DEPARTMENT OF NATIONAL RESOURCES
BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS

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The Precambrian Geology of The Victoria River Region, Northern Territory

I. P. SWEET

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ABSTRACT

The Victoria River region, in the northwestern Northern Territory, is underlain by Precambrian rocks and flanked to the east, south, and west by Lower Cambrian volcanics and younger sedimentary rocks.

The Precambrian rocks include a deformed belt of basement metamorphics, granites, and acid volcanics, all overlain by sandstone, in the northwest; and a stable platform (the Sturt Block) overlain by slightly deformed sedimentary rocks in the centre and southeast. The rocks in the deformed belt range in age from Archaean to Adelaidean (late Proterozoic). On the Sturt Block are several Proterozoic groups of sandstone, siltstone, and dolomite. The sequences developed are all shallow-water deposits, and are separated by several regional unconformities. They are overlain by late Adelaidean tillites and associated fluvioglacials.

Only minor production of tin, gold, and barite has been recorded, and the major resource presently being exploited is groundwater.

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SUMMARY

The Victoria River region is the partly dissected plateau and mesa country bordering the Joseph Bonaparte Gulf in the northwestern Northern Territory. The region was explored in the mid-1800s and settled by pastoralists in the 1880s. Cattle raising is the only industry which has remained viable although some attempts at agriculture and mining have been made.

Mapping of the Precambrian rocks in the region was carried out by the Bureau of Mineral Resources between 1967 and 1970, and the results are presented in this Bulletin.

The rocks are described in terms of two main tectonic provinces: in the centre and southeast a thin sequence of little deformed sedimentary rocks overlies a craton called the Sturt Block, and in the northwest basement metamorphics and intrusives and strongly deformed sedimentary rocks occupy the Halls Creek and Fitzmaurice Mobile Zones, the Litchfield Block, and the Pine Creek Geosyncline. The two provinces are separated by a prominent lineament, the Victoria River Fault.

During the Archaean clastic sediments were laid down, probably over most of the region. They were invaded in the north by basic and ultrabasic magmas, and were folded and metamorphosed. Greywacke, conglomerate, sandstone, and siltstone were laid down during the Lower Proterozoic in a rapidly subsiding trough in the north (Pine Creek Geosyncline). During a period of folding the rocks were metamorphosed to greenschist facies, and the nearby Archaean rocks were retrograded to the same facies. Post-orogenic granites were intruded and associated acid lavas were extruded towards the close of the Lower Proterozoic. The geological history of the Sturt Block is virtually unknown until the end of the Lower Proterozoic as the block is covered by younger Precambrian rocks.

The first major period of sedimentation on the Sturt Block, after the area was cratonized, took place in the south during the Carpentarian. A sequence of dolomite, sandstone, and shale was deposited in the Birrindudu Basin which extended well south of the area mapped, and the sequence possibly spread eastwards across a stable platform to the McArthur Basin which contains sediments of the same age. The sequence was gently folded and the dolomitic rocks silicified at the land surface.

A major transgression early in the Adelaidean resulted in widespread deposition of sandstone and siltstone (Wattie Group) in the Victoria River Basin. As surrounding areas stabilized, carbonates became the dominant rock type; they were laid down in shallow marine, lagoonal, and salt-flat environments, and the position of the shoreline fluctuated widely (Bullita Group).

The sandstone, siltstone, and carbonates were the first rocks laid down in the Victoria River Basin. They were uplifted and partly eroded before a second transgression inundated the region and resulted in the deposition of glauconitic sandstone, then carbonaceous siltstone and shale. After another period of uplift, the sediments were gently folded and partly eroded.

A third major transgression resulted in the deposition of arenaceous and dolomitic sediments on the Sturt Block and a much greater thickness of sediment in the Fitzmaurice Mobile Zone and adjacent East Kimberley region (Auvergne, Fitzmaurice, and Carr Boyd Groups). Uplift and erosion preceded more sandstone deposition, after which folding and faulting occurred in a zone on either side of the present-day Victoria River Fault. The fault, which probably lies along a hinge zone, developed at that time (mid-Adelaidean).

Erosion ensued, and the region was probably above sea level for the remainder of the Proterozoic, including the time near the end of the era when the region was glaciated and discontinuous drift, fluvial, and lacustrine sediments were laid down (Duerdin Group).

At about the beginning of Phanerozoic time vast quantities of tholeiitic lava (Antrim Plateau Volcanics) were poured out, and blanketed the whole region.

The sequence developed on the Sturt Block is gently folded but strongly faulted along a series of northwest-trending lineaments. The sandstones in the Fitzmaurice Mobile Zone are moderately folded and strongly faulted; some of the faults have transcurrent movement.

Except for tin and gold, of which small quantities have been won from the Pine Creek Geosyncline sediments in the north, the only mineral that has been exploited is barite. Production has ceased, but extensive reserves probably exist, mostly in Antrim Plateau Volcanics. Minor shows of copper, lead, and manganese are known but are not of economic importance. The extensive carbonate units may contain some concentrations of lead minerals but little exploration has been carried out.

Surface water is abundant in the north, but groundwater is of major importance in the central and southern districts where most cattle are raised. The best flows of good-quality water come from weathered basalt, alluvium, and fractured Precambrian rocks.

INTRODUCTION

The Victoria River region is the partly dissected plateau and mesa country bordering the southeastern Joseph Bonaparte Gulf in northwestern Northern Territory between latitudes 13° and 18°S, and longitudes 129° (Western Australian border) and 132°E. This Bulletin describes the Precambrian geology of the region, which embraces the entire Victoria and Fitzmaurice River catchments and parts of the Katherine-Darwin region southwest of the Daly River (Fig. 1).

Although the Victoria River was discovered in 1839 by Lieutenant J. L. Stokes (Stokes, 1846), the region was not explored further until 1855-56, when A. C. Gregory explored the southern part (Gregory, 1857). Alexander Forrest traversed the region in 1879, and the first pastoral properties were stocked in the same year. Most of the better grazing country was occupied by pastoralists during the early 1880s and since that time cattle raising has been the only industry to survive. Gold and tin were discovered in the early 1900s around Fletchers Gully and Buldiva, but most workings were short-lived. An exception is a tin prospect near Collia Waterhole which has been worked intermittently since 1922. With the introduction of the beef-road scheme and the development of new markets for meat in USA during the 1960s, the pastoral industry changed rapidly. Stock control was improved by fencing and breeding programs, and groundwater supplies became increasingly exploited. Cattle stations are still large, ranging in area between 1280 and 15 750 km^2 (the largest properties are Victoria River Downs and Wave Hill). The best grazing land is in the east, on black soils underlain by basic volcanics, and carrying capacity is lowest in most of the rugged hilly country.

Agricultural development has not yet been attempted on a large scale, and many small schemes in the past have failed through lack of research on local problems. The Ord River Scheme in the nearby East Kimberley region is well under way, and the main dam, completed in 1971, will allow irrigation of 72 000 hectares of black-soil plains, including about 18 000 hectares in the Victoria River region. Many pastoralists are investigating the irrigation of smaller areas of sorghum for fattening cattle before marketing.

There are no towns in the region: Katherine (population 2500 in 1971) to the east, and Kununurra (1200 in 1971) to the west are the nearest supply centres. They are linked by sealed roads to Darwin and Wyndham respectively, the main ports serving the region. Daily air services link the towns to southern cities and most stations are served by weekly aerial mail and passenger services. The total population of the region is about 1500, mostly Aboriginals. Port Keats Mission with a population of over 600, and Wave Hill settlement are the main population centres. Many Aboriginals live permanently on station properties, and have been the main source of labour in the pastoral industry.

The region is administered by the Department of the Northern Territory whose headquarters are in Darwin.

Communications and access

The Victoria Highway is sealed from Katherine to the Western Australian border and the Buchanan Highway is sealed from Top Springs to Wave Hill; a sealed road from Willeroo to Top Springs connects the highways. Most other roads are earth or gravel and are regularly impassable after heavy rain. Effects of the summer wet season are most severe in the north, where tracks have to be remade almost annually to be useful. Station tracks provide access to most valleys of the region, but rugged ranges and plateaux between them are inaccessible to vehicles. Aircraft, particularly helicopters, are now a much used form of transport both by survey teams and by pastoralists, and were used in the present survey to reach areas inaccessible to vehicles.

Both the Victoria and Fitzmaurice Rivers are navigable for many kilometres from the coast, and in the past most supplies for the region were shipped from Darwin to Timber Creek Depot in shallow-draft vessels. Although the Depot no longer exists, the Victoria River can still be navigated for about 150 km from the coast in vessels of less than 1.5 m draft. Strong tidal currents, sand banks, and rock bars make navigation somewhat hazardous.

Climate

The climate is monsoonal: a long dry cool season from April to September is followed by a hot wet season from October till March. During the 'winter' months the region is influenced by southeast trade winds, but in October and November these weaken and westerly and northwesterly winds predominate until about March. The inflow of humid tropical air results in heavy and frequent thunderstorms be-

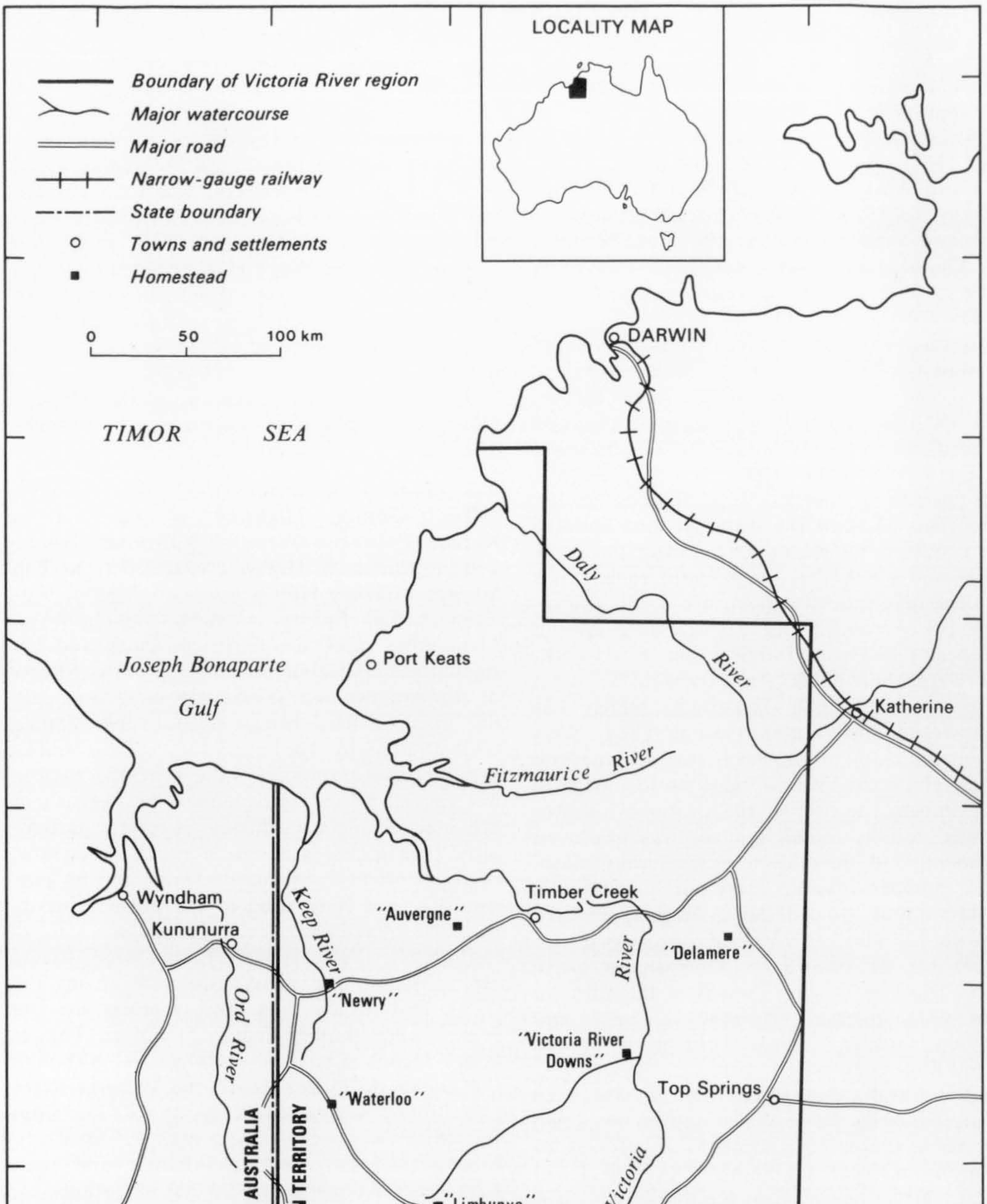

Fig. 1. Locality map.

TABLE 1. MONTHLY RAINFALL AVERAGES (IN MM) FOR RECORDING STATIONS IN AND NEAR THE VICTORIA RIVER REGION †

Station	*Jan.*	*Feb.*	*March*	*April*	*May*	*June*	*July*	*Aug.*	*Sep.*	*Oct.*	*Nov.*	*Dec.*	*Year*
Port Keats	343.5	363.9	253.4	61.8	39.4	6.2	5.3	1.0	4.3	26.4	78.5	222.5	1386.2
Katherine	232.1	201.5	156.2	34.2	5.6	2.0	0.8	0.5	5.8	29.8	83.8	199.6	951.9
Newry	198.0	170.0	117.0	25.6	8.1	3.6	3.6	0.8	2.0	20.8	65.3	143.0	757.8
Rosewood	158.0	135.0	83.3	20.4	8.4	4.3	4.8	0.8	4.3	22.4	63.5	111.8	617.0
Waterloo	158.0	149.0	94.0	13.7	8.1	2.8	5.6	1.0	2.0	16.0	55.1	101.9	608.2
Limbunya	148.5	148.0	79.3	16.0	7.9	4.6	5.8	2.0	2.0	18.6	38.1	90.9	561.7
Victoria River Downs	144.1	132.1	96.0	19.3	5.6	2.3	2.8	1.0	3.3	15.7	56.9	117.4	596.5
Wave Hill	110.2	112.0	67.1	19.8	10.7	0.5	6.9	0.3	4.6	11.7	34.0	68.3	446.0

Source—Bureau of Meteorology, Darwin.

TABLE 2. MEAN MONTHLY MAXIMUM AND MINIMUM TEMPERATES (°C) OF REPRESENTATIVE RECORDING STATIONS IN AND NEAR THE VICTORIA RIVER REGION †

		Jan.	*Feb.*	*March*	*April*	*May*	*June*	*July*	*Aug.*	*Sep.*	*Oct.*	*Nov.*	*Dec.*	*Year*
Port Keats	Max.	32.5	32.2	33.1	33.6	32.7	30.4	30.8	32.4	32.5	33.4	34.2	33.3	32.6
	Min.	23.9	24.3	23.3	20.7	17.5	14.7	14.2	14.8	18.6	22.4	24.0	24.4	20.3
	Mean	28.4	28.3	28.2	27.2	25.1	22.6	22.5	23.6	25.5	27.9	29.1	28.8	26.4
Katherine	Max.	37.1	34.5	34.6	34.1	32.5	30.2	30.6	32.3	35.6	38.2	38.3	36.5	34.4
	Min.	23.5	23.5	23.0	20.2	16.8	14.1	13.7	14.9	19.3	23.8	24.7	24.5	20.1
	Mean	29.3	29.0	28.5	27.2	24.4	22.1	22.2	24.7	27.5	31.0	31.5	30.5	27.2
Victoria River Downs	Max.	39.5	40.8	34.2	34.8	33.6	29.8	27.3	33.1	36.6	38.7	39.5+*	38.2	35.5
	Min.	24.6	26.0	23.8	17.2	16.9	15.1	8.8	15.0	18.7	24.4	26.5	26.0	20.2
	Mean	32.0	33.4	29.0	26.0	25.2	22.4	18.1	24.0	27.6	31.5	33.0+	32.1	27.9
Wave Hill (Police Station)	Max.	37.6	37.9	35.4	34.9	30.8	27.7	27.9	30.6	34.6	37.9	39.0	38.9	34.3
	Min.	24.0	23.8	22.6	18.6	15.4	12.8	11.1	13.7	17.3	22.0	23.9	24.2	19.1
	Mean	30.8	30.8	29.0	26.7	23.1	20.2	19.5	22.1	25.9	30.0	31.5	31.6	26.7
Cattle Creek	Max.	37.9	37.8	35.8	34.0	31.0	27.5	27.8	30.4	34.4	37.7	39.0	38.4	34.3
	Min.	24.2	23.8	22.6	18.9	15.7	12.3	11.2	13.5	17.1	22.0	23.9	24.0	19.1
	Mean	31.0	30.8	29.2	26.5	25.4	19.9	19.5	22.0	25.8	29.8	31.4	31.2	26.7

Source—Bureau of Meteorology, Darwin. * Insufficient records—estimated only.

† More accurate climatic statistics are now available in 'Climatic Averages—Australia'. *Dep. Sci. Consumer Affairs Bur. Meteorol.* Metric Edition, August 1975.

tween December and March, although occasional heavy falls have been received in April owing to cyclones. Annual rainfall is greatest in the north (about 1500 mm north of the Daly River); it decreases steadily with increasing distance from the coast, and areas south of Wave Hill receive less than 450 mm a year. Average monthly rainfalls for several stations in the region are shown in Table 1. The chances of receiving substantial rain during the 'dry season' are greater in the south where cold fronts can be effective during the winter.

Temperatures also show marked variation with latitude and distance from the coast. At Port Keats (on the coast) summer maxima are lowered, and minima raised, by heavy cloud during the months January to March. In April, when cloud cover is much less, a slight increase in the average daily maximum is evident. Victoria River Downs, Wave Hill, and other inland centres (Table 2), are far hotter in the wet season and cooler in the dry season, and diurnal variation is greater all year, than coastal centres. Wave Hill in the south is slightly cooler than Victoria River Downs all year, but extremes of temperature are greater: absolute maximum is 45.6°C and absolute minimum is —2.2°C.

Slatyer (1970) discusses the climate of the region and places emphasis on its relation to plant growth. Gentilli (1971) discusses in detail climates of Australia, including the trade wind and monsoon systems of the tropical north.

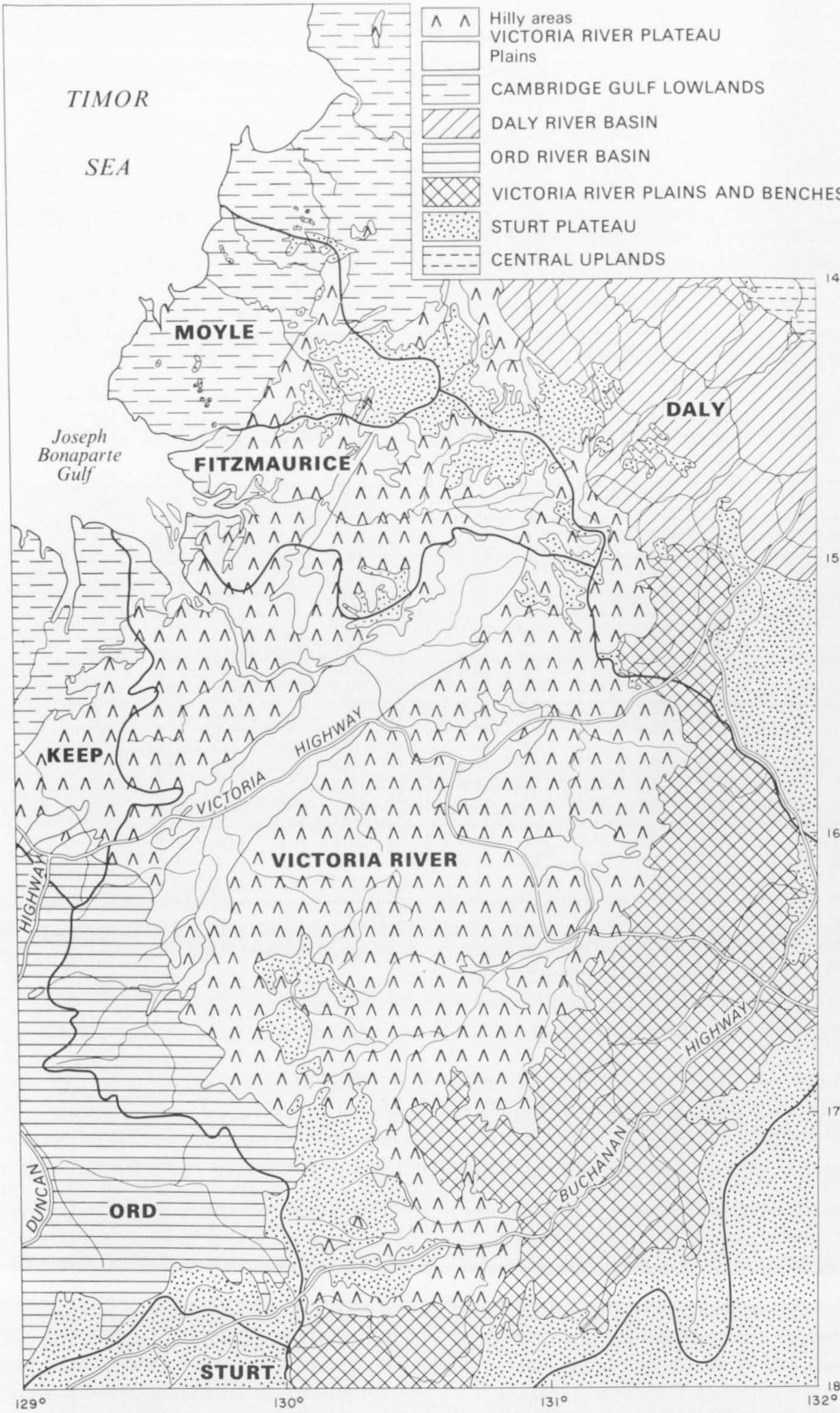

Fig. 2. Physiographic sketch map.

Vegetation

Perry (1970, p. 104) states that '. . . the vegetation of all but the lowest-rainfall parts is typified by woodlands with grassy understoreys'. The long dry season has had a dominant role in the selection of plant species in the area, and although the annual rainfall is high in the north there are only very small patches of rainforest associated with permanent springs.

There are two main tree communities in the higher-rainfall areas (Perry, op. cit.): stringybark-bloodwood woodlands on acid rocks and laterite, and northern box-bloodwood woodlands on most other soils. In the south in areas receiving less than 700 mm of rain a year, snappy gum (*Eucalyptus brevifolia*) becomes dominant on sandy and ferruginous soils, and bloodwood and southern box on dolomitic and other soils. Clayey soils such as those of the West Baines valley and those developed on basic volcanics support the best grasslands of the region; their sparse tree community usually includes bean tree (*Bauhinia cunninghamii*), nutwood (*Terminalia arostrata*), and rosewood (*T. volucris*).

The most prominent members of the grass-layer community are annual sorghum and spinifex. Annual sorghum species are ubiquitous in the higher rainfall areas. They grow rapidly with the onset of the wet season and are rank, tall grasses 1 to 3 m high. They dry out quickly and are commonly burnt off, either by accident or design, early in the dry season. Virtually all of the ranges north of the Fitzmaurice River are clothed in annual sorghums, but south of the river spinifex (*Triodia* spp.) grows in the poor soils in sandstone ranges. The Auvergne Sheet area shows a transition from sorghums to spinifex, and three-awn spear grass and spinifex are the major species farther south.

Blue grass (*Dichanthium* spp.) and other tall grasses are common in the north, but the best grazing lands are developed farther south on basic volcanics on which various tussock grasses thrive (particularly Mitchell grass).

Most major watercourses contain pools which persist through the dry season, and the banks are lined with gum trees (*Eucalyptus camaldulensis* and other eucalypts) and paperbarks (*Melaleuca* spp.). Paperbarks, pandanus and other palms, and *Grevillea* spp. are common on the well watered northern plains. Coastal estuaries and inlets are lined with mangroves which are generally backed by salt and samphire flats. Farther inland swampy areas support mainly reeds, and are lined by thick stands of 'swamp paperbark'.

A tree of outstanding appearance is the baobab or bottle tree (*Adansonia gregorii*). It is common in the Auvergne Sheet area, but was not seen farther north than the Fitzmaurice River, nor farther southeast than the Humbert River.

A few stands of native cypress pine (*Callitris* spp.) were observed growing in sandy skeletal soils in rugged country between the Victoria and Fitzmaurice Rivers, and are believed to also occur north of the Fitzmaurice River.

Physiography

Drainage. Most of the region is drained by coastal river systems of which the Ord (only its eastern tributaries occur in the region), Victoria, and Daly Rivers are the most important (Fig. 2). Sturt Creek, in the south, is the only large stream draining into the interior; the remainder of the south and southeastern parts of the region have virtually no surface drainage.

Physiographic subdivisions. Gentilli & Fairbridge (1951) made the first systematic attempt to name physiographic subdivisions of the region. However, the subdivisions used here (Fig. 2) are based largely on Traves (1955) and Paterson (1970) who studied the Ord-Victoria region, and Noakes (1949) and Walpole, Dunn, & Randal (1968), who geologically mapped the Katherine-Darwin region.

Paterson (1970) included most of the Victoria River region in the Ord-Victoria geomorphic region, which he subdivided into subregions, the most important of which are listed below.

(i) *Cambridge Gulf Lowlands* consist of erosional and alluvial coastal plains; they include the western plains of Walpole *et al.* (1968). The relief of the Lowlands does not exceed 50 m except for a few isolated mesas north of the Fitzmaurice River. The unit is developed on Palaeozoic sediments except in the north, where granite forms plains and low rises.

(ii) *Victoria River Plateau* (Pls 1-5) is a partly dissected hilly region which includes most of the Victoria and Fitzmaurice River catchment areas, and is underlain by Precambrian rocks. The plateau includes a wide variety of landforms, and during the survey an attempt was made to subdivide them; the results are presented in the Explanatory Notes listed in Figure 3. In this Bulletin (Fig. 2) the only distinction made is between hilly areas and plains. The plains are developed on silty and

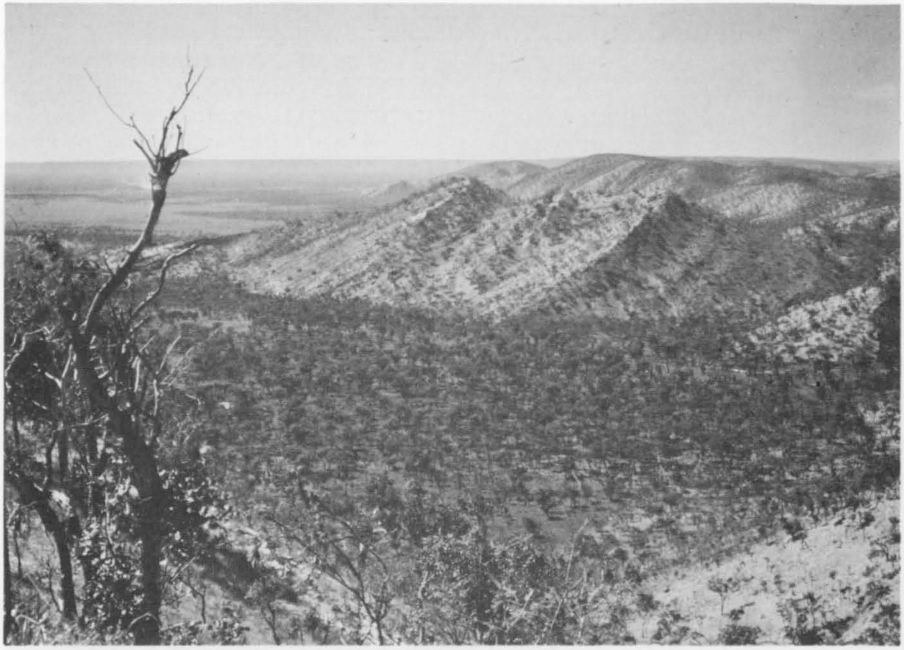

Plate 1. Victoria River Plateau: the Koolendong Valley is on the left, and cuestas cut into sandtsone on the right. (GA/1453)

Plate 2. Dissected plateaux (Victoria River Plateau) bordering the Victoria River near Curiosity Peak; Mosquito Flats are in the middle distance. The bare outcrops in the foreground are Angalarri Siltstone; the cliffs in the distance are Pinkerton Sandstone. (GA/563)

Plate 3. Tower Hill, 26 km east of Tolmer Creek, consists of a small remnant of Jasper Gorge Sandstone perched on Bynoe Formation. The terraced hills in the foreground are Skull Creek Formation dolomite. (M/796)

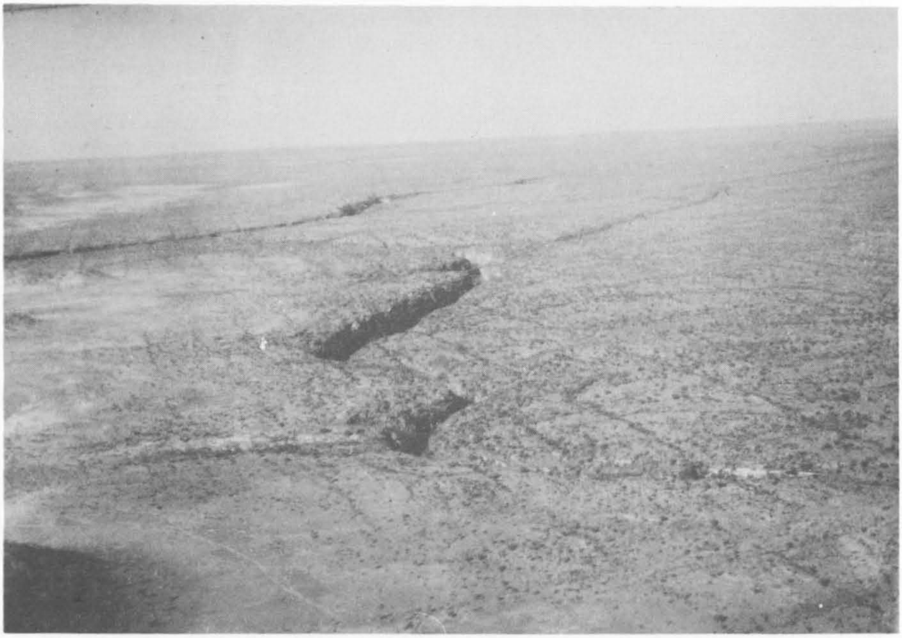

Plate 4. Victoria River Plateau 50 km southeast of Kildurk homestead. Well jointed, gently dipping Jasper Gorge Sandstone is deeply incised by tributaries of the West Baines River. (GA/1432)

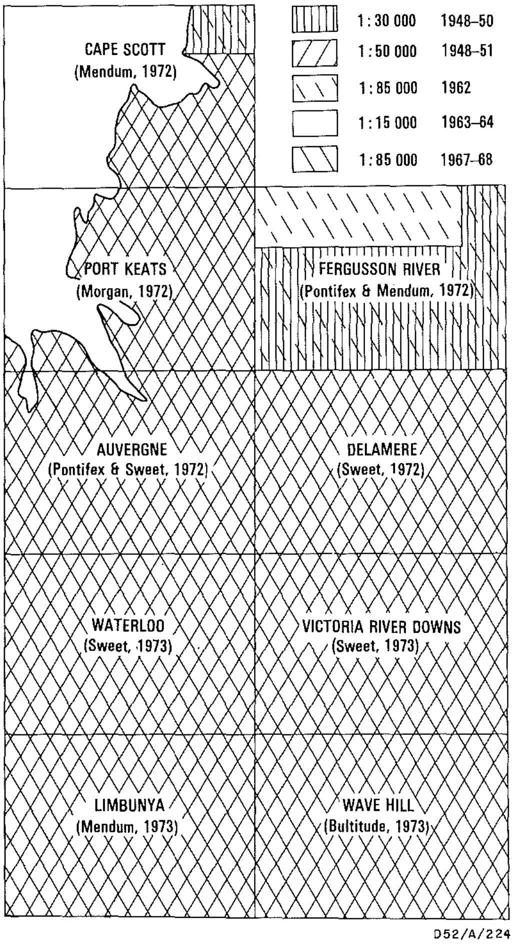

Fig. 3. Index to 1:250 000 Sheet areas, authors of Explanatory Notes, and aerial photographs.

shaly rocks, and include Koolendong Valley and Whirlwind Plain in the Auvergne Sheet area, and less extensive plains between Timber Creek and Victoria River Downs.

