# Lands of the Alligator Rivers Area, Northern Territory

Comprising papers by R. Story, R. W. Galloway, J. R. McAlpine, J. M. Aldrick and M. A. J. Williams

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## MAPS

## PART I. INTRODUCTION

By R. Story*

### I. General

The foundation for this work was a proposal for a national park in the area now covered by this survey (Fig. 1), and the discovery of high-grade uranium ore in and

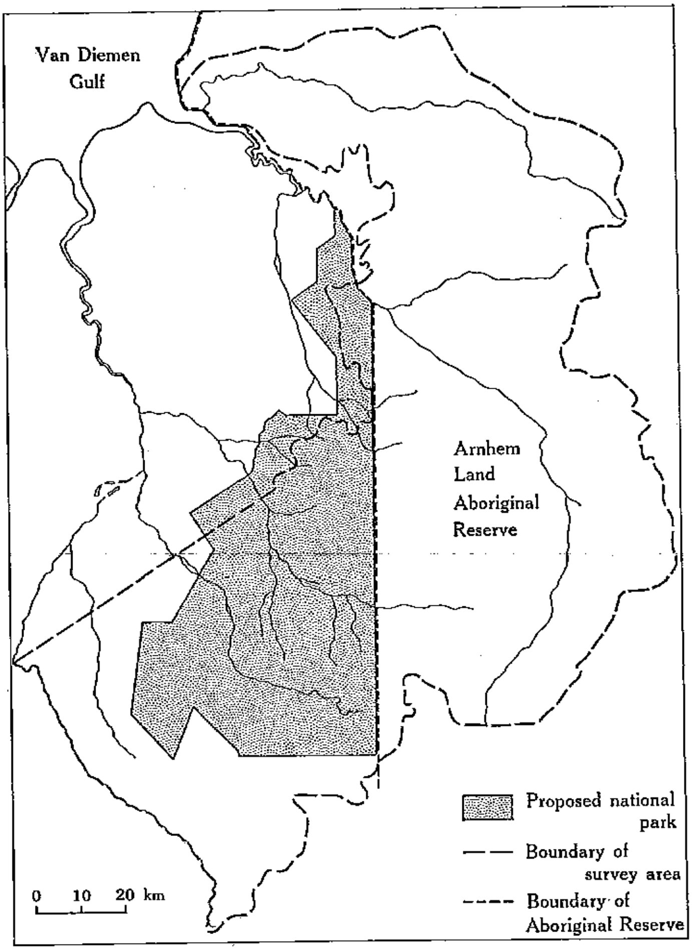


Fig. 1.—Location of the proposed national park.

around the same area. In order to obtain a balanced view of the implications from both angles the Government and the mining industry established a joint fund from which they could meet the expenses of a comprehensive series of environmental surveys.

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Between them the surveys deal with entomology, wildlife, freshwater fish, water quality, hydrology, landscape together with recreation and forestry, geology, archaeology, aboriginal art, atmospheric conditions, climate and water balance, and physical features and vegetation. All were tabled towards the end of 1973, together with a review report of the main findings. The present report is a combination of the last two surveys (climate and water balance with physical features and vegetation) suitably amended for publication.

The area of interest comprises the total catchments of Cooper Creek and the East Alligator River, and the eastern catchment of the South Alligator. Part of this area has already been covered by two reports in the Land Research Series. The first, carried out in 1946 (Christian and Stewart 1953), was a broad reconnaissance covering nearly 70 000 km$^2$, with a map at a scale of 8 miles to the inch (about 1 : 1 000 000).

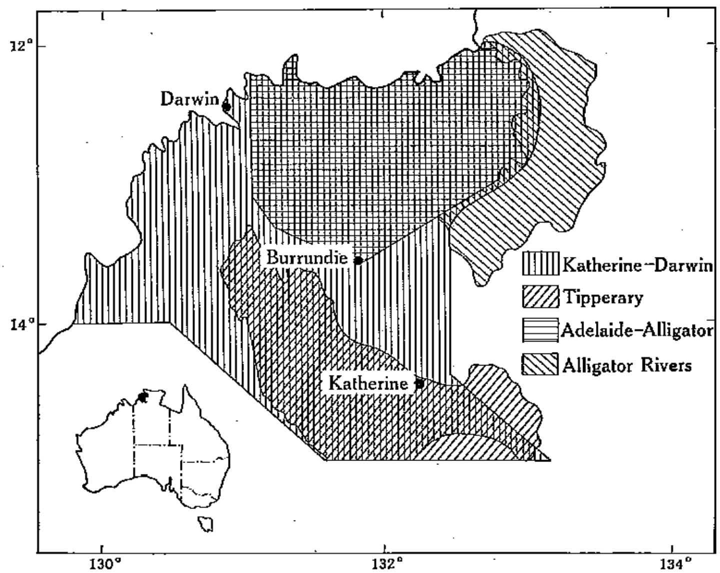


Fig. 2.—Location of Alligator Rivers area and of previously surveyed adjacent areas.

The second, undertaken in 1965 (Story *et al.* 1969), was a more detailed survey, covering roughly the north-eastern third of the larger area, with a map at a scale of 1 in 250 000. This survey (the third) extends eastwards from where the second survey ended (Fig. 2). The area has been mapped into 37 different types of country or land systems (Christian and Stewart 1953, see also Part III), 20 of which occur in the Adelaide–Alligator area as well. Since some of the Alligator Rivers occurrences differ in varying degrees from their Adelaide–Alligator counterparts they are distinguished by a Roman I to avoid confusion.

Large tracts of the survey area are extremely uniform, so much so that about 80% is covered by only 7 land systems. These are Buldiva I, 6795 km$^2$; Knifehandle I, 1585; Kysto I, 585; Bedford, 520; Viney, 495; Effington I, 350. Some of them are in general monotonous, e.g. Knifehandle I and Kysto I, which make up 2000 km$^2$ of undulating mixed scrub and woodland over the western lowlands. Others are uniform in a broad sense but in detail richly complex and scenically striking, e.g. the 6800 km$^2$ of Buldiva I, with crags and sandstone scrub, where many plants are new to science and highly localized.

Former reports in this series have presented a catalogue of above-ground resources in a generalized form with emphasis on their agricultural or pastoral value. In view of the national park interest, this report also takes into account the smaller features of scientific or popular interest that have no direct economic value, and adds some background information on their origin and behaviour.

## II. Survey Procedure

The land system mapping is done jointly by a scientific team of three who do the preliminary work from aerial photos, checking their results in the field thereafter and amending the mapping as necessary. In view of the monsoonal climate field work was done in two spells, one in the dry season and one in the wet, so that an adequate sample of the vegetation could be obtained. The first period extended through most of July 1972 and the second was during the latter half of February the following year. Both times a helicopter was used, the only practicable way of sampling this generally remote and inaccessible country.

## III. Location of the Area

The area comprises the eastern catchment of the South Alligator River except where covered by the Adelaide–Alligator survey, and the catchment of the East Alligator and its tributaries, including Cooper Creek (Fig. 2).

## IV. History

This is given in detail by Bauer (1964) and is briefly summarized by O'Ferrall (1969) with special reference to the Adelaide–Alligator survey area. His account applies in all essentials to the Alligator Rivers survey area as well.

The recent history was uneventful until about the time of the Adelaide–Alligator survey. When the field work for that survey began in July 1965 the main access road to Jim Jim from Darwin was through Pine Creek, the northern road (north of Spring Peak) being indistinct, very rough and unmapped. The shop at Jim Jim was still being built, the hotel had not been started, there was no store at Cahill's Crossing, interstate tourists in private cars were rare and no tourist buses were seen. The main outside influence was from Darwin trippers during weekends. Some derelict trenches near Spring Peak were the only signs of prospecting encountered by the Adelaide–Alligator team in the area which is now the centre of such activities. An addendum to the introductory chapter was necessary owing to the many changes in the area during the few years in which the report was being written. This foreshadowed even more rapid development and the great increase in the numbers of people passing through and living in the area. It is perhaps a significant rider that the Adelaide–Alligator team in 1965, which took for granted, and found, a plentiful supply of barramundi, fished without success during the field work for the Alligator Rivers survey.

## V. Acknowledgments

We acknowledge with thanks the permission of Mr L. Andrews, manager of Mudginberri station, to establish our dry-season camp on the property; also the generous help of Mr P. Kitto and his staff (Geopeko Mines) who looked after the survey vehicles for more than a year and freely extended to us the facilities of the mining camp during the wet season. Messrs T. Wolfe-Milner, G. Tadgell, A. le Lec and J. Roberts, of Airfast Helicopter Utilities, kept us airborne or set us down safely and accurately as the occasion demanded; Drs R. D. Bond and B. G. Williams and Mr E. C. B. Langfield of CSIRO, Messrs A. D. L. Hooper, B. A. Forster, D. F. Howe and G. L. Kirby, of the Department of the Northern Territory, and Mr S. Needham of the Bureau of Mineral Resources assisted with advice, information and practical help on soils and geology and geomorphology; and Messrs N. Byrnes, C. Dunlop and C. S. Robinson of the Department of the Northern Territory and Dr L. J. Webb of CSIRO gave us the benefit of their botanical knowledge.

The chapter on erosion (Part IX) was made possible through the kind co-operation of Professors A. J. Rose and J. L. Davies of Macquarie University and Dr J. N. Jennings of the Australian National University, who supervised the original work.

The aerial photographs are Crown Copyright reserved and were reproduced from material supplied by the Department of Minerals and Energy, Canberra, A.C.T.

We record with appreciation the help of the staff of the Division of Land Use Research in the field and in Canberra.

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# PART II. SUMMARY DESCRIPTION OF THE ALLIGATOR RIVERS AREA

By R. W. Galloway*

## I. Introduction

The Alligator Rivers area occupies 13 800 km$^2$ lying to the east of Darwin in the Northern Territory, Australia. It comprises the entire catchments of the East Alligator River and Cooper Creek, plus some of the eastern half of the South Alligator River catchment. It is a remote little-developed area; the eastern two-thirds forms part of the Arnhem Land Aboriginal Reserve. Major discoveries of uranium ore have been made in the area and a national park of great potential interest has also been proposed.

The present population is about 1200, including approximately 700 Aborigines and mixed-bloods (1971 census). Prospecting for uranium has recently brought several hundred people to the area.

The distribution of the five major physical regions and also some locality names used later in the report are shown in Fig. 3.

## II. Climate

The climate is tropical with marked wet and dry seasons. The wet season is hot and extends from October to April with 60% of the annual precipitation falling in the three months January to March. The dry season is very warm and lasts from May to September. Mean annual precipitation decreases inland from about 1500 mm at the coast to 1200 or 1300 mm at the southern end of the area. Evaporation is high, particularly in the dry season, and totals about 2000 mm per annum.

## III. Physical Regions

### (*a*) *Arnhem Land Plateau*

That part of the Arnhem Land plateau occupying the eastern two-thirds of the area is a wild, inaccessible, uninhabited, deeply dissected plateau about 200–300 m above sea level and formed on gently dipping quartz sandstone of Proterozoic age (Kombolgie Formation). Most of the plateau is mapped as Buldiva I land system. The steep western edge of the plateau forms the spectacular Arnhem Land escarpment which generally rises 50–250 m above the adjacent lowlands (Amhurst land system). A number of isolated outliers of the plateau lie to the west and north of the main escarpment.

Fully one-third of the plateau consists of practically bare rock with little soil or vegetation. A further third has shallow sandy soils supporting a varied flora of heath-like shrubs and spinifex (sandstone scrub). Sandstone woodland and tall open forest dominated by evergreen eucalypts occur on deeper sands in restricted pockets

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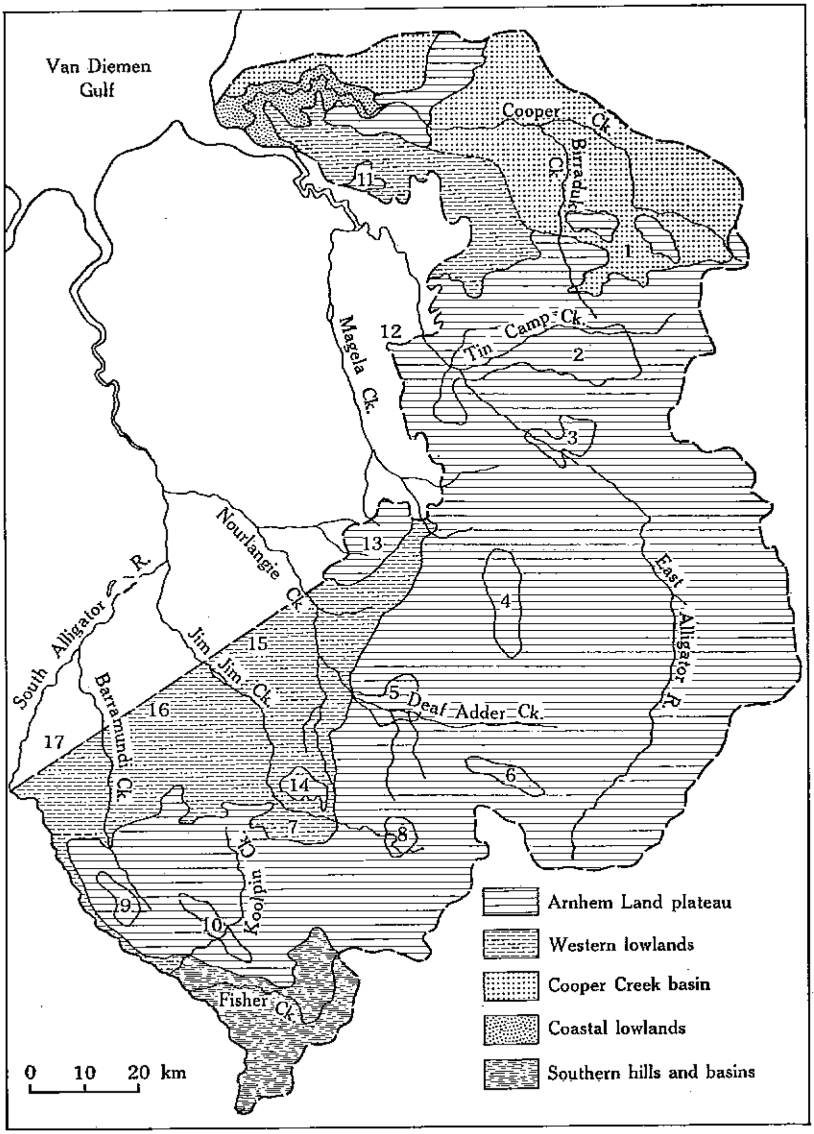


Fig. 3.—Physical regions and major streams. Features within the physical regions are: 1, Nabarlek basin; 2, Tin Camp Creek basin; 3, East Alligator River basin; 4, Magela Creek basin; 5, Lower Deaf Adder Creek basin; 6, Upper Deaf Adder Creek basin; 7, Lower Jim Jim Creek basin; 8, Upper Jim Jim Creek basin; 9, Waterfall Creek basin; 10, Koolpin Creek basin; 11, Mt Borradaile plateau outlier; 12, Cannon Hill–Obiri Rocks; 13, Mt Brockman; 14, Lower Jim Jim plateau outlier; 15, Mt Basedow; 16, Mt Partridge; 17, Mundogie Hill.

or on undissected portions of the plateau (part of Queue I land system). A peculiar monospecific forest of *Allosyncarpia* is found mainly in dissected areas (Bedford land system). There are small areas of subcircular basins and rises (Honeycomb land system) and meandering dry valleys (Dual land system).

Within the Arnhem Land plateau a number of valleys and basins have been cut through the sandstone to the underlying metamorphic, sedimentary and igneous rocks. The varied soils range from gravelly and lateritic to deep clays under a surface cover of boulders; the vegetation is dominantly eucalypt woodland. The land systems include Ararat and parts of Kysto I and Knifehandle I with Valley, Venlaw and Viney.

Restricted sandy fans below the Arnhem Land escarpment carry a vegetation of scrub and eucalypt woodland (Bundah land system).

### (*b*) *Western Lowlands*

The western lowlands consist of gently undulating erosional plains cut across folded Proterozoic sedimentary, metamorphic and intrusive rocks. Fairly thin laterite crusts are common and there are extensive sand sheets derived from the Arnhem Land plateau. The dominant land systems are Knifehandle I, Kysto I, Currency I, Somerville and Verity. The major rivers are fringed by alluvial tracts in the wide shallow valleys; extensive swamps are a feature of their downstream segments. Major alluvial land systems are Effington I, Flatwood I, Levee and part of Queue I. A few steep ridges on more resistant rocks rise from the lowlands (Baker I land system).

In keeping with the variety of rocks and degrees of weathering there is a wide range of soils. Gravelly lateritic red and yellow earths are widespread, as are shallow stony soils on slopes in excess of a few degrees. On alluvial areas silty organic brown earths are common with sands on levees and gradational soils on terraces. Other soils include loamy yellow earths and fairly deep clays.

The vegetation is highly variable like the soils but woodland predominates. Some tall open forest exists and there are minor areas of mixed scrub, especially on alluvium, and stunted woodland.

The western lowlands are scenically less interesting than the Arnhem Land plateau but have some pastoral potential and it is here that most of the uranium prospects known at the time of writing occur.

### (*c*) *Cooper Creek Basin*

The Cooper Creek basin resembles the western lowlands in relief, soils and vegetation but it includes an extensive low plateau on Cretaceous siltstone with deep loamy soils and tall open forest forming part of Queue I land system.

### (*d*) *Coastal Plains*

The coastal plains consist of young depositional plains of estuarine clay and mud laid down in coastal areas and the lower parts of the major river valleys. The slightly higher parts, which tend to lie near the river channels, are seasonally flooded for a few months and have black cracking clay soils supporting sedgeland (Cyperus I land system). Areas at intermediate levels are flooded for longer periods and support herbaceous swamp vegetation (Copeman I land system). The lowest areas, often on the landward margin of the plains, are permanent swamps with paperbark forest (Pinwinkle I land system).

Near the actual coast strongly saline, weakly cracking clays support samphire or sedges or are completely bare. Low shell sand ridges support narrow bands of semi-deciduous forest.

### (*e*) *Southern Hills and Basins*

In the south a small area of ridges on folded sedimentary rocks, volcanics and dolerite (Bend I, Verrucose and part of Viney land systems) plus dissected stony country on granite and schistose rocks (Currency I and Ararat land systems) is drained by the headwaters of the South Alligator. A sandy plateau occupies the southernmost tip of the area (Murray land system). In this relatively dry area the dominant vegetation is woodland and low woodland with some species differing from those common further north. Patches of *Allosyncarpia* forest exist on dissected sandstone sites. Most soils are shallow and stony but deeper cracking clays exist on fine-textured sediments and volcanic colluvium.

# PART III. LAND SYSTEMS OF THE ALLIGATOR RIVERS AREA

By R. W. Galloway,* J. M. Aldrick,† M. A. J. Williams‡ and R. Story*

## I. Introduction

The Alligator Rivers area is divided into 37 land systems, 20 of which extend into the Adelaide–Alligator area. They are distinguished in this Alligator Rivers report by a Roman I (see Part I).

The basis for mapping land systems is the subjective recognition and delineation of air-photo patterns which are related to differences in vegetation and relief. They are interpreted from experience supplemented by maps and other records, and interpretation is checked by field observations (Christian and Stewart 1953§).

Within each land system land units have been established by topographic position (e.g. crests, upper and lower slopes), distinctive photo patterns and the affinities of our field observations (e.g. the repeated occurrences of a plant community or soil type). They are too small for mapping at the scale used in the report but their descriptions should enable them to be recognized in the field.

The artificial key in section III gives the diagnostic features by which each land system can be recognized, with clarity as the first consideration and fundamental differences incidental. Under section IV they are listed alphabetically and described firstly by a short generalized description and then by more detailed descriptions of their component land units.

The areas of the land systems were calculated by means of a dot grid to the nearest 5 $km^2$, and those of the land units were done subjectively from the aerial photographs and from field experience.

The land systems are illustrated by the stereograms listed in the descriptions.

The geology of the area was remapped in considerable detail by officers of the Bureau of Mineral Resources during and after the time when the land resources survey was being carried out. The new geological information was available too late to be utilized in the present survey which depended largely on earlier reconnaissance mapping.

## II. Criteria for defining Land Systems

The land systems have been defined according to eight criteria: geology; weathering; erosional stage; relief; alluvium; vegetation; soil; adjustment to the previous Adelaide–Alligator survey.

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§ Christian, C. S., and Stewart, G. A. (1953). General report on survey of Katherine–Darwin region, 1946. CSIRO Aust. Land Res. Ser. No. 1.

The use made of these criteria is considered more fully in the parts dealing with geomorphology, vegetation and soil. Only a brief account of the principles is given here.

Geology is the primary criterion. Buldiva I, Bedford and Honeycomb land systems, for example, all have quartz sandstone as their basis and another group of five is on volcanic rocks.

The weathering status of the rocks is related to the former occurrence of deep weathering, the susceptibility of the rocks and the extent of later erosion. Different types of country can develop on similar rocks according to whether they are deeply weathered or not, e.g. Knifehandle I and Bend I land systems on weathered and unweathered Lower Proterozoic sediments respectively. The intensity of weathering is highest on metamorphic rocks and volcanics and lowest on quartz sandstone and quartz greywacke.

The erosional stage significantly affects the degree of preservation of deep weathering; in some areas the younger weathered land surface is almost intact (Kay I land system), whereas in others the surface has been reduced to fragments on the interfluves and the valleys have been cut down into the underlying weathered zone to give a different suite of soils and vegetation (Knifehandle I and Jay I land systems).

Obviously a variety of relief exists even on the same rock, and a very rough categorization of relief has been made. Rugged or mountainous relief has steep slopes generally in excess of 20°, a local relief greater than 100 m, and extensive areas of bare rock. Hilly relief generally has local relief from 30 to 100 m and a majority of slopes steeper than 10°. Rolling relief has dominant slopes between 5 and 10° and local relief about 10–30 m. Undulating terrain has most slopes between 1 and 5° and local relief up to 10 m. Although there can be both steep and gentle terrain on rocks which have been grouped into the same lithology, in many cases the different relief is really related to lithologic contrasts not brought out in the highly generalized geologic classification, e.g. the rocks of Baker I land system are more quartzose and resistant than those of Bend I land system.

Age, form and texture of alluvium have been used to distinguish several types of alluvial country, Flatwood I land system, for example, being of predominantly silty alluvium and Effington I predominantly sandy.

Vegetation differences have been used to distinguish between several land systems with apparently similar geologic, geomorphic and soil characteristics, e.g. the sandstone of the Kombolgie Formation, Buldiva I land system, has woodland or scrub while Bedford land system has forest, and Fabian I and Flatwood I are grassy and wooded respectively although both are on silty alluvium.

Soils have been used as distinguishing criteria in a few cases where our field observations indicate consistent soil differences between areas despite similar geology, geomorphology and vegetation. Since soils cannot be observed directly on the aerial photographs the extent of land systems defined at least partly according to soils criteria is uncertain, e.g. within the two groups Kay I–Queue I–Levee and Flatwood I–Effington I.

The necessity to ensure harmony between this survey and the Adelaide–Alligator survey has caused some modification of the land systems as defined in the earlier survey.

Descriptions of several land systems that were not closely examined in the Alligator Rivers survey were taken over directly from the earlier publication, e.g. McKinlay I and Pinwinkle I land systems.

The formally expressed definition of land systems and their mapping within well-defined boundaries suggests that they are clearly separated, a suggestion that is heightened by the terseness of the descriptions. Land systems separated on a presence-or-absence basis are in fact in this category, but those separated according to the proportions of their characters are not. For example, Cyperus I land system comprises the seasonally flooded coastal plains under sedge and is clearly distinguishable from Pinwinkle I which is similarly flooded but under paperbark. The key character of Littoral I land system, however, is the tidal influence which is indefinite and varies according to the weather and state of the rivers. Here the practical mapping difficulties are obvious, and the boundary remains a matter of opinion.

## III. Key to the Land Systems

- Seasonally flooded
  - Clays
    - Tidal .......... Littoral I
    - Not tidal
      - Sedgeland .......... Cyperus I
      - Herbaceous swamp vegetation .......... Copeman I
      - Paperbark .......... Pinwinkle I
  - Not clays
    - 30% channels and sandbars, forming a pattern mottled and streaked with white .. McKinlay I
    - 15% or less channels and sandbars, pattern not as for McKinlay I
      - Sandy .......... Effington I
      - Silty
        - Grassland .......... Fabian I
        - Wooded .......... Flatwood I
- Part seasonally flooded .......... Rumwaggon I
- Not seasonally flooded
  - Old levees with gradational red and yellow earths .......... Levee
  - Steep scarps capped by sandstone of Arnhem Land plateau .......... Amhurst
  - Not as for Levee or Amhurst
    - Sand sheets
      - Level .......... Queue 1
      - Undulating .......... Murray
      - Foot slopes .......... Bundah
    - Not sand sheets
      - On sandstone
        - Regularly alternating bare hummocks and vegetated depressions .......... Honeycomb
        - No regularity in the pattern
          - Vegetation predominantly *Allosyncarpia* forest .......... Bedford
          - Vegetation predominantly sandstone woodland or scrub .......... Buldiva
          - Vegetation predominantly tall open forest .......... Dual

On granite
- Hilly ........ Currency I
- Undulating ........ Cully I

On volcanics and dolerite
- In Cooper Creek catchment ........ Verity
- Outside Cooper Creek catchment
  - Soils of light texture
    - On Edith River Volcanics ........ Verrucose
    - Not on Edith River Volcanics
      - Soils with lateritic gravels ........ Valley
      - Soils without lateritic gravels ........ Venlaw
  - Soils of heavy texture ........ Viney

On Mullaman Beds ........ Klatt

On mica schists ........ Ararat

On Proterozoic metamorphic rocks ........ Nova

On other rocks
- Unweathered, laterite uncommon and sporadic
  - Undulating ........ Somerville
  - Low hills, gentle slopes ........ Bend I
  - Rugged hills ........ Baker I
- Weathered, aterite common and general
  - Remnants of Koolpinyah surface present
    - 90% or more Koolpinyah remnants
      - Tall open forest ........ Kay I
      - Woodland ........ Explanado
    - 40% Koolpinyah remnants ........ Knifehandle I
    - 10% Koolpinyah remnants ........ Jay I
  - No remnants of Koolpinyah surface
    - Alternating bands of tall open forest and woodland ........ Kysto I
    - Vegetation not banded, *Pandanus* scrub and rain forest present ........ Kosher I

## IV. Descriptions of Land Systems

### (A) Amhurst Land System (120 km$^2$, 4 observations, Plate 8, Fig. 1)

Steep scarps capped by quartz sandstone cliffs; skeletal soils; mainly tall open forest with smooth-barked bloodwood present.

*Unit 1* (100%)

Lower slopes of escarpment, slopes generally around 50% declining to 10% at the foot, littered with sandstone boulders and very rocky, relief 30–250 m, on unweathered folded Proterozoic sediments, mica schists and dolerites, also granites (not examined); overlooked by cliffs 30–150 m high.

Skeletal soils of variable depth with gravel and boulder admixture, cliffs bare.

Tall open forest of *E. miniata* and *E. tetrodonta* with *E. bleeseri*, very rocky areas with mixed and shrubby woodland, in either case with perennial grasses; scattered patches of *Allosyncarpia* forest.

### (Ar) Ararat Land System (185 km$^2$, 11 observations, Plate 8, Fig. 1)

Closely dissected hilly and rolling terrain on mica schists; loamy red earths and shallow gravelly loams, some skeletal soils; woodland of broad-leaved bloodwood and box, annual grasses on skeletal soils, perennial grasses and fewer trees on soils of heavier texture.

*Unit 1* (90%)

Closely dissected low hills with short slopes 10–100 m long and gradients generally 15–50%; numerous small outcrops and stony surface; sharply incised minor valleys.

Loamy red earths (Zamu), shallow gravelly loams (Partridge) and skeletal soils. Soils are redder and loamier near volcanic dykes.

Woodland mainly broad-leaved bloodwood and box, dominants variable; annual grasses on skeletal soils, perennial grasses on soils of heavier texture, and fewer trees.

*Unit 2* (10%)

Narrow colluvial foot slopes and occasional colluvial patches on slopes, also narrow alluvial flats with recent gullies and signs of active flooding; stony colluvium and silty alluvium from mica schists.

Micaceous silty yellow earths (Myra) and minor solodic soils on alluvial flats; shallow gravelly loams (Partridge) on colluvial slopes.

Woodland of broad-leaved bloodwood and box with perennial grasses, non-eucalypts dominant along channels (*Planchonia*, *Ficus*, *Tristania*).

*Unit 3* (<5%)

Steep linear ridges with quartz dyke cores and metasediment flanks, slopes 30–45%.

Shallow loamy red earths.

Woodland, *E. bleeseri* dominant, scattered *E. setosa*, *E. patellaris*, *E. tetrodonta*; annual and perennial grasses.

### (B) Baker I Land System (245 km$^2$, 21 observations, Plate 1, Fig. 1)

Steep rocky strike ridges on resistant sediments; skeletal soils and shallow gravelly loams; woodland mainly red-barked bloodwood and box with perennial grasses, increasingly heterogeneous downslope.

*Unit 1* (65%)

Steep linear ridges 20–200 m high of steeply dipping quartz greywacke, sandstone, minor conglomerate and mica schist; slopes mainly 30–60%; bouldery surface with numerous outcrops; crests generally less than 50 m wide but widening to a plateau 800 m wide south of Mt Partridge.

Skeletal soils, usually micaceous, some shallow gravelly loams (Partridge).

Woodland mainly *E. dichromophloia* and box with shrubs and perennial grasses; some areas of low woodland, mixed and without perceptible dominance.

*Unit 2* (25%)

Low strike ridges 10–50 m high, of quartz sandstone, siltstone, chert, algal reefs; slopes 5–20%; sporadic linear outcrops on crests, stony shallow regolith elsewhere.

Skeletal soils, usually micaceous; some shallow gravelly loams recorded (Partridge) and one shallow red loam (Howship); soils probably deeper than in unit 1.

Woodland variable mixed eucalypts and shrubs and perennial grasses.

*Unit 3* (10%)

Minor silty alluvial flats; probably silty to sandy colluvium with thin lag gravel veneer.

Shallow gravelly loams and yellow earths.

Woodland as for unit 2.

(Bf) BEDFORD LAND SYSTEM (520 KM$^2$, 7 OBSERVATIONS, PLATE 8, FIG. 2)

Very rugged dissected portions of the Arnhem Land plateau on quartz sandstone of Kombolgie Formation; deep red sands in ravine floors, skeletal soils, bare areas, and deep yellow sands on plateaux; *Allosyncarpia* forest.

*Unit 1* (75%)

Ravines, cliffs, screes, and tors; sand in pockets and ravine floors.
Deep reddish sand (Cockatoo), often water-repellent, regosols and skeletal soils.
*Allosyncarpia* forest.

*Unit 2* (20%)

Colluvial sandy wash slopes derived from dissected quartz sandstone; gradients probably 2–5%; narrow ill-drained alluvial flats in larger valley floors.
Deep yellow siliceous sand (Arnhem), hydrophobic surfaces.
*Allosyncarpia* forest.

*Unit 3* (5%)

Highly dissected tableland.
Regosols, deeper sands and bare rock.
Sandstone scrub, sandstone woodland and bare rock.

(Be) BEND I LAND SYSTEM (295 KM$^2$, 12 OBSERVATIONS, PLATE 1, FIG. 1)

Undulating lowlands on folded Lower Proterozoic sediments, generally unweathered but with abundant surficial gravel; shallow gravelly loams and skeletal soils; woodland of broad-leaved bloodwood and box, species variable, annual or perennial grasses.

*Unit 1* (50%)

Crests and upper slopes of low strike rises and ridges with lag gravel of angular vein quartz and siltstone fragments and some outcrop; local relief 5–20 m; slopes up to 8%.
Shallow gravelly loams (Partridge) and skeletal soils.
Mainly woodland of broad-leaved bloodwood and box, but some areas dominated by *Livistona* or *Melaleuca*; annual or perennial grasses. No correlation apparent with soils.

*Unit 2* (45%)

Stony colluvial lower slopes, slopes generally 2–5% and 100–300 m long; quartz lag gravel cover widespread; minor sheet erosion.
Lateritic red and yellow earths (Partridge, Koolpinyah, Woolner) and wet sandy or loamy soils (Baroalba, Fisher); some skeletal soils.
As for unit 1 but no *Livistona* recorded.

*Unit 3* (5%)

Narrow alluvial flats of silt and sand up to 100 m wide, channels probably 1–2 m deep, in places extending by headward erosion.
Dark cracking clays (Brockman) and yellow mottled clays (McKinlay).
Dense perennial grassland, in places with scattered trees, usually *E. papuana*.

(Bd) BULDIVA I LAND SYSTEM (6795 KM$^2$, 25 OBSERVATIONS, PLATE 7, FIG. 1)

Rugged dissected Arnhem Land plateau on quartz sandstone of Kombolgie Formation; regosols and bare areas, deeper sands in pockets and fissure floors; mostly sandstone scrub and sandstone woodland over about half the area, the rest bare rock.

*Unit 1* (50%)

Bare, fairly smooth tableland with occasional low rocky scarps and steps and cavernous weathered outcrops.

Some sandy regosols and skeletal soils, otherwise bare rock.

Scattered patches and individual plants of the sandstone scrub.

*Unit 2* (35%)

Rocky plateau cut by fissures 4–40 m deep with sandy floors.

Skeletal soils, occasional deeper sands (Kombolgie) and bare areas.

Sandstone scrub, scattered eucalypts (commonly *E. dichromophloia*); *Allosyncarpia* forest in deeper fissures.

*Unit 3* (15%)

Residual and colluvial sand on undissected plateau surface in shallow pockets and depressions.

Skeletal soils with some areas of deeper sand (Cockatoo, Kombolgie).

Sandstone woodland or tall open forest, occasional patches of *Allosyncarpia* forest.

### (Bda) Bundah Land System (170 km², 5 observations, Plate 4, Fig. 1)

Sandy aprons below Arnhem Land escarpment; sands and skeletal soils, sandy seepage areas and wet sandy humic gleys; mixed scrub and eucalypt woodland, variable and with many non-eucalypts.

*Unit 1* (90%)

Sandy aprons 100–800 m wide with slopes 2–5%; sandstone boulders on upper part.

Skeletal soils with wet sands on lower slopes (Kapalga, Baroalba); some well-drained sands (Evelyn).

Mixed scrub or eucalypt woodland, variable and with many non-eucalypts, upper parts often tall open forest (*E. miniata*, *E. tetrodonta*); annual grasses.

*Unit 2* (10%)

Alluvial fans and low levees of well-sorted fine to medium sand associated with streams issuing from the Arnhem Land plateau.

Wet sandy humic gleys (Buldiva) or moist organic brown earths (Argoolook).

Mixed scrub with abundant *Melaleuca* and sedges where ill drained (humic gleys), non-eucalypt woodland where better drained (brown earths).

### (Cm) Copeman I Land System (45 km², 2 observations supplemented from Adelaide–Alligator records, Plate 1, Fig. 2)

Low swampy channelled estuarine plains, mainly estuarine clays and muds; shallow poorly differentiated cracking clays; herbaceous swamp vegetation.

*Unit 1* (50%)

Plains on margins of estuaries, very gradual slopes down to landward margins (*c.* 0·05%); flooded 6–12 months per year to depths of 1 m; equivalent to unit 2 of Cyperus I land system.

Shallow weakly differentiated cracking clay (Carmor, Wildman).

Herbaceous swamp vegetation.

*Unit 2* (30%)

Shallow channels, generally wide (up to 500 m) and broadly meandering; feeding into swamps and shallow permanent lagoons.

Shallow cracking clays (Wildman, Carmor).

Herbaceous swamp vegetation.

*Unit 3* (15%)

Slight rises, usually forming broad levees up to 1 km wide and up to 1 m above swamps of unit 1, equivalent to unit 1 of Cyperus I land system.

Poorly differentiated shallow cracking clays (Wildman).

Patchy sedgeland and herbaceous swamp vegetation (mostly sedgeland).

*Unit 4* (5%)

Narrow complex channels up to 20 m wide, presumably in estuarine clay, partially tidal, 1–3 m deep, draining swamps of unit 1.

### (Cu) CULLY I LAND SYSTEM (125 KM², 16 OBSERVATIONS, PLATE 7, FIG. 2)

Undulating to rolling lowlands on moderately weathered granite; coarse sands; woodland, mainly stringybark and narrow-leaved bloodwoods, variable grasses.

*Unit 1* (70%)

Interfluves and mid slopes of undulating terrain, gradients 2–5%; occasional low tors on convex slopes; surface pavement of coarse residual sand.

Coarse sands (Cullen) and loamy granitic soils (Malone), sometimes imperfectly drained.

Woodland of *E. tetrodonta*, *E. dichromophloia* and *E. bleeseri*, with annual grasses; imperfectly drained places woodland of *E. tetrodonta* and *Melaleuca* with variable grasses.

*Unit 2* (15%)

Colluvial foot slopes; gradients 2–5%; coarse sand plus admixtures of varied materials derived from outcrops upslope and ironstone gravel.

Imperfectly drained sands (Cullen, poorly drained phase) and loamy granitic soils (Malone).

Woodland, sometimes without perceptible dominance of any tree (*E. latifolia*, *E. dichromophloia*, *E. bleeseri*, *E. tetrodonta*, *E. miniata* recorded), mostly annual grasses; grading into mixed crub in places, with *Melaleuca* common where imperfectly drained.

*Unit 3* (10%)

Gently sloping interfluves up to 1 km wide; slopes 0–3%; fine transported sand over granite.

Deep siliceous sands.

Tall open forest (*E. tetrodonta*, *E. miniata*) with perennial and annual grasses.

*Unit 4* (5%)

Highly variable alluvium ranging from clay to coarse sand, all derived from granite, forming narrow flats 25–100 m wide; generally unchannelled except where recent accelerated erosion has cut channels to 1 m deep.

Poorly drained soils: layered yellow podzolics (Scinto) in channelled areas, heavy humic gleys (Koolpin) on broader unchannelled flats and minor gleyed podzolics.

Channelled areas mostly annual grassland with sedge and patches of *Pandanus* and *Melaleuca viridiflora*, unchannelled flats mostly sedgeland with perennial grasses and scattered *M. viridiflora*.

### (Cr) CURRENCY I LAND SYSTEM (160 KM², 1 OBSERVATION, PLATE 6, FIG. 1)

Rugged hills on granite; shallow gradational soils and skeletals; low woodland of ironwood and bloodwoods, annual grasses.

*Unit 1* (100%)

Rugged hills and rolling terrain with numerous tors and extensive outcrop.

Shallow gradational soils (Malone) and skeletals.

Low woodland of *Erythrophleum*, *E. dichromophloia* and broad-leaved bloodwoods with the characteristic associated non-eucalypt woody species; annual grasses.

### (Cp) Cyperus I Land System (120 km$^2$, 6 observations, Plate 5, Fig. 1)

Seasonally flooded coastal plains, marine and some freshwater muds and clays; shallow poorly differentiated cracking clays, sometimes calcereous; sedgeland.

*Unit 1* (65%)

Very broad (1–2 km) low rises in seasonally flooded plains forming wide low levees adjacent to main tidal channels; slopes estimated 0·1%; relief to 2 m; seasonally flooded 3–6 months only; marine clay, probably with some freshwater clay in places, shell fragments below 50 cm; equivalent to unit 3 of Copeman I land system.

Poorly differentiated shallow cracking clays (Wildman, Carmor).

Sedgeland, rare grassland (mainly *Xerochloa*).

*Unit 2* (25%)

Low marginal zones of estuarine plains; probably 1–2 m below unit 1; seasonally flooded 6–12 months; equivalent to unit 1 of Copeman I land system.

Poorly differentiated cracking clays (Carmor, Wildman).

Herbaceous swamp vegetation.

*Unit 3* (5%)

Complexes of narrow, winding, partially tidal channels up to 10 m wide and 3 m deep, also clay flats with mud plates fringing the channels and up to 50 m wide.

Weakly developed calcareous clays (Carmor).

Bare or with thin algal mats.

*Unit 4* (5%)

Meandering tidal estuaries of lower Cooper Creek and East Alligator River; 100–1000 m wide; bed load clay and silt.

Mangrove scrub along the banks.

### (D) Dual Land System (40 km$^2$, 2 observations, Plate 9, Fig. 2)

Old meandering valleys on sandstone of Kombolgie Formation; yellowish sandy soils of mixed origin, skeletal soils and bare areas on plateaux; tall open forest over perennial grasses in valleys, sandstone scrub on plateaux.

*Unit 1* (90%)

Broad valley floors, many now devoid of streams, with occasional low sandstone outcrops and shallow to moderately deep sandy and weakly lateritic infill.

Yellowish sandy soils formed on mixed lateritic and arenaceous materials (Evelyn, Ramil).

Tall open forest (*E. tetrodonta*, *E. miniata*).

*Unit 2* (10%)

Steep-sided largely bare sandstone hills and dissected plateaux 20–50 m high.

Skeletal soils or none.

Sandstone scrub.

### (Ef) Effington I Land System (350 km$^2$, 21 observations, Plate 7, Fig. 2)

Flood-plains of dominantly sandy alluvium with a single or few channels; predominantly sandy soils with little profile differentiation; little consistency in the vegetation.

*Unit 1* (40%)

Younger levees and back plains 50–200 m wide; relief 1–3 m; loose sandy surface; flooded in most wet seasons.

Siliceous sands on alluvium (Manbulloo); some less well-drained layered soils (Barramundi) on younger back plains.

No consistency, varying from bare through scrub to woodland; as a rule without shrubs.

*Unit 2* (25%)

Older swales and billabongs 100–500 m wide, 1–5 m deep, liable to shallow flooding; alluvial sand, silt and clay, ironstone concretions common.

Layered alluvial soils (Barramundi) and sands of mixed origin (Baroalba); some heavy-textured soils.

Poorly drained places have perennial grassland, commonly *Eriachne burkittii*, better-drained places mixed scrub, commonly *Melaleuca* with annual grasses and occasional shrubs.

*Unit 3* (15%)

Channels, usually anastomosing, 2–5 m deep, 10–50 m wide; permanent waterholes on larger streams; sandy rises between channels; well-sorted alluvial sand and silt; all liable to flooding in the wet season.

Variable alluvial soils, mostly coarse alluvial regosols.

Usually paperbark forest (*Melaleuca argentea* along main channels, *Melaleuca* spp. on smaller channels), otherwise grassland or mixed scrub with *Barringtonia* and *Pandanus*, very variable.

*Unit 4* (10%)

Younger back swamps and billabongs behind younger levees, 50–200 m wide; floors 0·5–2·0 m below levee crests; flooded for several months per year.

Mainly alluvial soils (Barramundi) with some areas of more stable brown earths and earthy sands (Leichhardt).

Paperbark forest in wet places, otherwise mixed scrub with *Melaleuca*; as a rule no shrubs.

*Unit 5* (10%)

Older levees and gently dissected sand terraces in major valleys; relief 1–5 m; slopes generally 1–2% but increasing to 5% near major lines of dissection; alluvial sand, but concretionary ironstone common, locally forming thin laterite horizons.

Gradational red earths (Katherine); some yellow sands (Evelyn) or sandy yellow earths on smaller levees.

Tall open forest, occasionally woodland, in either case *E. tetrodonta* dominant, usually with some broad-leaved bloodwoods; shrubs and grasses variable in species and quantity.

### (E) Explanado Land System (35 km$^2$, 2 observations, Plate 6, Fig. 2)

Partly incised, level to gently undulating plain on shallow weathered zone of folded Lower Proterozoic siltstone and shale; loamy gradational or texture-contrast red earths; tall woodland, stringybark dominant, or low woodland, ironwood dominant, perennial grasses.

*Unit 1* (95%)

Level to gently undulating erosional plain with thin laterite.

Loamy red earths (Zamu), sometimes texture-contrast, formed from soft sedimentary rocks; some layered soils.

Tall woodland, *E. tetrodonta* dominant, with perennial sorghum and spinifex; on texture-contrast soil low woodland, *Erythrophleum* dominant, with perennial sorghum and no spinifex.

*Unit 2* (5%)

Shallow incised valley with silty or clayey alluvium now extensively gullied.

No observations on soils.

No observations on vegetation.

### (Fb) Fabian I Land System (15 km$^2$, 2 observations, Plate 4, Fig. 2)

Flood-plains of dominantly silty alluvium; silty brown earths and yellow earths; perennial grassland, scattered paperbark.

*Unit 1* (100%)

Stable back plains up to 1 km wide, slopes probably less than 1%; alluvial silty clay; ironstone concretions common; shallow flooding in wet season.

Silty brown earths (Argoolook) or yellow earths (McKinlay).

Perennial grassland, scattered *Melaleuca.*

### (Fw) Flatwood I Land System (130 km$^2$, 2 observations, Plate 4, Fig. 2)

Flood-plains of dominantly silty alluvium; silty brown earths, gradational red earths and minor siliceous sands; patchy and variable savanna and woodland.

*Unit 1* (70%)

Older levees, back slopes to 2%; 2–5 m above younger levees of unit 3.

Hard gradational red earths (Katherine) and silty brown earths (Argoolook).

Patchy and variable savanna or woodland (mixed eucalypts, *Pandanus*, *Tristania*).

*Unit 2* (15%)

Younger levees 100–500 m wide, 5–8 m above main channel, back slopes up to 4%; occasionally covered by floods.

Siliceous sands on alluvium (Manbulloo).

No consistency, as for unit 1 of Effington I land system.

*Unit 3* (10%)

Back swamps and billabongs 100–200 m wide, probably regularly flooded.

No observations on soils.

No observations on vegetation.

*Unit 4* (5%)

Braided channels with medium sand; main channel 5–7 m deep with permanent pools, neighbouring channels to 4 m probably flooded 3–6 months per year; along South Alligator River.

As for unit 3 of Effington I land system, variable alluvial soils.

No consistency—varying from grassland through savanna to paperbark forest and scrub of *Pandanus* and *Bambusa.*

### (H) Honeycomb Land System (100 km$^2$, 11 observations, Plate 7, Fig. 1)

Hummocky surfaces and intervening shallow depressions on quartz sandstone formerly overlain by volcanics; bare, with yellow podzolics or siliceous sands in depressions; no consistent vegetation.

*Unit 1* (50%)

Network of low rises and hillocks up to 20 m high, 100–500 m wide.

Mostly bare. Some sandy regosols and skeletal soils.

Sandstone scrub, or bare.

*Unit 2* (35%)

Flat-floored subcircular basins mostly 100–300 m in diameter surrounded by low ridges of unit 1; varied fill dominantly sandy but including ironstone nodules and clays derived from recently stripped volcanics; generally 50 cm to 2 m deep.

Variable poorly drained yellow podzolics (Honeycomb) and well-drained siliceous sands (Kombolgie). Some skeletal soils.

No consistency, varying from sedgeland through mixed scrub to tall open forest.

*Unit 3* (15%)

Low domed hills on weathered volcanics or Mullaman Beds, 5–15 m high, capping sandstone plateaux with honeycomb pattern developed to varying degrees; sporadic occurrences.

Dominantly skeletal soils with dense ferruginous gravel.

Tall open forest or woodland, in either case *E. dichromophloia* dominant, dense shrubs.

(J) JAY I LAND SYSTEM (130 KM$^2$, 6 OBSERVATIONS, PLATE 9, FIG. 1)

Dissected, gently rolling lowlands on weathered rocks; lateritic red earths and less well-drained yelow earths; woodland or tall open forest.

*Unit 1* (50%)

Crests and upper slopes.

Lateritic red earths (Koolpinyah, Basedow).

Tall woodland on slopes, tall open forest on crests, in either case usually of *E. tetrodonta* and *E. miniata* with broad-leaved and narrow-leaved bloodwoods and annual grasses.

*Unit 2* (45%)

Lower slopes and colluvium.

Lateritic red earths (Hotham) and mottled yellow earths (Fisher).

Woodland, broad-leaved bloodwoods dominant, over annual grasses on lateritic red earths and perennial grasses on mottled yellow earths.

*Unit 3* (5%)

Alluvium.

Poorly drained sands (Baroalba) and clays.

Savanna on poorly drained sands, grassland on clays.

(K) KAY I LAND SYSTEM (230 KM$^2$, 2 OBSERVATIONS, PLATE 5, FIG. 1)

Level to gently undulating, undissected lowlands on deeply weathered rocks; lateritic red and yellow earths; tall open forest.

*Unit 1* (90%)

Level to gently sloping weathered land surface with ferruginous or quartzose lag gravel.

Moderately deep lateritic red earths.

Tall open forest of *E. tetrodonta* and *E. miniata,* usually with annual grasses.

*Unit 2* (5%)

Laterite outcrops, on crests or as sheets.

Bare laterite or shallow lateritic yellow earths (Koolpinyah).

Short annual grassland grading with deeper soil to leguminous–myrtaceous scrub.

*Unit 3* (5%)

Alluvial flats and channels.

No observations on soils.

No observations on vegetation, probably variable as for unit 4 of Knifehandle I land system.

(Kl) KLATT LAND SYSTEM (35 KM$^2$, 8 OBSERVATIONS, PLATE 8, FIG. 1)

Small plateaux and bounding scarps with thick laterite on deeply weathered Cretaceous sediments (Mullaman Beds); shallow gravelly lateritic red and yellow earths, some skeletal soils and bare laterite; tall open forest or woodland (woollybutt, stringybark), mixed annual and perennial grasses.

*Unit 1* (50%)

Plateaux and mesas 100–2000 m wide capped by thick laterite standing 10–50 m above surroundings.

Shallow lateritic red and yellow earths (Hotham, Koolpinyah) and skeletal soils; some bare laterite.

Tall open forest or woodland of *E. tetrodonta* and *E. miniata* with *Acacia* and perennial grasses; some areas of short annual grasses or leguminous–myrtaceous scrub.

*Unit 2* (45%)

Undulating to hilly foot slopes of breakaways and dissected plateaux; local colluvial spreads of sand and ironstone gravel.

Lateritic red and yellow earths (Basedow, Koolpinyah).

Tall open forest (*E. tetrodonta, E. miniata, E. bleeseri*) with abundant shrubs, annual grasses.

*Unit 3* (5%)

Breakaways 5–25 m high, littered with blocks of concretionary laterite over weathered Cretaceous sediments.

Skeletal soils and bare rock.

Tall open forest (*E. miniata, E. tetrodonta, E. bleeseri*) with *Acacia* and mixed grasses.

### (Kn) Knifehandle I Land System (1585 km$^2$; 41 observations, Plate 4, Fig. 1)

Undulating lowlands on weathered Lower Proterozoic sediments, metasediments and granitic rocks; lateritic red and yellow earths and siliceous sands; woodland of broad-leaved bloodwood and box or tall open forest, ground cover mainly annual grasses.

*Unit 1* (45%)

Middle and lower slopes 100–500 m long, gradients probably 2–4%; patchy gravel pavements; colluvium ranging from coarse vein quartz and ironstone gravel to silt.

Lateritic red and yellow earths (Basedow, Woolner, Koolpinyah) and sands (Evelyn).

Woodland, mainly *E. foelscheana, E. confertiflora* and *E. tetrodonta*, with annual grasses.

*Unit 2* (40%)

Broad rises and interfluves up to 1 km wide, gradients up to 3%; residual gravel pavement of vein quartz and concretions.

Lateritic red earths (Basedow) and shallow lateritic yellow earths (Koolpinyah).

Tall open forest of *E. tetrodonta* and *E. miniata* and occasional *E. dichromophloia* or *E. bleeseri* with shrubs and annual grasses.

*Unit 3* (10%)

Lower slopes, gradients 2–6%, mainly with sandy colluvium, occasional stony surfaces without colluvium.

Siliceous sands (Evelyn; Kapalga at seepage points) with alluvial soils (Barramundi) in wetter areas; some loamier soils of mixed origin.

Mixed scrub (*Melaleuca, Grevillea pteridifolia, Terminalia grandiflora, Petalostigma, Acacia*); with annual grasses on siliceous sands and perennial grasses on loamier soils.

*Unit 4* (5%)

Floors of shallow valleys predominantly with fine-textured alluvium, overlying gravel in places; smaller examples have broadly concave floors 50–200 m wide without channels or levees; larger examples 100–500 m wide with meandering channels 1–2 m deep, levees and locally billabongs.

Silty alluvial soils (Siltavel) with wet sandy alluvial soils (Barramundi) in larger valleys.

Heterogeneous, eucalypt and non-eucalypt woodland, mixed scrub, grassland or sedgeland.

### (Kh) Kosher I Land System (75 km$^2$, 3 observations, supplemented from Adelaide–Alligator records, Plate 5, Fig. 1)

Low promontories and gentle slopes on moderately weathered Mullaman Beds adjacent to Cyperus land system; gravelly lateritic earths and skeletal soils, some humic gleys; patchy grassland, *Pandanus* scrub and mixed scrub.

*Unit 1* (40%)

Upper and middle sandy slopes with occasional ironstone concretions; 50–200 m long; bed-rock near surface; gradient 1–3%.

Gravelly lateritic soils, deep wet sands (Baroalba), and humic gleys (Murrabibbi) in seepage areas.

Mixed scrub or *Pandanus* scrub, occasional patches of rain forest or paperbark forest.

*Unit 2* (25%)

Middle and lower slopes with weathered sandstone gravels and ironstone and occasional bare bed-rock slabs.

Lateritic yellow earths (Koolpinyah) with minor Baroalba on lower slopes.

Mixed scrub or *Pandanus* scrub.

*Unit 3* (20%)

Middle and lower slopes as for unit 2.

Soils as for unit 2.

Leguminous–myrtaceous scrub or short grass.

*Unit 4* (15%)

Lower colluvial sandy slopes generally next to swamps of Cyperus I and Pinwinkle I land systems.

Skeletal soils and shallow loams.

Short annual grassland.

### (Ks) Kysto I Land System (585 km$^2$, 18 observations, Plate 3, Fig. 2)

Undulating lowlands on weathered Lower Proterozoic sediments with strong strike control of soil and vegetation; lateritic red and yellow earths and earthy sands, with yellowish siliceous sands on sand-plain remnants; patches and bands of tall open forest and woodland, very variable, often strike-aligned.

*Unit 1* (45%)

Very shallow swales, 100–300 m wide parallel to strike, on middle and upper slopes; gradient 1–4%; gravel pavements of vein quartz, other rock fragments and ironstone concretions, occasionally concealed by silty colluvium washed from adjacent slightly higher areas.

Lateritic red earths (Woolner, Basedow) and earthy sands (Cahill) overlying heavy mottled red or yellow clays.

Woodland of broad-leaved bloodwood; on loamier soils (Basedow) of box and *E. dichromophloia*, in either case over annual grasses.

*Unit 2* (40%)

Very shallow rises, 100–350 m wide parallel to strike, on middle and upper slopes; gradient 1–4%; gravel pavements generally present.

Lateritic red earths (Basedow, Hotham) and earthy sands (Cahill) overlying weathering micaceous sediments.

Tall open forest of *E. tetrodonta* and *E. miniata* and occasional *E. dichromophloia* or *E. bleeseri* with shrubs and annual grasses, or with perennial grasses and no shrubs on loamier soils.

*Unit 3* (10%)

Lower slopes of undulating terrain as for unit 3 of Knifehandle I land system.

Shallow soils: gravelly lateritic yellow earths (Koolpinyah) and minor loamy yellow earths (Fisher).

Mixed scrub (box, broad-leaved bloodwood, *Acacia*), annual grasses.

*Unit 4* (5%)

Floors of shallow valleys, predominantly with fine-textured alluvium as in unit 4 of Knifehandle I land system.

Heavy yellow earths (McKinlay) and alluvial soils (Siltavel, Barramundi).

Savanna or open woodland with perennial grasses on heavy yellow earths; mixed scrub and grassland elsewhere.

### (Le) Levee Land System (25 km², 4 observations, Plate 7, Fig. 2)

Old sandy and silty levees fringing streams draining the Arnhem Land plateau; gradational red earths; tall open forest, or woodland of varied eucalypts, annual grasses.

*Unit 1* (100%)

Old sandy and silty levees.

Gradational red earths on alluvium (Katherine), soft and sandy or hard and loamy.

Tall open forest of *E. tetrodonta* and *E. miniata* on soft sandy soils, woodland of varied eucalypts on hard loamy soils.

### (L) Littoral I Land System (10 km², 3 observations, Plate 1, Fig. 2)

Tidal flats and coastal plains; weakly differentiated saline marine clays and muds; samphire, sedgeland or mangrove scrub.

*Unit 1* (85%)

Tidal flats, slope imperceptible, clay with saline surface and shells below 30 cm; flooded by spring tides.

Strongly saline weakly cracking clays (Carpentaria).

Scattered mangrove seedlings, patches of *Arthrocnemum* and *Sporobolus virginicus*.

*Unit 2* (10%)

Low linear beach ridges 1–2 m high, 20–50 m wide, of coarse shell sand resting on blue marine clay.

Coarse gritty calcareous sand over gleyed marine mud.

Semi-deciduous forest, *Dodonaea* common, otherwise very mixed.

*Unit 3* (5%)

Tidal foreshore sloping 2–8%, 50–100 m wide; active bioturbation; marine mud with thin shell sand cover.

Undifferentiated gleyed marine mud.

Mangrove scrub or bare.

### (M) McKinlay I Land System (30 km², no ground observations, Plate 4, Fig. 1)

Channels and flood-plains, presumably with uniform sands and silts, gradational acid loamy and sandy soils, gradational alkaline loamy soils and alkaline texture-contrast soils as in Adelaide–Alligator area; paperbark forest or savanna, very variable.

### (Mu) Murray Land System (50 km², 4 observations, Plate 5, Fig. 2)

Undulating low plateau cut on pallid zone of deeply weathered Mullaman Beds; deep siliceous sands, some stony skeletal soils; woodland, mainly non-eucalypt, with abundant shrubs, spinifex and annual grasses.

*Unit 1* (95%)

Sandy undulating plateau surface about 350 m above sea level; gradients generally about 2%; very minor low laterite-capped mesas.

