 in.

TABLE 5
WATER BALANCE AT CLIMATOLOGICAL STATIONS

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
Newcastle													
Potential evapotranspiration (in.)	4·74	4·02	3·79	2·66	2·47	1·25	1·10	1·40	2·00	2·89	3·61	4·43	34·96
Precipitation (in.)	3·43	4·06	4·60	4·72	4·60	4·14	4·33	3·17	3·12	2·84	2·51	3·19	44·70
Soil storage (in.)	1·55	1·59	2·40	4·00	4·00	4·00	4·00	4·00	4·00	3·95	2·98	2·16	
Actual evapotranspiration (in.)	4·04	4·02	3·79	2·66	2·47	1·25	1·10	1·40	2·00	2·89	3·48	4·01	
Moisture deficit (in.)	0·70	0	0	0	0	0	0	0	0	0	0·13	0·32	1·15
Moisture surplus (in.)	0	0	0	0·46	2·13	2·89	3·23	1·77	1·12	0	0	0	11·60
Maitland													
Potential evapotranspiration (in.)	5·40	4·40	3·90	2·52	1·45	1·01	0·91	1·24	1·90	3·05	4·06	5·12	34·96
Precipitation (in.)	3·22	3·19	3·58	3·16	2·52	3·07	2·67	2·10	2·53	2·17	2·25	3·06	33·73
Soil storage (in.)	0·68	0·50	0·46	1·10	2·17	4·00	4·00	4·00	4·00	3·19	2·01	1·19	
Actual evapotranspiration (in.)	3·73	3·37	3·62	2·52	1·45	1·01	0·91	1·24	1·90	2·98	3·43	3·88	
Moisture deficit (in.)	1·67	1·03	0·28	0	0	0	0	0	0	0·07	0·63	1·24	4·92
Moisture surplus (in.)	0	0	0	0	0	0·23	1·76	0·86	0·63	0	0	0	3·48
Cessnock													
Potential evapotranspiration (in.)	5·14	4·30	3·84	2·43	1·64	0·91	0·86	1·24	1·92	3·02	3·81	4·39	33·49
Precipitation (in.)	2·72	3·10	2·78	2·63	2·25	2·41	2·12	1·59	1·73	2·02	2·18	2·93	28·84
Soil storage (in.)	0·72	0·53	0·41	0·61	1·22	2·72	3·98	4·00	3·81	2·95	1·94	1·33	
Actual evapotranspiration (in.)	3·33	3·29	2·90	2·43	1·64	0·91	0·86	1·24	1·92	2·88	3·19	3·54	
Moisture deficit (in.)	1·81	1·01	0·94	0	0	0	0	0	0	0·14	0·62	0·75	5·27
Moisture surplus (in.)	0	0	0	0	0	0	0	0·33	0	0	0	0	0·33
Singleton													
Potential evapotranspiration (in.)	5·51	4·69	4·08	2·39	1·52	0·99	0·89	1·21	1·71	3·04	4·14	5·19	35·36
Precipitation (in.)	2·89	2·92	2·86	2·19	1·70	2·25	2·11	1·49	1·72	1·94	2·31	2·86	27·71
Soil storage (in.)	0·53	0·35	0·26	0·24	0·42	1·68	2·90	3·18	3·19	3·02	1·89	1·04	
Actual evapotranspiration (in.)	3·40	3·10	2·95	2·21	1·52	0·99	0·89	1·21	1·71	2·11	3·44	3·71	
Moisture deficit (in.)	2·11	1·59	1·13	0·18	0	0	0	0	0	0·93	0·70	1·48	8·12
Moisture surplus (in.)	0	0	0	0	0	0	0	0	0	0	0	0	0

Jerry's Plains													
Potential evapotranspiration (in.)	5·69	4·59	4·03	2·41	1·47	0·89	0·80	1·10	1·24	3·07	4·03	4·92	34·24
Precipitation (in.)	2·88	2·63	2·30	1·85	1·46	2·01	1·84	1·40	1·59	1·87	2·26	2·57	24·79
Soil storage (in.)	0·37	0·22	0·14	0·12	0·12	1·24	2·28	2·58	2·93	2·14	1·36	0·75	
Actual evapotranspiration (in.)	3·26	2·78	2·38	1·87	1·46	0·89	0·80	1·10	1·24	2·66	3·04	3·18	
Moisture deficit (in.)	2·43	1·81	1·65	0·54	0·01	0	0	0	0	0·41	0·99	1·74	9·58
Moisture surplus (in.)	0	0	0	0	0	0	0	0	0	0	0	0	0
Scone													
Potential evapotranspiration (in.)	5·54	4·40	3·78	2·21	1·34	0·81	0·74	1·03	2·32	2·90	3·93	4·65	33·65
Precipitation (in.)	2·79	2·70	2·07	1·68	1·48	1·83	1·66	1·60	1·67	1·84	1·96	2·60	24·46
Soil storage (in.)	0·32	0·20	0·13	0·11	0·25	1·27	2·19	2·76	2·34	1·78	1·08	0·64	
Actual evapotranspiration (in.)	3·11	2·82	2·14	1·70	1·34	0·81	0·74	1·03	2·09	2·40	2·66	3·04	
Moisture deficit (in.)	2·43	1·58	1·64	0·51	0	0	0	0	0·23	0·50	1·27	1·61	9·77
Moisture surplus (in.)	0	0	0	0	0	0	0	0	0	0	0	0	0
Murrurundi													
Potential evapotranspiration (in.)	5·31	4·13	3·65	2·86	1·28	0·75	0·69	0·93	1·62	2·90	3·68	4·35	32·15
Precipitation (in.)	3·21	3·07	2·42	2·16	1·97	2·92	2·50	2·43	2·20	2·70	2·57	3·18	31·42
Soil storage (in.)	1·24	0·94	0·69	0·57	1·26	3·43	4·00	4·00	4·00	3·80	2·86	2·11	
Actual evapotranspiration (in.)	4·08	3·37	2·67	2·28	1·28	0·75	0·69	0·93	1·62	2·90	3·51	3·93	
Moisture deficit (in.)	1·23	0·76	0·98	0·58	0	0	0	0	0	0	0·17	0·32	4·04
Moisture surplus (in.)	0	0	0	0	0	0·24	1·50	0·58	0	0	0	0	2·32
Dalkeith													
Potential evapotranspiration (in.)	5·20	3·96	3·43	2·23	0·75	0·68	0·71	0·90	1·55	2·89	3·66	4·69	28·65
Precipitation (in.)	2·29	2·04	2·06	1·86	1·28	1·66	1·98	1·40	1·55	1·71	2·17	2·42	22·42
Soil storage (in.)	0·47	0·29	0·20	0·18	0·71	1·73	3·00	3·50	3·51	2·58	1·76	0·91	
Actual evapotranspiration (in.)	2·73	2·22	2·15	1·88	0·75	0·68	0·71	0·90	1·55	2·64	2·99	3·27	
Moisture deficit (in.)	2·47	1·74	1·28	0·35	0	0	0	0	0	0·25	0·67	1·42	8·18
Moisture surplus (in.)	0	0	0	0	0	0	0	0	0	0	0	0	0

Thirdly, that only when the soil moisture reservoir is close to capacity can plants use water at the potential rate, and that moisture stress builds up, and plant growth is restricted, as the soil moisture reservoir is depleted. Thornthwaite and Mather (1957) give tables of available water at different soil moisture reservoir levels.

At Maitland and Cessnock the period of moisture adequate for unrestricted growth is reduced to the 6 winter months, April to September, and the soil moisture reservoir falls close to wilting point in late summer (Table 5). Between October and March a total deficit of 4·92 in. accumulates at Maitland, and of 5·27 in. at Cessnock. Although rainfall totals exceed current demands for the winter months at

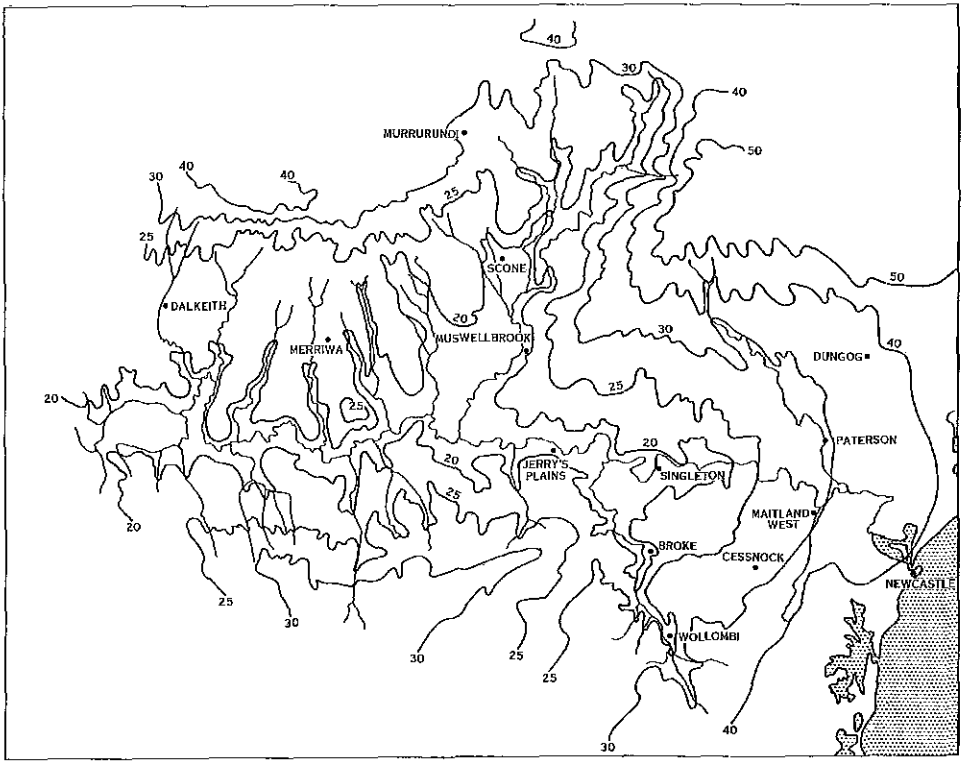


Fig. 7.—Period (wk) of moisture adequate for unrestricted plant growth.

Singleton, Jerry's Plains, Scone, and Dalkeith, the surplus in normal years is not adequate to bring the soil moisture reservoir to capacity, so that the higher demands of summer reduce soil moisture practically to wilting point in autumn. High moisture deficits accumulate in summer and autumn to give a total of 8·12 in. at Singleton, 9·58 in. at Jerry's Plains, 9·77 in. at Scone, and 8·18 in. at Dalkeith. Lower summer values of potential evapotranspiration and higher rainfall figures reduce the severity and duration of drought at Murrurundi. Current rainfall or a soil moisture reservoir at capacity is adequate to provide moisture for unrestricted plant growth at Murrurundi from May to October and the cumulative deficiency in the summer months totals 4·04 in.

A wider application of these water balance procedures by an adjustment of temperature to altitude and the use of measured rainfall records from 62 stations has been used in the compilation of Figures 6–8. Figure 6, of the total annual moisture deficits for the region, shows that a total deficit of 7·5 in. annually is typical of half the valley. Deficits increase westward to a maximum of 12·5 in. in the upper Goulburn area and decrease to a negligible amount in the higher parts of the Barrington plateau. The pattern of the intensity of moisture stress is repeated in the map of length of the growing season unrestricted by moisture (Fig. 7). The direction of increasing values is reversed, a growing season approaching a year in length on the higher north-east and

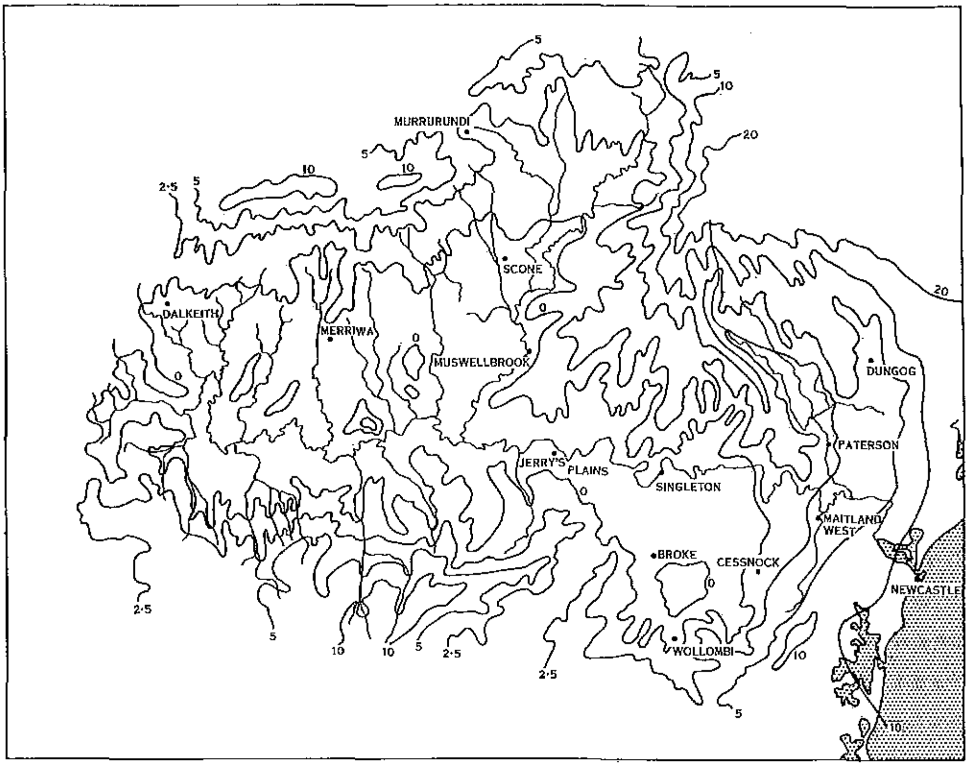


Fig. 8.—Annual moisture surplus (in.).

the coastal fringe decreasing to one of 20 wk in the lowland reaches of the central and western parts of the valley.

However, the season in which moisture is adequate for plant growth in all cases falls in the cooler months so that the periods shown in Figure 7 need to be interpreted in the light of frost data given in Table 4. Only in the coastal fringe is this growing season uninterrupted by lower temperatures. Elsewhere there is an average interruption ranging from 6 wk at Maitland to 20 wk at Dalkeith when frost risk inhibits plant growth. In the latter case, indeed, the growing season unrestricted by moisture stress is almost entirely eliminated by frost hazard.

The combination of the heat and moisture factors as limitations on the length of the season for unrestricted plant growth reveals that for most of the region, as shown elsewhere for the Yass valley (Slatyer 1960), growth is most favoured in two separate periods of the year. The first is in spring when plants are able to use water stored over winter in the soil moisture reservoir together with spring rainfalls under conditions of rising temperature. The second is in summer and autumn when sporadic rains but an inadequate soil moisture reservoir may give short-lived conditions of adequate moisture under conditions of high temperature. Shallow-rooted herbaceous vegetation would be able to take advantage of both these seasons; but for much of the Hunter valley, autumn rains do not restore the soil moisture reservoir to a level beneficial to deep-rooted arboreal species. These would be more favoured by the conditions for active growth in spring.

III. Climate in Relation to Soil Character

In the absence of any single numerical value to express the total climatic factor conditioning soil properties it is necessary to consider individually the components of heat and moisture.

(a) *The Heat Factor*

Soil temperature data in the region are restricted to short-term records taken at the Soil Conservation Experiment Station at Scone. It is improbable that they will be representative of any large area, and they have accordingly been disregarded. It is necessary to rely instead on the assumption that air temperatures are related to soil temperatures and that standard temperature data from the 10 climatological stations in the region or immediately adjacent areas will give some indication of temperature conditions affecting soil character.

Jenny (1941) has suggested that although the mean annual temperature is an abstraction that masks many variations in heat conditions throughout the year, it has proved a satisfactory index in soil investigations in many parts of the world. By the application of a standard lapse rate of 1°F per 300 ft of elevation to the mean annual temperatures recorded at the eight climatological stations, values of the mean annual temperatures were computed for other sites in the area. From these Figure 9 has been constructed to show variations in this index for the area. Throughout, temperature gradients show a marked correlation with relief. For most of the Hunter valley mean annual temperatures higher than 60°F are characteristic, the highest value in excess of 65°F being typical of the valley floor between Maitland and Warkworth. Values lower than 50°F are restricted to the higher parts of the Barrington plateau where rapid changes in values of temperature correspond with steeper slopes. Adjustment for altitude for mean daily temperatures in the winter months in this higher area brings values close to freezing, but the area where, and the period when, the freezing of soil moisture might be expected will be restricted.

(b) *The Moisture Factor*

Annual precipitation in the region (Fig. 2) provides a very generalized assessment of the moisture factor in soil development. As with vegetation it is the effectiveness of precipitation rather than its measured amount which is critical. However, many of the studies cited by Jenny (1941) point to critical changes in soil character which correlate with an annual precipitation of about 26 in. In particular, in the world pattern, changes between soils developing pedalferric characteristics and those of pedocalcic character seem to occur at about this point. The critical isohyet of 26 in. (Fig. 2) encloses about half of the region so that pedocalcic conditions in soil character may be expected in the region as far downstream as Branxton, and soils of pedalferric character will be restricted to the coastal fringe and the higher land to the south and north.

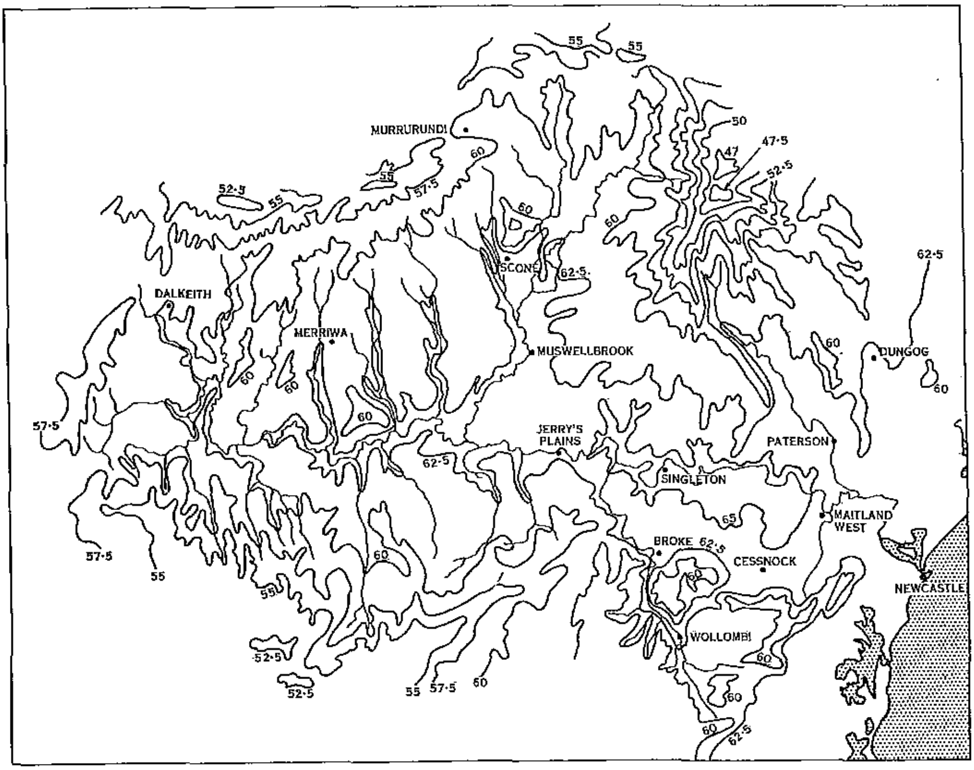


Fig. 9.—Mean annual temperature (°F).

Moisture for subsurface drainage and active leaching, however, will depend not only on total precipitation but also on the demands of evapotranspiration. The water balance studies outlined above allow some measure to be made of water available for free drainage above field capacity, and values of this computed for rainfall recording stations in the region have been used for the compilation of Figure 8—the annual moisture surplus in inches. This is the amount which can be expected as subsurface drainage after all soil moisture reservoir and evapotranspiration requirements have been met. Although it ignores the effect on soil formation of water moving downward to recharge the soil moisture reservoir before leaving the soil by processes of evapotranspiration, the figure does indicate the varying degrees of active leaching that will occur.

There is a general sympathy of pattern between the isohyets of Figure 2 and the isolines of annual moisture surplus, but there are also what might be significant differences. In particular the isohyet for 26 in., though coinciding fairly well with an annual moisture surplus of 2·5 in. in the lower valley, embraces a smaller area in the north-west and south, so that soils in these areas might exhibit more arid characteristics than the annual rainfall totals might suggest.

For a large part of the region there is no moisture surplus for subsoil drainage. If one ignored the effect of heavy sporadic rains, which is masked in the average monthly values used in these computations, water movement in the soil would be restricted to precipitation entering the root zone to recharge the soil moisture reservoir and its subsequent movement in relation to evapotranspiration. Elsewhere soils reach field capacity for some time each year, so that leaching of material from the soil might be expected. With increasing moisture surplus as the coast is approached or as altitude increases, the leaching will increase, the impoverishment reaching a maximum in the high areas of the Barrington plateau where a total of 20 in. of rainfall a year, one-third of the amount precipitated, is estimated to pass through the soil in this fashion.

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PART IV. GEOLOGY OF THE HUNTER VALLEY

By R. W. GALLOWAY*

I. INTRODUCTION

This brief account of the geology of the Hunter valley is intended as a basis for an understanding of the land systems of the area. Following an outline of the geologic setting and of the stratigraphy, the geologic criteria employed in separating the major land system groups are tabulated.

For further information on the geology the best general source of information is David (1950). Information on the Devonian and Carboniferous rocks can be found in papers by Osborne (1922*a*, 1922*b*, 1925*a*, 1925*b*, 1926, 1927, 1928, 1929, 1950), Browne (1926), Scott (1947), Osborne, Jopling, and Lancaster (1948), Voisey (1958), Crook (1961*a*), and Roberts (1961). The Permian and Triassic rocks are discussed by David (1907), Dulhunty (1937, 1939, 1940, 1941), Jones (1939), Hanlon (1947), Osborne (1949), Booker, Bursill, and McElroy (1953), Booker (1960), and McElroy (1957). Other sources of information on the Permian and Triassic rocks include doctoral theses by Raggatt (1938*a*) and Booker (1953) and an unpublished report by Rose†. On the Jurassic rocks papers include those of Dulhunty cited above and Raggatt (1938*b*). References dealing with Tertiary basalt include Carne (1908), Crook (1961*b*), and the papers by Dulhunty. Information on other Tertiary volcanics can be found in Carne (1903, 1908), Raggatt (1929), and Raggatt and Whitworth (1932). Aspects of the Quaternary geology are dealt with by David and Etheridge (1890), David and Guthrie (1904), Browne (1926), Maze (1942), Scott (1947), Ritchie (1951), Brewer and Butler (1953), and Williamson (1958).

II. GEOLOGIC SETTING

The Hunter valley occupies part of four major geologic provinces of eastern Australia (Fig. 10): the New England Geosyncline in the north-east, the Sydney Basin in the centre and south, the Great Artesian Basin in the north-west, and the East Australian Tertiary Volcanic Province in the north and west.

The New England Geosyncline is the oldest of these provinces. During Devonian and Carboniferous times it was part of a great trough in which immense thicknesses of marine sediments, tuffs, lavas, and glacial beds accumulated. In Permian and Triassic times the centre and south of the area formed the northern part of the Sydney Basin in which thousands of feet of marine and terrestrial sediments were deposited, together with some lavas in the lower part of the sequence. During the latter part of the deposition of the Permian rocks there was a considerable amount of folding and faulting particularly in the north-east where the Carboniferous and Devonian rocks were uplifted along a great fault known as the Hunter Overthrust.

*Division of Land Research and Regional Survey, C.S.I.R.O., Canberra, A.C.T.

†The geology of the Triassic rocks in the southern section of the Hunter River catchment, N.S.W. Dep. Mines Prelim. Rep. No. 1, 1959.

After the Triassic period significant sedimentary rock formation was confined to the north-west where Jurassic terrestrial sediments related to those of the Great Artesian Basin were deposited. In the Tertiary period great basalt flows were poured out at many points in eastern Australia and they covered much of the north and west of the Hunter valley: their extent has since been greatly reduced by erosion. There was also some further movement along the Hunter Overthrust and related faults.