The hilly areas are underlain by flat-lying to moderately dipping sandstone, siltstone, and dolomite, and consist of 'a collection of structural plateaux and benches, mesas and buttes with a few cuestas, hogbacks, vales and karst areas' (Paterson, 1970, p. 86).

The relief varies from 100 to 300 m, and elevation of the tops of ridges and plateaux from 200 m in the north to over 400 m in the south. Although not very high, some of the sandstone ridges and plateaux are very rugged.

To the northeast and west of the Victoria River Plateau are the Daly River and Ord Basins. The Daly River Basin is a broad valley dotted with mesas rising up to 50 m above the general plain level. The Ord Basin (Pl. 6) is underlain by Cambrian volcanics, shale, limestone, and sandstone, and contains a variety of landforms including mesas, buttes, and plains on the volcanics, and plains, benches, cuestas, and plateaux on the sedimentary rocks. Their elevation ranges from 75 m in the north to about 500 m on plateaux in the south.

Victoria River Plains and Benches are cut in basic volcanics and limestone, around the eastern and southeastern margin of the Victoria River catchment area; their undulating grasslands provide some of the best grazing country in the region (Pl. 7).

Sturt Plateau is the name given to the vast undulating plains in the south and southeast. The plateau surface was formed during the Tertiary, and it has been modified only by modern uplift which has produced erosion and deposition. Several outlying remnants of this old surface, now isolated from the Sturt Plateau, are being eroded by the headwaters of coastal rivers; the largest of such outliers is the Wingate Plateau in the north.

A small area occupied by granite in the northeast of the region belongs to the Central Uplands of Walpole *et al.* (1968).

Previous investigations

Early reconnaissances of the northern part of the region, prompted by many mineral discoveries in the Katherine-Darwin region, were undertaken in the late 1800s by Tenison Woods (1886) and Brown (1895). Brown also traversed along the Victoria and Fitzmaurice Rivers, and between Timber Creek and Victoria River Downs. Brown and others recorded lithological logs of bores drilled near the coast south of the Daly River in the search for coal; a list of reports on these bores is given by Dickins, Roberts, & Veevers (1972, p. 101). Further observations on the geology between Willeroo and Wave Hill were recorded by Brown (1909).

After responsibility for the Northern Territory was assumed by the Commonwealth in 1911, Woolnough (1912) reported on the geology of the Territory, but virtually ignored the Victoria River region. Jensen (1915), who described the country between Pine Creek and Tanami, covered the same ground as Tenison Woods and Brown. Wade (1924) was commissioned to report on the petroleum prospects of northern Australia, and during his field investigations traversed both the East Kimberley and the Victoria River regions; his is the first report dealing with the country between

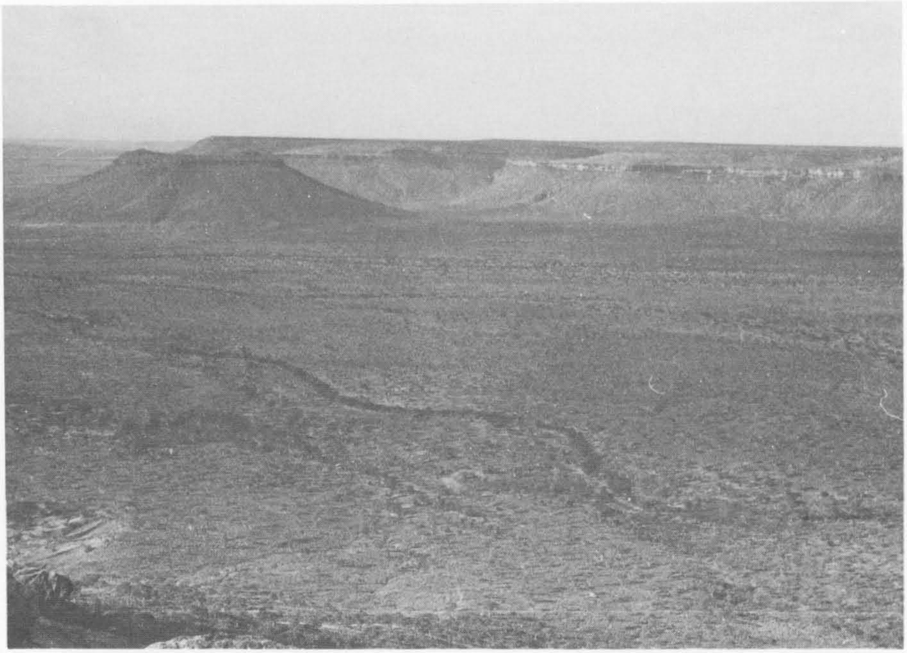

Plate 5. Victoria River Plateau: plains developed on siltstone of the Bynoe Formation are bordered by mesas and plateaux capped by Jasper Gorge Sandstone; view towards Stokes Range from Fitzroy Range south of Fitzroy homestead. (M/797)

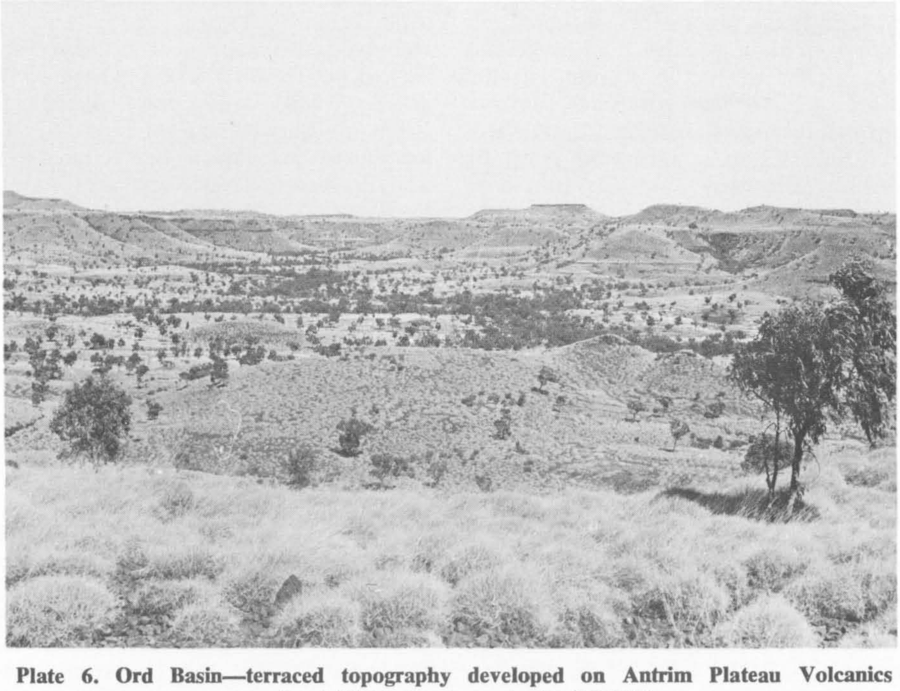

Plate 6. Ord Basin—terraced topography developed on Antrim Plateau Volcanics north of Kirkimbie homestead. (M/901)

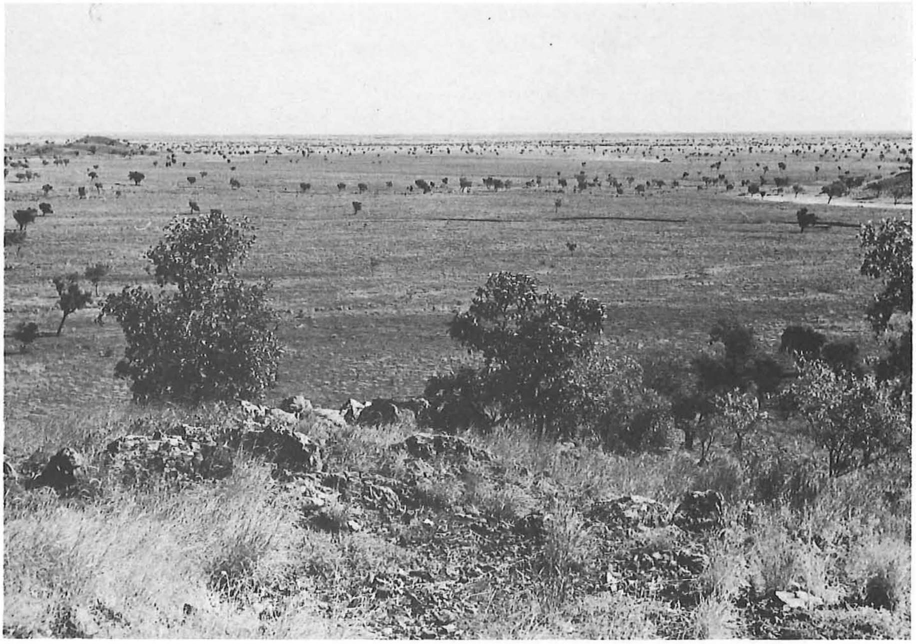

Plate 7. Victoria River Plains and Benches: extensive black soil plain taken from a bench of the Antrim Plateau Volcanics northeast of Wave Hill homestead in the Wave Hill Sheet area. (M/902)

the Osmond Range (East Kimberley) and Auvergne, and he named the shale and siltstone at both localities the Mount John series.

A second phase of geological investigations began in 1935, when the Commonwealth, Queensland, and Western Australian Governments formed the Aerial, Geological, and Geophysical Survey of Northern Australia (AGGSNA). However, the Victoria River region was again largely ignored because of the lack of any prospects and mines, and the reports of Hossfeld (1937a, 1937b) and AGGSNA (1937) only touch on the gold and tin workings at Fletchers Gully and the Buldiva-Collia area.

One of the few East Kimberley surveys to extend into the Victoria River region was that of Matheson & Teichert (1948), who examined Cambrian sediments in the Hardman Basin on both sides of the border. They also discovered Palaeozoic rocks in what is now known as the Bonaparte Gulf Basin.

In the late 1940s a third phase of geological investigation by the Commonwealth Scientific and Industrial Research Organisation (CSIRO) and the Bureau of Mineral Resources, Geology and Geophysics (BMR) included the first systematic geological mapping in the Victoria River region. The Katherine-Darwin region was described by Noakes (1949), and the Ord-Victoria region by Traves (1955). Later detailed reconnaissance mapping at 1:250 000 scale was carried out by BMR and reported by Walpole *et al.* (1968) and Crohn (1968) for the Katherine-Darwin region, and by Dow & Gemuts (1969) for the East Kimberley region. The Fergusson River Sheet area was mapped by Randal (1962) during the Katherine-Darwin investigations, and the present investigation was undertaken in order to complete the coverage of the Precambrian areas between Darwin and the Kimberleys.

Most of the Palaeozoic and younger rocks of the region have been mapped and described by BMR field parties. Veevers & Roberts (1968) and Kaulback & Veevers (1969) reported on the southern part of the Bonaparte Gulf Basin, and Dickins *et al.* (1972) on the northern part of the basin. Randal & Brown (1967) mapped the northern Wiso Basin to the east of the Precambrian rocks of the Victoria River region, and Walpole *et al.* (1968) its northerly extension, the Daly River Basin. The geology of the Ord Basin has been reviewed by Jones (1976) and the stratigraphy and palaeontology of the Lower Cretaceous rocks which crop out sporadically throughout the region have been described by Skwarko (1966).

Present investigations

This Bulletin summarizes the results of mapping carried out by BMR in the Victoria River region between 1967 and 1970. Three field seasons, each of 5 months, were spent in mapping the nine 1:250 000 Sheet areas. In 1970, 3 months were spent logging cuttings and cores from stratigraphic drill-holes, collecting age-determination samples, and studying glacial rocks in detail.

Several geologists took part in the field work and the subsequent report writing. Their names, areas mapped, and reports produced are as follows:

1967—I. R. Pontifex (party leader), C. M. Morgan, I. P. Sweet, A. G. Reid—Auvergne and part of Port Keats Sheet areas; progress report by Pontifex *et al.* (1968); and final Report by Sweet *et al.* (1974c).

1968—I. R. Pontifex (party leader), R. G. Horne, C. M. Morgan, I. P. Sweet, J. R. Mendum—completed Port Keats, Cape Scott, Delamere, and Fergusson River Sheet areas; progress report by Morgan *et al.* (1970), and final Report by Sweet *et al.* (1947b).

1969—C. M. Morgan (party leader), I. P. Sweet, J. R. Mendum, R. J. Bultitude—Waterloo, Victoria River Downs, Limbunya, and Wave Hill Sheet areas; progress report by Sweet *et al.* (1971) and final Report by Sweet *et al.* (1974a).

The Antrim Plateau Volcanics were studied in detail and the results presented in BMR Records by Bultitude (1971), Sweet *et al.* (1971), and Bultitude (in prep.).

Authorship of Explanatory Notes accompanying each of the nine 1:250 000 Sheets is shown in Figure 3.

Field methods

Aerial photographs at several scales are available (Fig. 3). Those at 1:50 000 scale were used by Perry (1966, 1967a, 1967b) and Maffi (1968, 1969) in the preparation of photo-interpretation geological maps. Field traverses were planned using these maps and carried out using 4-wheel-drive vehicles; areas inaccessible to vehicles were visited using helicopter and foot traverses. All geological boundaries were plotted on transparent overlays on aerial photographs and compiled onto photoscale sheets prepared from topographic base maps supplied by the Division of National Mapping. These sheets were reduced to 1:250 000 scale, and the final map was redrawn from the reduced transparencies.

Acknowledgments

The results presented in this Bulletin are the end results of several years' field and office study, and I gratefully acknowledge the contributions made by other geologists taking part in the project: I. R. Pontifex, C. M. Morgan, J. R. Mendum, R. J. Bultitude, A. G. Reid, and R. G. Horne.

I also wish to thank the many station people in the Victoria River region for their hospitality and help, particularly Ian Michael and staff at Victoria River Downs, and Messrs M. O'Neil, J. Shannon, and L. Fogarty at Fitzroy, Coolibah, and Auvergne stations, respectively.

STRATIGRAPHY

Regional tectonic setting

The region consists of basement metamorphics and intrusives of Archaean and Lower Proterozoic age, highly folded Lower Proterozoic geosynclinal rocks, and flat-lying and gently folded Upper Precambrian platform sedimentary rocks (Fig. 4). A zone of deformed rocks, the Halls Creek Mobile Zone (which includes the Fitzmaurice Mobile Zone) in the northwest of the region, contains rocks of all three tectonic provinces. It is bounded on the east by the Victoria River Fault, a major reverse fault which merges into the Halls Creek Fault in the southwest and possibly with the Giants Reef Fault in the northeast. The southwestern, northwestern, northeastern, and eastern margins of the area are occupied by the Ord, Bonaparte Gulf, Daly River, and Wiso Basins of Phanerozoic rocks; they are not described in this Bulletin.

Basement crops out as the Inverway Metamorphics at two localities within the area covered by the platform deposits; it is also exposed at the extremities, within the map area, of the Fitzmaurice Mobile Zone—the Hermit Creek Metamorphics of the Litchfield Block in the northeast, and the Halls Creek Group of metamorphosed sediments and volcanics in the

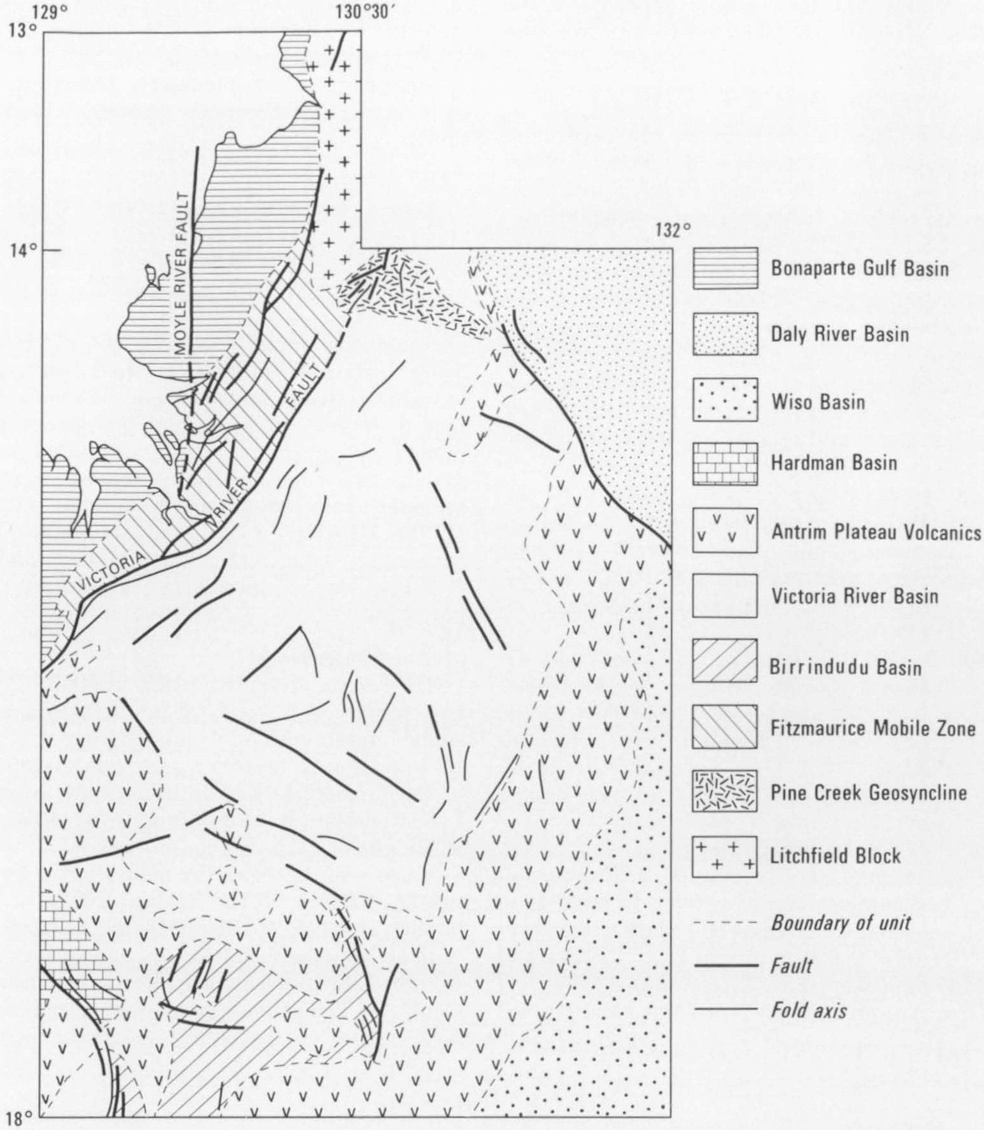

Fig. 4. Tectonic units.

southwest. The geosynclinal rocks of the Pine Creek Geosyncline crop out in the north and northeast. The platform deposits occupy the Sturt Block which extends through most of the region, and they overlap part of the geosyncline. The sedimentary sequence summarized in Table 3 was deposited in the Birrindudu and Victoria River Basins, and a younger unnamed basin (which contains Duerdin Group). The basins probably extended far beyond the present known limits of outcrops, and were parts of extensive stable shelves or platforms. The rocks in these basins are part of a vast, relatively thin sequence of Proterozoic and Palaeozoic sediments shown as Central Australian Platform Cover on the 1971 Tectonic Map of Australia (GSA, 1971, p. 14). The Fitzmaurice Mobile Zone (Table 4) is part of a mobile zone 700 km long, extending from Halls Creek to Darwin, which was named the Halls Creek Mobile Zone by Traves (1955). The platform deposits in the mobile zone comprise a sand-

TABLE 3. SUMMARY OF THE STRATIGRAPHY OF THE STURT BLOCK AND OVERLYING ROCKS, VICTORIA RIVER REGION (PALAEOZOIC SEDIMENTS OMITTED)

Age	*Unit*	*Maximum thickness* (m)	*Lithology*
ADELAIDEAN OR CAMBRIAN	ANTRIM PLATEAU VOLCANICS	300+	Basalt; sandstone, chert, limestone, minor agglomerate
	KINEVANS SANDSTONE	15	
	UNCONFORMITY		
ADELAIDEAN	DUERDIN GROUP	300	Tillite, sandstone, conglomerate, siltstone, shale, dolomite
	UNCONFORMITY		
	BULLO RIVER SANDSTONE	300	Sandstone, conglomerate
	?UNCONFORMITY		
	AUVERGNE GROUP	1000	Sandstone, siltstone, dolomite, shale
	UNCONFORMITY		
	STUBB FORMATION	115	Siltstone, shale, sandstone
	WONDOAN HILL FORMATION	145	Sandstone, siltstone, shale, minor dolomite, siltstone
	UNCONFORMITY		
	BULLITA GROUP	700	Dolomite, siltstone; minor chert and sandstone
	WATTIE GROUP	400	Sandstone, siltstone; minor dolomite and claystone
	UNCONFORMITY		
CARPENTARIAN OR ADELAIDEAN	LIMBUNYA GROUP	1500+	Dolomite, siltstone, shale, sandstone, chert
	UNCONFORMITY		
CARPENTARIAN	BUNDA GRIT	1200+	Grit; sandstone, conglomerate; minor chert
	UNCONFORMITY		
ARCHAEAN OR LOWER PROTEROZOIC	INVERWAY METAMORPHICS	—	Schist

TABLE 4. SUMMARY OF THE STRATIGRAPHY OF THE FITZMAURICE MOBILE ZONE AND ADJACENT UNITS

Age	*Unit*		
Adelaide	FITZMAURICE GROUP (3600+ m of sandstone, siltstone, shale; minor conglomerate)		
	UNCONFORMITY		
Carpentarian	Bow River Granite Whitewater Volcanics		Allia Creek Granite Soldiers Creek Granite Koolendong Granite Ti-Tree Granophyre
Lower Proterozoic and Archaean	Halls Creek Group	Pine Creek Geosyncline	Henschke Breccia Chilling Sandstone Finniss River Group
			UNCONFORMITY
			Hermit Creek Metamorphics and Litchfield Complex

TABLE 5. PRECAMBRIAN TIME-STRATIGRAPHIC CLASSIFICATION IN AUSTRALIA

Time scale m.y.	*Precambrian Time-Stratigraphy* (After Dunn, Plumb, & Roberts, 1966)	
1000	PROTEROZOIC	ADELAIDEAN SYSTEM (1400)
1500		CARPENTARIAN SYSTEM (1770 ± 20)
2000		LOWER PROTEROZOIC ('Nullaginian') SYSTEM (2200-2250)
2500	ARCHAEAN	—

stone sequence called the Fitzmaurice Group. They are extensively faulted and folded into broad folds and some sharper folds, and the degree of deformation is much greater than that of the Sturt Block.

Stratigraphic classification and nomenclature

The time-stratigraphic terms used in this Bulletin are those introduced by Dunn, Plumb, & Roberts (1966), in which the base of the Adelaidean System is placed at 1400 million years (Table 5). New evidence, in particular that of Cooper & Compston (1971), suggests that the base of the type Adelaidean in South Australia may be much younger than 1400 million years. Although this may result in some modification of Precambrian time-stratigraphic terminology, the scheme of Dunn *et al.* (op. cit.) will be followed in this Bulletin.

The nomenclature of rock units in the region has been formalized as much as possible, and all units have been defined in BMR reports on the region (Sweet *et al.*, 1974a, b, and c). Rock unit names used by other authors have been modified where necessary, and others retained if the units to which they have been applied are still used as mapping units. Nomenclature used by other authors is described in the following paragraphs.

Brown (1895) used the terms 'Victoria River Sandstone', 'Victoria River Shale', and 'The limestone formation' to describe units along the lower reaches of the Victoria River. These were general terms applied to units which now form parts of the Fitzmaurice, Auvergne, and Bullita Groups. Brown believed that the rocks were of Carboniferous age, and that the overlying basalts were between Carboniferous and Cretaceous. Wade (1924) described rocks in the Auvergne area as the Mount John Series, and assigned them to the Lower Cambrian.

Matheson & Teichert (1948) demonstrated the Precambrian age of all sediments below the basalts by the discovery of Cambrian fossils in sediments above the basalts.

The Precambrian rocks of the Victoria River Region were included by Traves (1955) in the 'Victoria River Group', but he did not divide the group into formations. He considered that their age was 'Upper Proterozoic'.

Laing & Allen (1956) carried out the first detailed reconnaissance mapping of part of the region, and named six formations in the Upper Proterozoic succession. One of the formation names, Jasper Gorge Sandstone, has been retained, but the unit has been redefined, and their 'Coolibah Formation' has been subdivided into the Stubb, Wondoan Hill, and Bynoe Formations. Laing & Allen (op. cit.) regarded the 'Skull Creek Limestone' and Timber Creek Formation as lateral equivalents, but further mapping has shown that the Timber Creek Formation underlies the 'Skull Creek Limestone' (now called Skull Creek Formation).

Although Harms (1959) did not study the stratigraphy of the region in detail, he recognized the major lineament (now called the Victoria River Fault) which divides the Sturt Block and the Fitzmaurice Mobile Zone. He called the folded and faulted sandstones in the Fitzmaurice Mobile Zone the 'Macadam Range Beds', and considered that they could be Lower Proterozoic. These rocks are now mapped as the Fitzmaurice Group of Adelaidean age.

In the Fergusson River 1:250 000 Sheet area near the northeastern margin of the Victoria River Basin, the basin succession is incomplete and the relations between units are not clear. Accordingly, the conclusions in this Bulletin are different from those of Randal (1962) and Walpole *et al.* (1968), who previously mapped the Fergusson River Sheet area. They retained Traves's term 'Victoria River Group' and subdivided it into four units (Table 6).

Randal's nomenclature for the Tolmer Group and sedimentary and igneous rocks of the Pine Creek Geosyncline has been retained, although the distribution of some units has

TABLE 6. OLD AND NEW STRATIGRAPHIC NOMENCLATURE FOR PART OF THE FERGUSSON RIVER 1:250 000 SHEET AREA

	Randal (1962); Walpole et al. (1968)		*This Bulletin*
VICTORIA RIVER GROUP	Laurie Creek Beds	AUVERGNE GROUP	Shoal Reach Formation Spencer Sandstone Lloyd Creek Formation
	Yambarra Beds		Pinkerton Sandstone Saddle Creek Formation
	Angalarri Siltstone		Name retained
	Palm Creek Beds		Jasper Gorge Sandstone Bullita Group (part only)

been changed. For instance, Walpole *et al.* (1968) thought that the Chilling Sandstone cropped out extensively in what is now called the Fitzmaurice Mobile Zone (they called it the Chilling Platform). It is now known that the Chilling Sandstone occurs only north of the Fitzmaurice River, and that the remainder of the area is occupied by younger rocks, the Fitzmaurice Group.

The Precambrian rocks of the region are described in the order of the Sturt Block, Birrindudu Basin, Victoria River Basin, Halls Creek Mobile Zone, and Pine Creek Geosyncline. The Phanerozoic rocks of the Bonaparte Gulf, Daly River, Ord, and Wiso Basins are described in other BMR publications (see *Previous investigations*).

STURT BLOCK (Table 3)

The Sturt Block was defined by Traves (1955) as an area bounded to the northwest by the Halls Creek Mobile Zone, to the northeast by the Pine Creek Geosyncline, and to the south by the 'Warramunga Mobile Zone'. Its distinguishing feature was the presence of undeformed Proterozoic rocks, in contrast to the highly deformed, metamorphosed, and intruded rocks of surrounding areas. Although it is not possible to define an eastern boundary for the block, the term is useful to describe this stable area which was probably welded into a cratonic area early in the Proterozoic.

On the Sturt Block lies a sequence of over 5000 m of sediments which are deposited in three overlapping basins. The oldest basin, the Birrindudu Basin, contains the Limbunya Group which overlies a basement of Bunda Grit and Inverway Metamorphics. The Victoria River Basin contains the sequence from the Wattie Group to the Bullo River Sandstone (Table 3). The youngest basin, which has not been named, contains upper Adelaidean glacial rocks (including the Duerdin Group) and extends westwards into the Kimberley region.

