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# THE GEOLOGY OF THE NORTHERN TERRITORY

(Paper prepared for publication, without list of contents and summary, in the 'Encyclopedia of World Geology' to be published by Dowden, Hutchinson & Ross)

by

G.W. D'Addario

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# THE GEOLOGY OF THE NORTHERN TERRITORY


## Summary

The rocks in the Northern Territory range from Archaean to Cainozoic in age. The older metamorphic and igneous complexes and the thick succession of marine impure sandstone and argillaceous rocks (flysch-like deposits) laid down in extensive troughs of intracratonic geosynclines were strongly deformed between 2 200 and 1 900 million years ago. Towards the close of the orogenic phase and for some time after (1 900 to 1 750 m.y. ago) a thick sequence of continental argillaceous marl and sandstone (molasse-like deposits) was laid down, and was accompanied by abundant plutonic and volcanic activity and rare metamorphism. The Northern Territory, with its deformed older metamorphic and igneous complexes and synorogenic and post-orogenic sedimentary sequences, assumed the characteristics of a craton at the end of the Lower Proterozoic. This began with the deposition of the North Australian Platform Cover. Mild tectonism affected the central and northeastern parts of the Territory in Carpentarian and Adelaidean time. Deformation followed in the south and northwest between the Adelaidean and the early Middle Cambrian and in the Carboniferous while the central Australian Platform Cover was developing. Sequences of shallow water and continental sedimentary rocks of the Trans-Australian Platform Cover formed over the immediately preceding orogenic domain and associated transitional domain and spread across older basement rocks from the Permian to the Upper Cretaceous. Weathering, minor folding, and warping, from Cretaceous until recent times, have produced four land surfaces in the Territory.

Primitive forms of life such as stromatolites and oncolites have been recorded in the Proterozoic rocks. Archaeocyathids, algae, and sponges have been found in Lower Cambrian rocks from the southern part of the Territory. Trilobites are widespread in the Middle Cambrian. Ordovician graptolites, nautiloids, trilobites, brachiopods, and conodonts are also common. Brachiopods, marine molluscs, and plant fossils have been described from Devonian and Permian sequences in the Bonaparte Gulf Basin. Remains of Tertiary marine and terrestial animal life are abundant and well preserved in the Territory.

Mineral deposits are concentrated in three mineral provinces: between Katherine and Darwin, around Tennant Creek, and between the Barkly Tableland and the southwestern coast of the Gulf of Carpentaria.

Economic deposits include gold, copper, silver, lead, zinc, tin, tungsten, uranium, and iron ore. A large zinc-lead deposit at the McArthur River contains 200 million tons of ore averaging 9 percent zinc and 4 percent lead. Gold-copper deposits have recently been discovered near Tennant

Creek, and a 5-million ton orebody is being developed for production. The uranium reserves have not yet been fully delineated, but recent discoveries indicate that Australia will become one of the leading uranium producers in the world.

Bauxite deposits are on the western side of the Gulf of Carpentaria and large deposits of phosphate rock occur in the northwestern margin of the Georgina Basin. Lignite has been found in the Santa Teresa area 70 km southeast of Alice Springs.

At Mereenie and Palm Valley in the Amadeus Basin, proven gas reserves are estimated at $1.57 \times 10^{12}$ cubic feet; proven oil reserves at Mereenie are estimated at 60 million barrels. Exploration for oil and gas is continuing, particularly in the offshore Bonaparte Gulf Basin.