Since the basalt flows ceased, the Hunter valley has been continuously subject to erosion with only minor sedimentation in valleys and along the coast and there has been marked uplift in the north-eastern and southern margins as well as broad regional uplift of the whole area.

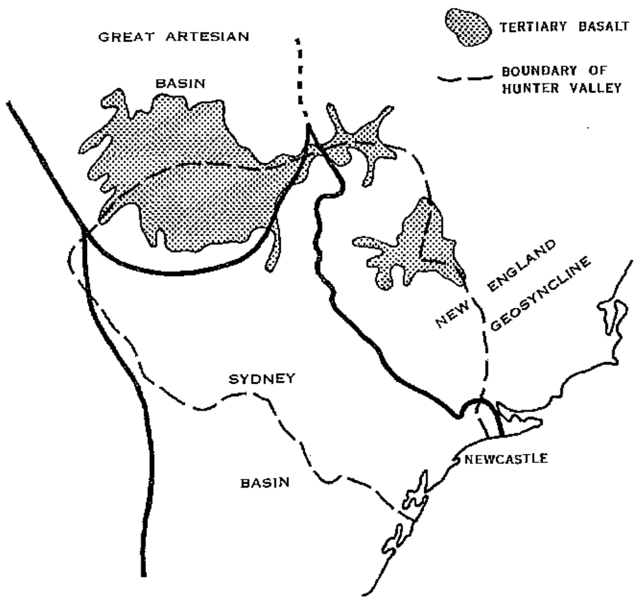

Fig. 10.—Geologic setting of the Hunter valley.

III. Stratigraphy

(*a*) *Devonian and Carboniferous*

Rocks of this age crop out over one-quarter of the Hunter valley east and north of the New England Highway. Within this area a distinction can be drawn between the dominantly marine sediments in the north-east and the terrestrial rocks which form a belt some 10 to 20 miles wide on the south-west, with small outliers near Pokolbin.

The marine sediments consist dominantly of siltstone, sandstone, and chert, interspersed with tuffs, conglomerate, and limestone. The rocks are strongly folded and dips of 20–30° are common. Faults are frequent, some having throws of thousands of feet, but they play little part in determining the present land forms and as a rule the major valleys are not aligned along them. The rocks are generally highly resistant and consequently much of the country is extremely rugged with thin stony soils. The steep dips preclude the development of structural plateaux. In the upper Isis valley near Timor, limestone beds several hundred feet thick form a distinct type of country with much rocky outcrop and some karstic features.

The terrestrial rocks were deposited contemporaneously with the upper part of the marine rocks discussed in the previous paragraph. They include resistant lava, conglomerate, and tillite, which commonly form rugged country, and less resistant tuffs and varve shales which generally form lowlands. These rocks have been moderately folded into a series of low domes and shallow basins; the basins have stood up better to erosion and now form hills such as the Colonel, while the domes have become the site of valleys such as Lambs valley. The intense faulting of the rocks has little significance for the present relief, except on the south-west margin, where the powerful Hunter Overthrust separates the Carboniferous rocks from the weaker Permian strata.

The terrestrial rocks, particularly the lavas, have high proportions of base-rich minerals, and consequently many of the derived soils are fertile, though often thin and stony on account of the resistant nature of the rocks.

Near Ulan, Palaeozoic granites have been exposed by removal of overlying younger sediments. Granitic rocks of uncertain age also exist in the Barrington Tops, where they appear to be old hills revealed by partial stripping of overlying basalt.

(*b*) *Permian*

Permian rocks occupy fully one-fifth of the Hunter valley and extend in a central belt from Newcastle to Murrurundi. Outlying occurrences are found in the west where southern tributaries of the Goulburn have stripped off overlying Triassic sandstone.

The Permian rocks consist of shale, tuffs, sandstone, and conglomerate, with some lava beds in the basal portion of the sequence. They attain a thickness of some 17,000 ft in the east and centre but thin out to no more than a few hundred feet in the west round Ulan. They have been folded into a series of more or less meridional elongated domes with moderate dips except in the vicinity of major faults.

As a whole the Permian rocks are only moderately resistant and consequently form lowlands although variations in resistance are reflected in the relief. The lower Permian rocks include lavas which give rise to rolling country with heavy soils round Lochinvar. East of Muswellbrook, Wingen, and Blandford, however, these lavas are more resistant, have been heavily faulted, and give rise to rugged country with thin, stony soils. Rocks in the middle of the Permian sequence are rather shaly and form undulating country, e.g. round Singleton, except where resistant sandstones and conglomerates form hills such as occur immediately west of Mulbring. The upper Permian rocks tend to be fairly resistant and form hilly country in the vicinity of Newcastle and at intervals from Broke to west of Aberdeen, while resistant Upper Permian conglomerates are responsible for marked structural benches in the Bylong, Growee, and Wollar valleys.

The varied composition of the Permian rocks results in varied soils, usually of moderate fertility. Some of the sandstone, particularly in the vicinity of Cessnock and Newcastle, is highly quartzose and the soils correspondingly poor; in the Widdin, Bylong, and Growee valleys in the west and in the Denman–Aberdeen district in the centre, on the other hand, the sandstone is often calcareous and weathers to a clayey soil.

(*c*) *Triassic*

Rocks of Triassic age occupy one-quarter of the Hunter valley, extending along the entire southern side of the catchment from Lake Macquarie to Ulan, with an extension running northwards from Sandy Hollow to Murrurundi. These rocks were laid down as sediments in lagoons and consist of sandstone, conglomerate, and shale.

Broadly speaking, the rock texture becomes coarser on passing to the west and north while the sequence becomes thinner, decreasing from nearly 2000 ft in the Lake Macquarie district to a few hundred feet in the Ulan and Murrurundi areas. Around Lake Macquarie the lower part of the sequence consists of shales and claystones with some sandstone beds; the middle part consists mainly of pebbly sandstones and some shale layers; the upper part comprises quartz sandstones. In the Wollombi area in the east, the rocks consist dominantly of quartz sandstone and lithic sandstone, interbedded with claystones, shales, and conglomerates; individual beds never exceed a few tens of feet in thickness. Westwards to Bylong in the centre the rocks resemble those of Wollombi area, except that the sandstone beds become much thicker and more continuous, often forming prominent cliffs extending for many miles along the valley sides; on the higher ridge crests quartz sandstone is dominant. From Bylong through Wollar to Ulan in the west the Triassic rocks become markedly thinner and take the form of a basal conglomerate overlain by medium-grained sandstones. This dual character is maintained and even accentuated north of the Goulburn River; the basal conglomerate becomes coarser on passing northwards from Denman (on the western side of the Kingdon Ponds valley it contains pebbles of jasper and quartz up to 6 in. long) while the overlying sandstone is much more shaly in the vicinity of Owen's Gap.

The rocks have suffered only gentle folding and practically no faulting except in the vicinity of Murrurundi, although vertical joints are prominent and have greatly influenced the development of the relief. From Lake Macquarie westwards to Martindale Creek the Triassic rocks dip gently south or south-west. In the Goulburn valley the dip is generally northwards, about one or two degrees, towards a basin underlying the Liverpool Range. From Denman to Murrurundi the dip is generally westwards and is locally up to 7°. In addition to these broad regional dips the rocks have warped into a series of more or less meridional shallow folds, several miles across, which are apparently related to folding of the underlying Permian rocks. Many of the streams are aligned along the axes of these shallow folds.

Being highly resistant, the Triassic sandstone forms extremely rugged country with shallow, infertile soils. The contrast in soil fertility with the underlying Permian rocks is often clearly expressed by an abrupt change in tree species at the stratigraphic boundary between the two land systems. In many places, however, the contact is masked by aprons of sand and gravel washed off the hills of Triassic sandstone.

(d) *Jurassic*

Jurassic rocks are confined to a tract west of Merriwa and a narrow belt to the north-east. They consist dominantly of soft, porous, lithic, orange sandstone about 300 ft thick which dips gently northwards at about 1° under the basalt of the Liverpool Ranges. This sandstone overlies clay shale, sometimes tuffaceous, which may be Lower Jurassic in age or which possibly forms the uppermost member of the Triassic sequence. These shales are only 30 ft thick at Merriwa, thickening to a few hundred feet to the west and north-east. The porous nature of the sandstone makes it an excellent aquifer.

(e) *Tertiary Basalts and Intrusives*

During Tertiary times great basalt flows were poured out over the landscape. It is possible that the basalt once covered the entire northern half of the Hunter valley or an even wider area, but subsequent erosion has reduced its extent and it now occupies just over one-sixth of the area. It is found in the Liverpool and Mt. Royal Ranges, around Merriwa, on the Barrington Tops, and as isolated patches in the southern part of the Goulburn catchment, notably Nullo Mountain. Underlying and interbedded with the basalts are old soils and beds of water-worn gravel, sandstone, and shale, representing riverine deposits laid down before, and during intervals between, the basalt flows. While individual flows rarely exceed a few tens of feet in thickness, the total accumulation exceeds 2000 ft in the Liverpool and Mt. Royal Ranges.

In addition to the extrusive basalt flows there are a number of igneous intrusions whose age relationship to the basalt is not clear. In the Barigan district in the south-west, dome-shaped alkali intrusions have been exposed by erosion of overlying Triassic sandstone. Necks, dykes, and sills of basalt and dolerite are known from the Triassic sandstone belt where their occurrence locally gives better soil; they also occur frequently in the areas of Permian rock.

The basalt and most of the Tertiary igneous rocks weather to a heavy, rich soil. In some places between and under basalt flows relics of old leached soils ("bole") are preserved and these can affect the character of the present soils.

(f) *Quaternary*

The Quaternary period was marked by great fluctuations of climate and sea-level which resulted in a complex interplay of erosion and deposition and the production of a wide range of unconsolidated deposits which are found throughout the Hunter valley, particularly in low-lying sites where they form the raw material for much of the soil. Over one-fourteenth of the area they compose the entire land surface and give rise to distinct types of country. The Quaternary deposits may be conveniently classified into four types according to their dominant mode of origin: marine, fluviatile, colluvial, and aeolian.

The marine deposits consist of sand, silt, and clay which accumulated in an estuary that formerly extended as far inland as Maitland. Borings have proved a maximum thickness in excess of 200 ft, and the deposits are currently accumulating along the present shore, in mangrove swamps, and in coastal lagoons.

The fluviatile deposits consist of riverine alluvium, generally forming terraces. The highest, oldest terraces are represented only by patches of weathered gravel and may date back to the preceding Tertiary period. The younger, better preserved terraces consist of sand, silt, and clay often overlying gravel; coarse material is dominant in headwater regions and fine material in the lower valleys. The nature of the alluvium varies according to the parent rock. It is dominantly a gritty clay when derived from granite; gravel and sand without much clay when derived from the Carboniferous marine and terrestrial rocks; sand, silt, and clay when derived from the Permian shales and sandstones; and sand or clay when derived from the Triassic and Jurassic rocks. Alluvium derived from basalt is distinguishable by a high proportion of cracking clay. The youngest fluviatile deposits are found on the present flood-plain and are still accumulating during floods. Below Maitland there is a transition to the marine deposits in swampy areas such as Hexham swamp. The friable structure, level sites, wide range of mineral composition, and the possibility of irrigation make the soils on the fluviatile deposits the most valuable in the Hunter valley.

The colluvial Quaternary deposits comprise a wide range of materials formed by weathering of the bed-rock. They include cemented rubble a few feet thick encountered between the rock surface and the overlying soil, stony uncemented rubble on high ground above 3500 ft, and colluvial debris on slopes. Peat is accumulating in swampy areas near the coast and on the high plateaux of the Barrington Tops.

The aeolian deposits comprise sand dunes and sand sheets. A narrow belt of active dunes fringes the present sea beach and behind it there are tracts of fixed dunes under forest. Sand dunes and sand sheets derived from dry river beds fringe the lower Wollombi and the Hunter below Singleton. Thin sand sheets also occur away from rivers near Cessnock, probably derived from weathering sandstone outcrops.

IV. Geology and the Land Systems

Lithology, through its influence on topography and soils, provides the basis for the initial division of the Hunter valley into major land system groups. Structure is also of some significance, but stratigraphy is less important. The stratigraphic divisions discussed in the previous section only partially correspond to lithologic categories and consequently the geologic information must be rearranged to emphasize lithologic rather than stratigraphic unities.

Eleven lithologic categories, each with a characteristic structure, have been recognized (Table 6). The nature of most of the land systems is clearly related to these categories, which are, therefore, used in the major headings of the key to the land system map. Resistant rocks form rugged country with thin, stony soils; weak rocks form lowlands with deeper soils. Lavas, intrusives, glacial beds, and calcareous sediments tend to give more fertile soils than do quartzose sediments since they contain a higher proportion of weatherable minerals. Flat-lying rocks tend to form plateaux and plains while highly folded and faulted rocks encourage the development of rugged country. Moderately folded rocks usually form rolling to hilly country with cuestas. Country on the unconsolidated Quaternary deposits is very different from that on all solid rocks.

However, in some cases the association of particular land systems with particular lithologic categories is not so close, because lithology plays a less important part in determining the character of the country, or because there is an overlap between one lithologic category and another, or because the geomorphic development had modified the lithologic control. Consequently Table 6 shows only the dominant correlations of land systems with lithology.

TABLE 6
LITHOLOGY AND LAND SYSTEMS

Dominant Lithology and Structure	Geologic Age	Associated Land Systems
Granite; massive, resistant	Palaeozoic	Rouse, Ulan
Limestone; folded, resistant	Devonian	Alston
Mudstone, chert, tuff; highly folded, resistant	Devonian, Carboniferous	Mt. Butterwicki, Benmore, Wallaroo, Upper Rouchel, Vacy, Timor
Mudstone, chert, tuff; highly folded, resistant; plus basalt; flat-bedded, moderately resistant	Carboniferous and Tertiary	Rainforest, Mt. Royal
Lavas, glacial beds, basic intrusives; folded, faulted, resistant	Carboniferous, Lower Permian, Tertiary	Cranky Corner, Colonel, Moonibung, Barigan, Apis, Parkville
Shale, sandstone, conglomerate; moderately folded, relatively unresistant	Permian and some Lower Triassic	Ogilvie, Redhead, Elrington, Glendower, Beresfield, Killarney
Calcareous sandstone and shale; moderately folded, weak	Permian	Bray's Hill, Blairgowrie
Sandstone, minor shale; gently folded, resistant	Triassic, some Jurassic	Watagan, Three Ways, Lee's Pinch, Munghorn Gap
Shale, sandstone, basalt; flat-bedded, weak	Jurassic	Greenhills, Roscommon
Basalt; flat-bedded, moderately resistant	Tertiary	Liverpool, Ant Hill, Bow, Tubrabucca
Alluvium, colluvium, aeolian sand; unconsolidated	Quaternary	Avicennia, Nesta, Hexham, Hunter, Yarramoor, Sandy Hollow, Duck Hole, Warkworth

Both the Mt. Royal and Rainforest land systems overlap two lithologic categories, but in these areas the dominant factors determining the nature of the country are rainfall and steep slopes, while lithology is of little significance. The Blairgowrie land system has an undulating topography and cracking clay soils and is generally found on calcareous shales and sandstones but can occur also on lavas and intrusives. In the Sandy Hollow land system sand and gravel aprons from adjacent rugged sandstone hills obscure the underlying Permian shale and sandstone and give rise to relief, soil, and vegetation not in accord with the solid geology. Resistant granite round Ulan (Rouse land system) does not give rise to really rugged country because deep dissection has not occurred. The greater part of the Roscommon land system is developed on sandstone and shale but owes much of its character to the residue of a former basalt cover and a deep pre-basalt soil.

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PART V. GEOMORPHOLOGY OF THE HUNTER VALLEY

By R. W. Galloway*

I. Introduction

The dominant theme in this account of the geomorphology of the Hunter valley is the close dependence of the land forms on geological structure; consequently Part IV on geology forms an essential introduction. A secondary theme is the importance of past climates, particularly during the Quaternary era.

Contributions concerned primarily with the geomorphology of the Hunter valley include papers by Browne (1924), Dulhunty (1937), Sussmilch (1940), and Maze (1942). Some discussion of geomorphic topics is also found in publications dealing mainly with geology, pedology, or hydrology (Brewer and Butler 1953; Browne 1926; David 1950; Osborne 1922, 1926, 1927, 1928; Raggatt 1938*a*, 1938*b*; Scott 1947; Williamson 1958).

II. General Description

The Hunter valley is scenically one of the most varied areas in Australia and includes a wide variety of land forms, ranging from rugged mountains to plains and extending from sea-level to over 5000 ft. It is bounded by mountainous terrain on all sides except on the west, where only a low rise divides it from country draining to the Darling River, and on the south-east where the sea forms the boundary (Fig. 11).

Four major elements can be distinguished in the drainage pattern. The western half of the valley is drained by the Goulburn, which flows eastwards to Denman and receives more or less meridionally-trending tributaries from the south and north. From the north-eastern part of the valley the upper Hunter flows south-west to unite with the Goulburn at Denman. The combined rivers then flow east-south-east as the lower Hunter to reach the sea at Newcastle. In the east, the Williams and Paterson drain the high country of the Barrington Tops and join the Hunter near its mouth.

The watershed of the Goulburn coincides with the Great Divide, which here swings west in a vast loop, so that the Hunter valley extends much further inland than most coastal valleys of New South Wales. The Lake Macquarie catchment, although separate from that of the Hunter, has been included in this survey because of its close association with the Hunter valley.

Eight major types of country may be distinguished in the Hunter valley (Fig. 11).

(*a*) *Southern Mountains*

The southern one-third of the Hunter valley is occupied by a wide tract of rugged mountains on Triassic sandstone. The highest ridges rise to about 3500 ft while the intervening valleys are as much as 1500 ft deep and have steep sides, often consisting in part of spectacular cliffs.

*Division of Land Research and Regional Survey, C.S.I.R.O., Canberra, A.C.T.

(*b*) *Central Goulburn Valley*

Along the Goulburn River is a belt of country some 20 miles wide with irregular plateaux and ridges rising to 1000–1500 ft above sea-level, and broken by steep-sided valleys 300–500 ft deep. The plateaux and ridges generally consist of Triassic sandstone but some are capped by basalt, particularly on the northern margin of this belt. Where the valleys are cut in hard sandstone they form veritable gorges, notably along the Goulburn itself; elsewhere the valleys widen out into undulating lowlands on less resistant Permian rocks, fringed by steep escarpments, e.g. round Wollar. Included in this belt is a small area of low, rocky granite hills and broad open valleys south of Ulan in the extreme west.

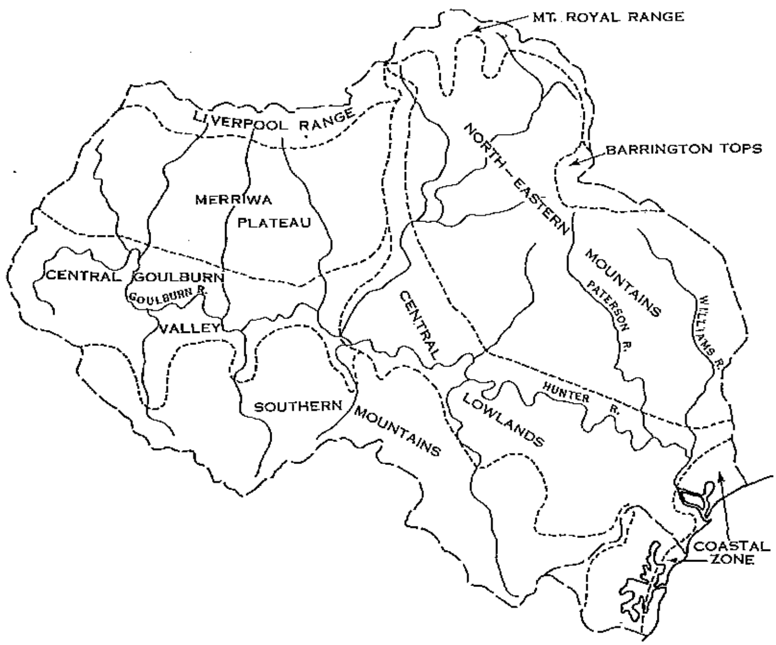

Fig. 11.—Drainage pattern and major types of country.

(*c*) *Merriwa Plateau*

North of the Goulburn River is an area of rolling to hilly basalt country here termed the Merriwa plateau. It rises northwards from around 1000 ft above sea-level near the Goulburn River to about 1500 ft at the foot of the Liverpool Ranges which mark its northern limit. The Merriwa plateau is crossed by parallel south-flowing streams which in the lower sections of their courses have cut valleys up to 300 ft deep in the plateau surface. On its western margin the Merriwa plateau passes into country of broadly similar topography developed on Triassic and Jurassic sandstone with some shales, which extends to the western boundary of the Hunter valley.

(*d*) *Liverpool and Mt. Royal Ranges*

The northern watershed of the Hunter valley is formed by the rugged Liverpool and Mt. Royal Ranges rising to over 4000 ft above sea-level and composed of basalt. Deep valleys, cliffs, and bouldery surface rubble are characteristic of these ranges. The summits generally take the form of narrow ridge crests, but locally consist of small plateaux.

(*e*) *Barrington Tops*

The more extensive plateau known as the Barrington Tops delimits the Hunter valley on the north-east. It ranges in altitude from 4000 to 5400 ft above sea-level and consists of basalt overlying folded Carboniferous sedimentary rocks.

(*f*) *North-eastern Mountains*

In the north-east is a tract of mountainous country some 25–35 miles wide traversed by deep valleys draining from the high Mt. Royal Range and from the Barrington Tops. This tract is formed on resistant, folded, sedimentary rocks and lavas of Devonian and Carboniferous age with basalt caps in the higher areas and it can be divided into three belts concentric to the Barrington Tops. Adjacent to the high watershed areas steep, narrow ridges rising to 4000 ft above sea-level are found with slopes cut by deep ravines tributary to the upper valleys of the Williams, Paterson, Glennie's Creek, Rouchel Brook, and Hunter. On the periphery of this belt is an area of rather lower broken hills occupying most of the Isis catchment and the lower valleys of Glennie's Creek, the Williams, and the Paterson. The third belt within the mountainous tract occupies its western and southern margin and consists of steep, massive hills and plateaux rising to 2000–3000 ft above sea-level between Blandford and Muswellbrook and recurring at somewhat lower altitudes south-eastwards to the Clarencetown district.

(*g*) *Central Lowlands*

Through the centre of the Hunter valley a belt of lowlands developed on relatively weak sedimentary rocks extends from Murrurundi to Newcastle. While the general altitude gradually rises inland from sea-level to 1600 ft at Murrurundi, the local relief in any given locality rarely exceeds a couple of hundred feet. The landscape is undulating or gently hilly, with an abrupt transition to the steep country on either side. The country round Lake Macquarie is generally similar and is likewise overlooked by steep sandstone hills immediately to the west. A line of alluvial flats between half a mile and 4 miles wide extends along the Hunter River and its major tributaries where they flow through the lowland belt.

(*h*) *Coastal Zone*

In the neighbourhood of the coast the landscape is very complex with many different types of country in close juxtaposition. East of the Hunter mouth there is a landward sequence of parallel belts of active dunes, forested dunes, swampy flats, and undulating sand flats; a small area of similar country also occurs in the Redhead–Swansea area on the east side of Lake Macquarie. Around the Hunter mouth occur mangrove, brackish, and freshwater swamps, together with flats on fine-textured riverine and marine alluvium. From Newcastle to Redhead undulating to hilly country on sandstones and shales extends to the sea where it terminates in high wave-cut cliffs or steep hill-sides plastered with wind-blown sand.

III. Geomorphic History

The land forms of the Hunter valley have been fashioned by many agents which have been at work with widely varying intensity over an immense span of time. Only a few salient points of this long and complex history can now be deciphered, and only in the later phases can some of the details be discerned.

Most of the land forms that existed during the Palaeozoic and Mesozoic eras have long since been destroyed, but some, buried by younger rocks, have been locally re-exposed at the present land surface in the granite area near Ulan and on the Moonibung plateau west of Paterson. Apart from these minor exceptions, the history of the present landscape can be said to have commenced about 140,000,000 years ago at the end of the Jurassic period when deposition of shales and sandstones in lagoons in the north-west ceased and the entire area became subject to sub-aerial erosion. The history can be divided into five phases: the pre-basalt phase of planation, the phase of basalt flows, the post-basalt phase of erosion, the Quaternary phase of fluctuating climate and sea-level, and the phase of European settlement.