ARCHAEAN OR LOWER PROTEROZOIC

Inverway Metamorphics

The Inverway Metamorphics form a basement to the Birrindudu Basin and consist of weathered mica schist, greywacke, and acid volcanics. They are exposed only in two small areas (totalling about 2 km^2) about 38 km south of Limbunya homestead. They bear some resemblance to the Halls Creek Group of Dow & Gemuts (1969) and the Tanami Group of Blake, Hodgson, & Muhling (1973), but because of their geographic isolation and uncertain age they are given a separate name. The metamorphics are overlain in both known outcrops by Stirling Sandstone which is the basal unit of the Limbunya Group; they are assumed to be overlain by the Bunda Grit, a strongly folded but unmetamorphosed arenite unit exposed 30 km west of Inverway homestead.

?LOWER PROTEROZOIC

Bunda Grit

The Bunda Grit is exposed in a north-trending anticline 30 km west of Inverway homestead, and in a small outcrop 5 km nearer to the homestead. It consists of coarse sandstone and grit containing pebble beds grading upwards into light-coloured blocky and massive medium quartz sandstone. The small outcrop consists of purple, thin-bedded, and laminated chert which is folded and brecciated; its relation to the sandstone and grit is not known and it is only tentatively included in the unit.

About 1200 m of sandstone and grit is exposed at the type section, where steeply dipping and overturned beds are overlain unconformably by almost flat-lying rocks of the Limbunya Group. The Limbunya Group unconformably overlies Inverway Metamorphics northeast of Inverway in the region of a north-trending basement ridge (Whitworth, 1970; Sweet et al., 1974a); it is possible that the Bunda Grit was never present over the ridge.

The Bunda Grit occupies a stratigraphic position between the Inverway Metamorphics and the Stirling Sandstone (basal Limbunya Group) similar to that of the Red Rock Beds between the Halls Creek Group and the Mount Parker Sandstone (Dow & Gemuts, 1969) 125 km to the northwest in the East Kimberley region. The Bunda Grit and the Red Rock Beds may be correlatives, although it is noted

TABLE 7. SUMMARY OF LIMBUNYA GROUP AND BUNDA GRIT STRATIGRAPHY

	Unit	Lithology	Thickness range (m)	Stratigraphic relations	Physiographic expression	Remarks
LIMBUNYA GROUP	Killaloc Formation	Siltstone above dolomite; minor sandstone	60	Unconformably below Wickham Formation. Conformable on Fraynes Formation	Low relief in type area	Youngest preserved formation of Limbunya Group
	Fraynes Formation	Silty dolomite, siltstone, dolomite; chert at top	110-130		Chert band at top forms low ridges, remainder is fairly low relief	Chert at top is of replacement origin
	Campbell Springs Dolomite	Dolomite, dolarenite, dolrudite	340-380		Lapies, rocky low hills	Stromatolites well developed
	Blue Hole Formation	Siltstone, shale, silty dolomite	160-320		Valleys, low-relief areas	Contains some stromatolites
	Farquharson Sandstone	Sandstone; minor siltstone	40-110		Hogbacks, cuestas	
	Kunja Siltstone	Siltstone, shale, silty dolomite	60-65	Conformable sequence	Valleys	
	Mallabah Dolomite	Dolomite	10-100		Low relief, rocky pavements	
	Amos Knob Formation	Dolomite, green siltstone; minor sandstone and shale	40-50		Low-relief areas	
	Pear Tree Dolomite	Dolomite, dolarenite; chert at top	75		Low terraced hills, chert forms small rocky ridges	Chert has replaced dolomite at top of unit; contains stromatolites
	Margery Formation	Chert (shale, dolomite), claystone	125		Valleys, some low hills	Rock types usually seen are altered from shale and dolomite
	Stirling Sandstone	Sandstone	120	Unconformable on Inverway Metamorphics and Bunda Grit	Cuestas, rocky pavements, plateaux	
	Bunda Grit	Grit, sandstone, and conglomerate; minor chert	1200+	Unconformably below Stirling Sandstone; base not seen	Hogbacks and rocky pavements	Assumed to be unconformable on Inverway *Metamorphics*

that several hundred million years elapsed between the end of deposition of the basement metamorphics and the beginning of deposition of the Limbunya Group. A confident correlation cannot be made without further isotopic age determinations, and it is doubtful if suitable material will be found. Similarly, a tentative correlation can be made between the Bunda Grit and the Pargee Sandstone in The Granites-Tanami Block (Blake, Hodgson, & Muhling, 1973).

BIRRINDUDU BASIN

CARPENTARIAN

Limbunya Group

Important outcrops of the Limbunya Group are located in three places in the Limbunya Sheet area: the western (Kirkimbie) area, the central (Limbunya) area, and the eastern (Farquharson Gap) area; small outcrops are known in the southeastern Waterloo and southern Auvergn Sheet areas.

Only the central Limbunya sequence is complete, and a sequence 1300 m thick has been divided into eleven formations (Sweet *et al,* 1974a) which are summarized in Table 7. The Stirling Sandstone unconformably overlies Inverway Metamorphics in the central area and Bunda Grit in the west. It consists of blocky and massive, thin-bedded medium and coarse sandstone with a clay matrix. Basal conglomerate is present in the west, indicating an easterly provenance, probably from a meridional basement ridge suggested from gravity evidence (Whitworth, 1970). The Limbunya Group in the central area overlies the ridge area and thickens both to the east and west.

All formations above the Stirling Sandstone, except the Farquharson Sandstone, are dolomitic and some contain beds of almost pure dolomite. Interbeds of siltstone and shale are common, and are the predominant rocks in the Kunja Siltstone.

Stromatolites, intraclasts up to several centimetres across, and less commonly cross-bedding in the carbonates indicate shallow-water deposition. The interbeds of siltstone and shale are also, by implication, shallow-water deposits, perhaps the product of an environment adjacent to and contemporaneous with that in which the carbonate was deposited. An 80-m sequence of laminated shale in the Blue Hole Formation is the thickest clastic unit in the group, and may indicate deeper quiet-water depsition.

The Limbunya Group is thus the product of an environment in which subsidence and sedimentation proceeded at about the same rate. Sedimentary conditions ranged from lagoonal to littoral, resulting in the deposition of predominant carbonate and rare clastic sediments. The presence of halite casts in some of the sediments indicates periodic desiccation during sedimentation. Minor imbalances in subsidence and sedimentation rates resulted in the formation of deeper-water shales such as those in the Kunja Siltstone and Blue Hole Formation, and very-shallow-water deposits such as the Farquharson Sandstone.

Stromatolites. Most of the carbonate units in the Limbunya Group contain stromatolites (as defined by Logan, Rezak, & Ginsburg, 1964). Recent stromatolites at Shark Bay (Logan, 1961) are presently forming only in the intertidal zone in hypersaline water in a marine embayment. It is not known whether such strict limits can validly be applied to Precambrian forms, but it is generally accepted that they indicate very shallow water.

Two types of stromatolites are found in the Limbunya Group. The first occurs in the lower formations of the group: Margery Formation, Pear Tree Dolomite, and Amos Knob Formation; and the second is found in the Blue Hole Formation and Campbell Springs Dolomite. A silicified band several metres thick, forming the top of the Pear Tree Dolomite, contains the best examples of the first type (Pl. 8). Vertical sections of the stromatolites are typically composed of steeply converging laminae; they may therefore belong to the genus *Conophyton,* which is characterized by laminae which form a central axial structure. Stromatolites occur as extensive biostromes and some bioherms in the Blue Hole Formation and Campbell Springs Dolomite; Plate 10 shows some common forms.

Age and correlations of the Limbunya Group. The Limbunya Group is confidently correlated with the Bungle Bungle Dolomite and Mount Parker Sandstone in the East Kimberley region of Western Australia. In that region Dow & Gemuts (1969) described a sequence of dolomite, shale, and sandstone which is of similar thickness to the Limbunya Group in the Kirkimbi area. The sequences are very similar in lithology and contained structures, and are regarded as equivalents. Table 8 summarizes the correlation made with the type section of the Bungle Bungle Dolomite and Mount Parker Sandstone. Dow & Gemuts (1969) stated that the age of the East Kimberley rocks was '. . .

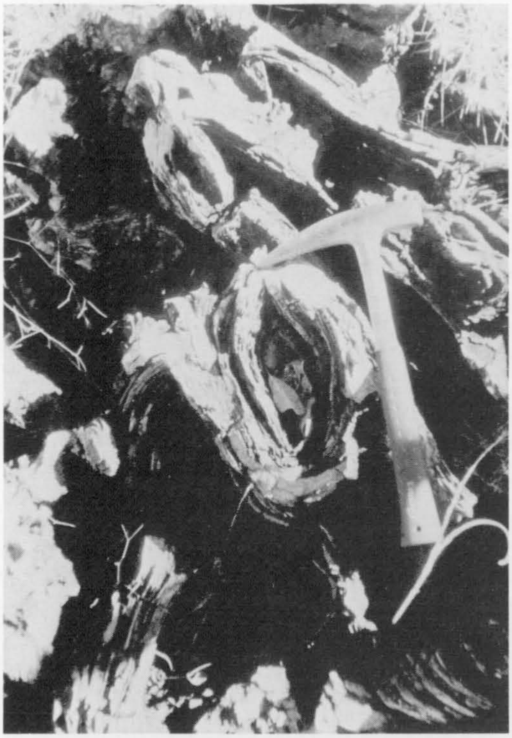

Plate 8. Bedding-plane view of partly silicified stromatolites in Pear Tree Dolomite near Swan yard, central Limbunya Sheet area. (GA/4588)

probably Adelaidean, but could be as old as Carpentarian'. The Limbunya Group, which is correlated with them, unconformably underlies Wattie and Bullita Groups which in turn unconformably underlie Wondoan Hill Formation which has been dated at 1200 to 1400 m.y. (Appendix 1). It is therefore highly probable that the Limbunya Group and Bungle Bungle Dolomite are Carpentarian.

A tentative correlation has been made between the Limbunya Group and the Birrindudu Group in The Granites-Tanami region (Blake & Hodgson, 1975), and recent isotopic age determinations on glauconite from near the base of the Birrindudu Group indicate an age of 1550 to 1620 m.y. (AMDL Rep. 3473/73, unpubl.).

Isotopic age determinations on both the Wondoan Hill Formation and Birrindudu Group indicate a Carpentarian age for the Limbunya Group. It is therefore suggested that the group is contemporaneous with the McArthur Group in northeastern Northern Territory.

VICTORIA RIVER BASIN

ADELAIDEAN OR CARPENTARIAN

Wattie Group

The Wattie Group, previously mapped by Traves (1955) as the Victoria River Group, was defined and described by Sweet *et al.*

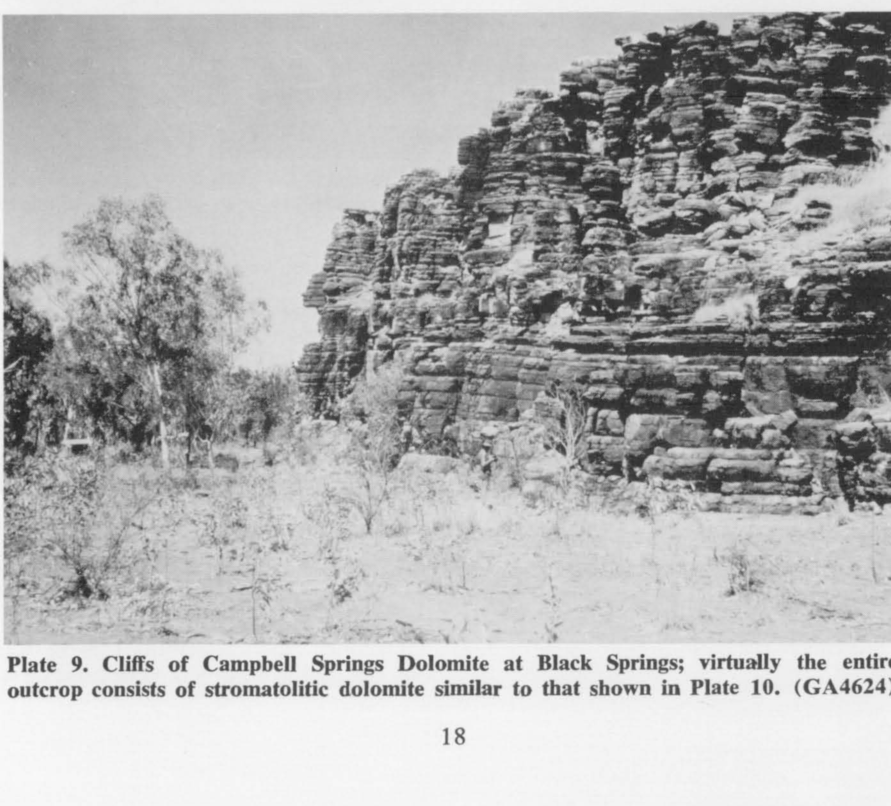

Plate 9. Cliffs of Campbell Springs Dolomite at Black Springs; virtually the entire outcrop consists of stromatolitic dolomite similar to that shown in Plate 10. (GA4624)

Plate 10. Large hemispherical stromatolites succeeded by parallel, rarely branching columnar forms which decrease in diameter upwards. Pocket knife 10 cm long. Same locality as Plate 9. (GA/2641)

(1974a). Seven formations were grouped together (Table 9) because they are composed mainly of clastic sediments. The overlying and underlying groups are predominantly of carbonate composition.

The base of the group consists of a chert member which is up to 30 m thick and is considered to represent a weathering profile of silicification developed on dolomitic units of the Limbunya Group. It could have formed at any time after folding of the Limbunya Group and before initial deposition of sand of the Wattie Group. Chert pebbles and sand grains common in the lower part of the overlying sandstone indicate that some chert was eroded from the silicified layer.

Although the Wattie Group is extensive, it is comparatively thin, and complete sections are uncommon. In the southwest, 315 m of sandstone believed to be Wickham Formation is preserved; this is nearly as thick as the whole group in the Wattie Creek/Neave Creek area (Fig. 5). In the latter area, and farther north near Depot Creek, sandstone forms just over 50 percent of the total section, the remainder being mostly quartz siltstone and dolomite. In the northernmost outcrops, in the Auvergne Sheet area, sandstone is subordinate to siltstone, dolomite, and claystone of the Mount Sanford and Gibbie Formations, and the Burtawurta Formation is absent.

Cross-bedding and ripple marks are ubiquitous in the sandstone beds of the Wattie Group, and the sandstone may have been laid down around the margins of a basin. Near the basin centre finer-grained clastic sediments and dolomite were deposited. Both the clastic and carbonate sediments contain mud cracks and flakes, ripple marks, and halite casts, which indicate a shallow-water environment with periods of subaerial exposure.

Age and correlations. The Wattie Group is overlain conformably by the Bullita Group which is correlated with the carbonate units in the Tolmer Group (p. 24). It therefore seems likely that the clastic part of the Tolmer Group (Buldiva Sandstone) is equivalent to the Wattie Group.

Because the Wattie, Bullita, and Tolmer Groups are so closely related, their correlation and age are discussed in one section on page 27.

Bullita Group (Table 10)

Rocks now assigned to the Bullita Group were first described by Traves (1955), and later by Laing & Allen (1956) who mapped an area southeast of Timber Creek. Laing & Allen recognized Timber Creek and Skull Creek Formations and thought they were lateral equivalents, but further mapping has shown that one overlies the other. The type section of the Timber Creek Formation at Timber Creek is retained (Sweet *et al.*, 1974a), and the base of the formation is not exposed. A complete section of the unit is exposed north of Mount Sanford in the Victoria River Downs Sheet area, where it is estimated to be at least 200 m thick. In the north the upper boundary is placed at the point where dolomite predominates over siltstone. In the south the Timber Creek Formation is almost as dolomitic as the Skull Creek Formation and the upper boundary is placed, somewhat arbitrarily, at the base of a distinctive chert-rich stromatolitic dolomite bed.

The Bullita Group comprises five formations in the Victoria River Downs Sheet area. Three other formations are included in the group, and their relation to the main sequence of 5 units is shown in Table 11. Carbonate rocks, particu-

TABLE 8. SUGGESTED CORRELATION OF THE TYPE SECTION OF THE BUNGLE BUNGLE DOLOMITE AND MOUNT PARKER SANDSTONE WITH FORMATIONS OF THE LIMBUNYA GROUP

Bungle Bungle Dolomite and Mount Parker Sandstone (Dow & Gemuts, 1969)			Limbunya Group	
Unit	*Lithology*	*Thickness* (m)		*Thickness* (m)
Bungle Bungle Dolomite	Quartz sandstone, dolomitic shale	70	Fraynes Formation	130
	Dolomite	210		
	Dolomite, limestone	25		
	Sandstone } Dolomite, shale }	160	Campbell Springs Dolomite	376
	Dolomite	120		
	Sandstone, dolomite	45	Blue Hole Formation	317
	Shale, siltstone	90		
	Limestone Breccia	25		
	Quartz sandstone	30	Farquharson Sandstone	112
	Shale, quartz sandstone	60	Kunja Siltstone	61
	Limestone, calcareous shale	75	Mallabah Dolomite	100
	Dolomite, shale	60	Amos Knob Formation	50
	Dolomite	130	Pear Tree Dolomite	105
	Shale	135		
Mount Parker Sandstone	Quartz sandstone	9	Margery Formation	125
	Silicified dolomite	18		
	Micaceous shale	9		
	Quartz sandstone	37		
	Cross-bedded quartz sandstone	Unknown	Stirling Sandstone	120
	Unconformably on Red Rock Beds and Halls Creek Group		Unconformably on Bunda Grit and Inverway Metamorphics	

larly dolomite, predominate although all formations contain some clastics. The stratigraphy of the Group is summarized in Table 10.

The Timber Creek and Skull Creek Formations and probably the Bynoe Formation are the product of cyclic depositional processes. In the Timber Creek Formation and the lower half of the Skull Creek Formation, dolomite beds 10 to 100 cm thick alternate with reddish purple and greyish green siltstone and fine sandstone; all facies contain mud cracks and halite casts. Except for the basal bed of the Skull Creek Formation, stromatolites are absent. These rocks appear to indicate lagoonal and evaporitic environments, perhaps similar to modern Persian Gulf lagoon/sabkha environments described by Illing, Wells, & Taylor (1965). Plate 11 illustrates common varieties of halite casts in the dolomite beds. Interbedded dolomite and siltstone continue to the base of the Supplejack Dolomite Member (Table 10) which marks the beginning of a new phase of carbonate sedimentation. In and above the Member the dolomite beds are more coarsely recrystallized pure carbonates, and many beds contain stromatolites. At least two forms are present, one characterized by conical laminae up to 1 m or more in height, and the other is a smaller columnar form (Pl. 12).

The Supplejack Dolomite Member is in most places a massive dark grey recrystallized dolomite easily recognized in aerial photographs by its highly distinctive photo-pattern (Pl. 13). In outcrops 30 km west-southwest of Victoria River Downs homestead, finely crystalline light grey dolomite is interbedded with coarsely crystalline cross-bedded dolarenite and dolorudite in which tabular pebbles of the finely crystalline dolomite are ubiquitous. It is suggested that the Supplejack Dolomite Member represents a marine transgression across sabkhas of dolomite, and that much of the rock was reworked and laid down as cross-bedded dolorudite during the transgression. Another period of cyclic

TABLE 9. SUMMARY OF THE WATTIE GROUP STRATIGRAPHY

Unit	*Lithology*	*Thickness range* (m)	*Stratigraphic relations*	*Physiographic expression*	*Remarks*
Seale Sandstone	Sandstone	5-100	Conformably below Timber Creek Fmn	Cuestas, hogbacks, rugged plateaux	Conformably below basal unit of Bullita Group
Gibbie Formation	Micaceous siltstone, sandstone	25-75	Conformable sequence	Valleys, smooth scarp-slopes	
Neave Sandstone	Sandstone; minor conglomerate	3-20	Evidence of minor reworking of Mt Sanford Fmn	Cuestas, hogbacks	May be locally unconformable on Mt Sanford Fmn
Mount Sanford Formation	Siltstone, dolomite; minor sandstone and claystone	25-200+		Valleys, terraced slopes	Thickens northwards
Hughie Sandstone	Sandstone	50-130	Conformable sequence	Cuestas, hogbacks	
Burtawurta Formation	Siltstone, sandstone, minor dolomite	20-40		Valleys, smooth scarp-slopes	Absent in northern Waterloo Sheet area
Wickham Formation	Sandstone, chert	175-315	Disconformable on Limbunya Group	Low rocky hills	Overlies various Limbunya Group units

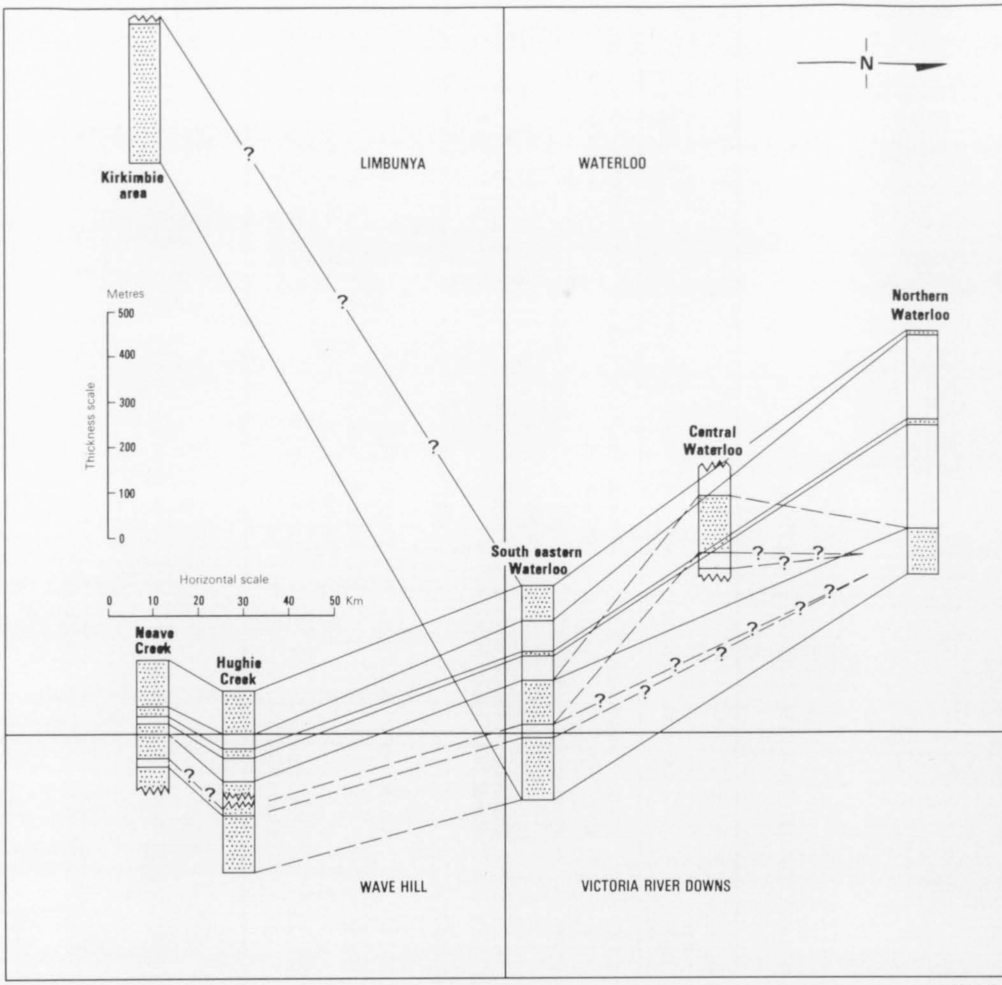

Fig. 5. Thickness and locations of sections measured through the Wattie Group.

sedimentation ensued, but it is thought that most beds were laid down in a marine environment.

The Bynoe Formation consists of dolomitic siltstone and thin sandstone and dolomite beds, and probably indicates a shallowing of the basin and a return to paralic sedimentation. Plate 14 shows the upper part of the Skull Creek Formation and the lower part of the Bynoe Formation in which at least 25 cycles are preserved as dolomite and siltstone interbeds.

The Banyan Formation overlies the Bynoe Formation in the Fergusson River Sheet area and consists of fragmental (clasts 1-5 cm) and stromatolitic limestone and dolomite with interbeds of sandstone and siltstone. Up to 200 m may be preserved near the centre of the outcrop area, but it is gently inclined and accurate measurements are impossible. The facies present indicate strong current activity and predominantly shallow-water conditions.

Throughout the Delamere Sheet area the top of the Bynoe Formation is eroded, but farther south in the Victoria River Downs Sheet area it is overlain conformably by a thin pebbly sandstone unit, the Weaner Sandstone, which in turn is overlain by the Battle Creek Formation, a sequence of ferruginous and manganiferous dolomite interbedded with siltstone and capped by sandstone. Stromatolites in some beds indicate shallow water but environments for other parts of the unit are unknown.

TABLE 10. SUMMARY OF THE BULLITA GROUP STRATIGRAPHY

Unit	*Lithology*	*Thickness range* (m)	*Stratigraphic relations* (see Table 11)	*Physiographic expression*	*Remarks*
Battle Creek Formation	Dolomite, siltstone, sandstone; minor shale	180+	In S. Unconformably below Wondoan Hill Fmn	Low hills, some hogbacks	
Weaner Sandstone	Sandstone, pebbly sandstone	0-15	Conformable on Bynoe Formation	Prominent cuestas	
Banyan Formation	Stromatolitic and oolitic dolomite and limestone, minor siltstone and sandstone	Probably 315 max.	Conformable on Bynoe Fmn. Unconformably below Stubb Fmn and Jasper Gorge Sst	Flat to undulating plains; some low rounded hills	Crops out only in Fergusson River Sheet area
Mount Gordon Sandstone	Sandstone	10+	Unconformably below Wondoan Hill Fmn; conformable on Nero Sltst	Gently dipping plateau surface	
Nero Siltstone	Siltstone; minor shale and sandstone	80	Lower contact not observed	Smooth scarp-slopes below capping of Mt Gordon Sst	
Bynoe Formation	Siltstone, dolomite, sandstone	120-?200	Lower contacts may be unconformable locally	Round hills with prominently terraced slopes	
Skull Creek Formation	Dolomite; minor siltstone and sandy dolomite	165	Both contacts conformable	Rounded, terraced hills; some low relief areas with rocky pavements	
Bardia Chert Member	Laminated chert	0-60	Lower contact transgressive across bedding		Secondary chert; replaces dolomite
Supplejack Dolomite Member	Dolomite, dolarenite, dolorudite	10-20	Upper and lower boundaries conformable	Prominent terrace; rocky pavements with lapies in flat areas	Very prominent photogeological unit
Timber Creek Formation	Siltstone, dolomite, sandstone	?200-?260	Upper and lower boundaries conformable	Rounded terraced hills	Upper boundary gradational; thickness estimated

TABLE 11. RELATIONS BETWEEN BULLITA GROUP FORMATIONS

Northern Area	*Central Area*	*Southern Area*
Banyan Formation	Battle Creek Formation	
	Weaner Sandstone	Mount Gordon Sandstone
	Bynoe Formation	Nero Siltstone
	Skull Creek Formation	
	Bardia Chert Member	
	Supplejack Dolomite Member	
	Timber Creek Formation	

The Battle Creek Formation is regarded as equivalent to the Banyan Formation and they have only been assigned different names because of the wide geographical separation of present-day outcrops.

The Nero Siltstone and Mount Gordon Sandstone, which are regarded as equivalents of the Bynoe Formation and Weaner Sandstone respectively (Table 11), crop out only in the Wave Hill Sheet area. The Nero Siltstone contains finer siltstone and shale than the Bynoe Formation, and may indicate a deeper-water environment.

Tolmer Group

The Tolmer Group was mapped by Randal (1962) and described by Walpole *et al.* (1968). It consists of three formations (Table 12): a lower sandstone, a middle dolomite, and an upper dolomite/siltstone/sandstone. The youngest unit, the Waterbag Creek Formation, was thought to extend south of the Wingate Plateau, but Sweet *et al.* (1974b) restricted the Tolmer Group to the northern side of the plateau. The rocks south of the plateau are assigned to the Bullita Group, with which the upper part of the Tolmer Group is correlated (Table 13).