Deep brownish siliceous sands (Sleisbeck).

Woodland, mainly non-eucalypts, with abundant shrubs and ground cover of spinifex and annual grasses; lateritic mesas, tall open forest or leguminous–myrtaceous scrub.

*Unit 2* (5%)

Steep, heavily dissected valley heads cut into margin of unit 1.

Skeletal pallid stony soils.

*Allosyncarpia* forest.

### (N) Nova Land System (15 km², 2 observations, Plate 3, Fig. 2)

Undulating and rolling terrain cut on Proterozoic metamorphic rocks, with distinctive pale air-photo pattern; probably mainly skeletal soils or shallow gravelly yellow earths; woodland, apple gum and quinine bush where sampled, mixed scrub with abundant paperbark on lower slopes, annual grasses. (Inadequate observations for establishment of units.)

### (Pw) Pinwinkle I Land System 10 km², 2 observations, Plate 5 Fig. 1)

Swampy depressions on the coastal plains; black uniform cracking clays over gleyed estuarine muds and riverine sands, texture-contrast peaty loam over clay soils; paperbark forest. (Inadequate observations for establishment of units.)

### (Q) Queue I Land System (490 km², 21 observations, Plate 3, Fig. 1)

Level to gently undulating sand sheets derived from the Kombolgie Formation and the Mullaman Beds; deep sandy soils; tall open forest with annual grasses.

*Unit 1* (85%)

Gently undulating to level terrain mantled by sand sheets generally more than 2 m deep and ranging from pockets 500 m wide on the Arnhem Land plateau to caps 10 km wide on low plateaux in the extreme north; also sand-mantled broad interfluves and dissected terraces on western lowlands; slope generally less than 2%.

Deep red and yellow siliceous sands (Cockatoo, Arnhem) with some shallower sands (Kombolgie); sands with gravelly subsoils on ancient levees (Evelyn), and deep sandy red earths (Killuppa) elsewhere.

Tall open forest of *E. tetrodonta* and *E. miniata*, usually with annual grasses, occasionally with spinifex.

*Unit 2* (10%)

Colluvial aprons and shallow depressions up to 1 km wide on Arnhem Land plateau, filled with sand from quartz sandstone, generally 1–2 m deep, gradient 1–3%.

Moderately deep yellow sands (Arnhem) with some shallower sands (Kombolgie); wet sands (Kapalga) at seepage points.

Woodland of *E. tetrodonta* or *E. miniata*, with annual grasses and spinifex, seepage points mixed scrub of *Grevillea pteridifolia* and *Melaleuca viridiflora* with abundant sedges.

*Unit 3* (5%)

Unchannelled, poorly drained, sandy alluvial flats up to 200 m wide in shallow valleys on Arnhem Land plateau.

Humic gleys; permanently wet peaty sands (Buldiva) and less wet organic loamy soils (Gilruth).

Sedgeland, grading to woodland with ground cover of sedges.

### (Rw) Rumwaggon I Land System (10 km², 1 observation)

Hills and intervening alluvial flats; skeletal soils and gradational yellow loamy soils on hill slopes, texture-contrast alkaline soils on flats; woodland and perennial grassland. (Inadequate observations for establishment of units.)

### (S) Somerville Land System (150 km², 13 observations, Plate 2, Fig. 1)

Lowlands on unweathered Lower Proterozoic shales and calcareous sediments; loamy yellow earths and deep red clays; woodland of broad-leaved bloodwood, or tall open forest with some broad-leaved bloodwood, annual or perennial grasses.

*Unit 1* (55%)

Undulating lowlands commonly with sparse lag gravel and giant termitaria; considerable sheet and gully erosion.

Generally deep but sometimes shallow yellow earths (Fisher), some mottled yellow earths (Yemelba) and occasional lateritic red earths (Basedow) formed on fresh sediments.

Woodland of broad-leaved bloodwood with occasional box and annual or perennial grasses, some low mixed scrub with *Melaleuca* on shallow soils, some patches of mixed open forest with no perceptible soil correlation.

*Unit 2* (40%)

Undulating lowlands without lag gravel or giant termitaria.

Deep clayey red earths (Mundogie).

Tall open forest of *E. tetrodonta* and *E. miniata* with some box and broad-leaved bloodwood, prostrate vines frequent, including legumes; perennial grasses. *Erythrophleum* not recorded.

*Unit 3* (5%)

Alluvial flats dominantly clayey with weakly developed channels.

Dark brown and olive cracking clays (Brockman), some mottled yellow earths (Yemelba).

Perennial grassland on flats, patchy mixed woodland with perennial grasses on fans.

### (Vl) Valley Land System (45 km², 3 observations, Plate 3, Fig. 1)

Broad shallow valleys floored with laterite, cut on weathered volcanics or dolerite in the Arnhem Land plateau; gravelly lateritic red earths; tall open forest and mixed eucalypt woodland, annual grasses.

*Unit 1* (80%)

Broad valley floors; ironstone gravel, sand and detrital laterite outcrops common.

Lateritic red earths (Hotham, Basedow), sometimes very gravelly.

Tall open forest of *E. dichromophloia* and *E. tetrodonta* with annual grasses; woodland of the same species in more gravelly places.

*Unit 2* (15%)

Colluvial sandy aprons from adjacent Kombolgie Formation.

Soils as for Bundah land system, skeletal soils and deep pale sand.

Vegetation as for Bundah land system, woodland, eucalypts dominant over annual grasses.

*Unit 3* (5%)

Poorly drained alluvial flats up to 250 m wide, alluvial sand and silt from Kombolgie Formation over alluvial clay from volcanics or dolerite.

Humic gleys that are intergrades to gleyed podzolics (Gilruth).

Grassland where recorded, with patchy communities of annuals and perennials; also *Pandanus* clumps and *Melaleuca*.

(Vw) VENLAW LAND SYSTEM (195 $km^2$, 8 OBSERVATIONS, PLATE 2, FIG. 2)

Rolling country on dissected, weathered volcanics on Arnhem Land plateau; skeletal soils and gravelly lateritic red earths; woodland of mixed bloodwoods, no consistent dominant, perennial or annual grasses.

*Unit 1* (80%)

Middle and upper slopes of rolling country and margins of low mesas, agates and opal common, isolated blocks and patches of sandstone.

Skeletal soils, some shallow gravelly red earths.

Woodland or stunted woodland of box and broad-leaved bloodwood on mesa margins, *E. latifolia* dominant, open woodland of the same trees on rolling country, or mixed scrub; annual or perennial grasses.

*Unit 2* (15%)

Colluvial foot slopes up to 300 m long, gravelly with numerous lateritic concretions.

Gravelly lateritic yellow earths.

Woodland (*E. latifolia*, *E. bleeseri*, *E. tetrodonta*) grading to mixed scrub; annual grasses.

*Unit 3* (5%)

Clayey alluvial flats.

Loamy to clayey yellow podzolic soils (Honeycomb) and seasonally dry humic gleys (Gilruth).

Grassland, annuals on podzolic soils, with patches of dense *Melaleuca*, perennials on humic gleys, with widely scattered *Melaleuca*. Occasional *Pandanus*, *Tristania* and *Eugenia*

(Vy) VERITY LAND SYSTEM (170 $km^2$, 13 OBSERVATIONS, PLATE 6, FIG. 2)

Undulating and rolling terrain on dissected, weathered, basic volcanics, dolerite and Proterozoic metasediments; lateritic red and yellow earths; mixed open forest or woodland.

*Unit 1* (40%)

Erosional mid slopes and colluvial lower slopes.

Lateritic yellow earths (Koolpinyah) and lateritic red earths (Basedow).

Mixed open forest, rarely eucalypt woodland.

*Unit 2* (40%)

Colluvial lower slopes.

Loamy red earths on dolerite (Zamu); probably yellow earths on other rocks.

Woodland, mainly broad-leaved bloodwoods with dense ground cover of prostrate vines including legumes, perennial grasses (mainly *Sorghum*); occasional mixed woodland, *Erythrophleum* dominant.

*Unit 3* (15%)

Crests with lateritic remnants.

Lateritic red earths (Basedow) and yellow earths (Koolpinyah) sometimes shallow, or loamy red earths (Zamu).

Mixed woodland, no dominant tree (box, broad-leaved bloodwood, *Erythrophleum*, *Terminalia canescens*), poor cover of annual grasses.

*Unit 4* (5%)

Alluvial flats, clayey but with some sand if adjacent to a source in the Kombolgie Formation.

Dark cracking clays (Brockman), slightly gilgaied.

Perennial grassland with scattered trees or short sedgeland with annual grasses.

### (Vu) Verrucose Land System (35 $km^2$, 2 observations, Plate 6, Fig. 1)

Undulating lowlands and low rocky hills on Edith River Volcanics; shallow gravelly sandy soils; stunted woodland, perennial grasses.

*Unit 1* (90%)

Undulating to rolling fairly closely dissected lowlands with much outcrop.

Shallow gravelly lateritic sandy loam on volcanics, droughty.

Stunted woodland (*E. foelscheana*, *E. tectifica*, *E. alba*, *E. tetrodonta*, *Petalostigma quadriloculare*) with perennial grasses.

*Unit 2* (10%)

Low, extremely rocky hills and knolls.

Practically devoid of soil.

Woodland of narrow-leaved bloodwood and spinifex.

### (V) Viney Land System (495 $km^2$, 39 observations, Plate 6, Fig. 1*)

Mainly hilly terrain on volcanics or dolerite; structured red clays, or red and yellow earths; woodland of broad-leaved bloodwood and box, perennial grasses, legumes common.

*Unit 1* (50%)

Middle and upper slopes of hills, steep valley sides and some rolling terrain, bouldery or stony.

Deep red structured clays under boulder pavement (Nungbalgarri); some shallow red earths (Zamu, Howship).

Woodland or stunted woodland of broad-leaved bloodwood (usually *E. foelscheana*) and perennial grasses (often *Sehima*), prostrate vines abundant, including legumes.

*Unit 2* (25%)

Stony, clayey colluvial lower slopes with local patches of sand and clayey alluvium; gradient less than 10%.

Various soils, mainly loamy red and yellow earths (Zamu, Zambina) sometimes gravelly (Howship); other sands and clays.

Variable vegetation, mainly woodland of broad-leaved bloodwoods with box and perennial grasses, prostrate vines often including legumes, non-eucalypt trees often dominant where bordering alluvium; *E. polycarpa*, *E. papuana* and *Melaleuca* in sandy places, with annual or perennial grasses; on alluvium perennial grassland, *Sorghum* often dominant.

*Unit 3* (15%)

Steep high strike ridges with extensive outcrop, largely on Edith River Volcanics and some Lower Proterozoic cherty siltstone.

Shallow skeletal soils.

Variable eucalypt woodland, bloodwoods common, occasional box, mainly perennial grasses.

*Unit 4* (5%)

Middle and lower slopes of low strike ridges.

Deep red structured clays under boulder pavement (Nungbalgarri), red earths (Zamu) and yellow earths (Zambina).

Woodland or stunted woodland of broad-leaved bloodwood, box and perennial grasses, vines and legumes as for unit 1; sandstone influence in places, with shrubby tall open forest and annual grasses.

* Illustrates part only; the land system is too complicated to be shown in one stereogram.

*Unit 5* (5%)

Stony middle and upper slopes in rolling or undulating terrain.

Shallow red structured clays (Nungbalgarri) on bouldery slopes, gravelly red earths (Howship) and skeletal soils.

Woodlands or stunted woodland, box dominant, usually with perennial grasses.

# PART IV. CLIMATE AND WATER BALANCE

By J. R. McAlpine*

## I. Introduction

### (a) General

The climate of the Alligator Rivers area of the Northern Terrtory has been previously described within a broad regional context by Christian and Stewart (1953), Anon. (1961) and McAlpine (1969).

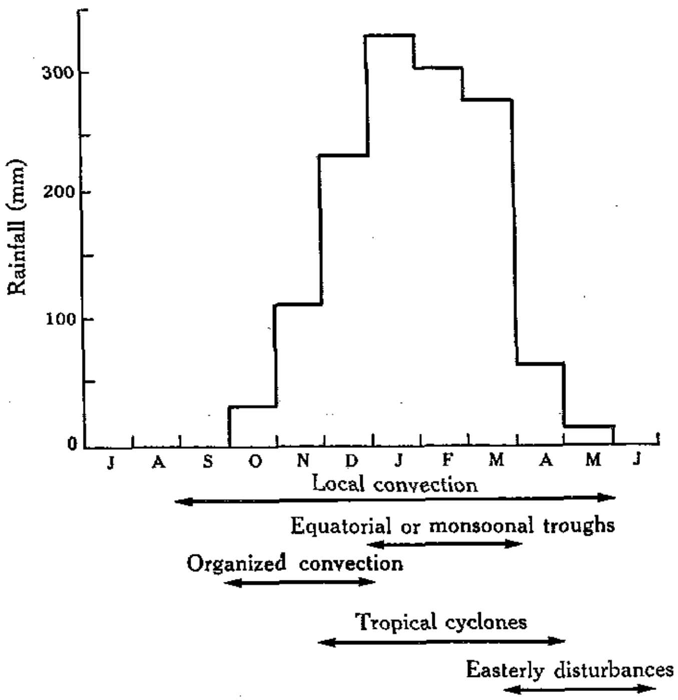


Fig. 4.—Annual rainfall regime at Oenpelli and five categories of rainfall-producing systems (after Southern 1966).

A preliminary report prepared by Mr F. P. E. Herry of the Bureau of Meteorology, Darwin, entitled 'A preliminary climatological survey of the Jabiru area', has been quoted verbatim for particular climatic aspects that would not otherwise be covered in this paper. Permission from Mr Herry to do this is gratefully acknowledged.

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TABLE 1

MEAN MONTHLY AND ANNUAL RAINFALL (MM)

| Station | Year | Jan. | Feb. | Mar. | Apr. | May | June | July | Aug. | Sept. | Oct. | Nov. | Dec. | Annual |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| El Sherana | 17/11* | 254 | 290 | 257 | 58 | 14 | 0 | 2 | 2 | 16 | 50 | 89 | 264 | 1297 |
| Jabiru | 4/0 | 284 | 256 | 420 | 54 | 8 | 0 | 0 | 0 | 3 | 33 | 201 | 152 | 1411 |
| Mudginberri | 10/6 | 316 | 352 | 307 | 49 | 26 | 1 | 0 | 0 | 10 | 32 | 103 | 244 | 1463 |
| Murganella | 7/4 | 348 | 370 | 356 | 54 | 49 | 0 | 2 | 0 | 1 | 11 | 55 | 172 | 1522 |
| Oenpelli | 62/60 | 325 | 302 | 272 | 68 | 13 | 2 | 3 | 1 | 4 | 28 | 107 | 226 | 1343 |

* Indicates 17 years of record, 11 of which are complete.

*(b) Data*

Most of the mining companies now operating in the area have established one or more climate and hydrologic recording stations. The data from these are naturally of short duration. Only one long-term climate station, Oenpelli, is found in the area

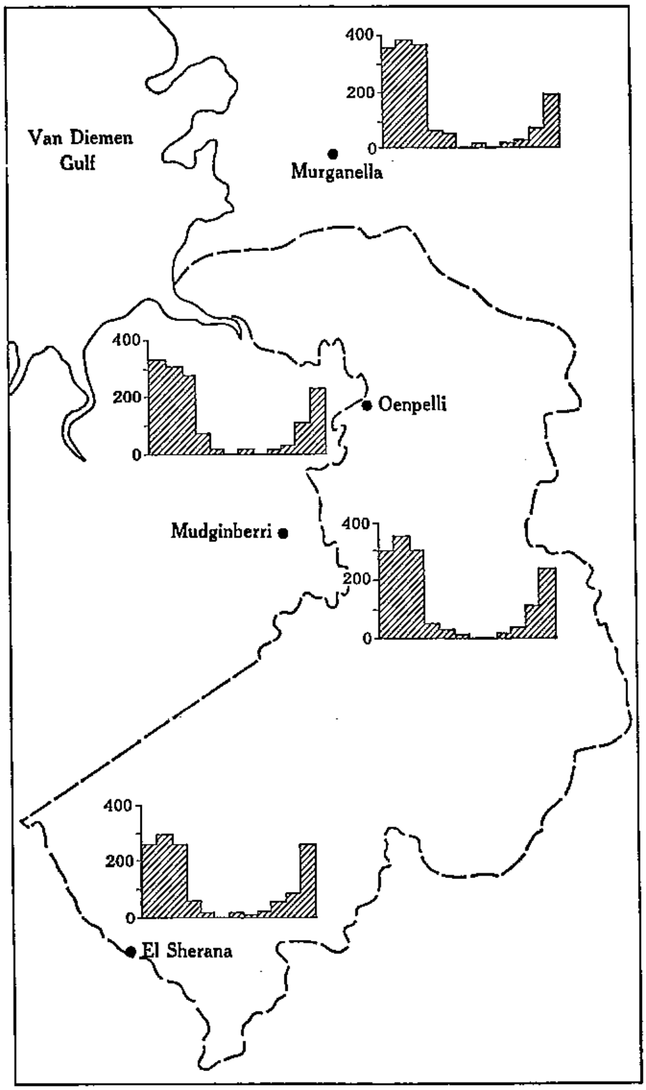


Fig. 5.—Distribution of mean annual rainfall (mm) (from January to December).

and the climatic analysis presented here is based largely on records from that station supplemented by the shorter climate records from the mining companies and the few other official rainfall stations.

TABLE 2

PROBABILITY OF MONTHLY RAINFALL (MM) AT OENPELLI

| | Jan. | Feb. | Mar. | Apr. | May | June | July | Aug. | Sept. | Oct. | Nov. | Dec. | Calendar year (Jan.–Dec.) | Seasonal year (July–June) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Median | 310 | 272 | 274 | 37 | 1 | 0 | 0 | 0 | 0 | 12 | 92 | 199 | 1290 | 1335 |
| Lower quartile | 245 | 221 | 165 | 13 | 0 | 0 | 0 | 0 | 0 | 1 | 58 | 152 | 1130 | 1171 |
| Upper quartile | 391 | 351 | 351 | 87 | 11 | 0 | 0 | 0 | 3 | 45 | 148 | 270 | 1588 | 1571 |
| Decile 1 | 213 | 177 | 101 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 39 | 122 | 1007 | 1020 |
| Decile 2 | 233 | 214 | 156 | 11 | 0 | 0 | 0 | 0 | 0 | 0 | 56 | 142 | 1097 | 1142 |
| Decile 3 | 247 | 234 | 175 | 24 | 0 | 0 | 0 | 0 | 0 | 2 | 60 | 165 | 1215 | 1192 |
| Decile 4 | 278 | 248 | 226 | 32 | 0 | 0 | 0 | 0 | 0 | 6 | 75 | 179 | 1239 | 1278 |
| Decile 5 | 310 | 272 | 274 | 37 | 1 | 0 | 0 | 0 | 0 | 14 | 92 | 202 | 1295 | 1335 |
| Decile 6 | 336 | 282 | 302 | 49 | 3 | 0 | 0 | 0 | 0 | 20 | 110 | 242 | 1399 | 1405 |
| Decile 7 | 378 | 337 | 325 | 72 | 9 | 0 | 0 | 0 | 1 | 27 | 128 | 262 | 1505 | 1513 |
| Decile 8 | 399 | 380 | 384 | 94 | 18 | 1 | 0 | 0 | 10 | 54 | 158 | 281 | 1661 | 1624 |
| Decile 9 | 449 | 498 | 473 | 143 | 24 | 2 | 2 | 0 | 17 | 91 | 199 | 362 | 1749 | 1771 |
| No. of values | 61 | 61 | 61 | 61 | 61 | 61 | 61 | 60 | 61 | 62 | 62 | 62 | 60 | 59 |

### (c) *Principal Climatic Controls*

Two distinct seasons occur in the area, an almost rainless dry season from May to September and a wet season from November to March. Southern (1966) in discussing rainfall types differentiates between organized rainfall, typified by monsoonal or cyclonic weather and widespread convection, and non-organized rainfall, typified by apparent random or mesoscale convection. He distinguishes five categories of rain-producing systems, the interplay of which produces the seasonality and character of the rainfall in the area. His discussion has been synthesized and presented diagrammatically in Fig. 4.

## II. General Climatic Characteristics

### (a) *Rainfall*

The rainfall regime of the area has three major characteristics: it is highly seasonal, it is highly reliable (on both an annual and monthly basis) and in average terms does not appear to vary greatly in seasonality or amount from place to place.

Table 3

Average number of days per month with rainfall within specified classes at Oenpelli

| Class (mm) | Oct. | Nov. | Dec. | Jan. | Feb. | Mar. | Apr. |
|---|---|---|---|---|---|---|---|
| 0 | 28·70 | 21·68 | 16·15 | 12·60 | 9·98 | 14·43 | 24·67 |
| 1–24 | 1·92 | 6·90 | 11·90 | 14·08 | 14·03 | 13·00 | 4·70 |
| 25–49 | 0·28 | 1·18 | 2·07 | 3·15 | 3·12 | 2·68 | 0·43 |
| 50–74 | 0·10 | 0·18 | 0·72 | 0·82 | 0·73 | 0·55 | 0·13 |
| 75–99 | 0 | 0·03 | 0·10 | 0·30 | 0·23 | 0·15 | 0·03 |
| 100–124 | 0 | 0·02 | 0·03 | 0·02 | 0·12 | 0·05 | 0·02 |
| 125–149 | 0 | 0 | 0·02 | 0 | 0·05 | 0·08 | 0·02 |
| >150 | 0 | 0 | 0·02 | 0·03 | 0 | 0·05 | 0 |

Mean monthly and annual rainfalls for five stations are given in Table 1 and the spatial distribution of these data is presented in Fig. 5. The wettest months are December to March inclusive while June to September are virtually rainless. May and October–November are transitional. The data indicate that spatial variability in mean annual rainfall from north to south is approximately 200 mm (1500–1300 mm) and that the rate of decrease with distance appears to be fairly uniform.

Actual monthly data from Oenpelli have been analysed to indicate rainfall probability. The results are presented as median, quartiles and deciles in Table 2. The low variability in monthly rainfall is clearly indicated by comparing the monthly inter-quartile range with the median. In the wetter months 50% of years have a monthly rainfall which varies by less than one-third of the median from that value. In 90% of years the rainfall in December–February increases to only 60% of the median.

Table 2 also presents the same type of analysis for whole calendar years and on an annual seasonal basis. Here again 50% of years have a rainfall which varies by less than 25% of the median from it, and in 90% of years the rainfall increases to only 75% of the median. The coefficient of variation (standard deviation as a percentage

TABLE 4

MEAN MONTHLY TEMPERATURE CHARACTERISTICS (°C)

| | Jan. | Feb. | Mar. | Apr. | May | June | July | Aug. | Sept. | Oct. | Nov. | Dec. | Annual |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Oenpelli (10 years) | | | | | | | | | | | | | |
| Extreme max. | 37·0 | 36·0 | 35·[illegible] | 37·0 | 36·0 | 35·0 | 34·0 | 37·0 | 38·0 | 39·0 | 40·0 | 38·0 | 40·0 |
| Mean max. | 33·3 | 32·1 | 32·4 | 34·0 | 32·8 | 31·7 | 31·5 | 33·7 | 35·7 | 37·0 | 37·1 | 34·2 | 33·8 |
| Mean | 28·8 | 28·2 | 28·2 | 28·4 | 27·0 | 25·4 | 24·6 | 25·9 | 27·6 | 29·6 | 30·2 | 29·1 | 27·8 |
| Mean min. | 24·2 | 24·2 | 24·1 | 22·9 | 21·1 | 19·0 | 17·8 | 18·1 | 19·6 | 22·1 | 23·4 | 24·0 | 21·7 |
| Extreme min. | 20·0 | 21·0 | 17·0 | 17·0 | 10·0 | 10·0 | 4·0 | 10·0 | 11·0 | 14·0 | 19·0 | 12·0 | 4·0 |
| Jabiru (from Herry) (2 years) | | | | | | | | | | | | | |
| Mean max. | 34·1 | 33·3 | 32·5 | 34·0 | 32·9 | 30·3 | 31·0 | 34·2 | 35·9 | 37·8 | 36·9 | 35·6 | |
| Mean min. | 24·0 | 24·1 | 23·7 | 22·8 | 20·9 | 18·0 | 17·0 | 18·8 | 20·6 | 23·0 | 24·5 | 24·2 | |

TABLE 5

PERCENTAGE FREQUENCY DISTRIBUTION OF DAILY MAXIMUM AND MINIMUM TEMPERATURES AT OENPELLI (YEARS)

| Temperature (°C) Min. | Max. | Jan. | Feb. | Mar. | Apr. | May | June | July | Aug. | Sept. | Oct. | Nov. | Dec. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| <15 | <30 | | | | | | 4 | 4 | 0·4 | | | | 0·4 |
| <15 | 30·1–35·0 | | | | | 3 | 8 | 14 | 10 | 5 | | | |
| <15 | 35·1–37·0 | | | | | | | | 1 | 0·4 | 0·7 | | |
| | >37 | | | | | | | | | | | | |
| 15·1–20·0 | <30 | | | | | 2 | 9 | 9 | 0·4 | | | | |
| 15·1–20·0 | 30·1–35·0 | | | 1 | 6 | 25 | 37 | 47 | 49 | 14 | 1 | | |
| 15·1–20·0 | 35·1–37·0 | | | | 0·7 | 1 | | | 11 | 29 | 7 | | |
| 15·1–20·0 | >37 | | | | | | | | 0·4 | 3 | 8 | 0·4 | |
| 20·1–25·0 | <30 | 9 | 13 | 12 | 0·7 | 6 | 1 | 0·7 | | | | | 4 |
| 20·1–25·0 | 30·1–35·0 | 55 | 62 | 65 | 62 | 51 | 40 | 26 | 20 | 6 | 3 | 14 | 43 |
| 20·1–25·0 | 35·1–37·0 | 9 | 8 | 4 | 22 | 11 | 0·7 | | 8 | 33 | 33 | 29 | 31 |
| 20·1–25·0 | >37 | 0·7 | | | 2 | | | | | 8 | 46 | 47 | 3 |
| >25 | <30 | | 0·5 | | | 0·4 | | | | | | | |
| >25 | 30·1–35·0 | 21 | 17 | 18 | 4 | 1 | 0·4 | | | | | 0·9 | 9 |
| >25 | 35·1–37·0 | 6 | | 0·4 | 2 | | | | | 0·4 | 1 | 3 | 6 |
| >25 | >37 | | | | | | | | | 0·4 | 0·7 | 7 | 3 |

of the mean) for annual rainfall at Oenpelli is 21%. This climatic feature of a high degree of reliability in rainfall is significant for the regional water balance (see below).

Some indication of rainfall intensity is given in Table 3 which presents the percentage frequency of the occurrence of rain days of given intensity at Oenpelli. Daily falls of over 100 mm occur on average once every 2 years and falls of over 150 mm once in 10 years.

### (*b*) *Temperature*

Mean monthly temperature data, extremes and annual means for Oenpelli are presented in Table 4. The seasonal range in mean temperature is 5·6 degC. Data for two years for Jabiru are also included in Table 4 and this in conjunction with more general considerations indicates that the maximum temperature increases gradually inland (i.e. in a north–south direction) in summer and the minimum temperature decreases in winter.

In terms of human comfort it is the actual distribution of daily maximum and minimum temperatures rather than statistical averages which gives the better indication of likely stress. Table 5 presents such data and it can clearly be seen that in terms of days with maxima above 37°C and minima above 20°C October–November is the most unpleasant time of the year, September and December being only marginally better.

### (*c*) *Inversion* (*after Herry*)

In this area low-level inversions are caused by radiational cooling at night. As the elevation of the sun decreases in the afternoon the air near to the earth loses more heat by radiation than it receives (under clear sky conditions) and surface temperatures decrease rapidly. As a consequence the air near the ground is in turn cooled more rapidly than that above it, producing an inversion of temperature, in which air temperature increases with height.

These inversions are very frequent during the dry season, especially during the months of May to August, and usually last for a period of 12 hours from 9.00 p.m. until 9.00 a.m. the following morning. Preliminary investigations using established indirect measurement techniques have indicated that during the dry season the height of the inversion is between 100 and 300 m and lasts for not more than 12 hours. The strength of the inversion is 5–7 degrees.

In strong wind situations low-level inversions fail to develop, because of mixing processes. Such a phenomenon occurs once or twice a month during the dry season when a strong high-pressure ridge causes fresh to strong SE. winds over the area. During such a period the inversion is completely destroyed at night or is relatively very weak. Some idea of the frequency of strong winds can be seen from the wind roses for Jabiru (Fig. 6). However, they do not indicate whether the occurrences are at night or by day.

During the monsoon period, December to March, thunderstorm activity and cloudy periods inhibit radiational cooling of the atmosphere and hence strong inversions are uncommon. During the pre-monsoon and the pre-dry season when thunderstorms are sporadic, inversions are somewhat more frequent.

*(d) Evaporation*

Estimates for Oenpelli of evaporation from a standard Australian tank have been obtained by applying the method of Fitzpatrick (1963) to standard meteorological data at that station. The results are presented in Table 6 as are the data from 19 months of observations from the U.S. Class A pan at Jabiru. An acceptable relation between

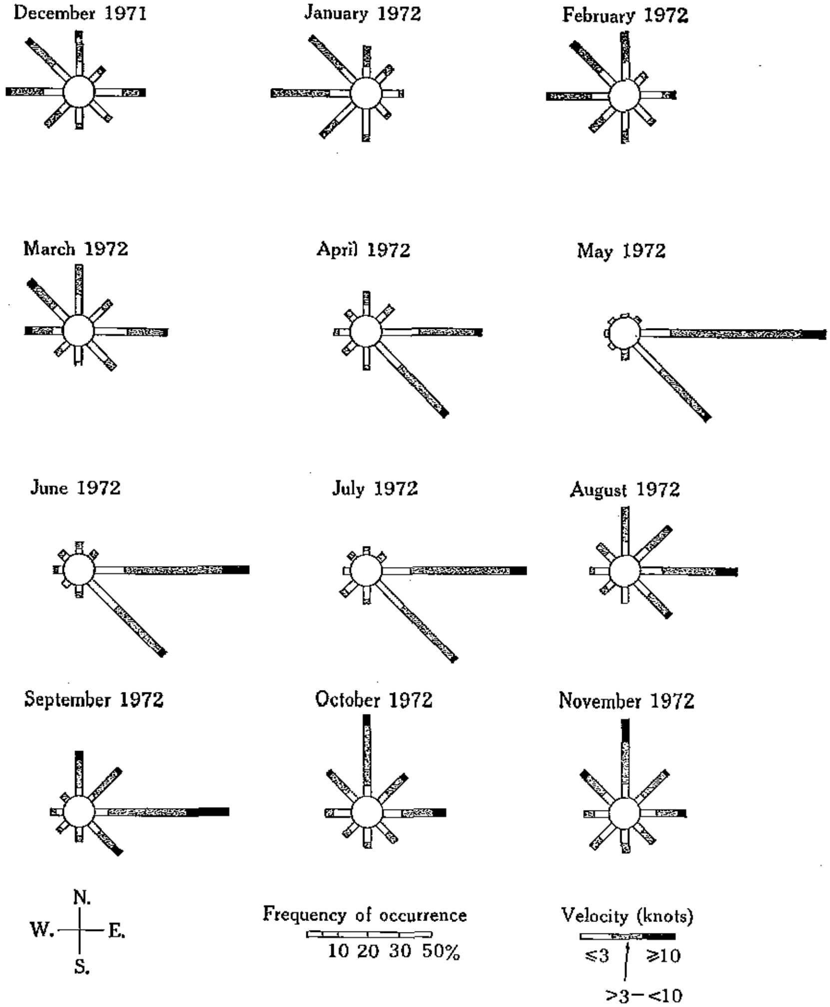


Fig. 6.—Wind roses for one year based on hourly observations at Jabiru (after F. P. E. Herry, unpublished data).

the Australian tank and the U.S. pan equipped with a bird screen is E (Aust.) = 0·9 E (U.S.) and on this basis the two sets of data are in agreement. Figures obtained by using Fitzpatrick's (1963) estimate have been adopted in Section III of this Part.

Annual evaporation is approximately 2200 mm with a monthly maximum of 260 mm in October and a minimum of 100 mm in February.

TABLE 6

MEAN MONTHLY EVAPORATION (MM)

| | Jan. | Feb. | Mar. | Apr. | May | June | July | Aug. | Sept. | Oct. | Nov. | Dec. | Year |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Oenpelli* | 148 | 105 | 116 | 156 | 173 | 172 | 193 | 221 | 245 | 263 | 245 | 177 | 2214 |
| Jabiru† | 200 | 180 | 150 | 200 | 200 | 200 | 230 | 250 | 250 | 230 | 200 | 230 | 2520 |

* Estimates based on method of Fitzpatrick (1963).
† U.S. Class A pan evaporation for 19 months.

TABLE 7

MEAN MONTHLY RELATIVE HUMIDITY (%)

| | Jan. | Feb. | Mar. | Apr. | May | June | July | Aug. | Sept. | Oct. | Nov. | Dec. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Maximum (Jabiru)* | 99 | 98 | 98 | 97 | 93 | 88 | 97 | 95 | 95 | 95 | 95 | 98 |
| 0900 (Oenpelli)† | 91 | 91 | 91 | 82 | 75 | 71 | 71 | 73 | 75 | 78 | 80 | 85 |
| 1500 (Oenpelli)† | 68 | 61 | 69 | 55 | 51 | 40 | 33 | 30 | 37 | 39 | 52 | 57 |
| Minimum (Jabiru)* | 52 | 55 | 54 | 38 | 36 | 39 | 35 | 31 | 27 | 28 | 34 | 44 |
| Av. index of R.H. (Oenpelli)‡ | 80 | 82 | 80 | 80 | 62 | 58 | 54 | 57 | 58 | 62 | 67 | 76 |

* Two years of observations.
† Ten years of observations.
‡ Ratio of average 0900 vapour pressure to saturation vapour pressure at average mean temperature.

### (e) *Other Climatic Characteristics*

Humidity data for Oenpelli and for two years at Jabiru are presented in Table 7. While the two data sets are not absolutely comparable they give an adequate indication of the mean seasonal and diurnal variation in humidity. The average index of relative humidity varies from 54 in July to 82 in February and the relative mean diurnal variation in humidity is least during the wet season and highest at its onset during September–November.

Sunshine and day-length data and time of sunset and sunrise are presented in Table 8. Day length varies by only 1·5 hours through the year and the total number of hours of sunshine per annum is approximately 3200.

Wind roses for one year based on hourly observations at Jabiru prepared by Herry are shown in Fig. 6. Again the seasonal variation from northerly and westerly winds during November–February to southerly and south-easterly in the remainder of the year is clearly apparent, as are the associated changes in velocity.

TABLE 8

SUNSHINE AND DAY-LENGTH DATA

| | Jan. | Feb. | Mar. | Apr. | May | June | July | Aug. | Sept. | Oct. | Nov. | Dec. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Mean daily sunshine (hr)* | 7·1 | 6·3 | 4·5 | 8·7 | 9·9 | 10·2 | 10·2 | 10·1 | 9·7 | 9·6 | 8·5 | 8·0 |
| Day length (hr)† | 12·7 | 12·1 | 12·0 | 11·9 | 11·6 | 11·2 | 11·3 | 11·8 | 12·0 | 12·2 | 12·4 | 12·5 |
| Sunrise (time)† | 0630 | 0640 | 0640 | 0640 | 0650 | 0700 | 0700 | 0650 | 0630 | 0610 | 0600 | 0610 |
| Sunset (time)† | 1900 | 1850 | 1840 | 1830 | 1810 | 1820 | 1830 | 1830 | 1830 | 1830 | 1840 | 1850 |

* Jabiru (2 years' data). † Oenpelli.

Note: March mean daily sunshine would more probably be *c*. 7 hours for a longer-term record.

## III. WATER BALANCE

### (a) *Method*

Simple water balance models using actual weekly rainfall as input and appropriate functions related to mean weekly evaporation as withdrawals have been used to:

(i) estimate the occurrence and length of pasture and vegetation growing seasons;

(ii) simulate for any dams that may be built in the area seasonal changes in levels together with potential and actual water loss rates.

The general methodology and computer systems employed have been described elsewhere (Keig and McAlpine 1969; McAlpine 1970). The data used in the models were actual weekly rainfall from 1912 to 1972 at Oenpelli and Fitzpatrick's estimate of mean weekly evaporation for the same station.

### (b) *Pasture Growing Season*

The model has firstly been applied to estimate when pasture and vegetation growing periods would commence and cease. In this highly seasonal climate the major limiting factor to plant growth is assumed to be the availability of soil moisture. The commencement date for *useful* growth for any year is assumed to be that week in which the model indicates that any level of available soil moisture storage above 1 mm is reached. The maximum available water capacity is assumed to be 100 mm. Growth is assumed to cease in that week in which available water storage again drops to zero.

TABLE 9

CHARACTERISTICS OF THE PERIOD OF PASTURE GROWTH AT OENPELLI

| | |
|---|---|
| Commencement of estimated useful pasture growth | |
| Median date | Nov. 11 |
| Early quartile | Nov. 2 |
| Late quartile | Nov. 26 |
| Cessation of estimated useful pasture growth | |
| Median date | May 10 |
| Early quartile | May 3 |
| Late quartile | May 16 |
| Total duration of estimated useful pasture growth (i.e. annual number of weeks with available water >1 mm) | |
| Average | 25 |
| Longest | 39 |
| Shortest | 17 |
| Total duration of estimated active pasture growth (i.e. annual number of weeks with available water >50 mm) | |
| Average | 17 |
| Longest | 24 |
| Shortest | 10 |

In addition, the period of *active* as against useful growth has been estimated assuming that this occurs when the estimated available water storage rises above 50% of the maximum capacity (i.e. 50 mm). Table 9 presents the estimates derived from such an analysis. The growth season commences mid November and lasts until mid May. The variation from these dates in 50% of years is small as is the variation in length of the growth season. False starts in the *useful* growth season (i.e. one or more weeks

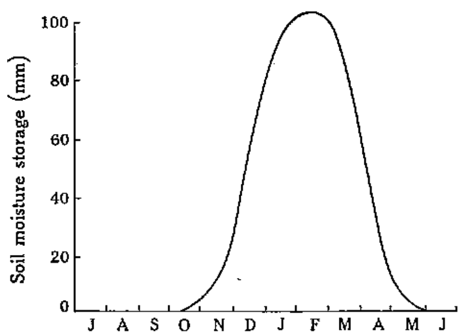


Fig. 7.—Mean weekly soil moisture storage at Oenpelli.

early in the wet season in which the level of soil moisture rises above 1 mm followed by one or more weeks with complete depletion) occur in 50% of years. False starts are mostly of one week's duration and in the records analysed never more than two.

Output from the model also provides a curve of mean weekly soil moisture through the year. This is presented in Fig. 7 and clearly indicates the highly seasonal nature of the water balance in the region.

### (c) *Dam Simulation*

The point water balance model referred to above was modified to provide estimates of changing seasonal dam levels that would occur in the region, given catchments of various sizes. Again weekly rainfall at Oenpelli was used as input. A modification (Nimmo 1964) of Fitzpatrick's estimate of Australian standard tank evaporation designed to estimate evaporation from a large surface of water was used to estimate mean weekly withdrawal. (The modification gave results only very slightly less than the figures given in Table 6.)

TABLE 10

OENPELLI—UNUSED POTENTIAL EVAPORATION

60 yr records, 1912–1972 (excl. 1923)

| Amount | Year | Amount | Year | Amount | Year |
|---|---|---|---|---|---|
| 0 | 1964 | 515 | 1971 | 747 | 1933 |
| 0 | 1969 | 532 | 1958 | 762 | 1937 |
| 107 | 1919 | 546 | 1954 | 766 | 1920 |
| 131 | 1916 | 548 | 1960 | 774 | 1947 |
| 194 | 1917 | 569 | 1927 | 788 | 1967 |
| 214 | 1913 | 583 | 1959 | 791 | 1928 |
| 221 | 1956 | 587 | 1945 | 823 | 1944 |
| 261 | 1943 | 630 | 1949 | 827 | 1946 |
| 281 | 1930 | 632 | 1938 | 849 | 1963 |
| 287 | 1962 | 636 | 1966 | 863 | 1970 |
| 372 | 1957 | 652 | 1931 | 882 | 1936 |
| 400 | 1932 | 663 | 1924 | 905 | 1953 |
| 422 | 1968 | 665 | 1912 | 909 | 1915 |
| 431 | 1922 | 666 | 1948 | 918 | 1951 |
| 433 | 1950 | 692 | 1941 | 929 | 1935 |
| 455 | 1934 | 704 | 1918 | 930 | 1926 |
| 455 | 1965 | 724 | 1929 | 933 | 1939 |
| 494 | 1921 | 727 | 1914 | 976 | 1961 |
| 497 | 1972 | 730 | 1955 | 1068 | 1952 |
| 504 | 1940 | 739 | 1925 | 1123 | 1942 |

Total 36 462 mm, median 644 mm, mean 608 mm.

The first simulation carried out was for a turkey nest dam situation in which catchment size is equal to dam surface water area, such as might be built for a mine tailings disposal dam or sewage sludge evaporation. Starting empty, the highest water level the simulated dam reached in the 60 years of record was 1371 mm in 1969, the lowest was 306 mm in 1942. The mean annual highest level was 737 mm and peaks occurred mostly during March. In every year, except for 1964 and 1969, the model indicated that such a dam would dry out (i.e. there would be no carry-over of storage in the dam from one season to the next). In 1964 and 1969 the carry-over levels were minimal (15 mm and 24 mm respectively). In practice, because evaporation rates would be somewhat higher than the mean at very low water levels, even these amounts could be ignored. Thus, in 97% of years there is potential evaporation not used for rainfall evaporation that could be taken up by the evaporation of waste water. For the want of a better term this amount has been termed 'unused potential evaporation'. The annual average for this term is 608 mm. Table 10 indicates the actual annual values on a ranked basis; the median is 644 mm, the lower quartile 455 mm, the upper 791 mm. Table 10 also indicates that in a significant number of years the unused potential evaporation available for evaporating waste water is quite low.

The range of water levels that would result from runs of good and bad seasons if 600 mm of waste water were disposed of each year has been calculated from the data in Table 10 and is shown in Fig. 8. Thus Fig. 8 shows some very clear-cut trends

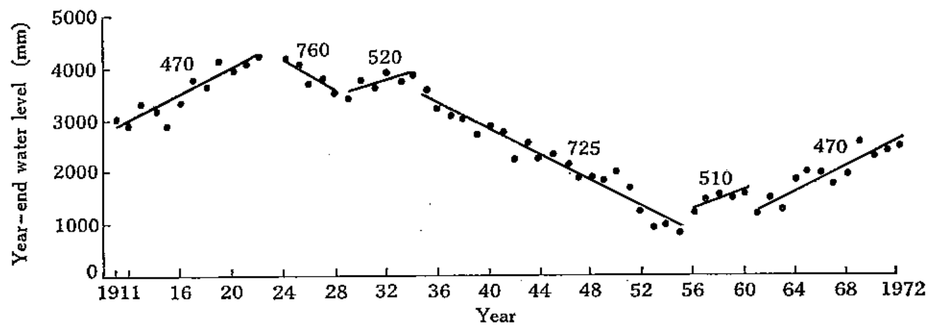


Fig. 8.—Estimated water level in a turkey nest tank at the end of each year, assuming a water level of 3000 mm at the commencement and an annual disposal of 600 mm. Numbers on each trend line indicate the annual waste water disposal that would give a horizontal trend line (i.e. no overall change in water level).

which have been indicated by 6 trend lines that span from 4 to 21 years, with all calculated end-of-year levels differing by less than 900 mm from the trend lines. From the slope of the trend lines calculations have been made of the amount of waste water that could be disposed of annually to give a horizontal trend line, i.e. an overall maintenance of water level over the trend period. Two wetter periods, between 1912 and 1922 and 1961 and 1972, have an estimated annual waste water disposal capacity of 470 mm. These two periods, totalling 24 years, include the 6 years with the lowest estimated annual unused potential evaporation, i.e. less than 220 mm. A long drier period between 1934 and 1955 has an estimated annual disposal capacity of 725 mm, while a short very dry period from 1924 to 1928 has an estimated annual disposal capacity of 607 mm.

A further simulation was carried out where twice the actual weekly rainfall was used as input to the dam but with evaporation still assumed to be that from a large water surface. This simulation was designed to model a dam with a small catchment (say 2–3 times larger than the dam surface area with a 30–40% run-off factor). In this case a dam wall of 10 m was assumed. Starting empty in 1912 the dam overflowed in 1921 and kept overflowing in most years thereafter.

In summary, the results of these simulations indicate that the point water balance regime in this region is fairly evenly balanced in terms of water surplus but has some unused potential evaporation available for waste disposal. Once an areal run-off component is added to the water balance the water surplus is not fully containable within the confines of a dam.

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# PART V. GEOLOGY OF THE ALLIGATOR RIVERS AREA

By R. W. GALLOWAY*

## I. INTRODUCTION

The best general reference on the geology available at the time of writing is by Needham *et al.* (1973). A much fuller bulletin is in preparation. Important earlier references are the Explanatory Notes to the 1 : 250 000 Geological series, sheets Alligator River and Mount Evelyn (Dunn 1962; Walpole 1962), and also Skwarko (1966). This Part gives only a very brief outline of the geology, based on the publication by Needham *et al.* (1973) to which readers seeking fuller information are referred.

## II. STRATIGRAPHY

Lower Proterozoic rocks intruded by granite and dolerite occupy the western and north-eastern parts of the area. Middle Proterozoic sandstone with interbedded volcanics form the rugged Arnhem Land plateau in the east. Patches of Mesozoic sediments occur in the north. Cainozoic sand, alluvium and deep weathering zones cover much of the older rocks in the west and north.

The Lower Proterozoic rocks include the Mount Partridge Formation (sandstone, siltstone, conglomerate, slate, phyllite and schist), the Koolpin Formation (chert, phyllite, schist, quartzite, dolomite and magnesite) and the Fisher Creek Siltstone (phyllite, schist and quartzite). These rocks grade from unmetamorphosed sedimentaries in the west and south-west to intensely metamorphosed gneisses, migmatites and granitic rocks in the centre and north-east where they form the Nanambu and Nimbuwah Complexes; the carbonate rocks and quartzite of the Koolpin Formation were less affected by the metamorphism.

Intrusive masses of pink biotite granite crop out in the south (Jim Jim Granite) and sporadically in the north-east. Doleritic intrusions include the Zamu Complex of sills and dykes, which has been altered to amphibolites in the heart of the migmatite complexes, and the slightly younger Oenpelli Dolerite which forms extensive undulating sills underlying much of the Arnhem Land plateau.

The Lower Proterozoic rocks were very extensively eroded before deposition of the subhorizontal Middle Proterozoic rocks consisting of the Edith River Volcanics (rhyolite, dacite and sediments) and the Kombolgie Formation. The latter is the dominant geological formation in the area and forms the Arnhem Land plateau. It is mainly a lacustrine quartz sandstone but contains a basaltic volcanic member and a thin tuffaceous member.

The Mesozoic Mullaman Beds consist of clayey, poorly consolidated lacustrine sandstone which occurs in the north of the area, though not usually well exposed.

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Cainozoic rocks include laterite, sand sheets, fluviatile and marine alluvium, coarse scree below the Arnhem Land escarpment and beach ridges of shell sand.

The following extract from Needham *et al.* (1973) summarizes the position regarding mineralization in the area: 'Since 1970, four major uranium discoveries have been made in the study area; intensive exploration is continuing, and it is most likely that further discoveries will be made. . . . All deposits so far discovered in the study area lie in Lower Proterozoic rocks within 300 m of the base of the Kombolgie Formation, but mineralization probably extends to still greater depths.' Minor deposits of gold, tin and copper have also been found.

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# PART VI. GEOMORPHOLOGY OF THE ALLIGATOR RIVERS AREA

By R. W. GALLOWAY*

## I. INTRODUCTION

This account of the geomorphology is designed to give background information for the tabular descriptions of land systems elsewhere in this report. In addition, attention is paid to aspects which may be relevant to mining, future national park development and general public interest in the area. Locations are named according to the physical regions outlined in Part II and in Fig. 3. Attention is largely concentrated on the Arnhem Land plateau and escarpment. Little has been added to the account of the lowland and coastal plain given by Williams in Story *et al.* (1969).

## II. DRAINAGE

Most of the survey area is drained northward to Van Diemen Gulf by the East Alligator River with its major left-bank tributary Magela Creek, and by the South Alligator River and its major right-bank tributaries Fisher Creek, Koolpin Creek, Barramundi Creek, Jim Jim Creek and Nourlangie Creek–Deaf Adder Creek (Fig. 3). The extreme north of the area is drained westward by Cooper Creek. The upper reaches of these rivers flow across the Arnhem Land plateau in either shallow valleys or deep gorges; there are numerous waterfalls and little or no alluvium. The middle reaches cross the western lowlands in braided channels with extensive freshwater swamps, numerous waterholes and sandy levees. The lower reaches are tidal with single wide meandering channels flowing across alluvial and estuarine clay plains.

In keeping with the climate these rivers have a highly seasonal regime with peak discharges in January to March but little or no flow in the dry season when the major rivers are reduced to a string of waterholes and the minor ones are completely dry. Paperbark swamps along the lower reaches are flooded 6–12 months of the year.

## III. HISTORY OF THE LANDSCAPE

The history of the landscape can be divided into five major stages which are treated individually here for simplicity (Fig. 9). Doubtless there was considerable overlap in time of these stages and the full story was vastly more complex.

### (*a*) *Formation of the Sub-Cretaceous Land Surface*

During the immense span of time between the Middle Proterozoic when the Kombolgie Formation was deposited and the Cretaceous when the Mullaman Beds were laid down, erosion removed thousands of metres of rock to produce a land surface that probably sloped northwards and may have culminated in the vicinity of

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the knot of hills round Mt Gilruth, still the highest point of the area. In the north-west this surface now plunges below the present sea level but this may be due in part to subsequent tectonic down-warping. In the north, and possibly elsewhere, the erosion surface featured low rounded hills on the resistant Kombolgie Formation (quartz sandstone) and a shallow valley existed over at least part of the modern Cooper Creek basin. Over most of the Arnhem Land plateau the sub-Cretaceous surface lay not far above the present land surface.

### (b) *Formation of the Older Weathered Land Surface*

In the Cretaceous period a protective blanket of Mullaman Beds (siltstone and sandstone with minor shale and conglomerate) was laid down over the sub-Cretaceous surface. Renewed erosion cut a smooth surface on the Mullaman Beds which sloped gently northwards and which may have been subject to further tectonic down-warping near the present coast. This surface was deeply weathered with a laterite profile including a ferruginous zone of concretionary and pisolitic ironstone (Williams in Story *et al.* 1969). The deep weathered profile seems to have been developed mainly in the Mullaman Beds but there are indications that it penetrated through them in

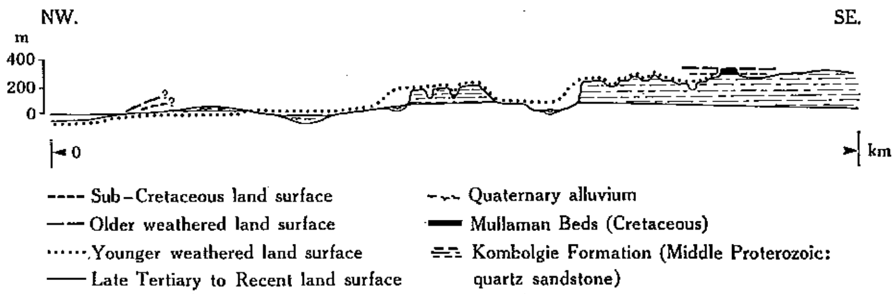


Fig. 9.—Generalized cross profile showing relationship of major stages in the landscape history.

places to affect both the quartz sandstone and the volcanic members of the underlying Kombolgie Formation. This land surface is equivalent to the Bradshaw surface of Wright (1963) and the Tennant Creek surface of Hays (1967) to the west and south. Because of subsequent erosion only fragments now survive on or near the north-eastern and southern watersheds of the area. It is probably also present at low altitude in the north-west where it is concealed under younger sediments and passes below the present sea level.

### (c) *Dissection of the Older Weathered Land Surface and Formation of the Younger Weathered Land Surface*

Prolonged erosion during the second half of the Tertiary era largely destroyed the older weathered land surface, removed almost all the Mullaman Beds and together with localized deposition in the north-west produced a new landscape that was in turn weathered with the development of a lateritic cover wherever there was sufficient iron in the rocks. This younger weathered land surface is still extensively preserved and is equivalent to the mainly depositional Koolpinyah surface in the Adelaide–Alligator area to the west (Williams in Story *et al.* 1969).

On the Arnhem Land plateau almost all the unresistant Mullaman Beds were removed and an erosion surface, dotted with low but steep hills such as Mt Howship, was cut across the underlying Kombolgie Formation. The major streams flowed across this surface in shallow, broadly meandering valleys, most of which are still followed by the larger rivers although one example on the south-western part of the plateau is no longer occupied by a major stream. Deep weathering caused the resistant sandstone to break down into extensive spreads of residual sand, relics of which still survive on the main divide in the south-east and sporadically on other interfluves. Some of these sand spreads may include relics of Mullaman Beds. Laterite was not formed on the sandstone because of the lack of iron but did develop locally on the volcanic members of the Kombolgie Formation. Deep weathering may also have contributed to the accumulation of common opal and agates in the volcanics as well as to the silicification of sandstone surfaces under the volcanics.

Where geological features such as basement highs and horsts favoured removal of the Kombolgie Formation, erosion excavated basins in the underlying Proterozoic rocks. Examples include the basins of Tin Camp Creek, upper Jim Jim Creek and Waterfall Creek. Detrital laterite containing abundant pebbles of quartz and sandstone developed on the floors of these basins and sheets of coarse waterworn gravel were deposited near Nabarlek.

In the Cooper Creek basin erosion removed the Mullaman Beds in the centre and west and cut a gently undulating lowland across the underlying Proterozoic rocks. This lowland was then weathered with the development of laterite. Some of the Mullaman Beds survived in the east of the basin but the older weathered land surface was apparently stripped off and replaced by the younger weathered land surface at a lower level.

On the central and southern parts of the western lowlands erosion caused the Arnhem Land escarpment to retreat southwards and cut a gently undulating surface across the rocks beneath. This surface was moderately weathered in the wake of the scarp retreat, and sandy gravelly detritus was deposited on it.

### (*d*) *Late Tertiary Dissection*

This phase saw renewed erosion, with further retreat of the Arnhem Land escarpment to more or less its present position, and dissection or stripping of parts of the younger weathered land surface. Basins on the Arnhem Land plateau were affected to varying degrees by this renewed dissection. In some, the wave of erosion has not yet arrived and the younger weathered land surface is preserved almost intact (e.g. Koolpin Creek basin). Dissection has just reached the western end of Waterfall Creek basin and is beginning to remove the lateritic cover of the younger weathered land surface which still survives intact over the rest of the basin (Plate 13, Fig. 1). Erosion has largely stripped the weathered land surface from the upper Jim Jim Creek basin and completely stripped it from the upper Deaf Adder basin to expose fresh Lower Proterozoic rocks. In the central part of the Tin Camp Creek basin erosion removed almost all the younger weathered land surface to leave a rolling to hilly landscape on relatively unweathered Lower Proterozoic rocks. Relics of the formerly widespread laterite survived behind a resistant strike ridge which restricted erosion in the eastern part of the basin. Other relics of the weathered surface on mica schist, together with the presence of amphibolite, are responsible for the unusually red colour of soils west of Myra Falls.

Deaf Adder Creek and the East Alligator River were sharply incised along lines of weakness in the floors of their former open valleys leading to rejuvenation of their tributaries by headward erosion along favourable structures. The formerly widespread cover of detrital sand on the plateau was largely stripped and redeposited as sand sheets and wide levee tracts on the western lowlands. Relics of the cover survive on the south-eastern rim of the area.

In the Cooper Creek basin headward extension of tributaries further reduced the area of Mullaman Beds, but downstream there was only slight incision into the younger weathered land surface because the creek flows over resistant sandstone which impeded down-cutting in its lower course.

The Arnhem Land escarpment scarcely changed position in the north but in the south it retreated possibly as much as 25 km. Basins within the Arnhem Land plateau, especially the Tin Camp Creek basin, were significantly enlarged at this time. Where scarp retreat was active the modern scarp is steep and vigorous; areas of inactive retreat have subdued scarp forms. The relative recency of this retreat (believed to have occupied the last third or half of the Cainozoic era, about 25 million years) has enabled the more resistant siliceous formations in the Lower Proterozoic sequence to survive as hills standing above the western lowland (e.g. Mt Partridge) and is attested to by the paucity of deep weathering on the southern part of the western lowland where lithological control of soils, vegetation and relief is very obvious and laterite much sparser than to the north. Similarly, the intensity of deep weathering on Lower Proterozoic rocks north of Mt Brockman increases with distance from the scarp because the more distant sites were the first to be exposed by scarp retreat.

In the north-west the lower reaches of major rivers were incised into the younger weathered land surface to depths well below the present sea level, indicating that the land then stood relatively high.

In the extreme south the South Alligator River cut back rapidly along lines of weakness in Lower Proterozoic rocks and extended its headwaters at the expense of the Katherine River catchment by capturing Upper Fisher Creek.

### (*e*) *Quaternary Developments*

During the Quaternary era several generations of alluvium were laid down by the major rivers on the western plains and in major valleys of the Arnhem Land plateau (Fig. 10). Extensive areas of estuarine and marine clays and muds were deposited in the lower reaches of the valleys and along the coast. There is little or no evidence of former wind action.

The older alluvial deposits comprise sand sheets up to 3 km wide and levee tracts up to 1 km wide consisting of sand where derived directly from the sandstone of Arnhem Land plateau, but containing lateritic and vein quartz gravel where the source was the Kombolgie volcanic member or the Lower Proterozoic rocks.