(*a*) *The Pre-basalt Phase of Planation*

During this phase the landscape, apart from granitic hills in the north-east, appears to have been worn down into a gently undulating erosion surface cut across all rocks, probably under warm and humid climatic conditions which favoured deep weathering. Towards the close of this phase, probably as a result of regional uplift, a system of fairly shallow valleys developed. Much of this landscape was covered by basalt during the next phase and has since been partially re-exposed by removal of the basalt cover. Consequently, the present land surface in the vicinity of the surviving remnants of the basalt flows is largely inherited from the pre-basalt phase of the geomorphic history and retains the generally level form cut across various rock strata, the shallow valleys, and sometimes the deep weathered profile. Examples include the plains south-west of Merriwa, plateau summits round Wollar, and valley-side benches along Page's Creek.

Where no protective basalt cover existed, or where it was early removed, the landscape formed during this first phase of the geomorphic history was entirely destroyed or can only be tentatively reconstructed from the accordant summits found in the upland areas of Triassic and Carboniferous rocks.

(*b*) *The Phase of Basalt Flows*

The great basalt flows which were poured out some time during the lower or middle Tertiary era entirely covered at least the northern half of the area. The actual eruption of the basalt appears to have occupied only brief intervals, between which erosion took place, deep soils formed, and thick gravel layers accumulated locally. The type of soils and sediments indicates that the warm, humid conditions of the previous phase continued to prevail. Where exposed today the old soils by their highly leached nature affect the character of the contemporary soils developed on them.

The basalt filled the shallow valleys cut towards the end of the previous phase, but in many cases the streams subsequently re-occupied their old courses and thus many of the present-day valleys originated in pre-basalt times: examples are the upper Hunter above Gundy, the Goulburn, and at least the lower parts of some valleys on the Merriwa plateau. On the other hand, some valleys were completely obliterated, and their surviving remnants, traceable under the basalt, show no relation to the current drainage pattern; one such valley appears to underlie the basalt-capped range just south of Murrurundi.

(c) The Post-basalt Phase of Erosion

It was during this phase, which probably occupied the last 30,000,000 years of the Tertiary era, that the major and many of the minor features of the present landscape evolved. It was a phase of intermittent uplift and valley planation when the work of erosion was guided primarily by contrasts in lithology and secondarily by the relation to the base level of erosion at the coast.

The weaker (Permian) rocks were reduced to an undulating lowland while the more resistant Triassic and Carboniferous rocks survived as uplands in which fairly wide valleys developed, generally along lines of weakness. These lowlands and valley floors were partially dissected when regional uplift reactivated stream incision, but their form is still preserved in rounded, accordant summits on the Permian tract and on valley-side benches in the Carboniferous tract. (On the Triassic rocks and on the basalt, it is not easy to distinguish between such remnants of old valley floor, and structural benches.) Valley incision was more rapid and effective near the sea, and consequently valleys were more deeply cut and old erosion surfaces more thoroughly destroyed in the east than in the west and north. Indeed, erosion associated with the last major fall in base level has not yet penetrated to the head of the Goulburn or of the upper Hunter and here the wide old valley floors survive practically intact.

On the granite at Ulan the major lines of the relief appear to have been inherited from an ancient planated landscape buried under Permian sediments and later exhumed as these sediments were stripped off. This pre-Permian land surface has not been extensively modified by erosion on account of the lack of marked uplift in this area and the distance from the base level of erosion at the coast. Consequently, although granite is a resistant rock, it does not form high country in this locality.

On the Carboniferous marine sediments, narrow valleys with rugged broken interfluves developed where dips were steep, streams transverse to the structure, and the available relief considerable. Open valleys with more rounded interfluves formed where the rocks dipped less steeply and where streams were aligned along the strike, particularly in the northern headwaters of the Hunter (e.g. the valleys of the Isis River and Page's Creek). Resistant, gently-dipping sandstone beds often formed summit plateaux of limited extent as on Mt. Ararat, or gave rise to cuestas and structural benches.

On the Carboniferous and lower Permian terrestrial rocks, thick, resistant lavas, conglomerates, and tillites formed massive hills, escarpments, and plateaux, often fringed by cliffs and locally dissected by deep ravines following prominent joints or faults. Lowland areas were largely restricted to outcrops of less resistant varve shales and tuffs.

On the Permian sedimentary rocks structural control of the land forms was somewhat less in evidence and erosion largely planed off faults, domes, and basins. Some gently-dipping sandstone or conglomerate layers, however, proved more resistant and formed cuestas such as the Broken Back Range south of Cessnock. Weak shaly layers tended to form the smoother, lower parts of the landscape. Some streams developed courses cutting indifferently across the structure; others, particularly the smaller tributaries, became aligned along the strike of the rocks or along faults. The generally unresistant Permian rocks did not develop steep slopes except where a resistant cap of sandstone or conglomerate acted as a protection against erosion, e.g. the north slopes of Myall Range south of Cessnock.

On the Triassic rocks, the land forms evolved during this fourth phase of geomorphic evolution were particularly closely controlled by the geological structure. Erosion took place by vertical incisions of the major streams along lines of weakness, followed by undermining of shaly beds near the foot of the resultant steep valley sides, causing the latter to retreat parallel to themselves without losing much of their initial steepness. Where resistant beds extended down to the level of the valley floors, the valleys remained narrow. This is the case in the Goulburn gorge from the vicinity of Bylong to Kerrabee and in the narrow bottleneck exit of the Widdin and Wollar valleys. Thick and homogeneous sandstone beds formed cliffs such as those lining the Widdin and Bylong valleys or overlooking Broke; thinner beds alternating with shales formed stepped slopes with low bluffs and benches such as characterize the Wollombi area. The joint pattern largely determined the detailed form of the cliffs, bluffs, and benches, and the location of gullies. Because of the horizontal bedding, interfluves tended to have flattish tops, though few are wide enough to be termed plateaux.

On the Jurassic sandstone and shale, the forms produced were undulating lowlands with broad valleys on the softer materials and low rocky hills and escarpments on the harder rocks. Much of the relief has been inherited from the pre-basalt landscape and only in the vicinity of the few deeply incised valleys has this old landscape been extensively modified through headward erosion by tributary creeks.

Contrasted land forms developed on the basalt according to the altitude of the sub-basalt surface. On the Merriwa plateau this underlying surface was at a moderate altitude (800–1700 ft) and consequently extensive areas of basalt were preserved as undulating lowlands and hills, and only on the southern fringe did the major streams penetrate the basalt to expose, and locally cut into, the underlying pre-basalt surface. South of the Goulburn, the sub-basalt surface was higher (2000–2800 ft) and the basalt cover was reduced to plateau remnants capping the ridges, notably the Nullo Mountain plateau. In the upper Hunter, the base of the basalt was also high (2200–2800 ft) and consequently erosion cut through it and bit deeply into the underlying folded Carboniferous rocks, leaving the basalt as cappings on the ridges.

The horizontal layering of the basalt flows favoured the development of cliffs and bluffs in the rugged Liverpool and Mt. Royal Ranges and around the margins of the Barrington Tops. The structure also favoured the preservation of plateaux on the summits, some of which may well approximate to the initial surface of the basalt flows.

On less steep country, the layered basalt structure resulted in stepped slopes where more or less flat soil-covered benches alternated with rocky bluffs.

During the post-basalt phase of erosion it is probable that the climate had a tropical character since relics of old laterites and silcrete layers are preserved on level sites in many places. However, these relics are all of very limited extent and play no significant part in determining the present soils, unlike the old sub-basalt and inter-basalt soils which affect the present surface on parts of the Merriwa plateau. It is probable that these old soils were formerly much more extensive but were stripped off during the succeeding phase of geomorphic history.

(*d*) *The Quaternary Phase of Fluctuating Climate and Sea-level*

This phase occupied the last million years and was characterized by marked fluctuations of climate and sea-level associated with the growth and decay of the great ice sheets in other parts of the world. The climatic fluctuations were most significant for inland areas, while in coastal areas it was the sea-level changes which were important.

Under climatic conditions favouring dense vegetation and moderate run-off the slopes were stable and a thick mantle of soil and weathered material accumulated; under conditions inducing scanty vegetation and high run-off the slopes were unstable and subject to erosion by surface wash and soil creep. During the Quaternary phase the overall rate of stripping appears to have exceeded the rate of weathering, and consequently unconsolidated material was removed from steep slopes (slopes in excess of 12% have very little soil) and deposited on adjacent lowlands or valley floors. This transported material provides the raw material for the present soil except on level sites where soil formation from the underlying rock took place *in situ*.

The material involved in this stripping and deposition varied according to the source rock and, presumably, the climate. On granite it consisted of gritty clay or quartz sand, the end products of prolonged chemical weathering. On hard Carboniferous rocks and on resistant Permian sandstones a stony rubble formed on the lower slopes, presumably as a result of some process of mechanical disintegration followed by mass movement, and was subsequently cemented into a breccia. On more shaly rocks, a stony clay accumulated to depths of up to 15 ft in minor valleys. Steep slopes on Triassic sandstone became littered with boulders of sandstone and conglomerate, while surface wash spread gravel and sand over the gentler slopes below. On basalt at moderate altitudes unconsolidated stony silts and clays accumulated to depths of many feet at the foot of slopes; downslope creep of the material was facilitated by the tendency for basalt-derived clay to expand and contract with wetting and drying. Coarse, angular basalt rubble found above 3500 ft was probably produced by frost shattering during cold climatic phases.

The formation of alluvial terraces can be correlated with stable and unstable phases on the slopes. During unstable phases, the streams were heavily laden with debris supplied from the slopes and consequently they deposited alluvium on the valley floors. When slopes were stable, on the other hand, the less heavily-laden streams cut into the alluvium to form a terrace. This sequence must have happened many times during the Quaternary, but in general only one main terrace is now well preserved with older remnants at higher levels and with younger minor terraces cut into it adjacent to the streams.

The main terrace usually consists of sandy or silty material overlying gravel (in basalt areas it is a cracking clay over gravel) and has a level surface, rarely flooded, with mature soils. Probably during a phase of slope instability when the rivers had particularly wide, sandy beds, north-west winds piled up sand dunes on the main terrace along the Hunter below Singleton and along the lower Wollombi. In certain areas of high run-off, the slopes have been unstable at all times and alluvium has been deposited more or less continuously without intervening phases of slope stability and stream incision. Consequently terraces have not formed and the entire valley floors are subject to flooding and have a complete microrelief of levees, back-swamps, and abandoned channels.

Near the coast, the land form evolution was largely determined by fluctuations of sea-level. During periods of low sea-level, the lower Hunter and its tributaries cut deep valleys as much as 250 ft below present sea-level. During succeeding phases of high sea-level, these valleys were transformed into a gulf or estuary which was then filled by fluviatile and marine sediments.

Before the last glaciation sea-level was 10–20 ft higher than at present and a marine gulf extended as far inland as Maitland, Paterson, and Clarencetown over what is now the delta and lower flood-plains of the Hunter, Paterson, and Williams Rivers. Waves cut cliffs around the margins of this gulf and subsequently, as it was filled in, an undulating sandy plain composed of low beach ridges developed from Hexham to Port Stephens. With a fall in sea-level this plain was subject to wind action which locally piled up dunes on its surface. Sea-level was low during the succeeding glacial period, and the Hunter re-excavated and modified the deep valley cut during previous periods of sea-level; it did not, however, remove all the deposits which had accumulated during the last interglacial. At the close of the last glaciation sea-level rose rapidly until by 6000 years ago it stood as high as, or even a few feet higher than, at present. The former marine gulf reformed and shore-line features developed on its margins, but it was soon filled in partly by a combination of marine or estuarine sand and clay and partly by fluviatile material brought down the Hunter and its tributaries. A second, outer sand beach ridge plain was formed, extending from Stockton to Anna Bay and enclosing a shallow strait now occupied by the swamps along Tilligerry Creek and Fullerton Cove. On this sand plain three parallel belts of dunes developed; the outermost belt is actively forming today, the inner belts are stabilized under forest.

A somewhat similar sequence of events, complicated by the presence of islands, took place along the eastern side of Lake Macquarie and transformed a former bay into the brackish lake of today. Since no large river carries great quantities of sediments into the lake, it has not been filled in by alluvium as is the case with the former marine gulf of the lower Hunter.

Between the mouth of the Hunter and Lake Macquarie, high land on Permian sandstone terminates at the sea, the complex depositional features found to the north and south are missing, and instead the erosional forms of a cliffed coast are found.

(e) *The Phase of European Settlement*

This latest phase has lasted only 150 years but, short as it is, has brought about considerable changes in the landscape. Forest-clearing, burning, grazing, and cultivation have significantly increased soil erosion on the slopes, causing concomitant deposition in the valley bottoms in areas of high run-off and along the lower Hunter.

Gullying has been particularly effective in drier parts of the valley on the stony clay formed during the Quaternary on shaly rocks and on the stony silts and clays derived from basalt. Slumping has mostly occurred after forest clearance in steep country with a fairly high rainfall. On cleared slopes of 40–100% in the basaltic Liverpool and Mt. Royal Ranges the slumps tend to form sickle-shaped scars fronted by low, irregular mounds; on Carboniferous marine sediments the slumps usually occur as narrow, steep-fronted tongues filling valley heads. Run-off and sheet wash have been particularly violent on the Triassic sandstone country, causing the deposition of sterile sand over the alluvial flats in the valley bottoms, especially after fire. Sheet wash has also occurred widely on the Permian rocks in the dry central and western areas, encouraged by less dense vegetation.

It should not be forgotten, however, that European settlement has only augmented a marked natural tendency to serious soil erosion, bush fires, and flooding. Evidence for this is provided by layers of charcoal, ash, and fire-reddened sand grains in the alluvial terraces, and by historical records of great floods in the early days of settlement when most of the valley was untouched by Europeans. Buried soils in the alluvial deposits of streams in the Triassic sandstone country show that sudden floods, spreading masses of sterile sand over the valley floors, have frequently occurred in the past.

IV. Geomorphology and the Land Systems

The initial division of the lands of the Hunter valley was made according to lithology, as outlined in Part IV. Further subdivision can now be made according to geomorphic criteria (Table 1).

In the Hunter valley, with its steep average slopes and consequent rapid geologic erosion, the distinctive characteristics of the old land surfaces (e.g. laterite) have been mainly destroyed, lithologic factors have largely controlled the development of the land forms, and a chronological classification of the landscape is of little value in understanding its nature. Accordingly, simple descriptive geomorphic criteria have been adopted for the erosional land forms which occupy the pre-Quaternary rocks: rugged, hilly, undulating, and plateau types of country have been recognized.

On Quaternary deposits, the land forms are predominantly depositional and consequently are closely related to the mode of accumulation of the materials on which they are developed. Thus the break-down into deposits of dominantly marine, fluviatile, colluvial, and aeolian origin outlined in Part IV is also used here as the basis of the geomorphic classification.

(*a*) *Rugged Country*

The rugged type of country has mean maximum slopes in excess of 25% and local relief greater than 300 ft, a preponderance of rocky outcrops, skeletal soils, and high risk of erosion by sheet wash, gullying, and slumping. Most of the rugged country is found on resistant rocks: Triassic sandstone (Lee's Pinch, Three Ways, and Watagan land systems); Devonian and Carboniferous marine sediments (Benmore and Mt. Butterwicki land systems with parts of the Mt. Royal and Rainforest land systems); Carboniferous, lower Permian, and Tertiary lavas, glacials, and intrusives (Colonel, Cranky Corner, and Barigàn land systems). From 40% to 90% of the area occupied by these rocks is classified as rugged.

Rugged country is also found on the basalt (Liverpool land system) covering 33% of the area occupied by this rock. This moderately resistant rock appears to form rugged country on account of its horizontally bedded structure which has impeded downward erosion of hill tops and favoured the retreat of valley-side slopes without loss of their initial steepness.

Limited occurrences of rugged country on Permian sediments (13% of the Permian outcrop) are correlated with the presence of resistant cap rocks (Ogilvie land system) or with marine cliffing (Redhead land system).

The rugged land systems all show a high degree of structural control, with prominent cliffs and bluffs coinciding with resistant beds. Valleys are deep and narrow and access from one to another across the divides is extremely difficult. These land systems provide the bulk of the run-off supplying the Hunter River and should be protected from indiscriminate clearing, grazing, and fire.

(b) Hilly Country

The hilly country has mean maximum slopes between 10% and 30%, local relief less than 500 ft, frequent outcrops on the upper slopes, thin soils except in the valley bottoms, and considerable risk of gully and sheet erosion. This type of country is found on all the non-Quaternary rocks of the Hunter valley. On the granite at Ulan (Rouse land system) the major forms are inherited from the pre-Permian landscape and at least one dome-shaped hill could have originated as a tropical inselberg. On the Devonian and Carboniferous marine rocks, hilly country is widespread in the upper Hunter catchment (Upper Rouchel land system), where distance from the coast has precluded really deep dissection, and along the Paterson and Williams (Wallaroo land system) where this type of country seems to consist of dissected remnants of old valley floors. On Carboniferous, lower Permian, and Tertiary lavas, glacials, and intrusives the limited areas of hilly country (Apis and Moonibung land systems) are particularly rocky on account of the resistant lavas present.

On the Permian rocks, most of the hilly country (Elrington and Glendower land systems) is found on the more resistant sandstones and where streams are dissecting the undulating surface of a former broad valley floor. The small Bray's Hill land system is unusual in that, though hilly, it is partly on rather weak shaly sandstone. Hilly basalt country (Ant Hill land system) is characteristic mainly of the northern half of the Merriwa plateau; this landscape has benched slopes where rocky bluffs alternate with small, soil-covered flats. The Alston land system on Devonian limestone is particularly rocky, with soil confined to the lower slopes and a few pockets between the outcropping strata.

On the Triassic sandstone all uplands have been classified as rugged and no hilly landscape has been recognized, since almost all areas on this rock are so bare and stony that a distinction between rugged and hilly country is not worth while from the point of view of soil, run-off, and vegetation.

(c) *Undulating Country*

The undulating country has mean maximum slopes less than 15%, local relief less than 100 ft, widely-spaced shallow valleys, usually few outcrops, deep soils, and only moderate risk of sheet and gully erosion. As is to be expected, it is best developed on weak, shaly rocks, but it is also encountered on granite (Ulan land system) where deep dissection has been largely precluded by distance from the sea. The most extensive tract of undulating country is found on the Permian rocks (Beresfield and Killarney land systems), particularly inland in the centre and west of the valley where dissection of an undulating lowland formed during the post-basalt phase has not proceeded as far as in areas nearer the coast. There are also extensive tracts of undulating country on basalt (Bow land system) on the southern half of the Merriwa plateau. To the south, between the Merriwa plateau and the Goulburn River, undulating country on Jurassic and Triassic sandstone and shale (Roscommon and Greenhills land systems) probably owes its form to resurrection of the old pre-basalt land surface. The occurrence of resistant beds in these sandstones makes outcrops more frequent than in other undulating land systems.

Undulating country on the resistant Carboniferous marine sediments (Timor and Vacy land systems) is confined to narrow tracts in the main valleys, consisting of survivals of pre-Quaternary valley floors. Undulating country with heavy soils (Blairgowrie and Parkville land systems) extends across Carboniferous, Permian, and Tertiary rocks with a high base content, but is most extensively developed on the weakest rocks in this group, shales and calcareous sandstones around Scone.

(d) *Plateau Country*

The plateaux have undulating surfaces and range in altitude from 2700 to 5400 ft. They are developed only on rocks with a horizontally layered structure: basalt and Triassic sandstone. Easily the most extensive are those on the basalt comprising the Tubrabucca land system, subdivided into units according to altitude. On the Triassic sandstone, plateaux of limited extent (Munghorn Gap land system) are found only on the extreme western watershed. They are relics of an extensive erosion surface cut across the sandstone in pre-basalt times and have survived on account of their position in a headwater area.

(e) *Marine Deposits*

Two very small land systems occur on recently emerged and contemporary marine or estuarine silts and clays (Nesta and Avicennia land systems).

(f) *Fluviatile Deposits*

Strips of alluvium in the valley bottoms are encountered throughout the area, and when over $\frac{1}{4}$ mile wide have been mapped as the Hunter or the Yarramoor land systems. If less than this width, they have been incorporated as units in other land systems. The Hunter land system is found on non-basaltic alluvium and the Yarramoor on basaltic alluvium which gives a heavy cracking clay soil. Differences in age, microrelief, and liability to flooding between the various terraces have served as criteria for distinguishing the various units within these two land systems.

In the infilled estuary which once extended inland to Maitland, extensive swamps remain between the river levees and the former shores of the estuary. These swamps form the Hexham land system.

(*g*) *Colluvial Deposits*

Unconsolidated terrestrial deposits of various types mantle lower slopes throughout the Hunter valley, masking the underlying rock, modifying the land forms, and providing the raw material for most soils. Only in one case has it been possible to distinguish a separate land system (Sandy Hollow) on such deposits. This land system comprises fans and sheets of sand and gravel laid down on gentle lower slopes overlooked by rugged Triassic sandstone hills. These deposits are no longer accumulating to a significant extent, and consequently have mature soils.

(*h*) *Aeolian Sand*

The Duck Hole land system consists of sand dunes up to 100 ft high overlying undulating flats composed of old beach sand ridges. The old dune and beach ridge complex extending from Hexham to Port Stephens has deep podzols; the younger complex between Stockton and Anna Bay has shallower podzols, while the active coastal dunes have no soil profile. Wind-blown sand derived from the beach is plastered over the high ground that reaches the sea between Newcastle and Redhead (Redhead land system), largely concealing the underlying Permian rock and resulting in soil and vegetation like those of the true sand dunes.

The Warkworth land system consists of low dunes fringing the lower Hunter and Wollombi; the deep soil on these dunes indicates a considerable age. Thin sand sheets near Cessnock, probably derived from weathering sandstone outcrops, have been included in this land system.

V. Climate and the Land Systems

Further subdivisions of the lithologic and geomorphic divisions outlined in this and the preceding Part have been made according to climatic differences (mainly rainfall), as revealed primarily in the vegetation. However, these differences are also significant from the geomorphic point of view, since for a given slope and rock type, outcrops, sheet wash, and gullying are more prevalent in dry areas than in humid areas, on account of the more open vegetal cover.

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PART VI. SOILS OF THE HUNTER VALLEY

By R. H. M. van de Graaff*

I. Introduction

This Part is divided into three sections. The first section contains a short discussion on the five main factors which control soil formation in general. With this concept as a theme, some major differences between the soils are explained on a regional basis. The second section deals with some different classification schemes in use and with the value of the criteria on which they are based. It also summarizes the criteria that play an important role in this report. The last section consists of descriptions of each great soil group or combination of great soil groups and the soil families into which they have been subdivided. Their relationships with more or less equivalent great soil groups as defined in some other classifications are also briefly discussed.

This report has drawn heavily on the work of Brewer and Butler (1953), who did a detailed soil survey of 120,000 acres (2·2% of the area described in this report) on the flood-plains and the adjoining valley slopes of the Hunter River between Denman and Scone.

II. Soil Formation and Regional Distribution

Soils, which result from the weathering of rocks, differ according to the influence of climate, organisms, topography, parent material, and time (Jenny 1941). There is a wide range of these factors in the Hunter valley, and as a result there is an enormous variety of soils.

A large proportion of the Hunter valley consists of erosional surfaces on fresh rock or with a shallow regolith. Ancient soils, such as "Tertiary" laterites, which most likely were present in the past have been almost completely removed. Therefore most soils can be called young, although they are sufficiently mature to have developed well-expressed and characteristic pedological properties. This relative youthfulness of the soils is significant because young soils reflect their parent materials better than very old soils, and it is in striking contrast with many areas in other parts of the Australian continent. In these other parts the soils are often found on land surfaces of great antiquity, and are the original soils or have formed from parent materials which were already highly weathered.

Depositional surfaces are much less extensive and the age of their soils is of the same order as that of the soils of the erosional surfaces. They are mostly of Holocene age or older. Very recent (present-day) alluvial soils are restricted to small areas.