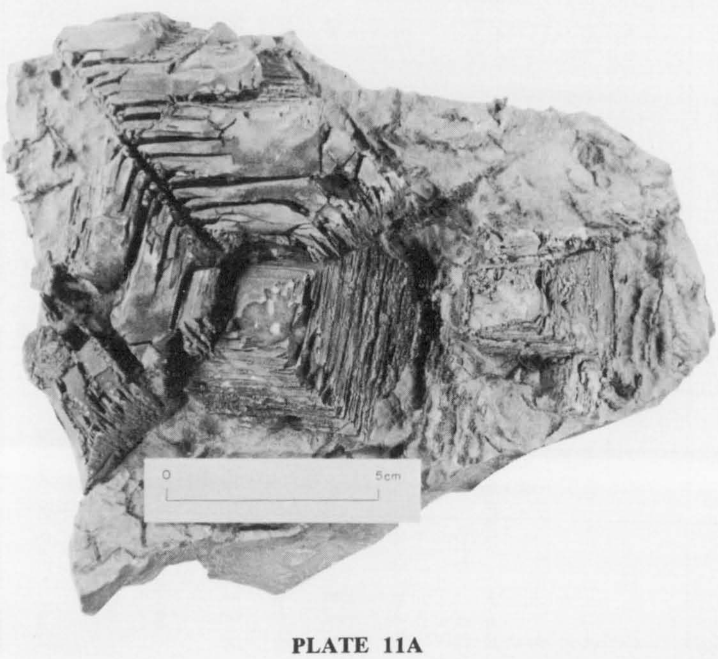

PLATE 11A

PLATE 11B

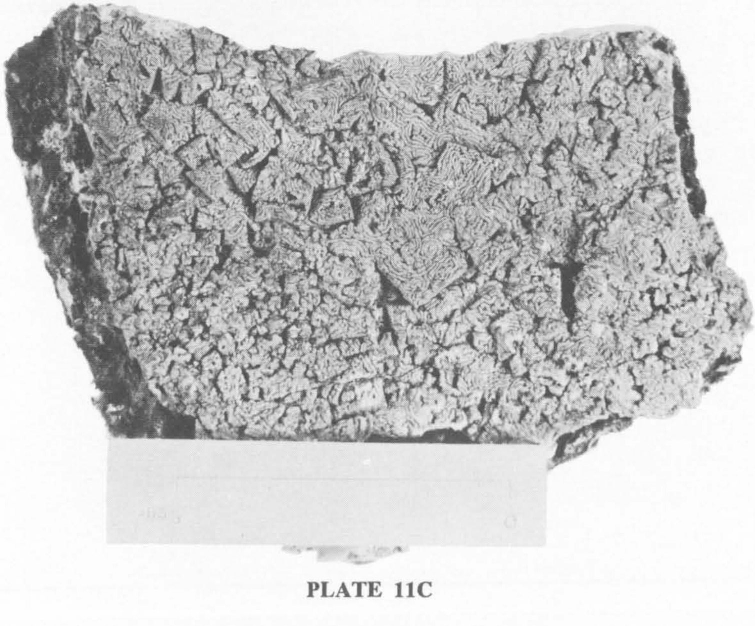

PLATE 11C

Plate 11. Halite casts in the Skull Creek Formation: (a) Very large casts in which crystal surfaces have been replaced by chert (GA/8007); (b) Smaller casts in which chert has replaced halite only along crystallographic axes, resulting in a herringbone structure (GA/8011); (c) Small casts of chert after halite. Southern end of Fitzgerald Range, Victoria River Downs Sheet area. (GA/8006)

Plate 12. Small columnar stromatolites in medium-bedded dolomite from the Supplejack Dolomite Member about 10 km west of Fitzroy homestead, Delamere Sheet area. (GA8009)

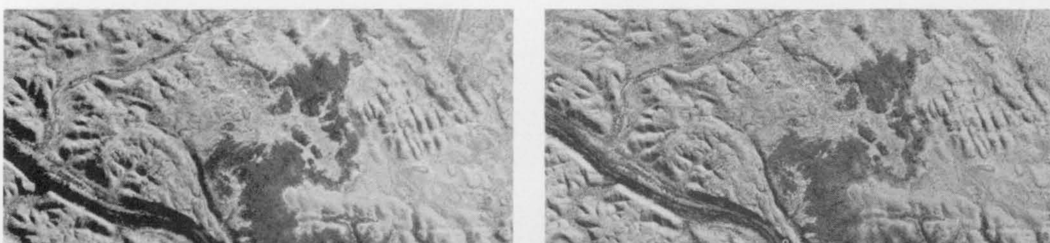

Plate 13. Distinctive photo-pattern of the Supplejack Dolomite Member of the Skull Creek Formation. The very dark tone results from the low reflectivity of the bare irregular surfaces of massive dark grey dolomite. Dolomite and siltstone above and below the member form light-coloured soil and support grasses which increase reflectivity. Aerial photographs at 1:85 000 scale. The area shown is 10 km northwest of Bullita homestead; the East Baines River traverses the centre of the photograph. (Waterloo RC9, Run 1, Photos 82, 84)

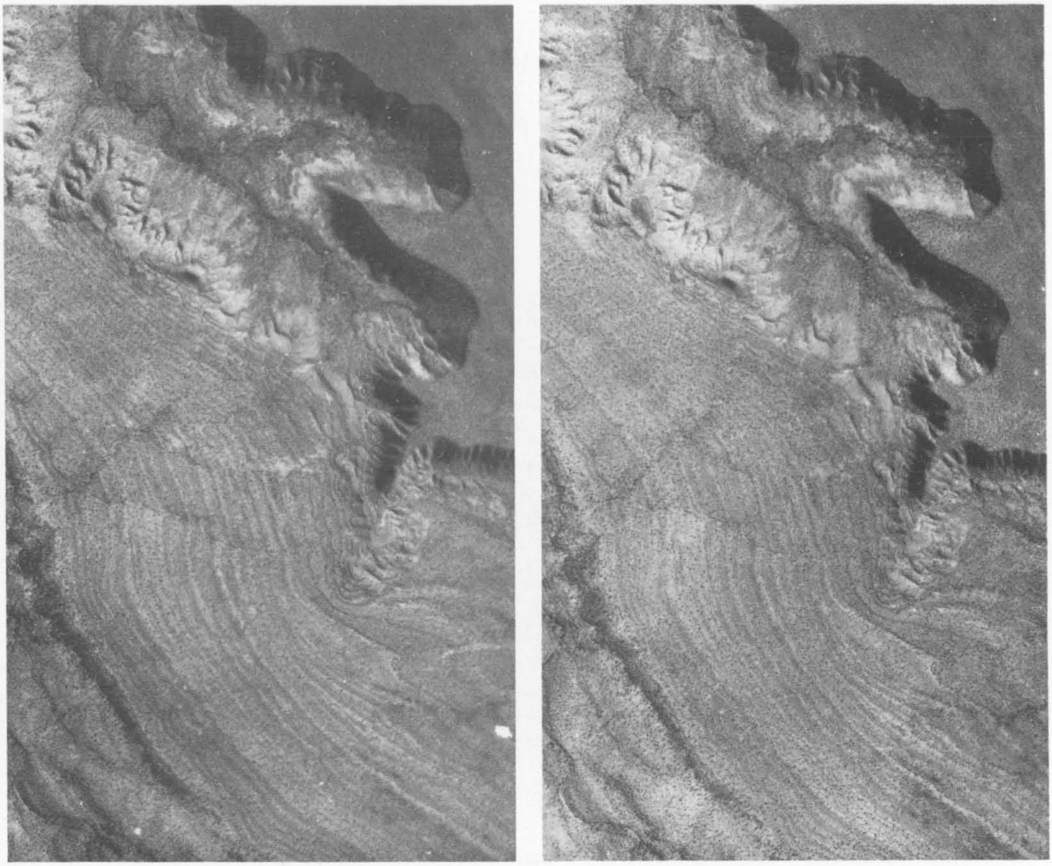

Plate 14. Distinctive photopattern and terraced topography of the Skull Creek Formation. The broad dark band in the lower left corner is the Supplejack Dolomite Member, which is overlain by interbedded dolomite and dolomitic silstone. These produce the banded photopattern in the centre of the photograph. The terraces on the right are developed at the Skull Creek/Bynoe Formation contact, a gradational boundary in which the siltstone content increases upwards. The mesa consists of flat-lying Jasper Gorge Sandstone. About 20 km south-southwest of Bullita homestead. (Waterloo K17, Run 4, Photos 05, 06)

The Tolmer Group was previously thought to be equivalent to or younger than the Auvergne Group, and perhaps to have been the first sediments deposited in the Daly River Basin (Walpole *et al.,* 1968). However, the Tolmer Group is more extensive than the Palaeozoic rocks in the Daly River Basin, is folded differently, and is not part of the sequence in that basin. It is considered to be part of the first main cycle of deposition in the Victoria River Basin.

Walpole *et al.* (1968, p. 89) considered that the Tolmer Group overlies the 'Victoria River Group' (now largely Auvergne Group). However, the relations they saw were between Cretaceous Mullaman Beds and Auvergne Group rocks. No contact between Auvergne and Tolmer Groups has been found. It is possible that the two groups are equivalent because the Depot Creek and Stray Creek Sandstone Members are somewhat similar to the Jasper Gorge Sandstone and Angalarri Siltstone respectively. However, the upper two formations of the Tolmer Group bear such strong similarity to the Bullita Group that a correlation with the latter is preferred.

Age and correlations of the Wattie, Bullita, and Tolmer Groups. The Wattie and Bullita Groups form a conformable sequence which is exposed in the southern and central Victoria River Basin. In the northern part of the basin the Tolmer Group crops out and is best exposed

TABLE 12. SUMMARY OF THE TOLMER GROUP STRATIGRAPHY

Unit	*Lithology*	*Thickness* (m)	*Stratigraphic relations*	*Physiographic expression*	*Remarks*
Waterbag Creek Formation	Sandstone, siltstone, dolomitic sandstone and dolomite	150-300+	Conformable on Hinde Dolomite. Unconformably below Antrim Plateau Volcanics	Low rounded hills and areas of low relief. Soft beds commonly covered by Cainozoic units	Halite casts common
Hinde Dolomite	Dolomite with interbeds of siltstone	120	Conformable between Waterbag Fmn and Stray Creek Sandstone Member	Low - relief areas usually with small sharp ridges cropping out on soil-covered interfluves. Outcrop poor	
Buldiva Sandstone Stray Creek Sandstone Member	Coarse siltstone and fine sandstone; coarser sandstone near base	180	Conformable between Hinde Dolomite and Depot Creek Sandstone Member	Softer beds; gentle slopes and low rises. Harder beds: cuestas	Commonly micaceous and glauconitic
Depot Creek Sandstone Member	Quartz sandstone with pebbly beds	300-600	Conformably below Stray Creek Sandstone Member. Unconformable on granite and Noltenius Fmn	Cliffs, plateaux, cuestas	Very well indurated

TABLE 13. RELATIONS BETWEEN THE WATTIE, BULLITA, AND TOLMER GROUPS

	Central Victoria River Basin		*Northern Victoria River Basin*
BULLITA GROUP	Banyan Formation Weaner Sandstone Bynoe Formation	TOLMER GROUP	Waterbag Creek Formation
	Skull Creek Formation Timber Creek Formation		Hinde Dolomite
WATTIE GROUP			Buldiva Sandstone Stray Creek Sandstone Member
			Depot Creek Sandstone Member

on the northwestern margin of the Daly River Basin. Between these outcrops of known groups is a series of siltstones and carbonates west of Dorisvale in the Fergusson River Sheet area. They were included by Randal (1962) in the Waterbag Creek Formation of the Tolmer Group, and by Pontifex & Mendum (1972) in the Bynoe and Banyan Formations of the Bullita Group. This is the basis of the correlation between the Waterbag Creek Formation and the Bynoe and Banyan Formations. This in turn has led to the conclusion that the Hinde Dolomite is probably equivalent to the main carbonate units in the Bullita Group (Timber Creek and Skull Creek Formations), and that the Buldiva Sandstone is equivalent to the Wattie Group. These proposed relations are shown in Table 13.

The Wattie, Bullita, and Tolmer Groups cannot be correlated with any rocks in either the Kimberley region or the McArthur Basin. Isotopic age determinations suggest equivalence to the Roper Group in the McArthur Basin, but lithologically the sequences are dissimilar, and the isotopic ages are not accurate enough to allow firm correlations.

The Wattie Group has been tentatively correlated with the Redcliff Pound Group in the Tanami region (Blake, Hodgson, & Muhling, 1973).

ADELAIDEAN

Wondoan Hill and Stubb Formations

The Wondoan Hill and Stubb Formations were included by Traves (1955) in the 'Victoria River Group' and by Laing & Allen (1956) in the 'Coolibah Formation'; both names have now been discarded. The 'Coolibah Formation' was subdivided into the Bynoe, Wondoan Hill, and Stubb Formations by Sweet *et al.* (1974b) who considered that the formations were separated by unconformities. A reappraisal of the mapping data suggests that the Wondoan Hill and Stubb Formations are conformable, and that the Stubb Formation is overlain unconformably by the Jasper Gorge Sandstone; the Stubb Formation is therefore excluded from the Auvergne Group.

The two formations consist of sandstone, siltstone, and shale (Table 14). Glauconite from the basal sandstone of the Wondoan Hill Formation, and brown mudstone from higher in the unit were used in the age determinations summarized in Appendix 1. The glauconitic sandstone was collected 17 km south of Victoria River Downs homestead, as were samples of a thin limestone bed containing cone-in-cone structures. Plate 15 illustrates the concentric pattern formed by the cones on a bedding plane.

Environments of deposition. If it is accepted that the Wondoan Hill and Stubb Formations represent one episode of sedimentation in the Victoria River Basin, it is apparent that they reflect a marine transgression followed by

TABLE 14. SUMMARY OF THE STRATIGRAPHY OF THE WONDOAN HILL AND STUBB FORMATIONS

Name	*Lithology*	*Thickness* (m)	*Stratigraphic relations*	*Physiographic expression*
Stubb Formation	Micaceous dark grey and purple shale and siltstone; sandstone interbeds near top	0-115	Conformable on Wondoan Hill Formation; unconformably below Jasper Gorge Sandstone	Smooth and vaguely terraced slopes; some cliffs capping mesas
Wondoan Hill Formation	Glauconitic and quartz sandstone; glauconitic siltstone, claystone, minor dolomitic siltstone	30-145	Unconformable on Bullita Group	Vaguely terraced slopes in mesas

Plate 15. Cone-in-cone structures in a thin limestone bed in the Wondoan Hill Formation. The concentric pattern results from differential weathering of calcite and thin films of clay which outline the cones about 15 km south of Victoria River Downs homestead. (GA/8008)

deposition in moderately deep water, and finally shoaling or uplift. Conglomeratic and glauconitic sandstone at the base of the Wondoan Hill Formation reflects the passage of the marine transgression, and the overlying mudstone and shale deposition in deeper water. Water-depth or sediment-supply fluctuations gave rise to a series of interbedded siltstones and sandstones. Reducing conditions during sedimentation may have caused organic carbon or sulphides to be incorporated in grey and black shale of the Stubb Formation. Mudcracks and ripple marks in sandstone beds indicate a return to shallow-water conditions and, finally, uplift and erosion caused removal of the Stubb Formation and part of the Wondoan Hill Formation in many areas.

Age and correlations. The only unit outside the Victoria River region that could be correlated with the Stubb Formation is the Mount John Shale Member of the Wade Creek Sandstone in the East Kimberley region. This conclusion was based on the firm correlation of the Jasper Gorge Sandstone with the Wade Creek Sandstone (see discussion on Auvergne Group).

Isotopic age determinations on mudstone from the upper part of the Wondoan Hill Formation yielded an age of 1431 + 440 m.y., and on glauconite from the basal sandstone ages of 1080 ± 14 m.y. (K-Ar method) and 1124-1190 m.y. (Rb-Sr method). For discussion of the age determinations see Appendix 1. Micaceous shale from the Stubb Formation yielded a Rb-Sr age of 1347 ± 150 m.y. The shale ages are not very useful because of the large error, and if the mica is detrital the age for the Stubb Formation may be too great. The glauconites ages, which may be slightly more reliable, are similar to a date of 1128 ± 110 m.y. obtained from shale in the Mount John Shale Member in the East Kimberley region (Dow & Gemuts, 1969).

Auvergne Group

The rocks now known as the Auvergne Group were included by Traves (1955) in the 'Victoria River Group', a term used to embrace almost all Precambrian rocks in the Victoria River region. Table 6 (p. 15) lists the terminology used by Randal (1962) and that described by Sweet *et al.* (1974b, 1974c), and used in this Bulletin. The stratigraphy of the Auvergne Group is summarized in Table 15.

The Jasper Gorge Sandstone, the basal formation of the group and also the most widely outcropping, is a product of a marine transgression through most of the region. Conglomerate (Pl. 16) and pebbly sandstone at the base of the formation closely reflect the erosional resistance of underlying formations: residual deposits derived from the relatively soft Stubb, Wondoan Hill, and Bynoe Formations

TABLE 15. SUMMARY OF THE AUVERGNE GROUP STRATIGRAPHY

Unit	*Lithology*	*Thickness* (m)	*Stratigraphic relations*	*Physiographic expression*	*Sedimentary structures*
Shoal Reach Formation	Sandy and silty dolomite with minor siltstone in S; siltstone with minor dolomite and sandstone in N	60-100	Conformable on Spencer Sst; disconformably below Bullo River Sst	Recessive weathering; forms smooth slopes where capped by resistant rocks	Small cross-beds, ripple marks, mudflakes, intraformational dolomite conglomerate
Spencer Sandstone	Fine quartzitic and dolomitic sandstone, silty sandstone	50-150	Conformable on Lloyd Creek Fmn	Basal sandstone forms resistant bench in scarps; remainder forms rounded terraced hills	Ripple marks, mud flakes, halite casts, glauconite
Lloyd Creek Formation	Siltstone; oolitic, sandy, silty, and stromatolitic dolomite	30-75	Conformable on Pinkerton Sst	Recessive weathering; forms smooth slopes capped by basal Spencer Sst	Ooids, stromatolites, halite casts
Pinkerton Sandstone	Fine and medium white orthoquartzite; minor siltstone and mudstone	50-100	Conformable on Saddle Creek Fmn	Resistant to erosion; forms ridges and plateaux bounded by cliffs	Small and medium cross-beds; ripple marks and mud flakes ubiquitous; some mud cracks
Saddle Creek Formation	Basal fine and medium clayey and quartzitic sandstone overlain by siltstone, oolitic dolomite, and minor shale	20-100	Conformable on Angalarri Sltst in all outcrops except one near Skinner Point where it is unconformable	Basal sandstone resistant, forms a bench in scarps; remainder is recessive weathering and forms vaguely terraced slopes	Basal sandstone contains large-scale cross-beds, slump and flammate structures, current lineations; mud flakes, ooids, glauconite, mud cracks and halite casts
Angalarri Siltstone	Greyish green siltstone and shale; minor sandstone, limestone, and dolomite	230+	Conformable on Jasper Gorge Sst	Recessive weathering; forms extensive plains and smooth slopes; resistant in S, forms cuestas and mesas	Large low-angle crossbeds in sandstone in south; many varieties of ripple marks, particularly interference and oscillation ones in Auvergne Sheet area; skip moulds
Jasper Gorge Sandstone	Medium quartz sandstone; minor siltstone and conglomerate	45-200	Unconformable on Stubb and Wondoan Hill Fmns and on Bullita and Limbunya Groups	Resistant to erosion; forms ridges and plateaux bounded by cliffs	Cross-bedding ubiquitous; ripple marks

Plate 16. Poorly sorted conglomerate at the base of the Jasper Gorge Sandstone. About 20 km south of Timber Creek. (M/796)

Plate 17. Newcastle Range, 1 km west of Timber Creek. The lower slopes of the scarp are Timber Creek Formation and the prominent cliff is the basal sandstone of the Jasper Gorge Sandstone. (GA/8833)

are virtually free of pebbles, but those derived from cherty dolomites are composed of massive breccias and pebble conglomerates (Pl. 16). Micaceous siltstone and strongly cross-bedded sandstone forming the upper part of the Jasper Gorge Sandstone are probably open-shelf deposits formed in slightly deeper water than the basal member; the strongly outcropping nature of the basal member is illustrated in Plate 17.

A thick siltstone and shale unit, the Angalarri Siltstone, conformably overlies the Jasper Gorge Sandstone; the contact, although photogeologically sharp, is lithologically gradational. The formation is 300 m or more thick throughout the area, and shows marked facies changes. In the Fergusson River, Delamere, and Auvergne Sheet areas the Angalarri Siltstone consists of a coarse siltstone-fine sandstone sequence overlain by a fine siltstone-shale sequence; glauconite is ubiquitous. Two prominent sandstone interbeds in the lower part near Mount Thymanan (Delamere Sheet area) are not present in the Auvergne Sheet area, and suggest a sediment source to the east or northeast. Farther southwest, in the Waterloo Sheet area, a marked facies change southwards into coarse siltstone and fine and medium sandstone can be traced. Extensive low-angle cross-beds are present in the sandstone. Dolomite and limestone interbeds, some capped by pyrite crystals, are present only in association with the finer siltstones and shales. The above factors indicate a marine basin of moderate depth, probably with strongly reducing conditions in the deeper portions, being supplied with fine sand, silt, and clay from sources in the south or southwest and the east or northeast.

Above the shales which constitute most of the upper part of the Angalarri Siltstone is several metres of thinly interbedded sandstone and siltstone which probably mark uplift and a return to shallow-water sedimentation. An unconformity between the Saddle Creek Formation and the Angalarri Siltstone 1 km north of Skinner Point indicates that some erosion occurred during the uplift, although the contact is conformable in most other localities. The five formations in sequence above the Angalarri Siltstone represent a period of sedimentation in shallow-water marine, lagoonal, and evaporitic (salt flat or sabkha) environments.

It can be seen from the accompanying 1:500 000 Sheet that these units form a northeast-trending belt up to 60 m wide roughly paralleling, and bounded to the northwest by, the Victoria River Fault. Within this belt the sediments are not of uniform thickness, particularly in the southwest and central Auvergne Sheet area where the Saddle Creek Formation and Pinkerton Sandstone thicken towards the Victoria River Fault.

Age and correlations. The first attempt to correlate East Kimberley and Victoria River region rocks was made by Wade (1924) who, on the basis of supposed trace fossils, called rocks in both areas the Mount John series. From his descriptions it appears that he was describing and correlating the Mount John Shale Member and Angalarri Siltstone, both of which contain peculiar sole markings on some beds. These have not been proved to be organic markings, and similar markings have been observed by the author in much older rocks of the South Nicholson Group in Queensland. Plate 18 depicts the markings seen on the base of a bed in the Angalarri Siltstone. They are best described as skip and prod casts because they are preserved in coarse siltstone and fine sandstone beds overlying the fine siltstone or shale beds. It is probable that they were caused by current scour of mud laminae.

Correlations between several formations in the Victoria River and East Kimberley regions are shown in Table 16. The most positive correlation is between the Angalarri and Helicopter Siltstones, which are virtually identical lithologically; it follows that the Jasper Gorge Sandstone is equivalent to the Wade Creek Sandstone. Dow & Gemuts (1969) discuss the evidence for an unconformity within the Wade Creek Sandstone at the top of the Mount John Shale Member. If an unconformity is present it strengthens the case for correlation of the Stubb and Wondoan Hill Formations with the lower Wade Creek Sandstone and Mount John Shale Member respectively and of the Jasper Gorge Sandstone with the upper part of the Wade Creek Sandstone (Table 16).

Isotopic dating on the Mount John Shale Member yielded an age of 1128 ± 110 m.y. (Dow & Gemuts, 1969). Similar determinations on the Wondoan Hill and Stubb Formations, yielding ages of 1431 ± 440, 1347 ± 150 m.y. respectively (Appendix 1), suggest, but do not provide conclusive evidence of, equivalence with at least the lower part of the Wade Creek Sandstone (including the Mount John Shale Member). Because the Angalarri Siltstone and Helicopter Siltstone are confidently correlated, the age of 838 ± 80 m.y. for the Angalarri (Appendix 1) is only feasible if a break exists in the East Kimberley sequence above the Mount John Shale Member.

Plate 18. Sole markings (skip casts) of unknown origin on the base of a fine sandstone bed in the Angalarri Siltstone. Victoria River highway crossing of the East Baines River. (GA/847)

Because the age of 838 ± 80 m.y. was based on limited information it should be viewed cautiously. The relations between the Auvergne Group and the Fitzmaurice and Carr Boyd Groups are discussed on page 56.

Bullo River Sandstone (including Black Point Sandstone Member)

The rocks now mapped as Bullo River Sandstone were first recognized as a separate unit by Perry (1967a). The unit is preserved only in the central and southwestern Auvergne Sheet area, where it overlies the Shoal Reach Formation, probably disconformably. It is overlain disconformably by the Duerdin Group, which in several localities fills valleys cut more than 100 m into the Bullo River Sandstone.

The Black Point Sandstone Member, which forms the basal part of the formation, crops out as a bench-forming feldspathic sandstone 45 to 60 m thick. It is better sorted, and less ferruginous than the remainder of the formation, and comprises medium sandstone, conglomeratic in the basal metre. The formation above the Black Point Sandstone Member consists of moderately to poorly sorted fine, medium and coarse ferruginous quartz sandstone with many pebbly lenses; cross-bedding is ubiquitous. Well rounded zircon and tourmaline grains indicate that the sandstone is probably a recycled sediment, and finely divided hematite colours the rock red.

Minor truncation of the Shoal Reach Formation by Bullo River Sandstone is seen in the southwestern Auvergne Sheet area, but in the central area near Bullo Gorge up to a metre of concretionary limonite is present at the contact. In the northeast the contact appears gradational and sedimentation may have been continuous, indicating uplift in the southwest (Fig. 6). A major time break between the Shoal Reach Formation and the Bullo River Sandstone is not envisaged; rather, marine and paralic sedimentation of the Auvergne Group was terminated by a combination of basin filling, lack of detritus, or mild uplift of the basin. Renewed uplift in the East Kimberley region led to erosion and consequent fluvial sedimentation.

Only two estimates have been made of the thicknesses of the Bullo River Sandstone, and both (300 m and 320 m) were made near the Victoria River Fault where the beds are almost vertical; elsewhere much of the formation has been removed by erosion.

Age and correlations. The Bullo River Sandstone is of similar age to the Auvergne Group (mid-Adelaidean) because it overlies the group conformably in the northeast and probably disconformably in the southwest. It has no known correlatives within the Sturt Block but Plumb & Derrick (1975) have suggested that it may be equivalent to the Stonewall and Lalngang Sandstones, both of which crop out in mobile zones northwest of the Sturt Block.

Big Knob Beds

The Big Knob Beds do not form a tabular continuous body of rock as do all the other stratigraphic units mapped, but consist of at least 130 separate knobs of massive silicified sandstone up to about 20 m high (Pl. 19); they have been given a formal name for ease of reference and are described more fully in Sweet *et al.* (1974c). Bedding is absent in most outcrops, but an ill defined gradation from ferruginous and micaceous sandstone upwards into conglomerate appears in some knobs.

The bases of most knobs are on Spencer Sandstone and Shoal Reach Formation, and the contacts are assumed to be unconformable.

EAST KIMBERLEY REGION		VICTORIA RIVER REGION	
HALLS CREEK MOBILE ZONE	STURT BLOCK		FITZMAURICE MOBILE ZONE
Pincombe Formation			Legune Formation
Stonewall Sandstone		Bullo River Sandstone	Laingang Sandstone
Glenhill Formation			
Lissadell Formation		Auvergne Group above Angalarri Siltstone	
Golden Gate Siltstone	Helicopter Siltstone	Angalarri Siltstone	Goobaieri Formation
Hensman Sandstone	Wade Creek Sandstone (upper part)	Jasper Gorge Sandstone	Moyle River Formation
	Mount John Shale Member	Stubb Formation	
	Wade Creek Sandstone (lower part)	Wondoan Hill Formation	

D52/A/234

TABLE 16. PROPOSED CORRELATIONS BETWEEN SEQUENCES IN THE EAST KIMBERLEY AND VICTORIA RIVER REGIONS.

Three origins for the Beds have been considered, but none can be proven:

(a) The knobs are similar to silicified blocks of Bullo River Sandstone, and could be blocks of that formation which were left behind as the present-day erosion cycle proceeded.

(b) Solution of dolomitic rocks in the Shoal Reach Formation could have given rise to caves which were filled with sediment (e.g. Bonte, 1963), most probably Bullo River Sandstone.

(c) Based on a slight similarity to some beds in the Ranford Formation, which is a periglacial deposit, it is possible that the Big Knob Beds may be glacial, that is they are remnants of eskers or kames.

It is possible that the Big Knob Beds are Adelaidean and related to either the Bullo River Sandstone or Ranford Formation, but this cannot be proved using the information presently available.

ADELAIDEAN

Duerdin Group

Precambrian glacial rocks were first reported from the Kimberley region by Guppy, Lindner, Rattigan, & Casey (1958) and Harms (1959), and have been more fully described by Dow (1965), Dow & Gemuts (1969), and Roberts, Gemuts, & Halligan (1972).

Dow & Gemuts (1969) described two major glaciations in the East Kimberley region and defined rocks representing the older as the Duerdin Group. Several formations can be traced northeastwards into the Auvergne Sheet area, and the East Kimberley nomenclature is therefore used (Table 17). A summary of the group stratigraphy is presented in Table 18. Tillite at Skinners Point is called Fargoo Tillite, although it is about 130 km northeast of the nearest outcrops in the East Kimberley region. The name is retained because of similar litho-

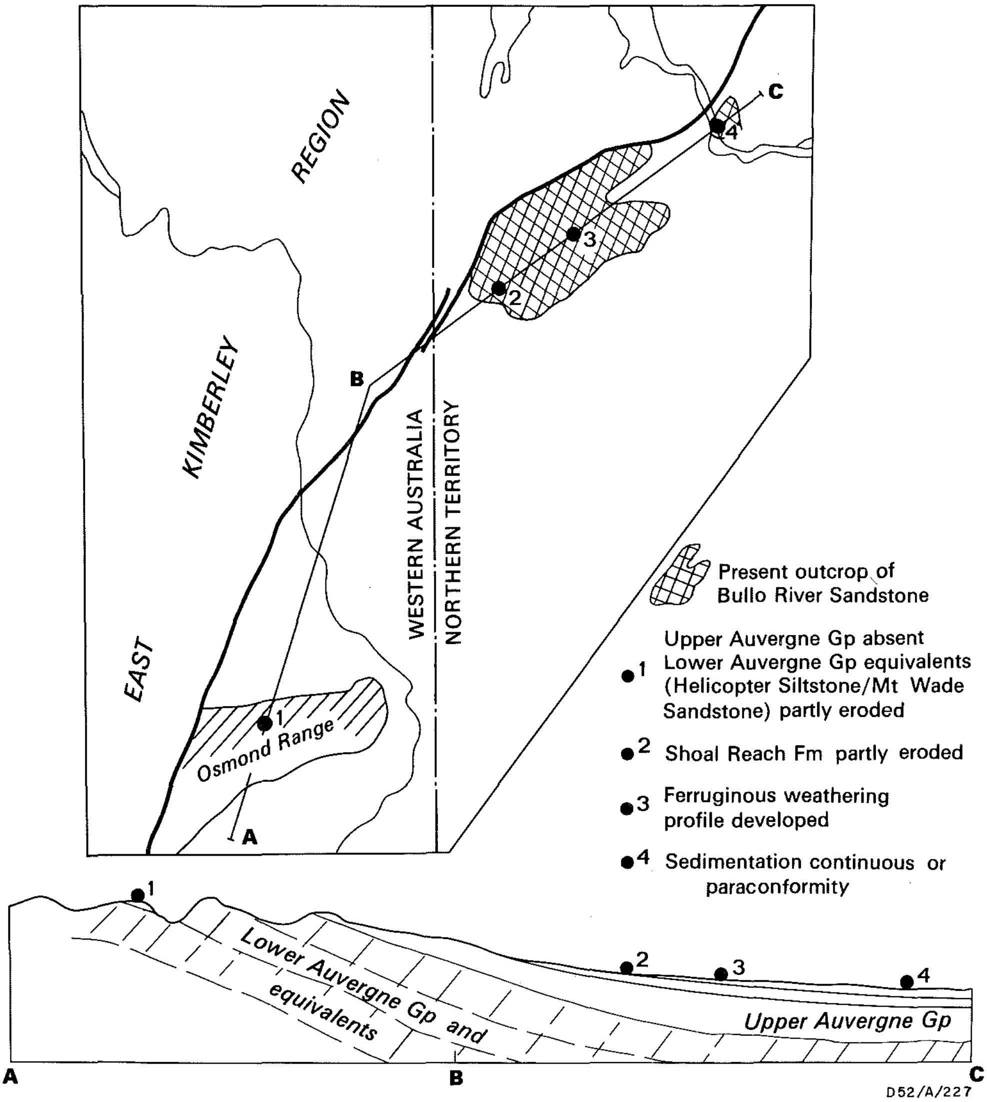

Fig. 6. Map and section showing the Bullo River Sandstone and its relations to underlying units. The East Kimberley region was the probable sediment source.

logy and stratigraphic relations. The Ranford Formation is divided into three new members in parts of the Auvergne Sheet area, but in some other outcrops Jarrad Sandstone and possibly Johnny Cake Shale Member are recognizable.