The younger alluvial deposits consist of two well-developed sets of alluvial features. These two sets are universally present on the western lowlands and they probably occur along all major streams of the area. The higher set is not accumulating today and stands 5–10 m above the river at low water. The lower set is developing under present conditions and its levees are occasionally overtopped by floods in the wet season and subject to minor wind action in the dry season.

According to our limited observations there are textural differences between the two sets of younger alluvial deposits. On the South Alligator and East Alligator Rivers the higher set includes fine sand or silt levees and clayey back plains and the lower set consists of medium sand. On Magela Creek on the other hand the higher set of alluvial features is dominantly composed of coarse sand while the lower set consists of better-sorted, finer sand. It seems that in both cases the higher set of alluvial deposits is derived from rocks in the vicinity while the lower set is derived by longer transport from the Arnhem Land plateau.

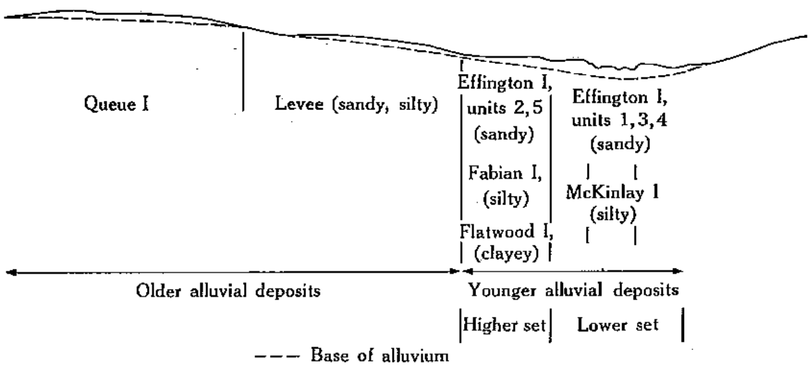


Fig. 10.—Generalized cross profile of alluvial deposits and associated land systems.

Levees of the younger alluvium have acted as barriers damming tributaries to form a series of billabongs, particularly on lower Jim Jim and Tin Camp Creeks. Deltas at the riverward end of these billabongs show that in the wet season they are filled to at least some extent by spill-over from the major rivers.

On the Arnhem Land plateau even the larger streams, such as Jim Jim Creek, have very restricted amounts of alluvial sand without recognizable levees and their shallow channels usually flow directly over rock.

Estuarine muds filling valleys on the coastal plains have the form of extremely wide (several kilometres) low-angle levees, falling about a metre from near the channel in the centre to paperbark swamps on the margins. The source of the mud is problematic. On the one hand, the broad levee form suggests that the upper layer at least is a freshwater clay deposited by the river; on the other hand, there hardly seems an adequate source for such clay in the river catchments and certainly marine muds are being deposited at the coast today, so that the muds may have a marine origin. The paperbark swamps gradually become filled with clays and turn into sedge or grass-covered plains. Deep cracking of the clays occurs in the dry season and there is a limited amount of flocculation in more saline sites and the formation of thin clay plates which are transported short distances as small flakes by wind during the dry season.

At the coast narrow tidal flats with mangrove occur on the seaward side of a thin belt of sand ridges. These ridges never rise more than a few metres above the present sea level and consist of lenses of coarse shell sand; they may be produced by waves during tropical cyclones or may have formed just offshore and are now exposed by a slight and geologically very recent emergence.

## IV. Land Systems in Relation to Geology and Geomorphology

The land systems fall into eight groups according to criteria of geology and weathering status.

### (*a*) *Land Systems associated with Quartz Sandstone* (*Kombolgie Formation*)

This group of land systems covers fully 8000 km$^2$ (58 % of the area). In keeping with the resistant, strongly jointed, highly quartzose and more or less flat-lying nature of the rock most of these land systems comprise a plateau, cut by deep narrow valleys and gorges and having a high proportion of bare rock surfaces (Fig. 11). Deep

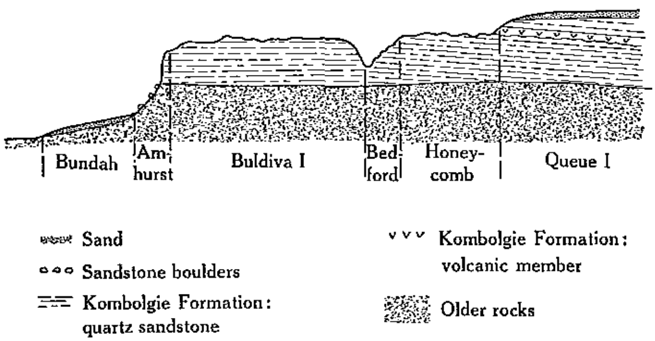


Fig. 11.—Land systems associated with Kombolgie Formation.

weathering has only slightly affected the sandstone, and soils are confined to patches and pockets of sand except on major watersheds where dissection has not yet removed more extensive areas of residual sand.

Most of the rocky plateau is mapped as Buldiva I land system. Limited areas with *Allosyncarpia* rain forest, usually bouldery dissected sites sheltered from fire, form Bedford land system. The more extensive patches of residual sand form part of Queue I land system which is discussed in section (*f*). Dual land system occurs in the south where an old river system has been dismembered by capture to leave a winding flat-floored valley bounded by steep, bare low plateaux. Honeycomb land system consists of low bare rock rises and intervening subcircular shallow basins and has apparently formed by the sandstone buckling through pressure from overlying volcanic rocks which have now been removed.

The Arnhem Land plateau and basins within it are rimmed by a steep escarpment. Where narrow, the scarp has been included in Buldiva I or Bedford land systems, but where wider it has been mapped as Amhurst land system in which sandstone cliff overlooks steep lower slopes cut on a variety of rocks and littered by boulders of sandstone. An apron of sandy detritus at the foot of the scarp, usually with marked seepage zones, forms Bundah land system.

### (*b*) *Land Systems on Dolerite and Volcanics*

Dolerite and volcanics occupy nearly 1000 km$^2$ (7% of the area). Differences between the dolerite and the various volcanic rocks together with contrasts in the depth of weathering have led to the existence of a variety of land systems (Fig. 12). The geological interpretation of these igneous rocks is currently being extensively revised (R. S. Needham, personal communication, 1974) and not all interpretations presented here may be correct.

Valley land system occurs on the Arnhem Land plateau where the younger weathered land surface survives intact in shallow valleys on dolerite or volcanics (notably upper Magela Creek basin). Lateritic gravelly soils and thin spreads of sand from adjacent sandstone are features. Venlaw land system also occurs on the Arnhem Land plateau where volcanics formerly overlain by modest thicknesses of sandstone have been exposed. Very shallow soils of unusual colour and agates are features of this land system. Verity land system, confined to lowlands in the north, is dominantly on dolerite; lateritic gravels are common on crests and upper slopes, light clays on mid slopes, and heavy clays on colluvial lower slopes and valley floors.

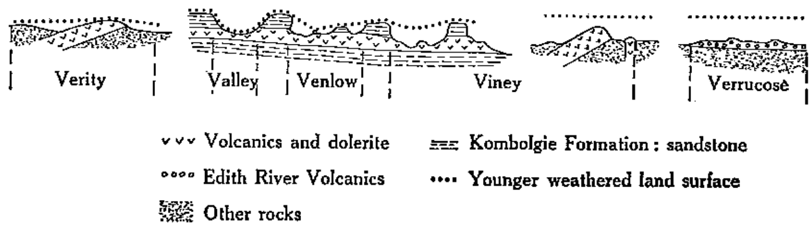


Fig. 12.—Land systems associated with volcanic rocks and dolerites.

Viney land system occurs on igneous rocks exposed mainly in major valleys. Fairly deep red clay soils between and under a mantle of cobbles and boulders are a predominant feature. Relatively unweathered strike ridges in the south ranging from low rises to mountains and with generally similar but shallower soils have been included in the Viney land system. The small Verrucose land system in the extreme south is rolling terrain with occasional low steep hills and very shallow soils developed on little-weathered Edith River Volcanics.

### (*c*) *Land Systems on Weathered Metamorphic and Sedimentary Rocks*

These land systems occupy fully 2700 km$^2$ (20% of the area) and despite the variety of rocks have a degree of similarity in relief, soils and vegetation imposed by their erosional history and by deep weathering. Most of them are associated with the younger weathered land surface (Koolpinyah or 'K' surface of the Adelaide–Alligator area to the west): the minor Murray and Klatt land systems are related to the older weathered land surface.

In Kay I land system the weathered surface is almost intact; low relief with few slopes exceeding 4% and gravelly lateritic soils supporting tall open forest on crests and woodland on slopes predominate. Kay I land system is not readily distinguished on aerial photographs from tall open forest on deep sandy or loamy soils (Queue I land system) and its extent may be greater or less than as mapped.

In Knifehandle I land system extensive relics of the weathered land surface survive on the interfluves but the valleys are cut into the underlying fresher bed-rock; the valley slopes may have thin detrital laterite derived from the initial cover on the interfluves. Some sandy terrain in the Waterfall Creek basin and near the Arnhem Land scarp is included in this land system. Near the major rivers of the western lowlands Knifehandle I land system is not always distinguishable on the aerial photographs from some of the older alluvial features. In Jay I land system the weathered land surface has been still further dissected into low rounded rises. Part of Verity land system is on these rocks.

Kysto I land system has a distinctive air-photo pattern of groves and glades, aligned along the strike of the underlying Lower Proterozoic schists and phyllites; the weathered land surface survives only as occasional patches on interfluves; thin detrital laterite also occurs sporadically on the slopes. In general, weathering is not intense on this land system which could well be grouped with those on fresh rocks (*d*, below).

Other land systems in the group are minor. Nova land system is probably formed on moderately weathered rocks, and its distinctive pale air-photo pattern is possibly related to a widespread surface lag of vein quartz fragments. Explanado land system in the far south is gently undulating lowland with a relatively shallow weathering zone and thin laterite cover developed on siltstone and shale. Kosher I land system comprises low headlands with shallow soils occurring where the siltstone and sandstone of the Cretaceous Mullaman Beds reach the edge of the coastal plains. Klatt land system comprises small lateritic mesas and associated breakaways, and colluvial slopes on patches of Mullaman Beds perched high on the easternmost rim of the area. Murray land system too is on deeply weathered Mullaman Beds but is developed on the pallid zone of a truncated deep weathering profile.

### (*d*) *Land Systems on Fresh Metamorphic and Sedimentary Rocks other than Quartz Sandstone*

Where erosion has removed the deeply weathered zone entirely or a protective cover of younger rocks has been cut away, the land systems are developed on fresh rocks which exert strong lithological control of landscape features. These land systems occupy nearly 1200 km$^2$ (fully 8% of the area). They occur on the southern part of the western lowlands exposed in the late Cainozoic by retreat of the Arnhem Land escarpment, in the upper valleys of the South Alligator and Tin Camp Creek and in the upper Deaf Adder Creek basin where dissection has been active, and in the north-eastern corner of the Cooper Creek basin where a cover of comparatively unresistant Mullaman Beds has been stripped off.

Bend I and Baker I land systems on Lower Proterozoic sediments and low-grade metamorphics are essentially undulating and steep strike ridge-and-vale country respectively. There are some indications of weathering on parts of Bend I land system with lateritic gravel, whereas Baker I land system shows practically no effects of deep weathering. Ararat land system comprises closely dissected terrain on mica schist

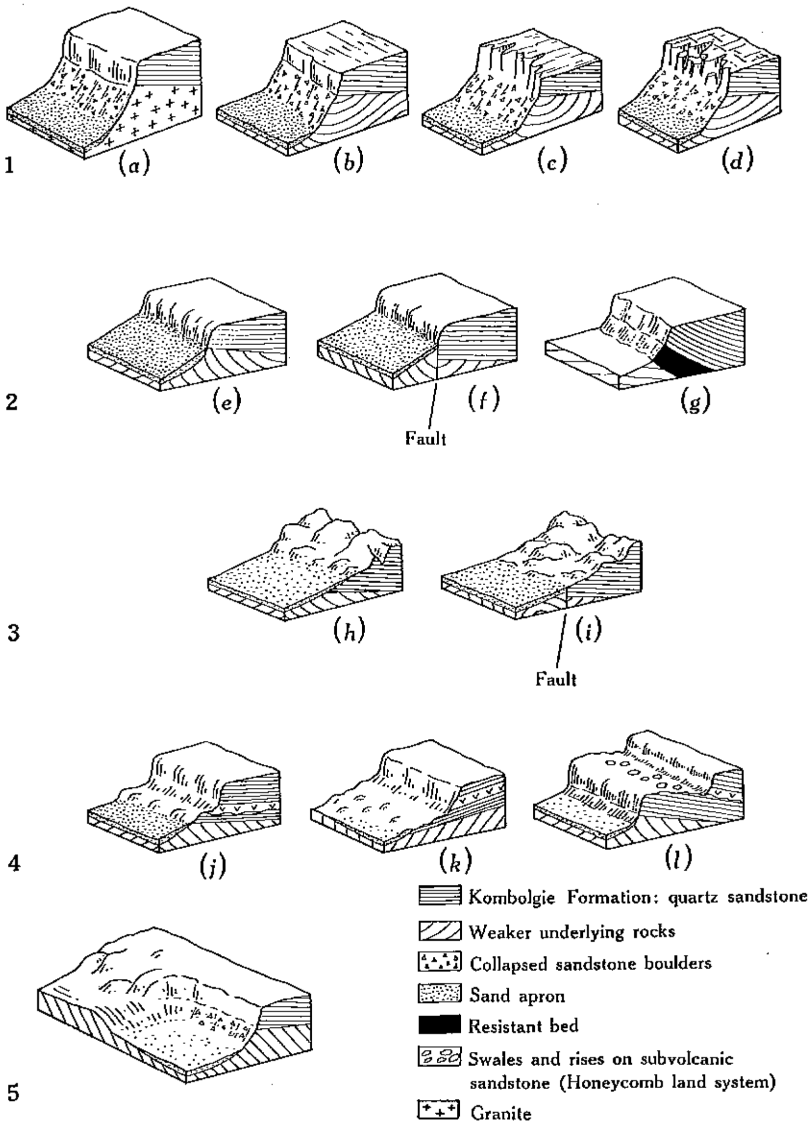


Fig. 13.—Aspects of the Arnhem Land escarpment.

1, Actively developing scarp: weak rock below sandstone cap is well exposed, details of scarp form controlled by jointing in the sandstone. (*a*) Sandstone moderately jointed, e.g. S. side of lower Jim Jim basin. (*b*) Stong jointing parallel to scarp, e.g. SE. of Oenpelli. (*c*) Strong joints transverse to scarp, e.g. SE. end of Tin Camp Creek basin near East Alligator River. (*d*) Strong joint network giving intricately dissected scarp, e.g. part of S. side of Tin Camp Creek basin.

2, Stabilized scarp: weak rock no longer exposed. (*e*) Sandstone dips below local base level of erosion, e.g. W. end of Tin Camp Creek basin. (*f*) Base of sandstone faulted below local base level of erosion, e.g. SE. side of Mt Brockman massif. (*g*) Highly resistant bed exposed below sandstone cap, e.g. NW. of El Sherana.

with a distinctive pattern of short slopes and a dendritic drainage pattern; a surface lag of rock fragments is extremely common. Locally, well-developed quartz breccia dykes impose a more linear pattern on the relief. The gently undulating Somerville land system at the southern end of the western plains is developed on shaly and calcareous sedimentary or weakly metamorphosed rocks; loamy and clayey soils with only sporadic surface gravel predominate.

### (*e*) *Land Systems on Granite*

Most of the granite in the area has been exposed comparatively recently by removal of overlying Proterozoic or Cretaceous rocks. Consequently, it is little weathered. Cully I and Currency I land systems together occupy nearly 300 $km^2$, some 2% of the area. Cully I land system is undulating to rolling with moderately deep soils; Currency I is steep with much outcrop. Granitic rocks also underlie part of the weathered Knifehandle I land system but are poorly exposed and consequently have not been recognized as a separate category within the group of weathered rocks (*c*, above).

### (*f*) *Land Systems on Sand Sheets*

Level to gently undulating sand sheets occur in three situations. On the Arnhem Land plateau residual sand sheets occur on undissected interfluves and smaller patches and pockets have accumulated in depressions. Low plateaux at the north-east and south-west ends of Cooper Creek basin are covered with deep residual red sands developed on Cretaceous sandstone and siltstone. Sheets of sand derived from the sandstone of the Arnhem Land plateau cover considerable areas of the western lowlands, particularly near Nourlangie Creek.

Sand sheets in all three situations have deep sandy or loamy soils supporting tall open forest and they have been grouped as Queue I land system. There are certain fairly consistent differences in soil between the three situations. On the aerial photographs Queue I land system is not really distinguishable from Kay I land system (gravelly soils, tall open forest) and the relative extent of these two land systems is uncertain. However, it is unlikely that any Kay I land system exists on the Arnhem Land plateau where tall open forest is definitely on sand.

### (*g*) *Land Systems on Fluvial Deposits*

The various bodies of fluvial sediments laid down in the late Cainozoic are associated with land systems covering about 700 $km^2$ (5% of the area). The older alluvial deposits comprise Levee land system and part of Queue I land system (Fig.

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3, Prolonged scarp stability: dissected, poorly defined scarp backing a pediment cut across lower part of sandstone. (*h*) Without fault, e.g. NE. of Nabarlek. (*i*) With fault, e.g. WNW. of Nabarlek.

4, Scarp associated with volcanic member within the Kombolgie Formation. (*j*) Volcanics dip away from the scarp and only minor thickness of underlying sandstone, e.g. N. of Jim Jim Falls. (*k*) Volcanics dip towards the scarp and extensive pediment cut across the underlying sandstone, e.g. N. side of lower Deaf Adder Creek basin. (*l*) Double scarp: lower one is normal type, upper one formed by sandstone overlying the volcanics, deformed subvolcanic surface exposed, e.g. SE. of Noranda.

5, Scarp rejuvenation by lowering of local base level of erosion, e.g. ENE. of Oenpelli.

10). Both these land systems are formed on sand derived from the Arnhem Land plateau and both have sandy or loamy soils and a high proportion of tall open forest. Queue I is older and more dissected, generally further from the present streams, and has some minor gravel.

The higher set of younger alluvial deposits is associated with Flatwood I and Fabian I land systems which are silty and clayey plains, and also with the higher units of Effington I land system above direct present stream influence. The lower set of younger alluvial deposits consists of modern channels, levees and back plains subject to flooding which are associated with McKinley I land system and the lower units of Effington I land system; the former has a complex pattern of alluvial relief with anastomosing channels and levees while the latter has a simpler pattern.

### (*h*) *Land Systems on Estuarine and Coastal Deposits*

Clay and mud plains subject to inundation by floods or tides fringe the coast and extend up the major valleys. They are associated with four land systems covering 200 km$^2$ (about $1 \cdot 5\%$ of the area). These land systems are better developed in the Adelaide–Alligator area to the west and are more fully described in the report dealing with that area (Story *et al.* 1969). Cyperus I land system is above flood level for at least half the year, whereas Copeman I land system is slightly lower and is flooded for at least half the year. Cyperus I land system tends to be near the main river channel and has the form of a very low levee which descends to Copeman I land system further from the stream. Pinwinkle I land system is still lower, lies still further from the main river and consists of permanently flooded paperbark swamp.

Littoral I land system, as the name implies, comprises the almost bare coastal clay plains, most of which are covered only occasionally by the highest tides but which include a narrow fringe of mangroves and tidal foreshore as well as low ridges of shell sand.

## V. Topics of Scenic and Educational Interest

### (*a*) *The Arnhem Land Escarpment*

The Arnhem Land escarpment is the most striking scenic feature of the area and exemplifies many relations of land form to geological structure. The escarpment ranges from about 30 to 330 m in height and is formed by the resistant quartz sandstone of the Middle Proterozoic Kombolgie Formation unconformably overlying a variety of less resistant rocks. As erosion attacks these weaker underlying rocks the resistant sandstone is undermined and collapses and the scarp gradually retreats across the landscape. The average rate of retreat may be of the order of 1 m per 1000 years and occurs as occasional collapses of the cliff followed by centuries of near stability. The boulders produced by the collapse protect the weaker rocks below the cliff from further erosion until they are reduced to sand and washed away.

The form of the scarp is largely determined by the geologic structure and some of the commonest types are illustrated in Fig. 13. Where the underlying beds are well exposed the scarp is steep and fresh with the lower slope littered by blocks of sandstone and with sandy aprons extending over the adjacent lowlands.

As illustrated in Fig. 13, 1, the jointing in the sandstone cap largely controls the details of the scarp. Variations in the resistance or degree of exposure of the weaker underlying rocks have also significant effects on the scarp plan. More resistant portions, down-faulted zones and synclines are associated with reduced rate of erosion of the softer beds and consequently with promontories of the scarp. Less resistant portions, up-faulted zones and anticlines give greater erosion of the weak beds below the sandstone and consequently increased scarp retreat and the development of embayments. As shown in Fig. 14, vigorous fresh scarps predominate in the southern

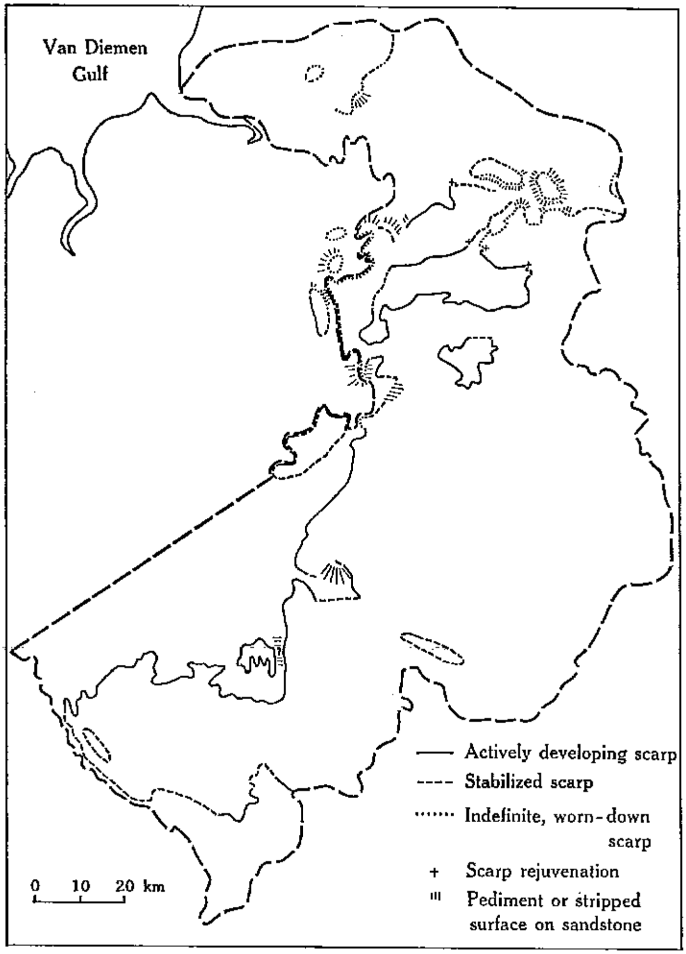


Fig. 14.—Distribution of major types of escarpment.

half of the area and rim some of the basins in the Arnhem Land plateau which are associated with basement highs, domes or up-faulted areas.

Eventually the scarp retreats to a position where the weaker underlying beds are no longer exposed and it becomes stabilized. Stable scarps are less sharply defined than active scarps and have rounded profiles with few boulders on their lower slopes and no exposure of the underlying weaker rocks. Stability can be attained when the sandstone bed dips, or is down-faulted, below the local base level of erosion (Fig. 13, 2e and f) or when a particularly resistant bed is exposed below the sandstone cap (Fig. 13, 2g).

With prolonged stability the scarp is gradually worn back further and becomes extremely indented and irregular and indeed scarcely recognizable; a pediment with a thin patchy veneer of sand is cut across the lower part of the sandstone exposed in front of the scarp. If the scarp has been stabilized because the sandstone has dipped below the local base level of erosion, the lower edge of the pediment is ill defined (Fig. 13, 3h); if the stability of the scarp has resulted from down-faulting of the sandstone, the pediment has a clearly defined lower edge along the fault except where obscured by a veneer of sand (Fig. 13, 3i).

Stable scarps and associated pediments predominate in the north of the area, particularly in the Cooper Creek basin (Fig. 14), implying little retreat of the scarp for long periods of time—probably many millions of years. Indeed, parts of the scarp in the north existed before being blanketed in the Cretaceous by the Mullaman Beds. Stability has also been attained along faults forming the south-east edge of the lower Deaf Adder Creek basin and the south-western edges of the upper Deaf Adder and Waterfall Creek basins, but this stability is relatively recent since pediments are practically absent. Stability of the scarp overlooking the South Alligator River is also comparatively recent and related to the exposure of underlying resistant Edith River Volcanics.

A further complicating factor is the occurrence of volcanic member(s) within the Kombolgie Formation. This rock is relatively unresistant and consequently its presence affects the development of the scarp. If it occurs near the base of the sandstone and dips back from the scarp (Fig. 13, 4j), a more or less normal scarp is formed with a minor pediment below on the underlying portion of the sandstone. If the volcanics dip gently towards the scarp, an extensive stripped surface, slightly modified by erosion, is exposed as the scarp retreats and forms a pseudo-pediment that may still bear signs of the former presence of volcanics (Fig. 13, 4k). Such a pseudo-pediment has developed in the lower Deaf Adder Creek basin. If the volcanics occur well up in the sandstone, the underlying portion of the latter rock forms a normal scarp and a secondary scarp develops above the volcanic member (Fig. 13, 4l). Deformation structures related to the overlying volcanics are usually present on the stripped subvolcanic surface exposed in front of this secondary scarp (Honeycomb land system).

Worn-down stable scarps are rejuvenated if the local base level of erosion is lowered and the weak rocks below the sandstone scarp are consequently re-exposed to attack. This has occurred in the north where more vigorous neighbouring catchments are encroaching on the long-stable Cooper Creek basin. Rejuvenation of the scarp initiates renewed retreat and a clear-cut cliff with a relatively straight plan soon replaces the previous rounded and indefinite forms (Fig. 13, 5).

Scarp-foot benches or sloping benches covered by cemented detritus from the escarpment commonly occur near the foot of scarps in tropical and subtropical Australia. However, they are absent from this area because the Kombolgie Formation breaks down to sand which streams can remove rather than to gravel which would tend to accumulate below the scarp, and because there is little iron in the rocks to provide a strong cement for any detritus.

### (*b*) *Caves*

Cavernous weathering develops when a hard crust forms on steep rock faces (usually sandstone) as the result of migration of silica or iron-bearing solutions; when erosion pierces this crust the softer material behind is readily removed to form rounded cavities ranging from a few centimetres to several metres deep. Such caves are rare in this area, presumably because of the absence of iron from the Kombolgie Formation.

Curved slabs spall from the lower sides of clefts and ravines to give shallow arcuate caves, which are a more common form. The spalled blocks break down to sand. Partial collapse of the roof along bedding planes gives a flat roof to caves such as those at Obiri Rocks. If considerable thicknesses of sand accumulate on the ravine floors the enhanced soil moisture weathers and weakens the adjacent rock, leading to undermining and further shallow cave development with widening of the ravines. Sometimes the cave roof is formed by the basal bed of the Kombolgie Formation and the actual cave has been excavated in the underlying rock by spring sapping.

More complex caves penetrating for many tens of metres also exist. Their original form has been extensively modified by collapse from the roof and by spalling. They may have originated by subsurface water erosion along joints and bedding planes when the plateau surface was higher or by ground-water solution during deep weathering.

### (*c*) *Drainage Evolution*

When drainage diversion occurs, one catchment expands at the expense of another and the trunk stream of the less successful catchment may be captured by the more 'aggressive' stream. The survey area occupies the core of a peninsula north of lat. 15°S. where the drainage is radial and where there have been complex diversions as a result of the considerable relief energy, changes in stream gradients as the Arnhem Land escarpment retreated, strong contrasts in rock resistance, some tectonism and the presence of marked lines of weakness.

The quality of the evidence for diversion is variable and some of the reconstructed diversions are speculative. The more actively eroding catchments have fewer relics of old weathering surfaces, a stronger control of drainage pattern by structure and a generally lower altitude than have less rapidly eroding neighbouring catchments, and are often situated on structures which favour valley deepening. Divides which are migrating as a result of diversion tend to be steeper on the side of the expanding valley and often the highest points are not on the present divide but lie within the more actively eroding catchment where they have been left behind as the divide migrated. Stream piracy is indicated by dry valleys which have lost their stream, by reverse-flowing streams, by anomalous angles of intersection between streams ('elbows of capture' and 'boat-hook bends') and by fluvial deposits unrelated to modern stream patterns. All these indications of diversion are present in the Alligator Rivers area but their reliability as evidence is variable and some of the reconstruction of the history of drainage based on them is speculative.

Nothing is known of the history of drainage prior to the time of formation of the younger weathered land surface about the middle of the Cainozoic era. At this time the dominant drainage was westwards, the main drainage axes being Cooper

Creek, Tin Camp Creek, Deaf Adder Creek, Jim Jim Creek and an unnamed river system on the plateau south of the lower Jim Jim basin; this last has since been dismembered but its meandering course is clearly preserved on the plateau. The extreme south of the area drained south-eastwards to the Katherine River system which at that time extended its catchment northwards into what is now part of the East Alligator drainage area. Probably the central and lower sections of the East Alligator River developed at this time in a shallow valley aligned along a fault.

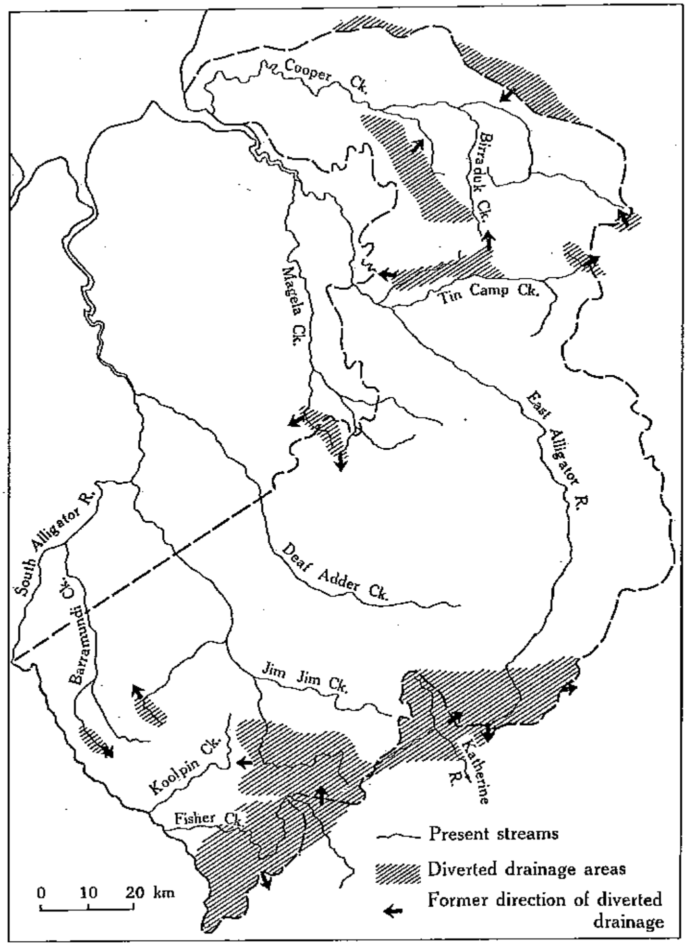


Fig. 15.—Drainage diversions.

Substantial drainage diversion accompanied dissection of the younger weathered land surface (Fig. 15). Cooper Creek catchment shrank as surrounding, more favourably situated catchments were lowered more rapidly and expanded at its expense. Lower Tin Camp Creek was diverted to the East Alligator leaving a dry valley through the sandstone range due east of Cahills Crossing. The headwaters of the East Alligator began to recapture territory from the Katherine River. Fisher Creek was captured by the South Alligator River working back along favourable structures. The East Alligator River and Deaf Adder Creek became deeply incised and erosion completely removed the younger weathered land surface from both their valleys and the south Deaf Adder basin. The opening up of lower Jim Jim Creek basin on granite greatly lowered the local base level and caused a notable diversion of an old east–west river on the plateau to the south; this diversion was effected by reversal of a tributary which now flows northwards in a narrow joint-controlled inner gorge *up* its former valley (Fig. 16).

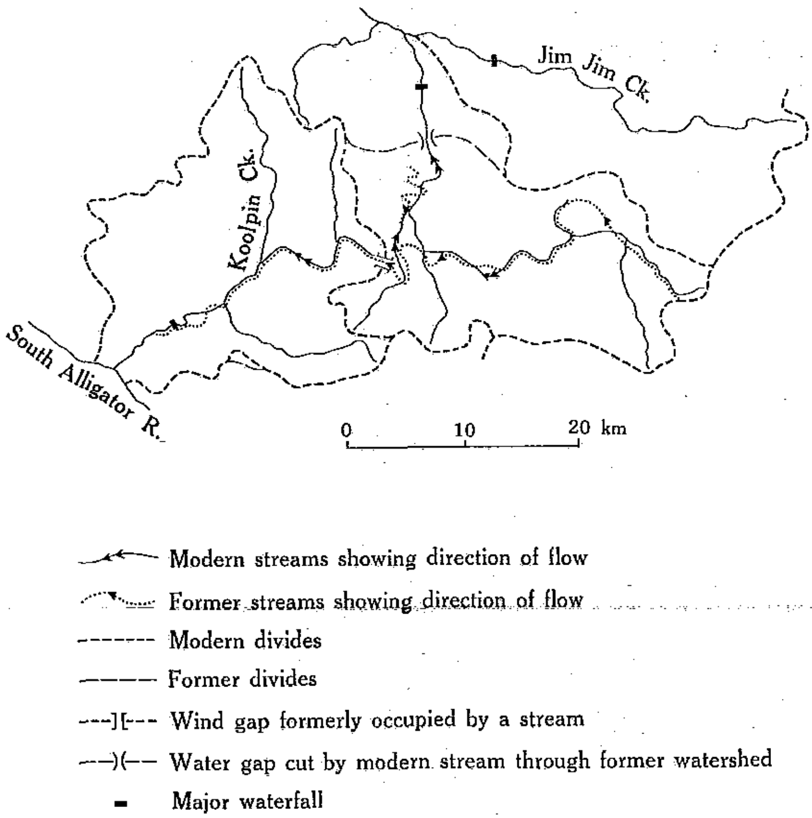


Fig. 16.—Diversion of former upper Koolpin Creek to Jim Jim Creek.

On the western lowlands there has been some drainage diversion between Magela and Nourlangie Creeks but the low relief and generally parallel courses of the rivers have precluded extensive captures subsequent to the retreat of the Arnhem Land escarpment from this area.

### (*d*) *Waterfalls*

The Arnhem Land plateau is a land of waterfalls where streams spill off the tableland into ravines and tumble down the scarp and valley sides. Most waterfalls flow only during and shortly after the wet season but a few have some water throughout the year, particularly Jim Jim Creek which receives some dry-season flow of water seeping out of the extensive sand sheets in the upper catchment. The Jim Jim Falls are the most impressive, with a sheer drop of over 100 m at the head of a narrow gorge. There are also striking unnamed falls 10 km to the south-west.

Waterfalls are evanescent features in geological terms and are generally soon reduced to rapids. Their unusual abundance in this area depends on several factors.

(1) The quartz sandstone of the Kombolgie Formation is extremely resistant to abrasion. Furthermore, it breaks down to sand rather than gravel so that streams have no effective tools with which to wear down their beds.

(2) The dominant modes of slope development, with spalling on lower valley sides and collapse along vertical joints due to undermining, keep slopes very steep.

(3) Prominent lines of weakness are rapidly excavated by headward erosion leaving tributary streams perched high above on the flanks. Waterfalls are thus characteristic of the margins of lines of weakness but are poorly developed along them.

(4) Rapid retreat of the scarp, particularly during the opening up of the lower Jim Jim basin, has juxtaposed lowlands and plateaux and so favoured the development of waterfalls.

### (e) *Giant Load Casts*

One of the most striking patterns on the aerial photographs resembles a honeycomb with a light-coloured background pitted by rather regular dark depressions, subcircular or elongated (Honeycomb land system). The light areas are low rises and swells of bare rock, up to 20 m high and 100–500 m wide, while the depressions are flat-floored swales with shallow but variable thickness of sand and clayey sand, often with fragments of weathered volcanics and laterite. All examples occur on the Arnhem Land plateau on surfaces of the Kombolgie Formation exposed by stripping of the volcanic member. The rises correspond to up-warpings of the originally flat-lying beds.

The most satisfactory explanation of this unusual pattern is that it represents dimpling of the sandstone by the denser overlying volcanics. Dimpling may have been assisted by fusing and softening of the sandstone by heat from the molten volcanics, although the silicification observed may in fact be a later weathering phenomenon. Recent geologic information (S. Needham, personal communication) indicates that the volcanics were extruded onto the underlying sand possibly before it had been fully consolidated into sandstone. This makes the extensive distortion of the bedding more readily understandable.

Distortion of a sedimentary bed by an overlying denser member is well known in unconsolidated sediments on a small scale, of the order of up to a metre or so, but has rarely if ever been described on such a large scale.

## VI. Some Implications of Geomorphology in Relation to Economic Development

### (a) *Preservation of Scenic Features*

Obviously most of the scenic features discussed here will not be affected to any notable degree by mining and associated development. On present indications the scenery of the scarp may be locally damaged, but proposed mining developments are extremely limited in relation to the extent of the scarp as a whole, and are largely restricted to the scenically uninteresting lowlands.

The giant load casts are a unique feature and are small enough to suffer damage if they should prove to be associated with mineralization. However, their location well within the Arnhem Land Aboriginal Reserve should ensure their protection.

### (*b*) *Waste Disposal*

It may be planned to discharge effluent into the main rivers during the high flows of the wet season in the expectation that there would be sufficient water to dilute it to a safe level and carry it out to sea. However, there are reasons to believe that high local concentrations could accumulate. As pointed out above, some major streams on the western lowland have steep levees which dam back tributaries to form a series of lagoons. The presence of small deltas in these lagoons shows that they are filled to a significant degree by water spilling over the levee from the main river. Consequently, if effluent is discharged down the major streams some could be trapped in these lagoons and concentrated by evaporation during the following dry season. The upstream lagoons dry out completely and the downstream lagoons are permanent and the locus for fish and bird life at all seasons. Lagoons and swamps (Pinwinkle I land system) on the coastal plains are also filled to some extent by water from the rivers and here too effluent could be concentrated.

### (*c*) *Soil Erosion*

This topic is discussed more fully by Williams in Part IX.

Over most lowland areas a lag gravel 2–10 cm thick covers the ground and protects the soil from erosion. The gravel is usually vein quartz on the Lower Proterozoic sediments and metamorphic rocks, and its ubiquity even where there are practically no quartz veins in the bed-rock demonstrates that it is the product of long evolution where the fine material has been gradually washed out or removed in solution as the ground surface becomes lowered. It would therefore be difficult to replace should it be damaged or removed. In some areas ironstone nodules originally formed in the soils have become concentrated at the surface to form a similar protective cover.

The surprisingly modest extent of current soil erosion in the area, despite the intense wet-season rains, is due largely to the presence of this gravel layer. In places it overlies quite deep soils which would surely suffer severe erosion if the protective layer were removed (Plate 12, Fig. 2). Removal of the lag gravel for road construction or prospecting or by concentrated run-off from roads and cleared areas is thus likely to initiate severe soil erosion.

The areas most liable to erosion are in the Somerville land system, where the gravel cover is sparse, and silty alluvial flats subject to heavy grazing by buffalo.

### (*d*) *Construction Materials*

The widespread lateritic gravel and laterite on the lowlands offer material for road construction, but because occurrences are generally thin fairly extensive areas would be required to provide reasonable volumes and this could involve soil erosion problems. This laterite is widespread on rises and interfluves of Knifehandle I and

Kysto I land systems which coincide with dark air-photo patterns related to tall open forest or fairly dense woodland dominated by *Eucalyptus miniata* and *E. tetrodonta*. It also covers, though very thinly, much of the Explanado land system. Locally on the western lowlands detrital laterites up to 1 m thick exist on lower slopes and could be a more abundant source; however, it does not seem possible to identify such sites on the aerial photographs. Further potential sources of lateritic gravel are the older levees on the western plains and Cooper Creek basin, situated well out from the scarp where there has been a supply of iron in the form of oxides from the surrounding Lower Proterozoic rocks. Older levees near the sandstone scarp (Levee and Queue I land systems) contain little or no laterite but consist of fine and medium quartz sand which is possibly suitable for concrete and mortar.

While surface gravels of other material (quartz, schist, shale) are common (particularly in Kysto I, Ararat and Bend I land systems), the occurrences are thin and the stones generally friable. No silcrete suitable for aggregate was found.

### (e) *National Parks and Tourism*

While most of the features discussed here, in contrast to biotic phenomena, can be regarded as permanent and indestructible in terms of human lifetimes, there are nevertheless certain problems to be faced in developing them as features of a national park.

Access to much of the most attractive scenery is extremely difficult and any road-building would be prohibitively expensive. Intricately dissected sandstone country with intersecting ravines offers scope for fascinating nature walks, but great care will be needed to confine access to limited areas in order to reduce the very real risk that people would become lost.

Aspects of geomorphology such as river capture and scarp development can prove interesting to the public but are very hard to demonstrate on the ground, unlike plants, animals or archaeologic sites. From examination of aerial photographs and contour maps, it seems possible that the fairly accessible area around the headwaters of Barramundi Creek and the west end of Waterfall Creek basin (actually just outside the proposed National Park) could be developed to demonstrate these features. This general locality also has examples of the giant load cast features, caves, gorges, waterfalls, the escarpment and a fault.

The agates which occur in volcanic members of the Kombolgie Formation, though generally of poor quality, are likely to arouse public interest and there is a case for making at least one of the deposits accessible for the public to indulge in fossicking. On the other hand, long-term considerations may call rather for strict protection, which should be feasible in view of the difficulty of access.

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# PART VII. SOILS OF THE ALLIGATOR RIVERS AREA

By J. M. ALDRICK*

## I. INTRODUCTION

### (a) Previous Work

There are few reports of previous soils investigations in areas east of the East Alligator River but some work has been done further to the west.

Following a broad-scale reconnaissance survey in 1946 (Christian and Stewart 1953), Stewart (1956) described the soils of the Katherine–Darwin region in general terms. This was followed in 1956 by a more detailed description of the soils from the same region. This survey covered a large area and included the area between the South Alligator and East Alligator Rivers, and approximately 750 km$^2$ to the east of the East Alligator.

A more detailed survey was subsequently carried out by Story *et al.* (1969) covering an area as far east as the East Alligator River and including the flood-plain on the right bank of that river. In that survey report Hooper described the soils of the area in more detail (Hooper 1969).

Since 1965 the soils of the Coastal Plains Research Station have been studied in greater detail by Hooper and a map and a report have been prepared (unpublished).

Investigations into the morphology and particularly the chemistry of some solonetzic soils of the Marrakai land system of Christian and Stewart (1953) and the heavy clay soils of the subcoastal plains were carried out in 1964–65 by Baseden and Martin.

The Department of the Northern Territory (then the Northern Territory Administration) has resurveyed some parts of the Adelaide–Alligator area described by Story *et al.* (1969) in more detail since 1969. These surveys produced 'land-unit' maps at a scale of 1 : 50 000, and during the work further definition of the soils was undertaken (K. J. Day, unpublished report;† B. M. Schaffer, unpublished report‡).

The object of this survey was to extend the land system mapping of Story *et al.* (1969) to the new area, so logically the classification of the soils has primarily followed that of Hooper (1969). This work is also influenced by the work of Day (unpublished). However, many soils encountered on this survey had not been previously described so some new families have been recorded.

### (b) Sampling Considerations

A total of more than 300 profiles was examined over an area of approximately 13 800 km$^2$, giving a low sampling intensity of about 1 per 45 km$^2$. However, much of

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† Soil report, coastal plains survey 1968–70. Dep. Northern Territory, Darwin.

‡ Report on soils of part of Mudjinberri station, 1969. Dep. Northern Territory, Darwin.

TABLE 11

NUMBER OF OBSERVATIONS OF SOIL FAMILIES IN THE LAND SYSTEMS

| Soil family | Land system: Ararat | Amhurst | Baker I | Bedford | Bend I | Buldiva I | Bundah | Copeman I | Cully I | Currency I | Cyperus I | Dual | Effington I | Explanado | Fabian I | Flatwood I | Honeycomb | Jay I | Kay I | Klatt | Knifehandle I | Kosher I | Kysto I | Levee | Littoral I | Murray | McKinlay I | Nova | Pinwinkle I | Queue I | Rumwaggon I | Somerville | Valley | Venlaw | Verity | Verrucose | Viney |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Argoolook | | | | | | | 1 | | | | | | | 1 | 1 | 1 | | | | | | | | | | | | | | | | | | | | | |
| Arnhem | | | | 2 | | | | | | | | | | | | | | | | | | | | | | | | | | 12 | | | | | | | |
| Baroalba | | | | | 1 | | 1 | | | | | | | 1 | | | | | | | 1 | | | | | | | | | | | | | | | | 1 |
| Barramundi | | | | | | | | | | | | | | 7 | | | | | | | 6 | | 1 | | | | | | | | | | | | | | |
| Basedow | | | | | | | | | | | | | | | | | | 1 | 1 | 1 | 6 | | 2 | | | | | | | | | 1 | 1 | 1 | 4 | | |
| Brockman | | | | | 1 | | | | | | | | | | | | | | | | 1 | | | | | | | | | | | 2 | | | 3 | | 1 |
| Buldiva | | | | | | | 1 | | | | | | | | | | | | | | | | | | | | | | | 2 | | | | | | | |
| Cahill | | | | | | | | | | | | | | | | | | | | | 1 | | 3 | | | | | | | | | | | | | | |
| Carmor | | | | | | | | 1 | | | | 2 | | | | | | | | | | | | | | | | | | | | | | | | | |
| Carpentaria | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Cockatoo | | | | 3 | | 1 | | | | | | | | | | | | | | | | | | | | | | | | 3 | | | | | | | |
| Counamoul | | | | | | | | | | | | | | | | | | | | | | | | | | | | | 1 | | | | | | | | |
| Cullen | | | | | | | | | 8 | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Dashwood | | | | | | | | | | | | | | | | | | | | | | | | | | | | | 1 | | | | | | | | |
| Dune sands | | | | | | | | | | | | | | | | | | | | | | | | | 1 | | | | | | | | | | | | |
| Edith | | | | | | | | | | | | | | | | | | | | | 1 | | | | | | | | | | | | | | | | |
| Emu | | | | | 1 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Evelyn | | | | | | | | | | | | | 1 | 1 | | | | | | | 5 | | | | | | | 1 | | 3 | | | | | | | |
| Fisher | | | | | 1 | | | | | | | | | | | | | | | | | | 1 | | 1 | | | | | | | 3 | | | | | 1 |
| Gilruth | | | | | | | | | 1 | | | | | | | | | | | | | | | | | | | | | 1 | 1 | | | 1 | | | |
| Honeycomb | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | 1 | | | |
| Hotham | | | | | | | | | | | | | | | | | | 1 | | 1 | 1 | | 1 | | | | | | | | | | 1 | | | | |
| Howship | | | 1 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | 7 |
| Kapalga | | | | | | | 1 | | | | | | | | | | | | | | 2 | | 1 | | | | | | | | | | | | | | |
| Katherine | | | | | | | | | | | | | | 1 | | | | | | | 1 | | | 4 | | | | | | | | | | | | | |
| Killuppa | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | 3 | | | | | | | |
| Kombolgie | | | | 1 | | 2 | | | | | | | | | | | 2 | | | | | | | | | | | | | 3 | | | | | | | |
| Koolpin | | | | | | | | | 1 | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Koolpinyah | 1 | | 1 | | | | 1 | | | | | | | | | | | 1 | 1 | 2 | 11 | | 2 | | | | | | | | | | | | 4 | 1 | |
| Leichhardt | | | | | | | | | | | | | | 1 | | | | | | | | | | | | | | | | | | | | | | | |
| Malone | | | | | | | | | 3 | 1 | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Manbulloo | | | | | | | | | | | | | | 6 | | | | | | | 1 | | | | | | | | | | | | | | | | |
| Mundogie | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | 2 | | | | | |

| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Murrabibbi | | | | | | | | | | | | | | | | | | | | | 1 | | | | | | | | | | | | | | | | |
| Myra | 1 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| McKinlay | | | | | 1 | | | | | | | | | | 1 | | | | | | | | 1 | | | | | | | | | | | | | | |
| Nungbalgarri | 1 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | 13 |
| Partridge | 3 | | 2 | | 4 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Ramil | | | | | | | | | | | | 1 | | | | | | | | | 1 | | | | | | | | | | | | | | | | |
| Saline mud | | | | | | | | | | | | | | | | | | | | | | | | | 1 | | | | | | | | | | | | |
| Scinto | | | | | | | | | 2 | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Siltavel | | | | | | | | | | | | | | | | | | | | | 2 | | 1 | | | | | | | | | | 1 | | | | |
| Skeletal soils | 3 | 4 | 14 | 2 | 4 | 20 | 1 | | | | | | | | | | 6 | | | 3 | | 1 | | | | 1 | | 1 | | | | | | 4 | | 1 | 6 |
| Sleisbeck | | | | | | | | | | | | | | | | | | | | | | | | | | 1 | | | | | | | | | | | |
| Wildman | | | | | | | | 1 | | | 4 | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Woolner | | | | | 1 | | | | | | | | | | | | | | | | 4 | | 1 | | | | | | | | | | | 2 | 1 | | |
| Yemelba | | | | | | | | | | | | | | | | | | 1 | | | | | | | | | | | | | | 3 | | | | | |
| Zamu | 3 | | | | | | | | | | | | | 1 | | | | | | | | | | | | | | | | | | | | | 1 | | 6 |
| Zambina | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | 2 |
| Other soils | | | 1 | | | | | | | | | | 4 | 1 | | 1 | | 1 | | 1 | | 1 | | | | | | | | | | | | | | | |

TABLE 12

OUTLINE OF SOIL CLASSIFICATION

| Great soil group (Stace *et al.* 1968) | Soil family | Summary description | Principal profile form (Northcote 1971) | Equivalent soil names* |
|---|---|---|---|---|
| No profile development | | | | |
| Solonchak | Carpentaria | Saline dark clays over olive-grey clay; soft puffy surface. Subject to marine inundation | Ug5.5 | Carpentaria (2) (3) |
| Alluvial soils | Saline mud | Layered alluvial clay under mangroves; odour of hydrogen sulphide. Subject to marine inundation | Uf1.31 | Saline muds (3) |
| | Siltavel | Greyish mottled silty loam overlying dense ferruginous gravels. Shallow; imperfectly drained | Um4.11, 4.13 | |
| | Barramundi | Variable yellowish profiles with sandy and clayey layers. Mottled, imperfectly drained | Not applicable | |
| Lithosols | Skeletal soils | Shallow stony soils on various lithologies | Uc1.4 (1.21), Um1.4 | Skeletal soils (3) (4) |
| Calcareous sands | Dune sands | Coarse gritty soils; shell and sand ridges | Uc1.11 | Dune sands (3); sand dune (4) |
| Siliceous sands | Kombolgie | Greyish or brownish sands up to 150 cm deep over weathering sandstone of the Kombolgie Formation. Well drained | Uc1.21 | |
| | Kapalga | Greyish sands at seepage points on colluvial slopes. Moderately well drained | Uc1.21 | Kapalga (2) (3) |
| | Sleisbeck | Deep brownish sands, reddish below 60 cm, on southern sand plains. Well drained | Uc5.11 | |
| | Cockatoo | Deep reddish brown sands formed from sandstones of the Kombolgie Formation. Well drained | Uc5.11 (Uc1.23) | Cockatoo (1) (2) (3) (4) (5) (6) |
| | Arnhem | Deep yellowish sands formed from sandstones of the Kombolgie Formation. Well drained | Uc5.11 (Uc4.21) | Pago (4) |
| | Manbulloo | Deep brownish or yellowish fine sands on lower set of younger river levees. Well drained | Uc5.11 | Manbulloo (1) (4) (5) (6) |
| | Evelyn | Yellowish sands overlying dense ferruginous gravels at 80–100 cm. Well drained | Uc5.11 (Uc4.21) | |

| | | | | |
|---|---|---|---|---|
| Siliceous sands gritty subgroup | *Cullen* | *Coarse sandy soils on granite* with large angular sand grains. Well or moderately well drained | Uc4.3, 5.2 (Gn2.14) | Cullen (3) (4) (5) (6) |
| | Cullen, poorly drained phase | Coarse sandy soils derived from granite, strongly mottled and imperfectly drained | Uc4.3, 4.2 | Cullen (3) (4) (5) (6) |
| Earthy sands | Baroalba | Deep yellowish sands or sandy loams, mottled and poorly drained | Uc5.11 (Gn2.84) | Baroalba (2) (3); Magela (3) |
| | Cahill | Gravelly lateritic soils, sandy and reddish with an unbleached $A_2$ horizon. Moderately well drained | Gn2.15 (Uc 4.3) | Cahill (2) (3) |
| | Leichhardt | Black highly organic sandy soils formed in river back plain situations. Moderately well drained | Uc1.2 (O) | |
| Minimal profile development | | | | |
| Grey, brown and red clays | Wildman | Black cracking heavy clays of estuarine origin. Alkaline, mottled and poorly drained | Ug5.4 | Wildman (2) (3) (4) (5) |
| | Carmor | Black cracking heavy clays of estuarine origin; abundant secondary carbonates. Mottled, poorly drained | Ug5.4 | Carmor (2) (3) |
| | Brockman | Dark cracking clays of freshwater origin, gilgaied and structured. Imperfectly drained | Ug5.1, 5.2 (Ug5.4) | Brockman (2); Cununurra (4) (5) (6); Banyan (1) |
| Mildly leached dark soils | | | | |
| Wiesenboden | Counamoul | Dark organic silty clay overlying pale mottled gleyed subsoils. Poorly drained; seasonally inundated | Gn2.81 (Ug5.4, 6.4) | Counamoul (2) (3) |
| Mildly leached brown soils | | | | |
| Brown earths | Argoolook | Silty loamy soils formed on old flood-plains; brownish, moderately organic; moderately well drained | Gn2.01, 2.11 | Mary (3) |
| | Argoolook, organic phase | Silty loamy soils formed on back plains under paperbark; highly organic. Moderately well drained | Gn2.01 | Mary (3) |
| Soils with profiles dominated by sesquioxides | | | | |
| Red earths | Killuppa | Deep reddish loamy sand grading to sandy clay loam. Well drained | Gn2.11 | Killuppa (2) |
| | Zamu | Massive reddish brown loamy soils on dolerite, volcanics or metamorphics. Well drained | Gn2.12 | Tippera (1) (4) (5) (6) |
| | Mundogie | Reddish light to medium-textured structured clays with some mottles and a weak $A_2$. Good soil moisture status | Gn3.14 (Uf4.2) | |
| | Howship | *Loamy colluvial gravelly soils of volcanic and other (mixed) origin*; well or moderately well drained | Gn2.44, 2.12 | |

TABLE 12 (*Continued*)

| Great soil group (Stace *et al.* 1968) | Soil family | Summary description | Principal profile form (Northcote 1971) | Equivalent soil names* |
|---|---|---|---|---|
| Red earths (*continued*) | Emu | Deep reddish silty and fine sandy loams formed on siltstone. Well drained | Um5.52 | Emu (1) |
| | Katherine | Deep reddish silty and sandy gradational soils on higher set of younger river levees. Well drained | Gn2.11, 2.14 (Gn2.44) | Katherine (1) (3) (4) (5) (6) |
| Lateritic red earths | Hotham | Gravelly sandy to loamy soils formed on laterite. Red, well drained | Gn2.11, 2.12 | Hotham (2) (3) |
| | Basedow | Gravelly sandy to loamy soils formed on laterite | Gn2.12, 2.14 (Uc4.32, Gn2.21, 2.45, 2.42) | Basedow (2) (3); Munmarlary (3) |
| | Woolner | Gravelly sandy to loamy soils on laterite. Yellowish A horizons; mottled poorly drained reddish subsoils | Gn2.44, 2.45 | Woolner (2) (3) |
| Yellow earths | Myra | Brownish or yellowish silty loamy soils on nicaceous alluvia. Well drained | Gn2.23 | |
| | Zambina | Mottled reddish loamy soil on volcanics with brown upper horizons. Moderately well drained | Gn2.45, Um5.52 | |
| | McKinlay | Poorly developed yellowish brown clayey soils in drainage floors. Impeded drainage | Uf6.31 (Uf4.4) | Coolibah (1) |
| | Ramil | Deep yellowish loamy sand grading to sandy clay loam. Well to moderately well drained | Gn2.64, 2.81 | Ramil (2) |
| | Edith | Deep yellowish silty and clayey soils on higher set of younger river levees. Well to moderately well drained | Gn2.24 | Edith (1) (6) |
| | Yemelba | Yellowish mottled light to medium-textured structured clays with imperfect or poor drainage | Gn3.74 | |
| | Fisher | Silty loamy soils with yellowish mottled profiles. Imperfect drainage | Gn2.65 (Gn2.62) | |
| | Partridge | Shallow gravelly sandy clay loams formed on micaceous schist or siltstone. Well drained | Gn2.21, 2.22, Um5.51, 5.52 | Angelara (3) |

| | | | | |
|---|---|---|---|---|
| Lateritic yellow earths | Koolpinyah | Gravelly sandy to loamy soils on laterite. Yellowish mottled profiles, moderately well drained | Gn2.65, 6.24 (Gn2.44, Uc1.42) | Koolpinyah (2) (3) (4) (5) |
| | Koolpinyah, shallow phase | Gravelly predominantly sandy shallow soils on laterite. Yellowish, well drained | Uc4.22, 4.21 (Uc4.11) | Koolpinyah (2) (3) (4) (5) |
| Krasnozems | Nungbalgarri | Dark red medium clays with strong blocky structure, formed on volcanics. Well drained | Uf6.31 | |
| Mildly to strongly leached highly differentiated soils | | | | |
| Yellow podzolic soils | Scinto | Coarse gritty layered soils with bleached $A_2$ horizons; mottled, yellowish and imperfectly drained | Not applicable (Dy) | Cullen (3) (4) (5) (6); Umbrawarra (1) |
| | Honeycomb | Loamy topsoils with an $A_2$ horizon; yellowish mottled clay subsoils. Imperfect to poor drainage | Dy (Gn2.84) | |
| Red podzolic soils | Malone | Coarse sandy A horizons over loamy reddish mottled B horizons with drainage impedance | Dr3.61 (Gn2.44) | |
| Organic soils | | | | |
| Humic gleys | Dashwood | Black organic clays with pale gleyed subsoils. Acid, with odour of hydrogen sulphide; poorly drained, seasonally *inundated* | Uf6.32 | Dashwood (2) (3) (4) (5) |
| | Murrabibbi | Black organic predominantly sandy soils with pale mottled subsoils. Poorly drained | Not applicable | Murrabibbi (2) (3) |
| | Buldiva | Thick peats and peaty sands over pale, mottled, permanently wet sand. Poorly drained | O (Uc) | |
| | Gilruth | Loamy organic mottled soils on alluvia, with $A_2$ horizons and pale subsoils. Imperfect drainage | Gn2.84 (Gn3.52) | Marrakai (1) (3) (4) (5) (6) |
| | Koolpin | Thick peats and peaty loams over mottled grey heavy clay. Permanently wet; poorly drained | Not applicable (O) | |

* Names used by other authors: (1) Aldrick (1972); (2) Day (unpublished report 1971); (3) Hooper (1969); (4) Stewart (1956); (5) Stewart (1970); (6) van de Graaff (1965).

the area consists of rugged Kombolgie sandstone formations with skeletal soils of great uniformity, so that excluding this area a sampling intensity of 1 per 25 $km^2$ would be more relevant.