Old soils, which possibly pre-date the last glacial period, exist only in small areas. Examples are the transitional alpine humus soils of the Barrington plateau (Tubrabucca land system, unit 1). Elsewhere old soils are restricted to the Roscommon and Mt. Butterwicki land systems and some other units of the Tubrabucca

*Division of Land Research and Regional Survey, C.S.I.R.O., Canberra, A.C.T.

land system, where krasnozems occur on basalt as relics from earlier and probably wetter climates. Many of these old soils would not have formed under present-day conditions on the same parent materials.

The factor of parent material can best be discussed by comparing extremes, the Triassic sandstones and conglomerates on the one hand and the Tertiary basalts of the Merriwa plateau on the other. *In situ*, the dominant soils on the first are shallow, coarse-textured skeletal soils of extremely low fertility (Lee's Pinch, Three Ways, Watagan, Munghorn Gap, and Greenhills land systems), while the soils on the basalts range from deep cracking clays to clayey skeletal soils of moderate to high fertility (Bow, Ant Hill, and Liverpool land systems). Colluvium and alluvium tend to retain many of the properties that belong to the source rocks. For example, sheets of colluvial sand and gravel low in weatherable minerals (Sandy Hollow land system) flanking hill slopes which are wholly or partly in Triassic rocks are dominated by coarse-textured infertile earths. The soils differ from those formed *in situ* on the sandstones only in that their topographical situation permits them to become deep. In the same way, deposits derived from basalt (Yarramoor land system and colluvial parts of Bow land system) give rise to the same cracking clays which can also be found *in situ* (other parts of the Bow land system).

The natural chemical and physical fertility of the soils is also strongly influenced by the composition of the rock. It influences the grain size of the soils, the type of clay minerals, the initial amounts of plant nutrients, and the capacity of the soil to retain these against removal by leaching. However, a survey by Wild (1958) indicated that Australian soils generally have low contents of total phosphorus which could not be attributed to low phosphorus contents of the parent rock. It was suggested that the phosphorus was lost by leaching from the soil. In the absence of representative data from rocks and soils in the Hunter valley, the applicability of this finding remains obscure. It should be noted here that, whilst the basalts are undoubtedly among the richest rock types, the chemical fertility of basalt-derived soils should not be exaggerated. There is, for instance, some evidence that fertilizers containing phosphorus (also sulphur) give significant responses on the cracking clays of the Merriwa area (Monteith 1954; Kaleski 1962).

High rainfall has produced many different but highly leached soils, often having pH values between 4 and 6 and with low base saturation percentages in their subsoil. They occur in the eastern lowlands and hills (Redhead, Duck Hole, Beresfield, Elrington, Vacy, and Wallaroo land systems) on a great variety of Permian and Carboniferous sedimentary rocks and Quaternary dune sands, and on the Barrington Tops (Tubrabucca land system), where the soils are of basaltic origin. In contrast, less heavily leached soils, with subsoil pH values between 6 and 9, were produced in the drier central and north-western parts such as the cracking clays on basalt, shales, and alluvium (Bow, Ant Hill, Blairgowrie, Parkville, Bray's Hill, Yarramoor, and Hunter land systems).

Similarly, the leached texture-contrast soils with acid subsoils of the eastern lowlands and hills can be contrasted with those with subsoils which are alkaline owing to the presence of free lime or high base saturation percentages, occurring mainly in the western and central parts (Blairgowrie, Parkville, Timor, Upper Rouchel, Killarney, Glendower, and Bray's Hill land systems). In this report these two groups of soils are termed respectively podzolic and solonetzic. Obviously the composition of the parent materials determines the amounts of soluble components that can be removed by the process of leaching and consequently the time it takes to reach certain stages of depletion. The rate of leaching is presumably also influenced by the porosity of the parent material. With regard to the sedimentary rocks, none of these factors can be considered as constant in the Hunter valley and this could explain such phenomena as gradual and sharp soil boundaries, small inclusions of soils differing from those immediately surrounding them, and in places highly complex soil patterns. Downes and Sleeman (1955) report leached acid texture-contrast soils from the low-rainfall areas west of the Dividing Range. This example illustrates that the relationships may not be simple and that a different combination of soil-forming factors may result in soils that are, as yet, indistinguishable from one another.

The soil-forming factor "organisms", which consists of the combined effects on soil formation of the vegetation, the microorganisms that live in the soil, and the fauna, will not be discussed here because, except for the general principles that apply universally, no facts are known which are especially pertinent to the Hunter valley.

Differences in relief and steepness of slopes give rise to differences in the stability of the soils. The low-lying areas are generally also those with gentle slopes and deep stable soils, while in the rugged and steeply sloping parts the rate of natural erosion is so much faster that the soils tend to be shallow and to contain many fragments of the parent rocks. Such skeletal soils are also more prevalent when the parent rock is poor (Triassic sandstones, Carboniferous granites) or more resistant to weathering (Carboniferous lavas), or where the climate is drier.

III. Soil Classification

(*a*) *Various Classification Systems*

Soils can be classified according to suitability for a certain crop, erodability, acidity, properties important to road engineers, morphology, or factors which played a role in their formation, to name only a few. A classification according to the last two criteria is more permanent and natural.

The traditional classification of Australian soils is by Stephens (1956). This system is not quite satisfactory, for three reasons. First, it is based not only on observable or measurable properties of the soil, but also on its geographical distribution, its presumed pedogenetical evolution, and the climate. Second, it does not cover all soils. Third, it is in parts somewhat vague or ambiguous.

A new American classification (United States Department of Agriculture 1960), although not yet in its final stage, is very different. It is a natural or taxonomic system, also based on observable or measurable soil properties, with emphasis on those that affect soil genesis or result from it. However, even for higher orders it often leans heavily on laboratory analyses, which handicaps field workers. Moreover, the proposed soil names may be somewhat awkward, although not more so than the scientific names used by botanists. Despite its shortcomings it is likely to be univer-

TABLE 7

RELATIONSHIPS TO PREVIOUSLY DESCRIBED SOILS AND OTHER SOIL CLASSIFICATIONS

Brewer and Butler (1953)		Classification used in this Report		U.S.D.A. (1960)†		
Soil Series or Type*	Great Soil Group	Great Soil Group	Family	Order	Suborder	Great Group (Subgroup)
Rouchel series	Alluvial soils	Alluvial regosols	Rouchel	Entisols	Psamments	Orthospsamments (Orthic)
			Maitland		Udents	Hapludents (Orthic)
			Errington		Udents	Hapludents (Orthic)
			Fullerton		Aquents	Hydraquents (Orthic)
		Sandy aeolian regosols	Warkworth Coastal sands	Entisols	Psamments Psamments	?Quarzopsamments ?Orthopsamments
		Skeletal soils		Entisols and Inceptisols		
		Alpine humus soils	Barrington	Inceptisols	Umbrepts	Cryumbrepts (Orthic)
Mangoola series	Grey soils of heavy texture	Meadow soils	Mangoola	Entisols and Inceptisols	Udents, Aquents, and Aquepts	
			Eskdale			
			Devon	Mostly Entisols	Psamments	Mostly Orthopsamments

		Acid swamp soils		Entisols	Aquents	Hydraquents
		Moor peats		Histosols	(Not further subdivided)	
Abermusden series, Kooringa series	Chernozems	Chernozems	Abermusden	Mollisols	Udolls	Hapludolls and Argudolls
			Bylong		Udolls	Hapludolls
		Prairie soils		Mollisols	Udolls	Hapludolls and Argudolls
Segenhoe clay, Kyuga clay, St. Aubin's clay, Balmoral clay, Scone clay	Black earths	Cracking clays	Segenhoe	Vertisols	Mostly Aquerts, some Usterts	Mainly Grumaquerts and Grumusterts
			Guan		Usterts	Mainly Grumusterts
			Krui		Usterts	Mainly Grumusterts
			Springfield		Usterts	Mainly Grumusterts
			Moolarban		Aquerts	Mazaquerts (?Natraquollic and Natraqualfic)
Rowan clay loam, Russell clay loam, Macqueen clay loam	Degraded black earths	Degraded black earths	Rowan	Vertisols and/or Alfisols and possibly also Mollisols	Aquerts, Usterts, Ustalfs, Ustolls	Mazaquerts, Mazusterts, Haplustolls, Typustalfs, Argustolls
Roxburgh clay loam, Ellis clay	Red-brown earths		Ellis		Usterts, Ustalfs, Ustolls	Mazusterts, Haplustolls, Typustalfs, Argustolls

TABLE 7 (*Continued*)

Brewer and Butler (1953)		Classification used in this Report		U.S.D.A. (1960)†		
Soil Series or Type*	Great Soil Group	Great Soil Group	Family	Order	Suborder	Great Group (Subgroup)
Overton clay loam, Overton loam	Red-brown earths	Solonetzic soils	Overton	Alfisols		
Strathearn loamy sand	Red-brown earths		Strathearn			
Clanricard clay loam, Clanricard loam	Degraded black earths		Clanricard			
Merton series	Solonetz					
Brougham loam, Durham loam	Red-brown earths					
Muswellbrook loam	Degraded black earth					
Piercefield sandy loam, St. Hillier series, Kia Ora sandy loam, Togar sandy loam (part)	Solodized solonetz		Piercefield		Mainly Ustalfs	Typustalfs and Natrustalfs
Clanricard sandy loam	Degraded black earth					
Cropwell series, Brushy Hill series	Solonetz		Cropwell			
Togar sandy loam (part)	Solodized solonetz		Togar			
Glenbawn sandy loam	Solodized solonetz		Glenbawn			

Rosscole loam Vaux series	Red podzolic Yellow podzolic	Podzolic soils	Pokolbin Rosscole Binnie Vaux Buttai Singleton Quarrybylong	Alfisols and Ultisols	Aqualfs, Udalfs, Ochrults and Umbrults	Albaqualfs, Typudalfs, Rhodochrults, Typumbrults
		Meadow podzolic soils	Fal Brook	Alfisols and ?Ultisols	Aqualfs and ?Aquults	
		Humus–iron podzols		Spodosols	?Mostly Orthods	
		Earths	Moonan Baerami Cox's Gap Dusodie Mulbring Growee Cumbo Woolooma Ulan	Mainly Alfisols, also probably Ultisols and Entisols	Udalfs, Ustalfs, ?Ochrults, ?Umbrults, some Psamments and Udents	
		Krasnozems	Torrielodge Tunbridge Hook Roscommon	Oxisols	?Idox and ?Udox ?Ustox ?Aquox ?Ustox	
		Transitional alpine humus soils	Meehan	Oxisols	Udox	Class 9.31
		Solonchaks		Aridisols		

* In some cases there is a certain amount of overlap with other soil families.

† In the absence of adequate chemical, mineralogical, and physical data, the application of the new U.S.D.A. soil classification is tentative.

sally accepted. In Table 7 the soils of the Hunter valley are classified, where possible, according to the two systems. Table 8 gives the structure of the two systems in order of increasing detail.

In this report, for practicability and usefulness, a classification based on great soil groups according to Stephens (1956) has been employed, and also a further classification into soil families.

Because of difficulties in Stephens's system, minor alterations in the definition of some great soil groups are suggested, and some of his great soil groups have been grouped together. These alterations are dealt with under the respective great soil

TABLE 8

COMPARISON OF CLASSIFICATION SYSTEMS

Stephens (1956)	U.S.D.A. (1960)
Solum classes	Orders
Soil orders	Suborders
Soil suborders	Great soil groups
Great soil groups	Subgroups
Soil families*	Soil families
Soil series*	Soil series
Soil types	(Soil types)†
Soil phases*	

* Not described, only mentioned as categories.

† The lowest category in all previous American classifications, not to be retained in their new natural system.

groups. Soils which could not be accommodated in his system were classified according to other workers. The most important criterion in dividing the texture-contrast soils into two main groups, the solonetzic and the podzolic soils, has been subsoil reaction.

The great soil groups have been further subdivided into soil families according to texture, thickness of horizons, mineralogy, and colour, which should provide families fairly homogeneous with respect to plant growth. The range of differences within these families is still large enough to produce important differences in productivity, but further classification was beyond the scope of this survey.

The soils described by Brewer and Butler (1953) have been taken into account. These authors did not use the Munsell notation, and consequently it is not always possible to place their soil series correctly into the proposed soil families. There is little doubt that there are other unrecorded soils in the area which would not fit into any of the families listed.

(*b*) *Classification Problems Concerning Texture-contrast Soils*

These soils are particularly common in the undulating and hilly land systems on Permian and Carboniferous rocks and on older alluvial terraces (Beresfield, Elrington, Vacy, Wallaroo, Timor, Upper Rouchel, Moonibung, Killarney, Glendower, Bray's Hill, Blairgowrie, Parkville, and Hunter land systems). Elsewhere in Australia it has been found that in many texture-contrast soils the A and B horizons do not form a pedogenetical entity and that in fact the A horizon was a later colluvial deposit (*K* cycles of Butler 1959) which could have come from a different source altogether. The principle of *K* cycles is also applicable to the survey area. Some A horizons might therefore consist of younger *K* cycle material. Standard field techniques are inadequate to reveal the genetic unity, or lack of it, of A and B horizons in texture-contrast soils. However, it is the author's opinion that, whilst this explanation may be valid in some particular cases where potential sources for the later deposits can be readily indicated, in most other cases in the Hunter valley these A horizons are true pedogenetical features. The reasons for this belief are that these texture-contrast soils are often found occupying both isolated hill tops as well as the surrounding lower slopes, and that the thickness of their A horizons varies between fairly narrow limits. Moreover, when the soils occur on sedimentary rocks the two horizons cannot have been derived from different parent rocks because they run parallel with the soil surface and not necessarily with the bedding plane of the rocks.

The classical view on the genesis of a large group of texture-contrast soils—Stephens's (1956) solonetz, solodized solonetz, and soloth—is that sodium ions adsorbed on the clay render the clay particles mobile so that they can be moved downward with percolating rainwater to accumulate in the subsoil. In the Hunter valley such sodium is most likely to have come from the weathering rocks themselves. Another possible explanation that could apply to all texture-contrast soils is that the products of the decomposition of clay minerals in the surface are transported down the profile, where at a certain depth new clay minerals are formed. Both theories are incomplete as neither explains why the increase in texture from the A to the B horizon is sharp rather than gradual. It must be concluded that the different steps and processes of their formation are poorly understood. So far only hypothetical explanations can be offered with regard to their genesis, which is especially unfortunate because it is vital to a proper genetic classification.

IV. Description of the Soils

The soil families and great soil groups recognized in this survey are listed in Table 7 where their classification according to various systems is indicated. The distribution of the soils within land systems is shown in Table 9.

The descriptive terms are those of the United States Department of Agriculture (1951, 1960), and the soil colour names are those of the Munsell soil colour charts. The soil colours described are those of moist soils unless otherwise indicated. The terminology for soil depth is according to the United States Department of Agriculture (1959). For convenience the definitions of some of the terms are reproduced in Table 10.

In this report the soils are arranged in great soil groups, but as their pattern was too intricate to map, they were combined for mapping purposes into the broader soil associations. The land system boundaries have been used for the mapping associations because these were the most reliable boundaries available.

TABLE 9

DISTRIBUTION OF SOIL FAMILIES* BY LAND SYSTEMS (SIMPLIFIED)

Great Soil Group	Soil Family	Land Systems in which Soil Occurs to Major Extent	Land Systems in which Soil Occurs to Minor Extent
Alluvial regosols	Rouchel	Hunter	Most other land systems (alluvial units)
	Maitland	Hunter, Hexham	Most other land systems (alluvial units)
	Errington	Hunter, Hexham	Most other land systems (alluvial units), Avicennia
	Fullerton	Avicennia	Hexham
Sandy aeolian regosols	Warkworth	Warkworth	Hunter
	Coastal sands	Duck Hole, Redhead	
Skeletal soils		Lee's Pinch, Three Ways, Watagan, Greenhills, Ogilvie, Liverpool, Ant Hill, Benmore, Mt. Butterwicki, Upper Rouchel, Glendower, Elrington, Cranky Corner, Colonel, Moonibung, Apis, Barigan, Redhead, Rouse, Rainforest, Tubrabucca, Alston	Bow, Beresfield, Ulan, Munghorn Gap
Alpine humus soils	Barrington		Tubrabucca, Liverpool
Meadow soils	Mangoola		Hexham, most other land systems (alluvial units)
	Eskdale	Nesta	Most other land systems (alluvial units)
	Devon	Nesta	Most other land systems (alluvial units)
Acid swamp soils		Hexham	Duck Hole, Redhead, Hunter
Moor peats			Tubrabucca
Chernozems	Bylong	Hunter	Most other land systems (alluvial units)
	Abermusden	Hunter	Most other land systems (alluvial units)
Prairie soils			Ant Hill, Hunter

Cracking clays	Segenhoe	Bow, Ant Hill, Blairgowrie, Parkville, Bray's Hill, Yarramoor, Hunter	Killarney, Glendower, Liverpool, Roscommon
	Guan	Ant Hill, Liverpool	Bow, Tubrabucca, Glendower, Moonibung
	Springfield	Bray's Hill	Apis, Blairgowrie, Parkville
	Krui	Alston	Ant Hill, Apis, Bow, Glendower
	Moolarban		Ulan
Degraded black earths	Rowan	Blairgowrie, Parkville	Bow, Bray's Hill, Glendower, Killarney, Ogilvie, Roscommon (?)
	Ellis		Bray's Hill, Glendower, Killarney, Ogilvie, Blairgowrie
Solonetzic soils	Overton	Killarney, Glendower, Upper Rouchel	Blairgowrie, Benmore, Ogilvie, Bray's Hill
	Strathearn	Killarney, Sandy Hollow, Upper Rouchel	
	Clanricard	Timor, Killarney, Upper Rouchel, Glendower, Parkville	Benmore, Blairgowrie, Bray's Hill, Ogilvie, Greenhills
	Piercefield	Glendower, Killarney, Sandy Hollow, Timor, Upper Rouchel	Blairgowrie, Greenhills
	Cropwell	Parkville, Hunter	Blairgowrie
	Togar	Blairgowrie	Killarney
	Glenbawn		Parkville
Podzolic soils	Pokolbin	Glendower	Apis, Upper Rouchel, Vacy, Wallaroo, Mt. Royal, Killarney, Rainforest
	Rosscole	Blairgowrie, Killarney	Hunter, Glendower
	Binnie	Beresfield, Elrington, Killarney, Moonibung, Vacy, Wallaroo, Glendower, Mt. Butterwicki	Benmore, Hunter, Upper Rouchel, Mt. Royal
	Vaux	Beresfield, Glendower, Killarney, Wallaroo	Sandy Hollow
	Buttai		Beresfield
	Singleton		Beresfield
	Quarrybylong		Elrington
Meadow podzolic soils	Fal Brook		Hunter, also in some other land systems
Humus–iron podzols		Duck Hole	

TABLE 9 (*Continued*)

Great Soil Group	Soil Family	Land Systems in which Soil Occurs to Major Extent	Land Systems in which Soil Occurs to Minor Extent
Earths	Moonan		Upper Rouchel
	Baerami	Sandy Hollow	Watagan, Greenhills
	Cox's Gap	Barigan	
	Dusodie		Wallaroo, Killarney
	Mulbring		Greenhills, Lee's Pinch
	Growee	Munghorn Gap	Killarney, Watagan, Elrington
	Cumbo	Greenhills, Sandy Hollow, Glendower, Killarney	Hunter, Lee's Pinch, Three Ways, Mt. Butterwicki, Wallaroo, Watagan
	Wooloorna	Benmore, Glendower	Hunter, Killarney, Mt. Butterwicki, Mt. Royal, Timor, Wallaroo, Watagan
	Ulan	Ulan	
Krasnozems	Torrielodge	Roscommon, Tubrabucca, Rainforest	Alston, Ant Hill, Bow, Liverpool, Wallaroo, Mt. Royal
	Tunbridge	Roscommon	
	Hook		Roscommon, Tubrabucca
	Roscommon		Roscommon
Transitional alpine humus soils	Meehan	Tubrabucca	
Solonchaks			Killarney, Hunter, Glendower

* Mainly based on field impressions, but in one area on Brewer and Butler's (1953) detailed "soil group" map, depicting groups of morphologically and genetically related soils.

TABLE 10
DEFINITION OF DESCRIPTIVE SOIL TERMS

Soil Depth (U.S.D.A. 1954)		Soil Texture (U.S.D.A. 1960)			Soil Reaction (U.S.D.A. 1960)	
Very shallow	0–10 in.	Sandy soils	Coarse-textured	Sand	Extremely acid	pH <4·5
Shallow	10–20 in.			Loamy sand	Very strongly acid	pH 4·5–5·0
Moderately deep	20–36 in.	Loamy soils	Moderately coarse-textured	Sandy loam	Strongly acid	pH 5·1–5·5
Deep	36–60 in.			Fine sandy loam	Medium acid	pH 5·6–6·0
Very deep	> 60 in.		Medium-textured	Very fine sandy loam	Slightly acid	pH 6·1–6·5
				Loam	Neutral	pH 6·6–7·3
				Silt loam	Mildly alkaline	pH 7·4–7·8
				Silt	Moderately alkaline	pH 7·9–8·4
			Moderately fine-textured	Clay loam	Strongly alkaline	pH 8·5–9·0
				Sandy clay loam	Very strongly alkaline	pH >9·1
				Silty clay loam		
		Clayey soils	Fine-textured	Sandy clay		
				Silty clay		
				Clay		

The chemical analyses of the soil samples were mostly carried out by the Royal Tropical Institute, Amsterdam, Netherlands. X-ray analyses were carried out by Dr. Odd Gjems, Norwegian Forestry Research Institute. Analytical methods for phosphorus are: "available" phosphorus according to Truog, "total" phosphorus by boiling for 3 hr in 25% hydrochloric acid.

(*a*) *Alluvial Regosols*

The great soil group of alluvial soils (Stephens 1956) includes only those soils which are found on recent alluvial deposits and which on account of their immaturity have not developed any true pedological differentiation with depth, other than some accumulation of organic matter in the surface. If the profile consists of a sequence of layers of different textures, they are not the result of processes of soil formation (like the mobilization and translocation of clay particles), but of fluctuating conditions during deposition (like stream velocity and turbulence).

In order to differentiate them from mature soils which also can occur on alluvium, and because immature soils of any origin are called regosols (U.S. Department of Agriculture 1957), these soils will be called alluvial regosols in this report.

A general description would not be meaningful because of the extremely wide range of texture, gravel content, and thickness of layers which may occur.

The alluvial regosols are important in the agriculture of the Hunter valley, because they are often fertile and flat and occur mainly in the east, where the rainfall is high. They are intensively utilized at present. One profile of a medium- to moderately fine-textured alluvial regosol was sampled north of Duckenfield. This soil contains approximately 0·08% of "total" phosphorus over its full sampled depth of 36 in. About one-quarter of this phosphate is readily "available" to plants. Its exchange capacity ranges from 27 to 37 m-equiv./100 g and the saturation percentage remains uniform between 85% to 90%, with calcium dominant and magnesium subdominant. Reactions range from slightly acid to neutral (pH 6·1 to 7·3).

Four families are proposed on the basis of texture and origin.

(i) *The Rouchel Family*.—It is dominantly coarse- to moderately coarse-textured in the upper 24 in. of the profile. The soils are often single-grained when dry.

(ii) *The Maitland Family*.—It is dominantly medium- to moderately fine-textured in the upper 24 in. of the profile and consists of fertile arable soils.

(iii) *The Errington Family*.—It is dominantly fine-textured in the upper 24 in. of the surface and a fertile arable soil.

(iv) *The Fullerton Family*.—This family is of marine origin, saline, and dominantly fine-textured. It is too saline for any agricultural use. The definition of solonchaks excludes this family.

(*b*) *Sandy Aeolian Regosols*

Aeolian sands have been described by Stephens (1956) in a similar way to the alluvial soils, that is, recent aeolian sands which show little profile development beyond the accumulation of some organic matter in the surface or the solution and redeposition of lime in the profile. These soils can therefore also be called regosols, or, more appropriately, sandy aeolian regosols.

In some cases the parent material is so poor in weatherable minerals or weathering conditions are so weak or infrequent that hardly any soil development could take place. This is probably the case with the only named family proposed in this great soil group. It occurs scattered along the Hunter and Wollombi Rivers between Singleton and Warkworth. Elsewhere in high-rainfall areas humus–iron podzols have developed in older similar deposits. The regosolic sands of the most recent coastal dunes and the beaches have not been subdivided into named families, but are simply referred to as coastal sands. Fertility of all these aeolian sands is likely to be extremely low. The more recent coastal sands possess some lime in the profile, but because of their position they are also subject to salt spray from the ocean.