The presence of Duerdin Group in the Victoria River region was first noted by Perry (1966). Wade (1924) observed boulders of granitic gneiss in the Keep River at Newry and deduced that 'granitic gneiss outcrops to the S' (south) but the boulders were almost certainly erratics shed from nearby outcrops of Moonlight Valley Tillite.

Skinner Sandstone. The Skinner Sandstone, the basal unit of the Duerdin Group, forms three parallel, northeast-trending ridges (referred to as the northwestern, central, and southeastern ridges) between Newry and Auvergne homesteads. Overlain by tillite, it is considered to be a fluvial deposit derived from an earlier till, remnants of which are preserved beneath cliffs of Skinner Sandstone in the northwestern side of the Skinner Point mesa (which is part of the

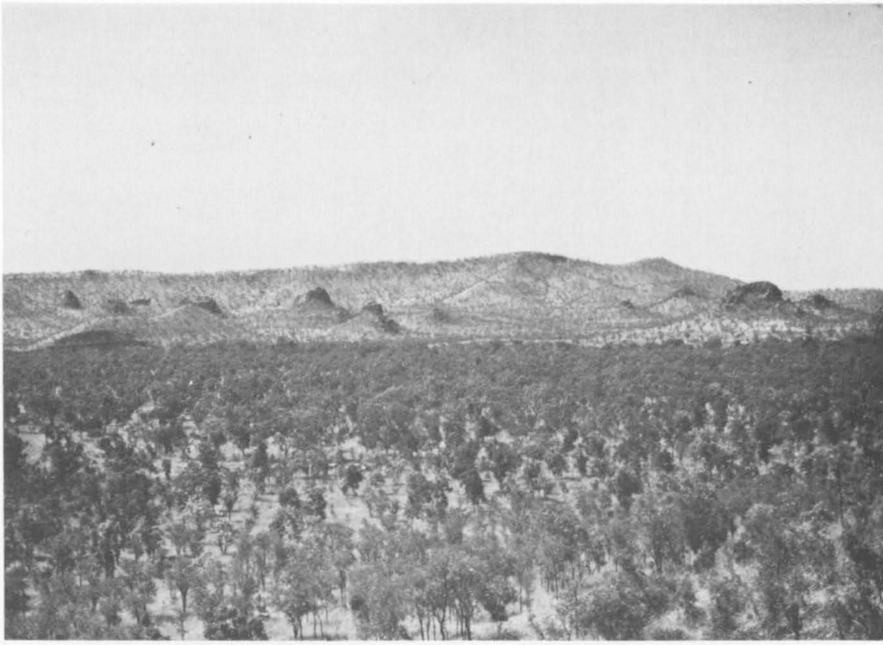

Plate 19. Big Knob Beds, 11 km south-southwest of Bullo Gorge, Auvergne Sheet area. (GA/527)

TABLE 17. NOMENCLATURE OF THE DUERDIN GROUP

<table>
<tr><th colspan="2">EAST KIMBERLEY REGION</th><th></th><th colspan="3">VICTORIA RIVER REGION</th></tr>
<tr><td rowspan="4">Ranford Formation</td><td rowspan="3">Johnny Cake Shale Member</td><td rowspan="8">DUERDIN GROUP</td><td rowspan="4">Ranford Formation</td><td rowspan="3"></td><td>Ernie Lagoon Member</td></tr>
<tr><td>Beasly Knob Member</td></tr>
<tr><td rowspan="2">Bucket Springs Member</td></tr>
<tr><td>Jarrad Sandstone Member</td><td>Jarrad Sandstone Member</td></tr>
<tr><td colspan="2">Moonlight Valley Tillite</td><td colspan="3">Moonlight Valley Tillite</td></tr>
<tr><td colspan="2">? HIATUS ?</td><td colspan="3">Blackfellow Creek Sandstone</td></tr>
<tr><td colspan="2">Frank River Sandstone</td><td colspan="3">? HIATUS ?</td></tr>
<tr><td colspan="2">Fargoo Tillite</td><td colspan="2">Fargoo Tillite</td><td>Skinner Sandstone</td></tr>
</table>

central ridge). The underlying Angalarri Siltstone has been ground up and incorporated in the lowermost metre of till and constitutes almost all of the pebbles and cobbles in the till. Clasts are difficult to identify because they and the matrix are of identical composition. Dolomite, quartzite, and other clasts are more common in a vaguely defined 1 to 2 m bed above the basal bed. The remainder of the Skinner Sandstone (the till is included in the unit for convenience) consists of medium-grained dolomitic quartz sandstone with pebbly lenses. In all three ridges some very massive conglomerate lenses contain clasts up to 1 m

TABLE 18. SUMMARY OF THE STRATIGRAPHY OF THE DUERDIN GROUP

	Unit	*Lithology*	*Maximum thickness* (m)	*Stratigraphic relations*	*Physiographic expression*	*Remarks*
RANFORD FORMATION	Ernie Lagoon Member	Quartz sandstone; minor grit and conglomerate interbeds	10	Conformable on Beasly Knob Member	Low steep scarps	Occupies central W Sheet area; youngest Precambrian unit
RANFORD FORMATION	Beasly Knob Member	Quartz sandstone, siltstone; minor pebble conglomerate and grit	130+ in SW	Conformable on Moonlight Valley Tillite. Overlaps onto Saddle Creek Fmn	Prominent hills	Occupies central W Sheet area. Correlation of outcrops in central W with those in SW not proved
RANFORD FORMATION	Bucket Spring Member	Siltstone, micaceous sandstone	55	Overlies Bullo River Sst	Low rounded hills or gently inclined talus slopes	Occupies central W Sheet area. Photo-pattern identical with Moonlight Valley Tillite
RANFORD FORMATION	Jarrad Sandstone Member	Sandstone	—	Overlies Moonlight Valley Tillite in W	Cuesta	Only one small outcrop identified
	Moonlight Valley Tillite	Mainly boulder tillite. Some conglomerate, sandstone, and siltstone. Pink laminated dolomite at top	130+	Overlies Auvergne Group and other older rocks with pronounced disconformity. Conformably below Ranford Fmn	Low rounded hills or gently inclined scarps where protected by hard caprock	Outcrop rare. Main key to recognition is thin pink dolomite band N of Hungry Billabong yard
	Blackfellow Creek Sandstone	Massive quartz sandstone; minor micaceous and conglomeratic sandstone	30+	Overlies Fargoo Tillite with minor unconformity	Flat mesa capping	Seen only in Skinner Point mesa
	Fargoo Tillite	Massive boulder tillite and coarse conglomerate containing dolomite clasts	160	Conformable on Skinner Sst	Smooth slopes on side of mesa	Seen only in Skinner Point mesa
	Skinner Sandstone	Cross-bedded quartz sandstone, pebbly sandstone; massive conglomerate, minor mudstone and tillite	60	Unconformable on Auvergne Group (generally over Angalarri Sltst)	Structural benches and low mesas	

across although most are 5 to 20 cm across; most clasts are grey crystalline dolomite, a few quartzite.

Fargoo Tillite. Dow & Gemuts (1969) described the Fargoo Tillite as a series of erosional remnants of true tillite unconformably overlain by Moonlight Valley Tillite, and containing a great variety of megaclasts, and lenses of conglomerate and dolomitic sandstone. Diamictite beds having similar stratigraphic relations form part of the Skinner Point mesa, and have been included in the Fargoo Tillite. The thickest section, 110 m at the northern end of the mesa, includes a 15-m lens of massive conglomerate. The tillite thins southwards and is absent in the southeastern ridge where Skinner Sandstone is overlain by Blackfellow Creek Sandstone. The thinning out of the tillite is interpreted as indicating an unconformity in the sequence. However, the thinning could be due to lensing of the till, an explanation supported by the presence of load casts at the base of the Blackfellow Creek Sandstone; these suggest that the till was soft and muddy, and that the sand sank into it. On the other hand, the even surface on which the overlying sandstone was deposited suggests it is more likely that the tillite was planed off before deposition of the sandstone.

Till-clast counts (Table 19) show that the vast majority of pebbles and cobbles in the tillite are grey crystalline dolomite. Some of the dolomite has a fetid odour when split, indicating the presence of organic compounds; some cobbles also contain stromatolites (Pl. 20).

Blackfellow Creek Sandstone. Known only from a restricted area at and south of Skinner Point, the Blackfellow Creek Sandstone differs from the Frank River Sandstone of the East Kimberley region in that it appears to be conformably overlain by Moonlight Valley Tillite (Table 17), and apparently lenses out in a southwesterly direction.

Moonlight Valley Tillite. The Moonlight Valley Tillite forms a thinner but more widespread veneer than the Fargoo Tillite. Because it is easily weathered, outcrops of the Moonlight Valley Tillite are rare, and the unit is generally recognized by the occurrence of rounded hills studded with smooth cobbles and boulders of quartzite. Till-clast counts (Table 19) in two outcrops proved that quartzite and sandstonc

TABLE 19. CLAST COUNTS ON TILLITES

Lithology of tillite clasts	Fargoo Tillite and tillite at the base of the Skinner Sandstone						Moonlight Valley Tillite			
	Skinner Point mesa (a)		(b)		(c)		35 km W of Skinner Point (d)		37 km W of Skinner Point (e)	
	Tillite at base of Skinner Sandstone		Near base of Fargoo Tillite		40 m above base of Fargoo Tillite		10 m above base of Tillite		5 m above base of Tillite	
	No. of clasts	*%*	*No. of clasts*	*%*	*No. of clasts*	*%*	*No. of clasts*	*%*	*No. of clasts*	*%*
Grey dolomite	51	72	22	44	32	84	16	26	1	2.3
Oolitic dolomite	7	9	2	4	1	3	—	—	—	—
Siltstone*	4	6	14	28	3	8	7	11	8	20
Chert	2	3	2	4	—	—	—	1.5	—	—
Claystone	1	1.5	—	—	—	—	—	—	—	—
Arkose	—	—	—	—	—	—	1	1.5	—	—
Quartzite† and sandstone	3	4	7	14	2	5	35	57	28	68
Granite and gneiss	2	3	—	—	—	—	1	1.5	1	2.3
Schist	—	—	1	2	—	—	—	—	1	2.3
Basic igneous	—	—	1	2	—	—	1	1.5	—	—
Quartz feldspar porphyry	1	1.5	1	2	—	—	—	—	—	—
Weathered igneous and metamorphic	—	—	—	—	—	—	—	—	2	5
TOTAL	71	100	50	100	38	100	62	100	41	100

* Includes dolomitic, micaceous, and quartz-rich varieties.
† A group of great diversity—includes pink, green, brown, and glauconitic, silicified, and non-silicified sandstone and meta-quartzite.

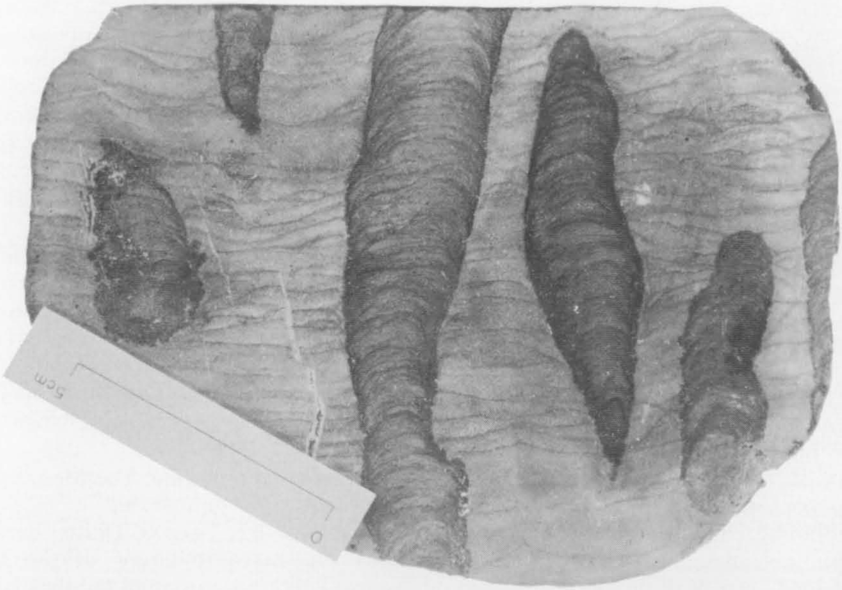

Plate 20. Polished slab of a laminated stromatolitic dolomite clast collected from the Fargoo Tillite at Skinner Point. The origin of this and similar clasts is not known. (GA/7998)

outnumber all other clast types. Although tillite does not crop out at Dingo Creek, rubble on the hillslope contains clasts including:

(a) a rounded boulder of pink feldspar granite at least 1.6 m across;

(b) a greyish brown dolomite boulder containing a stromatolite column up to 10 cm in diameter and 40 cm high; the boulder is more than 1 m across;

(c) several other boulders 1 to 2 m across, including one of well bedded, oolitic, partly silicified dolomite;

(d) a 1.5-m quartzite boulder with at least one strongly striated surface;

(e) cobbles and boulders of grey dolomite, sandstone, and quartzite of many kinds, fine-grained granite, gneiss, mica schist, conglomerate, and quartz feldspar porphyry.

This is the most diverse collection of clasts seen in any of the tillites in the Victoria River region, and is probably related to the proximity of the outcrop to the Halls Creek Mobile Zone which contains such a variety of rocks.

The Moonlight Valley Tillite at Dingo Creek and other areas is distinguished from the Fargoo Tillite by a distinctive laminated dolomite or limestone at the top of the unit (Pl. 21).

Ranford Formation. In the Victoria River region the Ranford Formation includes shale, siltstone, sandstone, and conglomerate and has been divided into four members (Tables 17 and 18). Dropped pebbles indicating a continuation of glaciation have not been seen within the region, but are reported from the East Kimberley region by Dow & Gemuts (1969). The Moonlight Valley Tillite, which is overlain by the Beasly Knob Member in the southwestern Auvergne Sheet area, apparently lenses out northeastwards because the oldest member of the Ranford Formation, the Bucket Spring Member, overlies the Bullo River Sandstone in the northeast. Two interpretations of the relations are possible (Fig. 7), and because two thin interbeds similar to the Bucket Spring Member are known from the northernmost outcrops of Moonlight Valley Tillite, the second interpretation is preferred.

The Jarrad Sandstone Member is reported by Dow & Gemuts (1969) to be 107 m thick at Mount Brooking, 53 km southwest of Newry homestead. It crops out 10 km east of Mount Brooking, but is absent at Dingo Creek, 6 km farther east, where the laminated dolomite at the top of the Moonlight Valley Tillite is directly overlain by purple and white ferruginous siltstone of the Ranford Formation. The siltstone is identical to the siltstone overlying the Jarrad Sandstone Member at Mount Brooking, where it is 61 m thick. The only three outcrops of Ranford Formation between Dingo

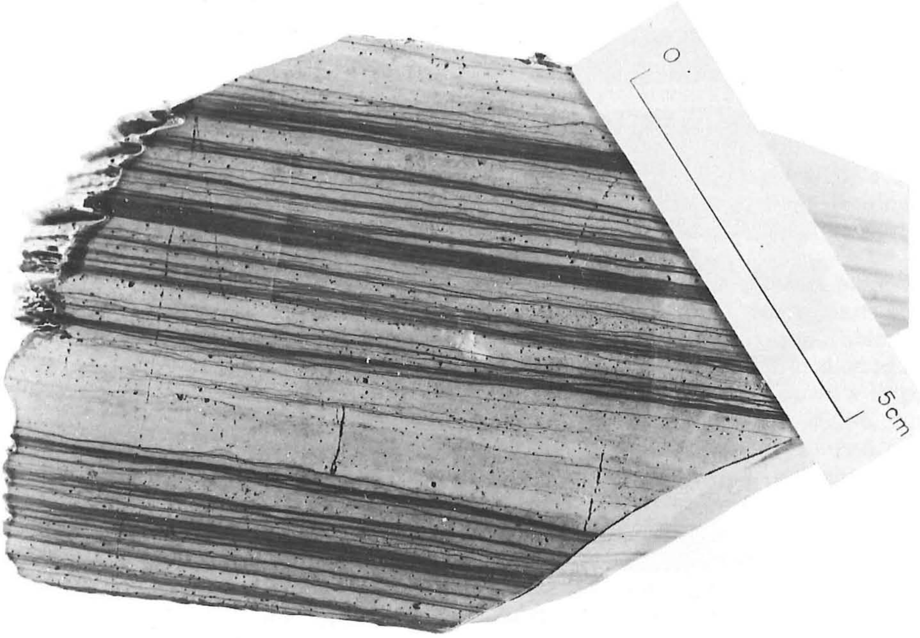

Plate 21. Varve-like laminae in dolomite from the top of the Moonlight Valley Tillite, about 10 km southeast of Newry homestead. (GA/8006)

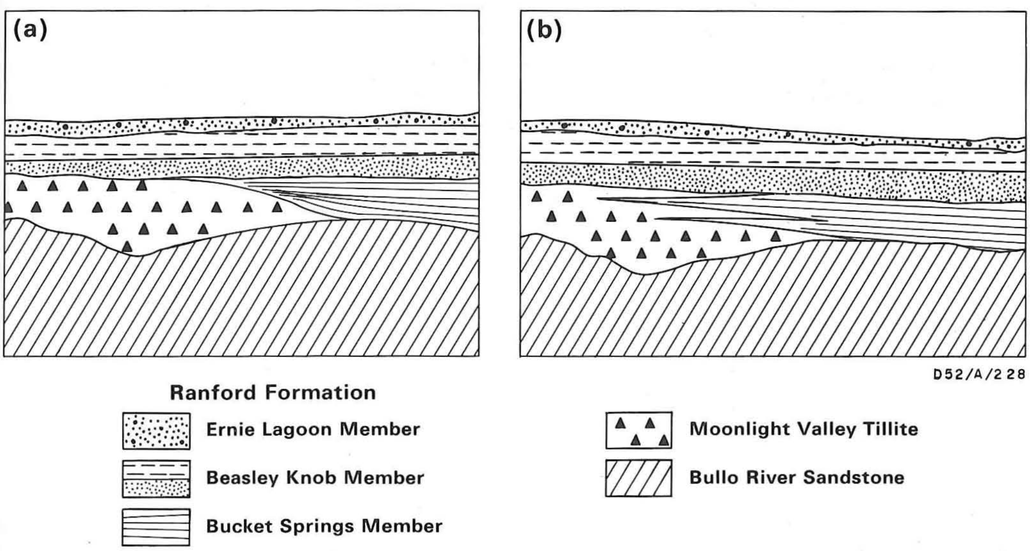

Fig. 7. Alternative explanations of relations: (a) that all the Ranford Formation units are younger than the Moonlight Valley Tillites; (b) that the lower Ranford Formation intertongues with the Moonlight Valley Tillite.

Creek and Skinner Point are purple siltstone; sandstone which overlies tillite in this region is thought to be Kinevans Sandstone, a younger unit unconformably overlying the Duerdin Group.

Apart from the Jarrad Sandstone, other members of the Ranford Formation have not been found in the Waterloo Sheet area. The ferruginous siltstone, however, bears a strong resemblance to siltstone in the upper part of

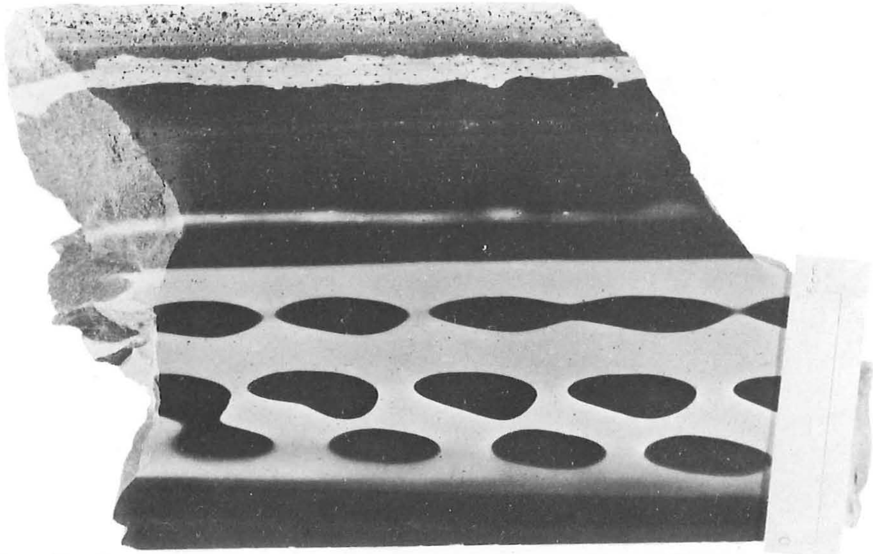

Plate 22. 'Zebra-stone' from the East Kimberley region, about 30 km west of Newry homestead, in the Lissadell Sheet area, Western Australia. (6A8005)

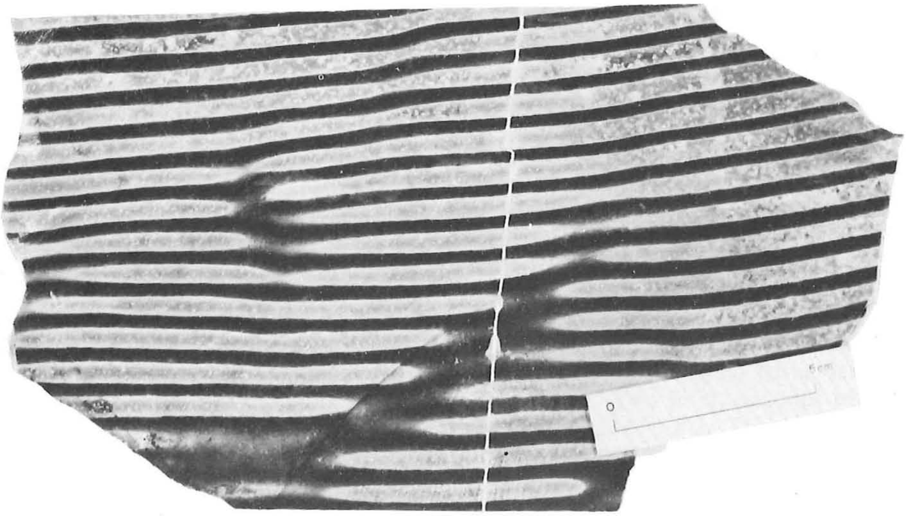

Plate 23. 'Zebra-stone' from the Victoria River region, about 40 km east of Newry homestead. (6A/8003)

the Beasly Knob Member. This suggests that the basal sandy unit of the Beasly Knob Member may be equivalent to the Jarrad Sandstone Member.

In both the Waterloo Sheet area and the East Kimberley region, the ferruginous siltstone contains a thin distinctive layer known as 'zebra-stone' (Pl. 22 and 23). This was first reported by Larcombe (1925, 1927), Blatchford (1928), and later by Hobson (1930). The rock is of uniform composition, and is a white clayey siltstone except for extremely regular patches of ferruginous siltstone. The peculiar pattern is probably due to an iron-leaching phenomenon, but the reasons for the manner in which it formed are unknown.

Recognition of glacial origin of Duerdin Group

Crowell (1957) warned of the danger of calling pebbly mudstone (diamictite) tillite unless supporting evidence is available. Dow

Plate 24. Fargoo Tillite in the Skinner Point mesa. Faint colour changes in the tillite such as that in the photograph may be bedding caused by a change from lodgement to ablation till deposition. (M/1049)

(1965) listed several features which are generally present in glaciated terrains and their associated sediments, and provides evidence in support of glacial origin for the East Kimberley diamictites. Most features listed by Dow are also present in the Victoria River outcrops of the Duerdin Group. Evidence in support that diamictites (Pl. 24) of the Duerdin Group are tillites include the following:

(a) *presence of very large erratics*—large erratics are common in the Moonlight Valley Tillite at Dingo Creek where several boulders exceed 2 m in diameter, but no boulders of the size Dow mentioned have been seen (i.e. 3-4 m). The Fargoo Tillite at Skinner Point contains very few large clasts; most clasts are of cobble size (64-256 mm).

(b) *great diversity of rock types*—Table 19 shows the most common rock types in the tillites. The nearest source of igneous and metamorphic rock is the Halls Creek Mobile Zone, and Moonlight Valley Tillite outcrops closest to it show the greatest diversity of rock types. Fargoo Tillite at Skinner Point, however, contains a high proportion (44-84%) of cobbles of grey crystalline and stromatolitic dolomite (e.g. Pl. 20). The dolomite is unlike any from the nearby Auvergne Group, and may have been derived from Bungle Bungle Dolomite, the nearest outcrops of which (during the late Adelaidean) would have been at least 100 km to the southwest.

(c) *polished and striated megaclasts* are common. Thirty-six of the 50 clasts counted at location b at Skinner Point (Table 19) were striated, and most were polished on at least part of their surfaces. Plate 25 shows a large cobble from the Moonlight Valley Tillite, which has been faceted, striated, and polished.

(d) *faceted or flat-iron-shaped megaclasts* (von Engel, 1930) such as that in Plate 25 are rare, and most clasts approach a flattened ellipsoidal shape (Pl. 26).

(e) *regional extent*—outcrops occur over a distance of more than 500 km in the East Kimberley and Victoria River regions.

(f) *polished and striated bedrock*—many pavements have been recognized in the West Kimberley and Kimberley Basin regions (Perry & Roberts, 1968), and one in the East Kimberley region. During this survey a second pavement was found in the East Kimberley, and one in the Victoria River region. The tillites overlie Angalarri Siltstone in much of the Victoria River region and pavements are not developed because of the softness of the shale and siltstone. The only pavement found was developed on the basal silicified sandstone of the Saddle Creek Formation.

Environment of deposition of the Duerdin Group

Dow & Gemuts (1969) discussed the depositional environment of the glacial rocks in the East Kimberley region. Two glaciations are represented, and the older Moonlight Valley glaciation extends into the Victoria River region. If the younger Egan glaciation was ever represented, all evidence has been removed by erosion.

Fargoo Tillite and Skinner Sandstone. These units are closely related, and it appears likely that the Skinner Sandstone is a large lens (or series of lenses) within a tillite mass, the lowest part of which is the thin remnant at the base of the Skinner Sandstone. Other lenses of cobble conglomerate within the Fargoo Tillite are of similar composition to, but are not as extensive as, the Skinner Sandstone. No evidence was found in support of the contention

Plate 25. Faceted, striated clast from the Moonlight Valley Tillite, southwestern Auverne Sheet area. (GA/849)

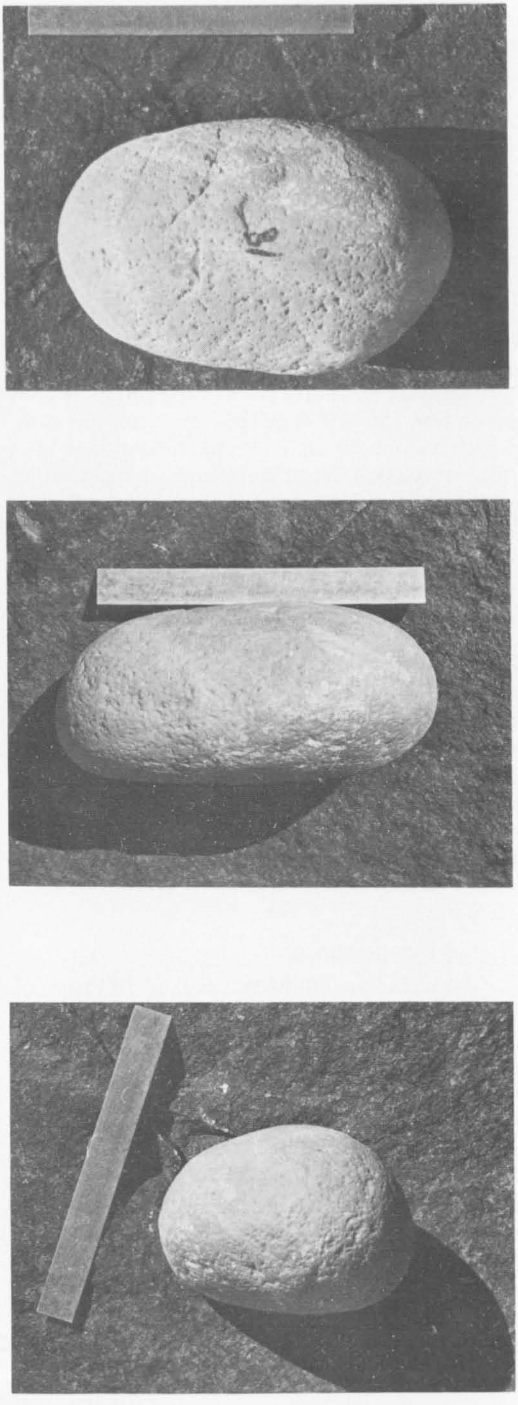

Plate 26. The most common shape of till clasts appears to approximate a tri-axial ellipsoid, or 'flattened ovoid'. Views along the three axes are shown above. Scale is a 6" (15.25 cm) rule. (M/1049)

of Dow & Gemuts (1969) that till was deposited in marine conditions from a melting glacier which had drifted from the landmass. In fact, there is strong evidence that sedimentation took place on land. The three northeast-trending ridges of Skinner Sandstone were deposited in valleys cut into the Auvergne Group, and Skinner Sandstone can be seen lapping onto the group at the northeasterly end of the northwestern ridge. Similarly, the central ridge at Skinner Point is flanked to the northwest by a plateau of Auvergne Group which must have formed the wall of a valley at least as high as the present-day topography (about 200 m), and probably much higher. It is apparent that the Skinner Sandstone is a fluvial deposit formed of outwash sand and gravel during a recessive phase of an early pulse of glaciation. Trough cross-bed sets more than 20 m wide are common, and consist of conglomeratic sandstone containing well rounded clasts of quartzite and dolomite. Cross-bed measurements on the northwestern ridge suggest a stream draining towards the southwest, but data from the central ridge are conflicting.