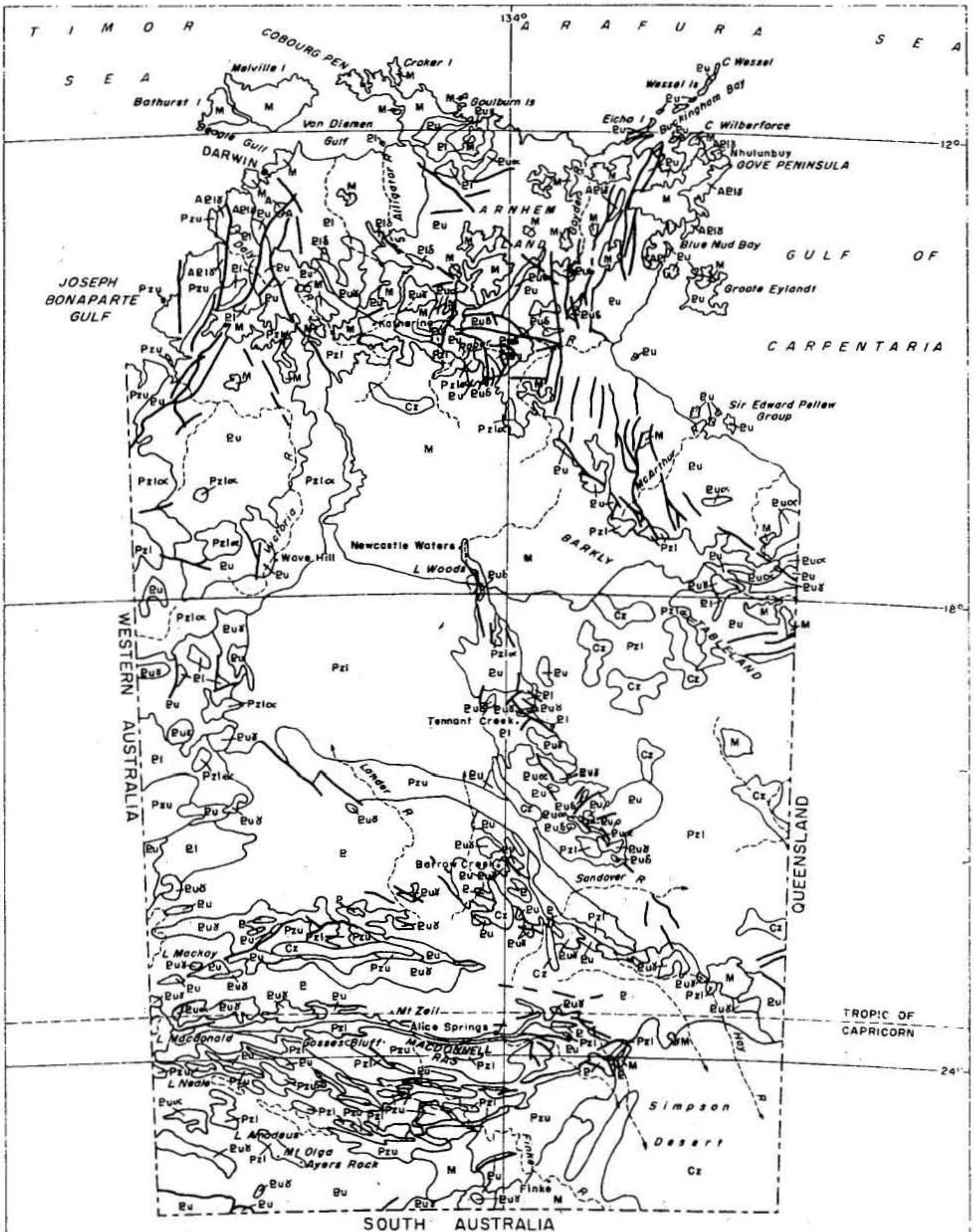
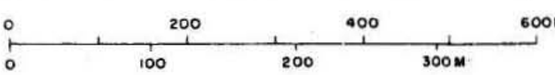



Fig I GEOLOGICAL MAP OF THE NORTHERN TERRITORY, AUSTRALIA




SEDIMENTARY AND METAMORPHIC ROCKS

| | | | |
|---|---|---|---|
| Cainozoic | Cz | *Superficial deposits omitted* | |
| Mesozoic | M | | |
| Palaeozoic | Pzu | Upper | |
| | Pzl | Lower | |
| Precambrian | Ꝑ | Proterozoic | |
| | Ꝑu | Upper Proterozoic | |
| | Ꝑl | Lower Proterozoic | |
| | AꝐl | Archaean to Lower Proterozoic | |
| | A | Archaean | |

IGNEOUS ROCKS

| | | |
|---|---|---|
| Plutonic and Hypabyssal | γ | Acid |
| | δ | Basic |
| Volcanics | ρ | Acid |
| | α | Basic |

——— *Geological boundary*

——— *Fault*

Ages of igneous rocks are indicated by the same age symbols as for sedimentary and metamorphic rocks

*To accompany Record 1972/91*

*NT/358*

## NORTHERN TERRITORY*

### Introduction

The Northern Territory (Fig. 1) occupies that part of Australia north of parallel 26°S and between meridians 129° and 138°E. It is bounded by the Timor and Arafura Seas and the Gulf of Carpentaria to the north, and by the adjacent states of Queensland, South Australia, and Western Australia. The total area of the Territory is 1 347 520 $km^2$; its greatest length from north to south is about 1700 km and its greatest breadth about 1 000 km. The low flat coastline, with its sandy beaches and its mud flats thickly fringed with mangroves, is about 1 700 km long. It is broken here and there by headlands of sandstone, marl, laterite, and granite, few of which rise above 30 m; it is indented by bays and inlets and intersected by numerous rivers, a few of which are navigable.

The largest of the many islands are Bathurst and Melville Islands in the northwest and Groote Eylandt in the Gulf of Carpentaria. Port Darwin and Melville Bay, Gove Peninsula, are the only sheltered deep water bays developed for shipping.

From the coast the land surface gradually rises to a height of about 300 m near the 17th and 18th parallel of south latitude. Here the higher lands form the watershed between the seaward-flowing streams and those which flow - mainly after heavy rainstorms - to the interior. Over a wide area towards the south the land elevation is about 600 m with several mountain ranges generally trending east-west. Mount Zeil (1 510 m) in the MacDonnell Ranges is the highest peak.

In the southwest there are a number of dry salt lakes, the largest of which is Lake Amadeus. Large areas of the interior are semi-desert, particularly in the west, and the Simpson Desert occupies the southeast portion of the Territory; but in the north, and on the Barkly Tableland in the northeast, there is plenty of good pasture. The climate in the northern part is monsoonal: rain falls mainly during the northwest monsoon between December and February, and tropical thunderstorms are experienced in the interior during the same period. The vegetation in the higher rainfall regions of the north shows strong affinities with that of Indonesia and Southeast Asia, but there are only very limited stands of rainforest. Cypress, ironwood, bloodwood, and paperbark trees are cut and milled for local use in the coastal areas. On the Barkly Tableland and part of the Victoria River district there are good natural pastures for cattle grazing and some shrubs. The sandy plains between the Barkly Tableland and the MacDonnell Ranges are covered by spinifex grass. The most common grass is the annual sorghum, which in places grows to a height of about 3 m during the wet season.