(i) *The Warkworth Family*.—This is derived from fluviatile sands and has a single-grained coarse-textured profile of speckled sand and hardly any accumulation of organic matter in the surface. Most of the sand grains consist of clear uncoated quartz particles. Because of the inertness of these leached sands their reaction is only slightly acid (pH 6·1–6·5).

(ii) *The Coastal Sands*.—These are derived from marine sands, originally containing seashell fragments (lime). The parts farthest inland consist of the oldest sands which have been longest leached. The lime has been removed completely from the soil profile. They may have developed an organic surface horizon. The youngest sands near the beach are not leached and have not changed since deposition. They do not have an organic surface horizon. In between these extremes are many transitional soils.

(*c*) *Skeletal Soils*

Skeletal soils are stony or gravelly soils showing no profile development other than organic matter accumulation in the surface. They are normally shallow and contain coarse-textured fragmented rock, which may show some weathering. Such soils are essentially non-arable. The name skeletal soils will be used here to cover also those immature soils of less than 10 in. depth which may already show some structure development.

No families are proposed for this group, but there are naturally differences in texture and organic matter content, which are important in determining their potential.

The humic varieties occur in areas with a high rainfall and commonly lower temperatures as well as on high mountain ranges. The texture of the soil between the rock fragments or stones depends on the parent rock. On the basalts of the Liverpool land system the textures are always fine, while at the other extreme the sandy conglomerates in the Lee's Pinch land system give rise to a sandy gravelly mass.

It is obvious that the humic and fine-textured skeletal soils have a greater potential, for instance for grazing or forest establishment, than the non-humic and coarse-textured ones.

(*d*) *Alpine Humus Soils*

The name alpine humus soils was suggested by Costin, Hallsworth, and Woof (1952) and Costin (1954) for a group of soils which have developed in high mountain areas. Subsequently these soils were adopted as a great soil group by Stephens (1956).

General description

A_1 Medium- to fine-textured soils with a conspicuous and thick black organic surface horizon; stable crumb structure; friable when moist; extremely acid to medium acid (pH $<4\cdot5$–$6\cdot0$)

Gradual transition

B Subsoil in which the organic matter content gradually decreases with depth; consistence changes from friable to firm when moist; structure becomes rapidly weaker with depth; colours change to brown, dark yellowish brown, and yellowish brown; little or no change in texture; soils usually shallow, often stony.

Since most or all these soils in the Hunter valley occur on Tertiary basalt, their morphology and chemical properties are probably also uniform. None was sampled for analysis, but from inference from the alpine humus soils from the Kosciusko region they are expected to be strongly acid and highly leached. The extreme climate under which they occur also limits their potential for more intensive use.

The *Barrington* family is the only family proposed for these soils in the Hunter valley.

(*e*) *Meadow Soils*

According to Stephens (1956), wiesenboden or meadow soils are black earths (cracking clays) of which the subsoils have been modified by the seasonal presence of ground water resulting in dull mottled colours. It is proposed here that the definition be widened to include all soils, with or without lime in the subsoil, which have gradational mineral profiles, high organic matter content in the surface, poor internal and external drainage, and subsoils which are periodically invaded by the water-table, causing mottled colours.

The majority of the meadow soils are permanently moist.

General description

A Dark soils, yellowish brown to brownish yellow (rusty) mottles along root channels common; coarse- to fine-textured; high content of organic matter in surface; may have fine crumb structure; friable when moist; strongly acid to neutral (pH $5\cdot1$–$7\cdot3$)

Usually gradual transition

AC Subsoil of same wide texture range; colours lighter, with much grey, often strongly mottled with dark yellowish brown, black, red, or yellowish brown; structure often massive; consistence varying with texture from plastic to non-plastic when wet; medium acid to moderately alkaline (pH $5\cdot6$–$8\cdot4$)

Three families are proposed on the basis of the texture of the surface 12 in.

(i) *The Mangoola Family*.—This family has fine-textured surface soils. Soils of the Mangoola series (Brewer and Butler 1953) reportedly often show gilgai features.

(ii) *The Eskdale Family*.—It has medium- to moderately fine-textured surface soils.

(iii) *The Devon Family*.—It has coarse-textured surface soils.

No chemical analyses are available but most meadow soils are of mixed alluvial origin and are probably fairly fertile. Periodic waterlogging is frequent in the natural state preventing their use for anything other than pasture. However, except perhaps for those of the fine-textured Mangoola family, most could probably be used for crop production where the surface soils could be drained of excess water.

(*f*) *Acid Swamp Soils*

Acid swamp soils are defined by Stephens (1956) as soils which have formed under the influence of a water-table at, above, or near the soil surface, and with an acid reaction. They are closely related to the meadow soils and can be regarded as acid, permanently waterlogged phases of them.

General description

A Black to dark grey surface, often with yellowish brown to brownish yellow (rusty) mottles; coarse- to fine-, but usually medium- to fine-textured; usually high content of decomposed organic matter or peat in surface; crumb or massive surface structure; slightly plastic when wet; friable when moist; acid

Gradual transition

AC Very dark grey, dark grey, sometimes black, usually strongly mottled subsoils; varying textures; may be peaty; massive structure; consistence varies with texture; acid, grading into neutral with depth

C Mainly stratified alluvial deposits

In their natural state acid swamp soils carry only low-grade pasture with many sedges and rushes, but when properly drained, they can be highly productive and support good grassland or various crops, especially vegetables and potatoes.

In the absence of more detailed morphological or chemical data, and because of the varied parent materials, no families are proposed at this stage.

(*g*) *Moor Peats*

Moor peats are defined by Stephens (1956) as black soils consisting predominantly of organic matter, and at or near saturation with water. The upper part of the profile may consist of brown, relatively undecomposed fibrous material. The main difference from the acid swamp soils of the lower altitudes is apparently that they should occur above the winter seasonal snow-line.

In the Hunter valley the moor peats occur exclusively in swamps on the Barrington plateau at altitudes of over 4500 ft. In some places the sphagnum peats overlie lake sediments. The peat swamps are extremely important in that they regulate the flow of water in creeks and rivers issuing from the plateau, giving them a steady discharge. However, most swamps on the plateau do not drain into the Hunter River system.

Because of their extremely small extent no detailed description is given and no families are proposed.

(*h*) *Chernozems*

The chernozems are lacking in Stephens's (1956) classification but they have been recognized by Brewer and Butler (1953) in the Hunter valley. Their classification was later confirmed by Thorp (1957), who agreed they were equivalent to the minimal southern chernozems in the United States of America.

General description

A Usually moderately fine-textured soil; colour rather uniform throughout solum, black, very dark greyish brown, dark and very dark brown, dark yellowish brown, are the most common; strong grade, fine, granular or crumb structure; slightly plastic when wet, very friable to friable when moist and slightly hard to hard when dry; slightly acid to neutral (pH 6·1–7·3)

Gradual transition

B Fine-textured, dark soil but coarser textures are possible; strong grade, fine to medium, angular blocky or blocky structure; consistence generally similar to A horizon but becoming slightly less friable with depth; neutral to moderately alkaline (pH 6·6–8·4) or even strongly alkaline (pH 8·5–9·0); lime usually finely dispersed or in nodules in lower B horizon

C Nearly always alluvial sediments

As can be seen from the general descriptions, the chernozems and the cracking clays both have little or no change in texture and colour with depth and are closely related. The most important differences are their structure and consistence. Whereas the cracking clays have a coarse structure and a consistence which allows them to be cultivated only at a narrow range in moisture content, the chernozems have a fine structure and are easily worked at a much wider range in moisture content. It would appear also that chernozems can hold more water which is available to plants, and the variety of crops which can be grown successfully is greater than for the cracking clays.

The content of organic matter of the solum is high, diminishing gradually with depth, and in general is greater than in the cracking clays (Stephens 1950; Brewer and Butler 1953). In both soils the exchange complex is dominated by calcium. As the parent material has been largely derived from basalt and as they have been formed in a climate of low leaching power, their fertility is generally high. Their phosphorus content seems to vary from 0·1 to 0·2% (Brewer and Butler 1953). Also they are youthful soils which still have weatherable minerals. Although small in area, they probably constitute the best of the arable land in the Hunter valley and are intensively used.

The chernozems have been subdivided into two families on the basis of depth of the solum, which reflects their history of evolution.

(i) *The Abermusden Family*.—The soils are deep and dark, and although not all of the same age they can be called mature chernozems. They were formed on alluvial terraces on which deposition was no longer active. They occur mainly along the Hunter and Goulburn Rivers.

(ii) *The Bylong Family*.—It has shallow dark soils (less than 12 in. deep) over stratified and little-altered alluvium, which is often coarser than the surface soil. They were formed on alluvial terraces in valleys under less stable erosional and depositional circumstances. Occasionally soil formation was interrupted by the deposition of a fresh, often thick layer of alluvium. Buried fossil A horizons are common and the soils are relatively immature. They occur mainly in valleys running north through the belt of Triassic sandstones and Permian shales in the south-west of the Hunter valley.

The Bylong family also includes some soils in which the water-table comes rather close to the surface and which can be regarded as intergrades between chernozems and meadow soils.

(*i*) *Prairie Soils*

The prairie soils (Stephens 1956) are very similar to the chernozemic soils, the main difference being the absence of lime from the solum owing to their formation under a slightly more humid climate with a greater leaching power. The stronger degree of leaching has also affected the reaction of the soil to some extent.

General description

A Usually moderately fine- to fine-textured soils; commonly dark brown, very dark greyish brown, dark greyish brown, and very dark brown; usually strong degree of crumb or fine blocky structure; friable when moist and slightly hard to hard when dry; slightly acid to neutral (pH 6·1–7·3)

Gradual transition

B Moderately fine- to fine-textured, dark soils, mainly 10YR Munsell hue; usually strong degree of a somewhat coarse, subangular blocky or blocky structure; consistence similar to A horizon; neutral to possibly mildly alkaline (pH 6·6–7·8)

C Alluvial deposits

The prairie soils occupy a relatively small area mostly in the more humid eastern parts where they merge with the young to recent alluvial regosols in the lower reaches of the major rivers. They occur also on alluvial terraces in headwater areas where the alluvial deposits are derived from basalt, and are then rather shallow and often contain waterworn basalt pebbles or cobbles. From field records it appears that they are somewhat poorer in organic matter than the chernozemic soils. Their natural fertility should not be very different but no analyses are available to substantiate this assumption. Since the total area of the prairie soils is small, the number of observations limited, and their parent materials varied, no families are proposed.

(*j*) *Cracking Clays*

The cracking clays are a group of soils which include Stephens's black earths, brown soils of heavy texture, and grey soils of heavy texture. Alternative names sometimes used are black soils, black plains soils (vernacular), or grumusols (used in the now outdated American classification).

The similarities, except for unimportant colour differences, between Stephens's black earths and brown soils of heavy texture are such that a separation of these two at great soil group level seems rather meaningless. They often occur very closely intermingled grading into one another, and the differences in colour could be caused by many factors, such as minor differences in drainage, parent materials, or maturity of the soil. Although the grey cracking clays of the Hunter valley (Stephens's grey soils of heavy texture) were observed always in alluvial situations under rather special conditions, they are similar enough to be regarded as cracking clays also.

General description

A Fine-textured throughout, no significant changes in clay content and colour with depth in solum; colours usually dark and ranging from black, very dark brown to dark yellowish brown and brown, but occasionally lighter colours ranging from grey to grey-brown; structure usually granular and self-mulching in surface, becoming coarse blocky or coarse subangular blocky in subsoil; firm to extremely firm when moist, plastic and sticky when wet, very hard to extremely hard when dry; usually slightly acid to mildly alkaline in surface (pH 6·1–7·8) and mildly to strongly alkaline (pH 7·4–9·0) in subsoil; lime often present in nodules throughout profile and on surface, and always present in the subsoils

C Weathering products derived from basic igneous rocks, fine-textured calcareous alluvium, and certain shales or sandstones

The cracking clays often give rise to a surface relief called gilgai. On sloping sites this usually takes the form of "linear gilgai", ridges and depressions at approximately right angles to the contour. On the flats circular depressions are found called "crabholey gilgai", but they are rare.

An important part of the clay minerals in the cracking clays consists of montmorillonite. At one site near Merriwa there was approximately 66% montmorillonite, 27% kaolinite, and 7% illite in a soil which contained between 50% and 78% of clay. At various depths the soil was either saturated or well supplied with calcium and magnesium, but "available" phosphorus was only a fraction of "total" phosphorus, which varied from 0·02% to 0·06% in the surface.

The effect of a large proportion of montmorillonite on the moisture regime of a soil is to increase the amounts of water that soil must hold before water becomes available to plants.

Also montmorillonite is a clay mineral which expands considerably on wetting and shrinks again on drying. This causes the deep cracks in dry cracking clays and is presumably responsible for the formation of gilgai relief. The cracks in the soil probably snap many plant roots and only certain species may be able to endure this. They also play a role in the high erodability of the cracking clays because run-off water tends to concentrate in the cracks and to form underground watercourses which may collapse to form gullies (Tewkesbury 1948).

It was found that otherwise common trees like ironbarks are absent from the cracking clays and that one grass species, *Stipa aristiglumis*, is almost exclusively dominant on soils of the Segenhoe family, which display the properties discussed above more strongly than other families in this group. Colonization of eroded patches, anti-erosion banks, etc., by the natural grasses is very slow. It seems that the Segenhoe soils offer a specialized environment in which only a few plant species are at home.

The cracking clays have been subdivided into five families on the basis of soil colour, depth, and stoniness.

(i) *The Segenhoe Family*.—The soils are dark, the most common colours being black, very dark brown, or very dark greyish brown. Typical Munsell colours are values 2 to 3, chromas 1 to 3, for hue 10YR. They are deep and usually free of stones. Where stones are present they are often concentrated in the upper part of the profile and on the surface. Linear gilgai is common.

(ii) *The Guan Family*.—It has dark-coloured soils with the same colour range as the Segenhoe family except that black is uncommon. The soils are shallow or moderately deep and usually stony, particularly on the surface. They are in less stable sites in the landscape and erosion seems to be removing them at approximately the same rate at which they are forming from the parent material. They are consequently somewhat less mature than those of the Segenhoe family. The vegetation is not as poor in species as that of the Segenhoe soils. The proportion of montmorillonite in the clay is probably lower than in the mature Segenhoe soils and linear gilgai is uncommon. The Segenhoe and Guan families grade into one another. A sharp division between the two cannot be proposed at this stage.

(iii) *The Krui Family*.—The soils are normally dark reddish brown although the surface may be very dark yellowish brown. Typical subsoil colours are Munsell hues 5YR and 2·5YR, values 2 to 3, chromas 2 to 4. Like the soils of the Guan family they are shallow and may be stony. They are rare, and linear gilgai has not been observed.

(iv) *The Springfield Family.*—The soils are reddish, normally dark reddish brown, and are deep and free of stones. They are rare, and linear gilgai has not been observed.

(v) *The Moolarban Family.*—The soils are greyish coloured and range from dark grey, grey, light brownish grey, to greyish brown, sometimes with a slight olive tinge. Typical Munsell colours are 10YR, values 4 to 6, chromas 1 to 2. They seem to be rather rare in the Hunter valley. They have been observed on alluvia in the Ulan land system where they may have formed on truncated solonetzic soils and where their high alkalinity may be the result of high exchangeable sodium content, although lime does also occur in the solum. On one occasion a soil of this description was found on the Yarramoor land system not far from a solonchak. In all cases there is a notable lack of vegetation except for some halophytic species.

(*k*) *Degraded Black Earths*

Degraded black earths are soils which presumably have been derived from black earths (cracking clays) by degradation through leaching and/or solonization, and are not necessarily black themselves. They are only mentioned by Stephens (1956) but a definition has been suggested by Brewer and Butler (1953). To simplify the profile morphology of the degraded black earths it is suggested in this report that their definition be narrowed so that soils which have an abrupt textural break, with or without an A_2 horizon, are excluded, and fall into the solonetzic category with which they have much more in common.

General description

A Usually medium- to moderately fine-textured rather dark soil; either granular or fine, subangular blocky structure; firm to friable when moist and very hard when dry; slightly acid to neutral (pH 6·1–7·3)

Gradual transition

B Fine-textured soil; black to very dark brown, dark and very dark yellowish or greyish brown, dark and light brown, reddish and dark reddish brown; blocky or subangular blocky like the cracking clays, structure coarser with depth; plastic when wet, firm when moist and very hard to extremely hard when dry, similar to consistency of cracking clays; lime usually present in upper but more often in lower B horizon; reaction neutral to strongly alkaline (pH 7·3–9·0)

C Weathering products derived from intermediate volcanic rocks, calcareous shales, basic colluvium or alluvium

It appears that the degraded black earths are similar in fertility to the cracking clays. Their coarser surface textures should make them somewhat easier to work although the difference is likely to be small. In most other properties, including their erodability, they should resemble the cracking clays.

The degraded black earths have been subdivided into two families on the basis of soil colour.

(i) *The Rowan Family.*—It has dark subsoils and seems to occur mainly on fine-textured alluvial deposits but was also observed *in situ*. Subsoil colour limits are Munsell hues 7·5YR to 10YR, values 2 to 4, chromas 2 to 6.

(ii) *The Ellis Family.*—It has commonly yellowish red, reddish, and dark reddish brown subsoils. Subsoil colour limits are Munsell hues 5YR and 2·5YR, values 3 to 5, chromas 3 to 8. This family seems to occur mainly on calcareous shales.

(l) *Solonetzic Soils*

This group includes soils with abrupt texture changes* of which the whole or at least the lower B horizon has a pH of more than 7·8.

From Brewer and Butler (1953) and field evidence it appears that a bleached A_2 horizon is strongly correlated with a coarse-textured A horizon. A bleached A_2 is diagnostic in distinguishing the great soil groups of Stephens, but texture differences of this nature in the A horizon do not seem significant enough for separation of soils on the great soil group level.

All these soils have high contents of exchangeable sodium in the B horizon (Brewer and Butler 1953) and all appear to have undergone appreciable solonization. Owing to the difficulty of recognizing a columnar (domed) structure from a prismatic structure in auger samples, differences in macrostructure of the B horizon are ignored in the present classification. It should be noted also that both types of structure are usually compound and consist of smaller and similar blocky aggregates. Lime frequently occurs in the lower B horizon or just below the solum in Stephens's solonetz or solodized solonetz profiles while—by definition—there is a lime accumulation in the lower B horizon in his red-brown earths and brown earths.

General description

A_1† Very dark greyish brown to yellowish brown; coarse- to moderately fine-textured; usually of massive structure; may be friable when moist, often hard when dry; usually slightly acid to neutral (pH 6·1–7·3)

Usually clear transition

A_2 Sometimes absent; similarly textured; colours lighter, e.g. very light grey or brownish grey or even more bleached, dry colours often very light; massive structure usually slightly acid to neutral (pH 6·1–7·3)

Abrupt transition

B_1 Fine-textured; wide range of colours from black, very dark greyish brown, dark brown, grey-brown, reddish brown, and yellowish brown or intermediate shades, often mottled; strong grade or subangular blocky, blocky, prismatic, or more rarely columnar structure; very hard when dry, plastic when wet; moderately to strongly alkaline (pH 7·9–9·0); lime may be present

Gradual transition

B_2 Texture and colours same range as for B_1 horizon, mottling often occurs; structure also similar, often weaker grade, or even massive; very hard when dry, plastic when wet; moderately to strongly alkaline (pH 7·9–9·0); lime often present

C Weathering material derived from colluvium or alluvium and *in situ* from bed-rock

The solonetzic soils are formed on alluvial materials of mixed origin and shales, arkosic sandstones, and intermediate volcanic rocks. Most by far occur west of the Wollombi River and Fal Brook, i.e. in an area with an annual rainfall of less than 24 in. To judge from the data presented by Brewer and Butler (1953) from a limited area in the centre of the Hunter valley it seems that their natural chemical fertility is generally low, the "total" phosphorus content being mostly low (in the order of 0·01% to 0·04%) with an exception perhaps for most alluvial solonetzic soils (0·09 to 0·16%).

*Profiles with true or pseudo A horizons could not be distinguished in this classification.

†The A horizon generally varies between 2 and 12 in. in thickness, but is mostly about 6 in. thick.

The high content of exchangeable sodium in the subsoil results in clays which are easily dispersable in water and consequently gully erosion is serious in some abused areas of the Hunter valley. Tunnel erosion (see podzolic soils) is reported to occur also.

The solonetzic soils have been subdivided into seven families on the basis of dominant subsoil colour and texture of the A horizon.

(i) *Red Solonetzic Soils*.—Colour limits for the subsoils are Munsell hues 5YR, 2·5YR, values 3 to 5, chromas 3 to 6.

The *Overton* family has medium- to moderately fine-textured surface soils and a typically reddish brown or dark reddish brown subsoil. This family is common.

The *Strathearn* family has coarse- or moderately coarse-textured surface soils and reddish brown or dark reddish brown subsoils. One profile with a columnar subsoil was also placed in this family. The family is common.

(ii) *Brown Solonetzic Soils*.—Subsoil colour limits are Munsell hues 7·5YR, 10YR, and 2·5Y, values 3 to 6, chromas 2 to 6.

The *Clanricard* family has medium- to moderately fine-textured surface soils and subsoil colours are various shades and intensities of brown, greyish brown, very dark grey-brown, yellowish brown. May contain waterworn gravel. The family is very common.

The *Piercefield* family has coarse- to moderately coarse-textured surface soils over brown, very dark grey-brown, greyish brown, or yellowish brown subsoils as above. The family is common.

(iii) *Dark Solonetzic Soils*.—Subsoil colour limits are 2/0, 3/0, 2/1, 3/1, and 2/2 for Munsell hue 10YR.

The *Cropwell* family has medium- to moderately fine-textured surface soils and black or very dark grey or in general very dark-coloured subsoils. This family is not common.

The *Togar* family has coarse- to moderately coarse-textured surface soils over very dark-coloured subsoils. This family is relatively rare.

(iv) *Grey Solonetzic Soils*.—Subsoil colours are values 4 to 6, chromas 0 to 1, for Munsell hue 10YR.

The *Glenbawn* family has coarse- to moderately coarse-textured surface soils over dark grey or grey subsoils. The family is rare.

(*m*) *Podzolic Soils*

The podzolic soils will be defined here as all texture-contrast soils* which have a pH of 7·8 or less in the B horizon. In the Hunter valley this group of soils occurs on a wide range of parent materials including alluvium, conglomerates, shales and shaly sandstones, intermediate volcanic rocks, and colluvium of mixed sedimentary and volcanic origin.

*True or pseudo A horizons are not distinguished.

The grouping of these soils can be justified on the uniformity of their profile forms and the absence of free lime in the solum, the colours of their subsoils being the major differences between them. According to Stephens (1956) the subsoil colours reflect to a large extent whether the internal drainage of the subsoil is good or restricted, or whether the subsoil is periodically invaded by the water-table.

The soloth or solodic soil answers the same general description and will therefore be regarded here as a podzolic soil, although some workers presume that it has developed from a solonetz by leaching. Its unconfirmable genesis is, however, not relevant to its classification. Its resemblance to podzolic soils is noted by Stephens (1956).

In this connexion it should be noted that a high proportion of sodium in the exchange complex is taken by some workers to mean that the soils are solodic rather than podzolic. Because this condition is likely to be common among the soils described in this section, they could also be called solodic. However, both names, solodic and podzolic, imply certain soil-forming processes which cannot be checked in the field and therefore they are far from ideal. In this report no new name will be suggested and the name podzolic has been arbitrarily chosen for all these soils. The podzolic soils occur mainly east of the Wollombi River and Fal Brook, but there is no sharp or regular boundary between them and the solonetzic soils because it is not rainfall alone that affects their distribution. Their parent material, internal drainage, and age play a role as well. As a rule the most acid podzolic soils occur in the higher-rainfall areas in the extreme east. In some of these soils the severe acidity (pH values of 4·5 may occur) may be expected to restrict or prevent the growth of otherwise well-suited crops and pastures.