The preponderance of dolomite clasts in the tillite and sandstone seem to preclude a till derived from the northeast because the dolomite is unlike any found to the northeast. Similarly, an easterly or southeasterly provenance does not solve the problem because although the clasts resemble some of the Bullita Group dolomites, the latter were almost certainly concealed beneath Auvergne Group at the time of glaciation. Thus, the provenance is probably westerly or southwesterly, where Bungle Bungle Dolomite may have cropped out. This agrees with Dow & Gemuts (1969). Between Skinner Point and the Osmond Range much of the area now concealed beneath Antrim Plateau Volcanics was being eroded by the Fargoo ice sheet, and Bungle Bungle Dolomite and Auvergne Group could have been transported east or northeastwards.

I strongly disagree with the interpretation of Dow & Gemuts (op. cit.) that the conglomerate lenses in the tillite indicate marine deposition, as they are typical of continental deposits described by Flint (1971). On the western side of the Skinner Point mesa an irregular surface of tillite is overlain by massive conglomerate containing crude bedding dipping at up to 45° adjacent to a hump of tillite (Fig. 8). This obviously represents minor reworking of the uneven surface of moraine material, and not marine sedimentation.

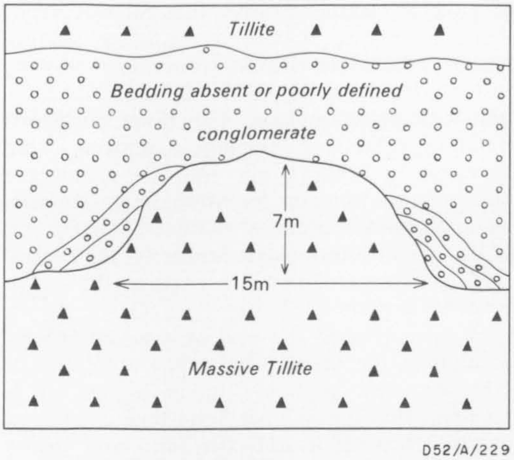

Fig. 8. Relation of tillite to conglomerate in the Fargoo Tillite.

Blackfellow Creek Sandstone. After deposition the Fargoo Tillite was partly eroded. The environment in which Blackfellow Creek Sandstone was laid down is not known because of a lack of diagnostic sedimentary structures in most exposures. Numerous flute casts, cross-bedding of pebbly sandstone, and thin mudstone beds at Skinner Point are not diagnostic.

Moonlight Valley Tillite. The Moonlight Valley Tillite was laid down unconformably on rocks of the Auvergne Group and Bullo River Sandstone except where it overlies (probably conformably) the Blackfellow Creek Sandstone southwest and south of Skinner Point. Only one pavement has been observed (54 km west-northwest of Skinner Point) and although grooves and striations are aligned at about 190°, the direction of ice movement cannot be deduced. However, in view of the parallelism of pavement striae with those in the Kimberley region (Perry & Roberts, 1968), it seems probable that the ice flowed from north to south. The presence of a large proportion of quartzite and sandstone clasts probably reflects the erosion of the Auvergne, Carr Boyd, and Fitzmaurice Groups which crop out to the north. A large clast of granite at Dingo Creek is probably Bow River Granite, and quartz feldspar porphyry is Whitewater Volcanics, both from the nearby Halls Creek Mobile Zone. The silicified oolitic dolomite at Dingo Creek could be locally derived Saddle Creek Formation, but the origin of the stromatolitic dolomite clast is unknown.

The Moonlight Valley Tillite must have been deposited from a grounded ice-sheet in order to produce striated bedrock. It cannot be said with certainty that the base of the ice was below sea level, but it seems probable that it was and that when the ice receded a thin layer of limestone or dolomite was laid down on top of the tillite. Although Dow & Gemuts (1969) state that the carbonate is dolomite, the specimen shown in Plate 21 is composed of calcite containing very thin laminae of clay minerals. It is very porous and may be a leached dolomite rather than a primary limestone. There must have been virtually no current activity when the limestone was laid down, and this indicates deep water, either in the sea or a lake. Sea water is necessary to give the required concentration of calcium and magnesium ions, which would be unlikely to accumulate in a lake developed from meltwater. If glaciation continued, as Dow and Gemuts suggest, it is strange that no erratics were dropped into the laminated dolomite by the melting of icebergs carrying moraine material.

Ranford Formation. Dow & Gemuts (op. cit.) consider that the Ranford Formation is a marine deposit, but none of its characteristics except carbonate content are necessarily indicators of a marine environment. It is an extensive unit, but is highly variable lithologically, a feature which could indicate either a marine or a lacustrine environment. Laminated ferruginous siltstone and claystone, and grit and pebble sandstone indicate a great range of water depths and current activity during sedimentation.

Age of the glaciation

Although thin mudstone beds at the base of the Skinner Sandstone may contain material suitable for Rb-Sr isotope dating, no dating has been attempted. Results quoted by Dow & Gemuts (1969) are from Bofinger (1967), and indicate that the Moonlight Valley glaciation probably took place about 700 m.y. ago. This figure is therefore accepted for the same units in the Victoria River region. The wider implications of this date have been recently discussed by Crawford & Daily (1971) and Dunn, Thomson & Rankama (1971).

Adelaidean or Lower Cambrian

Kinevans Sandstone

The Kinevans Sandstone lies with gentle angular unconformity on the Angalarri Siltstone, Moonlight Valley Tillite, and probably the Ranford Formation. Its upper contact with the Antrim Plateau Volcanics is concordant,

TABLE 20. SUMMARY OF THE STRATIGRAPHY OF THE HALLS CREEK MOBILE ZONE

Age		Unit	Lithology	Physiographic expression	Stratigraphic relations
CARPENTARIAN	Lamboo Complex	Bow River Granite	Coarse-grained and porphyritic biotite granite	Boulders or piles of boulders lying on soil plain	Contacts rarely exposed. Intrudes Whitewater Volcanics and Halls Creek Group in Kimberley region. Unconformably below Moyle River Fmn
		Whitewater Volcanics	Acid lavas, tuffs, intrusive quartz-feldspar porphyry	Low rounded hillocks with little outcrop	Overlain by probable Legune Fmn. Overlies Halls Creek Group unconformably and intruded by Bow River Granite
ARCHAEAN OR LOWER PROTEROZOIC		Halls Creek Group	Chlorite and mica schist and phyllite, andalusite schist	Dissected ridges with little outcrop	Unconformably below probable Legune Fmn; intruded by Bow River Granite

and quite possibly conformable. Its age is unknown, and in view of the uncertainty of the age of the Antrim Plateau Volcanics, it is considered to be late Adelaidean or early Cambrian. The unit is a thin sheet of sandstone 1 to 15 m thick, and is generally a well sorted, friable quartz sandstone (Sweet *et al.*, 1974a).

Antrim Plateau Volcanics

The Antrim Plateau Volcanics and similar tholeiitic basic volcanics of late Adelaidean or early Cambrian age (not conclusively proven) are described in detail by Bultitude (1976).

HALLS CREEK MOBILE ZONE

The Halls Creek Mobile Zone was defined as an intensely deformed belt of rocks extending from near Halls Creek township in the East Kimberley region to near Darwin (Traves, 1955). The term Fitzmaurice Mobile Zone replaces Halls Creek Mobile Zone for that part of the belt containing the Adelaidean Fitzmaurice Group.

Rocks of the Halls Creek Mobile Zone occur only in the southwestern part of the Auvergne Sheet area, and include isolated outcrops of Halls Creek Group, Whitewater Volcanics, and Bow River Granite (Table 20).

Nearly all of the Mobile Zone within the map Sheet area is occupied by Adelaidean unstable-platform arenites, the Fitzmaurice Group. The Fitzmaurice Group rests unconformably in the north on rocks of the Pine Creek Geosyncline and the Litchfield Block.

ARCHAEAN AND LOWER PROTEROZOIC

Halls Creek Group

In its type area in the East Kimberley region the Halls Creek Group consists of a thick sequence of basic volcanics, greywacke, and siltstone (Dow & Gemuts, 1969) which has been strongly folded and metamorphosed. Only a small fault-bound sliver (about 35 km by 7 km) of the group extends northeastwards into the Victoria River region, where its relations to other rock units are not clear. The rocks are chloritic and sericitic phyllites and schists containing some biotite and andalusite. Field relations in the adjoining Cambridge Gulf Sheet area indicate that they are intruded by Bow River Granite, and although contacts are soil-covered in the Victoria River region the same relation is assumed.

High-grade metamorphic equivalents of the Halls Creek Group (Tickalara Metamorphics) have been reliably dated at about 1960 m.y. (Bofinger, 1967). This date represents the age of regional metamorphism and formation of migmatite and granite, and indicates a younger limit for the depositional age of the Halls Creek Group. Accepting the Dunn *et al.* (1966) Proterozoic-Archaean boundary at 2200 to 2250 m.y., it is possible that much or all of the Halls Creek Group could have been laid down in early Lower Proterozoic time. Bofinger (op. cit.) obtained an age of 2700 m.y. for a pegmatite intruding Halls Creek Group. However, there are many uncertainties involved in deriving this age—the date from the Tickalara

Metamorphics should probably be regarded as more meaningful.

Whitewater Volcanics and Bow River Granite (Table 20)

Both Whitewater Volcanics and Bow River Granite crop out extensively in the East Kimberley region, where their relations are much more apparent than in the Victoria River region. The Whitewater Volcanics were thought to be of Carpentarian age (Dow & Gemuts, 1969), but Plumb & Derrick (1975) quoted ages of 1823 ± 17 m.y. for the volcanics in the East Kimberley (from Bofinger, 1967) and 1940 ± 110 m.y. for similar rocks in the West Kimberley (from Bennett & Gellatly, 1970).

The Whitewater Volcanics consist of uniformly greyish green and reddish brown quartz-feldspar porphyry, which probably includes both lavas and intrusive bodies (Sweet *et al.*, 1974c).

The Bow River Granite, which crops out over an area of about 20 km^2 in the south-western part of the Mobile Zone in the Victoria River region, consists of coarse-grained porphyritic biotite granite. It intrudes Whitewater Volcanics in the East Kimberley region (Dow & Gemuts, 1969) and has yielded a Rb-Sr isochron of 1854 ± 14 m.y.

Three small outcrops of highly weathered granite in the Fitzmaurice Mobile Zone adjacent to the Victoria River Fault, about 75 km northeast of known Bow River Granite, are tentatively included in that unit. The outcrops are midway between basement rocks of the Halls Creek Mobile Zone and outliers of the Pine Creek Geosyncline, and indicate that basement may occur at shallow depths along the Victoria River Fault.

LITCHFIELD BLOCK

The Litchfield Block is an area of metamorphic and igneous rocks west of the main Pine Creek Geosyncline, and bounds the Fitzmaurice Mobile Zone to the north. The block was formerly included in the Halls Creek Mobile Zone by Traves (1955) but designated Litchfield Block on the Tectonic Map of Australia (GSA, 1971). Two major units crop out within the block: the Hermit Creek Metamorphics and the Litchfield Complex.

ARCHAEAN AND LOWER PROTEROZOIC

Hermit Creek Metamorphics (Table 21)

Schist, gneiss, and quartzite thought to be older than Pine Creek Geosyncline rocks were first recognized southwest of the Daly River in 1955 and described by Randal (1962) and Malone (1962). Randal regarded them as Archaean on the basis of '. . . the structural and metamorphic unconformity between them and the Lower Proterozoic rocks of the Pine Creek Geosyncline'. The rocks are poorly exposed and no contacts were observed, but Walpole *et al.* (1968) stated that structural trends 'mostly strike west' (i.e. almost normal to fold and fault directions in nearby Lower Proterozoic rocks), and that the sedimentary and structural record suggests the presence of basement. Mapping in 1968 showed that neither reason is completely valid for some parts of the region: structural trends are *parallel* to those in Lower Proterozoic rocks in the Port Keats and Cape Scott Sheet areas, and parts of the Litchfield Complex, which intrudes Hermit Creek Metamorphics, have been dated at 1560 to 1605 m.y. by K-Ar measurements on micas (Hurley, Fisher, Pinson, & Fairbairn, 1961). These ages must be regarded as minimum values.

Because of the vagueness of the evidence that the Hermit Creek Metamorphics are Archaean, the initial impression is that they might be Lower Proterozoic rocks which had been subjected to a higher grade of metamorphism. However, two unconformable contacts have been found where Noltenius Formation overlies both the Hermit Creek Metamorphics and Litchfield Complex (Sweet *et al.*, 1974b; C. P. Cameron, pers. comm.). In addition, the metamorphic history of the Hermit Creek Metamorphics is more complex than that of the Noltenius and younger formations. Both pelitic sediments and basic and ultrabasic intrusives in the Hermit Creek Metamorphics have been metamorphosed to amphibolite facies and subsequently retrograded to greenschist facies (Mendum, 1972; Sweet *et al.*, 1974b). The second event probably coincided with prograde metamorphism of the Pine Creek Geosyncline rocks.

Richards, Berry, & Rhodes (1966) reported an age of 2500 to 2550 m.y. for zircons (isotope dilution U-Pb ages) from the Rum Jungle Complex which forms basement to Pine Creek Geosyncline rocks 100 km northeast of the nearest Hermit Creek Metamorphics. Richards & Rhodes (1967) subsequently dated the Complex by the Rb-Sr method and obtained a total-rock isochron age of 2400 m.y. These ages of basement igneous rocks are the only indication that basement metasediments must be at least 2400 m.y. old, and perhaps much older. The

TABLE 21. SUMMARY OF THE ARCHAEAN AND LOWER PROTEROZOIC STRATIGRAPHY

Age	*Unit*	*Thickness* (m)	*Lithology**	*Physiographic* expression*	*Distribution**	*Stratigraphic relations*
LOWER PROTEROZOIC	Henschke Breccia	1000	Coarse ferruginous sedimentary breccia and conglomerate with quartz fragments. Some sandstone interbeds	Massive rugged hills and ridges	Around Henschke Falls in N *Port Keats*	Unconformable below Moyle River Formation. May intertongue with Chilling Sst and Noltenius Fmn
	Chilling Sandstone	4800	White blocky and massive medium quartz sandstone; minor tuff	High rugged ridges and plateaux	N margin of *Port Keats* and *Fergusson River* and NW of Meeway Plain	Conformable on Noltenius Fmn (intertonguing). Intruded by Koolendong Granite, basic sills, and granophyre. Overlain by Meeway Volcanics
	Meeway Volcanics	1700	Porphyritic rhyolite and dacite, tuff, sandy tuff, some outcrops intensely sheared	Lavas form high rounded tors. Tuffs form rugged angular hills and steep slopes below sandstone units	W and NW of Meeway Plain and W of Koolendong Valley	Conformable on and intertongues with Chilling Sst. Unconformable below Moyle River Fmn
	Berinka Volcanics	840 min	Porphyritic grey rhyolite and dacite and minor acid intrusives in *Port Keats*. Tuff, agglomerate, rhyolite, altered spherulitic acid volcanics and amygdaloidal intermediate flows in *Fergusson River*	Very rugged hills and ridges in *Fergusson River*. Form valleys with gently undulating floor in *Port Keats*	NE *Port Keats* and NW corner *Fergusson River*	Interbedded with Noltenius Fmn, some sills
	Noltenius Formation	4200	Low-grade metamorphosed siltstone, greywacke, sandstone, conglomerate. Aureoles adjacent to granite	Extremely rough country. Ridges, angular hills. Some low-lying rough country	In N between *Port Keats* and *Fergusson River*. N of Collia Waterhole. In valleys W of Meeway Plain	Unconformable on Hermit Creek Metamorphics. Conformable below Chilling Sst. Intruded by granophyre, basic sills, Berinka Volcanics, granites
	Burrell Creek Formation		Massive grey-brown medium quartz greywacke, siltstone, and phyllite	Rugged hills	NE *Fergusson River*	Lateral equivalent of lower part of Noltenius Fmn
	Litchfield Complex		Coarse even-grained biotite granite, adamellite, granodiorite, tonalite, pegmatite. More acid towards W *Port Keats*. Garnetiferous in *Fergusson River*. Mafic xenoliths abundant. Migmatitic zones at contacts with Hermit Creek Metamorphics	Boulder piles on flat soil plains. Few rough hills up to 100 m high	NW *Fergusson River*, NE *Port Keats*, E *Cape Scott*	Intrudes Hermit Creek Metamorphics and probably basic sills. Unconformably below Moyle River Fmn
ARCHAEAN OR LOWER PROTEROZOIC	Hermit Creek Metamorphics		Ferruginous quartz-muscovite schist and phyllite. Tremolite schist, amphibolite, and serpentinite are believed to be metamorphosed basic and ultrabasic igneous rocks	Plains of low relief with little outcrop. Few low hills	NE *Port Keats* and SE *Cape Scott*	Intruded by Litchfield Complex and basic sills and dykes. Unconformably below Noltenius Fmn

* Sheet areas in italics.

Hermit Creek Metamorphics, which are assumed to be of similar age to metasediments in the Rum Jungle Complex, are thus probably more than 2400 m.y. old, and therefore Archaean.

Litchfield Complex

The name Litchfield Complex was first used by Malone (1962) and Randal (1962), who revised Noakes's (1949) nomenclature of Mount Litchfield Granite to describe all the granitic rocks on the western margin of the Pine Creek Geosyncline. Walpole *et al.* (1968) described the three main outcrops of the complex and reached the conclusion that both pre-Pine Creek Geosyncline and post-Pine Creek Geosyncline phases may be present.

Descriptions of the parts of the complex examined during the Victoria River region survey are given by Sweet *et al.* (1974b), who stated that it ranges from a leucocratic biotite granite to a melanocratic garnetiferous granodiorite, and is surrounded by migmatites and pegmatites.

The Litchfield Complex is overlain nonconformably by the Noltenius Formation; the contact is exposed 28 km east of Tom Turners Crossing (C. P. Cameron, pers. comm.). This is the first positive evidence that the Litchfield Complex contains phases which antedate sedimentation in the Pine Creek Geosyncline, although on the basis of its relation to the Hermit Creek Metamorphics this was suspected by Walpole *et al.* (1968) and Mendum (1972). Opposing evidence is provided by its probable intrusive relations with dolerite and gabbro and by various isotopic age determinations.

The dolerite and gabbro are similar to basic rocks which intrude the Finniss River Group, and are probably Lower Proterozoic or younger. They are unlike tremolite schist, amphibolite, and serpentinite in the Hermit Creek Metamorphics which are interpreted as basic and ultrabasic rocks of Archaean age.

The first isotopic age determinations on the Litchfield Complex were carried out on mineral separates, and yielded values of 1560 to 1630 m.y. (Hurley *et al.*, 1961). Rb-Sr whole-rock determinations of Leggo (*in* Walpole *et al.*, 1968) are quoted as 1760 m.y., but Compston & Arriens (1968) quoted a reassessed age as about 1800 m.y.

It therefore seems likely that part of the Litchfield Complex is a migmatitic complex of Archaean age, and intrudes only Hermit Creek Metamorphics. Other granites mapped as Litchfield Complex may be about 1800 m.y. old, and belong to the suite of granites which intruded the Pine Creek Geosyncline at that time.

PINE CREEK GEOSYNCLINE

Lower Proterozoic

All the Lower Proterozoic rocks examined in the northeast belong to the Pine Creek Geosyncline sequence and its associated intrusives (Tables 21, 22), and most were previously described by Walpole *et al.* (1968); only three new units are described. No new information is available on the age or duration of sedimentation in the Pine Creek Geosyncline, but the position of its western margin is now regarded as being farther southwest than envisaged by Walpole.

Greywacke and conglomerate (Noltenius Formation), acid volcanics (Meeway Volcanics), and granite have been mapped adjacent to the Fitzmaurice River, 70 km farther southwest than outcrops of similar rocks described by Walpole *et al.* (1968). Their presence indicates that the stable tectonic province ('Chilling Platform') proposed by Walpole *et al.* either did not exist or was farther west. Because most of the rocks which supposedly formed the 'Chilling Platform' are now known to be Adelaidean (Fitzmaurice Group) and not Lower Proterozoic, it is unlikely that any evidence remains to prove the existence of such a platform. The only large area underlain by Chilling Sandstone is immediately southwest of Fletchers Gully, and the area of outcrop (250 km^2) is insufficient on which to base the argument for a large platform.

Finniss River Group

A description of the Lower Proterozoic units is summarized in Table 21, and has been discussed in more detail by Sweet *et al.* (1974b). The Burrell Creek Formation was not examined, but Walpole *et al.* (1968) suggested that it intertongues with the Noltenius Formation. The Berinka Volcanics were previously known from only one outcrop in the Fergusson River Sheet area (Randal, 1962) where they overlie Noltenius Formation. During the course of this survey several outcrops were found in the Port Keats Sheet area, where they are overlain by Noltenius Formation, and in another outcrop volcanics appear to be surrounded by Chilling Sandstone. Similar volcanics north and south of the Fitzmaurice River, and named the Meeway Volcanics (Morgan, 1972), overlie Chilling Sandstone in one outcrop, and may overlie it in another. It thus appears that the volcanics consist either of a series of lenticular

TABLE 22. LOWER PROTEROZOIC IGNEOUS ROCKS

Rock unit	*Lithology*	*Physiographic expression*	*Distribution**	*Stratigraphic relation*
Edith River Volcanics	Coarse porphyritic dacite and rhyodacite, and related intrusives	Rugged hills and ridges	NE *Fergusson River*	Dykes in Cullen Granite and overlying flows 105 m thick
Allia Creek Granite	Medium to coarse porphyritic biotite-muscovite adamellite, granodiorite, tonalite	Soil plain with sporadic piles of boulders. Rough slopes below sandstone cappings	NW *Fergusson River*	Intrudes Noltenius Fmn. Unconformably below Depot Creek Sandstone Member of Buldiva Sst
Cullen Granite	Medium and even-grained biotite granite; coarse porphyritic biotite-hornblende granite and adamellite; syenite differentiates	Soil plain with sporadic outcrops	NE *Fergusson River*	Intrudes Burrell Creek Fmn. Intruded by Edith River Volcanics
Koolendong Granite	Even-grained and minor porphyritic coarse biotite and biotite-hornblende granite, adamellite, granodiorite	Pavements and boulder piles in soil plains. Rough slopes below sandstone cappings	W of Koolendong Valley and Meeway Plain, and in valleys NW of Meeway Plain	Intrudes Noltenius Fmn and Chilling Sst. Unconformably below Moyle River Fmn. Adamellite intrudes granodiorite in S
Soldiers Creek Granite	Porphyritic, even-grained coarse muscovite-biotite granite and adamellite. Numerous greisen and pegmatite veins. Cassiterite and tourmaline in greisen	Rugged hills up to 100 m high separated by soil plains	N of Collia Waterhole in *Fergusson River*	Intrudes Chilling Sst and Noltenius Fmn and contains Noltenius roof pendants. Unconformably below Depot Creek Sandstone Member of Buldiva Sst and Antrim Plateau Volcanics
Ti-Tree Granophyre	Pink or grey medium mesocratic granophyre	Forms valleys in sequences it intrudes. Outcrop restricted to few small piles of boulders	32 km E of Tom Turners Crossing, 24 km SW of Fletchers Gully mine	Sills up to 300 m thick in Noltenius Fmn and between Noltenius Fmn, and Chilling Sst. Most relations concordant
Basic and intermediate sills and dykes	Medium and coarse quartz diorite, and gabbro dolerite. Some chalcopyrite traces	Low boulder-strewn hills	NE *Port Keats* and NW *Fergusson River;* 8 km NW and SW of Tom Turners Crossing, 19 km SW of Hermit Hill	Intrudes Hermit Creek Metamorphics, Noltenius Fmn, and Chilling Sst. Unconformably below Moyle River Fmn. Probably intruded by Litchfield Complex

* Sheet areas in italics.

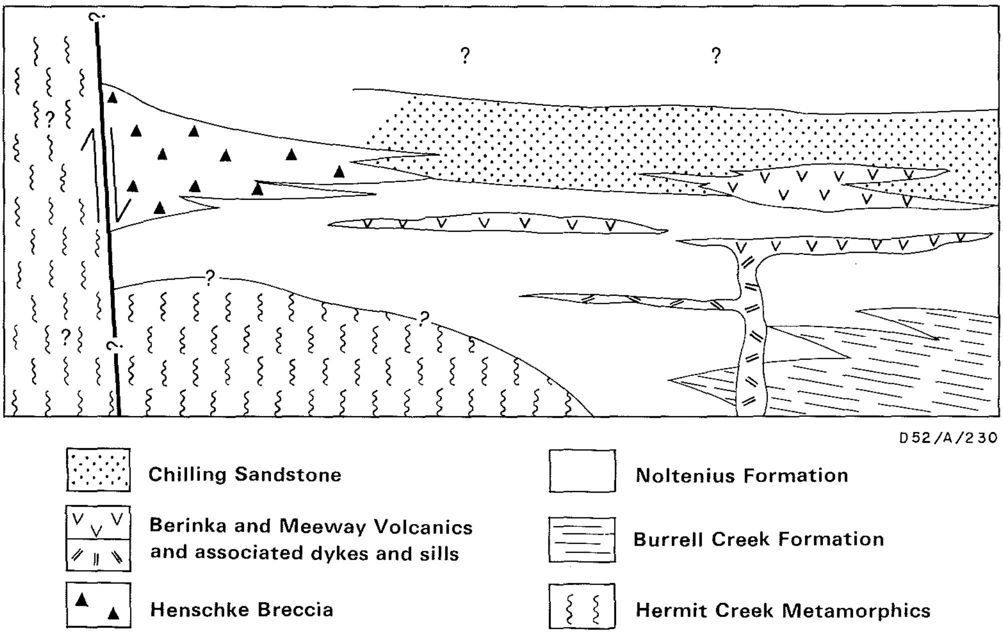

Fig. 9. Diagrammatic representation of relations between units in the Pine Creek Geosyncline.

flows, or that they intertongue with the sedimentary units. Because of their probable relation to the Berinka Volcanics, the Meeway Volcanics are included in the Finniss River Group. Altered sills within the Noltenius Formation are of similar composition to the Berinka Volcanics, and are included in them.

The Chilling Sandstone overlies the Noltenius Formation, and although it may interfinger with it in some places as suggested by Walpole *et al.* (1968), no evidence of this was seen in the field. The tongues and lenses of Chilling Sandstone shown on the Katherine-Darwin 1:500 000 Sheet (BMR, 1967) are fault-bounded outcrops, not tongues. However, minor tongues of sandstone interfingering with the Noltenius Formation near Fletchers Gully can be recognized on aerial photographs.

The contact between the Henschke Breccia and the Moyle River Formation is an angular unconformity; all its other contacts are faulted. It appears to grade eastwards into cross-bedded conglomeratic quartz sandstone, and contains at least one phyllite interbed, and thus it is thought that the Henschke Breccia is related to the Finniss River Group. It may be a wedge of breccia eroded from a fault west of its present outcrops.

The stratigraphic relations discussed above are represented diagrammatically in Figure 9.

Igneous rocks (Table 22)

Two main groups of igneous rocks intruding the Finniss River Group are described by Sweet *et al.* (1974b). They are basic and intermediate dykes, sills and stocks, and associated granophyres, and larger masses of mainly granitic composition.

Basic and intermediate intrusives. These rocks are probably part of a suite of rocks found throughout the Katherine-Darwin region and described by Bryan (1962) and Walpole *et al.* (1968). Only one of the outcrops in the northern Victoria River region was studied by Bryan, the remainder being beyond the margins of his survey area.

Six outcrops of dolerite, gabbro, and diorite were mapped, and of these only one has clearly intrusive relations with the Noltenius Formation. One other body, adjacent to the Soldiers Creek Granite, may intrude the Noltenius Formation, but the other four are surrounded by granite of the Litchfield Complex, to which their relation is unclear. It is not known whether the granite phases are Archaean or Lower Proterozoic, and the age of the basic rocks is therefore unclear. Because the Hermit Creek Metamorphics contain strongly metamorphosed basic and ultrabasic rocks, it is thought that the relatively unaltered basic rocks are probably Lower Proterozoic; that is, of similar age to the basic rocks described by Bryan (1962) and Walpole *et al.* (1968) elsewhere in the region.