Some of the land systems mapped have large areas of similar soils but others are quite variable. The very variable land systems may not have been adequately sampled and consequently the soils picture that emerges here may be over-simplified. However, a more detailed survey would be required in these areas to give proper definition to the soils, and this was outside the scope of this survey.

Most of the soils were inspected from a 2-in. augered profile to 150 cm, but some were from 3-in. augered samples. The upper 30 cm of each profile was inspected in greater detail in a shallow pit. The soils inspected during the wet season were to a depth of only 90 cm. Because the soils were augered some details of soil structure and horizonation may have been obscured and, considering the relatively low number of inspections, the reliability of some of the interpretations is probably low. However, many of the soils were straightforward massive sandy soils or clays and these are thought to be reliably represented.

The profiles have all been divided amongst 49 soil families so that there were relatively few sightings of each family. This raised no difficulty in definition of the families where the soils were familiar to the author from previous work to the west of the area, or where the soils clearly fitted the classifications of Hooper (1969) or Day (unpublished). However, some of the new families proposed here are based on inadequate data, a situation difficult to avoid in this sort of survey.

Table 11 shows the distribution of the soils in each land system. The actual number of observations of each soil in each land system is given but, while these figures provide an estimate of the importance of each soil, the observations were not randomly distributed and the figures are not a reliable guide to the relative areas of each soil.

## II. Soil Classification

Classification is at soil family level (Table 12; see also Appendix I). The United States Department of Agriculture (1951) describes a soil family as a category between a great soil group and a soil series, consisting of a number of similar series. The chief criteria used to define a family are morphological attributes, but there is a distinct agronomic bias. In some cases where particular soil characteristics vary, phases of the soil families are described.

Each profile was allocated a 'principal profile form' (Northcote 1971) in the field and these were used as a basis to help in classification. This grouping seems satisfactory in most cases but some difficulty was experienced in classifying the distinctly layered soils and the lateritic red and yellow earths. The distinctly layered soils have formed on layered alluvial or colluvial materials and, while pedogenesis is often well advanced in these soils (e.g. the humic gleys), parent material stratification has controlled soil texture to such a degree that the principal profile form becomes inapplicable. The lateritic red and yellow earths are all gravelly and vary mainly in their drainage, B horizon colour, profile textures and horizonation. The differences between most of them are often a matter of degree, and therefore the large range of principal profile forms recorded seems misleading.

Classification of these lateritic soils into soil families has been based on a number of morphological attributes but it is likely that soil drainage is the most important pedogenically. It is also likely that some of these soils are relict due to external landscape changes that have influenced soil drainage; however, the basic morphology of the original hydromorphic profile may have been retained. Northcote's (1971) principal profile form does not allow for this situation and is therefore less meaningful in these soils.

Northcote's (1971) primary profile forms are all represented in the area. Uniform- and gradational-textured profiles are the most common and account for nearly all the soils in the area. Duplex (texture-contrast) soils are rare, and apart from layered situations were found only in the depressions of Honeycomb land system and in some granitic areas. Organic profiles were recorded in some permanently moist areas. These have not previously been described in the Northern Territory.

## III. The Soil Environment

Throughout the survey area the nature and distribution of the soils are strongly influenced by lithology and the history of rock weathering and erosion.

With few exceptions, soils of appreciable depth do not occur on slopes exceeding 5%. A similar situation was observed by van de Graaff (1965) in the Tipperary area. This is attributed partly to the high rainfall intensities experienced in these areas and the consequently high erosion potential. The arid dry season would also contribute to the high erosion potential by restricting vegetative growth, and hence reducing the degree of plant cover afforded to the soils during high-intensity rains early in the wet season. The limited production of plant material and the regular dry-season fires that prevent its accumulation result in the low levels of organic matter found in most of these soils. This further increases their susceptibility to erosion.

Some marginal areas of the extensive and probably deep sand plains in Queue I land system have deep sandy soils on slopes of up to about 10%, but it is likely that these areas are slowly eroding and are not at present in equilibrium with their environment. Also, volcanic slopes of up to 40% in Viney land system were commonly observed to have clay soils up to 150 cm deep, but this occurred only where the soil surface was protected from erosion by an extensive pavement of large boulders.

Soil distribution is influenced by the topographic position of the soil in the landscape, and the degree of seasonal wetness of that position. These catenary sequences are not common but were observed repeatedly in some situations. Areas of Queue I land system with large catchments of deep permeable soils are usually surrounded on lower slopes by progressively more leached, paler-coloured soils that function seasonally as seepage areas and support some water-tolerant plant species. Below these seepage areas there is usually a creek or drainage flat (Fig. 17). Another common catena (Fig. 18) occurs across the inland margin of the estuarine clay plains. The sandy soils near the margin of the clay plains in Kosher I land system are distinctly hydromorphic and strongly influenced by lateral soil water movements and seepage. The wettest of these soils have a dense vegetative cover and a deep organic $A_1$ horizon has developed. Below this sequence water accumulates on the clay plain, often supporting paperbark forests (Pinwinkle I land system).

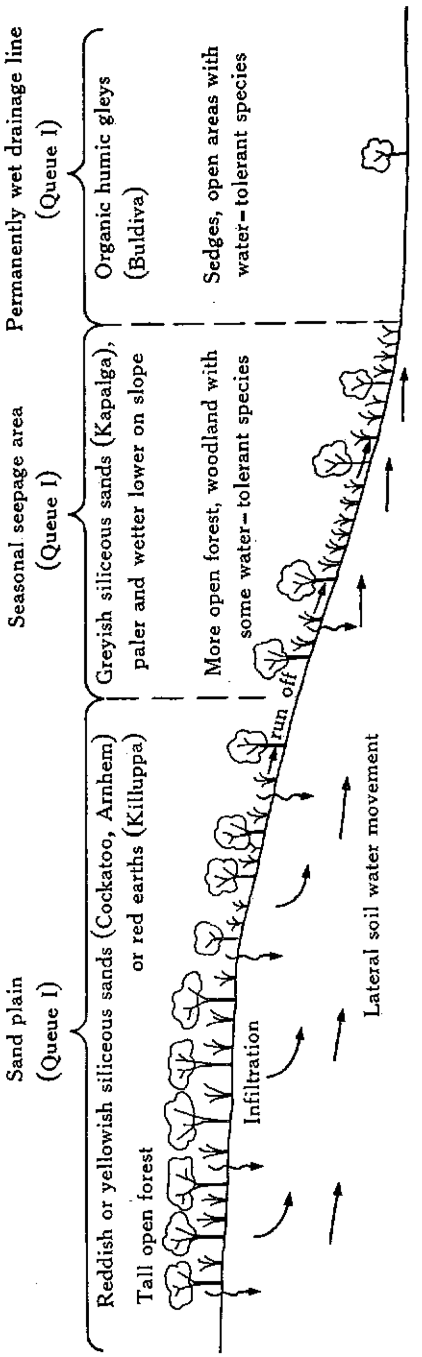


Fig. 17.—Soil catena in Queue I land system from sand plain to drainage line. Arrows indicate water movements.

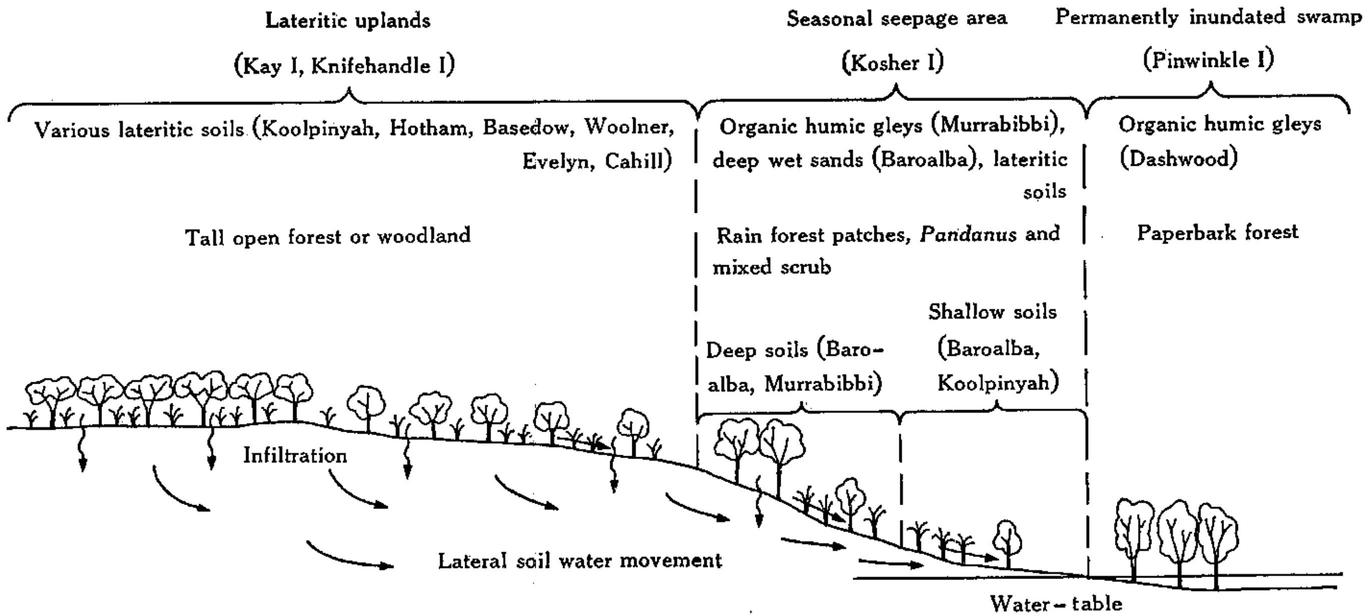


Fig. 18.—Soil catena from lateritic uplands to estuarine plains. Arrows indicate water movements.

The survey area has a history of lateritization (Williams 1969; Galloway, Part VI of this report). Lateritic weathering is still an important feature of many of the soils. The marked seasonality of the rainfall causes alternate wetting and drying of the profiles, and this is accompanied by alternate mobilization and precipitation of sparingly soluble compounds. It is possibly also accompanied in waterlogged soils by alternate reduction and oxidation. The zone of mobilization is not necessarily the same as the zone of precipitation and ferruginous compounds particularly tend to accumulate in some areas of the profiles, notably as mottles in B horizons and as nodules and concretions in A horizons. Surface lowering by erosion further concentrates the nodules and concretions at the soil surface.

## IV. Soil Geography

### (*a*) *Soils formed from Sandstone of the Kombolgie Formation*

Much of this area is entirely devoid of soil. The soils that do occur are coarse sandy soils, dominantly skeletal in dissected and sloping areas but up to 150 cm deep over weathering sandstone (Kombolgie) in flatter areas or contained depressions. The skeletal soils typically have a pale washed sand veneer 2 cm thick, but under this veneer they are darker and quite organic. The high organic content is probably due to concentration by the wet-season rains of organic matter in the depressions that contain the soil, but the absence of fires may also have an effect.

Even in the most rugged and skeletal areas of the plateau (Buldiva I and Bedford land systems) the soils are free of stone and gravel. Some have a coarse colluvial boulder admixture but weathering rates seem so high within the soil that rock material does not survive for long.

Very deep soils (Arnhem, Cockatoo) occur on extensive sand plain areas (Queue I land system) on the plateau top, and these are commonly bordered on their lower margins where seepage is an important factor by paler-coloured seasonally wetter soils (Kapalga). Few pedological differences are observable between the Cockatoo and Arnhem soils under *Allosyncarpia* forest and those under eucalypt forest. Those which form under *Allosyncarpia* forest (mainly in Bedford land system) have been found to be 'moderately water-repellent' by R. D. Bond (personal communication). They also seem to have a cooler, moister and more stable soil climate. However, these factors are probably a result of the presence of the *Allosyncarpia* forest rather than a reason for the location of the forest in those areas.

In the more erosionally stable areas of the plateau significant drainage flats occur. These function as perennial aquifers and support dense stands of sedges. The soils are dominantly sandy with a thick organic mat (Buldiva) but in some areas that dry out for a short period the soils are loamy in texture and, though still sedge-dominated and organic, they exhibit ochrous mottling in the A horizons (Gilruth). Depressions in Honeycomb land system contain various soils, some of them yellowish clayey duplex soils (Honeycomb).

The clay in Gilruth and Honeycomb soils may have weathered from arkosic areas of the Kombolgie sandstone and accumulated in depressions and drainage floors. The clay in Honeycomb soils might also be related to a prior volcanic or other formation that once overlay the sandstones and has since been removed by erosion.

### (*b*) *Soils formed on Dolerite, Volcanics and Weathered Metamorphic Rocks*

Soils derived from these lithologies are predominantly clayey or loamy in texture. Topographically most areas of these soils are sloping, often steeply sloping, and many are boulder-strewn. The soils formed under the protective cover of a boulder layer in Viney land system are dark red strongly structured medium clays (Nungbalgarri). Where the boulder cover is absent on steep slopes the soils are skeletal. On lower slopes ($<5\%$) the soils are not boulder-strewn and are probably largely colluvial. The catena observed in this situation begins with reddish brown loamy soils (Zamu), followed by soils with yellowish brown or strong brown A horizons over mottled reddish B horizons (Zambina), with pale yellowish hydromorphic soils (undescribed) lowest in the sequence. This catena is not common, as these soils were not often observed on slopes less than 5%.

Other Zamu soils form in Ararat land system on high crest sites on micaceous schists that have been subjected to pre-weathering within the weathering zone of the younger weathered land surface. These intergrade with Nungbalgarri soils. Nungbalgarri soils also occur in these pre-weathered areas.

Where there are dykes of dolerite and related rocks (mainly in Ararat and Bend I land systems) soils of mixed origin occur. These are immature gravelly colluvial soils, usually reddish, and with some swelling clay in their subsoils (Howship). These soils are fairly common, but in steeper areas they become relatively less weathered and merge with the skeletal soils.

### (*c*) *Soils formed on Granite*

The most common soil formed on granitic rocks is a coarse gritty well-drained siliceous sand (Cullen). These soils are common in Cully I land system and are about 120 cm deep over weathering granite. On lower slopes or in contained pockets within the granite less well-drained versions of these coarse gritty sands occur (Cullen, poorly drained phase). Red podzolics (Malone) occur in some areas. Drainage-line soils in upper granite areas are aften layered and strongly leached, with bleached $A_2$ horizons and mottled, poorly drained subsoils (Scinto). However, in more stable areas humic gleys have formed where perennial sedges filter out the coarse sand fraction from the local colluvium, but allow clay to pass and accumulate in the drainage floor. Consequently the soils are pale greyish heavy kaolinitic clays overlain by a thick organic $A_1$ horizon (Koolpin).

### (*d*) *Soils formed on Estuarine Sediments*

The subcoastal plains appear basically to be old estuarine sediments extensively re-worked by the river systems. The original materials were probably fine sandy and silty marine muds containing shell fragments, and were mostly highly calcareous. During and after deposition, re-working by the rivers would have allowed selected flooding and leaching to occur and would have added some new material from the river catchments. Soil patterns would therefore be expected to be more complex than on a purely estuarine plain, but not as complex as in a purely fluvial situation.

The most common soil on the plains (in Cyperus I and Copeman I land systems) is a massive black clay, usually about 50–100 cm deep over olive-grey transitional calcareous marine material (Wildman). In some areas the soils have secondary carbonate accumulations (Carmor) and these are reported by Hooper (1969 and personal communication) to occur on slightly raised old levee situations. Near the edges of the plains in Pinwinkle I land system are humic gleys, with black organic medium clay A horizons with prominent ochrous mottling and pale gleyed subsoils (Dashwood). These soils have a distinct odour of hydrogen sulphide. They are inundated for most of the year, partly by flood-water from the river systems and partly by the increment of seepage water they receive from the adjoining sandy country. Wiesenboden soils also form in these situations (Counamoul).

Similar soils to the west of this area have been described as being formed in a freshwater clay layer overlying estuarine clay (Williams 1969), but evidence from this survey suggests that the soils are formed mainly in clays of marine origin. The soils on the plains are consistently about 90 cm deep and are probably of the order of 5000 years old. Production of this high apparent rate of aggradation (about 0·2 mm per year) would have required the presence of a large source of clay in the river catchments. However, no such source is readily apparent, and there is no evidence in the river levee sediments above the plains of the transport of large amounts of clay.

Many of the soils on the clay plain (particularly Carmor) are calcareous, and so usually is the underlying mud. The source of the carbonate is problematic. No substantial freshwater source is apparent and there is no evidence of carbonates in the river levees above the plains. It seems easier to postulate a marine source.

The occurrence of broad levees on the clay plains is consistent with the theory of their marine origin. Following exposure of the plains active re-working of the material by the rivers would have occurred. Seasonal increments of highly competent river-water and strong flows associated with tidal movements would bring the underlying calcareous muds into suspension and re-deposit them during floods onto broad levees. The presence of the more highly calcareous soils (Carmor) on some of the levees and near old river channels (Hooper 1969) suggests such a redistribution of the material.

More detailed studies including heavy mineral analyses are needed but the pedological evidence gathered so far also argues for a marine source of the clay. Clay mineral distribution was found by Day (unpublished report) to be very uniform to a depth of 150 cm on six profiles studied on similar plains to the west of this area. Texture analysis of both the main soil horizon and the underlying marine mud of one soil on the East Alligator plain shows great similarity—65% clay in each case, 21 and 23% silt, and 14 and 12% fine sand respectively (no coarse sand at all). Soil fabric as seen by the eye and × 10 magnification is also similar for the soil and the underlying marine mud.

Along the perimeter of the plains at seepage points in Kosher I land system another humic gley occurs. This soil also has black organic A horizons with prominently mottled, pale-coloured substrata (Murrabibbi), but it is much sandier than Dashwood or Counamoul soils.

The seaward edge of the plains (Littoral I land system) has a mangrove-dominated fringe with juvenile clay soils forming on recent marine alluvia (saline muds), and a second somewhat older treeless fringe of immature dark clays with a puffy saline surface (Carpentaria).

Beach ridges observed on the Cooper Creek plain were coarse, shelly and calcareous (Dune sands) and superimposed directly on Carpentaria soils. Elsewhere these soils are reported as sandy with only traces of shell (Hooper 1969; Day and Forster 1975; D. F. Howe, personal communication). They are commonly visible on aerial photographs for distances of several kilometres from the present shoreline (Williams 1969).

The structure of the dark clay soils on the estuarine plains is difficult to define, possibly because of the relative youth of the soils. The surface microrelief and structural features are largely obscured by hardened footprints and wallows made during the wet season by feral buffalo. Gilgai are only rarely evident in this area but the soils crack extensively when dry. The cracking pattern seems irregular, and peds cannot readily be identified by reference to the USDA (1951) system for describing structure. However, soil pits dug at the Coastal Plains Research Station in similar soils have revealed the presence of inclined systems of slickensides in lenticular or rhombic patterns (B. G. Williams, personal communication). These clays have been described here as having smooth-faced peds, for the purpose of applying Northcote's (1971) notation.

Similar clay plains have been observed by the author at Port Keats and Wagait where there are very few buffalo and by Day and Forster (1975) on Croker Island. These areas are flat, permanently wet and densely covered with para grass, *Oryza* sp. and *Hymenachne* sp., with shallow cracking clay and humic gley soils. It is possible that some parts of the northern continental coastal plains were like this too but have fairly recently been overgrazed, eroded, channelled and finally drained by feral buffalo and pigs, and that fires have subsequently encroached on the organic mat, leaving an apparently seasonally dry plain.

### (*e*) *Soils formed on Freshwater Alluvial Deposits*

The drainage-line soils of the Kombolgie sandstone and igneous areas have been described in preceding sections and will be dealt with only briefly here.

The soils of the freshwater drainage floors are highly variable. The parent materials of these soils vary with the nature of the catchment and the characteristics of the stream concerned, and with local topography which controls stream velocity and competence. The strongest pedogenic influences here have been vertical and lateral soil water movements, degree of soil wetness and the number of wet months per year. Vegetative cover has also had an important influence.

The wettest soils are the humic gleys, which have been described in sections (*a*), (*c*) and (*d*). Of these, Buldiva and Koolpin families are permanently wet and have highly organic peaty surface horizons. Murrabibbi and Gilruth families dry out for short periods seasonally, at least in their upper horizons, but are still distinctly hydromorphic.

Three other families are moistened by seepage for most of the year but their moisture supplies decline throughout the dry season. One of these is Leichhardt family, a highly organic earthy sand that forms in the back swamps of Effington I land system in catchments where igneous rocks and Kombolgie sandstone are both represented. Another is an organic silty brown earth (Argoolook) and its very organic homologue (Argoolook, organic phase). Argoolook soils form on the fine sandy and silty alluvial fan of the East Alligator River, where entry onto the relatively flat estuarine plain and consequent loss of competence have caused the river to deposit its suspended load. Analysis of soil from this fan shows the profiles to be composed of about 70% fine sand and 20% silt, while further upstream a sandy levee (Manbulloo) was dominated by 80–90% fine sand and had very little silt. A distributary pattern of relict channels, levees and back plains is still discernible on this fan but relief differences are minor and the soils are similar throughout. The organic phase of Argoolook soils forms under paperbark forests in back-plain situations in Effington I land system. The third family is an alluvial soil, with alternate coarse sandy aquifers and less permeable sandy clay layers (Barramundi).

Two sets of younger river terraces are evident along the major streams. The higher levees, mainly in Levee land system, have reddish gradational-textured soils (Katherine, some Edith) and the lower levees, mainly in Effington I land system, have paler-coloured highly erodable siliceous sands (Manbulloo).

Other drainage floors may have heavy clays (Brockman), yellow earths (McKinlay), alkaline loamy soils with conspicuous micaceous flakes (Myra), pale earthy sands (Baroalba) or greyish silty pulverulent material over dense gravels (Siltavel), depending on their geomorphic history.

### (*f*) *Soils formed in Lateritic Areas*

A variety of soils has formed in these areas, with red earths, siliceous sands, lateritic red and yellow earths and lithosols all represented.

Two deep sandy soils form on sand plains in the lateritic areas. One is a reddish gradational-textured soil with textures rising to sandy clay loam in the B horizons (Killuppa, in Queue I land system) and the other, which was observed only in the extreme south of the area, is a deep brownish siliceous sand (Sleisbeck, in Murray land system).

Lateritic red and yellow earths are common in several land systems. They are mostly formed by typical lateritic weathering processes and differences between them are mostly a matter of degree. In this classification the nomenclature of Hooper (1969) has been retained. These soils can form from a variety of parent materials and have been recorded on laterite, igneous rocks and Lower Proterozoic rocks. The ferruginous gravel in these profiles is probably partly inherited from the parent material where it is laterite, but would have been largely formed within the soil by lateritic weathering processes. The actual amount of gravel would depend upon the intensity of the weathering as well as on the nature of the parent material itself. Where laterite is the parent material and the weathering zone at the laterite interface is constantly moist for long periods, weathering will be intense and few gravels will survive, especially where the laterite is relatively soft. Gravel-free red earths may form under these circumstances.

In waterlogged soils the same conditions apply at the laterite interface and weathering would be intense. However, because of fluctuations in the water-table gravel will re-form at higher levels in the profile, become case-hardened, and after surface lowering by erosion will appear throughout the upper profile. These soils have distinct $A_2$ horizons and are close to the lateritic podzolics.

Where the weathering zone is less moist and is subjected to cycles of wetting and drying, weathering would be relatively less intense, case-hardening of gravels and laterite fragments will occur at the weathering interface, and a number of them would be expected to survive and ultimately appear within the soil profile or on its surface. These drier soil situations can be related to the degree of slope, which affects soil moisture by causing run-off and lateral drainage of moisture from within the soil. The soils formed under these circumstances are gravelly red or yellow earths or skeletal soils.

The lateritic red earths show a hydromorphic relationship, although it is not known to be a true catenary sequence. Hotham soils are gradational-textured, gravelly, red and well drained. Basedow soils are also gradational-textured and gravelly, but they have yellowish or brownish upper horizons and less red, slightly mottled subsoils and a moderate degree of drainage impedence. The other lateritic red earth family (Woolner) has somewhat sandier and more gravelly soils, with thick yellowish or brownish upper horizons and a strongly mottled yellowish red subsoil, and is imperfectly drained. This family is an intergrade with the red podzolic soils.

Only one family of lateritic yellow earths was observed. This family (Koolpinyah) has gradational-textured gravelly soils with brownish or yellowish colours throughout. Subsoils are mottled, but drainage is only moderately impeded. A shallow phase of Koolpinyah soils has also been recorded. These soils have predominantly sandy textures and they merge with the skeletal soils. Koolpinyah soils do not belong to the lateritic red earth hydromorphic sequence and it is possible that they form on different parent materials.

A family of deep, predominantly sandy yellow earths (Ramil) is of very minor importance in this area. These form mainly in colluvium in lateritic areas.

Two other gravelly lateritic soils occur within the survey area (Evelyn, Cahill). These are basically sandy soils and are well drained. Evelyn soils form either on the older gravelly levees (mapped in Queue I land system) or on laterite or lateritic detritus. They are partly gravel-free but have a dense gravel layer below about 80–100 cm.

Cahill soils occur most commonly in Kysto I land system in both unit 1 and unit 2. In unit 1 they overlie heavy clays but in unit 2 they overlie weathering micaceous rock. Some areas of Kysto I land system are thought to be underlain by steeply dipping alternating beds of micaceous schist and phyllite (S. Needham, personal communication) and it is possible that the different subsoils encountered represent these different lithologies. Clay mineral analysis of the heavy clay from unit 1 revealed 90% montmorillonite, which is probably a characteristic inherited from the phyllite.

### (g) *Soils formed on Siltstones and Fresh Micaceous Schists*

Topographically, most of these areas slope by more than 5% and the soils formed on them are shallow or skeletal. These soils occur mainly in Amhurst, Ararat, Baker I and Bend I land systems. The skeletal soils have pedogenically undifferentiated profiles with high amounts of siltstone fragments, and they merge with their parent rock at a depth of about 30 cm. In some areas an almost continuous cover of siltstone gravels affords a degree of protection from erosion and the soils are slightly deeper.

On lower slopes and in erosion-resistant areas moderately deep to shallow soils have formed (Partridge). These soils are gradational-textured, sometimes silty, well drained and generally yellowish. They have low to moderate amounts of micaceous or siliceous siltstone gravels throughout the profile with a siliceous veneer at the soil surface.

In Somerville land system where unweathered Lower Proterozoic shales and dolomitic sediments occur two other soils have formed. One is a deep red medium clay with a very good soil–water status (Mundogie) and the other is a yellowish mottled hydromorphic derivative of this soil (Yemelba).

Two other soils were recorded on siltstones in the area. One was a well-drained red earth (Emu) and the other an imperfectly drained silty yellow earth (Fisher). Neither soil is extensive.

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# PART VIII. VEGETATION OF THE ALLIGATOR RIVERS AREA

By R. STORY*

## I. INTRODUCTION

### (a) General

The nomenclature is applied in the same way as in the Adelaide–Alligator report (Story *et al.* 1969), and the relevant paragraph is quoted here for easy reference.

(1) Where only the generic name is given it refers to the genus in general, or to one particular species if only one is listed in Appendix II.

(2) The available common names of the plants mentioned are listed in Appendix II.

(3) *E.* is used throughout for *Eucalyptus*.

(4) Trees, shrubs and grasses are listed alphabetically if they are equally common, otherwise the most common come first.

Field work in the present survey area has shown that except for minor amendments the lowland vegetation is adequately catered for by the classification and description given in the Adelaide–Alligator report. The high country of the Arnhem Land plateau, however, which was scarcely touched upon in that survey and which is dramatically different in many ways from the lowlands, needs several new categories to cope with the additional vegetation. One can subdivide it to the point of utter confusion into community after community. We have decided to erect three structural formations to deal with all of them—*Allosyncarpia* forest, sandstone scrub and sandstone woodland. They and the vegetation of the lowlands are described in the sections that follow.

### (b) The Environment

(i) *Climate.*—This is monsoonal (see Part IV).

In the southern parts of Australia one finds unmistakable correlations of vegetation with temperature and wind as well as rainfall (Story 1969); here the apparent correlations are with rainfall only. Mean annual rainfall drops from about 1500 mm in the north to about 1300 in the south, and except on the Arnhem Land plateau the decrease is accompanied by a decrease in the height and frequency of the more moisture-demanding trees.

The anomaly shown by the Arnhem Land plateau is discussed in section II(*l*).

(ii) *Fire.*—The survey area is burnt piecemeal and irregularly, except for a few small areas. The effect on the non-eucalypt forests is discussed in section III(*b*, iv).

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We have no observations on the fire sensitivity of the eucalypt species. The *type* least often burnt is the tall open forest. This was clearly apparent from the helicopter after the widespread burning that had already taken place when we did the dry-season part of the survey, for many of the patches of tall open forest showed up as unburnt islands within the scorched and blackened woodlands that surrounded them.

TABLE 13

SEASONALITY AND HEIGHT OF GRASSES IN WOODLAND AND TALL OPEN FOREST

| | No. of samples | % Samples with dominant grasses | | | | | % Top cover of all grasses |
|---|---|---|---|---|---|---|---|
| | | Annual | Perennial | Tall | Mid-height | Short | |
| Woodland | 97 | 49 | 51 | 57 | 30 | 13 | 82 |
| Tall open forest | 47 | 56 | 44 | 45 | 35 | 20 | 57 |

The reason for their relative immunity is probably that the tall open forest grasses are too sparse and short to give a flame hot enough to scorch the leaves, and this is borne out by the fact that many such patches still have an unburnt floor, i.e. the grasses were too sparse even to maintain the fire. An additional factor is the greater height of the tall open forest trees than those of the woodland, which would put more of the foliage out of harm's way. The figures are given in Tables 13 and 14.

TABLE 14

NUMBERS AND DIMENSIONS OF TREES IN WOODLAND AND TALL OPEN FOREST

Diameter breast height 75 mm or more

| | No. of samples | No. per ha | Max. height (m) | Av. height (m) | Max. bole (m) | Av. bole (m) | Max. diam. (mm) | Av. diam. (mm) |
|---|---|---|---|---|---|---|---|---|
| Woodland | ±65* | 229 | 11·3 | 7·2 | 5·3 | 2·8 | 285 | 112 |
| Tall open forest | ±43* | 261 | 15·5 | 11·2 | 9·0 | 5·7 | 386 | 163 |

* A few samples have incomplete records.

(iii) *Animals.*—The position is as described in detail in the Adelaide–Alligator report, pages 116–17. The herbage is overall little utilized except on the alluvium and colluvium, where the influence of the buffalo overshadows that of all other grazing animals and where some grass-cutting termites are found.

(iv) *Edaphic factors.*—The relationships are discussed in Appendix III.

### (c) *Diagnostic Characters of the Vegetation Types*

For the purposes of this survey the vegetation is divided into 19 types. Seven fairly clear and unrelated types may be recognized, while the rest may be arranged in three groups with the members interconnected as shown in Fig. 19, i.e. savanna can grade into grassland or mixed scrub or woodland, and so on. For descriptive purposes the order in which they are arranged is of little consequence.

(1) *Tall open forest.*—evergreen eucalypts, *E. tetrodonta* and/or *E. miniata* dominant, canopy height over 13 m, visibility up to about 100 m, crowns mostly touching.

(2) *Mixed open forest*—non-eucalypts dominant, crowns mostly touching, often *Erythrophleum* and *Planchonia*, with *E. tetrodonta* and *E. miniata* and prostrate vines.

(3) *Woodland*—eucalypts usually dominant, some deciduous, crowns mostly separate, canopy height under 13 m, visibility 100–300 m.

(4) *Stunted woodland*—mainly deciduous eucalypts and non-eucalypts, crowns separate, canopy height under 7 m, visibility about 200 m.

(5) *Mixed scrub*—mainly evergreen non-eucalypts, with *Pandanus* and shrubs, height 8 m, visibility 60 m.

(6) Pandanus *scrub*—as for mixed scrub, *Pandanus* dominant.

(7) *Savanna*—scattered trees, height under 13 m, visibility over 400 m.

(8) *Grassland*—tall, mid-height or short grasses, heights 2, 1, and 0·3 m respectively.

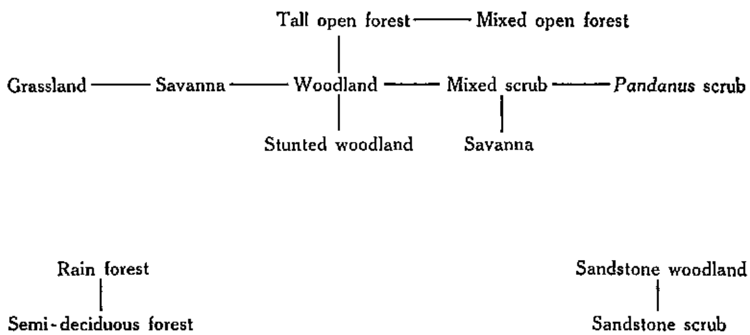


Fig. 19.—Relationships of some of the vegetation types.

(9) *Sandstone woodland*—evergreen eucalypts, commonly *E. miniata*, *E. dichromophloia* and *E. phoenicea* with members of the sandstone scrub, canopy height under 12 m, density very variable.

(10) *Sandstone scrub*—rich and varied flora of heath-like shrubs and spinifex, height and density very variable.

(11) *Rain forest*—rich flora of evergreen non-eucalypt trees, unbroken canopy, height up to 25 m.

(12) *Semi-deciduous forest*—rich flora of non-eucalypt trees, broken canopy, height under 13 m.

(13) Allosyncarpia *forest*—*Allosyncarpia* dominant, unbroken canopy, height about 12 m.

(14) *Paperbark forest*—*Melaleuca leucadendron* dominant, broken or unbroken canopy, height 17 m.

TABLE 15

VEGETATION TYPES IN THE LAND SYSTEMS

(Areas in km$^2$)

| Land system | Tall open forest | Mixed open forest | Woodland | Stunted woodland | Mixed scrub | *Pandanus* scrub | Grassland, savanna | Sandstone woodland | Sandstone scrub | Rain forest | Semi-deciduous forest | *Allosyncarpia* forest | Paperbark forest | Mangrove scrub | Leguminous-myrtaceous scrub | Sedgeland | Herbaceous swamp vegetation | Samphire | Bare, or scanty cover | Waterways | Not sampled | Mixture | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Amhurst | 95 | | 20 | | | | | | | | | 5 | | | | | | | | | | | 120 |
| Ararat | | | 185 | | | | | | | | | | | | | | | | | | | | 185 |
| Baker I | | | 245 | | | | | | | | | | | | | | | | | | | | 245 |
| Bedford | | | | | | | | 10 | 10 | | | 495 | | | | | | | 5 | | | | 520 |
| Bend I | | | 280 | | | | 15 | | | | | | | | | | | | | | | | 295 |
| Bundah | | | 85 | | 85 | | | | | | | | | | | | | | | | | | 170 |
| Buldiva I | 340 | | | | | | | 680 | 2715 | | | | | | | | | | 3060 | | | | 6795 |
| Copeman I | | | | | | | | | | | | | | | | 5 | 35 | | | 5 | | | 45 |
| Cully I | 15 | | 100 | | 5 | | 5 | | | | | | | | | | | | | | | | 125 |
| Currency I | | | 160 | | | | | | | | | | | | | | | | | | | | 160 |
| Cyperus I | | | | | | | | | | | | | | | | 80 | 30 | | 5 | 5 | | | 120 |
| Dual | 35 | | | | | | | | 5 | | | | | | | | | | | | | | 40 |
| Effington I | 30 | | 10 | | 70 | | 50 | | | | | | 50 | | | | | | | | | 140[1] | 350 |
| Explanado | | | 30 | | | | | | | | | | | | | | | | | | 5[3] | | 35 |
| Fabian I | | | | | | | 15 | | | | | | | | | | | | | | | | 15 |
| Flatwood I | | | 45 | | | | 45 | | | | | | | | | | | | | | 15[2] | 25[1] | 130 |
| Honeycomb | 10 | | 5 | | | | | | 25 | | | | | | | | | | 25 | | | 35[5] | 100 |
| Jay I | 25 | | 100 | | | | 5 | | | | | | | | | | | | | | | | 130 |
| Kay I | 210 | | | | | | 5 | | | | | | | | 5 | | | | | | 10[2] | | 230 |
| Klatt | 25 | | 10 | | | | | | | | | | | | | | | | | | | | 35 |
| Knifehandle I | 635 | | 710 | | 160 | | | | | | | | | | | | | | | | | 80[4] | 1585 |
| Kosher I | | | | | 25 | 25 | 20 | | | 1 | | | | | 5 | | | | | | | | 75 |
| Kysto I | 235 | | 265 | | 70 | | 15 | | | | | | | | | | | | | | | | 585 |
| Levee | 15 | | 10 | | | | | | | | | | | | | | | | | | | | 25 |

| | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Littoral I | | | | | | | | | | | 2 | | | 1 | | | | 2 | 5 | | | | 10 |
| McKinlay I | | | | | | | | | | | | | | | | | | | | | 30[1] | | 30 |
| Murray | | | 48 | | | | | | | | | 2 | | | | | | | | | | | 50 |
| Nova | | | 10 | | 5 | | | | | | | | | | | | | | | | | | 15 |
| Pinwinkle I | | | | | | | | | | | | | 9 | | | | | | 1 | | | | 10 |
| Queue I | 415 | | 50 | | 10 | | | | | | | | | | | 15 | | | | | | | 490 |
| Rumwaggon I | | | 4 | | | | 6 | | | | | | | | | | | | | | | | 10 |
| Somerville | 60 | 15 | 55 | | 15 | | 5 | | | | | | | | | | | | | | | | 150 |
| Valley | 35 | | 5 | | | | 5 | | | | | | | | | | | | | | | | 45 |
| Venlaw | | | 105 | 10 | 70 | | 10 | | | | | | | | | | | | | | | | 195 |
| Verity | | 65 | 95 | | | | 5 | | | | | | | | | 5 | | | | | | | 170 |
| Verrucose | | | 5 | 30 | | | | | | | | | | | | | | | | | | | 35 |
| Viney | | | 325 | 145 | | | 25 | | | | | | | | | | | | | | | | 495 |
| Total (rounded) | 2180 | 80 | 2960 | 185 | 515 | 25 | 230 | 690 | 2755 | < 5 | < 5 | 500 | 60 | < 5 | 10 | 105 | 65 | < 5 | 3100 | 10 | 60 | 280 | 13820 |

Estimated: 1. Paperbark forest, mixed scrub, savanna; 2. savanna/grassland; 3. woodland (eucalypts); 4. woodland, mixed scrub, savanna/grassland, sedgeland; 5. sedgeland, mixed scrub, sandstone woodland, tall open forest.

(15) *Mangrove scrub*—unbroken canopy, height 7 m, visibility 50 m or less.

(16) *Leguminous–myrtaceous scrub*—shrubs dominant and dense, height up to about 3 m.

(17) *Sedgeland*—Cyperaceae or Restionaceae dominant, height 0·6 m.

(18) *Herbaceous swamp vegetation.*

(19) *Samphire*—*Arthrocnemum* dominant.

The relation of vegetation types to land systems is shown in Table 15.

## II. Description of the Vegetation Types

### (*a*) *Tall Open Forest* (*2190 km*$^2$)

The distance between the easternmost occurrences of this type and those along the western border of the Adelaide–Alligator survey is more than 500 km, extending over a rainfall gradient of 1500 to about 1300 mm and over very distinct rock types (deeply weathered lateritic rocks and fresh quartz sandstone); yet the botanical differences are small and inconsistent. Those observed in the present survey were (*a*) the absence of *Cycas media* in the east (which is mentioned in the Adelaide–Alligator report) and rare occurrences of another *Cycas* species, (*b*) the increasing prominence of *Livistona loriphylla* to the east (C. S. Robinson, personal communication), (*c*) the prominence of *Acacia* below the canopy of the eastern forests, (*d*) the occasional and patchy occurrences of *Livistona* and *Pandanus* in the east as contrasted with the abundance reported in the Adelaide–Alligator survey and (*e*) the greater number of perennial grasses which make up 44% of the ground cover in place of the 25% of the Adelaide–Alligator survey.

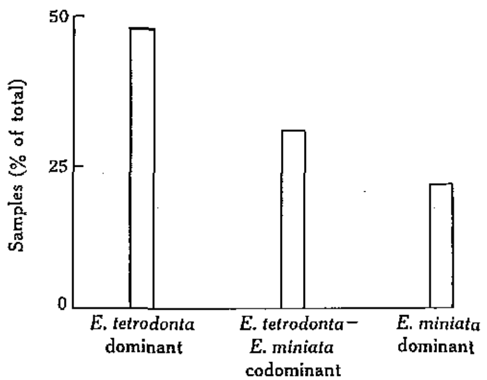


Fig. 20.—Dominance of the two diagnostic trees in tall open forest (85 samples).

For the rest, the account given in that survey is applicable here. In brief, tall open forest is dominated by *E. tetrodonta* and *E. miniata* in the proportions given in Fig. 20, usually about 11 m high and with some *Erythrophleum* contributing to the canopy. Smaller trees are abundant (*Acacia, Terminalia ferdinandiana, Xanthostemon, Planchonia, Petalostigma quadriloculare, Buchanania*), with grasses mainly annual, and variable in species, height and density. Puzzling features are evident in the distribution of the subordinate plants—in one place there will be striking concentrations of certain species while in another a few kilometres away these species will be absent; or one species which has hitherto been a constituent of every tall open forest patch will now occur erratically.

Tall open forest is usually on soils of lighter texture, and except on Amhurst land system nearly always on level ground or on slight rises. We observed no correlations between the geomorphology and the overall dominance of *E. tetrodonta* or *E. miniata* but did note that *E. tetrodonta* was commoner towards the centre of each patch. These two species are invariably dominant, singly or in combination, very rarely in combination with *E. dichromophloia* or *E. bleeseri*, and then mainly where the soils are shallow or rocky.

Tall open forest is absent from dolerite or volcanic rocks except where they are deeply weathered (Valley land system) or have an additional surface wash of sandy material. These situations are often marked by the presence of scattered broad-leaved bloodwoods or box below the canopy (*E. clavigera, E. confertiflora, E. latifolia, E. tectifica*). We recorded it on clay only in Somerville land system, and in an atypical form, namely with a ground cover of *Themeda* or *Sehima*, with broad-leaved bloodwoods, and lacking some of the ubiquitous non-eucalypt trees.

### (*b*) *Mixed Open Forest* (*80 km*$^2$)

This vegetation type has the same structure as the tall open forest but the non-eucalypts are dominant, usually as a mixture but otherwise with *Erythrophleum* dominant. The species are those of both the upper and lower layers of the tall open forest, that is *Terminalia, Buchanania, Gardenia, Planchonia, E. tetrodonta, E. miniata.* Also present are some trees foreign to the tall open forest, including figs, broad-leaved bloodwoods and box (*Ficus, E. confertiflora, E. setosa, E. tectifica*). Prostrate vines with *Ampelocissus* and legumes common among them constitute roughly half the ground cover and scramble also over the shrubs and seedling trees to a height of 2 m or so. Other vines include *Dioscorea, Smilax* and members of the Convolvulaceae and Asclepiadaceae. We recorded both annuals and perennials dominant in the grass cover, with no bias either way.

This mainly non-eucalypt mixture has about the same amount of canopy as the tall open forest but is prominently darker in its air-photo pattern. It covers only a small fraction of the survey area, being characteristic of some of the richer soils derived from dolerite or volcanic rocks, in particular on Verity land system. It occurs also in smaller patches here and there in Baker I, Cully I and Somerville. The break between it and the adjacent eucalypt-dominant communities is usually abrupt, with an equally abrupt soil difference (see Appendix III). Topography and climate do not appear to have any influence on its distribution.

The key character separating it from the rain forest, the semi-deciduous forest and the *Allosyncarpia* forest is the presence of the eucalypts.

### (*c*) *Woodland* (*2985 km*$^2$)

We have amplifications to make to the descriptions given in the Adelaide–Alligator report but no amendments except that some eucalypts were listed as deciduous in that report and almost none of these were leafless during the dry-season field work of the Alligator Rivers survey. However, among the deciduous species some are erratically deciduous and the rest drop their leaves late in the season (N. Byrnes, *personal communication*). The Adelaide–Alligator field work was completed one month later than our dry-season spell.

We still do not consider there is any point in erecting formal subdivisions of the woodland in view of differences in degree rather than in kind, at least at this scale of survey, and we have used instead descriptive words that are self-explanatory, namely eucalypt, non-eucalypt, mixed and open. The stunted woodland, however, is distinct and homogeneous enough to be treated separately, as in the Adelaide–Alligator report.

In its structure woodland is not nearly as uniform as tall open forest and is lower and more open (Table 14). Most of it is dominated by broad-leaved bloodwoods, less often non-eucalypts are dominant (*Erythrophleum*) or co-dominant with the eucalypts. Subordinate smaller trees are common and comprise those listed under the tall open forest.

The grass cover is a little denser than in tall open forest and contains more of the taller species, especially annual sorghum, which is in places up to 2 m high. In tall open forest the sorghum does not attain this size, but whether this is through stunting or because of some difference in species we cannot say. The comparison of the grass cover in general is given in Table 13.

Kysto I land system has an interesting striped air-photo pattern with narrow strips of tall open forest, generally on faint rises, alternating with narrow strips of woodland aligned along very shallow swales. The strips follow the strike of the underlying rocks with the forest as a rule on schists and the woodland on phyllites.

Detailed floristic studies would doubtless show many features that we missed on our survey, and establish reasons for those we did observe, e.g. sharply delimited occurrences of *E. pruinosa, E. grandifolia* and *E. alba.* We were able to carry a stage further the observation made on the Adelaide–Alligator survey that boxes (*E. patellaris* and *E. tectifica*) occurred only on shale—they occur on loamy soils regardless of their origin, as shown in Appendix III.

We are uncertain of the influence of lateritic gravels on the occurrence of woodland and tall open forest, for in some places abundant surface gravel supports woodland (Valley land system) and in others tall open forest (Klatt).

Like tall open forest, woodland reaches from near Darwin to the east of our survey area. In general, it occupies the slopes of undulating or rolling country in the western lowlands whatever the land system, being sandwiched between tall open forest on the tops of rises and scrub or grassland on colluvium and alluvium at the bottom of the sequence, e.g. Bundah, Cully I, Knifehandle I and Jay I land systems. In hilly country it extends over the ridges too, and further downslope, occupying nearly all the landscape, e.g. in Ararat, Baker I and Currency I land systems and the steeper parts of Bend I. One may infer that woodland soils are usually shallower than tall open forest soils, and on the ridges at least this is apparent from the air, as shown by a scanty grass cover with soil and rocks showing through.

### *(d) Stunted Woodland (185 km$^2$)*

This is a variant of the stunted woodland described in the Adelaide–Alligator report—similarly low and open and of crooked dwarfed trees, but with a dense grass cover. Either *E. foelscheana* or *E. latifolia* is dominant, often with scattered boxes (*E. tectifica*, *E. patellaris*) and *E. tetrodonta*. The non-eucalypt trees usually comprise *Hakea*, *Erythrophleum*, *Buchanania*, *Cochlospermum* and *Acacia*, and low shrubs are on the whole uncommon.

The only annual grass noted with any consistency was *Schizachyrium*, perennials being dominant without exception, nearly always *Sehima* or *Heteropogon triticeus* with several subordinates usually including *Sorghum plumosum*, *Chrysopogon*, *Coelorachis* and *Rottboellia*. Non-grass herbs are conspicuous and abundant during the wet season, with many prostrate vines which in places contribute more to the ground cover than do the grasses, but during the dry season their above-ground parts largely disappear. In this respect the Adelaide–Alligator report is probably incomplete, as this field work was confined to the dry season.

Stunted woodland is found mainly on soils derived from volcanic rocks. On the deep red clays that predominate in Viney land system *E. foelscheana* is the dominant tree, but on the lateritic red earths and sandy loams of Verrucose and Venlaw land systems the dominant is *E. latifolia*.

### (*e*) *Mixed Scrub* (*615 km*$^2$)

Except on the sandstone of the Kombolgie Formation mixed scrub is widespread and common on gentle slopes throughout the survey area. In terms of floristics and structure it is a variable and heterogeneous vegetation type which is not easy to subdivide. One distinct community (e.g. *Grevillea pteridifolia–Banksia*) will by small changes in floristic composition grade into another (e.g. *Melaleuca*) with only an artificial and arbitrary boundary between the two. The situation is made even more uncertain by structural changes grading from dense through more open communities to woodland, savanna and eventually grassland. For these reasons and because we consider it expedient to avoid confusion with the scheme adopted in the overlapping Adelaide–Alligator survey, we do not subdivide the mixed scrub into other vegetation types but discuss it in terms of the most common indicator plants which are present or not according to the type of parent rock or nature of the soil. The most definite correlations were as follows:

(i) *On Dry Sandy or Gravelly Soils.*—The general picture is one of shrubby deciduous non-eucalypt trees about 3 m high with a scattering of emergent eucalypts and smaller evergreen shrubs and a varied lower layer of annual or perennial grasses. Visibility fluctuates widely but probably averages about 50 m.

The commonest trees and shrubs are *Petalostigma quadriloculare*, *Acacia*, *Terminalia*, *Erythrophleum*, *Cochlospermum*, *Grevillea decurrens*, *E. tectifica* and *E. confertiflora*. The grasses include any of those recorded for the woodland, but *Sorghum stipoideum*, *Schizachyrium*, *Eriachne*, *Chrysopogon fallax* and *Sorghum plumosum* are the most common. Small annual and perennial sedges are ubiquitous.

These drier habitats support the most extensive areas of mixed scrub in the survey area.

(ii) *On Damp Sandy Soils.*—*Grevillea pteridifolia* and *Banksia dentata* are found in damp sandy places, often in unit 3 of Knifehandle I land system and unit 1 of Bundah, and often with *Melaleuca* (*M. nervosa* and other species). Communities in the ground flora are evidently more sensitive to edaphic factors than trees and shrubs since their boundaries are often sharp and striking without any corresponding change in the woody vegetation. In one area three equal bands were arranged along the contour, in descending order *Sorghum plumosum*, *Pseudopogonatherum–Platyzoma* and *Leptocarpus–Eriachne*. Ubiquitous members of the ground flora include *Chrysopogon*, small Cyperaceae, *Ectrosia*, *Eriachne triseta*, Restionaceae, *Schizachyrium* and small brightly flowering herbaceous plants. Common shrubs are *Verticordia* and *Xanthostemon*; *E. polycarpa* occurs as an occasional emergent tree.

Usually the sand is well drained but this appears to be incidental, for we recorded both diagnostic species on a poorly drained sandy clay as well. Local experience suggests that a constant or nearly constant supply of water is essential (J. M. Aldrick, personal communication).

(iii) *With Extreme Water Relations*.—The second situation appears where soils are waterlogged for at least the duration of the wet season, that is on alluvial flats, or with clay or laterite not far below the surface. Typical field notes are 'sand over impermeable clay pan, . . . seasonally inundated, silty over clay, . . . sand, too wet to auger beyond 55 cm, . . . poorly drained texture-contrast soils with pan of low permeability', etc. In such places *Melaleuca* is dominant, sometimes in pure communities (see also Robinson 1972). The two most common species are *M. viridiflora* and *M. nervosa*, probably in that order, but they are not easy to distinguish in the field. The trees average about 6 m in height, with rounded crowns and slender, twisted, sparingly branched stems that permit more visibility than is usual in other parts of the mixed scrub.

As most of the community is dense enough to be classified as scrub we shall avoid the rather extravagant formality of dealing with it also under woodland and savanna. The progressively more open communities referred to in the first paragraph under heading (*d*) relate to increasingly sluggish drainage and presumably to a gradually increasing clay content, for the grassland at the end of the sequence was recorded only on clay.

(iv) *On Volcanic Rocks*.—The *Grevillea* and *Banksia* of sandy soils were not recorded on volcanic rocks, nor were *Pandanus* or *Livistona*. They were recorded on Valley and Venlaw land systems nevertheless, but only where the rocks had been buried under outwash from adjoining sandstone. *Pandanus* does not seem to be linked with a particular soil texture, for we recorded it on both deep sands and clayey alluvial flats. However, the delimitation of the species is in doubt, and it may be that two species are involved.

### (*f*) Pandanus *Scrub* (*25 km*$^2$)

*Pandanus* scrub occurs in only a few parts of the survey area, namely on Kosher I and Knifehandle I land systems and on Flatwood I, in the lower reaches of Tin Camp Creek. The name is self-explanatory, and an account of the associated plants is given under the relevant headings on page 124 of the Adelaide–Alligator report.

### (*g*) *Savanna and Grassland* (*330 km*$^2$)

(i) *General*.—For the purposes of this report savanna is defined as a vegetation type consisting of scattered trees over grasses. The term grassland is self-explanatory.

At first sight this appears to be a reasonable classification, but in fact the grassland is so irregularly broken by scattered trees and clumps of trees as to preclude any clear subdivision under the two headings given above, and savanna and grassland are therefore grouped together according to the convention adopted in the Adelaide–Alligator report.

Spaces that would not generally be looked upon as anything more than glades are frequent, but most communities of any size are found on the alluvial land systems or on the alluvial strips associated with the remainder of the land systems.

(ii) *Trees*.—The savanna trees of our survey area are mainly non-eucalypts, of which the commonest are *Pandanus*, *Melaleuca*, *Tristania* and *Eugenia*. Eucalypts are represented mainly by sporadic occurrences of *E. polycarpa*, *E. papuana*, *E. alba* (or perhaps *E. bigalerita*) and *E. latifolia*. *E. alba* var. *australasica* is common on the fringes of the coastal plains (C. S. Robinson, personal communication).

(iii) *Grasses*.—The most meaningful classification of the grass communities appears to be based on annual or perennial habit rather than on height. This and differences observed between the communities of the Adelaide–Alligator and Alligator Rivers survey areas suggest modification of the arrangement set out on pages 128–9 of the Adelaide–Alligator report. The grasses are accordingly considered as follows.

(1) *Perennial grasses of riverine alluvium*.—Most are mid-height, but short grasses and sedges are always present and tall grasses usually, especially in association with bush clumps. As a rule, three or four of the following species will be present: *Eriachne burkittii*, *Themeda australis*, *Sorghum plumosum*, *Pseudopogonatherum*, *Alloteropsis*, *Ectrosia*, *Panicum*, *Heteropogon triticeus*, *Pseudoraphis*, *Ischaemum*, *Chrysopogon*, *Arundinella*, *Brachyachne*, *Capillipedium* and *Dichanthium*.

They usually grow on old back swamps or back plains with heavy-textured soils and somewhat impeded drainage, but we have one record of *Eriachne burkittii* and *Ischaemum* co-dominant with sedges on deep permanently moist sand covered by a 50-cm layer of peat.

(2) *Annual grasses of riverine alluvium*.—These are characteristic of freely draining sandy soils, but are uncommon, even in Buldiva I land system. Most are short grasses, but occasional patches of tall annual sorghum were encountered. We suspect that the short grasses may be secondary, for most of these areas showed unmistakable signs of trampling and grazing by buffalo. The main species recorded are: *Schizachyrium*, *Echinochloa colonum*, *Ectrosia*, *Digitaria*, *Panicum*, *Sorghum stipoideum*, *Eragrostis schultzii*, *Paspalum orbiculatum* and sedges.

(3) *Mixed grasses of riverine alluvium*.—Alluvial areas near main channels are unstable from sheet wash and gullying and are under patchy and hetereogeneous communities of different vegetation types, as one would expect. The grassy areas that occur are also patchy and heterogeneous, and very probably change in structure and species from year to year. They may include any of the species that have been listed in the previous two paragraphs.

(4) *Grasses of estuarine alluvium*.—As none of the native marsupials of the Northern Territory are aquatic, virtually all trampling and grazing in the estuarine

alluvium would have been done by water birds before the buffalo were liberated in about 1830. Since then, to judge from their hoof-prints, weight of numbers, dung and signs of grazing, the influence of the buffalo has been strong and far-reaching (Plate 15, Fig. 2). Because of the disturbance they cause it is not possible to present a comprehensive picture of the grass communities within the scope of this survey.