* By G.W. D'Addario, Bureau of Mineral Resources, Geology & Geophysics, Canberra; published with the permission of the Director.

Darwin is the capital of the Northern Territory, with a population of 32 943 (1970). It is the administrative centre for the whole Territory and one of the ports of entry into Australia for aircraft arriving from Europe and Asia. It was the site of the first permanent white settlement in 1869. Other principal centres are Alice Springs, Tennant Creek, Katherine and Nhulunbuy. The population of the Territory, including aborigines, totalled 71 383 at the Census of June 1970.

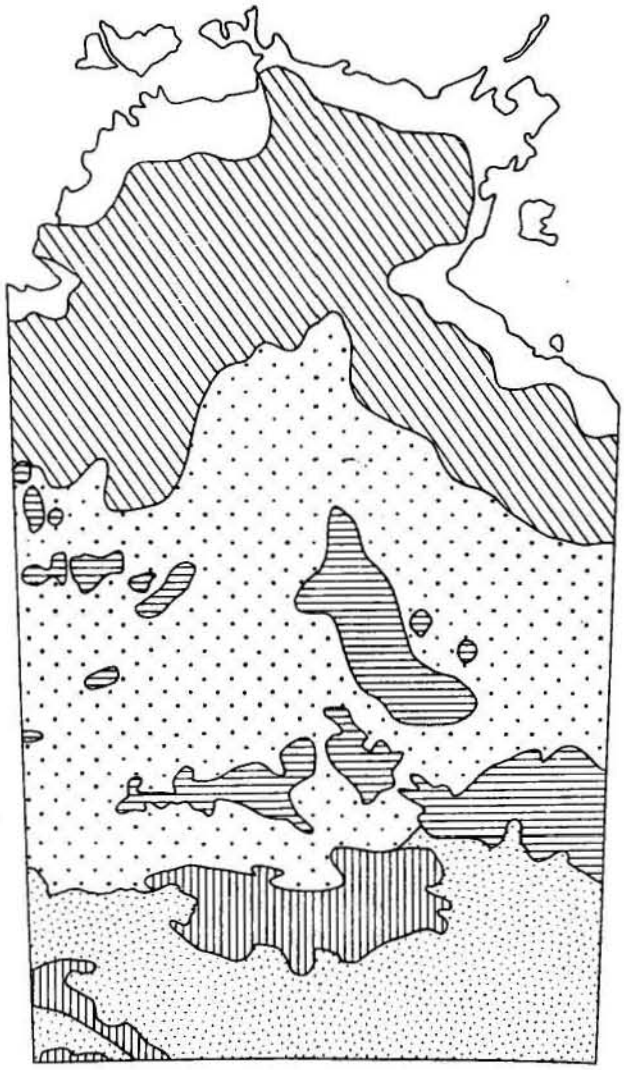
A 1530-km bitumen-sealed road, the Stuart Highway, links Darwin to Alice Springs. The Barkly Highway, 648 km long, connects Mount Isa in western Queensland to Tennant Creek; it joins the Stuart Highway some 26 km north of Tennant Creek.

Railways connect Darwin to Larrimah (500 km) and Alice Springs to Marree in South Australia (800 km).

Itinerant Malayan and Macassaran trepang-fishers used to visit the coast in the past, but they never settled for long. The first known European contact with the coast was made in 1923 by the Dutch ship Arnhem. Tasman surveyed the coast in 1644 and named a number of features, including Groote Eylandt. Flinders charted part of the coastline of Arnhem Land in 1803. Leichhardt, the first explorer, reached Port Essington in the Cobourg Peninsula after travelling overland from the east in 1845. In 1855-56 Gregory landed near the mouth of the Victoria River, in Bonaparte Gulf. He travelled 480 km southwest, returned to the lower Victoria River, and from there took a route parallel with the coast but some distance inland until he reached the eastern coast of Australia.

Stuart was the first explorer to cross Australia, through its centre, from south to north. In his first attempt, in 1860, he passed Tennant Creek and then returned by the same route. In 1861 he penetrated as far north as Newcastle Waters, and in his third attempt, in 1862, he reached the Van Diemen Gulf.

In 1872, the overland telegraph line from Adelaide to Darwin was completed. Giles explored the country west of the telegraph line in 1872-74. After exploring part of the northwest of Australia, Forrest moved eastward and reached the overland telegraph line in 1879. From 1860 to 1863 the Northern Territory was administered by New South Wales; from 1863 to 1910 by South Australia; and since 1911 by the Commonwealth Government.