The very scanty analytical information available indicates that most podzolic soils in the Hunter valley are of low natural fertility. Upland soils, probably for a large part podzolic, of the Williams and Paterson valleys show a number of deficiciencies, with phosphorus as the main one, but also involving molybdenum, sulphur, and copper (R. S. Wetherall, personal communication). Responses to lime are also reported and between 1000 and 2000 tons are used annually in this area.

The base saturation percentage of the soils may be very low. A podzolic oil 1·5 miles south-west of Beresfield, for instance, had saturation values of 12% to 17% with magnesium and sodium dominant and subdominant respectively. It is likely that magnesium and sodium play important roles in the exchange complex of the B horizon of most podzolic soils and this might explain the tendency of the clay to "run".

Provided the necessary predisposing factors are present, such as slope, cracking, and sheet erosion, resulting in high run-off and localized areas of high infiltration, tunnel erosion is a problem on these soils with high exchangeable sodium (G. H. Knowles, personal communication).

General description

A_1* Surface soil of coarse to moderately fine texture; colours ranging from very dark brown, very dark greyish brown to brown, greyish brown, or dark yellowish brown; usually massive structure; may be friable when moist, soft to hard when dry; usually strongly acid to neutral (pH 5·1–7·3)

*The A horizon varies generally from 2 to 12 in. in thickness, but is mostly about 6 in. thick.

Usually clear, sometimes gradual transition

A_2 Similarly textured to A_1; colours often lighter ranging from dark brown, greyish brown, dark yellowish brown, strong brown to brown and yellowish brown; dry colours often much lighter, resembling "ashy" greys and ranging from light grey via light brownish grey to very pale browns; always massive structure; strongly acid to neutral (pH 5·1–7·3)

Abrupt transition

B_1 Fine-textured subsoils; wide range of colours from very dark grey-brown, very dark brown, dark reddish brown, yellowish red to brown, yellow, and grey, often mottled; usually strong grade of subangular blocky or blocky structure, rarely massive; plastic when wet, firm to very firm but rarely friable when moist, and very hard when dry; normally strongly acid to neutral (pH 5·1–7·3) but never more than mildly alkaline (pH 7·4–7·8), sometimes very strongly acid (pH 4·5–5·0)

Gradual transition

B_2 Textures and colours same range as for B_1 horizon; structures often of a weaker grade or massive; plastic when wet, firm when moist, very hard when dry; strongly acid to mildly alkaline (pH 5·1–7·8)

C Weathering material derived from bed-rock, colluvium, or alluvium

The podzolic soils of the Hunter valley have been subdivided into seven families on the basis of surface soil texture, dominant subsoil colour, parent material, and gravel content.

(i) *Red Podzolic Soils*.—Colour limits are Munsell hues 5YR and 2·5YR, values 3 to 5, chromas 3 to 8.

The *Pokolbin* family has medium- to moderately fine-textured surface soils and a reddish subsoil, commonly with a yellowish tint. Dark red, red, dark reddish brown, and reddish brown subsoil colours also occur. The B_1 horizon is usually not mottled, but in a few cases where mottling did occur the reaction was strongly acid (pH 5·1–5·5). Only once was a soil observed with a fine sandy surface texture but a separate family for this soil is not proposed. The family is common.

The *Rosscole* family has moderately coarse- to moderately fine-textured gravelly surface soils, which may contain between 30% and 70% of waterworn gravel by weight. The subsoils are dark reddish brown and usually contain less gravel. These soils have been found only on remnants of old alluvial gravel terraces. This family is common in certain parts of the Hunter valley.

(ii) *Brown Podzolic Soils*.—Subsoil colour limits are Munsell hues 7·5YR, 10YR, 2·5Y, values 3 to 6, chromas 2 to 6.

The *Binnie* family has medium- to moderately fine-textured surface soils and brownish or yellowish coloured subsoils which are commonly mottled. The family is very common.

The *Vaux* family has coarse- to moderately coarse-textured surface soils. The Vaux series (Brewer and Butler 1953) is somewhat atypical because of its massive structure in the B horizon. This family is widespread.

(iii) *Dark Podzolic Soils*.—Subsoil colour limits are 2/0, 3/0, 2/1, 3/1, and 2/2 for Munsell hue 10YR.

The *Buttai* family has medium- to moderately fine-textured surface soils over very dark-coloured subsoils. This family is rare.

The *Singleton* family has coarse- to moderately coarse-textured surface soils and very dark-coloured subsoils which may be black or very dark grey, the latter colour probably being more common. The family seems to be rare.

(iv) *Grey Podzolic Soils*.—The subsoil colour limits are values 4 to 6, chromas 0 to 1, for Munsell hue 10YR or yellower.

The *Quarrybylong* family has medium- to moderately fine-textured surface soils over grey-coloured subsoils. This family is rare.

(*n*) *Meadow Podzolic Soils*

These texture-contrast soils have a great number of properties in common with the podzolic soils. The main difference in the meadow podzolic soils is the strong influence of the water-table on the solum, which causes mottling in the A horizon and dull colours and mottling in the B horizon. Apart from these differences, the general description of the podzolic soils applies. These soils occupy only very small areas in the Hunter valley and generally occur in natural depressions or on ill-drained alluvial terraces.

The *Fal Brook* family has coarse- to moderately fine-textured surface soils which may be black and often show slight mottling, especially along root channels. The subsoil colours generally vary from very dark grey to greyish brown with strong mottling.

(*o*) *Humus–Iron Podzols*

The humus–iron podzols of the Hunter valley are restricted to the older aeolian beach sands which occur under a humid climate in the Duck Hole land system. Because of the very variable profile morphology (Maze 1942) and the limited field observations, subdivision into families is not warranted.

General description

A_1 Dark grey often speckled sand to loamy sand; humic; extremely to strongly acid (pH $<4\cdot5$–$5\cdot5$); usually coherent; massive

A_2 Very light grey to nearly white sand or loamy sand; massive or single-grain structure; reaction very strongly acid to strongly acid (pH $4\cdot5$–$5\cdot5$)

Usually abrupt, sometimes clear transition

B Sand; coheres because of accumulation of humus or iron oxides or both; usually soft but sometimes hard and pan-like; colours vary from brown to black; very strongly acid to medium acid (pH $4\cdot5$–$6\cdot0$)

C Aeolian sand

The humus–iron podzols are very likely to be deficient in a number of plant nutrients. "Total" phosphorus in samples from one profile ranges between $0\cdot0028\%$ and $0\cdot0014\%$. Exchange capacities in these inert sands are extremely low, ranging from approximately $5\cdot4$ m-equiv./100 g of soil in the humic A_1 horizon to $0\cdot61$ m-equiv./100 g in the A_2 and $1\cdot65$ m-equiv./100 g in the B_1 horizon. The low exchange capacity for the B_1 horizon is perhaps atypical. This particular profile had very little organic matter in this horizon. It would not be surprising if trace elements were also in short supply.

Maze (1942), who did some detailed work in this area, distinguished three different kinds of podzols, which he called humus podzols, iron–humus podzols, and iron podzols according to the dominance of the cementing agent, which can be humus, iron, or a mixture of both.

A typical profile of the humus podzol of Maze (1942) is:

A_1 0–10 in. Dark grey sand with variable amounts of organic matter

A_2 10–36 in. Light grey-white sand

B_1 36–60 in. Black and brown sandy organic hard-pan of variable hardness

B_2 60 in. and deeper. Light brownish yellow sand

Maze (1942) also observed that the hard-pan varied in thickness and in depth below the surface. On the low-lying flat areas it was close to the surface, while it occurred at greater depth, 5 to 10 ft, on thetop of the sandy rises. Hard-pans were either compact, continuous, and uniform, or variable in thickness, thinning, broken at some points, or disappearing completely.

Limited areas had iron–humus podzols. These were reportedly characteristic of the small sandy rise areas south of Newcastle, in the vicinity of Jewell's Siding and Belmont. The hard-pan followed the general contour of the surface and was composed of black to brown cemented sand, containing irregular-shaped nodules of light brown to brown cemented sand.

Iron podzols were observed by Maze (1942) in swampy areas subject to periodical flooding.

(*p*) *The Earths*

This is a group of soils which exhibits gradational or uniform profiles and which covers large areas in the Hunter valley. The nearest equivalent in Stephens's classification is the brown soils of light texture. However, their range of colours and their texture profile have been so narrowly defined that many similar soils of different colours or different texture profiles cannot be accommodated anywhere in his classification. Since to widen the description of the great soil group without also changing its name would cause confusion, another name, earths, will be used. This has been done in accordance with earlier usage of the term (Prescott and Skewes 1941; Stewart 1956).

For the sake of convenience the earths have been treated here as one group but on the basis of soil colours they could also be separated into a number of great soil groups (as with Stephens's podzolic) and be called red earths, brown earths, etc.

General description

A_1 Surface organic horizon usually thin, dark; coarse- to moderately fine-textured; usually massive structure; very friable to friable when moist, soft to hard when dry, depending on humus content and texture; usually slightly acid to neutral (pH 6·1–7·3) although lower pH values might occur also

Clear or gradual transition

A_2 Subsurface soil with very wide range of colours from reddish to brownish, grey to yellowish; coarse- to moderately fine-textured; always massive structure; porous; very friable to friable when moist; usually slightly acid to neutral (pH 6·1–7·3)

Gradual transition

B Subsoil with similar colours, occasionally mottled; textures from coarse to fine, clay content may increase with depth; massive structure; firm to friable; usually slightly acid to neutral (pH 6·1–7·3), but sometimes moderately alkaline in lower B if some lime is present

C A great variety of materials

Very few analytical results are available on earths from the Hunter valley but some have been carried out on similar soils of the Macquarie region by Downes and Sleeman (1955), whose sandy solodized soils seem to be equivalent. From the available data their chemical fertility appears to be low to very low and depends to some extent on the texture of the soils. Physically there should be a big difference in the productivity between the coarser- and finer-textured members of the group. Those earths in which an increase in clay content occurs with depth should be more attractive for farming as percolation of rainwater is slowed down considerably by the clayey subsoil and the amount of water stored in the soil consequently increased.

Earths are found in the same areas where texture-contrast soils of the podzolic or solonetzic type occur. It appears that in most cases they occupy sites which are excessively drained or that they have formed on coarse-textured often very siliceous parent materials. Such parent materials give rise to very little clay which, moreover, in the course of time could be partly mobilized or broken down and removed to much deeper layers or downslope. This may have taken place in the Sandy Hollow land system, where on apparently the same parent material earths occupy the upper slopes and solonetzic soils the lower slopes. Occasionally one may find earths on relatively recent alluvial or colluvial deposits which appear to be suitable parent materials for solonetzic or podzolic soils.

The earths have been subdivided into nine families on the basis of subsoil colour, texture, mineralogy, or parent material. Most families exhibit a large range in depth and some members contain considerable amounts of gravel.

(i) *Red Earths.*—Colour limits are Munsell hues 5YR and 2·5YR, values 3 to 5, chromas 4 to 8.

The *Moonan* family has yellowish red soils and medium textures in the surface, grading into a fine-textured subsoil at less than 36 in. depth. This family seems to be rare.

The *Baerami* family has reddish brown, dark reddish brown, or yellowish red soils. Textures are coarse or medium throughout or coarse in the surface becoming medium at or before 36 in. depth. The soils range from shallow to deep and some contain varying amounts of gravel.

The *Cox's Gap* family has yellowish red, moderately coarse-textured soils which are developed from an intrusion of analcite bearing soda syenite (H. F. Whitworth, personal communication) near Cox's Gap; the heavy mineral fraction contains about 60% aegirine. Some contamination with sand, derived from surrounding Triassic sandstone, has probably taken place. These soils are mostly shallow, containing many coarse fragments of rock, and they grade into related skeletal soils. They occupy only a small area.

(ii) *Yellow Earths.*—Colour limits are Munsell hues 7·5YR, 10YR, and 2·5Y, values 3 to 6, chromas 6 to 8.

The *Dusodie* family is dominantly reddish yellow, brownish yellow, or dark yellowish brown in the subsoil. It is medium- to moderately fine-textured near the surface, with textures gradually becoming moderately fine to fine at or before 36 in. depth. In the shallow members, the textures do not become finer as described. This family is probably relatively rare.

The *Mulbring* family has dark yellowish brown, yellowish brown, strong brown colours and is coarse- to moderately coarse-textured throughout the profile or the upper 36 in. of the profile. Shallow members occur. Below 36 in. may be sand, clay, or bed-rock. This family is probably relatively rare.

The *Growee* family has yellow, yellowish red, or yellowish brown subsoil colours and mottling sometimes occurs in the deep subsoil. Textures are coarse to moderately coarse at the surface but a gradual increase in clay content results in moderately fine to fine textures at or before 36 in. depth. This family is probably relatively rare.

(iii) *Brown Earths.*—Colour limits are Munsell hues 7·5YR, 10YR, and 2·5Y, values less than 7, chromas 2 to 5.

The *Cumbo* family has a wide range of brownish colours among which strong brown, yellowish brown, pale brown, greyish brown, light yellowish brown, and dark brown were observed; subsoils are sometimes mottled. Textures are coarse to moderately coarse throughout or to a depth of 36 in. Shallow members occur. These soils sometimes have low to high amounts of gravel. This family is common.

The *Woolooma* family has dark yellowish brown, brown to dark brown, dark reddish brown, or very dark greyish brown colours; mottles sometimes occur in the subsoils. The textures at the surface are coarse to moderately fine, generally becoming moderately fine to fine at or before 36 in. Also included in this family are those brown earths which have moderately fine-textured surface horizons and become more sandy with depth (such soils have been observed occasionally in alluvial sites). Gravel in varying amounts sometimes occurs in the subsoil. This family is relatively common.

The *Ulan* family is developed on granite of the Ulan land system. The soil colours are pale brown, light yellowish brown, yellowish brown, or yellowish red; the subsoil is mottled in some cases. Surface textures are coarse to medium changing gradually to moderately coarse to moderately fine at or before 36 in. depth; these soils are gritty or their sand fraction is coarse. They are often less than 20 in. deep, except in places of accumulation, where they may be very deep.

(*q*) *Krasnozems*

The krasnozems (volcanic soils, latosols, red loams) of the Hunter valley are mostly palaeosols—old soils which acquired dominant characteristics under an earlier and different environment. They are developed on basalt (mainly Roscommon land system) which elsewhere in the same area but under the present dry warm climatic environment gives rise to cracking clays (Bow land system). Some krasnozems may be younger because according to Stephens (1950) they can develop from basalt in a humid temperate climate, such as exists at present in parts of the Tubrabucca land system.

It is possible that the basalt landscape once had a krasnozem soil cover, which was mostly removed by subsequent normal geological erosion. The present areas with krasnozems thus represent parts where these older soils have not been completely stripped. The soils that developed afterwards on the same parent rock reflect more or less the present climate. Owing to certain inherited characteristics the older soils could not change and behaved as if they were pedogenetically inert, even though the climate had changed (Bryan and Teakle 1949; Teakle 1952).

Most occurrences of krasnozems seem to point to the above hypothesis for they are found on hill tops and watersheds and a gently undulating plain with no surface drainage. It is likely that their excellent permeability has also been a factor in their continued existence at such sites. However, krasnozems occur in relatively few, small patches intermixed with the cracking clays on slopes of the Bow and Ant Hill land systems. Roberts (1952) has also mentioned such patchy occurrences. Here the soils might have been formed on highly sesquioxidic clays which at places occur interstratified in the basalt flows, as reported by McGarity and Munns (1954) from outside the Hunter valley, and which represent fossil leached soils buried by later basalt flows. Later weathering and erosion of the basalt landscape partly exhumed the buried soils. The fossil soil material then weathered easily into a krasnozemic soil even under low-rainfall conditions.

General description

A Medium- to fine-textured in the surface; generally dark owing to organic matter, turning red with depth; weak to strong, granular, crumb or fine blocky structure; slightly plastic to plastic when wet, friable to firm when moist and hard when dry; slightly acid, but sometimes neutral (pH 6·1–7·3)

Gradual, sometimes clear transition

B Moderately fine- to fine-textured subsoil; colours brighter; generally dark reddish brown, yellowish red, or dark red; similar structure but sometimes a little coarser; similar consistence; medium acid to moderately alkaline (pH 5·6–8·4)

C Decomposed basalt

The profiles are generally deeper than 36 in.

The description shows the wide range in degree of structure and in subsoil reaction. It is possible that some minor changes have taken place in these soils since they acquired their dominant characteristics. Continued weathering of the C horizon and the underlying basalt during a drier climatic phase would release metal cations like calcium and magnesium which could be taken up by tree roots and returned to the topsoil. This could be an explanation for the high base saturation (60% to 70% in the upper profile increasing with depth, with calcium dominant) found in a number of these soils under relatively dry conditions (20 to 25 in.). Supporting evidence is furnished by Downes and Sleeman (1955) from the adjoining Macquarie region west of the Hunter valley. In the Hunter valley one krasnozem profile had a horizon with lime concretions at 27 in. depth. A similar profile was reported from the Macquarie region also.

Krasnozems occurring in high-rainfall areas are more strongly leached. One profile from a basalt plateau (altitude approx. 3500 ft, rainfall 35 to 40 in.) 20 miles north of north-east of Cassilis showed a base saturation of 24 to 14% in the surface, increasing to 30% in the subsoil; total exchangeable metal ions were respectively 18·5 to 7·5 and 10·7 m-equiv./100 g soil. Calcium was the dominant cation in the surface but magnesium was a little more important than calcium over most of the profile. Organic matter in the surface was 7·7%. Roughly 0·4% "total" phosphorus was present but only 2·5% of that was "available". This soil was difficult to disperse.

In many ways it is intermediate between the lowland dry climate krasnozems and the transitional alpine humus soils of the high-altitude basalt plateaux.

Physically, most of the krasnozems are ideally suited to arable agriculture for they have a stable fine structure.

Analysis of one profile 9 miles south-west of Bow indicates a very low "availability" (traces) of phosphorus, although "total" phosphorus varies from 0·044 to 0·037%. This might be expected in soils containing a fairly high percentage of free ferric oxides (7 to 8%).

The krasnozems have been subdivided into four families on the basis of colour, structure, and content of ferruginous fragments.

(i) *The Torrielodge Family.*—These are krasnozems as described in the general description, with moderate to strong structure. Munsell colours are values 3 and 4, chromas 3 to 8 for hues 5YR and 2·5YR. The family occupies the largest area of those in this great soil group. It includes the profile with lime in the subsoil in the Roscommon land system and one profile at the foot of limestone hills of the Alston land system, which because of its derivation from limestone would have been classified as a terra rossa by Stephens. This family appears to be equivalent to Downes and Sleeman's (1955) red loams.

(ii) *The Tunbridge Family.*—This family has rather shallow soils with a weak structure, usually stony with angular fragments of basalt up to 9 in. diameter. Colours are similar to those of the Torrielodge family. It could be equivalent to Downes and Sleeman's (1955) residual brown acid soils.

(iii) *The Hook Family.*—This has yellowish brown to dark brown colours and is often mottled. Munsell colours are 10YR, values 3 to 5 and chromas 3 to 6. The structure is weak and ferruginous concretions sometimes occur in the profile. This family occurs in ill-drained sites associated with the krasnozems and it has therefore been classified with them. It is possible that in the Hunter valley such ill-drained sites are in close proximity to less permeable rocks or layers near the surface. They seem to be associated with the contact between the basalt and the underlying rocks.

(iv) *The Roscommon Family.*—This consists of red soils with weak structure and high amounts of small, angular, ferruginous, shale-like fragments. It occurs in a few small patches scattered through the Roscommon land system south-west of Merriwa where the contact zone between the basalt and the Jurassic sandstone is at the surface, and could be a geological rather than a soil phenomenon.

(*r*) *Transitional Alpine Humus Soils*

The group of transitional alpine humus soils was first proposed by Costin (1954) for soils transitional between the alpine humus soils of the high mountains and the podzolic soils of the lower altitudes. These soils resemble krasnozems in some respects but differ mainly in degree of structure, which becomes rapidly weaker with depth and finally massive, and in their colours, which are in general browner and yellower. Their Munsell colours are values 3 to 5, chromas 3 to 8 for hues 10YR and 7·5YR. They are formed in a cool moist climate and usually carry subalpine woodland. In the Hunter valley very often angular floaters of relatively fresh rock are dispersed throughout the profile, presumably owing to past periglaciation. This suggests that the soils are old.

General description

A Gradational profile of medium- to moderately fine-textured soils; strong brown, dark brown to brown, yellowish or dark yellowish brown, sometimes dark reddish brown, or reddish brown; strong to moderate, fine, crumb or granular structure; friable when moist; usually strongly to medium acid (pH 5·1–6·0); often with angular floaters of basalt

Gradual transition

B Moderately fine- to fine-textured soil; similar colours but becoming yellower or browner; mottles sometimes present; weak structure or massive; friable to firm; usually very strongly acid to medium acid (pH 4·5–6·0); often with angular floaters of basalt

The transitional alpine humus soils in the Hunter valley occur mainly on basalt plateaux above 4000 ft, but also on other rock types at lower altitudes with similar rainfall (60 in.). Soils classified as such have been observed on a small plateau at 1800 ft altitude 3 miles north-east of Dusodie as well as on the Barrington plateau, e.g. near Polblue Top at an altitude of 4500 ft. Analysis of one profile from the Polblue Top showed that the sum of exchangeable metal cations was very low, being less than 4 m-equiv./100 g soil. The base saturation varied between 3 and 5% in the upper part of the profile and increased slightly in the subsoil to 9%.

Phosphorus contents varied from 0·14% in the surface to 0·29% at 48 in. depth for "total" phosphorus, of which only a fraction (6 to 9 p.p.m in the surface, 95 p.p.m. at depth) was "available". Total phosphorus by fusion is even higher, being 0·31% and 0·42%. Free iron oxides take up 20 to 25% by weight of the soil and are probably responsible for the low availability of the phosphorus. The clay fraction varies from 26 to 37%, but it is extraordinarily strongly aggregated and difficult to disperse. Other laboratory evidence indicates that these values could be between 15 and 25% higher. The clay consists approximately of 60% kaolinite and 40% mixed layer minerals. Organic matter content in the surface is about 15%. Chemically this soil is not fertile, which is to be expected from the high leaching power of the very humid climate.

Transitional alpine humus soils developed on basalt are the most important group in the area, those developed on other rock types occupying only very minor areas. Only one family is proposed at this stage.

(i) *The Meehan Family*.—This family includes those transitional alpine humus soils developed only on basalt. They are deep soils.

(*s*) *Solonchaks*

Solonchaks are salty soils of any description. The salt may be present in undifferentiated recent alluvial deposits or in soils which have developed pedogenetical horizons in their profile. It is proposed here to limit the concept to those that have formed on inland deposits in order to exclude the saline muds of marine origin in the delta of the Hunter River. It is preferable to group the marine muds with the alluvial regosols, because the freshwater members of that group then would grade laterally into the saline members. In the Hunter valley the salts are often visible as thin crusts on slight rises of the ground surface or on the vertical sides of creek banks or gullies which run through these salty soils. Solonchaks are not common in the Hunter valley as a whole, but occur in patches in valley bottoms, especially in the Killarney land system. They were noted also by Monteith (1954), who describes them as widespread between Singleton, Muswellbrook, and Broke, and having a patchy vegetation with bare areas in between. Some of the larger solonchak areas are reported to occupy 30 to 40 ac.

Many creeks in a wide area around Singleton show thin salt crusts on their sides. The salt could have been cyclic salt precipitated by rain from the air, but it is more likely that most of the salt has been leached from weathering Permian shales or rocks of other geological formations and has accumulated in the depressions of the landscape.

Because of their great variety and relative unimportance no families are proposed and such soils will simply be referred to as salty soils or solonchaks.

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PART VII. VEGETATION OF THE HUNTER VALLEY

By R. STORY*

I. INTRODUCTION

In this report the ecological terminology is that of Beadle and Costin (1952), *E.* is used throughout in place of *Eucalyptus*, and the following recent changes in the nomenclature are followed (Johnson 1962):

E. eugenioides Sieb. ex Spreng. (= *E. wilkinsoniana* R. T. Bak.)
E. globoidea Blakely (= *E. eugenioides* auct. non Sieb. ex Spreng.)
E. goniocalyx F. Muell. ex Miq. (= *E. elaeophora* F. Muell.)
E. mannifera Mudie (= *E. maculosa* R. T. Bak.)
E. moluccana Roxb. (= *E. hemiphloia* F. Muell. ex Benth.)
E. oblonga DC. (= *E. sparsifolia* Blakely)
E. cypellocarpa (= *E. goniocalyx* auct. non F. Muell. ex Miq.)