Ti-Tree Granophyre. The Ti-Tree Granophyre is one of only two igneous intrusions named during the Victoria River region survey. The largest outcrop is in the form of a stock about 30 km^2 in area 37 km west-northwest of Collia Waterhole, but sills of similar composition intruding the Noltenius Formation 15 km farther west are included in the unit. Granophyre included by Walpole *et al.* (1968) in the Berinka Volcanics appears to intrude nearby gabbro, and has been included by Sweet *et al.* (1974b) in the Ti-Tree Granophyre. The granophyres are believed to be late-stage differentiates from the basic rocks, and their relation to the Finniss River Group makes it likely that the basic rocks also intrude that group.

Granitic intrusives. The only granitic rocks found during the Victoria River region survey which were not previously described by Walpole *et al.* (1968) are the rocks intruding probable Noltenius Formation near the Fitzmaurice River and called by Sweet *et al.* (1974b) the Koolendong Granite. The Soldiers Creek, Allia Creek, and Cullen Granites (Table 21) were only briefly examined as they have been described in detail by Walpole *et al.* (op. cit.).

The Koolendong Granite comprises leucocratic granite, biotite granodiorite, and a later phase consisting of leucocratic adamellite. Its contacts with the Noltenius Formation are sharp and discordant, and it is probably late or post-orogenic granite similar to most of those in the Katherine-Darwin region. No isotopic age determinations were carried out on the Koolendong Granite, but it is considered to be of similar age to the Cullen Granite and related bodies which have yielded Rb-Sr ages of 1820 to 1830 m.y.

Edith River Volcanics. These consist of dacite and rhyodacite which crop out in the northeastern Fergusson River Sheet area, and which have been described by Walpole *et al.* (1968).

FITZMAURICE MOBILE ZONE

ADELAIDEAN

Fitzmaurice Group

The Fitzmaurice Group is a thick sequence of sandstone, siltstone, and shale forming a belt 20 to 40 km wide and extending from the Western Australian border northeast for about 200 km; it has been divided into four formations (Table 23). An isolated outcrop of sandstone near the northern margin of the Cape Scott Sheet area is tentatively included in the group.

No single complete section of Fitzmaurice Group is known because faulting has extensively disrupted the sequence, but several composite sections have been built up. Because of faulting and a great change in thickness across the belt, difficulty was experienced in assigning rocks to particular formations. Virtually all sandstones in the group are medium-grained orthoquartzites with some finer and coarser sandstones and pebbly lenses; this, and a complete lack of marker beds of distinctive lithology also made subdivision difficult.

The oldest unit, the Moyle River Formation, is absent in the south, 400 m thick in the northeast, and up to 1000 m in between (Fig. 10). Previous estimates of over 10 000 m in the northwest (Sweet *et al.,* 1974b) are difficult to substantiate, but at least 4000 m is present and perhaps much more. Isolated lenses of conglomerate and pebbly sandstone occur at the base, and the remainder of the unit comprises fine and medium, flat and cross-bedded sandstone with some clayey matrix, and rare coarse sandstone. A siltstone unit several hundred metres thick, and sandstone below it in the northwest are tentatively included in the unit. Basement is seen only adjacent to the Victoria River Fault, where Moyle River Formation nonconformably overlies granite, acid volcanics, and sheared sedimentary rocks of the Litchfield Block and the Pine Creek Geosyncline in the north, and the Halls Creek Mobile Zone in the south.

Goobaieri Formation apparently conformably overlies Moyle River Formation, but because of its sparse outcrops its upper contact is not well enough exposed to determine its relation to the Lalngang Sandstone. It seems to be conformably overlain by the Lalngang Sandstone in the east, but is absent along the eastern flank of the Macadam Range in the west. Although faulting or stratigraphic thinning cannot be ruled out, it seems quite probable that an unconformity is present, and that in the west the Goobaieri Formation was removed by erosion before Lalngang Sandstone deposition. Dark grey, green, and purple shale and siltstone make up most of the Goobaieri Formation; several sandstone and quartz greywacke lenses are present. The unit ranges in thickness from 240 m in the north to 700 m in the centre, but is absent in the south (Fig. 10). Its absence in the south could be due to erosion below an

TABLE 23. SUMMARY OF THE STRATIGRAPHY OF THE FITZMAURICE GROUP

Unit	*Thickness* (m)	*Lithology*	*Physiographic expression*	*Distribution**	*Stratigraphic relations*
Legune Formation	2100	Interbedded, grey, white, green, or brown fissile laminated siltstone; white, grey, or green poorly sorted sandstone	Gently undulating plains, finely dissected slopes, rounded hills	*Port Keats*	Conformable on Lalngang Sst
Lalngang Sandstone	1800	Interbedded fine, medium, and coarse grey feldspathic sandstone, grit, minor pebble beds and siltstone. One 120-m bed of grey-green siltstone in S *Port Keats*	Rugged steep ridges up to 150 m high. Lower and less rugged hills W of Madjellindi Valley	S and central *Port Keats*	Conformable with Legune Fmn; may be unconformable on Moyle River and Goobaieri Fmns in Macadam Ra, but elsewhere conformable on Goobaieri Fmn
Goobaieri Formation	600	Interbedded grey and green shale and siltstone, and fine sandstone. Interbeds of medium and coarse white sandstone in upper part	Valleys with gently undulating floor. Coarser sandstone beds form ridges and cliffs in scarp sides	Central *Port Keats*	Conformable on Moyle River Fmn
Moyle River Formation	1050 in SE *Port Keats;* ?10 000 in NW	White fine or medium sandstone; few thin interbeds of siltstone and coarse sandstone; basal conglomerate in N	Rugged steep-sided ridges. Truncated by Mesozoic peneplain surface in Macadam Ra	Central and N *Port Keats*	Unconformable on Carpentarian and Lower Proterozoic rocks. Conformably below Goobaieri Fmn and possibly unconformably below Lalngang Sst

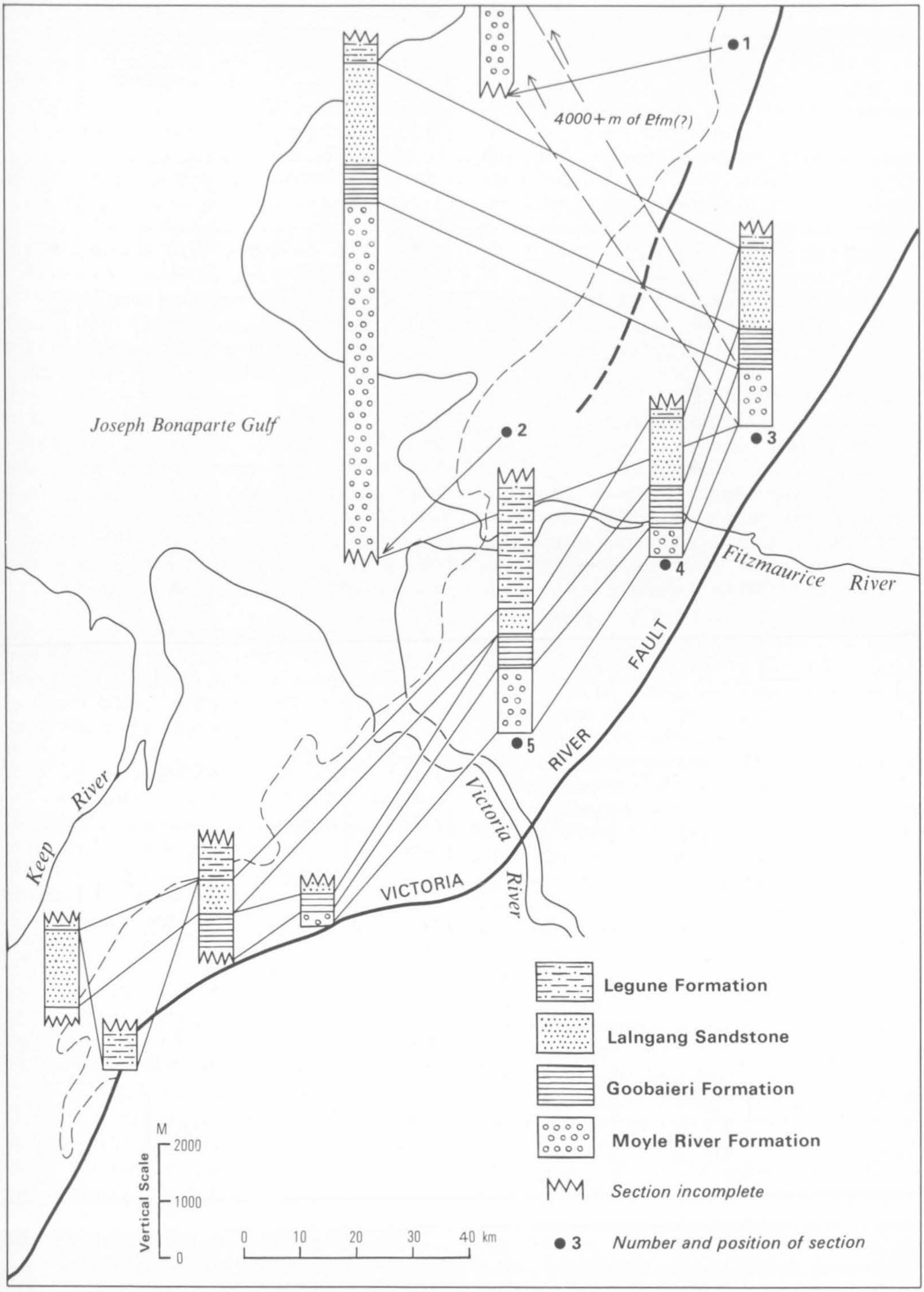

Fig. 10. Thickness range of the Fitzmaurice Group.

unconformity rather than to stratigraphic thinning. The Lalngang Sandstone ranges in thickness from 450 m in the centre to 1800 m in the northwest, and is also absent in the far southwest. It consists of cross-bedded medium-grained quartz sandstone and many beds and lenses of very coarse sandstone, grit, and pebble conglomerate. It is finer-grained in the northwest, where it is mostly fine to medium-grained sandstone. It was deposited in a shallow-water, high-energy environment.

The Lalngang Sandstone grades upwards into a sequence of alternating quartz sandstone, siltstone, and shale, the Legune Formation, which is the youngest formation preserved in the Fitzmaurice Mobile Zone. It is finer-grained in the north than in the south.

The Legune Formation appears to overlap the other three formations in the group in the southwest where it rests unconformably on a basement of Whitewater Volcanics. The other units may have been present but removed by erosion before Legune Formation deposition. Although its upper limits are unknown, between 600 and 2000 m of the unit is preserved.

Environments of deposition. The Fitzmaurice Group was laid down in a rapidly subsiding trough whose axis probably paralleled the present trend of the Fitzmaurice Mobile Zone. Sedimentation and subsidence must have remained roughly in equilibrium for much of the time because the texture of most of the sandstone indicates fairly shallow-water conditions. Sedimentation may have occurred in two major cycles: the first is represented by the Moyle River and Goobaieri Formations, and the second by the Lalngang Sandstone and Legune Formation. The first cycle records an influx of quartz-rich clastic sediment which was not completely sorted or rounded before burial, as shown by the clayey matrix and coarse pebbly beds. When the supply of sediment tapered off, deeper-water conditions became more prevalent as subsidence continued, and beds of laminated mud and silt, some with interference-rippled surfaces, were laid down. Uplift or shoaling due to increased sediment supply terminated the first cycle, and the second cycle, similar to the first, began. It seems likely that the Legune Formation, unlike the Goobaieri Formation, does not indicate deep-water conditions, but more probably an environment farther from the source area because many shallow-water features are preserved.

Virtually all of the sandstones and many of the coarser siltstones throughout the group are mineralogically very mature; that is, they are orthoquartzites and have little feldspar. Tourmaline and zircon are the most important accessory minerals, with subordinate muscovite and rutile. They are, however, relatively immature texturally. These factors suggest that the sandstones were derived largely from pre-existing sandstone, or perhaps partly from sandstone and partly from an acid igneous terrain, and were not sorted to a great degree before final deposition. The Victoria River Basin was not a source of sediment because it was an area of sedimentation also, and it is unlikely that sediment was derived from farther southeast. Thus sediment was supplied from the west, southwest, or north. Quartz-rich terrains are known to the southwest (Halls Creek Mobile Zone and the Kimberley Basin) and to the north (Litchfield Block and Pine Creek Geosyncline), and parts of these areas are thought to have been land during the sedimentation of the Fitzmaurice Group. Another possible source is the basement to the northwest beneath the Bonaparte Gulf Basin, but its history and potential as a source are unknown.

Age and correlations—relations between the Fitzmaurice, Auvergne, and Carr Boyd Groups. The Fitzmaurice Group overlies Pine Creek Geosyncline rocks with strong angular unconformity and is thus younger than about 1820 m.y., the age quoted by Compston & Arriens (1968) of several granites intruding the geosynclinal sediments. Although shales in the Goobaieri Formation are probably suitable for isotopic dating no samples were collected because of poor outcrop. The group is overlain unconformably by the Bonaparte Gulf Basin sequence including the Antrim Plateau Volcanics of probable Lower Cambrian or uppermost Proterozoic age. Thus stratigraphic relations alone only indicate an Adelaidean or Carpentarian age, and it has been necessary to attempt to correlate the group with other sequences of known age in order to define the age more closely.

The Carr Boyd Group in the East Kimberley region (Plumb & Veevers, 1971) is broadly of the same lithology and tectonic setting as the Fitzmaurice Group, and the Pincombe and Legune Formations are confidently correlated as their compositions and photopatterns are identical. It follows that the Stonewall and Lalngang Sandstones are also equivalent. These four units are preserved in what appears to be the separated flanks of a large open syncline (Fig. 11).

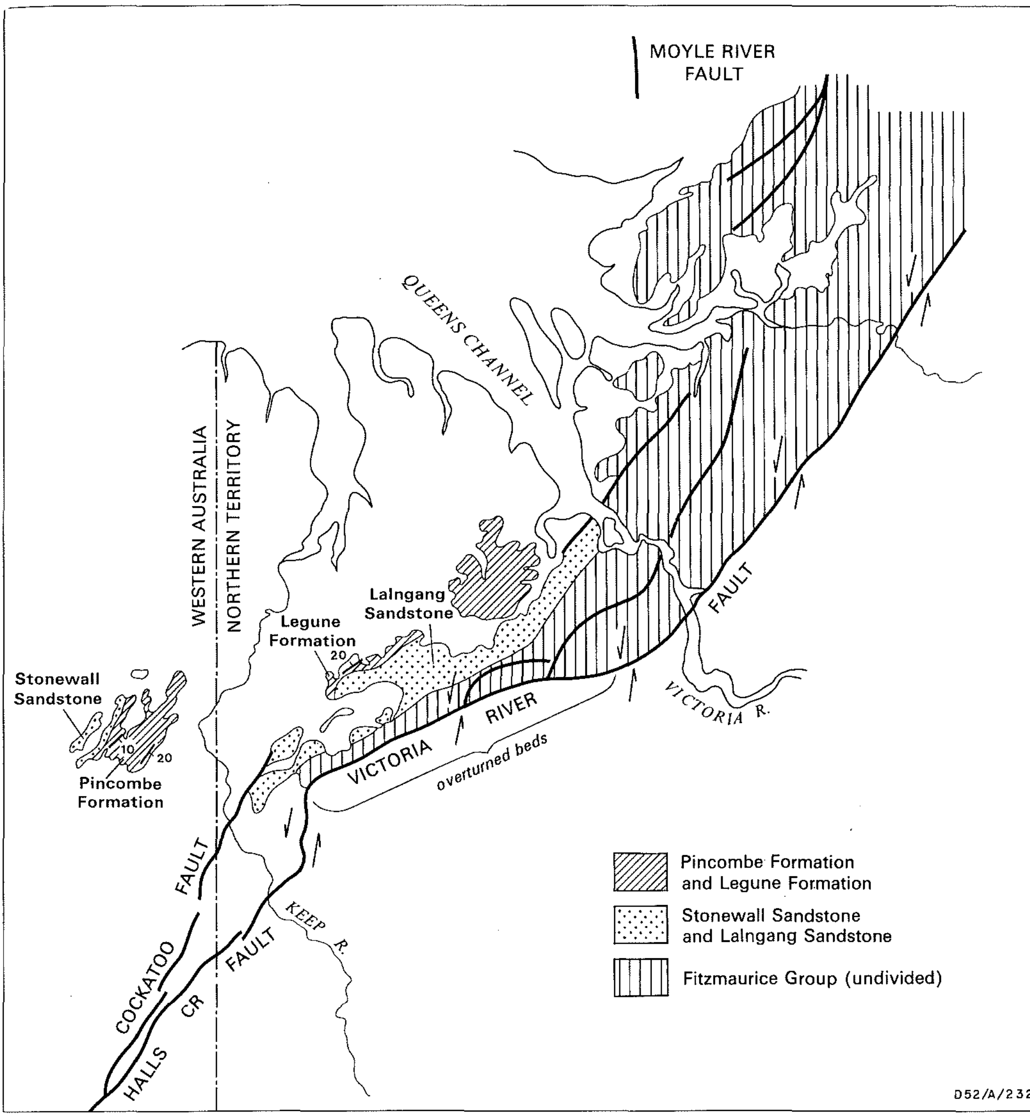

Fig. 11. The Victoria River Fault. Arrows show the probable movement and the zone of pronounced overthrusting.

Older formations in the Fitzmaurice and Carr Boyd Groups cannot be correlated directly, and tentative correlations have been made on the basis of their relations with the Auvergne Group (Table 16). Two correlations which are critical are:

(a) between the Angalarri Siltstone and the Golden Gate Siltstone. The correlation depends on recognition of Golden Gate Siltstone below Moonlight Valley Tillite by Plumb (1968) in the area 2 to 5 km southwest of Mount Brooking. Although this outcrop is separated from known Angalarri Siltstone by both Duerdin Group and Antrim Plateau Volcanics, the tectonic setting is such that the outcrop could equally well be regarded as Angalarri Siltstone. The outcrop is in the Sturt Block and in an area where no major faults separate it from the known Angalarri Siltstone. These factors, and the general similarity in lithology of the two formations suggest that they are equivalents.

The Golden Gate Siltstone thickens and changes from shallow-water to deep-water facies eastwards; it is about 2000 m thick west of the Halls Creek Fault, compared with less than 1000 m (and possibly less than 500 m) of Angalarri Siltstone east of the fault. The Halls Creek Fault therefore marks the position of a hinge-line, to the west of which a thick deep-water sequence was deposited in a rapidly subsiding area, and to the east of which a thinner deep-water sequence was deposited on a stable shelf.

The Jasper Gorge Sandstone may be equivalent to the Hensman Sandstone, and the Auvergne Group above the Angalarri Siltstone is probably equivalent to the upper part of the Golden Gate Siltstone (much of which was eroded before deposition of the Lissadell Formation. Alternatively, if a local unconformity at the base of the Saddle Creek Formation in the Auvergne Sheet area represents a significant time break, the Saddle Creek and younger formations could be equivalent to part of the Lissedell or Glenhill Formations. However, supporting evidence is lacking.

(b) between the Angalarri Siltstone and the Goobaieri Formation. Outcrops along the western margin of the Meeway Plain could be assigned to either formation. It is believed that the Victoria River Fault is not a major structure here but, as in the south, represents the position of a hinge-zone, to the west of which a thicker sequence developed.

Thus indirectly the Golden Gate Siltstone and Goobaieri Formation are correlated, and an unconformity is implied between the Goobaieri Formation and Lalngang Sandstone. Plumb & Derrick (1975) also correlated the Lalngang Sandstone with the Bullo River Sandstone. They are very similar lithologically, and it is possible that they are equivalent. The above correlations are summarized in Table 16.

Only one isotopic age determination has been carried out on the Victoria River region rocks shown in the table: an Rb-Sr whole-rock shale date on the Angalarri Siltstone yielded an age of 838 $\pm$ 142 m.y. (see Appendix 1). This does not overlap statistically with a determination of 1184 $\pm$ 123 m.y. on its equivalent, the Golden Gate Siltstone. Many unknown factors could affect results of shale dates, and they are therefore not used for detailed correlation purposes.

STRUCTURE

The two major tectonic provinces previously described, the Fitzmaurice Mobile Zone and the Sturt Block, are recognized by the structure of the rocks in them. In the Mobile Zone, the Fitzmaurice Group is moderately deformed into large open folds which are complicated in some areas by tight subsidiary folds and faulting. The widespread faulting results from the brittle nature of the sandstones which have fractured under stress rather than form tight folds. The four major faults in the Mobile Zone are near-vertical and have displacements of at least 1000 m. They are named the Indian Hill, Whirlpool Reach, Chalanyi Creek, and Tom Turners. The Tom Turners Fault may have major dextral transcurrent movement. On the Sturt Block, folding is gentle and faults are of small magnitude; almost flat-lying rocks crop out over very wide areas.

Victoria River Fault

The Victoria River Fault is the most important crustal lineament in the region, but is almost entirely obscured by superficial deposits. However, its effects in the form of steeply dipping rocks are preserved on both sides of the fault, particularly in the Auvergne Group on the Sturt Block side. Between Ernie Lagoon in the southwest and the Victoria River in the northeast, most or all of the Auvergne Group sediments are near-vertical or overturned adjacent to the fault. This attitude is undoubtedly due to the Victoria River Fault, because beds flatten rapidly southeastwards away from it. Northeast of the Victoria River where the fault trends north-northeast, the Auvergne Group is not as strongly deformed and is not overturned. This is probably significant, because the section of the fault where overturning occurs trends northeast and east-northeast. Such attitudes can be explained by a sinistral strike-slip movement which would give a fault with overthrusting in the central part (Fig. 11). The fault is probably near-vertical or steeply dipping in the northeast.

The Victoria River Fault cannot be traced under Cretaceous rocks on the Wingate Plateau, but farther north a complex fault zone trends north-northeast and merges with the Giants Reef Fault which has a major dextral transcurrent component (Walpole *et al.*, 1968). It is difficult to reconcile the opposite senses of probable transcurrent movement of the two faults with the fact that they both appear to be part of one major trend.

In the far southwest the Victoria River Fault may merge into the Halls Creek Fault, but this is uncertain because the Halls Creek Fault becomes complex and forms a wide zone of which the Cockatoo Fault is part. It is possible that the Halls Creek Fault extends northwards

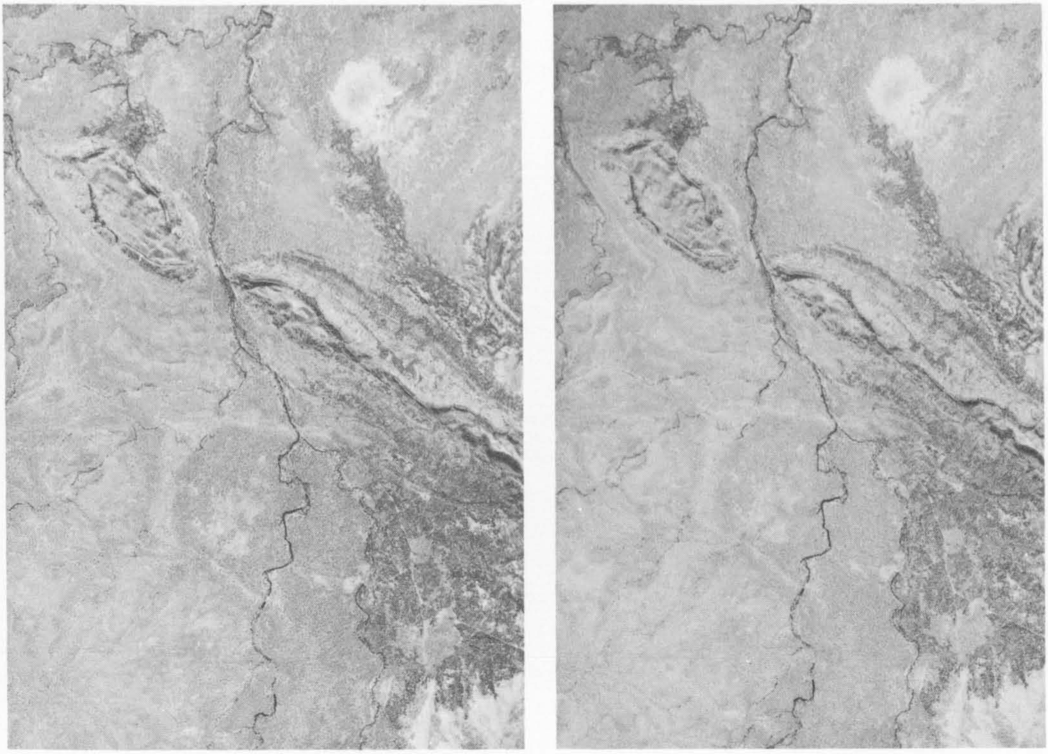

Plate 27. Northwesterly-trending closed anticlines developed in the Skull Creek Formation in the southwestern Delamere Sheet area. The anticlines are faulted, and displacement of the Supplejack Dolomite Member (dark-toned bed outlining the structures) demonstrates left-lateral movement of about 300 m with little or no vertical displacement. (Delamere RC9, Run 8, Photos 18, 20)

under or near the eastern margin of the Bonaparte Gulf Basin; the Moyle River Fault may be part of this extension, and the Victoria River Fault a separate branch from the main fault.

Structure of the Limbunya Group and Bunda Grit

The Bunda Grit and Limbunya Group have been assigned to The Granites-Tanami Block and Birrindudu Basin respectively, which are developed south of the Victoria River region (Blake, Hodgson, & Muhling, 1973). The Bunda Grit is moderately to strongly folded along a north-trending axis, and is overlain unconformably by the Limbunya Group which was also folded along roughly the same axis. This fold trend is maintained in the Limbunya Group east of Kirkimbie homestead, and is also evident in Cambrian rocks of the Hardman Basin where a monocline (east block down) is developed. To the south, in the Birrindudu Sheet area, the structures are concealed by flatlying Antrim Plateau Volcanics, showing that activity continued into the Palaeozoic only in the northwest.

Elsewhere the Limbunya Group is gently to moderately folded, but strongly faulted; faults are vertical and most have fairly small displacements of the order of a few hundred metres. Near the margin of the Limbunya and Wave Hill Sheet areas a series of closed anticlinal structures in the Limbunya Group are terminated on their eastern provinces by monoclines which are probably faulted in places. Several other monoclinal zones form prominent lineaments in the Victoria River region.

Structure of the Wattie and Bullita Groups, and the Wondoan Hill and Stubb Formations

These four units form a structurally homogeneous sequence because, although the Wondoan Hill Formation is unconformable on the Bullita Group, there appears to have been only minor uplift, erosion, and warping during the hiatus.

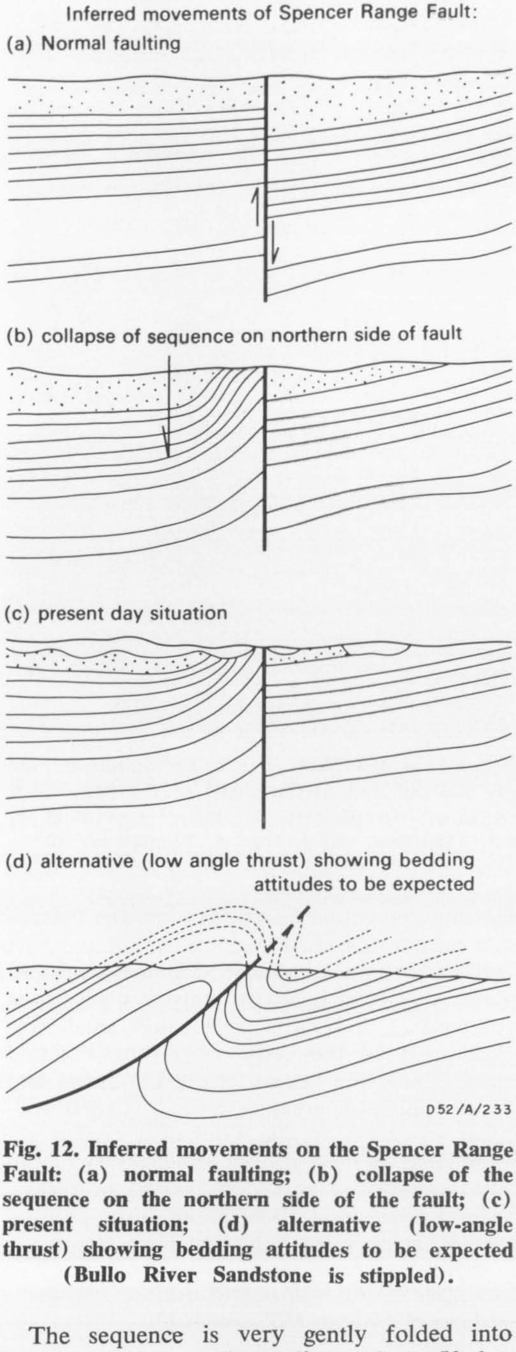

Fig. 12. Inferred movements on the Spencer Range Fault: (a) normal faulting; (b) collapse of the sequence on the northern side of the fault; (c) present situation; (d) alternative (low-angle thrust) showing bedding attitudes to be expected (Bullo River Sandstone is stippled).

The sequence is very gently folded into broad anticlines and synclines 10 to 50 km across; dips on the limbs are rarely steeper than 20°. Complicating this gentle fold pattern is a series of monoclines, faults, and tight anticlines which give rise to narrow zones of near-vertical strata; several such zones are evident in the Waterloo and Victoria River Downs Sheet areas. One in the southwestern Delamere Sheet area is shown in Plate 27, where three elongate closed anticlines formed of Skull Creek Formation form a low ridge up to 100 m high. A fault along the main fold axis has sinistral strike-slip movement of up to 300 m, but virtually no vertical displacement. In other anticlines movement is negligible and the 'fault' is really an axial fracture or joint.

Monoclines and associated faults which affect the Wattie and Bullita Groups in many localities are thought to be caused by movement of rigid crustal blocks which form the Sturt Block (Laing & Allen, 1956). It is envisaged that slight vertical and lateral movements of the blocks have caused deformation and faulting in the sedimentary cover. Such movements recurred at long intervals, because where monoclines have been eroded and later covered by Jasper Gorge Sandstone new movement has caused minor faulting in the sandstone.