PHYSIOGRAPHIC ZONES OF THE NORTHERN TERRITORY

SCALE
100 0 100 200 300 400 500 Kilometres
100 0 100 200 Miles

*Coastal plain*
*Dissected margin*
*Central plateau*
*Central ranges and uplands*
*Southern ranges*
*Southern deserts*

Fig. 2

History of Geological Investigations

Chewings was the first geologist to visit central Australia, in 1886. In 1889, East made geological observations along the telegraph line and between Alice Springs and the Harts Range 130 km northeast of Alice Springs; Brown in 1889 visited the area south of Alice Springs and Hale River 120 km east-northeast of Alice Springs, and recognized that sedimentary rocks unconformably overlie metamorphic and plutonic rocks. Brown and Thornton found fossils in the Amadeus Basin in 1890. Tate in 1882 and Tenison Woods in 1886 visited the Katherine-Darwin Region and produced records accompanied by geological sketch maps. Carnegie explored part of the southwest on a journey from Halls Creek to Coolgardie in 1897.

In 1901, the South Australian Government sent prospecting expeditions into the southwestern corner of the Northern Territory. Basedow led a prospecting and geological expedition into the southwest in 1903. In 1905 and 1908, George led a government prospecting expedition into the southwestern corner of the Territory and in 1912, after the Commonwealth had taken control of the Territory, Woolnough reconnoitred the Katherine-Darwin region; this was followed by the establishment of a small geological survey. Many investigations have been carried out since by government and company geologists and geophysicists.

In 1934 the Commonwealth, Queensland, and Western Australian Governments initiated the Aerial, Geological and Geophysical Survey of Northern Australia. This work was interrupted by the Second World War.

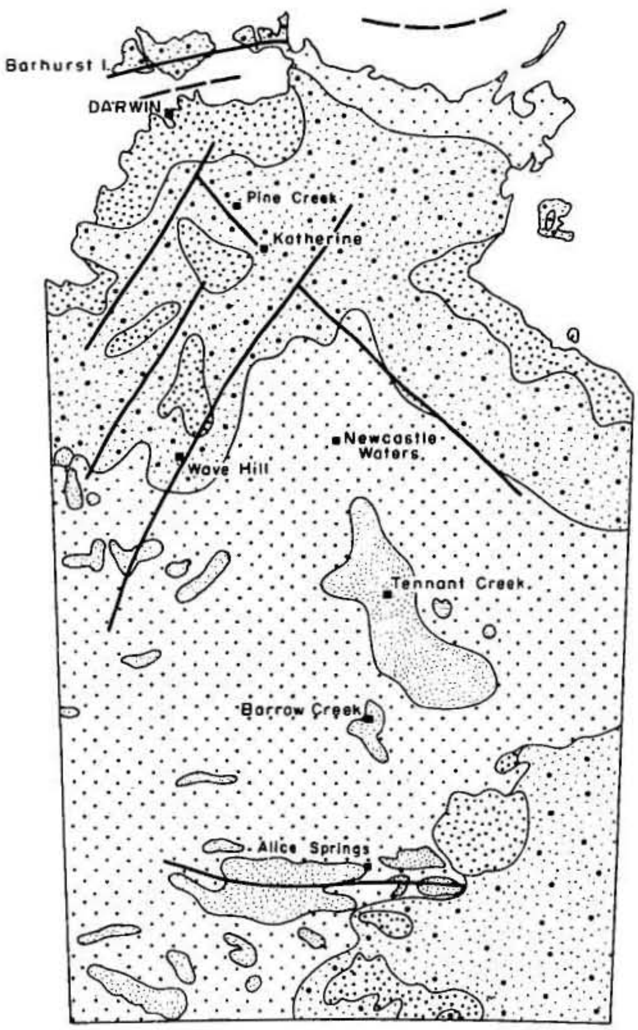
Noakes of the Bureau of Mineral Resources (BMR) compiled the first geological map of the Katherine-Darwin region in 1949.

From 1950 onwards, BMR field parties have carried out reconnaissance surveys, regional mapping, and airborne and ground geophysical surveys in the Territory, and from 1970 this work has continued in collaboration with the newly formed Northern Territory Geological Survey.

## Physiographic Zones

The Northern Territory can be divided into the following six physiographic zones from north to south (Fig. 2):

The Coastal Plain: The coastal plain is almost 150 km wide southeast of Darwin; in the Joseph Bonaparte Gulf and the Gulf of Carpentaria it has a maximum width of about 80 km; along the Arnhem Land coast it seldom




## LAND SURFACES OF THE NORTHERN TERRITORY

SCALE
100 0 100 200 300 400 500 Kilometres
100 0 100 200 Miles

- Residuals of early Cretaceous erosion surface (rising from late Cretaceous to middle Tertiary surface)
- Late Cretaceous to middle Tertiary surface (erosional and depositional)
- Miocene - Pliocene surface with residuals of late Cretaceous to middle Tertiary surface
- Pliocene - Pleistocene surface with residuals of older surfaces
- ——— Upwarp
- — — — Downwarp

Fig. 3

exceeds 30 km and is less than 2 km wide in places. Inland elevations range up to 80 m. Relief is low, with scattered low hills. Streams meander across the plain and generally merge into swamps.

Dissected Margin: Between the coastal plain and the central plateau is a dissected margin between 150 km and 300 km wide. It comprises the valleys of the tributaries of the Victoria River, with elevation between 25 m and 60 m above sea level, and the extensive plains and undulating terrains, with relief generally less than 15 m, along the Daly River. On the border streams have produced local relief up to about 180 m by carving narrow, steep-sided structurally controlled valleys.