We did not record any of the three communities listed on page 129 of the Adelaide–Alligator report (*Ischaemum*, *Panicum*, *Panicum–Heteropogon contortus*), but sampled one of *Xerochloa* in a poorly drained calcareous depression near the mouth of Cooper Creek. The surrounding areas were under sedge, and slightly higher. Other grasses recorded elsewhere as individuals among sedges and water weeds were *Echinochloa colonum*, *Panicum*, *Paspalum*, *Hymenachne*, *Pseudoraphis*, *Oryza* and *Sorghum*. The scarcity of grasses is at variance with the dense growth and excellent grazing reported for the coastal plains in general by Christian and Stewart (1953). N. Byrnes (personal communication) states that in spite of searching he has been unable to find *Hymenachne* near Cannon Hill, where it was reported to be common in 1946 (Blake 1954).

It is unlikely that we would have overlooked many grass communities, for in the light of Adelaide–Alligator experience they are conspicuous from the air and most of the estuarine plains were seen in this way.

(5) *Grasses of the Arnhem Land plateau.*—Communities of spinifex are common in this area, and in the aggregate large, but as they are usually much fragmented by areas of bare rock and patches of sandstone scrub they do not figure in the land unit descriptions. Several species of *Plectrachne* and *Triodia* are involved, usually mixed with sedges and patches of *Micraira*. Their detailed requirements are little known since specific determination of all these grasses is difficult in the field.

### (*h*) *Sandstone Woodland* (*700 km²*)

This also is confined to Buldiva I land system, and may be looked upon as eucalypt woodland with an understorey of sandstone scrub. In view of the frequent outcrop and the broken nature of the country, figures listing trees to the hectare are not meaningful.

*E. miniata* is easily the most common tree, followed by *E. dichromophloia* and *E. phoenicea*. A little *E. polycarpa* is also present, and *E. herbertiana* very rarely. Another eucalypt, of which only one specimen was found, has so far not been identified. Usually the trees are widely spaced over level sandy areas with a ground cover of spinifex and shrubs of the sandstone scrub, and with scattered non-eucalypt trees commonly including *Pandanus*, *Owenia*, *Xanthostemon* and *Erythrophleum*. The tree cover becomes denser with deepening sand and grades eventually into tall open forest. On steeper slopes and where the sand is shallow this vegetation type grades into sandstone scrub.

### (*i*) *Sandstone Scrub* (*2755 km²*)

Sandstone scrub is confined to Buldiva I land system, where it is the predominant vegetation. In the broad sense it is a uniform type of heath-like vegetation growing on quartz sandstone. In detail it is an immensely varied type additionally complicated by the many different land forms into which the plateau has been cut. Areas of deeper sand usually support scattered trees but for the most part the scrub is a mixture of shrubs and spinifex, in places intimately mixed and in others in small separate communities. Among the tallest shrubs, and certainly the most common, are various species of *Acacia,* in places up to 3 m high and forming dense thickets, in others low or trailing and widely scattered. They are among the few shrubs that would be recognizable to the layman, and even they would present problems through the diversity of their life form and foliage. Members of the Leguminosae and Myrtaceae make up the bulk of the species growing in this scrub.

Annuals, including many ephemerals, are abundant everywhere during the wet season, otherwise sedges, spinifex and *Micraira* are the most common plants of the ground layer, most abundant respectively in areas of slow drainage, fairly shallow sand and very shallow sand. *Micraira* is an interesting and little-known genus of creeping grasses which includes several undescribed species. Most have hard spine-tipped leaves, but one found under damp overhangs has soft leaves without spines.

As is usual in sandy areas with adequate rainfall the flora is extremely rich, and the remoteness and inaccessibility of the plateau have hitherto prevented much botanical collecting.

### (*j*) *Rain Forest* (<5 $km^2$)

The essential features of this type are that it varies in height from 16 to 25 m, is dense, evergreen, luxuriant and floristically rich, and has an unbroken canopy over which scattered emergents may extend for another 8 m or so. It is found in scattered patches along a strip within about 30 km from the coast, nearly always on Kosher I land system and surrounded by mixed scrub or *Pandanus* scrub. A fuller description will be found on page 126 of the Adelaide–Alligator report. Specht (1970) suggests that they represent 'a former, more continuous distribution of these communities over much of eastern and northern Australia'.

### (*k*) *Semi-deciduous Forest* (<5 $km^2$)

This is described on page 127 of the Adelaide–Alligator report. It is a diminished version of the coastal rain forest, i.e. shorter, less dense, partly deciduous etc., and furthermore floristically different. Many of the trees branch near the ground or have several stems, varying in height from 1 to 13 m without perceptible layering. There is no satisfactory dividing line between trees and shrubs.

It has a wider range than the rain forest, from the dunes along the shore to rocky ravines and patches of scree in Baker I, Bend I and Buldiva I land systems, the patches being up to several hectares in size towards the coast but smaller and floristically different inland, and less common. Those on the dunes are bordered by mangrove scrub and samphire flats, those inland by sandstone scrub (Buldiva I land system) or eucalypt woodland (Baker I and Bend I land systems).

The shorter extremes of this type are very different from the best specimens of the rain forest, but a few patches do occur which have an intermediate character, with the deciduous trees scattered among the evergreens. They could be classified either way.

### (*l*) Allosyncarpia *Forest* (*500 km*$^2$)

One may distinguish this community from the rain forest and the semi-deciduous forest by the presence, and usually the dominance, of a species from an undescribed myrtaceous genus, a large and rather massive tree with glossy dark green leaves which are borne in threes. The maximum height we recorded was 22 m, diameter 1 m; the averages, however, were about 11 m and 25 cm. Although it is common on the Arnhem Land plateau and was first collected by W. Bateman in 1955, the early material was incomplete, and its affinities remained uncertain until the recent examination of flowering and fruiting specimens collected by L. Beens in 1965 and N. Byrnes in 1972. R. Schodde (personal communication) has observed that it flowers widely for several weeks at the beginning of the wet season (late October–mid November). The name *Allosyncarpia* has been provisionally allotted to it (L. Pedley, personal communication).

Although many of the *Allosyncarpia* forest patches consist of only this one tree species it is not the only evergreen non-eucalypt tree on the sandstone, nor is the classification absolute. Predominantly evergreen patches without it are found in some sheltered ravines, but they are negligible in this context. Of the other trees and shrubs occurring in *Allosyncarpia* forest, most are deciduous with the smaller species concentrated in rocky places where the canopy is diffuse or broken. Epiphytes are rare, but lianes and scramblers are frequent. We could determine none from these three groups except *Gardenia megasperma*, *Smilax* and *Flagellaria*. For practical purposes the *Allosyncarpia* forest has no plants in common with the sandstone scrub. It contains few herbaceous plants.

Besides the diagnostic tree we recorded the following: *Cryptocarya*, *Coelospermum*, *Alyxia*, *Ixora*, *Owenia*, *Myristica insipida*, *Pouteria serica*, *Tristania lactiflua*, an unkown palm, and probable *Antidesma*, *Brachychiton* and *Diospyros*.

By far the greatest number of the patches is in the more broken areas of the Kombolgie sandstone plateau of Arnhem Land. They stand out conspicuously in the aerial photographs but are often thinly spread in relation to the rocks, and thus difficult to map consistently. Sporadic patches are scattered also on the sand sheets of the plateau (unit 3 of Buldiva I land system) and we have a record from the pallid zone of the Mullaman Beds (unit 2 of Murray land system). They vary from dense patches with an unbroken canopy casting a deep shade and abundant litter to individual trees among the eucalypts.

The range extends throughout the Kombolgie sandstone of the survey area, with an outlier of rather stunted trees on Murray land system in the southern tip—a distance of nearly 200 km spanning a rainfall grading from about 1500 to 1300 mm. Neighbouring communities are sandstone scrub, sandstone woodland or tall open forest.

It is significant that we did not observe any stunting of the *Allosyncarpia* forest on the Kombolgie sandstone itself, although the projected rainfall gradient is the same as it is down to Murray land system. A probable explanation is that the Murray soil is from the pallid zone of weathered siltstone, of heavier texture than the Kombolgie sands. A statement by Simonett (1950) with reference to sand dunes near Castlereagh, N.S.W., is relevant here: 'Thus we can envisage a situation in which a decline in rainfall which would leave the pure sandstone flora relatively unscathed would be catastrophic for the vegetation of the shales, clayey drifts, and Nepean clays . . .'.

### (*m*) *Paperbark Forest (130 km²)*

Only minor differences were found between the forests of the Alligator Rivers survey and the very much more extensive areas described in the Adelaide–Alligator survey report. Those in the Alligator Rivers area consist of belts along the landward margins of the coastal plains, and are of dense communities of *Melaleuca leucadendron* up to 15 m high. We noted an additional feature in the forests fringing the large streams, that *M. argentea* is usually dominant in the main channels of the rivers, and other species along the smaller channels. All species play an important part in binding the soil along and in the channels with a mat of fine roots. It is likely that destruction of these trees would lead to scouring, not only along the swifter streams but also in the swamps, where they carry out the same protective function.

### (*n*) *Mangrove Scrub (<5 km²)*

Most of the saltwater mangrove scrub that could be influenced by the South and East Alligator flood-water falls outside our survey area. It extends from the boundary westwards along the coast in a ribbon of distinct bands of vegetation, fluctuating in combined width from a few metres to about 500 m and in number from 1 to 5, and varying floristically or in height and density according to their position and the amount of tidal flooding that they undergo. The lowest band averaged 1 m in height, the highest 3, with a maximum of 7 and a visibility of 25 m.

The scrub extends also up Cooper Creek for about 40 km along the channel and a little further up the East Alligator, say 50 km, to the neighbourhood of Cannon Hill. The South Alligator mangroves reach beyond the entry of Nourlangie Creek, a distance of about 80 km. These gradually increasing distances reflect the amount of low-lying country in the catchments, as may be seen from the topographical map.

Mangrove scrub occurs discontinuously along the river channels. It is generally absent on the high, steep, concave banks of meanders which are subject to scouring and erosion but present on the lower gently sloping convex banks where tidal flooding occurs regularly and where fine-grained sediments are accumulating. It also fringes narrow tidal creeks which cut through the levees and connect the flood basins behind to the main river channel.

In all, it does not cover more than a few square kilometres of the survey area but, as it is known to be an effective stabilizer of the tidal zone and to shelter a rich marine fauna (Macnae 1966), even this small area deserves more than the very superficial investigation we could allot to it. We examined it only on the banks of the East Alligator, where it had a structure essentially similar to that described in the Adelaide–Alligator report but was of three bands instead of five, respectively on the levee, the swale, and the slightly higher ground on and bordering a low dune under semi-deciduous forest. Only three genera were recorded, *Bruguiera*, *Rhizophora* and *Avicennia*, in that order from the dune to the water but with some overlapping of *Rhizophora* and *Avicennia* in the centre.

The freshwater mangrove (*Barringtonia acutangula*) is tolerant of stagnant water and swift currents and appears to have few limitations as to soil type since it was recorded on both sands and clays. However, we did not record it within Buldiva I land system, which indicates that the virtually pure sand of Buldiva I alluvium is not a suitable medium. It is never massed as the saltwater species are but is found in sparse communities and as scattered individuals along billabong margins and channels beyond the reach of the salt water.

### (*o*) *Leguminous–Myrtaceous Scrub (10 km²)*

This vegetation type too is infrequent in the survey area, being made up of scattered patches on thin gravelly soils associated with lateritic pavements, mainly in Klatt, Kosher I and Murray land systems. They are dominated by *Calytrix*, *Acacia*, and *Melaleuca acacioides*, with a rich flora of lower shrubs and a very sparse herbaceous cover of spinifex, sedges and short annual grasses.

### (*p*) *Sedgeland (130 km²)*

Like the grasses, the sedges are found as subordinate members of practically every vegetation type, and as considerable and fairly pure communities in their own right. The number of cyperaceous species recorded (55) was a little under half the number of grass species, which gives some indication of their importance.

Most sedgelands are on estuarine alluvium and as described in the following extract from the Adelaide–Alligator report: 'Sedges are the characteristic and dominant vegetation of Cyperus land system. They are up to 24 in. high and wiry or robust, and on nearly all the slightly higher and better-drained parts form a dense unbroken cover. They become mixed and diffuse in the lower and more waterlogged parts, and in this form extend into Copeman land system where they merge with the hygrophilous swamp vegetation. As the total number of species on the coastal plains is without doubt much greater than the number collected on survey, it would be pointless to say more than that *Cyperus*, *Eleocharis*, *Fuirena*, and *Scirpus* are among the genera represented. Individual grasses and widely scattered patches of *Sesbania* were recorded, but they were rare, and other non-sedges were inconsiderable.

'Trampling by buffalo is incidental, for the sedgelands do not provide any appreciable grazing.'

A few sedgelands are on riverine alluvium, with or without grasses in any proportion up to 50%, after which they are classified as grasslands. They are less robust than those of the estuarine alluvium, about 30 cm high, erect and usually dense, with a scattering of smaller herbs near ground level (*Drosera*, *Mitrasacme*, *Utricularia*, *Xyris*). Because of their dense growth they have a strong influence on the soil (see Part VII), and their unpalatability is an additional asset in making them a stable safeguard against erosion.

### (*q*) *Herbaceous Swamp Vegetation (65 km²)*

This is an unstable and patchy mixture of water-plants which varies according to the depth of flooding, speed of current and influence of buffalo. It is characteristic of Copeman I land system and of great importance for the animal life it directly or indirectly supports, and probably also for playing a part in the trapping of silt and in building up the soil, but its floristics and ecology are a specialized study that was beyond the scope of this survey.

A few of the commonest plants are listed on page 130 of the Adelaide–Alligator report.

*(r) Samphire (<5 km²)*

This occupies most of Littoral I land system. It is mainly of fleshy salt-tolerant plants dominated by *Arthrocnemum*, with an admixture of saltwater couch and sedges.

## III. Rain Forests as a Basis for Ecological Studies

### *(a) Introduction*

It is a general rule that monotypic forests occur in more extreme conditions, like the beech forests of subantarctic New Zealand, Australia and South America, the pine forests to the immediate south of the arctic circle, the paperbark forests of the northern Australian swamps and the brigalow forests on the clay plains of Queensland. On the other hand, tropical rain forests are nearly always floristically rich and without specific dominants. Webb and Tracey (1973), for example, state that on 1 ha of rain forest in northern Queensland there may be over 150 woody species.

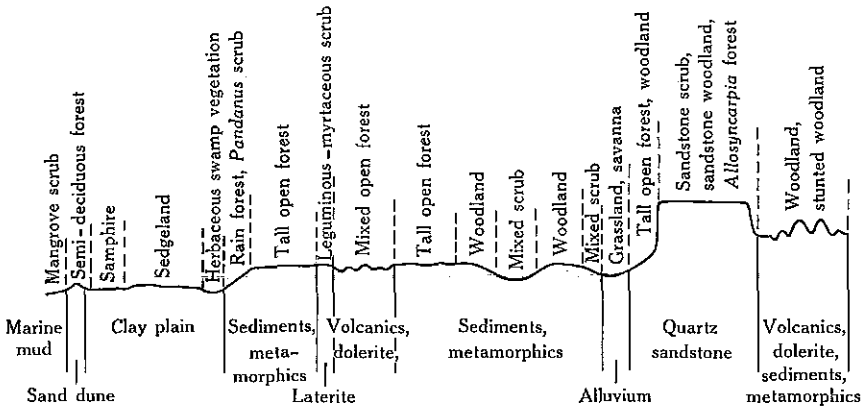


Fig. 21.—Disposition of the vegetation types.

Our survey area is peculiar in having a tropical monsoonal environment in which small but ecologically significant patches of floristically rich rain forest occur as well as larger areas of monotypic *Allosyncarpia* forest. Together and in the context of the surrounding vegetation they present an unusually wide range of interesting and informative features (Fig. 21).

L. J. Webb and C. Dunlop (personal communication) do not consider that *Allosyncarpia* forest should fall within the rain forest category. According to Richards (1952) and Schimper and von Faber (1935), points for its inclusion would be its deep closed canopy, the leathery dark green leaves of the diagnostic tree and the absence or rarity of deciduous components. Points for its inclusion would be its low height (average 11 m), the rarity of epiphytes and the fissured bark of the diagnostic tree.

*(b) The Situation in the Survey Area*

(i) *Climate.*—The rain forests, as their name implies, demand moist conditions; the eucalypts as a whole are far more adaptable (Story 1963). Herbert (1960) estimates that tropical and subtropical rain forest in Australia will grow where the annual rainfall approximates or exceeds 60 in. (1525 mm) a year, but only where the soils are suitable. However, Herbert is dealing with areas that have a fair amount of winter rain and our survey area has practically none (see Leeper 1970). The local rain forest would therefore need a higher compensatory rainfall to offset the seasonal drought, and Herbert mentions this point. Our maximum of 1500 mm of rain, the seasonal drought and the scattered occurrences of the rain forest make it fairly evident that the area is climatically marginal for it.

(ii) *Soils.*—As Webb (1969) and Tracey (1969) have pointed out, the details of soil and vegetation relationships are extremely complex and often contradictory. The broad picture is that the commonest parent rocks for rain forest soils are basalt, granite, andesite, acid volcanic rocks and fine-grained metamorphics (Isbell 1973), all of which produce some clay and plant nutrients. Webb (1968) has shown that in the absence of burning, adequate nutrients tip the balance in favour of rain forests where eucalypts would otherwise grow, but in our survey area this is not so. The rocks cited by Isbell all occur with the exception of basalt, and even this is represented by gabbro and dolerite which are closely related, yet we have found rain forest on none of them. It avoids the heavier soils that result from these rocks and grows instead on sand or podzolics derived from sedimentary rocks.

(iii) *Interrelationships.*—As has been stated, the differences between semi-deciduous forest and rain forest are sometimes indefinite; the *Allosyncarpia* forest on the other hand appears to be in a class of its own as is indicated by the notes that follow.

In respect of floristic richness the rain forests conform to those found throughout the tropics in general, while the *Allosyncarpia* forest is a curiosity which differs markedly in being monotypic or nearly so. It differs as well in its requirements, being less moisture-sensitive, so that besides growing in the sheltered and damper habitat of gorges and fissured rocky country it grows also, and in every respect normally, on north-facing hillsides and in fully exposed positions on gentle rises.

Our rain forest is anomalous in avoiding the rocks that support rain forests elsewhere. It is somewhat anomalous in its soils too, but only somewhat, since we found it growing on soils with at least some clay content. The anomaly of the *Allosyncarpia* forest is unqualified for it was on sand or rock, and we could not find any difference in the soils within this forest and under the adjacent eucalypts except for a slightly lower humus content where the eucalypts were. We recorded it also on pallid-zone clay, which is an exceptionally harsh environment for plants.

Most of these points indicate that *Allosyncarpia* forest is less discriminating in its habitat requirements and is adapted to severe conditions and, judging from our scanty observations, it seems fairly stable, with adequate regeneration through seedlings.

(iv) *Relationships with Eucalypts.*—We have no observations on the relationships of the rain forest and the eucalypts. As for the *Allosyncarpia* forest, we noted established seedlings of the diagnostic tree among and under the adjacent eucalypts and up to 50 m from the parent trees. We did not, however, find any eucalypts growing under the *Allosyncarpia* forest canopy or below scattered members of it, which is the general rule governing the relationships between mesophytic and sclerophyll vegetation (Cremer 1960). It appears therefore that the *Allosyncarpia* forest is not only secure against invasion but is also surrounded by a habitat into which it can and on occasion does extend at the expense of the eucalypts, and there seems no natural reason why it should not flourish under present-day conditions and spread over most of the plateau. One must therefore look for an imposed or unnatural reason for its very restricted range. Disturbance by animals is negligible, for the buffalo which are known to be destroyers of the rain forest, as has been pointed out in the Adelaide–Alligator report, do not frequent the Arnhem Land plateau. Frequent fires on the other hand are now part of the environment and probably the only answer. It is another general rule, which has been investigated for tropical Australia by Stocker (1971) and Webb (1968), that the rain forests give way to eucalypts in the face of regular burning. If one extends this rule to the Arnhem Land plateau one finds circumstantial evidence for it in the presence of most of the *Allosyncarpia* forest patches in fissured broken rocky country. Fires are not excluded even there, for of the seven we examined only one *Allosyncarpia* forest patch was found without charred indications of former fires; nevertheless, they would lose some of their effect and a total and severe burn would be a rarity.

(v) *Successional Position.*—In general, the undisturbed vegetation of a region is the most luxuriant it is capable of supporting, e.g. grassland will flourish where rain forest has been cleared, but if clearing, burning and heavy grazing are then withheld rain forest will re-establish itself. As the most luxuriant vegetation in the survey area is rain forest, the question naturally arises whether it would with time and without disturbance replace the *Allosyncarpia* forest and extend over the drier parts of the survey area. For the following reasons the answer appears to be no.

Firstly, Webb's observations (1968) show that oligotrophic soils, which are those deficient in nutrients, will support rain forest only if they are wet enough and are not burnt. This is to say that apart from the eucalypts no other than the highly specialized *Allosyncarpia* forest is likely to flourish on the Arnhem Land plateau with its extremely poor soils.

Secondly, the tallest and densest patch of rain forest on the Adelaide–Alligator survey was in the 1525-mm rainfall region near Koolpinyah, with a canopy height of 24 m. At the other extreme were a few open and low patches at Cahills Crossing, where by extrapolation from the Oenpelli records the rainfall would be about 1320 mm. These examples of small rainfall differences and large changes in the forests argue for a marginal situation with nothing to spare, for where the water supply is abundant a difference of 205 mm either way is of no great significance. This and the fact that the Cahills Crossing patches were at about the limit of the observed distribution indicates that any extension into the drier southern parts to the west of Arnhem Land plateau would be as unlikely as on the plateau itself.

Local water supplies may with fair safety be set aside in the examples cited, for two reasons. Firstly, the patches at Cahills Crossing are along distributaries of the

South Alligator and well watered, and secondly, local water supplies have surprisingly little influence in comparison with the climate. Desert springs and waterholes illustrate this.

(vi) *Soils and Water Relations.*—A broad but fairly clear correlation exists between the type of forest and the soil on which it grows, the picture in order of increasingly heavy soil texture being as follows.

At the sandy extreme is the *Allosyncarpia* forest on inert sands, then the semi-deciduous forest in similar situations, or on sands over clay, or on calcareous sands. The rain forest comes next, on podzolics, followed by the mixed open forest on loams and clay loams; and this is as far as the non-eucalypt or dominantly non-eucalypt forests extend—soils of heavier texture do not support them, with very few exceptions. A clear illustration is provided by the deep red medium clays of Viney land system which carry stunted woodland, indicating that they are a far more severe medium for tree growth than the clay loams, loams and sands of the forests. At the same time, their aspect of extreme aridity during the dry season and the contrasting luxuriance of their wet-season vegetation of perennial grasses and vines suggest the severity is not through a lack of nutrients in the soil but through moisture stress greater than usual during the dry season, stemming as much from the water-retaining capacity of the soil as from the rainfall regime.

The rainfall histogram of the Adelaide–Alligator report shows a gradual rise at the beginning of the rainy season and a tapering off at the end. Although the first rains may fall in August, only in November can one expect enough to break the dormancy of the grasses (Story 1969). Being shallow-rooted, they would utilize most of the light early-season rainfall before it reached the deeper roots of the trees (Story 1967). The trees would receive more water in sandy soil where some at least could percolate past before the grass roots utilized it, but would receive a great deal less in clay soils, both because of the relative slowness of the percolation and because of the much smaller amount of available water. There are many references on this subject. The paper by Smith (1949) is from a comparable tropical area of alternating dry and wet seasons and is probably most pertinent to our survey area. His work was in the Sudan, in a region of summer rain averaging from 380 to 890 mm. It illustrates how the sands compensate the vegetation for a low rainfall, and illustrates the contrastingly severe conditions imposed by the clays, e.g. 'Grasses sprout on the sands long before the early rains have restored the echard (non-available water) of adjoining clays and given a surplus of chresard (available water) which can initiate grass growth. . . . But the most striking and elementary fact in the distribution of Sudan trees, taking the country as a whole, is that the tree species which require 3x inches of rain on clay soils require less than 2x inches of rain on sands. . . . *Acacia senegal* which we have seen to have a belt occurrence on sands and another in higher rainfall on clays. . . .'

The incompatibility of clays with trees is striking on the heavy black cracking clays of the inland alluvial flats, treeless or with widely scattered trees. These flats, however, have the additional limitation of seasonal flooding, a factor which applies with even more force to the coastal plains (Cyperus I and Copeman I land systems) which are either treeless or support the specialized paperbark forest that is one of the exceptions referred to. Smith has also observed this relationship. 'The longer the seasonal inundation the "drier" the Acacia species required for successful plantation', and 'The more xerophytic types are in the hollows, even although these hollows are subject to flooding in the rains.'

Another exception consists of about a dozen patches of low evergreen non-eucalypt scrub on Viney land system near the abandoned Zamu mine, the biggest about 2 ha in size. We were unable to investigate them but, from their position and from similar occurrences in the survey area and elsewhere, we expect they are on boulder scree. This relationship occurs through a wide range of climates (Ellison 1954).

(vii) *Some Puzzling Features of the Ecology.*—The relationships of some of the plants and communities are difficult to explain. The more striking are the following.

(1) Why is semi-deciduous forest common on the sands of Littoral I land system, rare on those of Buldiva I and absent from those of Queue I?

Its rarity on those of Buldiva I is unlikely to be caused by any deficiency in the soil because where it does grow it is flourishing. The significant point is that its occurrences are not on the plateau itself but on boulder scree or in gullies. These are 'areas of compensation', like those discussed in connection with small inland occurrences of evergreen scrub, which, in some way as yet imperfectly understood, provide a less extreme habitat than the surroundings.

Its absence over Queue I correlates with a level or gently undulating surface without boulder scree or gullies. In Queue (in the Adelaide–Alligator area) it was recorded in only one place, on one of the northern extensions of Queue fronting on the estuarine plains near Cannon Hill, which to judge from the greater height and density of the eucalypt forests is an exceptionally well-favoured part of the land system.

The evidence thus indicates that it is not the sand that is an essential feature in its habitat but some compensation for conditions that would otherwise be too extreme for it. Better water relations and shelter from wind and fire may all contribute. N. Byrnes (personal communication) has pointed out that there would be no inflammable grass cover on scree, and fire starting inland would be hampered in its advance across the waterways and tidal samphire flats towards the coastal dune forests. Webb (1968) discusses in detail the implication of fire and of protection from it.

(2) Why are perennial grasses dominant on clayey soils and annuals on sandy soils? The points discussed in section III(*b*)(vi) suggest that the water relations of these two contrasting soil types are more likely to provide an explanation than their chemical composition, and Daubenmire (1972) draws the same conclusion from his work on the distribution of grass communities in a very different environment (eastern Washington). If this hypothesis is accepted the argument may be presented as follows. The Adelaide–Alligator rainfall histograms indicate that parts of the beginning and end of the rainy season are critical for plant growth. Evidence has already been given to show that the adverse effect would be greater on clayey than on sandy soils, which is in agreement with the observation by Lazarides *et al.* (1965) that reproductive development of annual sorghum (*S. stipoideum*) takes two weeks longer on Manbulloo sandy loam than on Blain sand. These two soils are not very different in texture, but water would be more freely available in the Blain soil because of its coarser sand (J. M. Aldrick,

personal communication). Lazarides *et al.* (1965) also point out that annuals must complete their life cycle well within the average length of the growing season if the species is to survive, and (as would naturally follow) that of the annual and perennial grasses they studied, 'The major distinguishing feature was the earlier completion of reproductive development by annuals'. The logical outcome of this is that the annuals run an increasingly greater risk of extinction with increasingly heavy soil texture.

While the foregoing may explain the scarcity of annuals on clay it does not explain the scarcity of perennials on sand. Competition for water is an unlikely reason since perennials are less affected by the early shortage which is a standing threat to annuals, and since copious water is available over the rest of the rainy season. Competition for light is also unlikely since the competing annuals would be mostly *Sorghum stipoideum* which although tall, abundant and quick-growing is not leafy and produces only about four tillers per plant (Lazarides *et al.* 1965).

Many possible reasons exist singly or in combination, but further investigation would entail observational and experimental work beyond the scope of this survey.

(3) Why is spinifex exceptional in being a perennial restricted to sands? Again there appears to be no answer except that it is specialized and simply does not conform. It is rare except on the Arnhem Land plateau, and even there it grows mostly on the shallower sand lenses among flat rock outcrops where conditions are not far removed from those of the bare rock which can store no water at all. In other words it seems that spinifex is extremely drought-resistant, will grow where most other grasses cannot, and is unable to compete with the more luxuriant vegetation that grows in moister places.

In behaviour it is closely similar to most of the species of *Micraira*. They, however, were recorded only on the Arnhem Land plateau.

(4) Why are the annual grasses *Schizachyrium* and *Thaumastochloa* exceptional in growing not only on sand but also on raised dry loamy areas and laterite pavements with very little soil, the last two habitats being liable to acute shortages of water? A possible explanation is that their growing season may be even shorter than that of most annuals, since they grow to a matter of 20 cm in contrast to the 2 m or more of the annual sorghum referred to by Lazarides *et al.* (1965). If this is so they are virtually ephemerals and independent of the deficiencies of soil moisture that have been discussed.

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# PART IX. EROSION IN THE ALLIGATOR RIVERS AREA

By M. A. J. Williams*

## I. Introduction

The Alligator Rivers area, comprising western Arnhem Land and the eastern third of the Adelaide–Alligator survey area (Story *et al.* 1969), is a remote, rugged and little-known region for which long-term climatic and hydrological records are virtually lacking. The climate is monsoonal, with a hot wet summer and a longer dry season. Over 90% of the rain falls during the 5 months from October to March, when almost all the erosion occurs. Although the rapid growth of annual grasses during the wet season alleviates the erosive impact of the rains, deep soils are absent from slopes steeper than about 5% (Williams 1969*a*), indicating that even on moderate slopes unprotected soils are vulnerable to erosion. The aim of this account is to consider certain results obtained from monitoring hill slope erosion in four localities in the Adelaide–Alligator area since 1965, and to apply some of the conclusions derived from this work to the Alligator Rivers area. Two of the localities were on granite and two were on greywacke sandstone of Lower Proterozoic age. The two granite areas were mostly on Cullen land system, but each had minor elements of Currency land system. The sandstone areas contained equal proportions of land units belonging to Baker, Bend and Rumwaggon land systems, notably the steep rocky hill slopes, the gentle foot slopes and the alluvial flats. These four practically undisturbed areas are physiographically very similar to the same land systems in the Alligator Rivers area. In the absence of further observations, conclusions derived from the one survey area have been applied to the other. The work reported here is based upon 9 visits and nearly 16 months of field work between May 1965 and July 1974, supplemented by aerial-photograph interpretation and associated land system mapping of the Alligator Rivers area by the writer during May 1972 and May 1973.

## II. Processes of Erosion

Six erosional processes may be distinguished in the survey area. For clarity they are listed separately, but in practice it is often hard to isolate the net effects of any one process. The processes are mass movement (which may be slow as in soil creep, or rapid as in landslides), rain-splash, overland flow, throughflow, gully erosion and fluvial erosion. Given the lack of a deep regolith on steep slopes, rapid mass movement is rare in this region, although the slower forms of mass movement (soil creep and surface rock creep) are important. Erosion by rain-splash is a major agent of soil detachment, and is particularly rapid at the onset of the wet season when bare soil is exposed to heavy convectional downpours. Erosion by overland flow depends upon slope length and gradient, soil type, rainfall amount and intensity, surface cover and

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land use. During the wet season, throughflow, the lateral movement of soil water downslope, is active. Throughflow is often a precursor to soil piping, as well as a cause of subsurface mechanical and chemical eluviation. Gully erosion is conspicuous along certain rivers, and gullies are often located along former cattle and buffalo tracks. Fluvial erosion is highly seasonal, with maximum sediment transport during the height of the wet season (February–March) when peak flows occur.

## III. Experimental Methods

Rates of erosion were monitored on 15 granite and 11 sandstone slopes in an attempt to provide at least some answers to certain important questions.

What is the seasonal variation in the rate of hill slope erosion?

How far does the plant cover reduce the erosive impact of rain?

What is the relative importance of soil movement by overland flow and soil creep on slopes on two dominant lithological types, granite and sandstone?

What factors control erosion by rain-splash, overland flow, soil creep and surface rock creep?

The results apply specifically only to the four localities monitored, and are limited by the very brief period of observation (1965–68 for overland flow, 1965–73 for soil creep), the monitoring techniques used and the small total number of observations. However, there are no other comparable measurements available for this region, so the results of this exploratory study of hill slope erosion must suffice until there are.

The methods used were standard and are well described in the literature. Young pits were used to measure soil creep (Kirkby 1967; Williams 1973). Wash trays were used to measure erosion by overland flow (Young 1960), except that in this study the trays were set in the soil so that the upper lip was flush with the soil surface rather than inserted into the topsoil, and the trays were built without a cover. Since all the hills studied were roughly conical, as opposed to linear, the catchment area of each tray was estimated at $0 \cdot 5WD$ where $W$ is tray width and $D$ is distance from the summit. Surface rock creep was monitored by using six fixed reference nails, each 15 cm long, hammered vertically into the ground on either side of a row of about 20 painted stones aligned parallel to the contour (Williams 1974). Rain-splash erosion was measured by the use of steel-framed run-off plots identical to those described by Costin and Gilmour (1970). Each plot was 3·05 m long and 1·83 m wide, i.e. 10 ft by 6 ft. The frame excludes all outside run-off from the enclosed area so that, except after very heavy rain, run-off is minimal within each plot. The method does not measure erosion by rain-splash alone, but does reduce the contribution of run-off erosion by reducing the distance of flow within the plot. Measurable soil loss occurred within the plots even when there was no perceptible run-off.

## IV. Results

### (a) *Seasonal Changes in Rain-splash and Run-off Erosion on Granite Slopes*

Rainfall intensity and duration, run-off, soil moisture content and soil movement were measured during and after each rain storm at two fixed run-off plots located on a long gentle granite slope on Cully I land system. One plot, situated upslope, was on a slope of 1°20′; the lower plot was on a 3° slope. Results obtained from the lower plot between 4 and 22 February 1967 are shown on Fig. 22. Rainfall is total rainfall in one rain storm, and soil loss is the volume of soil moved from the plot during the storm and trapped in the covered tray at the foot of each plot. The greater the rainfall the greater the volume of soil moved downslope by the combined action of rain-splash and run-off within the plot.

Since a heavy rain of short duration may be more erosive than a light rain of longer duration, although the total amount of rainfall may be similar in both cases, rainfall totals alone are a poor guide to likely erosion. An effort was therefore made to measure total raindrop momentum, which as Rose (1960) demonstrated is a significant factor in soil particle detachment. Raindrop size was measured by the flour pellet

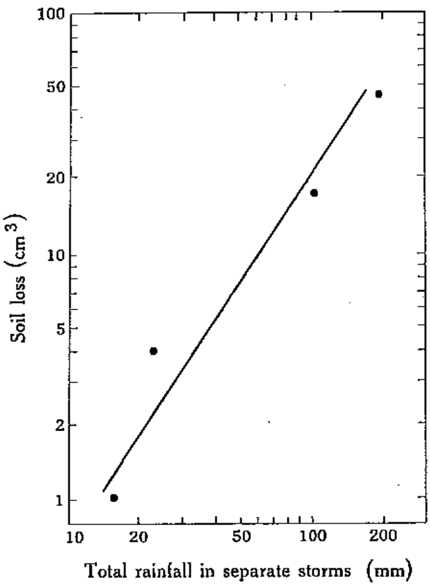


Fig. 22.—Rainfall and soil loss on a 5·6 m² plot on granite slopes near Brocks Creek during February 1967.

technique (Hudson 1963), calibrated using Hudson's conversion chart; and drop momentum was calculated for 0·25-mm drop size intervals by summing the products of terminal velocity and mass for the total number of drops in each size class. Terminal velocity was obtained using data from Best (1950) and Laws and Parsons (1943). Drops were assumed to be falling vertically with minimal disturbance from wind.

Two immediate conclusions may be drawn from Fig. 23 which gives the results obtained from the lower plot during 2 discrete periods of about 20 days each—the middle of the 1966/67 wet season, and the start of the 1967/68 wet season. Firstly, soil loss increased with total momentum within each period. Secondly, and perhaps more significantly, soil loss was over 30 times greater at the onset of the wet season for the same unit momentum of rainfall than during the middle of the wet season. When results from both the plots were averaged, soil loss per unit momentum was 20 times greater during November–December than during February.

These results clearly relate to the cover of grass protecting the soil. At the beginning of the wet season, when the grass cover was sparse to absent, rainfall of a given intensity caused 20 times more erosion than at the height of the season when grass cover attained its fullest development, in this case 35–40 % cover.

As the wet season progresses there is also an increase in rainfall intensity, expressed as rainfall per 24 hours, and, since total rainfall momentum is significantly related to rainfall intensity (Williams 1969*b*), the February rains would in fact be a great deal more erosive than the December rains were it not for the rapid seasonal growth of the grass cover. The data so far collected suggest that the effect of the increased protection afforded by grass cover as the wet season advances exceeds the effect of the increase in erosive potential due to rainfall intensity.

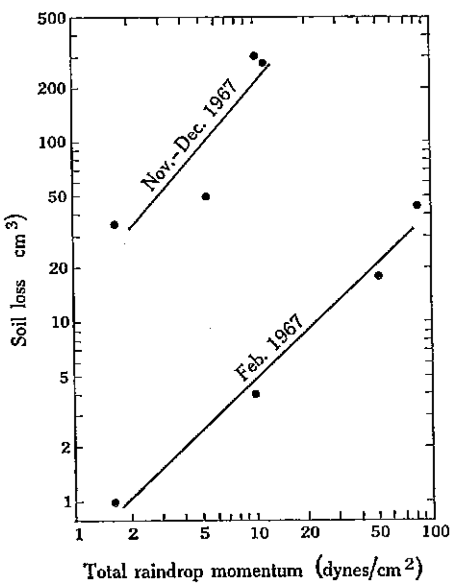


Fig. 23.—Raindrop momentum and soil loss at the start and during the middle of the wet season on a $5 \cdot 6\ m^2$ plot on granite slopes near Brocks Creek.

It is perhaps worth noting that after four years of soil loss studies in a part of Rhodesia climatically similar to the survey area, Hudson (1957) concluded that 'in almost all seasons more than half the total annual erosion will occur in the one or two heaviest storms of the year. In extreme cases, three-quarters of the year's soil loss will occur in ten minutes.

### (*b*) *Erosion by Overland Flow on Sandstone Slopes*

The volume of soil retained in wash trays on unconfined slopes was measured at nine sites during three wet seasons. Five sites were on stone-covered hill slopes and four were on stone-free colluvial–alluvial foot slopes. When slope angle was plotted against the percentage of total length of all measured slope segments (Fig. 24), the characteristic angles thus obtained were 11° for the hill slopes, 5° for the foot slopes and 0·5° for the alluvial flats. Mean annual soil loss from the foot slope sites amounted to 1850 $cm^3$, or nearly three times that from the hill slope sites, where the mean was

680 $cm^3$. There are at least four likely reasons for the lower rates of hill slope erosion and the faster rates of erosion on the colluvial–alluvial foot slopes.

The hill slope soils are more permeable, so that run-off is less upslope than on the lower less permeable slopes.

The stone mantles on the hill slopes protect the soil from erosion by raindrop impact.

The colluvial–alluvial soils flanking the hills are texture-contrast soils in which the topsoils become saturated and cohesionless during the wet season.

Return flow or seepage near the base of the rocky permeable hills augments run-off on the lower slopes.

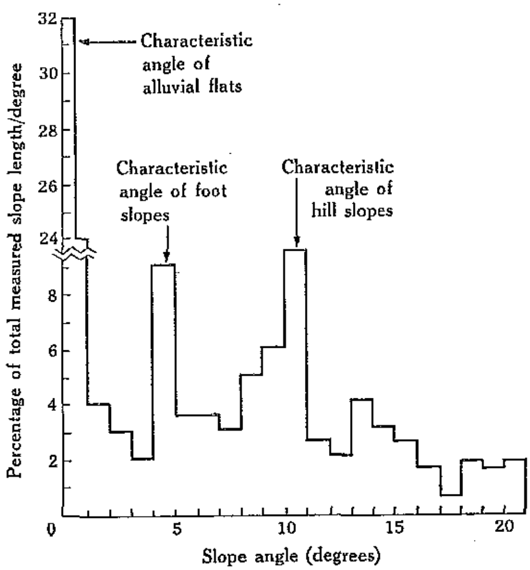


Fig. 24.—Histogram of slope frequency classes on monitored sandstone slopes.

## (c) *Erosion by Overland Flow on Granite Slopes*

On the gentle granite slopes of the two study areas on Cully land system soil loss increased with slope angle, and was greatest on the more convex slopes, where minor gullying and spring-sapping were also sporadically active. In one of the two areas recent rejuvenation and drainage incision were reflected in steep lower slopes, and there was a distinct tendency for erosion to increase with distance downslope. In addition, the volume and erosive power of run-off were increased by return flow on the lower steeper slopes during the wet season. Erosion, therefore, increased with distance downslope on both granite and sandstone slopes but for somewhat different reasons in each case.

## (d) *Soil Creep on Sandstone Slopes*

Although the erosion induced by catastrophic events is always spectacular, erosion by events of low magnitude but high frequency is also significant, though far from obvious. As the wet season progresses, the percentage area covered by grass increases and erosion by rain-splash diminishes, but the saturated ground becomes more prone to creep and other more rapid forms of mass movement. Creep is aided by any factor that disturbs the arrangement of particles within the soil, whether physical, biological or man-induced. During 1965–68 the mean volume of soil moved downslope on 10 monitored sites amounted to $4 \cdot 4\ cm^3\ cm^{-1}\ yr^{-1}$. The rate of creep decreased very rapidly with depth. Significant movement took place on both hill slopes and gentle foot slopes. The mean volume of soil moved downslope by overland flow during the same period was $22 \cdot 9\ cm^3\ cm^{-1}\ yr^{-1}$, or $5 \cdot 2$ times more (Williams 1973).

### (*e*) *Soil Creep on Granite Slopes*

As on the sandstone slopes, creep diminished exponentially with depth in the two granite study areas. The mean rate of creep at 15 sites amounted to $7 \cdot 3\ cm^3\ cm^{-1}\ yr^{-1}$ during 1965–68, which was five times slower than the corresponding rate of soil movement downslope under the influence of rain-splash and overland flow, which came to $36 \cdot 3\ cm^3\ cm^{-1}\ yr^{-1}$. Over half the variation in creep on both sandstone and granite was statistically attributable to the six factors, distance downslope, sine of slope angle, soil depth, percentage clay, percentage sand and slope convexity, no one factor being predominant. (Following Young (1963), slope curvature was obtained by dividing the distance to the nearest point of inflexion upslope by the angular difference between the segments; it was expressed as the difference in degrees per 33 m length.) Seasonal and local differences in plant root growth, termite activity, soil type and variations in soil moisture are probably responsible for the variable rate of creep.

### (*f*) *The Erosional Efficacy of Soil Creep and Run-off Erosion*

The efficacy of erosion may be expressed in two ways. One is to record the volume of soil moved past a given point each year, expressed as $cm^3\ cm^{-1}\ yr^{-1}$. The other is to calculate the mean rate of surface lowering by dividing the volume of material moved by the surface area from which the sediment is thought to have come. Method 2 involves the unproven assumption that all the sediment is derived from the total area upslope, and the resulting sediment yield is usually expressed as a volume per unit area, in $m^3\ km^{-2}\ yr^{-1}$, equivalent to slope lowering in mm $10^{-3}$ yr.

Method 1 shows that overland flow annually moved $5 \cdot 2$ times more sediment downslope on sandstone and $5 \cdot 0$ times more on granite than did soil creep during 1965–68. The rate of surface lowering effected by soil creep was 18 mm $10^{-3}$ yr on granite and 11 mm $10^{-3}$ yr on sandstone. Corresponding mean rates of lowering resulting from overland flow were 54 mm $10^{-3}$ yr on granite and 56 mm $10^{-3}$ yr on sandstone. To summarize, run-off erosion lowered the surface 3 and 5 times faster than soil creep on granite and sandstone slopes respectively (Williams 1973).

### (*g*) *Surface Rock Creep on Sandstone Slopes*

Although the protective cover of lag gravels found in many areas seems superficially to be remarkably stable, measurements of groups of 20 painted stones at each of 24 sites on sandstone slopes show that the surface stones are moving at mean rates of up to 4 cm/yr, and at maximum rates of 10–40 cm/yr, the percentage of stones moving at any one site increasing linearly with the sine of the slope angle (Williams 1974). Fig. 25 shows measured rates of surface stone movement in arid Arizona, semi-arid Colorado and seasonally wet Northern Territory. The stone sizes were 0·8–2·5 cm, 2–5 cm and 2–8 cm respectively in each. In all these areas, the steeper the slope the faster the rate of rock creep. A corollary to this is that on steep slopes a disturbed stone layer will regenerate far more rapidly than on gentle slopes, provided suitable disintegrated source rocks are exposed. Thus removal of lag gravels for ballast or road-building from slopes of 3° or less could actually cause more erosion than removal from steeper slopes.

### (*h*) *Accelerated Erosion*

Three striking instances of erosion accelerated by man were observed, one at Jabiru mining camp in the survey area, the second on the Stuart Highway north of Adelaide River township and the third on Cully land system near Brocks Creek in the Adelaide–Alligator area.

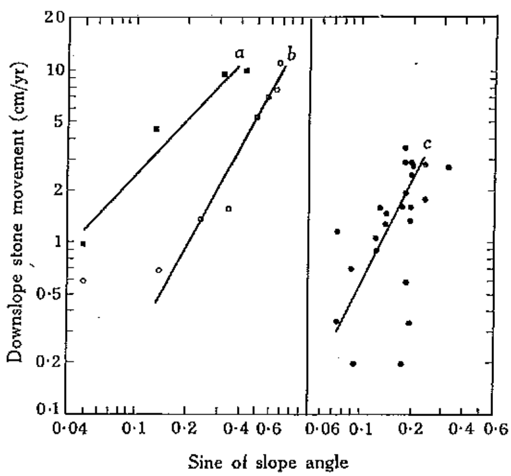


Fig. 25.—Surface rock creep and slope inclination: (*a*) in arid Arizona (after Kirkby in Carson and Kirkby 1972, p. 203); (*b*) in semi-arid Colorado (after Schumm 1964); (*c*) on sandstone hill slopes in the Adelaide–Alligator area.

In late August 1973, the writer and M. F. Clarke mapped a small alluvial fan at the mouth of a man-made gully draining from the track near Jabiru mining camp to the freshwater lagoon east of the camp: the camp had been used for two years only. The gully was eroded into an initially shallow man-made drain which split in two 120 m above the lagoon. The fan had a volume of *c*. 100 $m^3$ and was built of coarse angular quartz sand. The gully system had an area of *c*. 800 $m^2$ and a mean depth of *c*. 17·5 cm. It was cut into lateritized colluvium and deeply weathered *in situ* Lower Proterozoic metasediments rich in vein quartz. The bulk of the fan material seemed to stem from the gully, indicating a sediment yield of 100 $m^3$ from 800 $m^2$, or roughly 62 500 $m^3\ km^{-2}\ yr^{-1}$, a value which represents vastly accelerated erosion, a possible trebling of the initial depth of the drain and a trebling of its volume, all within two wet seasons.

Owing to the dearth of soil on slopes of more than 5%, and the well-drained sandy or gravelly nature of soils on all but the gentlest of other slopes, slides, slumps and mud-flows are normally very uncommon in this area. However, the undercutting of weathered phyllites and mudstones by widening the Stuart Highway north of Adelaide River township will undoubtedly generate rock slides during the 1973/74 wet season,* because the slopes exposed in the road cutting are far steeper than the natural slopes developed on this material, and some slumping was taking place even during the dry season. The characteristic hill slope angle on Lower Proterozoic sandstones and siltstones is 11°, an angle controlled by the residual shear strength of the weathered siltstone. Hill slope declivities range from 5 to 21°, the steeper slopes coinciding with the more massive quartz-rich sandstones. To build embankments or dig cuttings in relatively weak material with slopes over 11° is to invite slumping, gullying and rock slides.

Rock falls are also common around the Arnhem Land escarpment, and stem from tensional cracks developed in the sandstone cliffs as a result of erosional sapping of the underlying less resistant weathered Lower Proterozoic schists and metasediments. A similar process of undercutting and collapse is responsible for the retreat of laterite breakaways. Where a massive ironstone capping overlies the Lower Cretaceous sandstones and mudstones, the steep slope below the ironstone scarp is littered with very large tilted blocks of ironstone that have broken away from the free face. Sporadic in time and place, such a process is geologically slow, amounting to a scarp retreat of perhaps 1 metre every 1000 years, and is unlikely to be greatly accelerated by man.

In one of the two granite study areas, on which mean soil loss during the 1966/67 wet season was $87 \cdot 6$ m$^3$/km$^2$, 11 m$^3$/km$^2$ were eroded within 36 hours during February 19 and 20, 1967, when 135 mm of rain fell at Brocks Creek during the passage of a cyclone. Large boulders embedded in the stream banks were carried several scores of metres, and as stream levels fell small gullies which had previously been completely stable eroded headward by a combination of undercutting at the gully head, piping or subsurface tunnel erosion, and collapse. Vehicle tracks became streams, and wheel tracks were gullied to depths of 15 cm for distances of up to 100 m. Given prior disturbance of the surface, such an event would trigger off gully erosion even in hitherto stable areas, so that road-building and bush-clearing operations need to be planned with the possibility of cyclonic rain in mind. If we regard cyclonic rain as any rainfall in excess of 100 mm/day, severe erosion may be expected once in every two years in any area disturbed by man.

### (*i*) *Summary of Results*

The results discussed above may now be enumerated, with brief mention of certain implications.

(1) As the wet season progresses and the grass cover increases, there is less soil loss per unit momentum of rainfall. At the onset of the wet season soil loss per unit momentum of rainfall may be 20–40 times greater than during the middle of the wet season. These results were derived from gentle granite slopes with sandy topsoils.

* This prediction, made in October 1973, was borne out during the 1973/74 wet season, when the road was blocked for several days.

(2) Soil loss caused by run-off erosion on sandstone hills was three times greater on the gentle, stone-free colluvial–alluvial foot slopes than on the steep rocky hill slopes. The main reason lay in the protective action of the hill slope stone mantle.

(3) Erosion resulting from overland flow on low convex granite hills was greatest on the steep lower slopes. As on the sandstone foot slopes, surface run-off was augmented downslope by lateral seepage.

(4) The ratio of surface lowering effected by overland flow to that caused by soil creep was approximately 3 : 1 on granite slopes and 5 : 1 on sandstone slopes.

(5) Surface movement of stones on sandstone was least on gentle slopes and increased linearly with the sine of the angle of slope.

(6) Disturbance of the natural vegetation may accelerate the natural rate of erosion 100-fold or even 1000-fold, particularly if the plant cover is destroyed during the wet season.

(7) The characteristic slope angle for weathered sandstone–shale hills is 11°. Where road cuttings in weathered rock of similar lithology exceed this angle rapid mass movement may result.

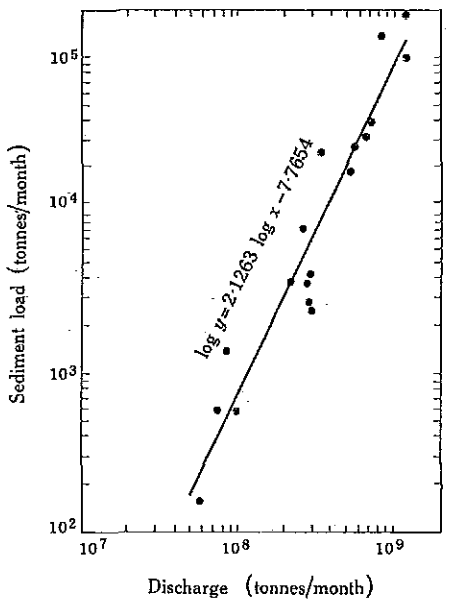


Fig. 26.—Discharge and sediment load, Adelaide River ($r$ = 0·919 with 17 degrees of freedom, and is significant at the 0·001 level).

## V. Fluvial Erosion

Douglas (1967) has shown that sediment yields from rivers in eastern Australia are far higher in seasonally wet northern Queensland than in south-east New South Wales with a more evenly distributed rainfall, and elsewhere in the world peak rates of denudation also coincide with seasonally wet monsoonal environments. Even in the absence of long-term measurements of river load and discharge we may conclude *a priori* that fluvial erosion is very effective in the survey area. The limited available factual data support this conclusion.

Using sparse data kindly supplied by the Water Resources Branch in Darwin, gauge height was related to measured discharge at Adelaide River township. Monthly discharge was estimated from monthly gauge height to give a rough estimate of mean monthly discharge during 1964–1968. Measured sediment concentrations were converted to sediment load (in tonnes/month) and plotted against discharge (Fig. 26). The relationship was highly significant. Mean monthly sediment yield was estimated from the calculated regression line using the monthly discharge values obtained previously. The results were plotted as a sedihydrogram in Fig. 27 (Wilson 1972).

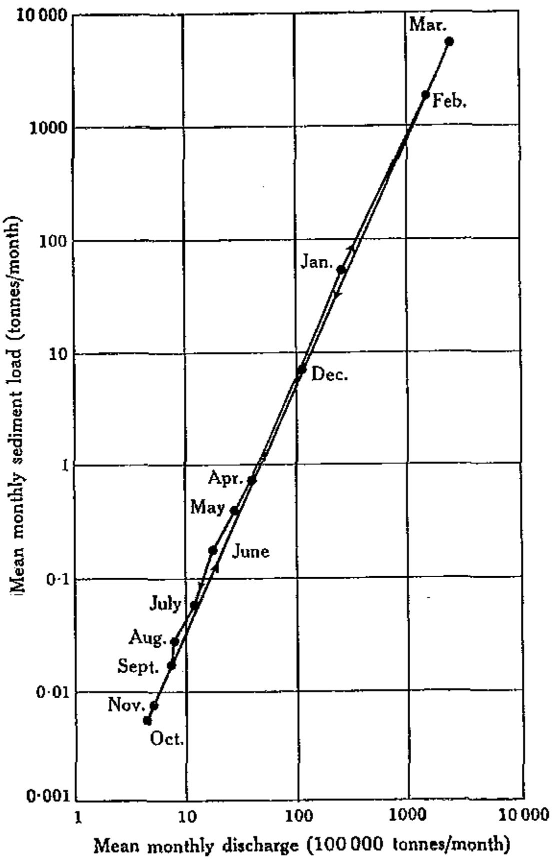


Fig. 27.—Sedihydrogram for the Adelaide River at Adelaide River township, 1964–68. The catchment area is roughly 660 km².

Discharge increased from a minimum of *c.* $35 \times 10^4$ tonnes/month in October to a maximum of *c.* $231 \times 10^6$ tonnes/month in March. Sediment load fluctuated more widely than discharge, increasing from *c.* 0·006 tonnes/month in October to *c.* 4800 tonnes/month in March. These values should be treated as crude approximations until checked against measurements for a much longer time span. The general trend of the sedihydrogram is probably correct and shows that sediment yield increases extremely rapidly between November and December and less rapidly thereafter, discharge increasing also but at a lower rate. This pattern of high erosion rates at the onset of the wet season reflects the initially rapid rates of slope-wash when plant cover is at a minimum. Sediment load increases progressively throughout the wet season owing to more frequent and heavier rainfall, greater discharge and greater erosive and transporting capacity. The sedihydrogram of the Adelaide River is probably very

TABLE 16

LAND SYSTEMS AND EROSION STATUS

| Lithology | Land system | Natural erosion status* | Erosion hazards |
|---|---|---|---|
| Quartz sandstone (Kombolgie Formation) | Buldiva I | A1, C1 | A2 |
| | Bedford | A1, C1 | A2, B1 |
| | Dual | A1 | A2 |
| | Honeycomb | A1 | A1 |
| | Amhurst | A1, C1 | A2, B1, C2 |
| | Bundah | A1 | A2, B1 |
| Volcanics and dolerite | Valley | A1 | A2, B1 |
| | Venlaw | A1 | A2, B1 |
| | Verity | A1, B1 | A2, B2 |
| | Viney | A1 | A2, B2 |
| | Verrucose | A2 | A3 |
| Weathered metamorphic and sedimentary rocks | Kay I | A1 | A2 |
| | Knifehandle I | A2 | A3, B1 |
| | Jay I | A2 | A3, B1 |
| | Kysto I | A1 | A2 |
| | Nova | A1 | A2 |
| | Explanado | A1, B3 (local) | A2, B3 |
| | Kosher I | A2 | A3, B1 |
| | Klatt | C1 | — |
| | Murray | A1, B1, C1 | A2, B2 |
| | Rumwaggon I | A1, B1 | A2, B2 |
| Fresh metamorphic and sedimentary rocks | Bend I | A1 | A2, B1 |
| | Baker I | A2, B1 | A3, B1 |
| | Ararat | A1 | A2, B1 |
| | Somerville | A2, B2 | A3, B3 |
| Fresh granite | Cully I | A2 | A3, B1 |
| | Currency I | A1 | A2 |
| Sand sheets | Queue I | A1 | A2, B1 |
| Fluvial deposits | Levee | A1 | A2, B1 |
| | Flatwood I | A1 | A2, B1 |
| | Fabian I | A1, B1 | A2, B2 |
| | Effington I | A1, B1 | A2, B2 |
| | McKinlay I | A2, B1 | A3, B3 |
| Coastal plains | Cyperus I | A1, B1 | B2 |
| | Copeman I | — | A1 |
| | Pinwinkle I | — | — |
| | Littoral I | A1, B1 | A2, B2 |

* A, sheet erosion; B, gully erosion; C, mass movement; 1, minor; 2, moderate; 3, severe.

similar to those of the Daly River and the Alligator Rivers, and may be considered typical of stream erosional regimes in the seasonally wet tropics of the Northern Territory, a region of regular and reliable but highly seasonal rain.