It is possible that the anticlines may also be formed by compression and lateral movement at the margins of the blocks. Alternatively, intrusion of magma or sediment diapirism may be involved. The lower part of the Bullita Group consists of dolomitic sediments and it is not inconceivable that soluble salts such as halite may have been present and formed diapiric cores in some anticlines. Alternatively, the thin-bedded dolomites and siltstones themselves may have been squeezed up under pressure, in a way similar to diapirs in the Adelaide Geosyncline (Parkin, 1969). In either hypothesis the lack of a great thickness of sediments makes such an explanation unlikely.

Structure of the Auvergne Group and Bullo River Sandstone

Sedimentation in the Victoria River Basin concluded with the deposition of the Bullo River Sandstone which was deposited on the Auvergne Group probably after slight uplift in the southwest (Fig. 6). In the southeastern part of the basin the Jasper Gorge Sandstone, which is the only unit of the Auvergne Group remaining, is virtually flat-lying. It is only northwest of a northeast-trending line approximately through Timber Creek that the sandstone is tilted gently, and dips 1 to 5° northwest. In the main belt of Auvergne Group, which parallels the Victoria River Fault, structures include folds and faults both parallel and normal to the Fault. The intensity of folding gradually increases towards the Fault, and adjacent to it beds are steeply dipping or overturned.

Spencer Range Fault

The Spencer Range Fault is a complicated structure which was originally thought to be a low-angle reverse fault (Morgan *in* Pontifex, Morgan, Sweet, & Reid, 1968) in which much of the Auvergne Group glided southeastwards over Bullo River Sandstone. This interpretation of the structure is unlikely as there is no evidence of drag on both sides of the fault. An alternative mechanism involving two periods of movement has been proposed (Pontifex & Sweet, 1972), and is shown in Figure 12. Similar problems exist in the explanations of faulting of the northwestern margin of the Bullo River Sandstone near the Victoria River Fault. In that area two movements of the fault appear to have taken place—one at the time of main movement on the Victoria River Fault, and a second smaller movement in the same direction after deposition of the Duerdin Group.

The southeast-trending faults affecting the Auvergne and Duerdin Groups are vertical and of small vertical displacement (less than 100 m). They developed later than the main folding and faulting because they (a) affect Duerdin Group (the Spencer Range Fault is partly concealed under the Duerdin Group) and (b) appear to displace the Victoria River Fault northeast of Bucket Springs.

The folds and faults within the Sturt Block trend generally north-northwesterly to west-northwesterly, with a northeasterly trend evident in the Auvergne Sheet area. The northeasterly-trending structures are probably caused by compression, but the northwesterly structures do not have such an obvious explanation. Much of the Precambrian of northern Australia displays similar trends and these have been explained by postulating rigid basement blocks separated by zones of weakness. It is proposed that continued minor movement along these zones gave rise to the fault and fold patterns in the overlying sedimentary rocks.

Structure of the Duerdin Group and younger rocks

The Duerdin Group was laid down after the last movement on the Spencer Range Fault, but is affected by north-northwest-trending faults. It is flat-lying or gently tilted except near the Victoria River Fault, where it has been moderately folded.

The Antrim Plateau Volcanics and Phanerozoic sediments are flat-lying or gently tilted around the margins of the Victoria River region, and display virtually none of the features described above. Only the most persistent lineaments affect them—for example, the West Baines, Blackfellow Creek, and Dorisvale Faults, and the unnamed fault forming the southwest margin of the Hardman Basin in the Northern Territory.

MINERAL POTENTIAL

The only mineral deposits in the Victoria River region that have been worked are tin and gold deposits in Carpentarian granites and Pine Creek Geosyncline sediments in the northern Fergusson River Sheet area and barite in Antrim Plateau Volcanics in the Limbunya Sheet area. The main recorded production in recent years has been of tin from near Collia Waterhole. The geology of the deposits is discussed briefly by Crohn (1968) and Sweet *et al.* (1974b).

No economic deposits are known in the sedimentary rocks of the Victoria River Basin. However, the minor known mineral prospects provide some encouragement to search for bigger deposits. All known mineral occurrences are described by Sweet *et al.* (1974a, 1974b, and 1974c).

The *Limbunya Group* is probably the same age as the McArthur Group, and should be prospected for base metals; virtually no exploration has been carried out to date (1973).

No mineralization is known in the *Wattie Group*, but the *Bullita Group* contains minor galena, chalcopyrite, and manganese minerals. Galena occurs in the carbonate rocks of the Timber Creek, Skull Creek, and Banyan Formations, but no concentrations are known. Anomalous lead values recorded by Euralba Mining N.L. (1971) in the Tolmer Group adjacent to the Dorisvale Fault may indicate that concentration of lead has occurred along the fault. The Banyan Formation near the fault southeast of Dorisvale is therefore an area which should be investigated. Specks of chalcopyrite are disseminated through at least one bed in the Bynoe Formation, but no concentrations have been seen and the potential appears to be small.

Manganese minerals, mostly pyrolusite, fill joints in the Battle Creek Formation between Battle and Waterbag Creeks in the Victoria River Downs Sheet area. Assays indicate 1 to 9 percent manganese, a content well below ore grade. The size of the deposit is not known but is probably small.

No base-metal occurrences are known in the Auvergne Group and younger rocks. However, barite veins occur as fault fillings east and southeast of Newry homestead, and more veins probably occur. These may eventually be exploitable if production continues from a large vein deposit in Antrim Plateau Volcanics north of Inverway homestead. Barite crystals, veinlets, and small veins have been observed in Wattie, Bullita, and Auvergne Group rocks, and it is probable that barium in the large veins has been derived from the surrounding rocks. It is likely that more veins will be found.

Copper occurrences in the Antrim Plateau Volcanics are discussed by Bultitude (in prep.).

WATER RESOURCES

Surface water

Surface water is abundant in the northern and central parts of the region where rivers flow strongly every wet season. Many rivers, particularly those in the north, are spring-fed and a small flow is maintained throughout the long dry season, but most watercourses in the south cease flowing and break up into a series of waterholes. They provide adequate supplies in many areas, but much of the best grazing land is not adjacent to permanent supplies, and groundwater must be used.

Wet-season stream flows are large, but of short duration. The long-term average annual flow for the Victoria River at Coolibah homestead is 3.16 million acre-feet, and for the Daly River near the Police Station 3.17 million acre-feet (AWRC, 1971). Should agriculture become a viable industry in the area, abundant water resources exist for irrigation, and there are several excellent dam sites on the major rivers. The economics of such projects, and the availability of large tracts of good soil for irrigation would probably be limiting factors.

Groundwater

Details of more than 700 bores drilled in the Victoria River region in the search for groundwater are given in the nine Explanatory Notes dealing with the region: Cape Scott (Mendum, 1972); Port Keats (Morgan, 1972); Fergusson River (Pontifex & Mendum, 1972); Auvergne (Pontifex & Sweet, 1972); Delamere (Sweet, 1972); Waterloo (Sweet, 1973b); Victoria River Downs (Sweet, 1973a); Limbunya (Mendum, 1973); and Wave Hill (Bultitude, 1973). Nearly half of the bores have been drilled into Antrim Plateau Volcanics, where they have had mixed success depending on whether they penetrated massive impermeable basalt or weathered porous or vesicular basalt, sandstone, or chert. The latter three rock types generally yield good supplies. Most bores drilled into the Precambrian rocks were drilled into the most impermeable rocks in the area because the impermeable rocks, of which the Angalarri Siltstone and the Bynoe and Battle Creek Formations are the most important, are predominantly siltstone which erodes easily and therefore forms good flat grazing country. Of 34 bores drilled in Angalarri Siltstone in the Waterloo Sheet area, 12 were successful and probably produced from weathered rock. The other 22 were dry holes or yielded less than 2300 l/h (500 gph). Bynoe Formation underlying Fitzroy station, and Battle Creek Formation in Victoria River Downs station have produced similar success/failure ratios.

The best bedrock bores are those sited in weathered rock and those on lineaments which indicate fractured rock; these features are sought on aerial photographs by government geologists when requests are made for bores to be sited.

The possibility of deep aquifers in sandstone beds has not been explored, but it is likely that even the sandstones, such as Jasper Gorge Sandstone, may have low permeability and therefore would not be good aquifers. However, at least one test bore to 400 m or more through Angalarri Siltstone in the Auvergne or Delamere Sheet areas is warranted to investigate this possibility.

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APPENDIX 1

GEOCHRONOLOGY OF GLAUCONITIC SANDSTONE AND SHALE BEDS IN THE VICTORIA RIVER REGION, NORTHERN TERRITORY

by

A. W. Webb and R. W. Page

The basal sandstone of the Wondoan Hill Formation includes a glauconitic bed (up to 1 m thick) which was sampled at six sites along a strike distance of 1 km (Fig. A). The rocks are partly silicified greenish quartz-sandstone, and the colour of the separated glauconite is dark green to fairly light green. The subrounded quartz grains have authigenic quartz overgrowths. Calcite is another prominent authigenically derived constituent.

Table A shows the K-Ar age results of nine glauconite samples collected from the six sites. The ages fall within a fairly restricted range, having a mean of 1080 ± 14 m.y. (standard deviation). This gives a minimum age for sedimentation of this part of the formation.

Seven of the glauconites and three glauconitic sandstones (total-rocks) were analysed by the Rb-Sr method, and these data are given in Table B and plotted in Figure B. The fit of the data to the isochron regression line is not within experimental error, and therefore suggests that some of the samples have not remained closed with respect to Rb and/or Sr movement. The indicated age for the seven glauconites is 1124 ± 82 m.y. with an initial Sr^{87}/Sr^{86} ratio of 0.834 ± 0.138 (95% confidence limits). Inclusion of the 3 total-rock points markedly increases the precision, giving an age of 1190 ± 30 m.y. (0.711 ± 0.002). This latter result will be the best estimate for the age of the rocks providing that all the authigenic minerals, including the glauconite, were crystallized and isotopically homogenized in the one diagenetic process. From the combined K-Ar and Rb-Sr data, it appears that the glauconites have lost about 10% of their radiogenic argon.

Wondoan Hill Formation Shales

Six Rb-Sr analyses of shales from the Wondoan Hill Formation are given in Table C and plotted in Figure C. There is a lack of collinearity of these analyses on the isochron diagram, and even after rejection of sample 7077-1038 B, regression of the remaining five samples produces a large residual variance. This regression gives an isochron of 1431 ± 440 m.y. and an initial Sr^{87}/Sr^{86} ratio of 0.7202 ± 0.061. It is possible that a family of parallel lines can be fitted to these points

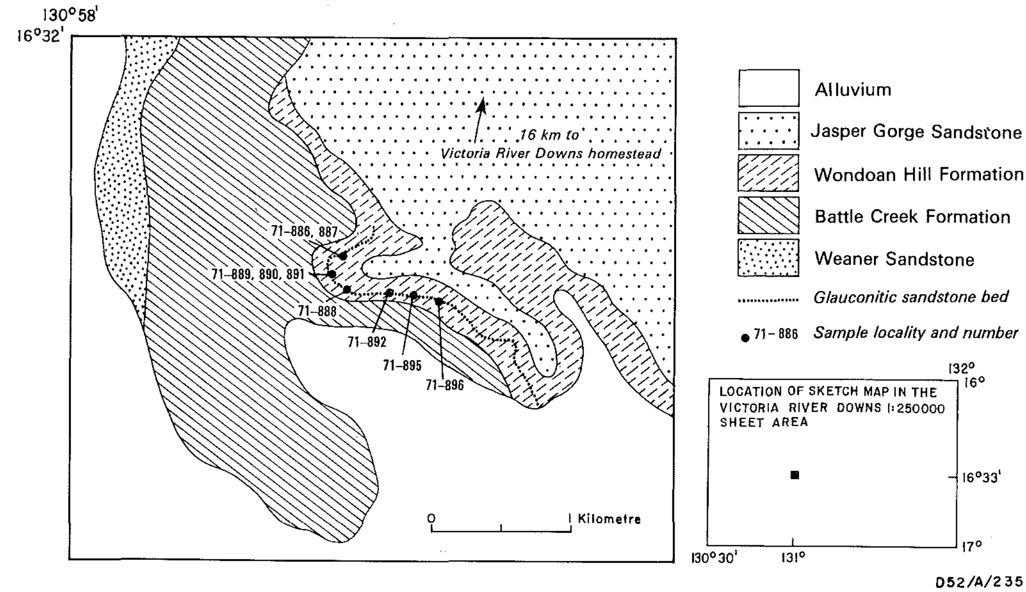

Fig. A. Location of glauconitic sandstone, Victoria River Downs Sheet area.

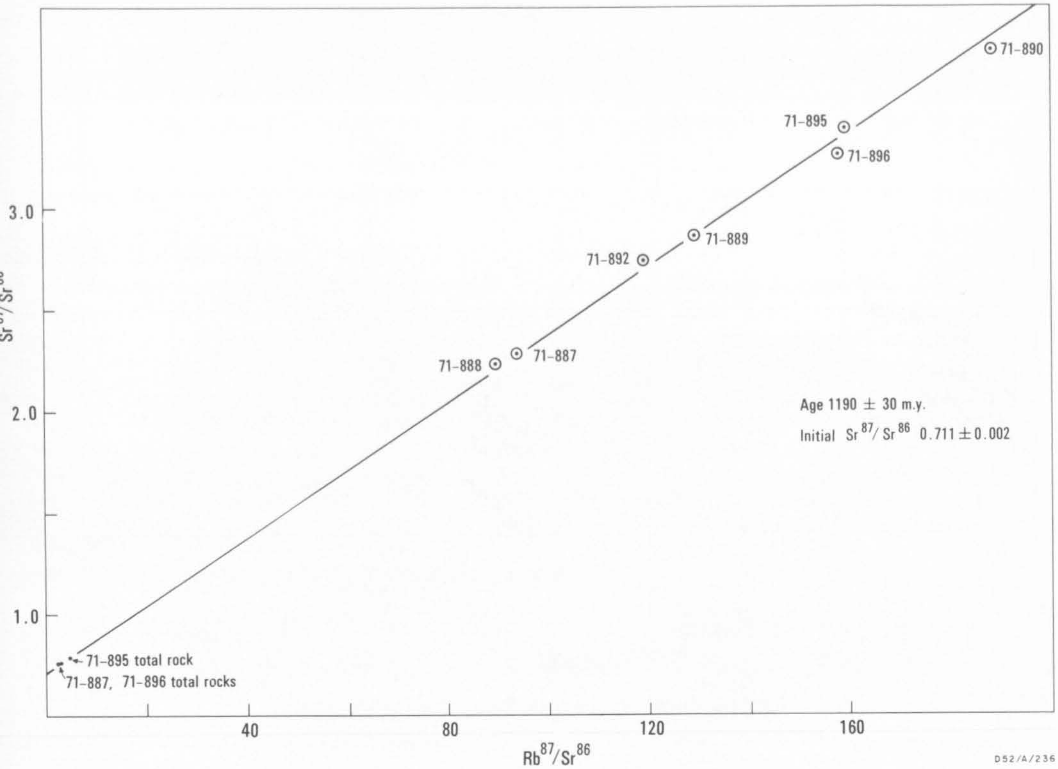

Fig. B. Rb-Sr analyses of Wondoan Hill Formation glauconites.

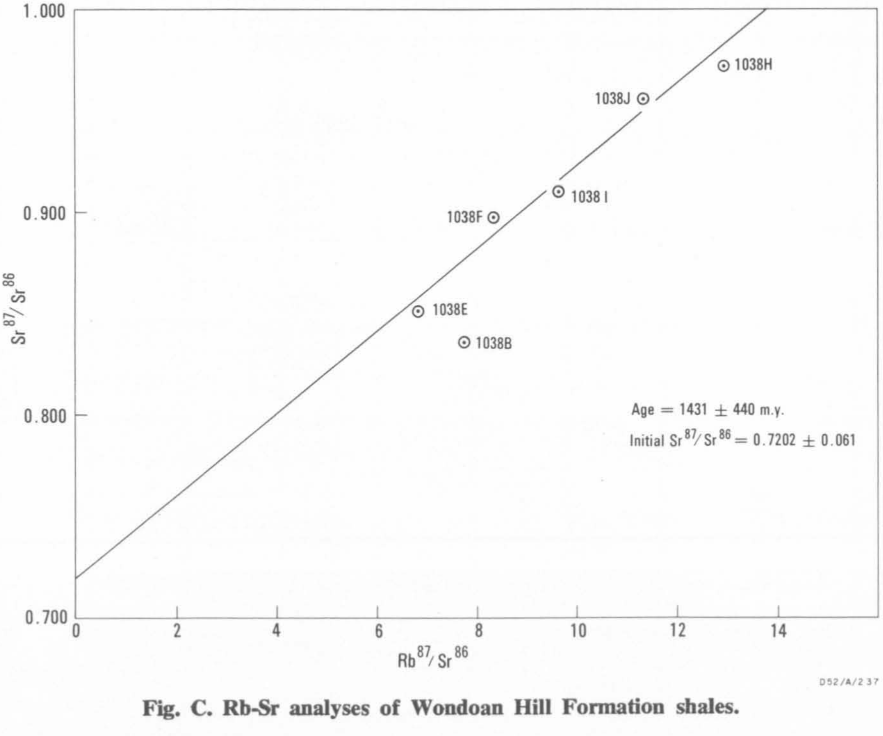

Fig. C. Rb-Sr analyses of Wondoan Hill Formation shales.

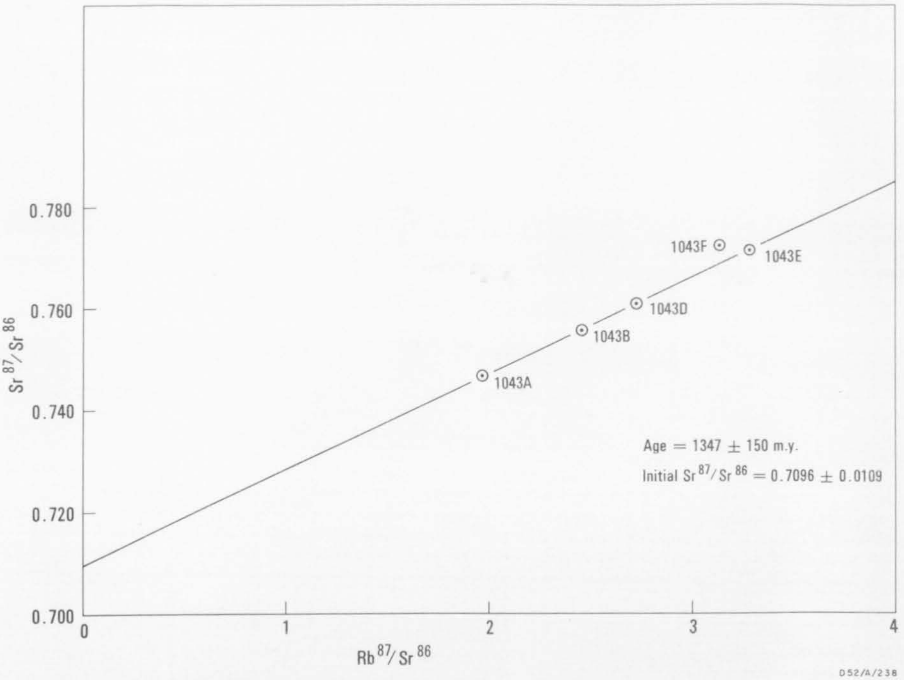

Fig. D. Rb-Sr analyses of Stubb Formation shales.

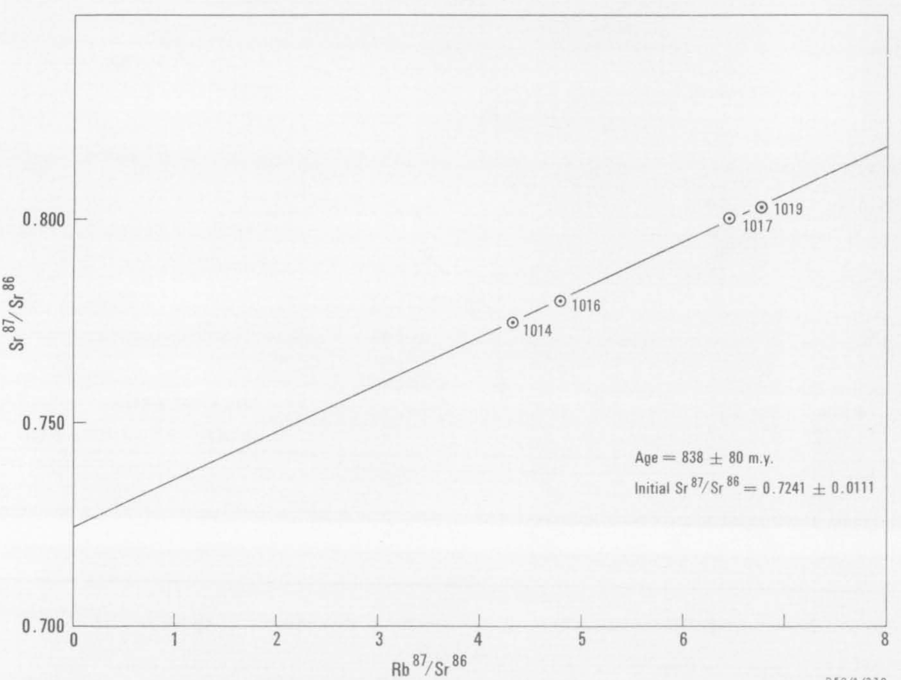

Fig. E. Rb-Sr analyses of Angalarri Siltstone rocks.

TABLE A. K-Ar AGES OF GLAUCONITE FROM THE WONDOAN HILL FORMATION

Sample No.	BMR No.	K%		Radiogenic Ar^{40} / K^{40}	% Radiogenic Ar^{40}	Age ± 2 s.d.
71-886	7077.1032 B	6.055 6.027	6.041	0.08439	99.2	1073 ± 22
71 887	7077.1032 B	6.062 6.073	6.068	0.08386	99.0	1067 ± 22
71-888	7077.1033	6.091 6.097	6.094	0.08557	99.5	1084 ± 22
71-889	7077.1034 A	6.243 6.285	6.264	0.08636	99.6	1092 ± 22
71-891	7077.1034 A	6.155 6.137	6.146	0.08752	99.5	1102 ± 22
71-890	7077.1034 B	6.215 6.150	6.183	0.08574	99.3	1086 ± 22
71-892	7077.1035 B	5.984 5.992	5.988	0.08229	99.5	1052 ± 22
71-895	7077.1036 B	6.139 6.125	6.132	0.08493	99.5	1078 ± 22
71-896	7077.1037 A	5.829 5.825	5.827	0.08660	99.5	1094 ± 22

Constants used:
$\lambda_\beta = 4.72 \times 10^{-10} yr^{-1}$
$\lambda_e = 0.584 \times 10^{-10} yr^{-1}$
$K^{40} = 0.0119$ atom percent

TABLE B. Rb-Sr DATA FROM GLAUCONITES AND GLAUCONITIC SANDSTONES FROM THE WONDOAN HILL FORMATION

Sample No.	Rb (ppm)	Sr (ppm)	Rb^{87}/Sr^{86}	Sr^{87}/Sr^{86}
71-887 Gl	399.1	14.2	93.711	2.2933
71-887 TR	21.8	17.6	2.286	0.7511
71-888 Gl	407.2	15.1	89.330	2.2441
71-889 Gl	395.1	10.7	129.010	2.8569
71-890 Gl	452.5	9.0	188.996	3.7822
71 892 Gl	384.9	11.2	119.008	2.7446
71-895 Gl	335.0	7.7	159.011	3.4016
71-895 TR	22.3	14.3	4.542	0.7854
71-896 Gl	386.7	8.8	151.920	3.2641
71-896 TR	13.4	15.6	2.499	0.7515

Measurements by isotope dilution.

Constants Used:
$\lambda Rb^{87} = 1.39 \times 10^{-11} yr^{-1}$
$Sr^{88}/Sr^{86} = 8.3752$
$Rb^{85}/Rb^{87} = 2.600$
Gl—Glauconite.
TR—Total rock.

TABLE C. Rb-Sr DATA FOR TOTAL-ROCK SAMPLES FROM THE WONDOAN HILL FORMATION

Sample No.	*Rb/Sr	Rb^{87}/Sr^{86}	†Sr^{87}/Sr^{86}
7077–1038 B	2.66	7.777	0.8345 0.8371
E	2.34	6.852	0.8516
F	2.85	8.382	0.8974
H	4.37	12.946	0.9724
I	3.28	9.659	0.9105
J	3.84	11.358	0.9566

TABLE D. Rb-Sr DATA FOR TOTAL-ROCK SAMPLES FROM THE STUBB FORMATION

Sample No.	*Rb/Sr	Rb^{87}/Sr^{86}	†Sr^{87}/Sr^{86}
7077–1043 A	0.68	1.971	0.7470
B	0.85	2.466	0.7560
D	0.94	2.729	0.7610
E	1.13	3.283	0.7718
F	1.08	3.138	0.7725 0.7724

TABLE E. Rb-Sr DATA FOR TOTAL-ROCK SAMPLES FROM THE ANGALARRI SILTSTONE

Sample No.	*Rb/Sr	Rb^{87}/Sr^{86}	†Sr^{87}/Sr^{86}
7077–1014	1.49	4.331	0.7750
–1016	1.65	4.798	0.7800
–1017	2.22	6.469	0.8004
–1019	2.32	6.762	0.8029

* Measured by X-ray fluorescence.
† Unspiked ratio, normalized to $Sr^{88}/Sr^{86} = 8.3752$.

Constants used:
$Rb^{85}/Rb^{87} = 2.600$
$\lambda Rb^{87} = 1.39 \times 10^{-11} yr^{-1}$

(Bofinger & Compston, 1968), e.g. one line to 7077-1038 F and J, and another to 7077-1038 E, I, and H. These lines, however, are subparallel to the 1431 m.y. isochron and do not make any significant alteration to the age.

The glauconite date of approximately 1200 m.y. remains the best estimate of the age of the Wondoan Hill Formation.

STUBB FORMATION

Five shale samples were analysed. The Rb and Sr analyses are listed in Table D and plotted on the isochron diagram (Fig. D). Regression of four of these analyses produces a model 1 isochron (age = 1347 ± 150 m.y., and an initial Sr^{87}/Sr^{86} = 0.7096 ± 0.0109). Inclusion of the fifth analysis (7077-1043 F) would increase slightly the slope of the isochron but would not make a significant difference to the age. The initial Sr^{87}/Sr^{86} ratio is lower than that found in many sedimentary rocks, hence it is unlikely that the age could be much greater than 1350 m.y.

When the 95% confidence limits are taken into consideration, there is probably no serious discrepancy between the shale date and that for the glauconites from the underlying Wondoan Hill Formation. The isotopic age correlation with the East Kimberley rocks (1128 ± 110 m.y., Dow & Gemuts, 1969) is also acceptable.

ANGALARRI SILTSTONE

Only four Rb-Sr analyses were made on rocks from this formation (see Table E and Fig. E). The regression produced a model 1 isochron of 838 ± 80 m.y. and an initial Sr^{87}/Sr^{86} ratio of 0.7241 ± 0.0111. This date is significantly younger than those determined on units lower in the sequence, and the difference appears too great unless there is a substantial time break between the Stubb Formation and the Auvergne Group.

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APPENDIX 2

PETROGRAPHY OF THREE GLAUCONITIC SANDSTONES FROM THE WONDOAN HILL FORMATION

The table below shows data from three thin sections of Wondoan Hill Formation. They are the three samples used in the total rock-mineral separate isochron shown in Figure 2 of Appendix 1.

The mineralogy of the samples is simple—they consist of quartz, calcite and glauconite. No feldspar or detrital heavy minerals are present.

Sample No.	*Quartz*	*Calcite*	*Glauconite*	*Other constituents*	*Comments*
7077-1032 B (71-887)	90%: Well rounded grains 0.3-0.6 mm, completely enveloped in syntaxial overgrowths	5%: interstitial, spar, appears to replace glauconite in some places; may replace quartz also, but in most cases relations are not clear	5%: light green pellets of similar size to the quartz; most of the complete grains are well rounded	Rare specks of limonite in calcite—probably an alteration product of glauconite	Glauconitic sandstone; no feldspar or accessory heavy mineral present
7077-1036 B (71-895)	90%: Not quite as well rounded as 7077-1032B; is sub-rounded to rounded; some grains up to 1 mm; syntaxial overgrowths present but original porosity lower and therefore less cement present; original grain boundaries prominently outlined by opaque oxides	5%: Rare, scattered coarse spar	5%: Slightly more glauconitic than 7077-1032B; many elongate grains; many grains have dark green zone near rim—may be a zone of alteration; grain centres are almost colourless and slightly coarser grainsize than outer parts	None	Glauconitic sandstone
7077-1037 A (71-896)	80%: rounded grains with syntaxial overgrowths—latter not as extensive as in other samples particularly where calcite cement is present	15%: coarse spar; embays glauconite grains in many instances and probably quartz in some	5%: most are rounded grains, but some irregular aggregates associated with calcite are either remnants of grains or irregular authigenic growths	Small limonite grains are common in the calcite—is assumed to be an alteration product of glauconite	Mineralogy same as other two sandstones, but much higher proportion of calcite

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PLATE 1a

GEOLOGY

OF THE

VICTORIA RIVER REGION

NORTHERN TERRITORY

1976

Geology 1966 by M.A.Randal, M.C.Brown, W.J.Perry (Wiso Basin), J.J.Veevers, J.Roberts, J.A.Kaulback, J.M.Dickins (Bonaparte Gulf Basin)
1967 by I.R.Pontifex, C.M.Morgan, I.P.Sweet, A.G.Reid, W.J.Perry
1968 by I.R.Pontifex, R.G.Horne, C.M.Morgan, I.P.Sweet, J.R.Mendum, P.R.Dunn
1969 by C.M.Morgan, J.R.Mendum, I.P.Sweet, R,J.Bultitude, P.R.Dunn
1970 by I.P.Sweet, R.J.Bultitude
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TRANSVERSE MERCATOR PROJECTION

GEOLOGY OF THE VICTORIA RIVER REGION

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