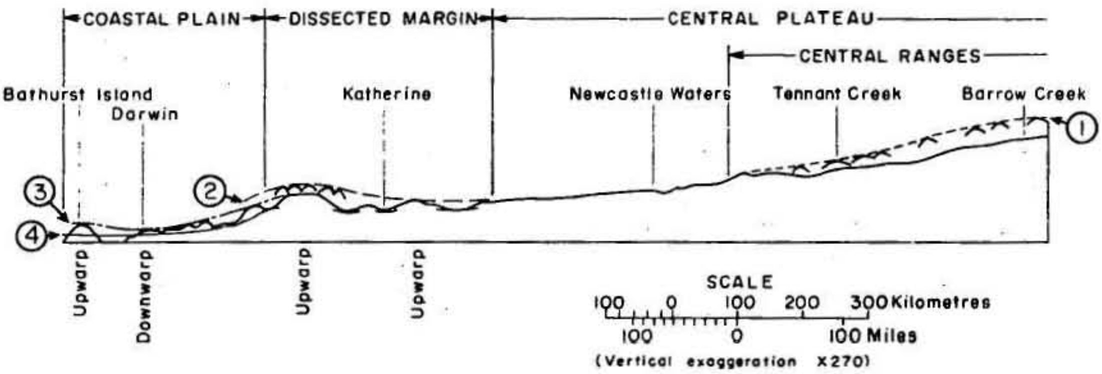
Central Plateau: Extensive plateaux and plains cover more than two-thirds of the total area. They form flat to gently undulating surfaces ranging in elevation from 180 m in the north to about 700 m above sea level in the centre. Drainage is internal.

Central Ranges and Uplands: The central ranges with heights from less than 15 m to about 150 m, in the centre and in the west, rise above the plains of the central plateau and in places are separated from them by steep scarps. Bevelled and plateau-like uplands extend from east to west, north of Alice Springs, with relief not exceeding 150 m.

Southern Ranges: The southern ranges occupy the southwest corner of the Territory and the area just south of Alice Springs, where they form an almost unbroken east-west belt about 500 km long and 100 km wide. They consist of parallel strike ridges. To the west summits are between 850 m and 900 m; relief is commonly up to 250 m, and on the northern end of the ranges relief exceeds 300 m at Mount Zeil (1510 m), the highest mountain in Central Australia.

Southern Deserts: Much of the landscape in the remaining southern portion of the Northern Territory is covered by dunes. In the east it includes part of the Simpson Desert with its SSE-NNW sand dunes, isolated plateaux and ranged near the western margin of the Simpson Desert, and salt pans and limestone plains farther west; in the north are sand plains and in the south are fringing granite hills and plains of the Mann and Musgrave Ranges. All drainage except the Finke River is internal; the Finke flows southeast into Lake Eyre in South Australia.

SCHEMATIC SECTION SHOWING THE NORTHERN TERRITORY LAND SURFACES AND THEIR RESIDUALS




① *Residuals of early Cretaceous erosion surface rising from late Cretaceous to middle Tertiary surface*

② *Late Cretaceous to middle Tertiary erosional and depositional surface*

③ *Miocene - Pliocene surface with residuals of late Cretaceous to middle Tertiary surface*

④ *Pliocene - Pleistocene surface with residuals of older surfaces*

*To accompany Record 1972/91* *NT/A361*

Fig. 4

8

## Land Surfaces

Four mature erosion surfaces have been distinguished in the Northern Territory (Figs 3 and 4).

Early Cretaceous Erosion Surface: The oldest and highest surface lies within the central plateau. It ranges in height from about 250 m above sea level in the north to about 550 m inland. Residuals are widely and irregularly distributed. The surface is best developed in the ranges which surround Tennant Creek. It has not been traced continuously west of Tennant Creek and is absent from large areas of the plateau, but is represented in the summits of scattered ranges in the southwest and in the extreme west.

Late Cretaceous to Middle Tertiary Surface: This surface is most extensively developed on the central plateau. Exposures are abundant in areas of active erosion, such as the central ranges and the rim of the plateau in the north. Northward from Tennant Creek, where it stands at about 350 m above sea level, the surface falls gently and then rises a little into the dissected margin, where it reaches the maximum height of 180 m above sea level. It is an erosional surface in most of the dissected margin. Its age ranges from late Cretaceous in the south to early or mid-Tertiary in the north.

Miocene-Pliocene Surface: This is a surface of advanced erosion and is developed in the dissected margin, where it stands lower than and encroaches upon the late Cretaceous to mid-Tertiary Surface. Local relief is restricted to particularly resistant structures. In its best preserved state the surface extends around Wave Hill at an altitude of 180 m. To the north the surface has been dissected by headwaters of the Victoria and Daly Rivers and survives as dissected plains or in accordant hill summits. It has been traced northwestward sloping gently towards the Joseph Bonaparte Gulf. To the northeast the surface rises to 300 m above sea level.

Pliocene-Pleistocene Surface: This multicyclic surface with lateritization still active is developing at present in the coastal areas and in a few inland basins on rocks of all ages from Lower Proterozoic upwards.