## VI. Deposition of Eroded Material

Erosion inevitably implies deposition elsewhere. The products of long-term geological erosion are removed from the area and ultimately deposited below sea level on the continental shelf and beyond. In the shorter term, much of the eroded material is deposited within the area in narrow alluvial tracts and on the coastal plains. Such depositional sites, particularly those with ponded or impeded drainage, impermeable clays and minimal slopes, are likely to present problems through the accumulation of toxic wastes if these are allowed to enter the drainage system.

It is not clear where the plentiful alluvial sand of the river beds is deposited: presumably it is carried well out to sea, as there are no extensive coastal sand plains and the rather limited dunes are composed mainly of shell sand, not quartz.

## VII. Land Systems and Erosion

The experimental results discussed in section IV apply specifically to Cully I land system (granite) and Baker I, Bend I and Rumwaggon I land systems (sandstone–shale hills and associated alluvium). Some of the more general principles stated in section IV(*i*) apply to almost any of the erosional land systems in the survey area, and the comments on the seasonality of river erosion (section V) and the deposition of eroded material (section VI) are valid well outside the two survey areas.

Table 16 is an attempt to summarize, in a qualitative and necessarily tentative fashion, some of the field observations made about erosion on particular land systems during the surveys of the Adelaide–Alligator and Alligator Rivers areas. It is based in part on Parts III, IV and VII of this report, in part on the writer's field observations since May 1965 and in part on observations made and passed on to the writer by officers of the Land Resources and Land Conservation Sections of the Agriculture and Animal Industry Branch of the Department of the Northern Territory, Darwin, between May 1968 and July 1974. The main aim of Table 16 is to focus the attention of field workers in the Northern Territory upon possible erosional processes likely to be common within particular land systems, by providing an estimate of the current natural erosional status and the possible erosion hazards of each land system. The land systems are grouped according to dominant lithology as in the reference to the land system map.

A protective lag gravel covers most of the hilly land systems, and outcrops of bare rock further reduce the easily erodable areas. Boulders and scattered outcrops occupy 65% of Baker I land system and stony quartz gravel a further 25%. A protective layer of ferruginous gravel and minor quartz gravel also covers up to half the lowlands and markedly reduces slope-wash erosion. On Kosher I land system, 65% of the surface may be covered in ironstone gravels with weathered sandstone fragments on the steeper middle and lower slopes. Mixed quartz and sedimentary gravels occur on up to 95% of Knifehandle I and Bend I land systems, 85% of Klatt land system and 35% of Kysto I. Disturbance of this protective mantle would probably lead to severe sheet erosion on Baker I, Kosher I and Knifehandle I land systems.

Gully erosion of alluvial flats, probably related in some degree to grazing and trampling by buffalo and cattle, has been noticed particularly in Ararat, Bend I, Explanado and Kysto I land systems.

The land systems most vulnerable to erosion are Verrucose, Cully I, Explanado, Somerville and McKinlay I. The least susceptible are those on the plateau and on the coastal plains. The remainder are prone to minor or moderate slope-wash, occasional gullying and rare minor mass movement. If disturbed, they become increasingly subject to slope-wash and local moderate gully erosion.

## VIII. Conclusions and Implications

The survey area has a markedly seasonal tropical climate, with five very wet months followed by seven very dry months. As a consequence, both fluvial and hill slope erosion are also highly seasonal, with peak discharge and peak sediment loads in February–March at the height of the wet season. Hill slope erosion is more severe at the start of the wet season, when raindrop impact and run-off detach and move soil particles downhill into the adjacent dry stream channels. Sediment thus deposited is removed later in the wet season, when the growth of herbage and grasses curtails the sediment supply from the hill slopes. That erosion is severe in this environment is demonstrated in two ways: there are no deep soils on slopes steeper than about 5%, and many of the soils on gentler slopes are protected from erosion by a layer of fine gravel, itself a lag deposit resulting from prior erosion. Periodic cyclones pass through the area, and there is a likelihood of very heavy rainfall and concomitant severe erosion roughly one year in two. Roads or tracks built along the base of hills in this area will be especially prone to erosion. Not only are the gentle, stone-free foot slopes a great deal more vulnerable to rain-splash and run-off erosion than the steeper but boulder-mantled hill slopes, but creep and return flow are also active along the base of the hills, Since the tracks in this region tend to skirt the steeper slopes sheet erosion is accelerated still further, culminating in washouts and gullying of the roads during the wet season.

Closer settlement of the survey area need not cause a drastic increase in erosion, provided there is minimal destruction of the plant cover. However, if extensive areas of bare soil are exposed as a result of mining, road-building and construction, an increase in erosion by a factor between 20 and 100 is almost certain to occur in the disturbed areas.

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# PART X. LAND USE IN THE ALLIGATOR RIVERS AREA

By J. M. ALDRICK* and R. STORY†

## I. HISTORY OF LAND USE

Although the Alligator Rivers area has been occupied by Aboriginal tribes for over 25 000 years, few white men were in evidence until the early 1800s. During the establishment of the early white settlements in the 1820s to 1840s, Banteng cattle, buffalo, pigs and cattle tick were introduced.

The main industry that followed during the 1880s and persisted into the 1960s was the shooting of buffalo for hides. Paddy Cahill, a renowned buffalo hide trader, established a property at Oenpelli in 1906. This was purchased by the Commonwealth in 1916 and converted to an agricultural experimental station, but was abandoned three years later. Then, in 1920, the Arnhem Land Aboriginal Reserve was declared.

Uranium was found at El Sherana in 1953, and as access to the region improved in the 1960s further mineral exploration was undertaken.

In the south of the area two pastoral leases were issued, Goodparla in 1961 and Gimbat in 1962. Both leases intrude only nominally into this survey area.

A proposal for the establishment of a national park in the Alligator Rivers area was made by the Northern Territory Reserves Board in 1965, and in 1969 a modified proposal was approved in principle, although no specific boundaries for the park were agreed on.

With the establishment of two pastoral leases to the west of the survey area in 1969 (Mudginberri and Munmarlary), the cattle industry grew and extended into this area, particularly at Oenpelli. The shooting of buffalo for hides had tapered off but initial interest grew in these animals as a source of meat for pets and later for humans. Domestication of the buffalo began as a result.

The discovery of a major uranium deposit at Nabarlek was announced by Queensland Mines in 1970. Since then more uranium has been discovered, and a regional townsite has been proposed for an area north-west of Mt Brockman. Two areas of scenic, ethnic and archaeological interest (Jim Jim Falls and Deaf Adder Gorge) were reserved from mining and associated activities in 1971, and much of the area proposed for a national park was declared a wildlife sanctuary in 1972. A small reserve was also established on Waterfall Creek, near El Sherana.

## II. PRESENT LAND USE

Beef cattle are run on an extensive system on the two pastoral leases (Goodparla and Gimbat) which intrude slightly into the southern part of the survey area, and there

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is a herd of about 1700 head at Oenpelli. Some pasture improvement has also been undertaken at Oenpelli. However, the beef industry has gained very little impetus in the area.

Feral buffalo abound in the north, particularly on the coastal plains along Cooper Creek and the East Alligator River. They do extremely well among the swamps and away from them but have caused and are causing significant ecological changes. The wetlands, which are favoured habitats for wildfowl and naturally fragile areas floristically, have suffered damage to both plants and soil, particularly where the buffalo increase to the point of starvation, as they have been known to do (Tulloch 1967).

In recent years efforts to domesticate and control buffalo have been made at Oenpelli and a buffalo-meat abattoir has been set up. However, the buffalo industry is at present of only moderate significance to the region as a whole.

At the time of this survey the whole of the survey area was held under mineral exploration licences and exploration was proceeding over most of it. Within the wildlife sanctuary (part of the area proposed for a national park), the Aboriginal reserve and other areas, vehicle tracks, drilling sites and some costeans were in evidence. Some very valuable uranium deposits have been located and it is predicted that more will be found.

The tourist industry is not yet well established. Apart from an area near where the Oenpelli road crosses the East Alligator River, few parts of the region have been penetrated by tourist operators. Private excursions by residents of Darwin and other centres do occur and these have resulted in the establishment of vehicle tracks, fires and some litter. However, the presence of the Arnhem Land Aboriginal Reserve and the newly formed wildlife sanctuary have restricted private excursions.

## III. Types of Grazing Country (Pasture Lands)

Well over half the survey area is unsuitable for any form of grazing, with our present knowledge, and as the remainder is with few exceptions dominated by trees and shrubs, with rank, uneven and patchy grasses, the term *pasture* is a little misleading in its lush connotation. Only extensive methods of grazing can be envisaged.

A valuable feature of the summer herbage is the widespread occurrence of herbaceous legumes, including species of *Tephrosia*, *Psoralea*, *Desmodium*, *Stylosanthes*, *Eriosema*, *Glycine*, *Rhynchosia*, *Galactia*, *Uraria* and *Zornia*. All die back in the dry season and would then contribute very little to the feed even where they are especially abundant.

As an aid to broad policy decisions the land systems have been combined into eight groups each roughly uniform in the quality of its grazing (Table 17). Six of them are common to the Adelaide–Alligator area as well, and are dealt with in more detail in Part IX of that report. All have been grouped according to the same scheme, which is briefly as follows.

The grasses are taken in four main groups, namely woodland and forest grasses (tall and mid-height annuals and perennials), scrub grasses (mid-height and short annuals and perennials), grasses of the alluvium and grasses of loams and clays (mid-height perennials) and swamp grasses (a palatable and specialized mixture). Land

TABLE 17

CHARACTERISTICS OF PASTURE LANDS

| Pasture land no. | Main grass communities | Topography | Relative grazing value | Constituent land systems | Area ($km^2$) | Proportion of grass communities* (%) (a) | (b) | (c) | (d) | (e) |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Woodland and forest grasses (tall and mid-height annuals and perennials) | Level to slightly hilly | Good wet season; poor dry season | Dual | 40 | 90 | | | | 10 |
| | | | | Explanado | 35 | 100 | | | | |
| | | | | Kay I | 230 | 90 | 5 | 5 | | |
| | | | | Klatt | 35 | 95 | | | | 5 |
| | | | | Kysto I | 585 | 85 | 10 | 5 | | |
| | | | | Levee | 25 | 100 | | | | |
| | | | | Queue I | 490 | 95 | | 5 | | |
| 2 | Woodland and forest grasses (tall and mid-height annuals and perennials | Hilly | Good wet season; poor dry season | Ararat | 185 | 100 | | | | |
| | | | | Baker I | 245 | 100 | | | | |
| | | | | Bend I | 295 | 95 | | 5 | | |
| | | | | Cully I | 125 | 90 | 5 | 5 | | |
| | | | | Currency I | 160 | 100 | | | | |
| | | | | Jay I | 130 | 95 | | 5 | | |
| | | | | Venlaw | 195 | | | | | |
| | | | | Verrucose | 35 | | | | | |
| 3 | As for 1, plus scrub grasses (short annuals and perennials) | Hilly | Good wet season; fair dry season | Bundah | 170 | 25 | 75 | | | |
| | | | | Knifehandle I | 1585 | 85 | 15 | | | |
| | | | | Nova | 15 | 50 | 50 | | | |
| | | | | Valley | 45 | 85 | 10 | 5 | | |
| 4 | Grasses of the alluvium (mid-height perennials) but very variable | Flat | Flooded wet season; fair dry season | Effington I | 350 | 30 | 45 | 15 | 5 | 5 |
| | | | | Fabian I | 15 | | | 100 | | |
| | | | | Flatwood I | 130 | 45 | 5 | 35 | 10 | 5 |
| | | | | McKinlay I | 30 | | 5 | 90 | | 5 |
| | | | | Rumwaggon I | 10 | 50 | | 50 | | |
| 5 | Spinifex and mid-height and short annuals | Undulating | Extremely poor | Murray | 50 | | 10 | | | 90 |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| 6 | Grasses of loams and clays (mid-height perennials) | Undulating to hilly | Very good wet season; poor dry season | Somerville | 150 | 45 | 10 | 45 | | |
| | | | | Verity | 170 | 55 | | 45 | | |
| | | | | Viney | 495 | 25 | | 75 | | |
| 7 | Scrub grasses (short annuals and perennials) | Gentle slopes with rounded summits | Meagre but good dry and wet seasons | Kosher I | 75 | | | 100 | | |
| 8 | Swamp grasses | Flat | Flooded wet season; fair dry season | Copeman I | 45 | | | | 85 | 15 |
| | | | | Cyperus I | 120 | | | | 25 | 75 |
| | | | | Pinwinkle I | 10 | | | 5 | 80 | 15 |
| Non-range country | Spinifex or negligible | Flat or rugged | Negligible | Amhurst | 120 | 80 | | | | 20 |
| | | | | Bedford | 520 | | | | | 100 |
| | | | | Buldiva I | 6795 | | | | | 100 |
| | | | | Honeycomb | 100 | | | | | 100 |
| | | | | Littoral I | 10 | | | | | 100 |

* Community (*a*), woodland and forest grass; (*b*), scrub grasses; (*c*), grasses of the alluvium; (*d*), swamp grasses; (*e*), useless.

systems are assigned to pasture lands according to all-round grazing value in terms of these four groups in conjunction with browse plants, non-grass herbs, water supplies, terrain and accessibility. The values are, of course, relative, as management policy probably accounts for success or failure as much as the natural features do.

Over half the pasture lands are dominated by woodland and forest grasses (*Sorghum*, *Chrysopogon*, *Alloteropsis*, *Schizachyrium*, *Thaumastochloa*).

In view of the large proportion of non-range country, we feel that a map of the pasture lands is not warranted. They can be readily assembled from the land system map.

### (*a*) *Pasture Land 1 (1440 km*$^2$)

This is equivalent to pasture land 1 of the Adelaide–Alligator report. Constituent land systems are Dual, Explanado, Kay I, Klatt, Kysto I, Levee and Queue I, all level to undulating and under tall open forest and woodland with the related tall and mid-height annual and perennial grasses. Klatt differs somewhat in being on lateritic plateaux and therefore less accessible, Levee is closely associated with the larger creeks and therefore well watered, with access to the changeable vegetation of pasture land IV. As a whole the pasture land is poorly watered and not suited to dry-season grazing.

### (*b*) *Pasture Land 2 (1370 km*$^2$)

This is equivalent to pasture land 2 of the Adelaide–Alligator report. Constituent land systems are Ararat, Baker I, Bend I, Cully I, Currency I, Jay I, Venlaw and Verrucose. The grasses are similar to those of pasture land 1 but the country is hilly and better watered, with a larger proportion of alluvium.

### (*c*) *Pasture Land 3 (1815 km*$^2$)

This is equivalent to pasture land 3 of the Adelaide–Alligator report. Constituent land systems are Bundah, Knifehandle I, Nova and Valley. The country is rolling and well watered, the herbage consisting of the grasses of pasture land 1 with an admixture of more palatable scrub grasses (short annuals and perennials).

### (*d*) *Pasture Land 4 (535 km*$^2$)

This, equivalent to pasture land 4 of the Adelaide–Alligator report, comprises the alluvial land systems Effington I, Fabian I, Flatwood I, McKinlay I and Rumwaggon I. They are put together more by virtue of their position than from any uniformity in their grass cover. It is patchy and variable, especially in Effington I land system and along the larger creeks where it is flooded each year and suffers in addition from being trampled and grazed by buffalo, but unchannelled areas are usually under dense perennials. On the whole, one could expect a somewhat higher carrying capacity than that of the first three pasture lands, with the grasses remaining greener for a longer time.

### (*e*) *Pasture Land 5 (50 km*$^2$)

Murray is the only land system—a waterless area of deep sand on which annual grasses would provide a little summer feed amongst the shrubs and spinifex. It is not recommended for more than opportunistic grazing, and would be easily eroded.

### (*f*) *Pasture Land 6 (815 km²)*

This comprises three land systems, Somerville, Verity and Viney. Viney is mostly hilly and from this point of view rather a misfit in company with two that are undulating to rolling. It is included because of a similarity in the herbage, which consists largely of mid-height perennial grasses, usually with a plentiful assortment of leafy legumes that would provide valuable summer feed. The legumes are deciduous and the winter aspect in general is harsh and uninviting. The steeper parts of Viney would prevent easy access and be liable to erosion unless managed with discretion. However, a protective cover of stones and boulders does lessen the danger.

Water supplies are fair.

### (*g*) *Pasture Land 7 (75 km²)*

This is equivalent to pasture land 7 of the Adelaide–Alligator report, with Kosher I the only land system. The terrain is of gentle slopes of clumpy mixed scrub and *Pandanus* scrub with the associated grasses, mostly short annuals, and naturalized *Stylosanthes humilis*. The herbage is of good summer quality, but meagre. It probably owes much of its character to the buffalo which are plentiful in and around this land system.

Water is easily available from neighbouring swampy areas.

### (*h*) *Pasture Land 8 (175 km²)*

Constituent land systems are Copeman I, Cyperus I and Pinwinkle I, forming an extension of pasture land 8 of the Adelaide–Alligator report. As the buffalo do not give the swamp herbage much respite through the year except where sedges are dominant, its detailed composition and potential stocking rate are little known.

Buffalo would be the obvious choice if this pasture land were to be exploited, since most of it is too swampy for cattle except in the higher parts which are valueless for grazing.

### (*i*) *Non-range Country (7545 km²)*

Littoral I land system is practically bare tidal flats. Buldiva I, Honeycomb and Bedford are on the quartz sandstone Arnhem Land plateau in the most inaccessible and rugged part of the survey area with nothing in the way of feed beyond a few scanty pickings. Amhurst is on steep rocky slopes, in places very scrubby and overall not worth exploiting in spite of a fair cover of perennial grasses.

## IV. Utilization of Pastures

Utilization of the grasses is mentioned in Part IX of the Adelaide–Alligator report. The following is a brief summary.

According to Katherine results, cattle on native pasture can maintain or gain weight for six consecutive months, from about late November to late May. They lose much of the gain, sometimes more than half, during the ensuing six dry months unless given a little high-protein supplement, when they will maintain weight for all but the last month of the six. Katherine has a rainfall of 940 mm and a period of useful pasture growth of 5·5 months (Fitzpatrick 1965), while Oenpelli figures are 1320 and 6.

TABLE 18

SUITABILITY OF SOILS FOR USE

| Form of use | Few limitations | Moderate limitations | Major limitation of seasonal freshwater inundation | Severe limitations | Limitations that preclude most forms of land use |
|---|---|---|---|---|---|
| Pastoral production | Suitable but best use is more intensive | Suitable | Some seasonal grazing. Improvement possible. Buffalo do well but many areas easily damaged | Not suitable, some rough grazing only | Not suitable |
| Agricultural | Suitable except for minor areas | Marginally suitable in small areas | May be suitable for rice on Wildman soils | Not suitable | Not suitable |
| Forestry | Suitable except for minor areas | Marginally suitable in some areas | Not suitable | Suitable only on sand-plain soils. Some native forests | Not suitable |
| Urban or industrial | Suitable | Suitable | Not suitable | Feasible, but high costs involved | Not suitable, but small structures could be erected at high cost |
| Road-building | Suitable | Suitable | Not without special techniques to cope with soil shrink/swell characteristics and inundation | Possible, but limitations substantial | Not unless special techniques used; high cost |

One could therefore expect conditions at Katherine and in the survey area to be roughly similar, give or take a little in the higher-rainfall area for a longer growing season and some extra leaching of nutrients from the dry-season herbage.

The swamp grasses are utilized almost exclusively by buffalo (see section II).

Paddocking and controlled grazing are not carried out on properties in the survey area, which is not surprising in view of a very low stocking rate for cattle and the difficulty of erecting and maintaining buffalo-proof fences in swamps. This position is unlikely to change until supplementary dry-season feeding calls for increased and intensive stocking of the native pastures in the wet season. This will probably induce an overall change towards annual short grasses, with unknown effects on quality and quantity of grazing.

## V. Limitations on Land Use

This section deals with a range of limitations inherent in the soils which control the various uses to which they can be put.

Land capability is often related to extrinsic factors such as intensity of management, economic purpose, relationship with neighbouring soils or land forms, cultural techniques used, accessibility and the state of technical knowledge at the time of development. However, the primary approach to land capability rating must be based on intrinsic factors which determine the ability of the soil to withstand various forms of use without deterioration.

The following groupings are based on intrinsic factors only, which include relief and microrelief, soil depth, water-holding capacity, the gravel, stone, and rock contents of the soil, erodability, drainage, permeability, flooding or inundation, especially by salt water, consistence, soil reaction and salinity. Each limitation varies in degree and the five groupings described below are intended to represent an increasing order of generalized severity. Some limitations such as flooding or microrelief may be alleviated by various means and are therefore intrinsic only under certain management conditions. Others such as soil depth or gravel content are permanent.

The groupings provide a general guide from which decisions on land use could be made (Table 18). Such decisions would depend upon specific extrinsic factors or would be made with a particular form of land use in mind. Where specific ventures are proposed reference to appropriate authorities would then be advisable.

### (*a*) *Soils with Few Inherent Limitations*

(Argoolook, Emu, Katherine, Killuppa, Mundogie, Zamu)

These soils are all red earths at least 150 cm deep with loamy textures, and are well or moderately well drained. Their water-holding capacity varies but only in the sandier surface horizons of Katherine and Killuppa soils is it low enough to form a substantial limitation. Indications from mechanical analysis and percentage water loss at 105°C are that Argoolook soils may have a very good water-holding capacity. Both physically and chemically, Argoolook soils are the most fertile in the study area. Other soils in this group are relatively infertile chemically but have no substantial physical limitations.

Erodability is a definite limitation on the more steeply sloping areas, as on Zamu soils where they occur on lower slopes in Viney land system, and particularly on the sandy-surfaced Killuppa soils that occur on slopes near the margins of some areas of Queue I land system. Argoolook soils are also an erosion risk because of their high content of fine sand and silt and their position on an old but possibly active alluvial fan of the East Alligator River.

Because there are few limitations on their use these soils have multiple use possibilities (Table 18). The largest areas of them are mapped in Queue I land system on Cretaceous sediments and in Levee land system, but minor areas occur in Bend I, Fabian I, Flatwood I, Somerville and Viney.

### (*b*) *Soils with Definite but Moderate Limitations*

(Basedow, Edith, Fisher, Hotham, Koolpinyah, Malone, Ramil, Woolner, Yemelba, Zambina, Zamu—on micaceous schist)

Soils in this grouping are mainly gravelly lateritic soils and yellow earths, but Zamu and Malone have different affinities. These soils have a wide range of limitations on their use both in kind and in degree, but they are mainly physical limitations due to adverse water relations and erodability.

Most of the soils (except Hotham, Koolpinyah and Zamu) suffer from poor seasonal drainage. Basedow, Edith, Ramil and Zambina are moderately well drained and Fisher, Malone, Woolner and Yemelba are imperfectly drained.

During the dry season they all dry out to the full depth of sampling, so that a seasonal moisture deficiency is another feature of these soils. This applies particularly to gravelly lateritic soils (Basedow, Koolpinyah, Hotham, Woolner) which have lower moisture storage capacities.

Many of the gravelly lateritic soils have a thick reddish black ferruginous gravel veneer on the soil surface that becomes very hot in sunlight and cold at night. This daily temperature fluctuation combined with the seasonal moisture deficiency of these soils would not be conducive to plant growth, particularly seedling establishment.

The gravel veneer is an erosion pavement and whilst intact it protects these soils from erosion, but disturbance of the veneer by overstocking, cultivation, earthworks, etc. is likely to precipitate erosion, particularly where run-off is appreciable or degree of slope is excessive.

Erodability is a distinct limitation on the use of all soils in this group. Zamu soils which form on micaceous schists in Ararat land system occur on crests and relatively steep slopes and, although they are not intrinsically highly erodable, they will erode if disturbed, because of their position in the landscape. The other soils are generally observed to be relatively easily detachable and transportable when wet, and are intrinsically erodable. This applies particularly to those yellow earths with a hard dry consistence (Fisher, Zambina). Many of the soils in this group are shallow which probably indicates that their rates of natural erosion are high.

These soils have more restricted use possibilities because of their more serious inherent limitations (Table 18). They occur throughout a wide range of land systems but particularly in Bend I, Cully I, Kay I, Kysto I, Knifehandle I, Jay I, Somerville and Verity. The only significant areas of these land systems occur between the South Alligator River and the Arnhem Land escarpment, and in the Cooper Creek basin.

### (c) *Soils with Seasonal Freshwater Inundation as a Major Limitation*

(Wildman, Carmor)

These soils warrant separate consideration from those included in (*b*) or (*d*) because of the different nature of their limitations. Soils that are inundated seasonally by salt water or that have other major limitations as well as freshwater inundation have been excluded from this group.

Both these soils are intractable cracking clays, sometimes weakly gilgaied, with slow permeability when wet. They dry out and crack seasonally to a depth of about 50 cm but remain moist below this. They are seasonally waterlogged and consequently seasonally impassable to conventional vehicles, and are also inundated for variable periods each year.

They also have chemical limitations, particularly salinity. Wildman soils may have calcareous subsoils but are slightly acid in the surface horizons. Carmor soils have more severe chemical limitations and are calcareous right to the soil surface.

These limitations preclude many forms of land use but there are some possibilities (Table 18). Wildman and Carmor soils occur only on the estuarine plains in Cyperus I and Copeman I land systems.

### (d) *Soils with Severe Limitations*

(Arnhem, Brockman, Cahill, Cockatoo, Cullen, Evelyn, Gilruth, Howship, Manbulloo, Murrabibbi, Nungbalgarri, Partridge, skeletal soils on siltstone)

Nungbalgarri soils occur on relatively steep slopes (up to 40%) but only where there is an almost continuous pavement of volcanic boulders. The pavement reduces soil loss by erosion to negligible levels but is in itself a severe limitation on the use of the soil.

Many soils in this group are very sandy (Arnhem, Cahill, Cockatoo, Cullen, Evelyn, Manbulloo) and have very low water-storage capacities. This effect is most pronounced in the upper soil horizons, and shallow-rooted plants on these soils suffer annually from drought. Native grasses growing on these soils are commonly either drought-resistant or drought-evading species.

The deeper horizons of Cockatoo and Arnhem soils and probably layers below the depth of sampling remain moist for a major part of the year and hence tree growth is unimpaired.

The sand-plain soils (Arnhem, Cockatoo) act as catchments and reservoirs for much of the seepage and spring water that keeps some of the creeks in the area (e.g. Jim Jim Creek) flowing for most of the year. It is possible that disturbance of these sand plains such as clearing of timber could lead to increased run-off (and erosion) and decreased infiltration, and this could have an effect upon the hydrological regime of the creeks concerned.

Low water-storage capacity is a feature of Howship and Partridge, and of the skeletal soils on siltstone also, because of their generally coarse gravelly textures and their situation in sloping run-off areas.

Another serious limitation affecting the use of most of these soils is their inherent erodability. The very sandy soils are loose or only weakly coherent and despite their high infiltration rate they are known to erode seriously if cleared and exposed to high-intensity rainfall (Aldrick 1972). Erosion is likely to be more severe where catchments are large (as they are on Cockatoo and Arnhem soils) and on steeper slopes such as occur around the margins of some of the sand plains.

Howship, Partridge and the skeletal soils on siltstone commonly occur on steeper slopes (5–10%). Because of their weak massive nature and the steep slopes they would erode if seriously disturbed, for example by overstocking. This would lead to increased run-off and reduced infiltration of water, and could affect plant survival adversely.

Murrabibbi soils occur on lower slopes in Kosher I land system where constant seepage has allowed a rich organic build-up. Because of their predominantly sandy textures, seepage characteristics and slope they are a definite erosion risk, particularly if their catchment areas are disturbed by clearing or other means so that run-off is increased.

Brockman and Gilruth soils occur in drainage lines and carry large volumes of run-off water seasonally. They are reasonably coherent soils and may provide some native pasture grazing in the dry season, but too much disturbance particularly in the wet season would lead to erosion. Like all drainage-line soils in this area they would also be susceptible to damage if run-off from their catchments was increased.

Poor inherent ability of the soil to supply nutrients to the plant cannot be alleviated by the addition of fertilizers as it can in some soils of low chemical fertility. These conditions of infertility may be associated with rapid leaching of applied nutrients, fixation of nutrients by the colloidal fraction of the soil or chemically induced nutrient imbalance. Nutrient fixation, particularly of phosphorus, is a possibility on the krasnozems (Nungbalgarri) and rapid leaching of applied nutrients is probable on the very sandy soils. Brockman and Gilruth soils and the skeletal soils on siltstone may not be so bad in these respects.

The severity of the limitations inherent in these soils greatly restricts their potential for use (Table 18). They occur throughout a large number of land systems scattered over most of the survey area. These are mainly Bedford, Bend I, Cully I, Effington I, Queue I and Viney with minor areas in Ararat, Baker I, Knifehandle I, Kosher I, Kysto I, Rumwaggon I and Verity.

### (e) *Soils with Limitations that preclude most Forms of Land Use*

(Baroalba, Barramundi, Buldiva, Carpentaria, Counamoul, Dashwood, dune sands, Honeycomb, Kapalga, Kombolgie, Koolpin, Leichhardt, McKinlay, Myra, Scinto, Sleisbeck, saline muds, Siltavel, skeletal soils on sandstone and volcanics, and the very gravelly lateritic soils)

Some of these soils (skeletal soils, Kombolgie, Honeycomb) occur on the sandstone plateau interspersed with large areas of bare rock, and consequently this group is the largest both numerically and in terms of area covered.

Dashwood and Counamoul are swamp soils that are inundated with fresh water for all or most of the year. Carpentaria, saline muds and dune sands are inundated by salt water or subjected to salt spray from daily to annual intervals. Buldiva and Koolpin soils are permanently waterlogged, Kapalga soils occur at semi-permanent seepage points, and Baroalba and Honeycomb soils are seasonally waterlogged. All the drainage-line soils (Baroalba, Buldiva, Barramundi, Koolpin, Leichhardt, McKinlay, Myra, Scinto, Siltavel) are subjected to brief periodic inundation during the wet season, when they become boggy and impassable.

Many of these soils are also highly erodable. The drainage-line soils carry substantial volumes of water seasonally and any disturbance of the soil or an increase in the volume, velocity or suspended load of the water would probably initiate erosion in these areas. Kapalga soils are also susceptible to erosion because of their non-coherent sandy surfaces, seepage characteristics and position on mid and lower slopes. Sleisbeck soils are very loose and sandy with gentle slopes and would also be erodable. Most other soils in this group, though intrinsically erodable, are not a serious erosion risk because of their more stable situation in the landscape.

Low water-holding capacity is a limitation on some soils, particularly Kombolgie, Scinto, Sleisbeck, the skeletal soils and the very gravelly lateritic soils. Some of these would have very low moisture reserves even during parts of the wet season.

Chemical limitations occur only on the soils of the estuarine plains but they are overshadowed by the serious inundation limitations there.

A relief limitation is common to only a few of the soils in this group but to much of the area in which they occur. Kombolgie, Honeycomb, the very gravelly lateritic soils and the skeletal soils occur only east of the Arnhem Land escarpment and typically in very rugged and dissected situations. Many such areas would be inaccessible to all machines but helicopters and, although they are accessible to climbers and bush-walkers, large animals would not use them.

These soils are of very little use (Table 18). They occur on the estuarine plains in Pinwinkle I and Littoral I land systems; in drainage floors in nearly all land systems but particularly in Effington I; and east of the Arnhem Land escarpment in a large number of land systems, mainly Amhurst, Buldiva I, Bundah, Currency I, Honeycomb, Klatt, Valley, Venlaw, Verrucose and Viney. Substantial areas of this type also occur in Ararat, Baker I and Murray land systems.

## VI. Suitability of Soils for Various Uses

The inherent capabilities of the land to support particular forms of use without undue damage to the basic soil resource will determine potential use. In some cases the full potential will be achieved only after water supplies are installed, for example, or improved pasture species are sown.

It should be noted that while the same soil groups are used in section V to illustrate limitations to land use and here to illustrate suitability for various uses, they do not correspond with those shown on the soil map. The reason is that the soil map is based on the land systems, which have assemblages of soils classified according to genetic and morphological characters that do not necessarily reflect the factors of importance to plant growth.

It follows that more detailed mapping will be necessary to delineate the land units before the information contained here can be fully utilized.

In this section the limitations inherent in the soils themselves are the primary consideration, but some account is taken of native vegetation and site factors such as slope, inundation and size of area in assessing the suitability of the soils for particular forms of use.

The following criteria have been used in defining the suitability of the soils for the types of use listed in Table 18.

For pastoral production the soils must be able to support palatable and nutritious pasture species (fertilizers may be necessary), erosion potential must be low under moderate stocking rates, they must be well or moderately drained if wet-season use is considered but for seasonal use soils with poorer drainage are acceptable. They must not be inundated, except for minor seasonal inundation, and if they are wetlands they must not be susceptible to floristic deterioration (particularly of hydrophytes).

For agricultural use erosion potential must be low under foreseeable forms of management (almost flat), soils must be well drained and loamy at least in B horizons and with good moisture retention qualities. They must be relatively free of physical and chemical constraints and have favourable qualities of structure, porosity and consistence.

For use for forestry the soils must be deep and well drained with good moisture reserves in subsoils all year round (mainly sandy or friable and porous). They must support substantial native timber cover, have no serious erosion risk after establishment (proper erosion control during establishment and harvesting is assumed) and areas of economic size must be available.

For urban or industrial use soils must have good or moderate drainage, no inundation, accessibility, stable foundation materials and low to moderate gradients.

For road-building there must be no seasonal or permanent inundation. There must be good drainage and stable foundations. Gradients must not be excessive or rugged. If the soils are cracking clays special foundations may be necessary.

## VII. Prospects for Development

The major land use conflict in the area at present is between uranium mining and national park requirements. A comprehensive assemblage of facts concerning the uranium mining/national park conflict and many other land use factors has been accumulated in the 12 study reports of the Alligator Rivers Region Environmental Fact Finding Study and summarized in a review report (Christian 1973).

Clearly the uranium mining industry is a very important one, and up to December 1973 announced reserves of uranium oxide exceeded 100 000 short tons, with a value then of about \$A1·5 billion. Exploration so far has probably discovered the more easily identifiable deposits and it is probable that larger quantities occur within the region (Christian 1973). The aspect of main concern as regards a national park is the possibility of environmental pollution, particularly of the wetlands, by waste products from both mines and treatment plants.

The area proposed for a national park contains much scenically attractive country including the Arnhem Land plateau and escarpment, permanent lagoons and swamps, flood-plains, major river systems, and a wide range of animal species and vegetation types. It also contains some relatively unattractive country. Aboriginal paintings and relics, and sites of significance both to the Aborigines and for scientific study exist in profusion throughout most of the area, especially in the vicinity of the escarpment.

There are some prospects for other forms of land use, although these may also be considered incompatible with either a national park or a wildlife sanctuary. Some of the area has prospects for grazing of existing native pastures (Table 17) and some parts could be improved and utilized more intensively by the pastoral industry (Table 18). A small area is considered arable (Table 18). There seem to be some prospects for forestry (Table 18) but only on certain soils. Of these, the sand-plain soils in Queue I land system already carry tall open forests.

However, these forms of land use affect large areas of country and there are possibilities of substantial environmental damage if the fundamental limitations on land use are disregarded. Soil erosion is a very real risk following clearing of native vegetation and/or disturbance by ploughing, road-building, mining etc., especially on the sandier soils and soils with slopes in excess of about 1%. High-intensity rains falling in the early part of the wet season when there is little ground cover (or worse, fresh cultivation) can cause serious erosion problems.

The introduced buffalo have already caused considerable environmental change to the coastal plains and in particular to the wetlands vegetation, and some soil erosion has resulted from frequently used buffalo 'pads' and from wallowing. Control of feral animals will be a necessary management consideration where wildlife reserves and national parks are involved or where more intensive forms of land use are considered.

Proper planning in conjunction with a knowledge of the intrinsic limitations of the basic resources of the land will be essential for all forms of land use if the most profitable use of land is to be made and environmental problems are to be minimized.

## VIII. References

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## APPENDIX I

### Description of Soil Families

By J. M. Aldrick*

### I. General

The soil profiles described below are mainly individual profiles but some have been compiled as composites of two or more. No range of depths is given for the various horizons in the profiles but a variation of about 20% in the quoted depths could be expected. Most of the profiles described were augered to about 140 cm and where impenetrable pans or rock were not encountered by that depth the full depth of the solum is unknown. A few profiles have been described from more limited information and descriptions to about 100 cm only are available for these.

The profile descriptions are based on field descriptions of texture, colour, fabric and pH. Some variation between field texture and texture from mechanical analysis figures is apparent but the variation is within normal limits. Soil colour names are those used in the Munsell Soil Color Charts and refer to the colour of moist soil in the shade. The fabric (Northcote 1971) of all siliceous sands and of most horizons acting as aquifers was sandy and that of the cracking clays, krasnozems and some red and yellow earths was smooth ped. Most other soils had an earthy fabric but some had a sandy-earth fabric as defined by Hooper (1969) and Aldrick (1972). The pH figures quoted were obtained in the field with an 'Inoculo' field pH kit and tend to be slightly higher than figures obtained during laboratory analysis.

The standards for sodicity that have been used are those defined by Northcote and Skene (1972) and soils are referred to as sodic (exchangeable sodium percentage 6–14) or strongly sodic (E.S.P. 15 or more).

Where ferruginous nodules are described they are usually rounded or subrounded with various internal skeleton fabrics. They are invariably case-hardened, strongly cemented and brittle. Their size varies from 2 mm to 4 cm with a mean of about 1 cm. Amounts of gravel are quoted as high (more than 40% of soil volume), medium (20–40%) or low (<20%) after Hooper (1969).

Throughout the text, soil chemical and mechanical analysis figures and clay mineral determinations are those listed in Tables 19 and 20 respectively.

### II. The Families

#### (a) *Solonchak*

*Carpentaria family* soils occur on the littoral fringes of the estuarine plains where occasional marine inundation occurs. They are calcareous and strongly sodic through-

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TABLE 19

SOIL ANALYSIS FIGURES

(T, trace; X, below detection limits)

| Sample depth (cm) | % $H_2O$ loss at 105°C | Mechanical analysis (%) <0·002 mm | 0·002–0·02 mm | 0·02–0·2 mm | 0·2–2 mm | pH | 1 : 5 Water extract E.C. (μmho) | T.S.S. (ppm) | N (Kjeld.) | Exchangeable cations (m-equiv. %) Na | K | Ca | Mg | C.E.C. (m-equiv. %) | Bicarb. P (ppm) | Org. C (%) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Skeletal (siltstone) | | | | | | | | | | | | | | | | |
| 0–15 | 1·3 | 5 | 26 | 32 | 37 | 6·1 | 17 | 145 | 960 | 0·05 | 0·10 | 3·15 | 1·10 | 5·2 | 9 | 1·48 |
| 15–40 | 1·1 | 10 | 26 | 23 | 41 | 5·9 | 9 | 90 | 390 | 0·05 | T | 0·40 | 1·00 | 2·8 | 3 | 0·33 |
| Skeletal (Kombolgie sandstone) | | | | | | | | | | | | | | | | |
| 0–30 | 2·4 | 0 | 4 | 19 | 77 | 6·7 | 40 | 230 | 2420 | X | 0·10 | 21·50 | 2·10 | 16·8 | 10 | 5·22 |
| Kombolgie | | | | | | | | | | | | | | | | |
| 0–15 | 0·4 | 0 | 2 | 29 | 69 | 5·2 | 10 | 100 | 460 | X | X | X | X | X | 2 | 0·74 |
| 15–50 | 0·3 | 1 | 2 | 53 | 44 | 5·2 | 7 | 75 | 390 | X | X | X | X | X | X | 0·40 |
| 50–70 | 0·2 | 3 | 4 | 51 | 42 | 5·1 | 10 | 100 | 250 | X | X | X | X | 0·1 | X | 0·21 |
| 70–120 | 0·1 | 1 | 3 | 55 | 41 | 5·2 | 10 | 100 | 40 | X | X | X | X | X | X | 0·17 |
| Kapalga | | | | | | | | | | | | | | | | |
| 70–150 | 0·4 | 0 | 3 | 25 | 72 | 5·6 | 6 | 70 | 120 | T | X | 0·05 | X | 0·6 | 8 | 0·10 |
| Cockatoo | | | | | | | | | | | | | | | | |
| 0–10 | 0·4 | 2 | 2 | 11 | 85 | 5·5 | 15 | 130 | 420 | T | T | 0·40 | 0·25 | 1·0 | 17 | 1·22 |
| 10–40 | 0·5 | 2 | 6 | 16 | 76 | 5·3 | 10 | 100 | 260 | T | X | 0·05 | 0·05 | 1·1 | 7 | 0·85 |
| 40–100 | 0·3 | 2 | 6 | 20 | 72 | 5·5 | 5 | 65 | 140 | T | X | 0·15 | 0·10 | 1·2 | 6 | 0·30 |
| Arnhem | | | | | | | | | | | | | | | | |
| 0–10 | 0·4 | 1 | 6 | 36 | 57 | 6·0 | 10 | 100 | 260 | T | T | 0·35 | 0·40 | 1·3 | 8 | 0·64 |
| 10–55 | 0·6 | 5 | 4 | 27 | 64 | 5·8 | 5 | 65 | 190 | T | X | 0·10 | 0·15 | 0·9 | 6 | 0·18 |
| 55–140 | 0·3 | 7 | 4 | 34 | 55 | 5·7 | 5 | 65 | 190 | T | X | X | X | 0·5 | 6 | 0·11 |
| Manbulloo | | | | | | | | | | | | | | | | |
| 0–20 | 1·2 | 2 | 3 | 89 | 6 | 5·2 | 20 | 150 | 1050 | X | T | 0·80 | 0·35 | 2·0 | 10 | 2·46 |
| 20–70 | 0·8 | 3 | 3 | 81 | 13 | 5·1 | 8 | 85 | 250 | X | X | X | T | 1·1 | 6 | 0·56 |
| 70–150 | 0·6 | 8 | 3 | 83 | 6 | 5·1 | 8 | 85 | 250 | X | X | X | T | 0·7 | 5 | 0·44 |
| Evelyn | | | | | | | | | | | | | | | | |
| 0–10 | 0·4 | 2 | 8 | 42 | 48 | 5·5 | 9 | 95 | 420 | T | T | 0·15 | 0·25 | 0·8 | 9 | 0·74 |
| 10–40 | 0·4 | 7 | 4 | 41 | 48 | 5·5 | 5 | 65 | 180 | T | X | 0·05 | 0·35 | 1·0 | 5 | 0·14 |
| 40–80 | 1·6 | 8 | 3 | 35 | 54 | 5·6 | 6 | 70 | 160 | 0·05 | X | 0·05 | 0·60 | 1·0 | 8 | 0·12 |
| 80–140 | 0·4 | 5 | 6 | 30 | 59 | 6·2 | 9 | 95 | 40 | 0·05 | X | 0·05 | 0·75 | 1·0 | 6 | 0·13 |
| Cullen | | | | | | | | | | | | | | | | |
| 0–10 | 0·1 | 0 | 1 | 35 | 64 | 5·6 | 11 | 110 | 230 | T | T | 0·10 | 0·05 | 0·9 | 11 | 0·51 |
| 10–45 | 0·2 | 2 | 4 | 27 | 67 | 5·6 | 7 | 75 | 230 | T | T | T | T | 0·7 | 5 | 0·19 |
| 45–70 | 0·5 | 16 | 2 | 22 | 60 | 5·6 | 8 | 85 | 230 | 0·05 | 0·05 | 0·10 | 0·50 | 1·4 | 5 | 0·15 |
| 70–140 | 1·2 | 23 | 3 | 19 | 55 | 5·7 | 8 | 85 | 160 | T | 0·10 | T | 1·05 | 2·3 | 5 | 0·13 |

TABLE 19 (*Continued*)

| Sample depth (cm) | % $H_2O$ loss at 105°C | Mechanical analysis (%) <0·002 mm | 0·002–0·02 mm | 0·02–0·2 mm | 0·2–2 mm | pH | 1 : 5 Water extract E.C. (μmho) | T.S.S. (ppm) | N (Kjeld.) | Exchangeable cations(m-equiv.%) Na | K | Ca | Mg | C.E.C. (m-equivo.%) | Bicarb. P (ppm) | Org. C (%) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Cahill | | | | | | | | | | | | | | | | |
| 0–15 | 0·5 | 2 | 5 | 51 | 42 | 6·3 | 20 | 150 | 440 | X | 0·05 | 0·85 | 0·40 | 1·4 | 10 | 0·66 |
| 15–60 | 0·8 | 3 | 5 | 59 | 33 | 5·7 | 10 | 100 | 190 | X | T | 0·25 | 0·55 | 0·9 | 18 | 0·26 |
| 60–80 | 2·2 | 10 | 8 | 45 | 37 | 5·9 | 8 | 85 | 330 | X | T | 0·30 | 2·35 | 2·8 | 5 | 0·25 |
| 80–110 | 2·4 | 16 | 14 | 27 | 43 | 6·0 | 8 | 85 | 300 | T | T | 0·55 | 3·60 | 4·3 | 9 | 0·21 |
| 110–130 | 8·9 | 30 | 34 | 22 | 14 | 6·3 | 15 | 130 | 230 | 0·50 | 0·15 | 0·45 | 33·30 | 32·8 | 3 | 0·10 |
| 130–150 | 14·4 | 13 | 47 | 37 | 3 | 6·5 | 37 | 215 | 190 | 1·00 | 0·10 | 0·85 | 60·00 | 48·0 | 2 | 0·14 |
| Leichhardt | | | | | | | | | | | | | | | | |
| 20–150 | 4·1 | 3 | 20 | 75 | 2 | 5·5 | 16 | 125 | 1680 | T | X | 0·35 | 0·20 | 1·6 | 7 | 2·26 |
| Wildman | | | | | | | | | | | | | | | | |
| 0–25 | 9·9 | 41 | 35 | 24 | 0 | 5·5 | 68 | 325 | 2010 | 1·55 | 0·35 | 0·65 | 15·00 | 24·2 | 28 | 2·34 |
| 50–95 | 10·9 | 65 | 21 | 14 | 0 | 6·3 | 600 | 1885 | 910 | 8·25 | 0·90 | 0·85 | 22·50 | 29·0 | 8 | 0·84 |
| 95–130 | 12·5 | 65 | 23 | 12 | 0 | 7·4 | 980 | 2950 | 610 | 11·00 | 3·00 | 9·00 | 23·00 | 36·0 | 40 | 0·34 |
| Counamoul | | | | | | | | | | | | | | | | |
| 0–25 | 9·0 | 3 | 19 | 46 | 32 | 3·8 | 6500 | 19 500 | 2000 | 27·20 | 0·20 | 3·00 | 12·50 | 13·9 | 45 | 3·61 |
| 25–65 | 3·8 | 20 | 11 | 29 | 40 | 3·6 | 1600 | 4700 | 280 | 8·70 | 0·35 | 1·30 | 5·85 | 11·3 | 12 | 0·26 |
| 65–110 | 2·3 | 18 | 6 | 27 | 49 | 4·0 | 1000 | 3000 | 190 | 5·45 | 0·25 | 0·85 | 3·50 | 6·0 | 8 | 0·38 |
| 110–150 | 2·0 | 0 | 4 | 45 | 51 | 2·7 | 3000 | 8750 | 280 | 3·95 | X | 0·75 | 2·95 | 12·2 | 6 | 1·35 |
| Argoolook | | | | | | | | | | | | | | | | |
| 0–25 | 7·9 | 7 | 26 | 62 | 5 | 5·2 | 19 | 150 | 2900 | 0·05 | 0·05 | 0·20 | 0·25 | 2·6 | 19 | 4·38 |
| 25–120(a) | 10·5 | 4 | 22 | 69 | 5 | 5·2 | 14 | 130 | 1520 | 0·05 | 0·05 | 0·10 | 0·05 | 1·7 | 12 | 1·68 |
| 25–120(b) | 5·2 | 1 | 17 | 68 | 14 | 5·4 | 8 | 85 | 1120 | 0·05 | T | 0·10 | T | 1·6 | 11 | 1·10 |
| 120–140 | 2·4 | 15 | 22 | 51 | 12 | 5·2 | 10 | 100 | 460 | 0·05 | 0·05 | 0·05 | 0·15 | 3·7 | 7 | 0·34 |
| Killuppa | | | | | | | | | | | | | | | | |
| 0–40 | 1·6 | 2 | 9 | 29 | 60 | 5·3 | 14 | 125 | 630 | 0·10 | T | 0·25 | 0·40 | 1·9 | 4 | 2·54 |
| 40–70 | 4·2 | 3 | 8 | 32 | 57 | 5·9 | 8 | 85 | 280 | T | X | X | 0·35 | 1·3 | 3 | 1·13 |
| 70–120 | 2·9 | 11 | 9 | 26 | 54 | 6·0 | 4 | 55 | 110 | X | X | X | 0·40 | 0·9 | 3 | 0·40 |
| 120–150 | 0·8 | 11 | 8 | 27 | 54 | 5·9 | 10 | 100 | 190 | T | X | X | 0·65 | 1·0 | 3 | 0·52 |
| Zamu | | | | | | | | | | | | | | | | |
| 0–15 | 1·5 | 1 | 15 | 43 | 41 | 6·5 | 26 | 170 | 810 | X | 0·45 | 6·00 | 1·80 | 6·9 | 10 | 1·36 |
| 15–60 | 5·9 | 18 | 12 | 34 | 36 | 6·5 | 10 | 100 | 460 | X | 0·35 | 3·30 | 2·00 | 5·4 | 5 | 0·52 |
| 60–110 | 5·2 | 30 | 12 | 28 | 30 | 6·5 | 9 | 90 | 280 | X | 0·40 | 3·80 | 2·65 | 6·3 | 3 | 0·32 |
| 110–150 | 6·5 | 28 | 14 | 22 | 36 | 6·6 | 8 | 85 | 280 | T | 0·45 | 4·00 | 3·35 | 7·4 | 9 | 0·22 |
| Emu | | | | | | | | | | | | | | | | |
| 0–15 | 1·9 | 3 | 15 | 70 | 12 | 5·5 | 20 | 150 | 1190 | 0·05 | 0·05 | 0·60 | 0·85 | 2·8 | 16 | 3·00 |
| 15–65 | 3·0 | 10 | 11 | 67 | 12 | 5·8 | 6 | 70 | 320 | 0·05 | 0·05 | T | 0·40 | 1·3 | 4 | 0·33 |
| 65–140 | 1·1 | 13 | 8 | 63 | 16 | 5·8 | 6 | 70 | 180 | 0·05 | T | T | 0·80 | 2·0 | 7 | 0·18 |

| | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Katherine | | | | | | | | | | | | | | | | |
| 0–10 | 0·5 | 1 | 7 | 21 | 71 | 5·6 | 13 | 115 | 530 | 0·05 | 0·05 | 0·20 | 0·35 | 1·2 | 20 | 0·69 |
| 10–50 | 1·2 | 15 | 10 | 27 | 48 | 5·7 | 7 | 75 | 260 | 0·05 | X | 0·05 | 0·25 | 2·1 | 4 | 0·18 |
| 50–80 | 5·5 | 27 | 14 | 27 | 32 | 6·0 | 6 | 70 | 250 | 0·10 | X | 0·05 | 1·15 | 3·6 | 7 | 0·25 |
| 80–150 | 5·1 | 32 | 10 | 37 | 21 | 5·9 | 6 | 70 | 250 | 0·10 | T | T | 2·15 | 5·2 | 15 | 0·19 |
| Basedow | | | | | | | | | | | | | | | | |
| 0–10 | 1·2 | 4 | 10 | 60 | 26 | 6·1 | 18 | 150 | 810 | T | 0·15 | 1·95 | 1·40 | 4·0 | 9 | 1·77 |
| 10–45 | 1·2 | 13 | 9 | 52 | 26 | 5·8 | 10 | 100 | 280 | T | 0·05 | 0·20 | 0·75 | 1·4 | 7 | 0·53 |
| 45–140 | 9·8 | 18 | 14 | 40 | 28 | 5·7 | 6 | 65 | 300 | 0·05 | T | 0·05 | 1·40 | 1·9 | 5 | 0·33 |
| Woolner | | | | | | | | | | | | | | | | |
| 0–10 | 1·3 | 6 | 9 | 25 | 60 | 6·0 | 13 | 115 | 600 | X | 0·15 | 0·25 | 1·25 | 2·0 | 1 | 1·09 |
| 10–40 | 2·3 | 16 | 12 | 28 | 44 | 5·8 | 15 | 130 | 390 | T | 0·20 | T | 2·55 | 3·5 | X | 0·66 |
| 40–70 | 6·6 | 21 | 11 | 21 | 47 | 6·1 | 6 | 70 | 320 | X | 0·15 | X | 3·60 | 2·8 | X | 0·29 |
| 70–125 | 7·0 | 12 | 10 | 28 | 50 | 6·2 | 6 | 70 | 250 | X | 0·15 | X | 4·45 | 4·2 | 6 | 0·10 |
| 125–150 | 4·4 | 13 | 12 | 27 | 48 | 6·1 | 6 | 70 | 160 | X | 0·15 | X | 4·00 | 3·2 | 11 | 0·11 |
| Zambina | | | | | | | | | | | | | | | | |
| 0–10 | 1·8 | 5 | 21 | 43 | 31 | 6·5 | 31 | 195 | 1160 | X | 0·35 | 8·75 | 2·80 | 10·2 | 6 | 2·21 |
| 10–60 | 4·7 | 19 | 21 | 31 | 29 | 6·2 | 10 | 100 | 280 | T | 0·25 | 2·50 | 2·70 | 5·1 | 10 | 0·46 |
| 60–90 | 5·1 | 21 | 18 | 29 | 32 | 6·6 | 10 | 100 | 300 | T | 0·25 | 2·10 | 4·15 | 6·1 | 2 | 0·34 |
| 90–150 | 9·8 | 26 | 19 | 28 | 27 | 6·6 | 10 | 100 | 120 | T | 0·30 | 2·10 | 6·50 | 8·5 | 4 | 0·18 |
| McKinlay | | | | | | | | | | | | | | | | |
| 0–15 | 2·5 | 11 | 28 | 53 | 8 | 5·6 | 22 | 160 | 1050 | 0·10 | 0·05 | 2·30 | 2·25 | 6·0 | 12 | 1·97 |
| 15–40 | 2·1 | 23 | 19 | 44 | 14 | 5·7 | 12 | 115 | 490 | 0·15 | T | 1·60 | 2·35 | 4·7 | 5 | 0·48 |
| 40–70 | 7·8 | 40 | 16 | 28 | 16 | 6·1 | 8 | 85 | 510 | 0·15 | T | 2·25 | 4·60 | 7·3 | 7 | 0·33 |
| 70–95 | 7·6 | 33 | 12 | 33 | 22 | 6·6 | 13 | 125 | 300 | 0·20 | T | 2·20 | 5·50 | 7·9 | 2 | 0·20 |
| 95–140 | 4·6 | 27 | 11 | 33 | 29 | 7·7 | 50 | 265 | 120 | 0·70 | T | 4·00 | 12·50 | 15·2 | 3 | 0·10 |
| Koolpinyah | | | | | | | | | | | | | | | | |
| 0–10 | 1·7 | 7 | 17 | 47 | 29 | 6·2 | 30 | 190 | 680 | 0·05 | 0·05 | 3·30 | 2·20 | 5·8 | 7 | 1·29 |
| 10–60 | 6·7 | 21 | 18 | 40 | 21 | 6·5 | 10 | 100 | 300 | 0·05 | T | 2·20 | 2·15 | 4·5 | 6 | 0·36 |
| 60–100 | 3·1 | 22 | 16 | 34 | 28 | 6·5 | 16 | 135 | 120 | 0·10 | X | 2·70 | 2·90 | 5·2 | 8 | 0·19 |
| 100–140 | 7·1 | 22 | 9 | 33 | 36 | 6·8 | 10 | 100 | X | 0·15 | X | 1·65 | 3·65 | 5·4 | 6 | 0·10 |
| Nungbalgarri | | | | | | | | | | | | | | | | |
| 0–20 | 4·5 | 12 | 31 | 43 | 14 | 6·4 | 45 | 250 | 1750 | X | 0·35 | 12·20 | 5·00 | 15·3 | 6 | 3·25 |
| Murrabibbi | | | | | | | | | | | | | | | | |
| 0–20 | 2·3 | 4 | 7 | 58 | 31 | 4·8 | 310 | 1060 | 1730 | 1·50 | 0·15 | 1·40 | 1·35 | 4·6 | 70 | 3·56 |
| 20–50 | 1·1 | 5 | 9 | 38 | 48 | 5·3 | 70 | 335 | 460 | 0·55 | 0·20 | 0·20 | 0·75 | 2·7 | 10 | 0·62 |
| 50–70 | 0·5 | 6 | 3 | 25 | 66 | 5·5 | 45 | 250 | 190 | 0·50 | 0·30 | 0·15 | 0·60 | 1·1 | 7 | 0·21 |
| 70–130 | 0·9 | 13 | 7 | 28 | 52 | 4·7 | 74 | 350 | 190 | 0·40 | 0·15 | 0·15 | 1·25 | 2·4 | 9 | 0·16 |
| 130–150 | 0·9 | 14 | 12 | 24 | 50 | 4·8 | 100 | 430 | 190 | 0·40 | 0·15 | 0·30 | 0·95 | 0·3 | 15 | 0·21 |
| Buldiva | | | | | | | | | | | | | | | | |
| 0–40 | 5·6 | 3 | 21 | 41 | 35 | 5·4 | 30 | 190 | 4700 | 0·10 | T | X | 0·05 | 0·2 | 8 | 6·97 |
| 40–110 | 0·4 | 3 | 7 | 11 | 79 | 5·2 | 7 | 75 | 190 | X | X | X | X | 0·9 | X | 0·15 |
| 110–140 | 0·5 | 5 | 6 | 17 | 72 | 5·2 | 9 | 95 | 70 | X | X | X | X | 0·6 | 2 | 0·23 |
| 140–150 | 0·2 | 6 | 2 | 9 | 83 | 5·2 | 15 | 130 | 140 | X | X | X | X | 1·1 | 1 | 0·16 |

out and could be regarded as immature cracking clays. Further west, these soils are known to have kaolinite as their dominant clay mineral, particularly in the upper horizons, and up to 8·0% total soluble salts (K. J. Day, unpublished report*).