The rain forest, the eucalypts, and the grasses are the three main types of vegetation in the Hunter valley. The simplified and basic requirements of each are discussed under the heading which follows; but it should be remembered that the details are imperfectly known, and that the action of physiological drought can cause the most puzzling inconsistencies.

A fuller description of the vegetation may be obtained from the Division of Land Research and Regional Survey.

II. INTERRELATIONS OF THE VEGETATION TYPES

The rain forest represents an ancient evolutionary form dating from the warm moist environment that was general when the Angiosperms originated, and this environment therefore can be logically regarded as the main influence that determines the presence of rain forest today. The most important inhibiting factor is dryness, which may be direct, through low rainfall, or induced, through features such as high temperatures or strong winds. The highest temperatures tend to occur in the early afternoon, making the north-western aspects the hottest. As to winds, although little information is available on their strength, duration, and direction in the Hunter valley, the piles of wind-blown panicum caught on the fences provide clear evidence each winter that the prevailing winds are north-westerly (Plate 1, Fig. 2). The combined influence of these two forces thus makes the south-east aspects the most favourable for rain-forest growth. The influence of wind seems to be more important than temperature. Evidence of this is provided by the fact that patches of rain forest sometimes face north if they are sheltered from the wind, but are absent from windswept places even when the environment is otherwise favourable. The prevailing north-westerlies are especially desiccating since they blow across the hot and dry interior of the continent.

*Division of Land Research and Regional Survey, C.S.I.R.O., Canberra, A.C.T.

Moist and sheltered habitats on a smaller scale are created by rocks in level country, which break the force of the wind and also increase the soil water. For example, if half of a given volume of soil is replaced by rock, the soil water from a light shower could be doubled, and such rocky places often provide a foothold for rain-forest stragglers and non-sclerophyll shrubs in country which is otherwise too dry for them.

The type of primitive environment in which the rain forest originated extends over less than 3% of the Hunter valley. Over most of the remainder the eucalypts are the natural dominants, being more recent in evolution and better adapted to withstand extreme conditions. They are tall and dense near the rain forest but where conditions become progressively more severe the eucalypts become progressively

TABLE 11
TYPES OF VEGETATION AND THEIR HABITATS

Vegetation Type	Habitat
Subtropical rain forest	Cool, wet, sheltered
Temperate rain forest (mapped with subtropical rain forest)	Cold, wet, sheltered
Non-sclerophyll shrubs	Warm, dry, rocky; or cool, wet, sheltered
Eucalypt wet sclerophyll forest	Cool, wet, exposed
Eucalypt dry sclerophyll forest	Equable, damp, sheltered, sandy; or cool, damp, exposed, sandy
Eucalypt subalpine woodland	Cold, wet, exposed
Eucalypt woodland of other forms	Fluctuating temperatures, damp or dry
(*a*) Savannah woodland of box and gum	
(*b*) Tall mixed woodland	
(*c*) Savannah woodland of box, gum, and ironbark	
(*d*) Shrub woodland of ironbark and gum	
(*e*) Anomalous woodlands	
Eucalypt tree savannah	Fluctuating temperatures, dry, exposed, heavy clay
Climax grassland (too small to map)	Very cold, wet
Heath	Cool or equable, damp, exposed, sandy, acid
Fen (swampy) vegetation	Muddy, non-saline
Scrub (mangroves)	Muddy, saline

sparser and floristically different and shorter. Towards the limit of their range they become scattered in a tree savannah (as in the exposed clays of the Bow land system) or dwarfed into shrubs (as in the cold swamps of the Tubrabucca land system), and here the grasses become dominant, being still more recent and still better adapted.

The grasses occur naturally as a subordinate community over most of the Hunter valley, but *predominate* naturally over only about 6%. Their present dominance over such large areas (Burley 1961) is mostly artificial, as is shown by the evidence from early records, from sharp and straight boundaries between grassland and woodland, and from stumps, mature trees, and seedling trees in open country. All these facts indicate that the original cover was mainly of eucalypts in varying density, with a grassy floor sparsest where the trees were densest (except in some high-rainfall areas) and conversely. Where settlers thinned or cleared the trees, the grasses of the floor thickened to form a pasture, apparently with three main subdivisions dominated respectively by *Stipa aristiglumis* on the black cracking clays of the Bow land system, *Poa* spp. on the high basalt country of the Tubrabucca, Liverpool, and Mt. Royal land systems, and *Themeda australis* elsewhere. *Themeda* has now been exterminated over much of its former range, most commonly in the part below about the 25-in. isohyet. It becomes progressively more stable towards the areas which lie between the 30-in. and 40-in. isohyets, where it is fairly common in association with *Aristida* spp. and *Dichanthium* spp., but beyond the 40-in. isohyet it becomes scarce again, giving way to *Poa* spp. where the increasing rainfall goes with increasing altitude and cold, and to *Paspalum dilatatum* where the increasing rainfall goes with a milder climate towards the coast. The transition to *Poa* appears to be controlled solely through climatic and edaphic factors, that to *Paspalum* is influenced at least to some degree by grazing.

The three main types of vegetation (rain forest, eucalypts, and grasses) have been subdivided for the purposes of this report, and subsidiary types have been considered also. A simplified picture of their habitats is given in Table 11. Their distribution is plotted in the vegetation map, with the minor exceptions noted.

III. Descriptions of the Vegetation Types

(*a*) *Subtropical Rain Forest*

Fraser and Vickery (1937, 1938, 1939) have made a detailed ecological study of this rain forest and the associated eucalypts. It almost invariably occupies slopes facing south or east and up to about 3000 ft in altitude. Most of it is where the rainfall exceeds 55 in., though minor patches of it occur in cool and damp places down to the 40-in. isohyet. It is, however, absent from the poorest soils even if the rainfall is adequate.

Trees, in an upper and lower layer averaging about 100 ft and 20 ft respectively, are dense, and shrubs, ferns, and herbs likewise, at least in the parts visited. Lianes and epiphytes are abundant, grasses virtually absent except for a little *Oplismenus* sp. Doubtless the floristic composition changes from place to place, but this was not established with certainty because of the richness of the flora and the absence of any noticeable dominance. More than 50 woody rain-forest species were collected on the survey, but these represent only a small part of the total.

This formation is sharply divided from the adjacent eucalypt wet sclerophyll forest, but it does include scattered representatives. They emerge above the canopy and are of the same species as those found in the Mt. Royal land system. As they cannot grow in the subdued light under rain forest, they mark disruptions known as "light breaks" (Cremer 1960; Fraser and Vickery 1938, p. 150), but whether these are through natural causes or logging operations was not investigated.

Although it contains good timber, the subtropical rain forest in this region of steep slopes and high rainfall should be considered not so much in terms of cash as in terms of its stabilizing influence on water supplies and the soil.

(*b*) *Temperate Rain Forest*

This figures also in the study by Fraser and Vickery. With a few negligible exceptions it occurs only in the Rainforest land system, on the same aspect as the subtropical rain forest but at a higher altitude. *Doryphora sassafras* is common locally (Fraser and Vickery 1939, p. 167), otherwise *Nothofagus moorei* is dominant, forming a canopy over 100 ft high which, because of its evenness and density and the lack of emergent eucalypts, shows up in the aerial photographs as a flat surface, without the granular appearance of the subtropical rain-forest canopy. Tree ferns are common in patches and *N. moorei* seedlings are scattered, but normally there is little or no undergrowth and the forest floor is open. Tree trunks and stones are deeply cushioned in moss, but no phanerogamic epiphytes were seen and, except for a little *Smilax australis*, no creepers.

The remarks on the value of the subtropical rain forest apply here as well.

(*c*) *Non-sclerophyll Shrubs*

These are tallest, most numerous, and richest in species in areas of high rainfall in and near the subtropical rain forest. In drier areas they occur on rocky ridges and in other sheltered places, the more mesophytic among them being replaced with decreasing rainfall by hardier shrubs with duller leaves, commonly the genera *Notelaea*, *Breynia*, *Citriobatus*, *Myoporum*, *Canthium*, and *Rhagodia*. They are mixed with a scattering of small dull-green trees (*Trema*, *Geijera*, *Ficus*, *Clerodendrum*, *Santalum*), twiners (*Gymnema*, *Cissus*, *Pandorea*), and xeromorphic grasses, and, although dispersed, show up from a distance as conspicuous darker patches and bands among the eucalypts. They are commonest in the Cranky Corner and Colonel land systems which have an abundance of resistant rocky outcrop, and frequent also among rocks or along ravines in all other land systems except where the rocks break down to sandy soils (Watagan, Three Ways, Lee's Pinch, Rouse, and Ulan land systems). Here the shrubs have affinities more with the heath than the rain forest, and are dealt with more fully under that heading.

(*d*) *Eucalypt Wet Sclerophyll Forest*

This is the most important source of timber in the Hunter valley. Patches along the northern watershed are of *E. laevopinea*, *E. viminalis*, *E. pauciflora*, *E. dalrympleana*, and *E. stellulata*, and along the southern watershed of *E. laevopinea*, *E. blaxlandii*, *E. bicostata*, and *E. saligna*. The bulk of the wet sclerophyll forests, however, are in the east, where two forms are recognizable—one of *E. campanulata* and *E. microcorys*, and the other of *E. saligna*, *E. pilularis*, and *Syncarpia glomulifera*. They occur respectively on the Mt. Royal and Watagan land systems.

(i) *The* E. campanulata–E. microcorys *Forest*.—This community is usually adjacent to rain forest, commonly on slopes facing north and north-west and along ridges. The dominant trees are *E. campanulata* and *E. microcorys*, with *Angophora floribunda* and *Casuarina torulosa* as a sparse second layer below the 100-ft canopy. At the upper limits *E. viminalis*, *E. fastigata*, and *E. obliqua* have been recorded, and in the moister and more sheltered localities there is an admixture of *E. saligna* and

Syncarpia glomulifera, with stragglers of rain-forest species where the rain forest itself is close at hand, commonly *Laportea gigas*, *Rhodamnia trinervia*, *Synoum glandulosum*, *Tristania conferta*, and tree ferns.

Shrubs are rare and *Poa* spp. dominate the ground cover, the commonest associates being Cyperaceae, *Eragrostis* spp., *Imperata cylindrica*, *Pteridium aquilinum*, and *Themeda australis*, with *Adiantum* spp. in rocky places.

With decreasing altitude other species of grass occur and *E. campanulata* becomes scarcer and eventually disappears, and towards the lower limits of the community where it merges with woodland associations the trees are shorter, with an admixture of the following: *E. acmenioides*, *E. canaliculata*, *E. eugenioides*, *E. globoidea*, and *E. propinqua*.

The community has been heavily exploited for timber and in steeper parts coppice and seedling trees in all stages of growth are common.

The more gentle slopes have been largely cleared and an attractive meadow-land is the result, with a good cover of *Paspalum dilatatum*, *Sporobolus capensis*, *Themeda australis*, and *Trifolium* spp. Patches of *Pteridium aquilinum* and tussocks of *Imperata cylindrica*, *Poa* spp., and *Lomandra* spp. are widespread and common.

(ii) *The* E. saligna–E. pilularis–Syncarpia glomulifera *Forest*.—These three trees, of which *E. saligna* is usually dominant, are together diagnostic of this community. The following additional trees have been recorded:

Acacia spp.	*E. microcorys*
Casuarina torulosa	*E. pellita*
E. acmenioides	*E. deanei*
E. agglomerata	*E. piperita*
E. gummifera	*E. sieberi*

The tallest trees, 100 ft high and more, project above the general level of the canopy, the margins of their crowns being 50–100 ft apart. The next tallest form a fairly even layer at 70–80 ft with a spacing of about 15 ft between the crowns. Below this are many smaller trees, some apparently mature and others young, which do not fall into any recognizable layers. Traces of burning and exploitation are common everywhere, but very little clearing has been done. Noteworthy absences are those of *Angophora costata*, *A. floribunda*, *E. amplifolia*, and *E. punctata*, which are found only near the transition from this wet sclerophyll community to the woodland and dry sclerophyll communities which surround it.

Although there are some places without undergrowth, most parts of the unit have a dense and varied shrub layer, particularly along the gullies. It is about 12 ft high and tangled with scramblers and creepers which are the more conspicuous because of their absence from among the trees. The shrubs recorded are:

Acacia spp.	*Maytenus* sp.
Banksia collina	*Oxylobium ilicifolium*
Citriobatus multiflorus	*Persoonia levis*
Commersonia fraseri	*P. linearis*
Gompholobium latifolium	*Pomaderris ligustrina*
Jacksonia scoparia	*Zieria smithii*

The following are the creepers:

Billardiera scandens	*Geitonoplesium cymosum*
Cissus spp.	*Hibbertia dentata*
Clematis spp.	*Kennedia rubicunda*
Comesperma volubile	*Sarcopetalum harveyanum*
Eustrephus latifolius	*Smilax australis*
Stephania sp.	

The ground cover is sparse except where there are breaks in the tree and shrub cover, and the grasses are poorly represented. *Imperata cylindrica* was occasionally seen but *Themeda australis*, which is one of the most tolerant grasses, was not recorded except from near the outskirts of this forest. The recorded ground vegetation was as follows:

Cyperaceae	*Hydrocotyle* sp.
Dampiera stricta	*Imperata cylindrica*
Eupatorium adenophorum	*Pteridium aquilinum*
Goodenia heterophylla	*Senecio amygdalifolius*
Helichrysum spp.	*Viola* sp.

(*e*) *Eucalypt Dry Sclerophyll Forest*

This is in an irregular belt which starts at the coast and extends inland along the southern border of the Hunter valley to Mt. Coricudgy in the west. The characters which separate it from the eucalypt wet sclerophyll forest are the smaller, more open trees, often of different species, and its associated heath vegetation. The canopy averages about 50 ft in height, with frequent light breaks, the commonest trees being *Angophora costata*, *A. floribunda*, *E. acmenioides*, *E. gummifera*, *E. maculata*, *E. punctata*, stringybarks, and broad-leafed ironbarks. They vary greatly in their species composition and proportions from place to place along this belt, being poorest in species at the two ends and richest in the middle.

At the coastal end on the deep sands of the Duck Hole land system and in sheltered places in the Redhead land system *Angophora costata*, *E. pilularis*, and *E. gummifera* are dominant separately or together, with scattered smaller trees below (*Banksia*, *Melaleuca*, *Persoonia*) and a complex heath undergrowth of 5-ft shrubs in which the Leguminosae and Proteaceae are well represented. The herbaceous vegetation, which is also fairly rich in species, is erect and slender rather than mat-forming, with few grasses, and the cover at ground-level is consequently poor. The timber is fair but the most valuable asset of the vegetation is its stabilizing influence on the potential drift sands which support it.

At the western end, on the higher sandstone country of the Three Ways land system, the vegetation is similar in appearance but different in composition. The three coastal dominants were not recorded, the commonest trees being *Angophora floribunda*, *E. punctata*, ironbarks, and stringybarks. The heath, although still largely of Leguminosae and Proteaceae, is poorer in species and seldom as dense. It is poorest under the ironbarks, which tend to form fairly well-defined communities on warm dry slopes. As in the coastal area, the vegetation is important mainly from the point of view of conservation, for the country is one of steep slopes and sandy soil in a high-rainfall zone. It adjoins the shrub woodland of ironbarks and gums, and the remarks on burning which are made under that heading apply here with equal force.

The central richer tree flora referred to is on the Ogilvie (eastern part), Beresfield, and Elrington land systems. It is a taller form than the other two, in respect of both tree and shrub layers. The commonest trees are *Angophora costata*, *A. floribunda*, *E. acmenioides*, *E. gummifera*, *E. maculata*, *E. pilularis*, *E. punctata*, broad-leafed ironbarks, and stringybarks. Below the canopy are occasional smaller trees (*Casuarina*, *Exocarpus*, *Persoonia*) and varied and often abundant shrubs, forming impenetrable thickets in the deeper valleys. These shrubs are still nearer in form to the heath than to the shrubs of the rain forest, but taller, with more species of *Acacia* among them. The ground cover is a fairly dense mixture of ferns, grasses, herbs, and shrublets, with an occasional specimen of *Doryanthes excelsa*, apparently confined to this part of the dry sclerophyll forest. The timber is fairly good, and production could probably be safely maintained except on the steep slopes of the Ogilvie land system.

(*f*) *Eucalypt Subalpine Woodland*

This woodland occurs in the Tubrabucca land system on the highest part of the Barrington Tops, above the temperate rain forest at an altitude of 4500 to 5000 ft. *E. pauciflora* is dominant, with *E. dalrympleana* subdominant and with sod tussock grassland below. The trees are about 25 yd apart, with the canopies all but touching. *E. pauciflora* is about 50 ft high, and its shallow root system together with the strong winds that occur in this land system make fallen trees one of the characteristic features. At this altitude *E. dalrympleana* is smaller than normal and does not emerge above the general level of the *E. pauciflora*. *E. stellulata* is distributed thinly through the community, a little commoner towards the margins than in the centre and this irrespective of whether the margin is on the warmer north-western aspect or the colder south-eastern one. The only non-eucalypt tree which, although rare, seems to be part and parcel of the community is *Banksia integrifolia*. A few specimens of *Elaeocarpus holopetalus* and stunted communities of *Nothofagus moorei* occur in sheltered places. The dominant shrub is a species of *Acacia* which grows in clearly defined communities up to 6 ft high. Also in shrub form is a sparse but fairly evenly dispersed layer of eucalypt seedlings, mostly *E. pauciflora*. The ground cover is nearly all *Poa* sp., probably *P. labillardieri*, dense everywhere except under the *Acacia* shrubs.

The *Acacia* and the grasses are in sharply defined communities, but no corresponding difference could be found in the habitat. This suggests that their distribution is linked with some form of disturbance and that one or both may be successional. The trees have every appearance of a stable community.

An extreme climate, poor soils, and indifferent timber make exploitation of the subalpine woodland inadvisable. Its management as a catchment area comes first in importance.

(*g*) *Eucalypt Woodland of Other Forms*

On 75% of the Hunter valley, the woodlands are probably the climax vegetation. They are characterized by a mixture of eucalypts about 30 ft high, in broken country usually dense enough to limit visibility to a matter of 100 yd or so, on gentle slopes often cleared away for grazing or agriculture. Besides being shorter and more open, they differ from the wet and dry sclerophyll forests in species composition as set out in Table 12, but there is no sharp dividing line.

TABLE 12

SPECIES CHARACTERISTIC OF SCLEROPHYLL FOREST AND WOODLAND IN THE HUNTER VALLEY

E. saligna		
E. viminalis		
E. campanulata		
E. microcorys		
E. pilularis		
Syncarpia glomulifera		
Angophora costata		
E. acmenioides	Wet and dry sclerophyll forests	
E. canaliculata		
E. laevopinea		
E. gummifera		
E. maculata		
E. fibrosa		
E. siderophloia		
E. paniculata		
E. tereticornis		
E. eximia		
E. trachyphloia		Woodland
E. dawsonii		
E. melliodora		
E. moluccana		
E. crebra		
E. sideroxylon		
E. blakelyi		
E. albens		
E. dealbata		
E. caleyi		
E. rossii		
Brachychiton populneum		
Casuarina luehmannii		

Gums and ironbarks predominate, boxes being also common but localized. For the most part the trees grow together in confusion, and the little order that becomes apparent with continued field observations is bound up more with individual species than with mixed communities. The general picture can best be given by considering the woodlands as they change progressively from the boundaries of the sclerophyll forests towards the drier country in the west of the Hunter valley. For the purposes of this report, five main subdivisions are recognized.

(i) *Savannah Woodland of Box and Gum*.—On the rugged country of the Liverpool land system the change from wet sclerophyll forest to woodland is often marked by *E. melliodora* mixed with *E. laevopinea* and *Angophora floribunda*, which is usually scattered but forms localized pure communities along gullies and streams and on rocky outcrops. There are sparse shrubs below (*Rubus*, *Acacia*, *Bursaria*, *Cassinia*, *Rapanea*, *Exocarpus* spp.), but a fairly good ground cover (*Poa*, *Themeda*, *Pteridium*, *Trifolium*, *Acaena*). The change is at about 3800 ft near the Barrington Tops, elsewhere it is lower than this.

As one descends through this high woodland the proportion of *Angophora* remains constant, but there is otherwise a gradual change, *E. laevopinea* becoming restricted more and more to the cooler southerly aspects together with most of the shrubs and *Poa*, *Themeda*, *Pteridium*, *Trifolium*, and *Acaena*. For the rest, the vegetation is of *E. moluccana*, *E. melliodora*, and *E. blakelyi* with a drier type of grassland made up of *Dichanthium*, *Aristida*, *Chloris*, and *Eragrostis*, and patchy *Stipa setacea*. *Medicago* is frequent throughout, and *Hordeum* and *Asperula conferta* abundant in heavily grazed areas. There is very slight segregation among the trees—*E. albens* tends to occupy the ridges and slopes, and the rest are more common in hollows and along streams. It should be noted also that under certain conditions *E. albens* grades taxonomically into *E. moluccana* and *E. blakelyi* into *E. tereticornis*, which are in each case closely related. Ironbarks are absent from this woodland except at the south-eastern extremity where it grades into the tall woodland which is next described. The proportions of trees and grasses differ widely and often suddenly from place to place, for much of this vegetation has been thinned or cleared. It predominates along the northern boundary of the Hunter valley where the annual rainfall is between 22 and 30 in., and covers the Timor, Upper Rouchel, and Ant Hill land systems, the lower parts of the Benmore and Liverpool, and the northern half of the Apis and Colonel land systems.

At present *Dichanthium* provides good grazing, but as harsh and stalky grasses are common there is scope for pasture improvement.

(ii) *Tall Mixed Woodland*.—A different type of woodland is found nearer the coast, best developed in the high-rainfall country drained by the Paterson and Williams Rivers. Here the change from wet sclerophyll forest to woodland is marked by trees larger in variety and size (50–60 ft) than those further inland. The commonest indicators of this change are *E. propinqua*, *E. canaliculata*, *E. piperita*, *E. eugenioides*, and *E. globoidea*, which with decreasing rainfall become mixed with *E. acmenioides*, various broad-leafed ironbarks, *E. maculata*, *E. tereticornis*, *E. amplifolia*, and *E. moluccana*. *Angophora floribunda* and *Casuarina torulosa* are evenly but thinly scattered throughout, shrubs are sparse except at lower altitudes near the border of the dry sclerophyll forest where the prevalence of the Leguminosae and Proteaceae gives the undergrowth an affinity to the heath vegetation. The herbaceous cover is rather sparse where the trees are dense, but otherwise good—*Imperata*, *Poa* (lax or tussocky species), *Paspalum*, sedges, and *Pteridium* in the moister parts, grading into *Themeda*, *Sporobolus*, and *Dichanthium* where drier, with *Trifolium* frequent throughout.

E. maculata and the ironbarks are often gregarious on their own or with each other but are as often scattered among the other eucalypts, and the only constant tree community of any size is of *Syzygium floribundum* which forms dense strips along many of the stream banks.

Much of the tree growth has been cleared to provide grazing land. *Themeda* is fairly frequent, but most of this country is under the introduced *Paspalum dilatatum* (in the wetter parts) or indigenous *Dichanthium* spp. (in the drier parts). All three of these grasses provide excellent feed, and where the slopes are gentle enough this woodland is well suited to grazing. The land systems on which it occurs are the Mt. Butterwicki, Wallaroo, Vacy, Cranky Corner, and Moonibung.

(iii) *Savannah Woodland of Box, Gum, and Ironbark.*—Widespread clearing and over a century of grazing have altered this vegetation drastically from the original form exemplified in some scattered protected areas, and it is taken for granted that the reader will keep this in mind and thus make repetition unnecessary.

The country is now mostly open, but dense trees in belts and patches border grassland or grade into parkland without any set pattern. As the trees have been cleared rather than selectively thinned, their proportions have been little altered and the change has been mainly quantitative. The grasses on the other hand have been selectively grazed and have changed qualitatively, but there is abundant evidence that *Themeda australis* is potentially dominant throughout.