Warping: Mild deformation and broad warping have affected the Northern Territory since Cretaceous sedimentation began. In Figure 3, two major upwarp axes, which parallel the boundary of the late Cretaceous to middle Tertiary surface, mark tectonic features which have been active since Lower Proterozoic and have controlled the north Australian coastline. Subsidiary axes of warping, west of the two main converging axes, coincide with axes of gentle folds. The Van Diemen Gulf is the result of downwarping on an

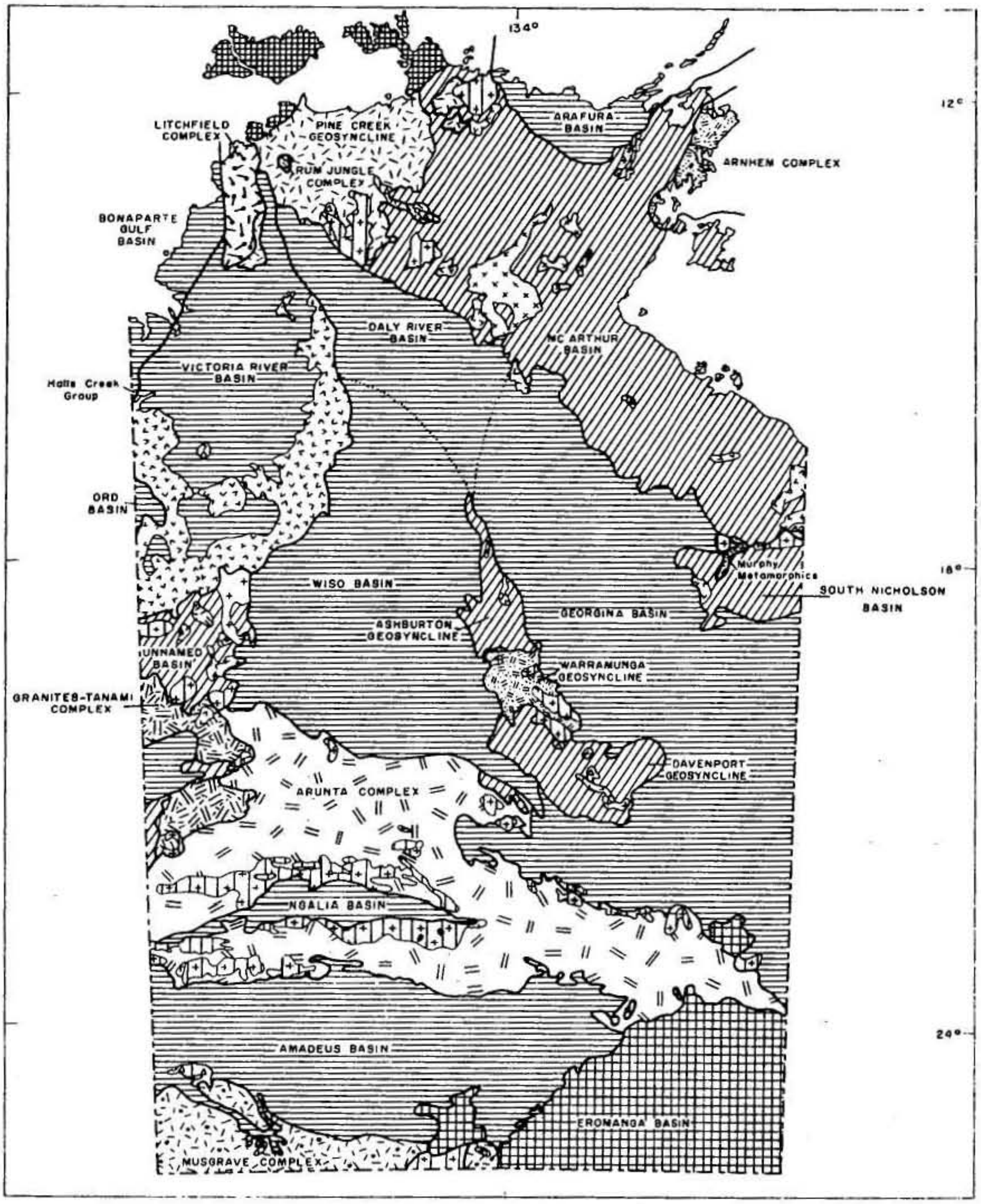
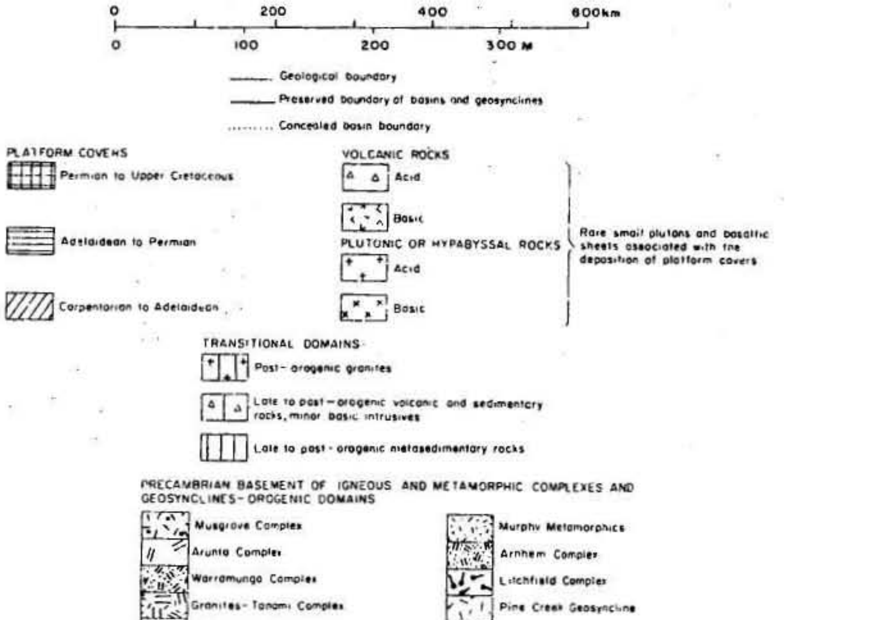