A typical profile is

$A_{11}$, 0–2 cm.—Finely fibrous powdery saline material with salt crystals and a thin crust; pH 9·0.

$A_{12}$, 2–60 cm.—Dark greyish brown to olive-grey heavy clay, extremely firm, with some polygonal cracking and weak blocky structure; pH 9·0.

60–80 cm.—Transitional zone; paler, lighter-textured and more massive.

C/D, 80–150 cm.—Olive or grey gleyed light or medium clay, wet, sticky and massive, with fine sand and shell fragments and reddish mottling; pH 9·0.

TABLE 20

CLAY MINERAL ANALYSIS

| Soil family | Montmorillonite (%) | Illite (%) | Kaolin (%) | Quartz (%) | Goethite (%) | Other (%) |
|---|---|---|---|---|---|---|
| Zamu | | | | | | |
| B, 15–60 cm | — | 30 | 50 | 5 | 15 | — |
| BC, 60–90 cm | — | 30 | 55 | Trace | 15 | — |
| Nungbalgarri | | | | | | |
| B, 20–100 cm | — | — | 65 | — | 20 | Talc, 15 |
| BC, 100–150 cm | 25 | — | 65 | — | 5 | Talc, 5 |
| Cahill | | | | | | |
| C, 120–140 cm | 90 | — | 5 | 5 | Trace | — |
| Koolpin | | | | | | |
| B, 60–140 cm | 10 | 10 | 50 | 30 | — | Ver.,* trace |
| Wildman | | | | | | |
| $A_{12}$, 25–50 cm | 10 | 15 | 45 | 30 | — | Ana.,† trace |

* Ver., vermiculite. † Ana., anatase.

### (b) *Alluvial Soils*

*Saline mud* occurs under mangroves along tidal creeks and coastlines. The mud is clearly layered with coarse greyish brown sandy and shelly bands alternating with sticky or firm grey clays. Hydrogen sulphide is produced as organic materials decompose within the soil. Reaction is alkaline (pH 9·0), salinity is high and all parts of these muds are calcareous.

*Siltavel family* are imperfectly drained two-layered drainage-line soils. The upper layer is always silty and the lower one gravelly. Drainage is imperfect. These soils suffer wet-season inundation but are droughty and pulverulent during the dry season.

* Soils report, coastal plains survey, 1968–70. Dep. Northern Territory, Darwin.

A typical profile is

A, 0–40 cm.—Very dark grey to black silty loam to silty clay loam, hard, massive and earthy, with some rusty root-line mottles, grading to an $A_2$ horizon of yellowish brown or pale brown silty clay with some yellowish or greyish mottles; pH 6·0.

D, 40–70 cm.—Dark brown coarse gravelly sand, densely packed and massive, with about 80% ferruginous and siliceous gravel. This horizon has a low permeability and a low water-holding capacity.

*Barramundi family* soils occur in drainage lines and are clearly layered and very variable. The layers are predominantly coarse and sandy but may be clayey. They function as aquifers and aquicludes respectively. Most profiles are mottled and imperfectly drained.

A typical profile is

$A_1$, 0–10 cm.—Very dark grey to dark brown organic sandy loam, with some rusty root-line staining, soft to hard, massive; pH 5·5.

$A_2$, 10–35 cm.—Yellowish brown or light yellowish brown sand or loamy sand, soft to loose (aquifer); pH 5·5.

$D_1$, 35–80 cm.—Brownish yellow to grey clay or sandy clay, very firm and massive, with reddish and yellowish mottles (aquiclude); pH 7·0.

$D_2$, 80–120 cm.—Brownish yellow clayey sand to sand, wet and loose, sandy fabric. Some yellowish and whitish mottles; pH 7·5.

### (*c*) *Lithosols*

*Skeletal soils* are widespread in the area, and their characteristics are closely related to those of their parent rock.

The skeletal soils formed over Kombolgie sandstone are stone- and gravel-free shallow organic sands with up to 5·2% organic carbon (over 8% organic matter) and a pale washed sand surface veneer.

The skeletal soils formed on fresh siltstones in Bend I and Baker I land systems are typically shallow, stony, gravelly loams with frequent rock outcrop and a surface gravel veneer. Because these soils support perennial grasses and cover large areas, one profile was submitted for analysis. The profile had a low clay content (5–10%) which on this lithology indicates an immature condition.

Skeletal soils on other lithologies are shallow and stony with characteristics related to their parent rock.

### (*d*) *Calcareous Sands*

*Dune sands* has been retained as the name for these soils although in this area they occur on beach ridges. They are coarse light yellowish brown gritty soils composed mainly of shell fragments with some sand. Reaction is strongly alkaline (pH 9·0) and the soils are calcareous throughout. These deposits overlie olive-grey heavy marine clays, at a depth dependent on the height of the ridge.

### (*e1*) *Siliceous Sands*

*Kombolgie family* soils are greyish or brownish sands forming directly over Kombolgie sandstone in small depressions and shallow basins. They have a weathering zone with fragments of softened sandstone at the rock interface. Shallower members of this family merge with the lithosols. Some Kombolgie soils function as aquifers and seepage points seasonally but they remain well drained.

Analysis figures show virtually no clay or silt in these soils, and all mineral nutrients at concentrations below normal detection limits. Approximately 1% organic matter and 0·5% nitrogen are present in the upper horizon and it is likely that native plants rely heavily upon the recycling of nutrients.

A typical profile is

$A_1$, 0–10 cm.—Very dark grey loose sand with a thin white washed sand surface veneer; pH 6·0.

$A_2$, 10–100 cm.—Greyish brown or pale brown loose sand; pH 5·5.

AC, 100–120 cm.—Pale brown soft sand with increasing amounts of weathered fragments of Kombolgie sandstone; pH 5·5.

*Kapalga family* soils are similar to Kombolgie family soils but they form on colluvial slopes at seepage points and suffer impeded drainage. Whereas Kombolgie family soils are pale-coloured because their parent rock is pale and siliceous, Kapalga family soils are pale-coloured partly because of strong leaching associated with constant seepage. Typically, Kapalga soils form on lower slopes around areas of Killuppa or Cockatoo soils in Queue I land system, or on mid to lower slopes in areas of Bundah land system.

A sample from within a subsoil aquifer was submitted for analysis and proved very similar to soils of the Kombolgie family. Clay and silt were almost absent, and most mineral nutrients were at very low levels or undetectable. However, levels of available phosphorus and exchangeable cations within the aquifer were significantly higher than in Kombolgie family soils, and it is likely that an inflow of nutrients in the seepage water contributes to the chemical fertility of these soils.

A typical profile is

$A_1$, 0–15 cm.—Dark grey loose sand; pH 6·5.

$A_2$, 15–100 cm.—Aquifer, of light grey or white loose clean sand, moist; pH 6·5–7·0.

Trans., 100–115 cm.—Light grey soft sand, moist, with some reddish mottles; pH 6·5.

D, 115–150 cm.—Strongly mottled impermeable light grey sandy clay, moist and firm; pH 5·5.

*Sleisbeck family* soils are deep brownish sands becoming reddish with depth. They occur only on sand plains to the south of the area in Murray land system. They are well drained and probably have a very low water storage capacity.

A typical profile is

A, 0–15 cm.—Very dark brown loose siliceous sand, single-grained, with a yellowish washed sand surface veneer; pH 6·0.

AB, 15–60 cm.—Very dark greyish brown loose sand similar to the above.

B, 60–140 cm.—Dark reddish brown soft sand similar again to the above.

*Cockatoo family* soils are deep reddish sands formed on sand plains over the Kombolgie sandstone plateau and in sandy valley floor deposits between outcrops of Kombolgie sandstone.

Cockatoo soils have very low clay and silt contents (2–6 %), and cation exchange capacities of *c.* 1 m-equiv./100 g. The organic matter content is usually less than 2% and the natural chemical fertility of these soils is therefore very low.

A typical profile is

A, 0–15 cm.—Very dark greyish brown loose sand, sometimes water-repellent; pH 6·0.

AB, 15–40 cm.—Reddish brown soft or loose sand; pH 6·0.

B, 40–140 cm.—Dark reddish brown or reddish brown soft sand; pH 6·0.

*Arnhem family* soils are the yellowish equivalent of Cockatoo soils. They also form on sand plains over the Kombolgie sandstone plateau but may occur on colluvial slopes below the plateau. Their chemical fertility is very low. These are well-drained soils, and their yellowish colour is probably related to the very low levels of iron in the parent material.

A typical profile is

A, 0–15 cm.—Dark greyish brown loose sand, sometimes water-repellent; pH 6·0.

AB, 15–50 cm.—Yellowish brown or olive-brown soft sand; pH 6·0.

B, 50–140 cm.—Brownish yellow or olive-yellow soft sand; pH 6·0.

*Manbulloo family* soils form on the youngest of the river levees, mainly in Effington I land system. They are yellowish or sometimes reddish fine sands, usually sloping and erodable. Particle-size analysis shows that these are very well sorted soils with 80–90 % fine sand dominating the profile. Chemical fertility is very low despite organic matter contents of about 3·5% in the upper horizon. A cation exchange capacity of 2 m-equiv./100 g was recorded.

A typical profile is

$A_1$, 0–10 cm.—Very dark greyish brown to black slightly organic fine sand, loose; pH 6·0.

$A_3$, 10–40 cm.—Dark brown to dark reddish brown soft fine sand; pH 5·5.

BC, 40–140 cm.—Dark yellowish brown to red soft fine sand, sometimes clearly layered; pH 5·5.

*Evelyn family* soils are yellowish sands, superficially gravel-free, but with a dense gravelly lower subsoil. The gravels are mainly ferruginous. These soils are formed mainly on ancient levees (mapped in Queue I land system) that once flanked streams draining the Kombolgie sandstone areas. Evelyn soils also form in association with laterite. The gravel in these soils is probably inherited.

Mechanical analysis shows a texture profile dominated by the sand fraction and very similar to that of Kombolgie family soils. Chemical fertility is again very low, and a cation exchange capacity less than 1 m-equiv./100 g was recorded.

A typical profile is

$A_1$, 0–10 cm.—Very dark greyish brown soft sand or loamy sand; pH 6·0.

$A_3$, 10–50 cm.—Dark yellowish brown soft or slightly hard sand or loamy sand; pH 5·5.

B, 50–120 cm.—Yellowish brown slightly hard loamy sand or clayey sand; pH 5·5.

BC, 120–140+ cm.—Yellowish brown sand with 30–80% ferruginous nodules and a few fine reddish mottles; pH 6·0.

### *(e2) Siliceous Sands, Gritty Subgroup*

*Cullen family* soils are well or moderately well drained and have a characteristic coarse gritty texture, with large angular sand grains and feldspar crystals. They are formed on granite or colluvial slopes in granitic areas and occur entirely within Cully I and Currency I land systems.

Analysis shows these soils to be very low in clay and silt, with over 60% coarse sand. Chemical fertility, as with other siliceous sands, is very poor.

A typical profile is

$A_1$, 0–10 cm.—Very dark grey coarse loamy sand, massive, hard and earthy with a veneer of white coarse sand; pH 6·0.

$A_2$, 10–40 cm.—Yellowish brown coarse sand to loamy sand, massive, hard and earthy; pH 6·0.

B, 40–100 cm.—Yellowish red coarse clayey sand, very hard, massive and earthy, with common yellowish or reddish mottles; pH 5·5.

BC, 100–120 cm.—Softened strongly weathered granite, with common mottling and some evidence of clay illuviation.

*Cullen, poorly drained phase* soils are similar to those of Cullen family, but have strongly mottled subsoils, much more evidence of clay illuviation in relatively less permeable BC horizons, and are imperfectly drained.

### *(f) Earthy Sands*

*Baroalba family* soils are poorly drained, predominantly sandy soils that form on lower slopes and in drainage floors within the Koolpinyah surface (see Part VI). Some seepage areas occur in these soils but they are generally below the seepage points, and waterlogged for long periods. The soil contains some clay particularly in the subsoil which renders these soils characteristically greasy and boggy in the wet season.

A typical profile is

$A_1$, 0–15 cm.—Dark greyish brown soft sand, massive; pH 6·0.

$A_2$, 15–40 cm.—Brownish yellow soft moist sand to loamy sand, earthy fabric; pH 5·5.

B, 40–90 cm.—Yellowish brown slightly hard wet clayey sand with some illuvial clay, massive and earthy, strongly mottled; pH 5·5.

*Cahill family* soils are sandy and well drained with moderate to high amounts of ferruginous gravel in the profile. They occur most commonly in Kysto I land system in both unit 1 and unit 2. The Cahill soils in unit 1 overlie heavy clays probably formed from phyllite but those in unit 2 overlie weathering micaceous schist. A sample of weathering micaceous schist from unit 2 had 67% coarse sand, and 11% each of clay, silt and coarse sand. A sample of the heavy clay material from unit 1 had 30% clay, 34% silt, 22% fine sand and 14% coarse sand. Clay mineral analysis of the heavy clay from unit 1 revealed 90% montmorillonite, which probably formed in the phyllite as a result of metamorphosis and is not likely to be a pedogenic feature.

A typical profile is

$A_1$, 0–10 cm.—Very dark greyish brown gravelly loamy sand, hard, massive and earthy, with a continuous surface pavement of ferruginous gravel.

$A_2$, 10–50 cm.—Yellowish brown gravelly sandy loam, hard, massive and earthy; pH 6·5.

B, 50–120 cm.—Dark reddish brown faintly mottled gravelly sandy loam to light sandy clay loam, hard, massive and earthy; pH 6·5–7·0.

C, 120–140 cm.—Weathering micaceous schist or heavy mottled clay, gravel-free.

*Leichhardt family soils* form in low-lying back plain areas along some streams in the Kombolgie sandstone area, but only if weathering volcanics or dolerite are well represented in the stream catchment. These soils have a predominantly sandy mineral fraction and very high organic matter levels to depths of at least 150 cm. At about 120 cm the mineral fraction of one soil was found to contain 75% fine sand and 20% silt, but only 3% clay. The high degree of particle size sorting is consistent with the alluvial origin of these soils. The organic matter content at a depth of 120 cm was *c.* 3·5%, and at the surface at least double this amount could be present.

A typical profile is

$A_{11}$, 0–20 cm.—Black organic loamy sand, soft, massive and earthy, with a surface litter of decaying vegetable matter; pH 5·5.

$A_{12}$, 20–150 cm.—Black to very dark brown friable organic loamy sand to silty sand, massive and earthy; pH 5·5.

### (*g*) *Grey, Brown and Red Clays*

*Wildman family* soils are widespread on the estuarine plains, in Cyperus I, Copeman I and to some extent Pinwinkle I land systems. They are basically shallow immature dark cracking clays, weakly structured or massive and showing very little evidence of gilgai activity. Most soils are only about 90 cm deep over gleyed marine clays. All profiles have rusty root-line mottling in upper horizons and strongly mottled subsoils. The reaction trend is usually alkaline but some are neutral or slightly acid. These soils are poorly drained, and waterlogged or inundated for several months each year.

Wildman soils are reasonably organic (3·5% organic matter in the upper horizon) and one profile had relatively high amounts of available phosphorus in the topsoil (28 ppm). Cation exchange capacity is also relatively high at over 24 m-equiv./100 g, but these are sodic soils and the exchange complex is dominated by sodium and magnesium. Clay mineralogy studies show these soils to have mainly kaolinite with subdominant illite and montmorillonite. Similar results were obtained by K. J. Day (unpublished report).

A typical profile is

$A_{11}$, 0–20 cm.—Black weakly structured heavy clay with many rusty root-line mottles, very firm; pH 5·5–6·5.

$A_{12}$, 20–80 cm.—Dark olive-grey or black massive heavy clay with some evidence of slickensides, very firm, strong yellowish mottling; pH 7·0–8·0 (rarely 6·0–7·0).

Trans., 80–100 cm.—Olive-grey to olive massive medium clay, moist and firm, strong yellowish or grey mottling; pH 8·0–8·5 (rarely 6·0–7·0).

C, 100–140 cm.—Olive-grey to grey mottled medium clay, massive, often calcareous; pH 8·0–8·5 (rarely 6·0–7·0).

*Carmor family* soils are similar to Wildman soils but are highly calcareous and less leached. They occur mainly on low river levees and in the vicinity of old river channels (Hooper 1969 and personal communication), probably as a result of calcareous marine materials from the lower layers of the plains being brought into suspension by rivers and redeposited on the low levees. Carmor soils are basically very immature but a degree of leaching has occurred in them and carbonates are usually concentrated below the $A_{11}$ horizon. They are strongly sodic, poorly drained and usually inundated for short periods each year.

Figures provided by K. J. Day (unpublished report) for soils to the west of this area show a dominance of kaolinite over montmorillonite and illite, as for Wildman and Carpentaria soils.

A typical profile is

$A_{11}$, 0–10 cm.—Black extremely hard weakly structured heavy clay, some fabric development, and common rusty root-line mottling; pH 6·0–8·0, non-calcareous. Structure is better developed in the more acid examples.

$A_{12}$, 10–40 cm.—Black extremely firm massive heavy clay, some reddish brown or yellowish mottles, calcareous; pH 8·5.

40–90 cm.—Transitional zone; black to olive-grey firm moist medium clay, massive, some mottling, calcareous; pH 8·5–9·0.

C, 90–140 cm.—Olive-grey to olive sticky light to medium clay, massive and earthy, strongly mottled, calcareous; pH 9·0.

*Brockman family* soils are highly variable morphologically and do not form a satisfactory group. However, they are all formed on alluvium deposited by fresh-water streams, commonly in unchannelled alluvial flats. They are poorly drained medium to heavy clay soils, often with a skeleton of coarse sand grains, and with varying development of structure and fabric. All have an alkaline reaction trend, but some have free carbonates at the soil surface whilst others are acid. Colour varies, being dominantly either black, very dark greyish brown or olive-grey.

A typical profile is

$A_{11}$, 0–10 cm.—Black weakly structured medium clay with a coarse sand skeleton, with broad shallow gilgai; pH 7·0.

$A_{12}$, 10–25 cm.—Dark grey weakly structured medium to heavy clay with a coarse sand skeleton, smooth ped fabric; pH 7·5–8·5.

$A_{13}$, 25–110 cm.—Olive-grey heavy clay with indistinct blocky structure and smooth ped fabric, slickensides evident, some coarse sand and free carbonates; pH 8·5.

AC, 110–140 cm.—Olive-grey massive medium clay with some mottling and free carbonates, coarse sand skeleton evident; pH 8·5.

(*h*) *Wiesenboden*

*Counamoul family* soils are shallow acid clays formed near the edges of the estuarine plains over buried D horizons. The nature of the D horizons varies with their origin (Hooper 1969) but it is likely that seepage water enters the lower profile via these relatively sandy D horizons. In conjunction with seasonal flooding, this leads to intermittent partial saturation of the subsoils and D layers, and the development of various gley features.

These are strongly sodic soils which sometimes have a surface efflorescence of salts. Analytical results for one profie show almost 2% total soluble salts in the surface horizon and almost 1% in the D layer. The exchange complex of this soil was dominated by sodium and magnesium. The topsoil was highly organic (almost 6% organic matter) and decomposing remnants of *Melaleuca* leaves and bark were abundant. The trees on this soil were dead or dying which could indicate a recent increase in salinity.

A typical profile is

$A_{11}$, 0–25 cm.—Very dark greyish brown organic clay loam to clay, massive and earthy; pH 4·5. (See note under section I on variations between field texture and texture from mechanical analyses.)

$A_{12}$/B, 25–65 cm.—Greyish brown and yellowish brown strongly mottled medium clay with some sand, massive and earthy, some development of gley features; pH 4·5.

D, 65–150 cm.—Various D layers, predominantly acid, sandy, wet, strongly mottled and gleyed.

### (*i*) *Brown Earths*

*Argoolook family* soils form on the fine sandy and silty alluvial fan of the East Alligator River. They are moderately organic, brownish in colour, and have faintly mottled subsoils. They are moderately well drained.

Moisture relations seem very favourable on these soils, possibly because of their depth, high content of fine sand and silt (total about 90%) and their low position in the topography. Soils with a similarly high content of fine sand and silt near Tipperary are known to have high available moisture reserves (K. J. Day, personal communication).

Organic matter (about 6%), available phosphorus (19 ppm in topsoil) and soil nitrogen levels (almost 0·3%) are very high in Argoolook soils. Physically and chemically these soils are the most fertile in the whole study area.

A typical profile is .

$A_{11}$, 0–20 cm.—Black organic silty loam, hard, massive and earthy; pH 6·0.

$A_{12}$, 20–40 cm.—Very dark greyish brown silty loam, hard, massive and earthy; pH 6·0.

AB, 40–65 cm.—Dark brown organic silty clay loam, moist and friable, massive and earthy; pH 5·5.

B, 65–90 cm.—Dark yellowish brown slightly organic silty light clay, moist and firm, massive and earthy with a few reddish brown mottles; pH 5·5.

BC, 90–110 cm.—Yellowish brown fine sandy light clay, moist and firm, massive and earthy, with common reddish mottles; pH 5·5.

D, 110–140 cm.—Dark yellowish brown fine sandy clay loam, moist and friable, massive and earthy, with common mottling; pH 5·5.

*Argoolook organic phase* soils are similar to Argoolook family but they are more organic to greater depths, and slightly darker in colour. This phase forms in back-plain situations under paperbark forest.

### (*jI*) *Red Earths*

*Killuppa family* soils occur in Queue I land system on extensive sand plains. They are a gradational-textured equivalent of Cockatoo soils but they occur on other lithologies, possibly of Cretaceous age, and in lateritic areas. These are deep, reddish, well drained, predominantly sandy soils with a maximum subsoil texture of sandy clay loam.

Mechanical analysis figures for one profile show very low clay contents rising to 11% in the lower horizons. Deep auger holes drilled in similar soils to the west show that the texture reached by about 100 cm depth normally continues to the full depth of the deposit, which may be over 7 m. On one occasion detrital laterite was recovered from beneath a deep Killuppa profile. Chemical analysis figures show a low inherent fertility with magnesium dominating the exchange complex.

A typical profile is

$A_1$, 0–30 cm.—Dark reddish brown loamy sand, soft or loose; pH 6·0.

$A_3$, 30–70 cm.—Reddish brown heavy loamy sand, soft or loose; pH 6·0.

$B_1$, 70–120 cm.—Red sandy loam, very friable, massive and earthy; pH 6·0.

$B_2$, 120–150 cm.—Red to dark red sandy clay loam, friable, massive and earthy; pH 6·0.

*Zamu family* soils are massive, loamy, reddish brown soils formed on colluvium from areas of dolerite and volcanic rock or on weathered micaceous metamorphics.

Where they form on colluvium from dolerite and volcanics they occur on lower slopes, often topographically above their more yellowish derivative, Zambina family, in Viney land system. Where volcanic rock is present under these profiles the colluvial soil merges with a more sedentary soil above the rock. Some blocky structure and a heavier texture are apparent in this more sedentary soil, which is similar to soils of Nungbalgarri family. Chemical analysis of one colluvial profile showed it to be of average fertility.

Where Zamu soils form on micaceous schist they occupy higher crest sites where the micaceous schist has been subjected to pre-weathering within the weathering zone of the younger weathered land surface (see Part VI). Elsewhere, the soils on unweathered micaceous schists are greyish and skeletal. These Zamu soils sometimes have weak blocky structure and they merge with the krasnozems of Nungbalgarri family. Clay mineralogy studies on one of these intergrades showed a dominance of kaolinite (50%) over illite (30%) with some goethite (15%). These figures show the weathered condition of the clays and indicate a similarity with the krasnozems.

A typical profile is

$A_1$, 0–15 cm.—Dark brown massive sandy clay loam, hard; pH 6·5.

$B_1$, 15–60 cm.—Yellowish red to red clay loam to light clay, silty on metamorphics, massive and earthy; pH 6·5.

$B_2$, 60–110 cm.—Dark red light clay, massive, but sometimes light–medium weakly structured clay; pH 6·0.

BC, 110–150 cm.—Dark reddish brown light clay on colluvial slopes; reddish brown micaceous sandy clay loam on pre-weathered schist.

*Mundogie family* has been described from inadequate data. These soils are gradational- or uniform-textured reddish medium clays with moderate structure and mild drainage impedance. They seem to have a more favourable soil moisture status than usual. They probably form on relatively fresh Lower Proterozoic sediments but there may also be an influence from dolerite and volcanics. These soils occur only in Somerville land system.

A typical profile is

$A_1$, 0–10 cm.—Dark brown organic clay with ash and charcoal.

$A_2$, 10–30 cm.—Strong brown or yellowish red medium clay with small ferruginous concretions.

$B_1$, 30–60 cm.—Reddish brown structured medium clay with some red mottles and a few small ferruginous concretions.

$B_2$, 60–90 cm.—Red to dark red structured medium to heavy clay with yellowish brown mottles and a few ferruginous concretions.

*Howship family* soils form on slopes in areas where dolerite dykes crop out and parent materials are consequently a mixture of volcanic material and local rock. They also occur interspersed with skeletal soils on the Edith River Volcanics. These are relatively immature gravelly soils with clear relationships with the skeletal soils.

Howship soils always have some mildly swelling clay in the lower parts of the profile and in that respect they differ from Partridge family soils.

A typical profile is

$A_1$, 0–10 cm.—Very dark greyish brown gravelly sandy clay loam, hard, massive, and earthy; pH 6·5.

$A_2$, *10–45 cm.—Strong brown to yellowish red gravelly clay loam, very hard,* massive and earthy; pH 6·5.

B, 45–90 cm.—Yellowish red faintly mottled light clay with a distinct tendency to swell when wet, massive; pH 6·5.

BC, 90–140 cm.—Yellowish red mottled clay loam with sand and fragments of weathering rock, and some slightly swelling clays; pH 7·0.

*Emu family* soils were observed in only one area (upper Jim Jim Creek basin) probably on fresh exposures of fine sandy siltstone. They are deep, reddish, silty and fine sandy soils with uniform-texture profiles and they support tall open forest of *E. miniata.*

Natural chemical fertility is low in Emu soils and a cation exchange capacity of only 2·8 m-equiv./100 g was recorded. The content of fine sand and silt in Emu soils is very high, 85% in the $A_{11}$ horizon of one soil. In this respect they are similar to Katherine family soils.

A typical profile is

$A_1$, 0–15 cm.—Dark brown hard fine sandy loam, massive and earthy; pH 6·0.

AB, 15–65 cm.—Brown firm silty loam, massive and earthy; pH 5·5.

B, 65–140 cm.—Yellowish red firm to friable fine sandy and silty loam, massive to earthy; pH 5.5.

*Katherine family* soils form only on the higher set of younger river levees and consequently they have a characteristic well-sorted silica skeleton. Their colour is also characteristic, particularly for the B horizons. Texture varies, depending on the source and competence of the stream concerned, and particular streams seem to be associated with particular textures. The loamier soils tend to have a hard consistence and usually support woodland, but the sandier soils are relatively soft and usually support tall open forest.

Because of their favourable soil moisture and consistence characteristics, and the fact that they may occur over large and relatively flat areas, these are arable soils. Where they occur on relatively large levees they have been mapped in Levee land system, but some smaller areas are included in Effington I.

Chemical analysis indicates a low natural fertility, and a response to applied fertilizer is highly probable.

A typical profile is

$A_1$, 0–15 cm.—Dark brown fine loamy sand to silty sandy loam, slightly hard or hard, massive and earthy; pH 6·0.

$A_2$, 15–40 cm.—Yellowish brown to strong brown slightly hard fine sandy loam, or hard silty loam, massive and earthy; pH 6·0.

$B_1$, 40–80 cm.—Yellowish red to strong brown friable fine sandy clay loam to hard clay loam with sand, massive and earthy; pH 5·5.

$B_2$, 80–140 cm.—Yellowish red to strong brown friable clay loam to firm silty clay, massive to earthy, sometimes finely mottled with yellowish or reddish brown colours; pH 5·5.

### (*j2*) *Red Earths, Lateritic Subgroup*

*Hotham family* soils are not common in this area. They are reddish loamy soils with medium to high amounts of ferruginous gravel throughout the profile and a 60–80% surface gravel veneer. Parent material was usually encountered by about 100 cm and it consisted of weathering laterite, probably detrital. These are well-drained soils.

A typical profile is

$A_1$, 0–10 cm.—Dark brown hard gravelly sandy loam, massive and earthy; pH 6·5.

$A_3$, 10–30 cm.—Dark reddish brown hard gravelly sandy loam, massive and earthy; pH 6·5.

B, 30–100 cm.—Dark red gravelly sandy clay loam to clay loam, very hard, massive and earthy; pH 6·5.

BC, 100–120 cm.—Dark reddish brown very hard gravelly gritty sandy clay loam to clay loam, very hard, massive, with fragments of laterite and a few yellowish mottles.

*Basedow family* soils are similar to Hotham soils in many respects. They have medium to high amounts of gravel throughout the profile and a 60–100% surface gravel veneer, and loamy textures at least in the B horizons. However, they are only moderately well drained, have an unbleached $A_2$ horizon and distinctly mottled B horizons.

A typical profile is

$A_1$, 0–15 cm.—Very dark greyish brown gravelly sandy loam to sandy clay loam, hard, massive and earthy; pH 6·5.

$A_2$, 15–45 cm.—Brown to yellowish brown gravelly sandy loam to sandy clay loam, hard, massive and earthy; pH 6·0.

B, 45–90 cm.—Yellowish red to red gravelly sandy clay loam to clay loam, very hard, massive and earthy, common reddish and yellowish mottles; pH 5·5.

BC, 90–120 cm.—Yellowish red to red strongly mottled gravelly gritty sandy clay loam, very hard, massive, with some illuvial clay and fragments of laterite; pH 5·5.

*Woolner family* soils are imperfectly drained gravelly soils with a distinct $A_2$ horizon and strongly mottled reddish loamy B horizons. These are not texture-contrast soils but there is a clear permeability break at the B horizon and they should be regarded as intergrades with the red podzolics. The illuvial clay build-up in the $B_1$ horizon is clearly evident from mechanical analysis figures. Gravel contents are medium to high but most gravel occurs in the upper B and A horizons. A 60–100% surface gravel veneer is usual.

A typical profile is

$A_1$, 0–15 cm.—Very dark greyish brown gravelly sandy loam, hard, massive and earthy; pH 6·5.

$A_2$, 15–40 cm.—Yellowish brown faintly mottled gravelly sandy loam to sandy clay loam, hard, massive and earthy; pH 6·0.

$B_1$, 40–70 cm.—Strong brown mottled gravelly sandy clay loam to clay loam with obvious illuvial clay, very hard to extremely hard, massive and earthy; pH 6·0.

$B_2$, 70–110 cm.—Yellowish red, red or dark reddish brown strongly mottled gravelly sandy clay loam, extremely hard, some illuvial clay, massive and earthy; pH 5·5.

BC, 110–130 cm.—Similar to the $B_2$ horizon but with less gravel, more grit, and fragments of laterite.

### (*k1*) *Yellow Earths*

*Myra family* soils are restricted to alluvial flats in Verity land system. They are well drained but occur in association with less well-drained solodic soils (undescribed). The alluvium derived from rocks in this land system is highly micaceous and this is evident in the soils.

A typical profile is

$A_1$, 0–15 cm.—Dark brown hard silty loam, massive and earthy, micaceous; pH 6·0.

$A_3$, 15–45 cm.—Dark yellowish brown very hard silty loam, massive and earthy, micaceous; pH 6·5–7·0.

B, 45–130 cm.—Yellowish brown very hard silty clay loam, massive and earthy, micaceous; pH 8·0.

*Zambina family* soils occur on colluvium on lower slopes in Viney land system, below and in catenary sequence with Zamu family soils. They are moderately well-drained loamy soils with yellowish profile colours and some mottling. Below about 90 cm depth these soils become redder and more similar to soils of Zamu family.

A typical profile is

$A_1$, 0–10 cm.—Very dark greyish brown hard sandy clay loam, massive and earthy; pH 6·5.

$A_2$, 10–50 cm.—Yellowish brown hard clay loam, massive and earthy; pH 6·0.

B, 50–90 cm.—Strong brown (rarely yellowish red) hard light clay, common reddish and yellowish mottles, massive and earthy with some illuvial clay; pH 6·5.

BC, 90–140 cm.—Red strongly mottled light to medium clay, hard, massive and earthy; pH 6·5.

*McKinlay family* soils occur on alluvial flats and flood-plains in Fabian I and Bend I land systems but sometimes in Kysto I also. They are loamy to clayey soils with some evidence of seasonal cracking. Drainage is impeded. McKinlay soils support dense perennial *Themeda* grassland. Although these soils are dry and hard in the dry season the presence of deep casts of buffalo footprints suggests waterlogging in the wet season. Lower-lying areas in drainage floors are occupied by dark cracking clays of Brockman family.

A typical profile is

$A_1$, 0–10 cm.—Black hard silty loam to clay loam, massive and earthy but with a few widely spaced cracks; pH 5·5.

$A_2$, 10–40 cm.—Pale brown very hard clay loam, massive and earthy, with a few fine yellowish mottles; pH 5·5.

$B_1$, 40–70 cm.—Yellowish brown extremely hard clay loam to light clay, massive and earthy, with common reddish mottles; pH 6·0.

$B_{21}$, 70–100 cm.—Brown extremely hard light to medium clay, massive and earthy but with some evidence of swelling clay, some smooth ped fabric development and a micaceous glint. Strongly mottled; pH 6·5.

$B_{22}$, 100–140 cm.—As for the $B_{21}$ but slightly higher clay contents, a greater tendency to swell, stronger mottling and more micaceous material; pH 7·0.

*Ramil family* soils are the yellow earth equivalent of Killuppa soils, but they occur in other land systems as well as Queue I. They may occur in moister areas of the sand plains in Queue I land system or on laterite in other land systems. The latter group is probably related to soils of Evelyn family.

A typical profile is

$A_1$, 0–10 cm.—Very dark greyish brown friable loamy sand, massive; pH 6·0.

$A_3$, 10–30 cm.—Dark yellowish brown friable sandy loam, massive and earthy; pH 6·0.

$B_1$, 30–60 cm.—Brown friable to firm sandy clay loam, massive and earthy but with medium to large amounts of ferruginous gravel where profiles are formed over laterite; pH 5·5.

*Edith family* soils have been described from inadequate data. They are uncommon in the study area. They form on the higher set of younger river levees in Effington I land system. They are yellowish moderately well-drained loamy soils with strong subsoil mottling.

A typical profile is

$A_1$, 0–5 cm.—Light brown sandy loam, massive and earthy.

$A_2$, 5–25 cm.—Strong brown light clay with sand, massive and earthy.

$B_1$, 25–50 cm.—Strong brown light clay with sand, massive and earthy.

$B_2$, 50–70 cm.—Strong brown light to medium clay with strong reddish mottles and weak structure, earthy fabric.

BC, 70–90 cm.—Yellowish red medium clay, strongly mottled with red and yellow, weakly structured, fine sand evident.

*Yemelba family* soils have been described from inadequate data. They are the yellow earth equivalent of Mundogie family soils and occur almost entirely in Somerville land system. They probably form on relatively fresh Lower Proterozoic sediments. Drainage is imperfect.

Yellowish termitaria are common on Yemelba soils.

A typical profile is

$A_1$, 0–10 cm.—Dark greyish brown organic clay loam, massive and earthy.

$A_2$, 10–35 cm.—Yellowish brown silty light clay with weak structure, earthy fabric.

$B_1$, 35–60 cm.—Yellowish brown light to medium clay with common reddish mottling and moderate blocky structure.

$B_2$, 60–100 cm.—Strong brown (or yellowish red) medium to heavy clay, strongly mottled with reddish and yellowish colours, moderate blocky structure.

*Fisher family* soils occur mainly in Somerville and Bend I land systems but also in Kysto I. They are gradational-textured mottled yellow earths, often shallow, and formed on relatively fresh sediments. They are massive or only weakly structured and have imperfect drainage. Field observations suggest that some Fisher profiles are texture-contrast and these would intergrade with the yellow podzolics. Compared with Yemelba family these soils are more massive, shallower and have a smaller moisture storage capacity.

A typical profile is

$A_1$, 0–10 cm.—Black to dark brown hard silty loam, massive and earthy; pH 6·5.

$A_2$, 10–35 cm.—Yellowish brown hard sandy loam to sandy clay loam, massive and earthy; pH 6·5.

B, 35–90 cm.—Yellowish brown to brownish yellow strongly mottled very hard silty clay to light medium clay, massive and earthy but sometimes weakly structured, with some siliceous gravel; pH 7·0.

BC, 90–120 cm.—As for the B horizon but containing fragments of decaying rock, often shale.

*Partridge family* soils are essentially well-drained, yellowish sandy to loamy profiles with abundant siliceous gravel throughout the profile, formed on micaceous schist or siltstone. They are relatively immature soils and fragments of weathering rock are common in them. Many profiles are shallow. They form on slopes in similar situations to Howship soils but not in the vicinity of dolerite dykes. The soil surface has a veneer of siliceous gravel.

A typical profile is

$A_1$, 0–15 cm.—Very dark greyish brown sandy loam with siliceous gravel, massive and earthy; pH 6·0.

AB, 15–35 cm.—Yellowish brown to strong brown sandy clay loam with siliceous gravel, massive and earthy; pH 6·0.

B, 35–70 cm.—Yellowish brown to brownish yellow sandy clay loam with siliceous gravel, some mottling, massive and earthy; pH 6·0.

BC, 70–100 cm.—As for the B horizon but containing fragments of various weathering rocks.

### (*k2*) *Yellow Earths, Lateritic Subgroup*

*Koolpinyah family* soils are yellowish sandy to loamy soils with medium to large amounts of ferruginous gravel throughout the profile and a 20–60% surface gravel veneer. Parent material varies. Lateritic weathering processes could cause Koolpinyah soils to form from a wide range of parent materials including laterite, alluvia and fresh or weathered sedimentary and igneous rocks. Minor variations in texture and fabric in the soils are probably related to this variety of possible parent materials. As for Cahill soils, some Koolpinyah profiles were found to overlie gravel-free medium or heavy clays. These could have been derived from phyllite, shale or dolerite.

A typical profile is

$A_1$, 0–15 cm.—Very dark greyish brown hard gravelly sandy clay loam, massive and earthy. Small amounts of gravel; pH 6·0.

$A_2$, 15–50 cm.—Yellowish brown very hard gravelly sandy clay loam to clay loam, massive and earthy. Small to medium amounts of gravel; pH 6·0.

B, 50–100 cm.—Strong brown (to yellowish red) extremely hard gravelly clay loam, massive and earthy, with common reddish mottles. Medium amounts of gravel; pH 6·5.

BC, 100–140 cm.—As for the B horizon but containing fragments of parent rock or gravel-free medium or heavy clay.

*Koolpinyah shallow phase* soils form mainly over laterite on slopes or crests. They are close to the skeletal soils. They are yellowish but sometimes reddish, very gravelly and predominantly sandy soils with considerably reduced water-holding capacity. The deeper, sandier and redder soils of this phase merge with soils of Cahill family.

### (*l*) *Krasnozems*

*Nungbalgarri family* soils are structured reddish clay soils formed from dolerite and volcanics. They form in Viney land system on slopes of up to 40% but only where rates of erosion are reduced by the presence of an almost continuous veneer of boulders.

The soils are only 100–150 cm deep over weathering rock, but the lack of floaters in the soils indicates that strong weathering conditions prevail within the soil. Nungbalgarri soils also form in association with the more massive Zamu soils on pre-weathered micaceous schist in Verity land system. These soils occur on crests and do not have a protective boulder cover.

Classification of these soils is difficult, as they are often essentially neutral with compact massive subsoils like euchrozems, but also often slightly acid and well structured like krasnozems. However, because they are uniform-textured, non-calcareous and well drained they have been included here as shallow krasnozems.

Clay mineralogy studies show a dominance of kaolinite (65%) with appreciable quantities of goethite (20%) and talc (15%) in the B horizon. These figures show the highly weathered condition of the clays. Chemical fertility, particularly soil nitrogen status, is relatively high and this may be related to the abundance of native legumes that grow on these soils during the wet season.

A typical profile is

$A_1$, 0–15 cm.—Dark reddish brown light-medium to medium clay, fine blocky structure and rough ped fabric; pH 6·5.

B, 15–100 cm.—Dark red light-medium to medium clay, weak blocky structure and smooth ped fabric; pH 6·5.

BC, 100–150 cm.—Yellowish red light or light-medium clay, very hard, massive and earthy, pH 6·5–7·0, with specks and fragments of weathering rock. Where the parent material is pre-weathered mica schist this horizon has a texture of silty loam, with abundant micaceous flakes and pH 7·0–7·5.

### (*m*) *Yellow Podzolic Soils*

*Scinto family* soils are imperfectly drained texture-contrast podzolics formed on alluvium derived from granite in Cully I land system (unit 4). The texture contrast may be due partly to layering of the parent material, but $A_2$ horizons are clearly present and clay illuviation into the B horizons is evident. Very coarse angular sand is characteristic of these soils.

A typical profile is

$A_1$, 0–15 cm.—Very dark greyish brown silty loamy sand, hard, massive and earthy; pH 5·5–6·0.

$A_{21}$, 15–45 cm.—Greyish brown to brown coarse sandy loam, hard, massive and earthy; pH 6·0.

$A_{22}$, 45–60 cm.—Light brownish grey to pale brown coarse sand, loose to friable, massive and sandy (this horizon may act seasonally as an aquifer); pH 6·0.

$B_1$, 60–90 cm.—Brown (to reddish brown) strongly mottled coarse sandy clay loam to light clay with illuvial clay, very firm, massive and earthy; pH 5·5.

$B_2$, 90–140 cm.—Brown (to reddish brown) strongly mottled coarse sandy medium clay, very firm, massive and earthy, some illuvial clay; pH 5·0.

*Honeycomb family* soils occur almost entirely in the subcircular depressions of Honeycomb land system (unit 2), although other soils (Kombolgie) may also occupy these positions. The parent materials are not known with certainty but the source of clay in these soils was probably the volcanics that once overlay this land system and have since been almost entirely removed. These soils form in separated depressions, each of which has different hydrological and pedological factors operating and, as a result, no two profiles are alike. However, in principle the soils are imperfectly drained and leached, with sandy to loamy acid A horizons overlying mottled acid to neutral clay subsoils.

A typical profile is

$A_1$, 0–10 cm.—Black hard sandy clay loam, massive and earthy; pH 5·5.

$A_2$, 10–40 cm.—Yellowish brown gritty sandy clay loam to clay loam, very hard, massive and earthy; pH 6·0.

B, 40–110 cm.—Yellowish brown extremely firm medium to heavy clay, sometimes weakly structured but usually massive, common reddish mottles and some ferruginous nodules; pH 7·5.

BC, 110–140 cm.—Brownish yellow strongly mottled massive medium clay, earthy fabric, very firm; pH 7·5.

### (*n*) *Red Podzolic Soils*

*Malone family* soils occur on crests and slopes in Cully I and Currency I land systems. They are imperfectly drained. Cullen soils occur in similar topographic positions, but whilst Cullen soils are coarse, sandy, poorly developed and often shallow, Malone soils are much better developed, loamy texture-contrast soils. Cullen soils are dominated by coarse angular sand with some unweathered feldspar crystals but Malone soils have mainly medium angular sand in the profiles. The relationship between these soils is not clear but there could be differences in the granites concerned and/or in the hydrological conditions that control intensity of weathering.

A typical profile is

$A_1$, 0–10 cm.—Very dark greyish brown coarse loamy sand, friable, massive and earthy; pH 6·0.

$A_2$, 10–25 cm.—Yellowish brown to strong brown coarse sandy clay loam, firm, massive and earthy; pH 5·5.

B, 25–60 cm.—Reddish brown very firm clay loam to light clay with coarse sand, common to many reddish and yellowish mottles, massive and earthy, some illuvial clay; pH 5·5.

BC, 60–100 cm.—As for the B horizon but very strongly mottled, sandier and with fragments of weathering granite.

### (*o*) *Humic Gleys*

*Dashwood family* soils are black organic clay soils that form under paperbark forests near the fringes of the estuarine plains. The organic matter in these soils is derived from decomposing *Melaleuca* remnants and the anaerobic conditions prevailing produce a strong smell of hydrogen sulphide. In this survey area the Dashwood soils were inundated at the time of inspection and could not be satisfactorily described. Similar soils were described by K. J. Day (unpublished report) as black medium clays with rusty mottles overlying greyish brown mottled clay at about 50–60 cm. Hooper (1969) provides the following description.

A, 0–15 cm.—Black silty clay or medium clay, firm when moist, hard when dry, with a weak granular structure or massive.

AC, 15–75 cm.—Grey to dark grey medium to heavy clay, moist, firm and massive, strongly mottled (brown, yellow-brown and black).

C, 75–150 cm.—Dark grey or olive-grey medium to heavy clay, massive, very firm and sticky.

*Murrabibbi family* soils form on the lower colluvial slopes of the Koolpinyah surface or its derivatives (usually Kosher I land system) where they abut on the estuarine plains. They commonly support *Pandanus* scrub or paperbark forest. They occur only at seepage points and are imperfectly drained. Topsoil organic matter contents are high (6%), probably because these are permanently moist areas. Layering is clearly evident in the colluvial parent material and because of the consequent textural fluctuations no principal profile form (Northcote 1971) can be applied to Murrabibbi soils.

A typical profile is

$A_1$, 0–20 cm.—Black friable organic clay loam, massive and earthy; pH 5·5.

$A_{12}$, 20–50 cm.—Black friable organic sandy clay loam, massive and earthy; pH 5·5.

$A_2$, 50–70 cm.—Greyish brown soft to loose loamy sand, massive. This horizon acts as an aquifer; pH 5·5.

B, 70–130 cm.—Light grey friable to firm strongly mottled sandy clay loam to sandy clay, massive and earthy. Water-table at 100 cm; pH 6·0.

D, 130–150 cm.—Yellowish brown gravelly sandy clay loam, friable, massive and earthy, with many reddish mottles. This horizon represents a buried gravelly lateritic soil; pH 6·5.

*Buldiva family* soils occur mainly on the Kombolgie sandstone plateau in Queue I land system (unit 3), and rarely in Bundah land system. They form in permanently moist unchannelled drainage flats on alluvial sand, where there is a dense perennial growth of sedges. These drainage flats are common in the less dissected parts of the Kombolgie sandstone plateau in the southern half of the survey area. They receive seepage water from large areas of sand plain nearby and never dry out.

Buldiva soils have a highly organic or peaty $A_1$ horizon with from 12 to 30% organic matter, overlying wet mottled sands.

A typical profile is

$A_1$, 0–50 cm.—Thick black peat, sometimes with some sand, friable and massive; pH 5·0.

$A_2$, 50–100 cm.—Light brownish grey very friable sand, acting as an aquifer; pH 5·0.

$B_{fe}$, 100–140 cm.—Yellowish red strongly mottled ferruginous sand, friable, massive and earthy; pH 5·5.

D, 140–150 cm.—Light brownish grey wet non-sticky sand, acting as an aquifer; pH 5·5.

*Gilruth family* soils are loamy mottled organic soils formed on alluvia, with $A_2$ horizons and pale mottled subsoils. These soils have lower organic matter contents than other humic gleys and have some rusty root-line mottling in the $A_1$ horizon, and it is likely that they dry out briefly each year. They are intergrades with the gleyed podzolics. They form in a variety of land systems in unchannelled alluvial flats with a seasonal supply of seepage water, and a moderately dense growth of sedges. Drainage is imperfect to poor.

A typical profile is

$A_1$, 0–10 cm.—Black organic silty loam, hard, massive and earthy, with some rusty root-line mottling, pulverulent when dry; pH 6·0.

$A_2$, 10–50 cm.—Light brownish grey silty sandy clay to light clay, hard, massive and earthy, some reddish brown root-line mottles, pulverulent when dry; pH 5·5.

$B_1$, 50–110 cm.—Grey to light grey silty clay to medium clay, very firm, massive and earthy, many yellowish mottles; pH 6·0.

$B_2$, 110–150 cm.—Light grey to light brownish grey silty medium clay to heavy clay, very firm, massive and earthy or weakly structured, strongly mottled; pH 7·0.

*Koolpin family* soils occur exclusively on broad unchannelled drainage floors in Cully I land system. They consist of a thick peaty $A_1$ horizon overlying pale mottled heavy kaolinitic clay. The clay is probably derived from weathering feldspars in the surrounding granite landscape. It is probable that the dense growth of permanent sedges induced by the perennial seepage water at these sites has filtered out colluvial sand at the edges of the drainage flat but allowed the clay to pass and accumulate within the drainage floor.

A typical profile is

$A_1$, 0–15 cm.—Black peat or peaty loam, slightly hard to friable, massive; pH 6·0.

$A_2$, 15–60 cm.—Dark grey very firm heavy clay, massive and earthy, with a few reddish mottles; pH 5·5.

B, 60–140 cm.—Grey extremely firm massive heavy clay, strongly mottled with reddish colours; pH 5·5.

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## APPENDIX II

### List of Plants mentioned with Available Common Names

| | |
|---|---|
| *Acacia* spp. | |
| *A. senegal* (L.) Willd. | |
| *Allosyncarpia ternata* S. T. Blake | |
| *Alloteropsis semialata* (R. Br.) Hitchc. | Cockatoo grass |
| *Alyxia spicata* R. Br. | |
| *Ampelocissus* spp. | Native grape |
| *Antidesma ghaesembilla* Gaertn. | |
| *Arthrocnemum* spp. | Samphire |
| *Arundinella nepalensis* Trin. | |
| *Avicennia marina* (Forsk.) Vierh. | Mangrove |
| | |
| *Banksia dentata* L. f. | |
| *Barringtonia acutangula* (L.) Gaertn. | Freshwater mangrove |
| *Brachyachne convergens* (F. Muell.) Stapf | |
| *Brachychiton* sp. | |
| *Bruguiera exaristata* Ding Hou | |
| *Buchanania obovata* Engl. | |
| | |
| *Capillipedium parviflorum* (R. Br.) Stapf | Scented top |
| *Calytrix* spp. | |
| *Chrysopogon fallax* S. T. Blake | Golden beard grass |
| *Coelorachis rottboellioides* (R. Br.) A. Camus | |
| *Cochlospermum fraseri* Planch. | |
| *Coelospermum reticulatum* (F. Muell.) Benth. | |
| *Cryptocarya cunninghamii* Meisn. | |
| *Cycas media* R. Br. | |
| | |
| *Desmodium* spp. | |
| *Dichanthium tenuiculum* (Steud.) S. T. Blake | Blue grass |
| *Digitaria* spp. | Finger grass |
| *Dioscorea bulbifera* L. | |
| *Diospyros ferrea* (Willd.) Bakh. var. *humilis* (R. Br.) Bakh. | |
| *Drosera* spp. | Sundew |
| | |
| *Echinochloa colonum* (L.) Link | Awnless barnyard grass |
| *Ectrosia leporina* R. Br. | Hare's-tail grass, hare's-foot grass |

| | |
|---|---|
| *Eleocharis* spp. | Spike-rush |
| *Eragrostis schultzii* Benth. | |
| *Eriachne burkittii* Jansen | Wanderrie grass |
| *E. triseta* Nees ex Steud. | Wanderrie grass |
| *Eriosema* sp. | |
| *Erythrophleum chlorostachys* (F. Muell.) Baill. | Ironwood |
| *Eucalyptus alba* Reinw. ex Bl. | Poplar gum, Timor white gum |
| *E. bigalerita* F. Muell. | |
| *E. bleeseri* Blakely | Smooth-barked bloodwood |
| *E. clavigera* A. Cunn. ex Schau. | |
| *E. confertiflora* F. Muell. | Apple gum |
| *E. dichromophloia* F. Muell. | Red-barked bloodwood |
| *E. ferruginea* Schau. | Rusty bloodwood |
| *E. foelscheana* F. Muell. | Cabbage gum |
| *E. herbertiana* Maid. | Yellow-barked mallee |
| *E. grandiflora* R. Br. ex Benth. | Moreton Bay ash |
| *E. latifolia* F. Muell. | Bloodwood, bastard bloodwood |
| *E. miniata* A. Cunn. ex Schau. | Woollybutt, melaleuca gum |
| *E. papuana* F. Muell. | Cabbage gum, ghost gum, carbeen |
| *E. patellaris* F. Muell. | Weeping box |
| *E. phoenicea* F. Muell. | Ngainggar, scarlet gum |
| *E. polycarpa* F. Muell. | Grey bloodwood |
| *E. pruinosa* Schau. | Kullingal |
| *E. setosa* Schau. | Rough-leaved bloodwood |
| *E. tectifica* F. Muell. | McArthur River box |
| *E. tetrodonta* F. Muell. | Darwin stringybark |
| *Eugenia armstrongii* Benth. | |
| | |
| *Ficus* spp. | Fig |
| *Flagellaria indica* L. | Supplejack |
| | |
| *Galactia* sp. | |
| *Gardenia megasperma* F. Muell. | |
| *G. suffruticosa* R. Br. | |
| *Glycine* sp. | |
| *Grevillea decurrens* Ewart | |
| *G. pteridifolia* Knight | |
| | |
| *Hakea arborescens* R. Br. | |
| *Heteropogon contortus* (L.) Beauv. ex R. & S. | Black spear grass, bunch spear grass |
| *H. triticeus* (R. Br.) Stapf | Giant spear grass |
| *Hymenachne acutigluma* (Steud.) Gilliland | |
| | |
| *Ischaemum* spp. | |
| *Ixora* sp. | |
| | |
| *Leptocarpus* spp. | |
| *Livistona humilis* R. Br. | |
| *L. loriphylla* Becc. | |
| | |
| *Melaleuca acacioides* F. Muell. | |
| *M. argentea* W. V. Fitzg. | Paperbark |
| *M. leucadendron* (L.) L. | Paperbark |

| | |
|---|---|
| *M. nervosa* (Lindl.) Cheel | Paperbark |
| *M. viridiflora* Sol. ex Gaertn. | Paperbark |
| *Micraira* spp. | |
| *Mitrasacme* spp. | |
| *Myristica insipida* R. Br. | |
| | |
| *Oryza rufipogon* Griff. | Wild rice |
| *Owenia* spp. | Emu apple |
| | |
| *Pandanus* spp. | |
| *Panicum* spp. | |
| *Paspalum orbiculatum* G. Forst. | |
| *Petalostigma haplocladum* Pax & K. Hoffm. | Quinine bush |
| *P. quadriloculare* F. Muell. | Quinine bush |
| *Planchonia careya* (F. Muell.) R. Knuth | Cockatoo apple |
| *Platyzoma microphyllum* R. Br. | |
| *Plectrachne pungens* (R. Br.) C. E. Hubb. | Soft spinifex |
| *Pouteria sericea* (Ait.) Baehni | |
| *Pseudopogonatherum contortum* (Brogn.) A. Camus | |
| *Pseudoraphis* spp. | |
| *Psoralea* sp. | |
| | |
| *Rhizophora stylosa* Griff. | Mangrove |
| *Rhynchosia* sp. | |
| *Rottboellia formosa* R. Br. | |
| | |
| *Schizachyrium obliqueberbe* (Hack.) A. Camus | Red spathe grass |
| *Sclerandrium grandiflorum* S. T. Blake | |
| *Sehima nervosum* (Rottl.) Stapf | |
| *Smilax australis* R. Br. | Sarsaparilla |
| *Sorghum plumosum* (R. Br.) Beauv. | |
| *S. stipoideum* (Ewart & White) Gardn. & C. E. Hubb. | |
| *Stylosanthes humilis* H. B. K. | |
| | |
| *Tephrosia* spp. | |
| *Terminalia* sp. | |
| *T. ferdinandiana* Exell | |
| *Thaumastochloa major* S. T. Blake | |
| *Themeda australis* (R. Br.) Stapf | Kangaroo grass |
| *Triodia* spp. | Spinifex |
| *Tristania lactiflua* F. Muell. | |
| | |
| *Uraria* sp. | |
| *Utricularia* spp. | Bladderwort |
| | |
| *Verticordia cunninghamii* Schau. | |
| | |
| *Xanthostemon paradoxus* F. Muell | |
| *Xerochloa imberbis* R. Br. | |
| *Xyris indica* L. | |
| | |
| *Zornia* sp. | |

# APPENDIX III

## Correlations between Plants and Soils

By J. M. Aldrick* and R. Story†

### I. Basic Problems

Table 21 and Figs 28–30 show some correlations between soil conditions and plant growth for this area. Because they have been established from limited data some may require modification if subjected to detailed testing or if applied elsewhere. However, experience in other parts of the 'top end' of the Northern Territory tends to support most of them (C. S. Robinson, personal communication).

Table 21

Correlation of certain species with sandstone or with volcanics and dolerite

(−, Absent; +, present)

| Species | Sandstone | Volcanics and dolerite |
|---|---|---|
| *E. bleeseri* | − | − |
| *E. clavigera* | − | + |
| *E. confertiflora* | − | + |
| *E. foelscheana* | − | + |
| *E. grandifolia* | − | − |
| *E. latifolia* | − | + |
| *E. miniata* | + | Rare |
| *E. papuana* | − | − |
| *E. patellaris* | − | + |
| *E. phoenicia* | + | Rare |
| *E. tectifica* | − | + |
| *Gardenia* | Rare | + |
| *Owenia* | + | Rare |
| *Ampelocissus* | − | + |
| *Heteropogon contortus* | − | + |
| *Themeda* | − | + |
| *Alloteropsis* | Rare | + |
| *Eugenia* | − | Rare |
| *Livistona* | Rare | Rare |
| *Cochlospermum* | Rare | + |

Correlations between plants and soils depend largely on the method of classification. Plants may be considered as individuals or as groups of species (communities),

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also on a presence-or-absence basis or according to size, vigour and frequency of occurrence.