The eastern edge of this 30-ft woodland is about 15 miles from the mouth of the Hunter River, where it abuts on the dry sclerophyll forest and the tall woodland. In this eastern area the box *E. moluccana*, the gums *E. tereticornis* and *E. maculata*, and the broad-leafed ironbarks are the trees, *Aristida* spp., *Sporobolus capensis*, *Paspalum dilatatum*, *Themeda australis*, and *Cynodon dactylon* the grasses. There is a slow transition inland, but so many species of grasses and trees are involved, each with its peculiar requirements and distribution, that no subdivision into vegetational regions is practicable. Communities are the exception. Shrubs are rare except among rocks or on sandy soils.

E. moluccana is the easternmost of the boxes. Inland it grades taxonomically by imperceptible stages into the closely related *E. albens* and *E. microcarpa* and mingles with *E. dawsonii* and *E. melliodora*. Boxes are absent from some areas, sometimes ending very sharply on the border of a poorer and sandier soil. This correlation is well known and has been put to good use in the past in the selection of agricultural lands. Some of the few definite, consistent, and extensive communities in the Hunter valley are of boxes. In the south-west they are particularly striking. Near Wollar *E. albens* dominates both the alkaline intrusives and the Permian rocks, standing out most clearly on the Permian where its grey foliage forms characteristic horizontal bands below the darker mixed vegetation on the Triassic rocks above. In the Widdin and neighbouring valleys the Permian rocks are dominated by *E. dawsonii*.

The common gums in the east, *E. tereticornis* and *E. maculata*, dwindle towards the west. *E. tereticornis* grades into the closely related *E. blakelyi* and *E. maculata* disappears about half-way across the Hunter valley. Another gum, *E. punctata*, takes its place here.

Like the boxes, the ironbarks also are absent from some areas, in this woodland at least, but this could not be related to any factors of the environment. Generally they favour sandy soils and rises, *E. crebra* more in the inland areas. *E. caleyi*, recorded only on Permian rocks, forms pure communities in the south-west near Cox's Gap.

Among the grasses, *Paspalum* and *Sporobolus* are important only in the eastern high-rainfall areas (30 in. and over). About 20 miles from the coast they become mixed with *Dichanthium sericeum*, which extends through this woodland to the western edge of the Hunter valley also. It is, however, rare on poor sandy soils and in dry areas. *Aristida* spp. accompany it through most of its range and beyond its range too, for they will grow on soils too poor and dry for *Dichanthium* and are in consequence common among the ironbarks.

Danthonia linkii begins at about the same latitude as *Dichanthium* but is more tolerant of dry conditions and poor soil, and commonest west of the New England highway.

Stipa setacea begins further westward than either of these two, about half-way between Singleton and Muswellbrook, and increases to the north and west, with a rather patchy distribution.

The trees are small for timber production but good grazing is provided by *Paspalum*, *Dichanthium*, and *Themeda*, and fair to rough grazing by all other grasses except *Aristida* spp., which stock avoid as long as other grazing remains. *Trifolium* and *Medicago* spp., common in the east and west respectively, are the best fodder producers among the non-grasses.

This woodland is on the following land systems: Apis (southern half), Colonel (southern half), Glendower, Greenhills, Killarney, Ogilvie (western part), Parkville, Rouse, Sandy Hollow, Ulan, and Warkworth.

(iv) *Shrub Woodland of Ironbark and Gum*.—This woodland is divided fairly sharply from the other three by the absence of the boxes and of *E. maculata*, this being correlated with a sandy soil poor in plant nutrients. Relatively little clearing has been done. The trees are about 30 ft high, visibility between them averaging 100 yd or so. With the exception of *E. caleyi*, which was not recorded, ironbarks are common (*E. crebra*, *E. panda*, *E. sideroxylon*, *E. fibrosa*) sometimes in pure stands but more often indiscriminately mixed with other eucalypts. *E. punctata* is probably the most widely distributed of the gums but is rarely abundant; *E. mannifera* and *E. rossii* on the other hand are patchy and tend to form communities separately or together. The stringybarks likewise tend to be gregarious (*E. laevopinea*, *E. oblonga*, *E. agglomerata*) but are not common except in the moister parts. Bloodwoods are patchy and thin, *E. eximia* in the east and *E. trachyphloia* further inland. The only large non-eucalypt tree is *Angophora floribunda*, but smaller trees and shrubs are in profusion and great variety, especially in craggy or rocky country (*Acacia*, *Bursaria*, *Dodonaea*, *Myoporum*, *Callitris*) and in sand (a 5-ft mixture allied to the heath vegetation, rich in Leguminosae and Proteaceae and typically with the genera *Oxylobium*, *Hovea*, *Boronia*, *Persoonia*, *Leucopogon*, and *Kunzea*). The ground vegetation is sparse and grasses scattered. *Aristida* and *Eragrostis* spp. and *Themeda australis* are the most frequent of them, with occasional *Panicum* and *Sporobolus*, and patches of *Triodia* sp. and *Arundinella nepalensis* in the driest areas. Common non-grasses are *Patersonia*, *Hardenbergia*, *Lomandra*, and *Pimelea*.

In the few parts where this woodland is protected, the living vegetation together with a layer of trash are enough to ensure the stability of the soil. Most of it, however, is periodically burnt, and the accessible parts are grazed. Burning in this highly inflammable combination of eucalypts and dense shrubs is usually complete and violent, and grazing among poor and scanty fodder plants leads to thorough denudation. The consequence is a most serious erosion and downstream flooding problem. Grazing can be stopped and should be, but accidental or irresponsible burning cannot, and research on controlled burning is urgently needed.

This woodland covers the Lee's Pinch and Munghorn Gap land systems.

(v) *Anomalous Woodlands*.—These comprise various woodland communities which differ from those described but are too insignificant to be considered separately.

(*h*) *Eucalypt Tree Savannah*

Large areas have been cleared for grazing and cultivation, but even in the remainder trees are poorly represented, with an average of about three trees to the acre and a maximum of double this density. Young trees are rare. This supports the view that the trees are naturally sparse, for a sparse community would need only a low replacement rate. *E. albens* is slightly more common on the slopes and *E. blakelyi* and *E. melliodora* on the low-lying parts, the only other trees being a few specimens of *Angophora floribunda*, usually near streams, and *Brachychiton populneum*, which grows patchily through the even scatter of the eucalypts, for example 6 miles from Merriwa on the road to Lee's Pinch. Although so many of the eucalypts present elsewhere in the Hunter valley are absent in the tree savannah, it is the ironbarks which are most conspicuously so, for they often stop short at its very edge.

Shrubs are virtually absent, and the grass is nearly all *Stipa aristiglumis*, which forms a community more uniform than any other of comparable size in the Hunter valley. It was seen only on heavy clay and where the annual rainfall was below 24 in. The over-arching leaves form a good top cover but the basal parts of the grass are tufted and the bottom cover, except for litter, is poor by comparison. The general appearance is of an even 3-ft stand, dark green in the growing season and when dormant pale grey, with the leaves often characteristically and conspicuously shredded, apparently from the effects of some disease. This shredding is a feature of other species of *Stipa* as well. The community contains few non-grasses except for *Medicago* spp. and weeds in disturbed areas, notably *Carthamus lanatus*.

Agriculture is widespread in the tree savannah but the erodable soil is a serious hazard. For stability the area as a whole is suited best to grazing, and fodder production could be high if the dominant *Stipa aristiglumis* were fully utilized in its young stages through modern aids to intensive farming.

Tree savannah as described covers nearly all of the Bow and Blairgowrie land systems. With variations in the grasses it extends also over the Bray's Hill, Roscommon, and Yarramoor land systems.

(*i*) *Climax Grassland*

The evidence from other similar areas is that the climax grasslands of the Hunter catchment owe their existence to "frost pockets"—hollows at high altitudes into which cold air drains and where it is trapped, thus denying the ground to all plants but those (mainly grasses and their allies) most tolerant of cold. These hollows, in the Tubrabucca land system on the Barrington Tops, are under a very dense turf of *Poa* spp., fairly pure on the sloping margins but in the level swampy parts mixed with other herbs (mainly *Plantago*), patchy with clumps of Cyperaceae and Restionaceae, and ragged with scattered sheets of *Sphagnum*. No trees are present, but a few specimens of *E. stellulata* grow in shrub form up to 3 ft high, and the runnels are sometimes bordered by a ribbon of sclerophyll shrubs.

(*j*) *Heath*

The heath is the Australian equivalent of the macchia or maquis, best known from the Mediterranean region but present in most parts of the world where a mild climate and a peaty or sandy soil are associated with unfavourable water relations, e.g. a low rainfall in the growing season, a seasonally frozen soil, or exposure to strong winds. In the Hunter catchment it is best developed on a narrow coastal belt south of Newcastle (Redhead land system) in an environment of on-shore winds and loose sand. Trees do not easily become established here except in the shelter of rocks or hollows and the heath has little competition in consequence. It has an exceptionally rich flora in which the Proteaceae, Leguminosae, and Epacridaceae are well represented and the herbs, including the grasses, poorly so. In form it is about 5 ft high, a dense layer of shrubs with small, hard, often prickly leaves. It gives excellent top cover but basal cover is sparse, and wind-blown places are colonized not by mat-forming herbs but by trailing ones and the laxer elements among the shrubs. As an understorey among the trees it extends inland mainly through the dry sclerophyll forests (Duck Hole, Beresfield, Elrington, and Three Ways land systems) and the short mixed woodlands of gum and ironbark (Lee's Pinch and Munghorn Gap land systems), with outliers in some sandy patches in other parts of the Hunter valley as well. It changes in composition with distance from the coast, and becomes poorer in species and sparser.

Scenically it is most attractive, being rich in flowering shrubs and in its pure form having the open character of grassland without its monotony. In terms of cash it is of little value, but it plays an important part in stabilizing the coastal drift-sands and in breaking the force of flooding rains in the vulnerable sandstone country along the southern watershed.

(*k*) *Fen* (*Swamp*) *Vegetation*

Characteristic trees are *Melaleuca* and *Leptospermum* spp. Communities of them occur inland along watercourses and sporadically on dry slopes as well, for example between Denman and Hollydeen and between Warkworth and Branxton, where they appear most frequent on brackish or gravelly soils. Most, however, are found on the damp soils of the Hexham and Nesta land systems. Where the ground is permanently waterlogged *Melaleuca quinquenervia* is probably the commonest species, extending even into shallow water. It forms a dense and rather gloomy 40-ft forest, on firmer ground with other species of *Melaleuca* (*M. nodosa*, *M. styphelioides*), *E. robusta* (the only eucalypt recorded from these swampy areas), and *Casuarina glauca*, and supporting a few lianes and epiphytes (*Parsonsia straminea*, *Platyceras* sp.). Some parts are under a shorter very dense vegetation mainly of *Leptospermum* spp., mixed with *Callistemon* and *Banksia* spp., ferns, and sedges.

Many of the swamps have been cleared and drained and are now under a turf of *Cynodon dactylon*, *Paspalum dilatatum*, *Stenotaphrum secundatum*, clovers, sedges, and weeds, with scattered specimens of the trees enumerated and a few palms (*Livistona australis*). Open water in this cleared country is often bordered by *Arundo* sp., *Phragmites communis*, and *Typha australis*, which are not found in the wooded areas.

(*l*) *Scrub* (*Mangroves*)

This covers the Avicennia land system and is rooted in tidal mud, forming an unbroken canopy with scattered seedlings below but no other phanerogamic flora. Only the one species, *Avicennia marina*, was recorded. On the landward side the mangrove scrub becomes attenuated into strips along the tidal creeks, and merges with the saline swamps of *Arthrocnemum* which border it.

IV. Utilization

The general ecological principles which have been discussed in Section II influence crops and pastures as well as the natural vegetation. Other things being equal, yields will usually be higher on a south-east aspect than on level ground, and higher on level ground than on a north-west aspect; and rocky ground is unfavourable only through the difficulty of cultural treatments. It can be highly productive under orchards.

The natural vegetation may be replaced by crops or pastures with a better yield if the requirements of economics and conservation are met, otherwise it should be maintained at its highest level of production. If this basic principle is known in the Hunter valley, however, it is, with a few notable exceptions, certainly not being put into effect, for the two most striking things about the natural vegetation today are waste and degradation.

It is within the province of ecology to point this out and to suggest remedies, but thereafter economics come into the picture. Almost any land can be grazed without harmful effects to the soil and vegetation if the grazing system is dictated by someone with a sound knowledge of the grasses and their requirements, but to do this on erodable country and make it pay may be impossible. With this proviso, the following observations are put forward.

The waste of timber appears to be a straightforward matter of elementary economics, for the trees would be sold if this were a paying proposition. The waste of grass, however, is often through bad management. The grasslands involved are mainly those dominated by either *Stipa aristiglumis* or *Poa* spp. These grasses are palatable only when the leaves are young. At this stage there is a flush of growth, which is so rapid that the stock usually find it beyond their needs and allow most of it to mature and become useless. For a while they feed adequately on the proportion which they are able to keep cropped, but as growth slows down this becomes insufficient, and they go hungry. Grazing under these conditions is either a feast or a famine. The pasture in the "famine" stage is of untouched fibrous tufts with short grass between them, and there is no doubt that the stock receive a considerable set-back and that the pasture could support much more than the usual number of stock if it were fully utilized in the growing season.

Degradation is less severe in these grasslands than over most of those formerly dominated by *Themeda australis*. This, one of the most palatable species, has been continually grazed and weakened, with the result that it has been virtually eliminated below the 25-in. isohyet. The unpalatable species on the other hand have been avoided and have increased in consequence. The process is in essentials similar to that causing waste—grazing too light to allow full and even utilization of the pasture.

Waste and degradation in the grasslands, then, are both caused by selective grazing, which in turn is caused by light stocking. One can counteract them by compelling the stock to graze the unpalatable elements as well, and this entails (with intervening periods of rest) *heavy* stocking. A warning, however, is necessary. Firstly, although it is a general rule that degradation means increased soil erosion and a drop in carrying capacity, this is not always so, and each pasture must be treated on its merits. Secondly, heavy grazing is not a fool-proof matter, and it would be dangerous to apply it by rule-of-thumb methods or without adequate experimental work and economic evaluation beforehand. It must be followed by a period of rest, for if it is overdone—and it has been overdone in many parts of the Hunter valley—it can totally destroy the cover.

The erosion which has followed damage to the grass cover is severe in many parts of the Hunter valley, often in the "sheet" form which is evident more from the accumulations of silt than from scarring of the soil surface. Whatever its form, it can be cured only by going to the root of the trouble, which is bad pasture management. It is entirely pointless to construct anti-erosion works if the superimposed farming practice continues to cause accelerated soil loss.

Examples like that shown in Plate 4, Figure 2, as well as conditions in the Hunter valley generally give the impression that advisory services are too thinly spread and that the farming community, while proficient in the care of crops and sown pastures, is generally unaware of the potential of the natural pastures and of the principles of their management. If the position is to be improved, further experimental and extension work is necessary. Methods which could be explored to aid efficient utilization include the feasibility of controlling the stocking rate by buying and selling stock on a short-term basis, varying paddock size with the aid of electric fencing, ensilage, artificial grass-drying, hay-making, burning, and the use of urea or protein supplements.

Legislation for application in extreme cases has already been enacted.

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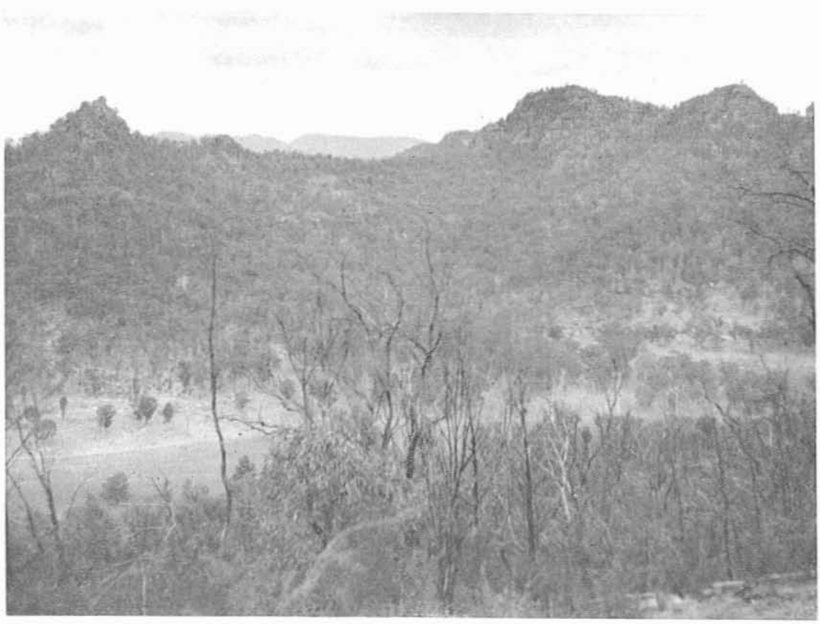

Fig. 1.—The southern third of the Hunter valley consists of rugged mountains on Triassic sandstone. The highest ridges rise to about 3500 ft while the valleys are up to 1500 ft deep and have steep sides. Soils are characteristically sandy and skeletal. In the higher-rainfall parts (Watagan land system) the vegetation is eucalypt wet sclerophyll forest, under moderate rainfall (Three Ways land system) it is eucalypt dry sclerophyll forest, and under low rainfall (Lee's Pinch land system, illustrated above) it is eucalypt shrub woodland.

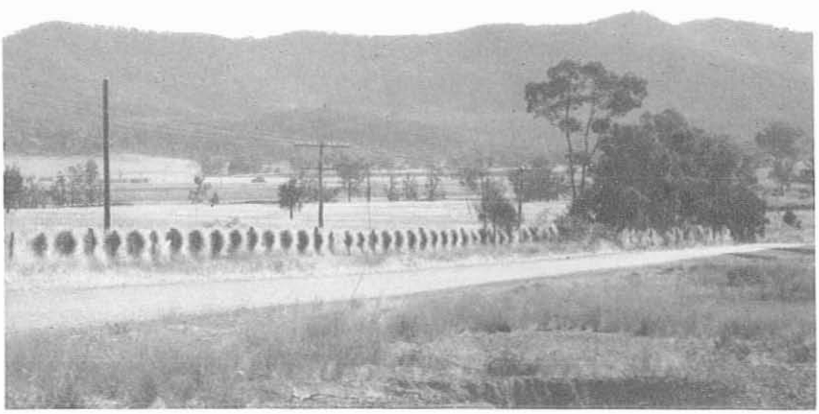

Fig. 2.—The central Goulburn valley is a belt of country about 20 miles wide with irregular plateaux and ridges rising to 1000–1500 ft above sea-level and broken by steep-sided valleys 300–500 ft deep. Where the valleys are cut in hard sandstone they form gorges, elsewhere they widen out into undulating lowlands. The plateaux and ridges are similar to the southern mountains. Killarney and Greenhills land systems occur on the undulating lowlands. Killarney land system (illustrated) has podzolic and solonetzic soils and savannah woodland, mostly cleared.

Fig. 1.—The Merriwa plateau is an area of rolling to hilly basalt country north of the Goulburn River. It rises from about 1000 ft above sea-level near the Goulburn River to about 1500 ft at the foot of the Liverpool Ranges which mark its northern limit and it is crossed by north–south valleys up to 300 ft deep (illustrated). The hilly parts with savannah woodland on rather shallow cracking clays constitute Ant Hill land system, the undulating parts on broad interfluves and in the more open valleys with eucalypt tree savannah and deep cracking clays form Bow land system. Both have been extensively cleared.

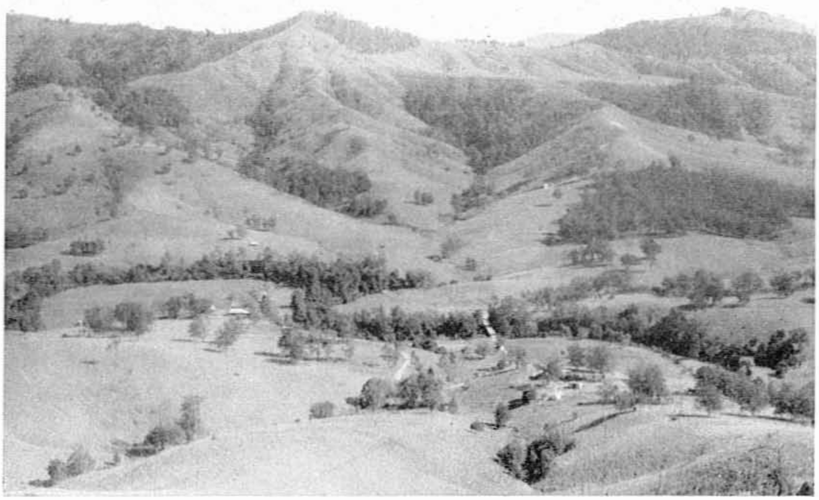

Fig. 2.—The north-eastern mountains form a tract of country 25–35 miles wide traversed by deep valleys draining from the high Mt. Royal Range and the Barrington Tops. They consist of mainly rugged topography on resistant folded sedimentary rocks and lavas. The valleys are generally rather narrow except in the extreme north where more open valleys occur (illustrated). Skeletal soils and shallow podzolic and solonetzic soils are important. The vegetation includes savannah woodland, tall mixed woodland, wet eucalypt sclerophyll forest, and small areas of rain forest. Clearing has taken place mostly in the lower undulating to hilly parts.

Fig. 1.—The central lowlands extend from Murrurundi to Newcastle through the centre of the Hunter valley. They are developed on relatively weak sedimentary rocks and gradually rise inland to about 1600 ft above sea-level. The landscape is undulating or gently hilly with local relief rarely exceeding 200 ft. Many land systems have been defined. The soils are commonly podzolics in the higher-rainfall areas and solonetzic under lower rainfall. Most of the area has been cleared. Alluvial flats ½ to 4 miles wide extend along the Hunter River and its major tributaries. The variable but fertile soils on these flats are intensively cropped.

Fig. 2.—Uncontrolled grazing since European settlement has profoundly changed the vegetation over the lowlands of the Hunter valley. The first stage of this process is the continued close grazing of the most palatable grass species while the less palatable species are avoided, as shown above.

Fig. 1.—If uncontrolled grazing continues, the most palatable grasses are exterminated and the process continues through those less palatable until the ground cover is totally destroyed. The photo shows the final stage (foreground) and the original cover of kangaroo grass (*Themeda australis*) where protected.

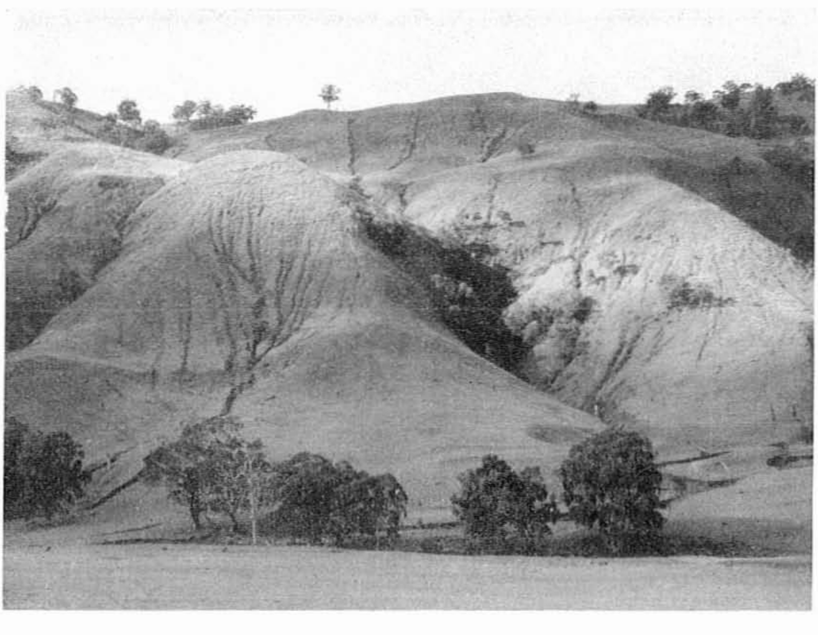

Fig. 2.—In the early days of settlement the stock was pastured on the lowlands, but with increases in stock numbers progressively steeper slopes have been cleared for grazing, as shown above. Stability of soil and vegetation is virtually impossible to maintain when this type of country is grazed.