Fig 5 TECTONIC UNITS OF THE NORTHERN TERRITORY

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east-northeast axis. In the southern ranges, near Alice Springs, there is evidence of broad post-Cretaceous updoming, with greater uplift towards the west. In the north the Miocene-Pliocene surface slopes northwards and westwards towards Joseph Bonaparte Gulf, except for that section of the dissected margin northeast of Katherine; the elevated position here is due to uplift which postdated the late Cretaceous to middle Tertiary surface. In the southern portion of the Northern Territory, the Miocene-Pliocene surface falls to the south and east owing to late Tertiary subsidence of the Lake Eyre basin in South Australia.

## Stratigraphy

The general distribution of the major rock assemblages within the Northern Territory is shown in Figure 1 and the tectonic units in Figure 5; for each broad structural element the stratigraphic sequences, major intrusions, and periods of folding are schematically represented in columnar sections in Figure 6.

### ARCHAEAN (older than 2 400 million years)

Small inliers of Archaean rocks are exposed in Proterozoic terrain in the northwestern and northeastern parts of the Territory. Rock types include migmatite, gneiss, and altered basic volcanics. Rum Jungle is one of a few places in Australia where the contact of the Archaean with Lower Proterozoic is exposed.

The Rum Jungle Complex occupies the core of an eroded dome of low-grade metasediments. It consists of schist, gneiss, granite, metadiorite, and minor banded ironstone. During a late period of folding and low-grade metamorphism, the metasediments were domed around the granitic basement. The granite has been dated at 2 450 million years.

The Arnhem Complex (Archaean-Lower Proterozoic) is a basement inlier of igneous and metamorphic rocks exposed within the McArthur Basin. It consists of granite, gneiss, and granulite.

The Litchfield Complex (Archaean-Lower Proterozoic) is an elongated belt of metamorphics and granite west of the Pine Creek Geoysncline. It is formed of schist, granulite, and amphibolite, intruded by granite, migmatite, and dolerite.