Soil variables are more difficult to isolate. Factors traditionally used in soil classification such as colour, texture, horizonation, gravel content and mottling do not directly affect plants but indicate processes in the soil which may in turn influence plant growth. Drainage, moisture-holding capacity, length of growing season (as influenced by soil moisture), soil surface temperature and stability of soil climate probably have a more direct influence on plants but cannot always be clearly linked in the field with soil morphological attributes and are not specifically catered for in traditional classifications.

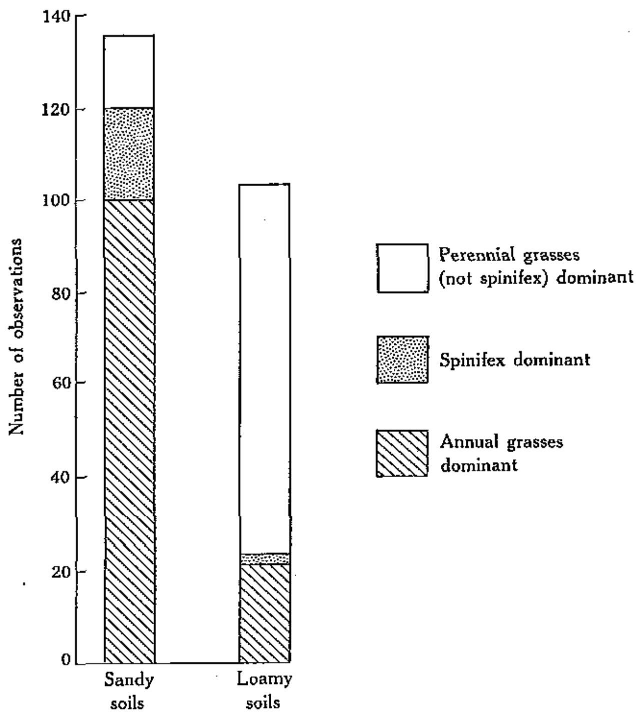


Fig. 28.—Distribution of annua and perennial grasses on sandy and loamy soils.

The soil classification used in this report is based on the systems proposed by Stace *et al.* (1968) and Northcote (1971), and is aligned where possible with the work of Hooper (1969). It is therefore traditional in its approach and sometimes fails to identify edaphic factors related to plant growth. This is most evident in the gravelly lateritic soils, where variations in plant growth within a soil family are sometimes greater than between families. For example, in Verity land system variations in the vegetation from non-eucalypt to eucalypt forest correlate with soil depth, moisture-holding capacity or drainage in two distinct edaphic units (units 1 and 3). However, the edaphic factors are not clearly separated by the soil classification and the same soil family may be represented in each unit. Consequently in the tables that follow, the various plant species have been correlated with specific soil factors and not with soil families.

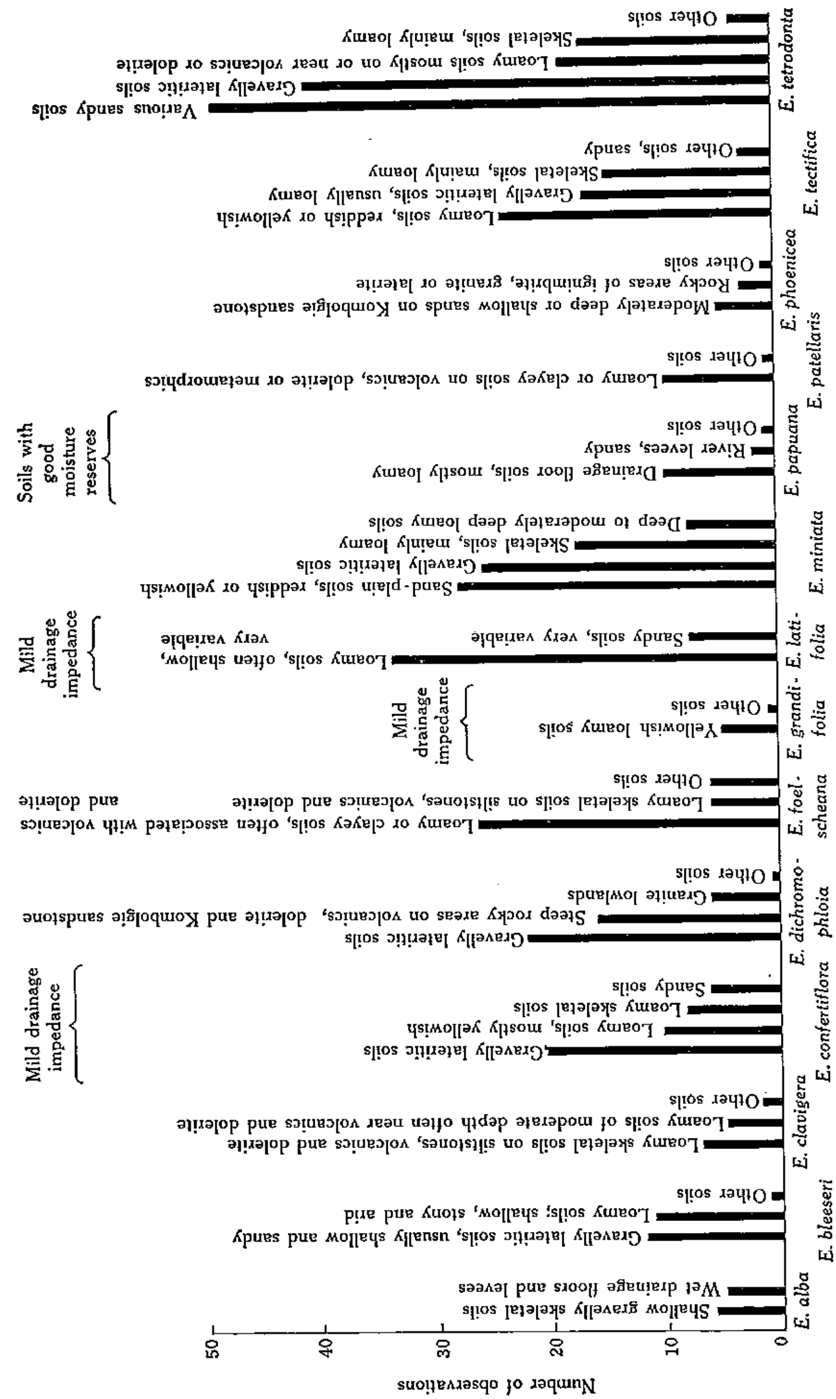


Fig. 29.—Relative abundance and edaphic relationships of eucalypts.

A source of substantial error in the correlations lies in the low sampling intensity of this type of survey, which entails applying the findings from one soil profile to the whole unit which contains it. The error was reduced by inspecting profiles in other examples of the same unit wherever possible. Some land units (e.g. unit 1 of Queue I land system) have relatively uniform edaphic characteristics throughout but others, particularly those in fluvial situations (e.g. unit 1 of Effington I land system), are complex and variable.

## II. The Correlations

Several species are conspicuously absent from the soils formed on the Kombolgie Formation and some are also absent from soils on volcanics and dolerite. These are listed in Table 21.

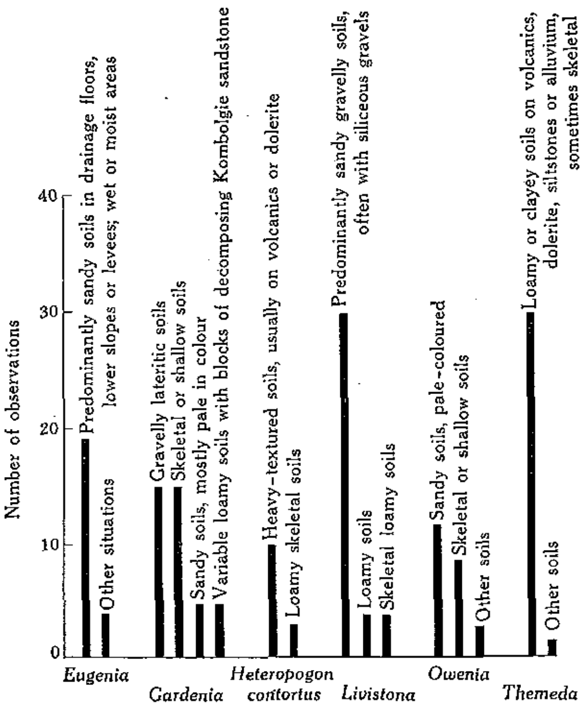


Fig. 30.—Relative abundance and edaphic relationships of non-eucalypts.

The distribution of annual and perennial grasses is shown in Fig. 28. The correlation of annual grasses with sandy soils is clear, and it is interesting to note that one perennial, spinifex, also grows mainly on sandy soils. Spinifex differs from other perennials in being a drought resister rather than a drought evader.

The gravelly lateritic soil families have generally been grouped together for these correlations unless specific subdivision can be related to some botanical character. For instance, *E. tetrodonta* and *E. miniata* seem to grow on any of these soils but *E. bleeseri* is usually found on the shallower sandier examples and *E. tectifica* on the more loamy soils.

*E. alba* was found to occur on rocky hills, wet clayey drainage floors and levees (Fig. 29). There is a strong possibility that these very different situations reflect differences in the plants concerned, for the closely related *E. bigalerita* is difficult to distinguish, as are the varieties within *E. alba*.

In a clear separation, *E. confertiflora* grows on less favourable soils than *E. clavigera*, generally on those with some drainage impedance (Fig. 29).

*Heteropogon contortus* (Fig. 30) also shows some correlation with disturbed areas, e.g. those trampled or heavily grazed. Disturbance was recorded in 7 of the 13 sites where this grass was growing.

Part VIII has a reference to the abrupt transition from mixed open forest to eucalypt woodland. Nine pairs of samples showed that the soils of the mixed open forest were all normal or better than normal lateritic red or yellow earths, i.e. they were low in gravel content and had reasonably good water-holding capacity, drainage and depth. Those in the eucalypt woodland had less favourable characteristics, being shallow and seasonally waterlogged or alternately waterlogged and very dry. These relationships involve plant communities rather than individual species and have not been represented in the tables.

Although sedges were usually common constituents of the ground flora regardless of the land system, they were lacking in some areas—in a total of 12 samples. Field checks of the habitat features showed no reason for this, and a later and more detailed check of the soils in question was also inconclusive. The position was similar with respect to herbaceous legumes, which were absent in 12 of the sites examined.

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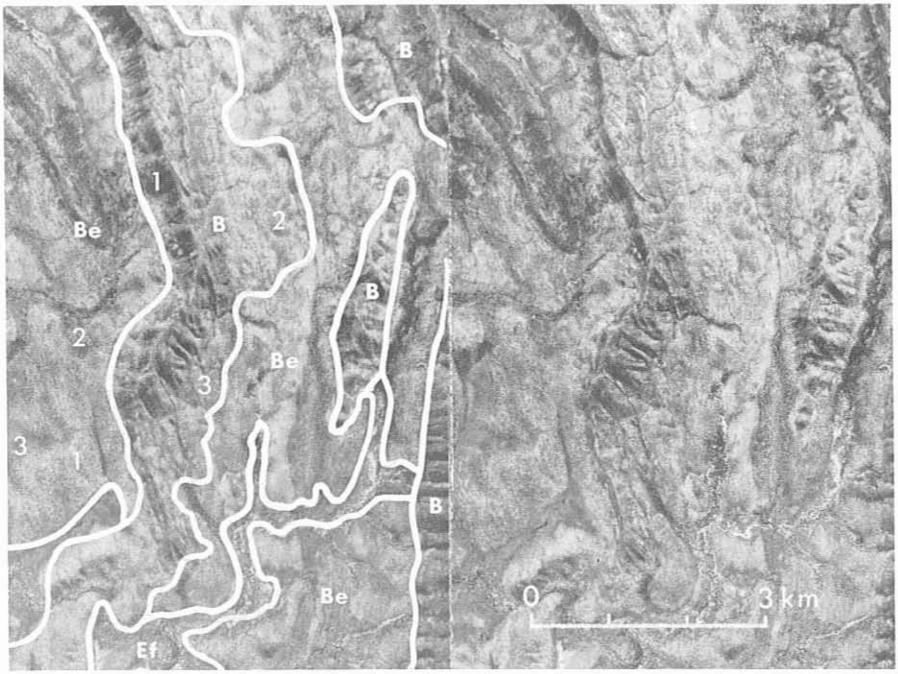


Fig. 1.—Baker I (B) and Bend I (Be) land systems.


Fig. 2.—Copeman I (Cm) and Littoral I (L) land systems.

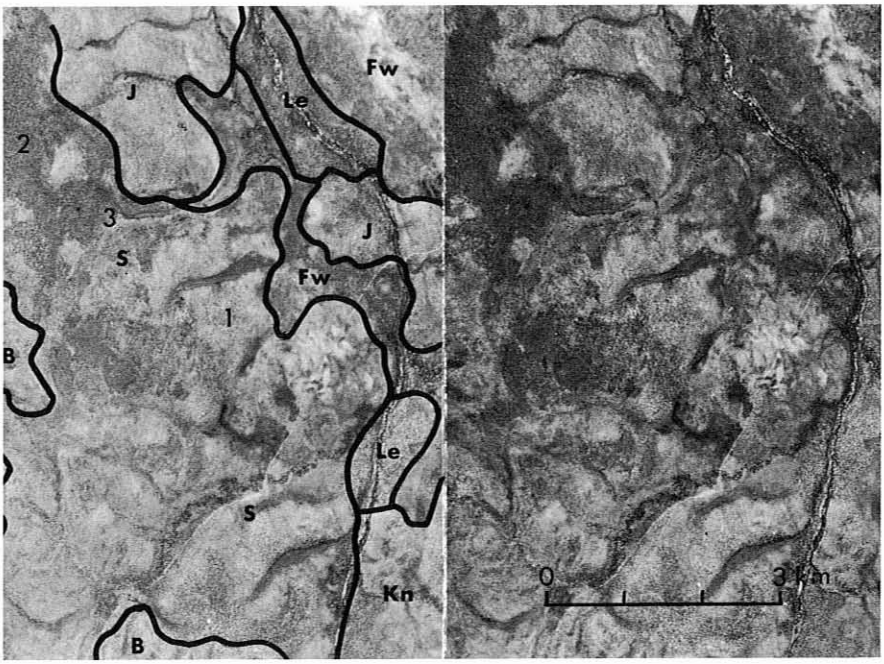


Fig. 1.—Somerville (S) land system.

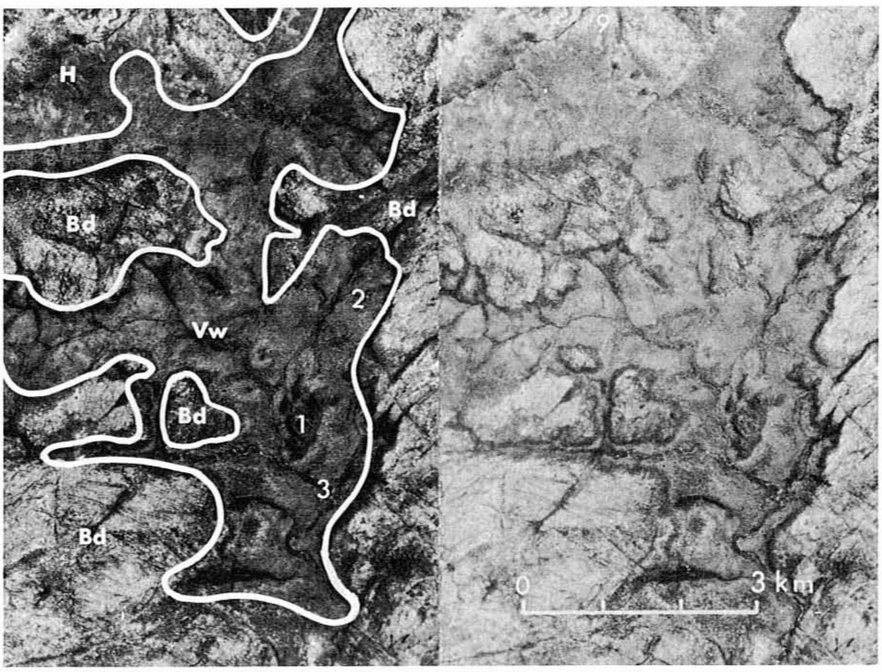


Fig. 2.—Venlaw (Vw) land system.

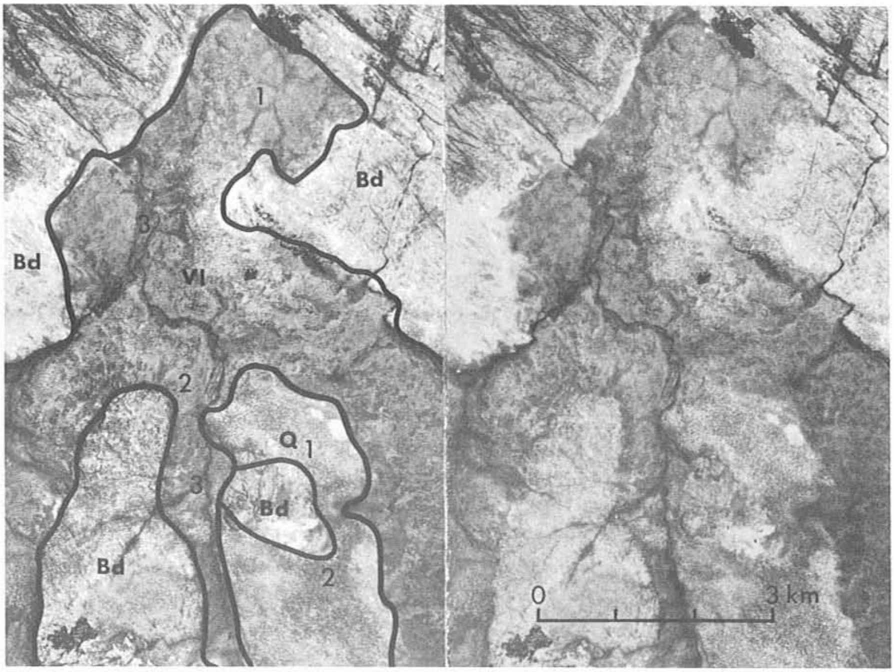


Fig. 1.—Queue I (Q) and Valley (Vl) land systems.

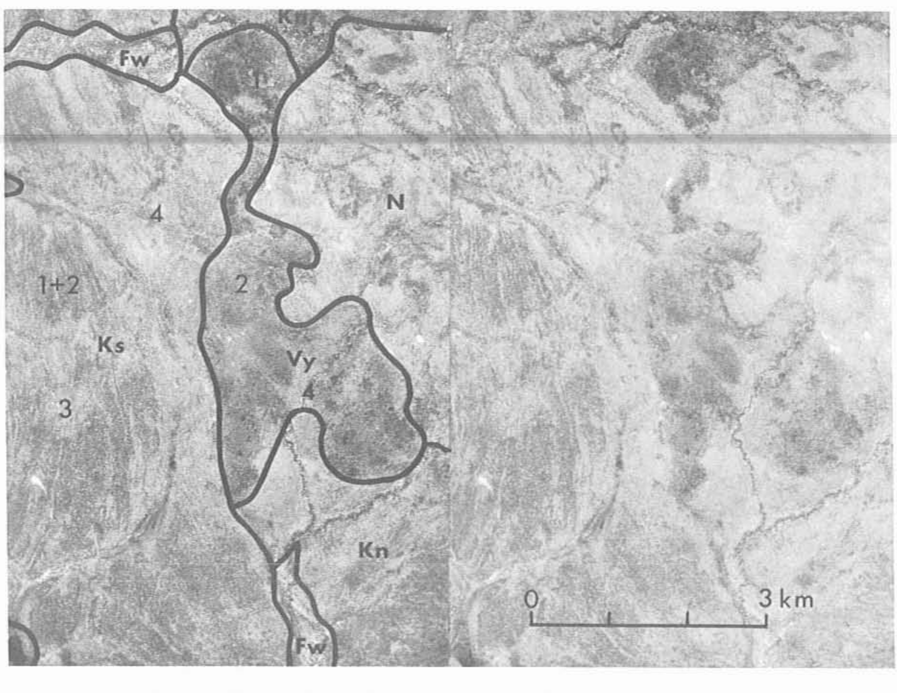


Fig. 2.—Kysto I (Ks), Nova (N) and Verity (Vy) land systems.

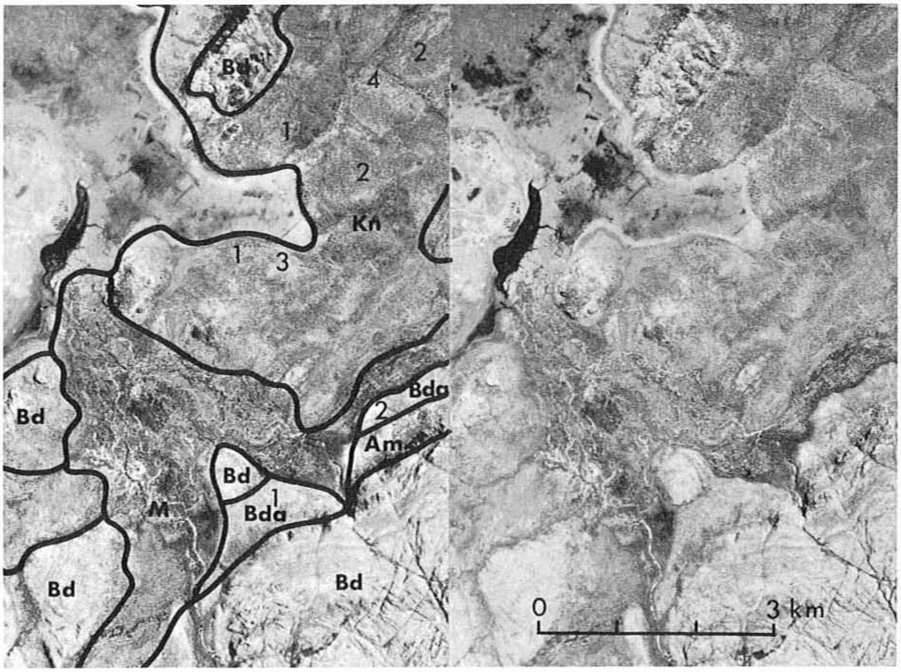


Fig. 1.—Bundah (Bda), Knifehandle I (Kn) and McKinlay I (M) land systems.

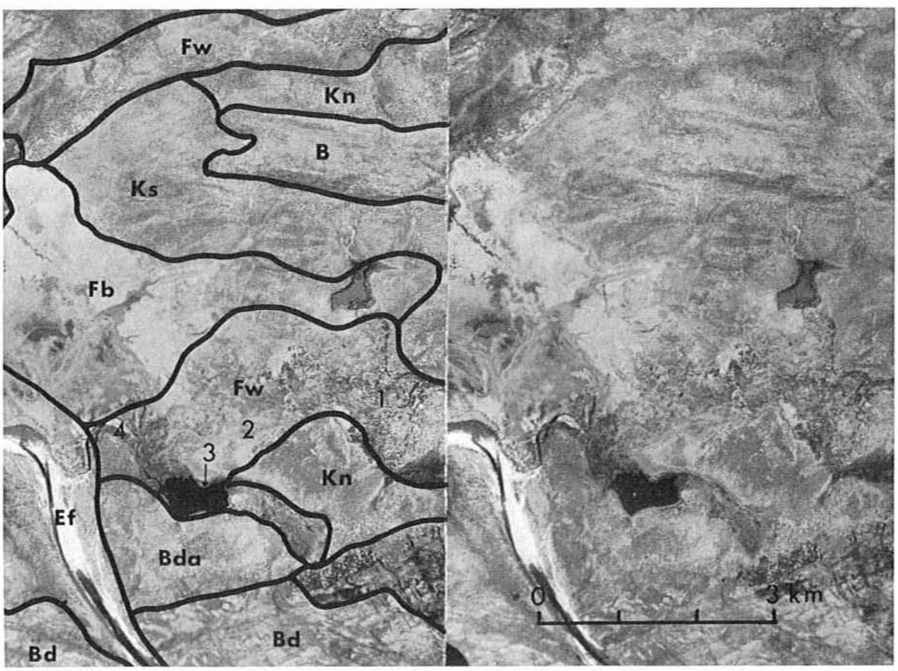


Fig. 2.—Fabian I (Fb) and Flatwood I (Fw) land systems.

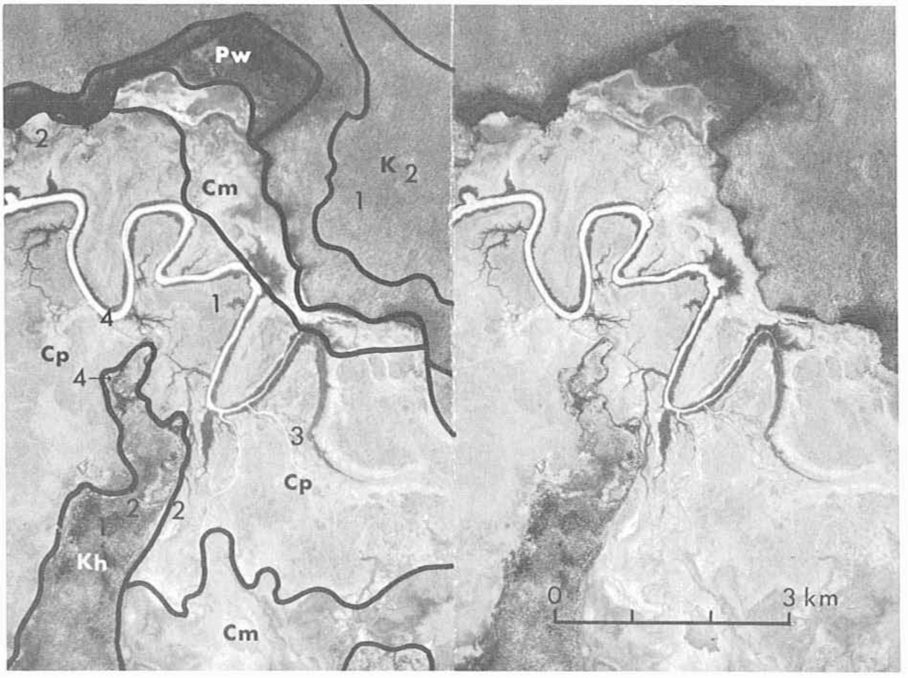


Fig. 1.—Cyperus I (Cp), Kay I (K), Kosher I (Kh) and Pinwinkle I (Pw) land systems.

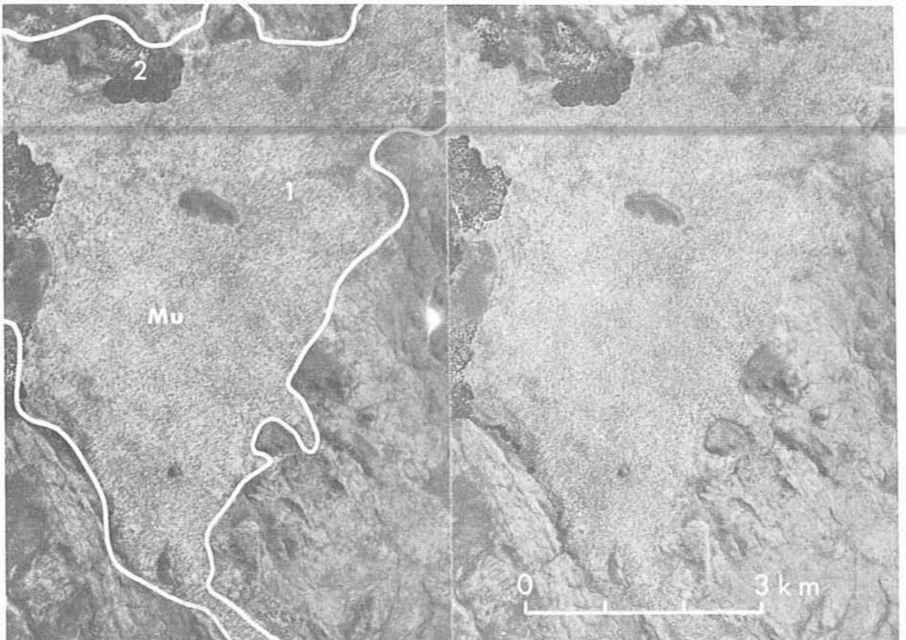


Fig. 2.—Murray (Mu) land system.

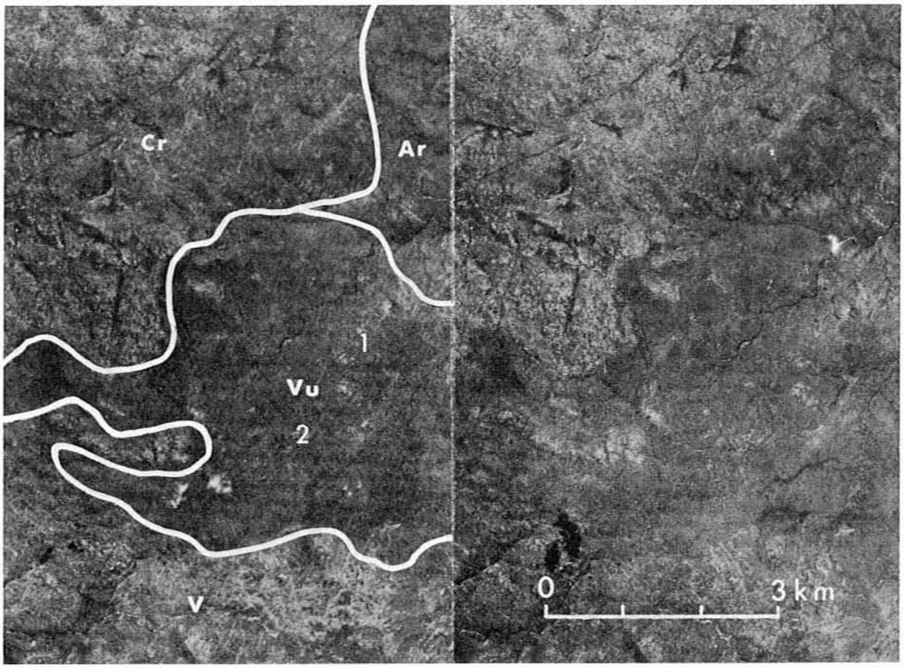


Fig. 1.—Currency I (Cr), Verrucose (Vu) and Viney (V) land systems.

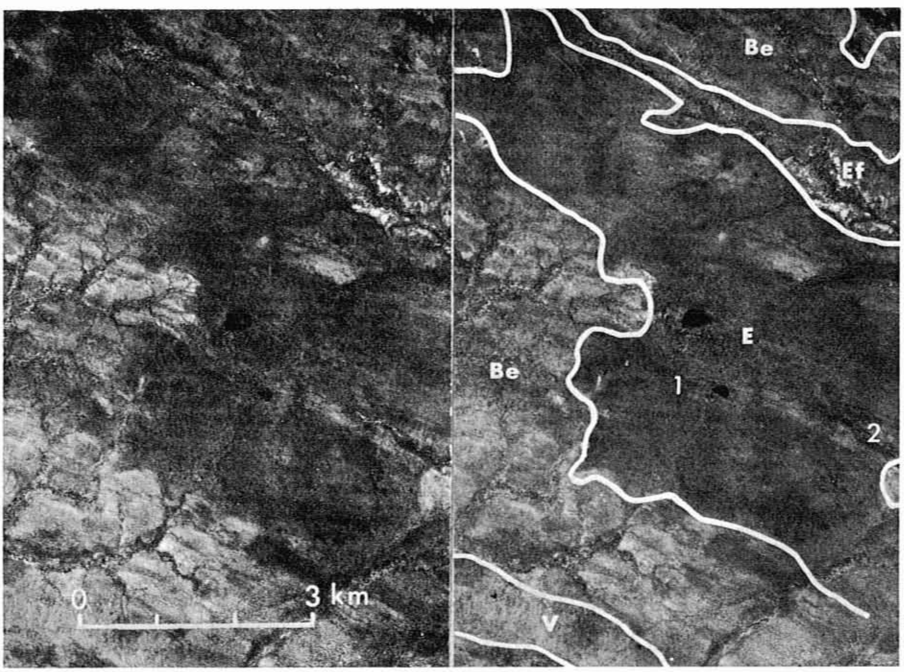


Fig. 2.—Explanado (E) land system.

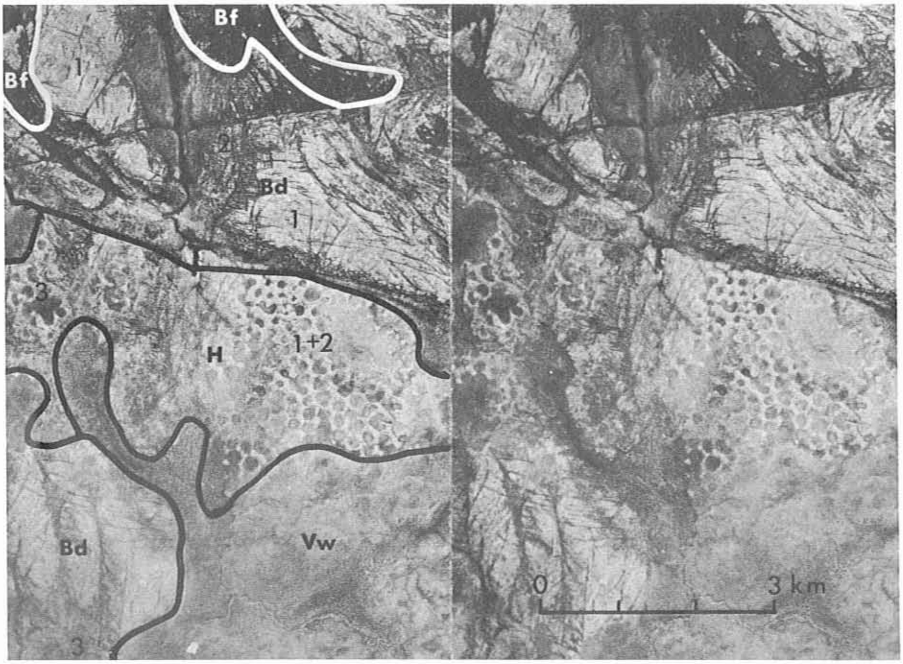


Fig. 1.—Buldiva I (Bd) and Honeycomb (H) land systems.

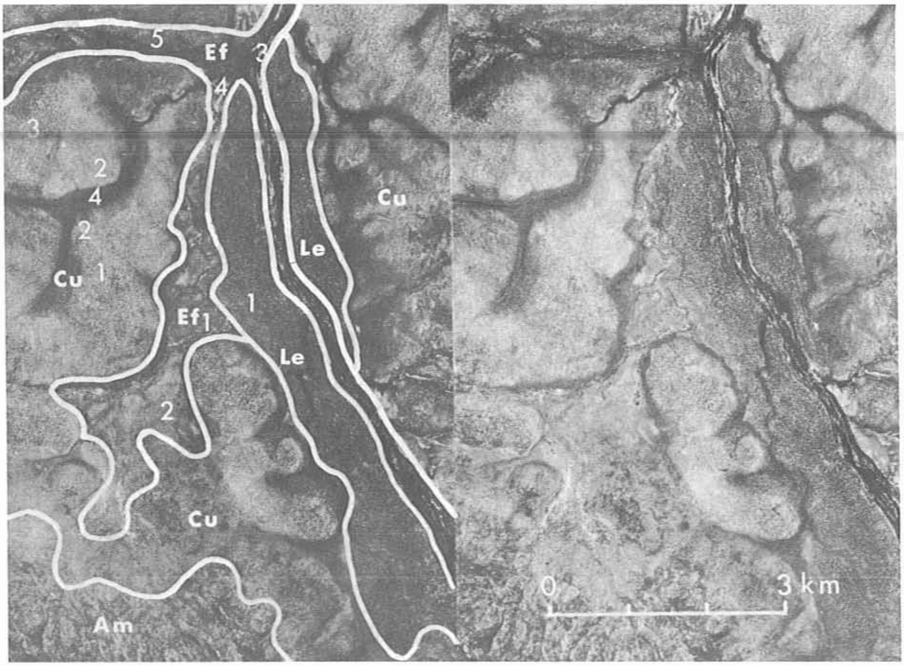


Fig. 2.—Cully I (Cu), Effington I (Ef) and Levee (Le) land systems.

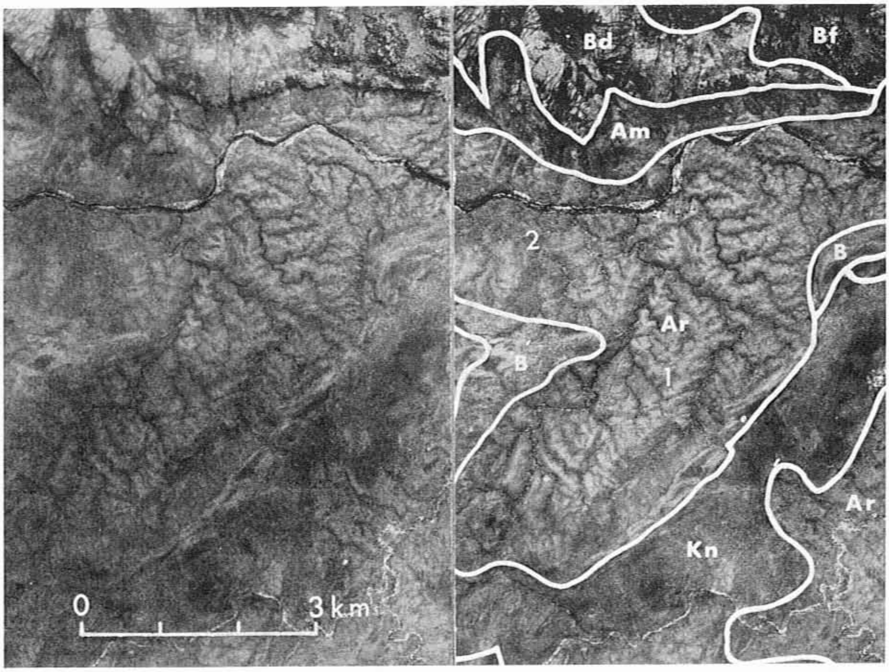


Fig. 1.—Amhurst (Am) and Ararat (Ar) land systems.

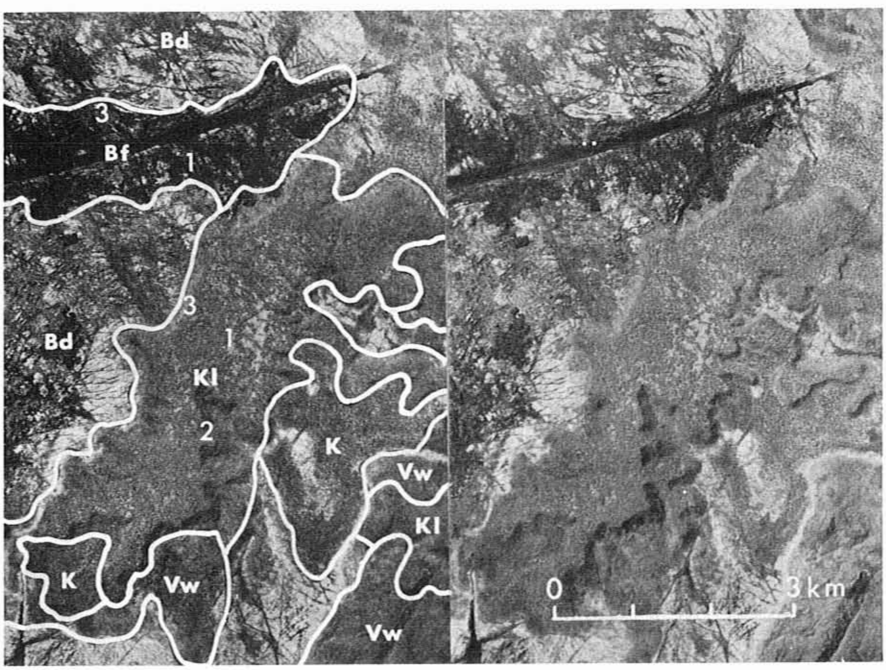


Fig. 2.—Bedford (Bf) and Klatt (Kl) land systems.

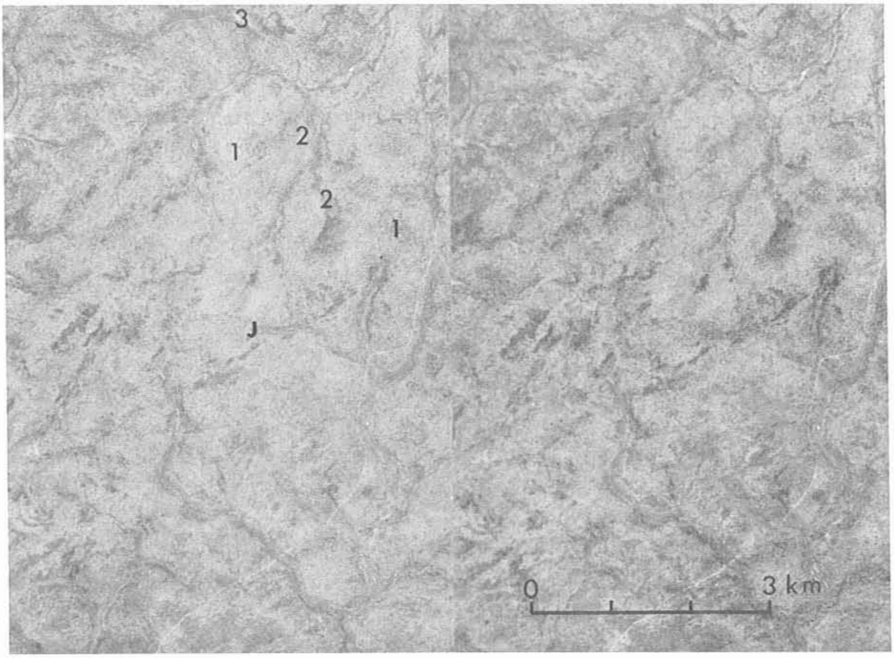


Fig. 1.—Jay I (J) land system.


Fig. 2.—Dual (D) land system.

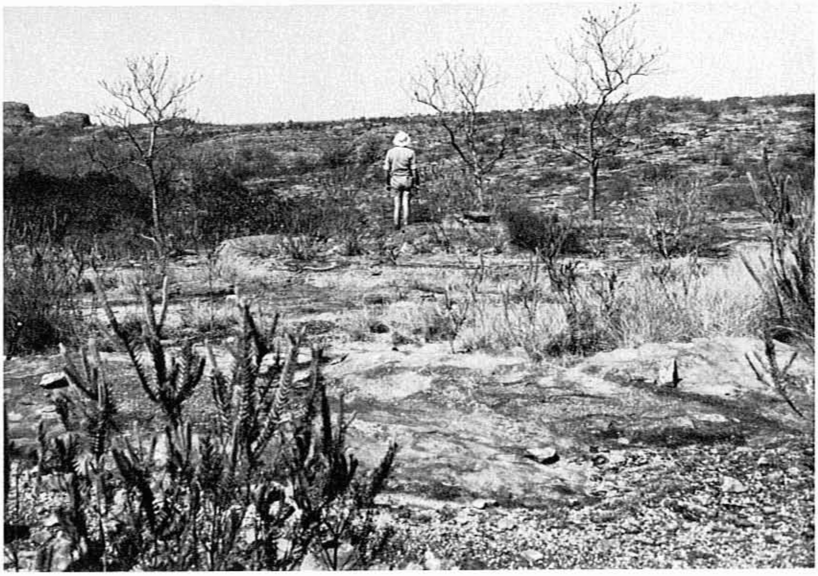

Fig. 1.—Much of the Arnhem Land plateau consists of bare rock with only scanty shrubs and spinifex growing in cracks and in pockets of sand.

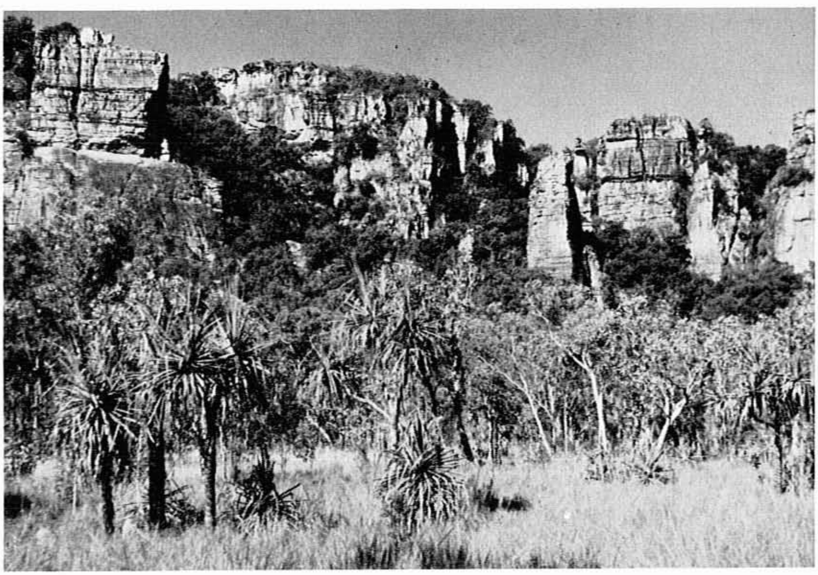

Fig. 2.—The impressive Arnhem Land escarpment rises up to 250 m above the lowlands to the west. Patches of forest occupy sheltered gullies and scrub grows on the sandy aprons below.

Fig. 1.—The western lowlands carry eucalypt woodlands of varying density. On loamy soils in the south, giant termitaria ('ant heaps') stand up to 5 m high.

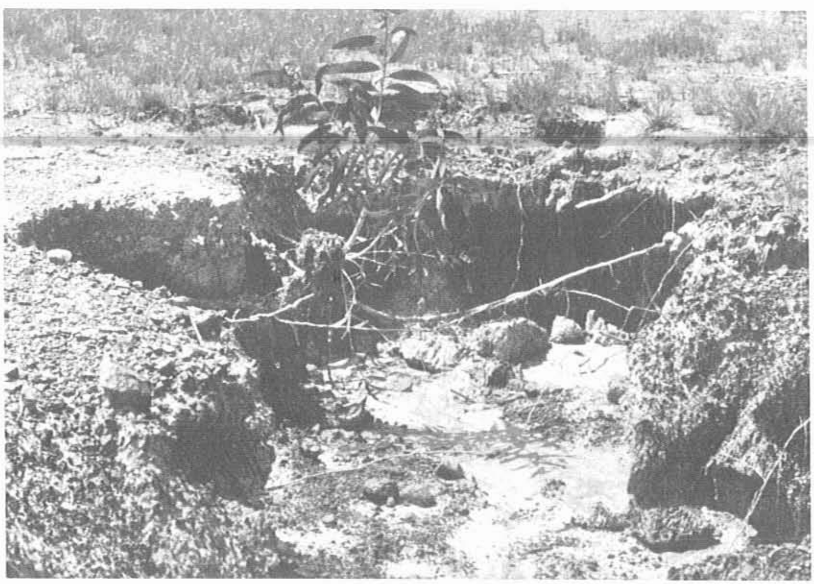

Fig. 2.—A thin layer of gravel protects the surface from erosion over extensive areas of the lowlands. If this layer is damaged, rapid gullying ensues in the underlying relatively stone-free soil.

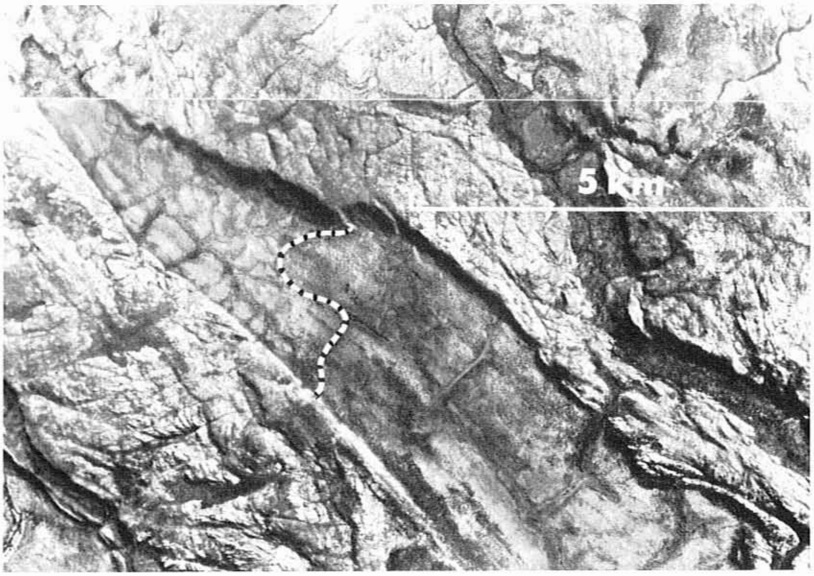


Fig. 1.—The floor of Waterfall Creek basin on the Arnhem Land plateau forms part of the younger weathered land surface. As a result of drainage diversion at the north-west end fresh rocks are being exposed.

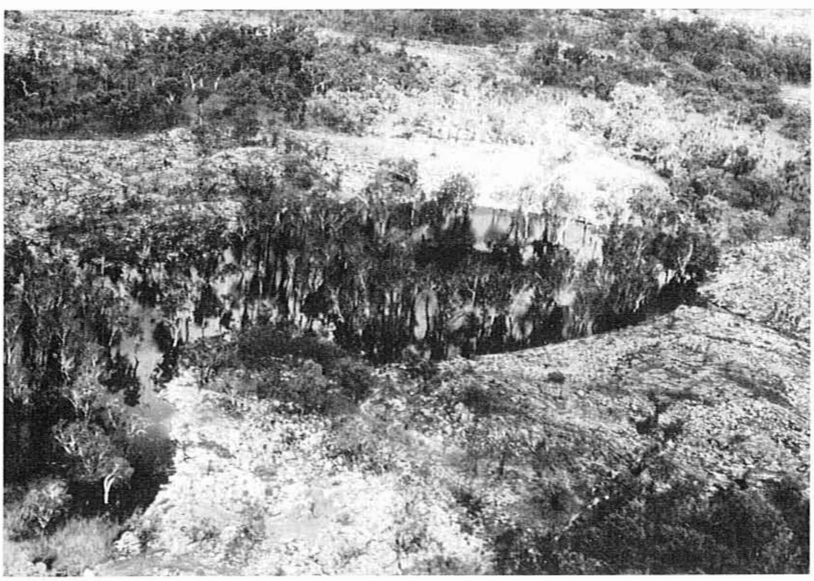

Fig. 2.—Sinuous low rises and shallow, subcircular basins on the Arnhem Land plateau were formed by the pressure of volcanics which have now been stripped off.

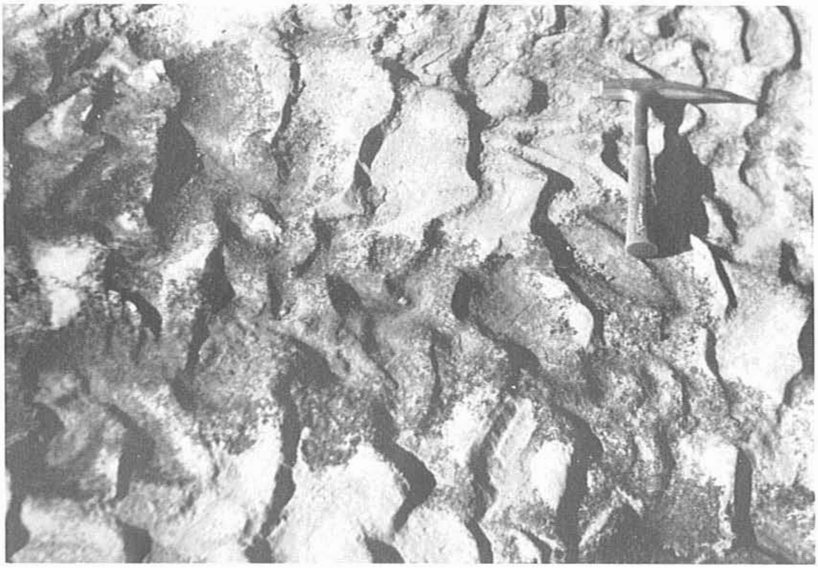

Fig. 1.—More than a thousand million years ago water flowing over sand formed ripples which are now perfectly preserved in the Kombolgie Formation.

Fig. 2.—A tall open forest of woollybutt and stringybark over smaller trees and shrubs characterizes sand sheets and the tops of gentle rises in the western lowlands. The same vegetation grows on the deeper sand sheets of the Arnhem Land plateau.

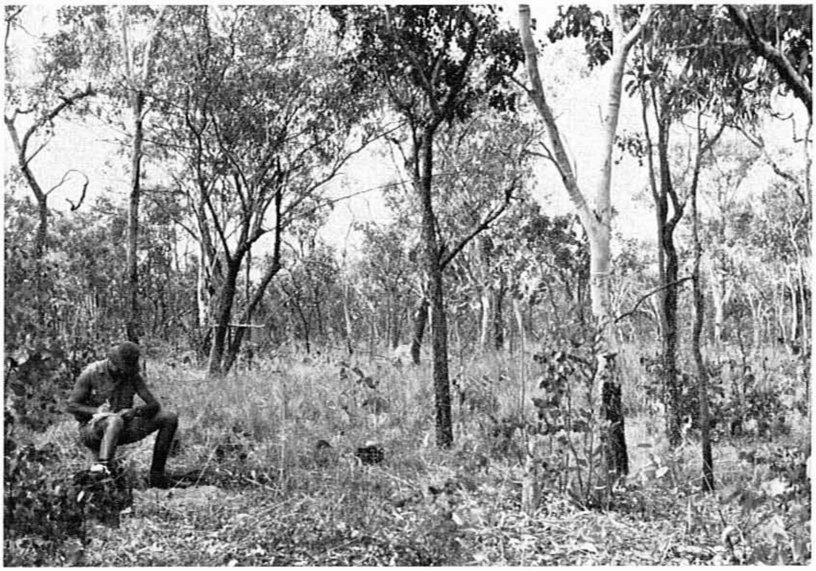

Fig. 1.—Where the soil is shallower the trees form a woodland, often of the same species as in the tall open forest but lower and more widely spaced and with an admixture of bloodwoods. This vegetation is characteristic of middle and upper slopes in the western lowlands and covers most of the survey area that is not on the Arnhem Land plateau.

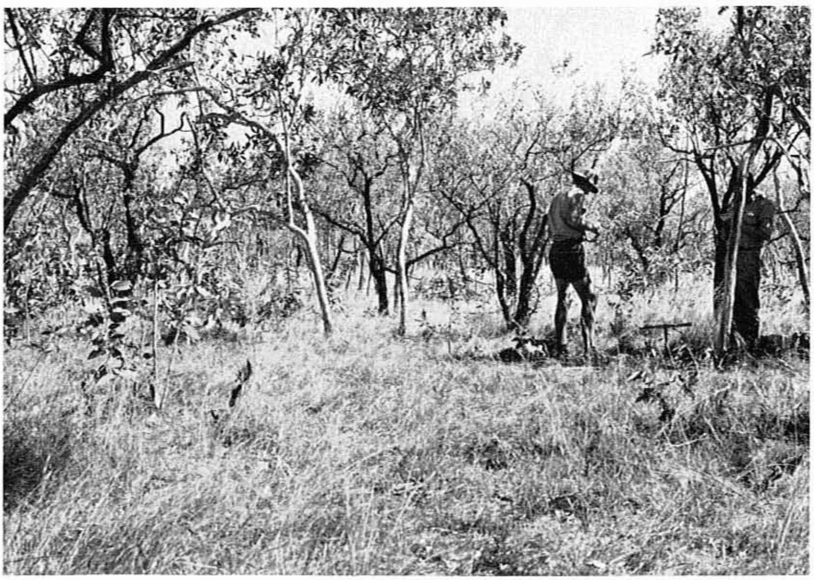

Fig. 2.—Mixed scrub of quinine bush and paperbark is common on slopes below the woodlands, especially on the poorer soils.

Fig. 1.—Drainage flats at the bottom of the sequence from tall open forest are under perennial grasses, with widely scattered trees and clumps of trees.

Fig. 2.—Only fragments remain of the grasses and water plants which have been eaten and tramped into the mud of the estuarine plains by buffaloes. This is the usual dry-season aspect on all but sedge areas which have very few fodder plants and remain ungrazed.

Fig. 1.—Stunted woodland characterizes clayey volcanic soils. The ground cover of perennial grasses is rich in legumes during the wet season but these die back during the dry season to give an arid and unattractive landscape.

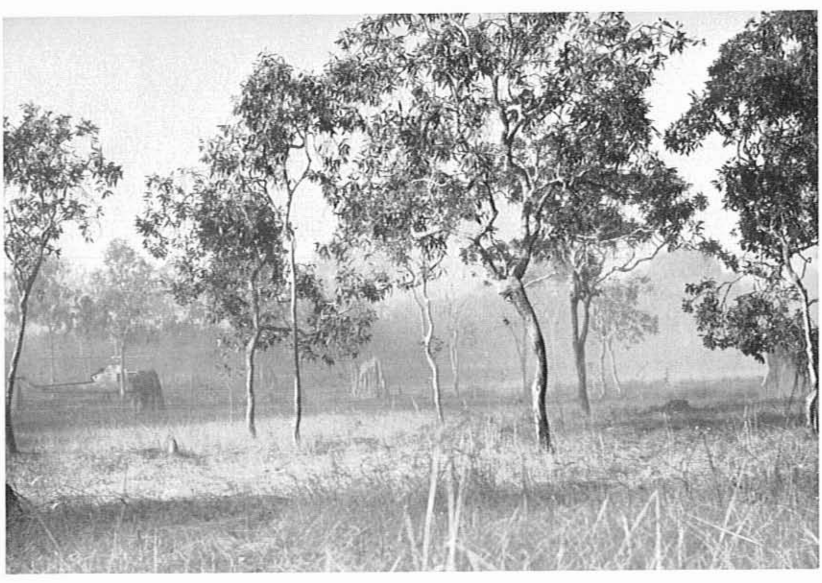

Fig. 2.—Seasonally waterlogged or poorly drained places carry paperbark woodland, usually with a scanty cover of annual grasses.