NORTHERN TERRITORY
TECTONIC DOMAINS AND STRATIGRAPHIC SECTIONS

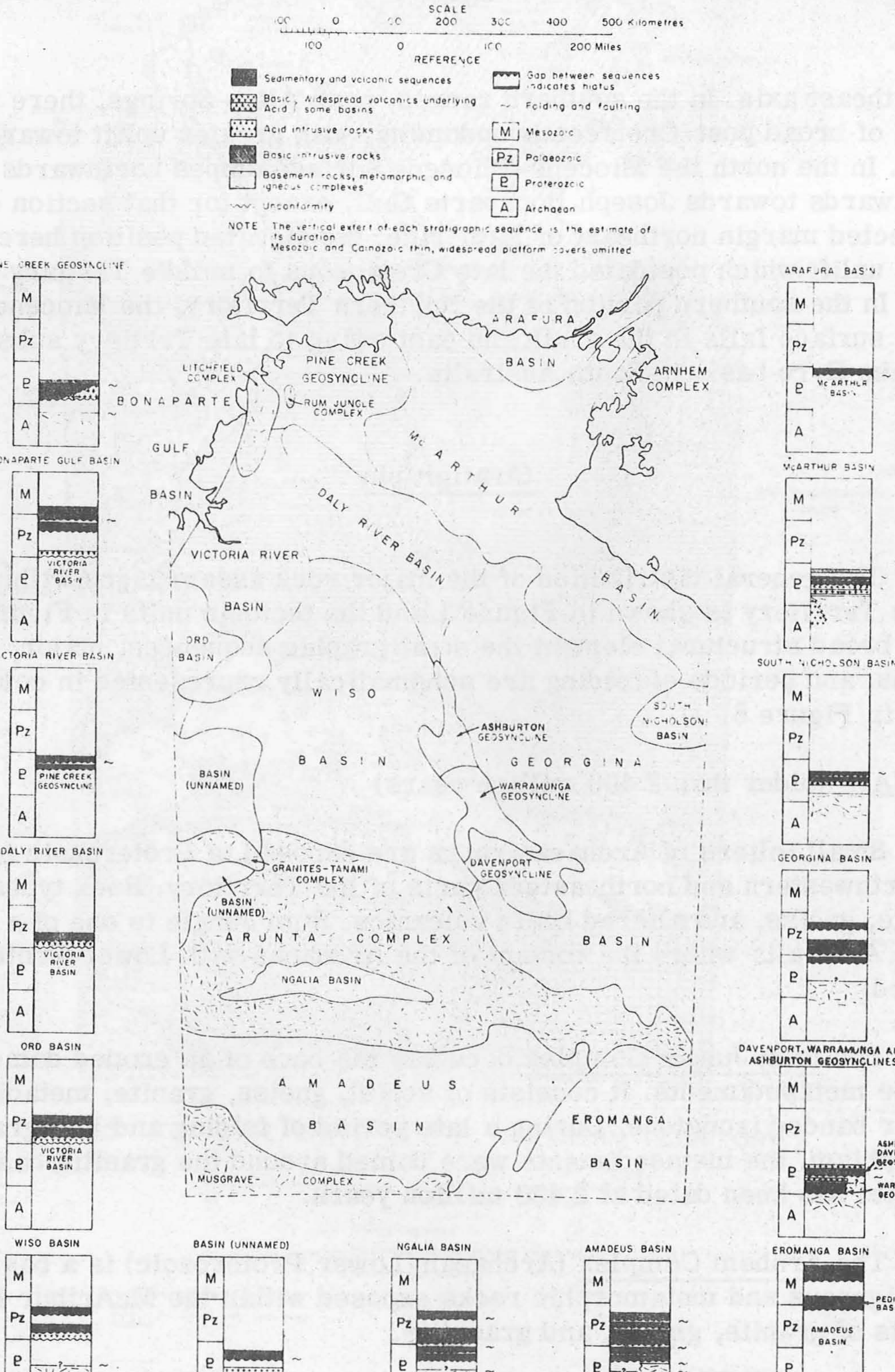


Fig. 6

The Halls Creek Group (Archaean-Lower Proterozoic) is not shown on the map, but its rocks crop out where the Victoria River Basin crosses the Western Australian border. It comprises deformed Archaean basic volcanics, quartz-rich conglomerate and greywacke, and shale and dolomite; these have been metamorphosed and intruded by acid and basic plutons.

## PROTEROZOIC

### Lower Proterozoic (2 400 - 1 800 m.y.)

Lower Proterozoic rocks crop out in three main areas: between Katherine and Darwin, in the Granites-Tanami Complex, and in the Tennant Creek area; they also crop out in a small area between the McArthur Basin and the South Nicholson Basin. In the area between Katherine and Darwin, Lower Proterozoic sediments were laid down in the Pine Creek Geosyncline, a composite, fairly shallow intracratonic structure which developed in stages over the Archaean basement. Arkose, quartz-greywacke, siltstone, chert, and dolomite, at least 3 000 m thick, were deposited before secondary troughs were formed along both sides of the geosyncline. Greywacke 2 800 m thick accumulated in the western trough and about 6 000 m of dolomite, chert, and carbonaceous rocks overlain by siltstone and greywacke siltstone in the eastern trough. Finally 1 300 m of sandstone was deposited on a newly developed platform along the western margin of the geoysncline extending southwest into the Victoria River area.

The rocks of the Granites-Tanami Complex (Archaean-Lower Proterozoic) comprise schist, phyllite, chert, dolomite, shale, and quartzite with some acid and basic volcanics and greywacke, locally intruded by granites. In the Tennant Creek area, the Warramunga Geosyncline deposits consist of at least 1 500 m of a greywacke-shale assemblage overlain by ignimbrites and intruded by massive and foliated granite and adamellite complexes and by granite porphyry.

In the Davenport Range, south of Tennant Creek, is a sequence of 7 500 m of quartz sandstone, argillaceous towards the base of the sequence, with porphyritic rhyolite, andesite, and basalt flows. In the Ashburton Range, north of Tennant Creek, a sequence more than 3 300 m thick is very similar to and coeval with the sequence of the Davenport Range. Those rocks were probably formed in secondary basins (Ashburton and Davenport Geosynclines) marginal to the Warramunga Geosyncline.

The Murphy Metamorphics (2 180-1 900 m.y. old) represent geosynclinal pelitic and quartz-feldspathic sedimentary rocks and volcanics, which were isoclinally folded about an east-west axis, subjected to low-grade regional metamorphism, and intruded by granite.

Lower to Upper Proterozoic

The Arunta Complex consists of metamorphic rocks which were deformed before and after the deposition of the sediments in the Amadeus Basin. Rock types present are granulite, schist, gneiss, amphibolite, calc-silicate rocks, and quartzite, which are intruded by acid and basic igneous rocks (granulites: 2 250 m.y. old?; metamorphism and granites: 1 800-1 300 m.y. old).

Upper Proterozoic

The Upper Proterozoic is subdivided into Carpentarian and Adelaidean systems. The Carpentarian System has a base dated at about 1 800 m.y. and the base of the Adelaidean is taken at about 1 400 m.y.

Rocks of the Carpentarian System crop out over wide areas in northern Australia. They have generally been little fo ded and rest on steeply dipping Lower Proterozoic beds. They consist mainly of sandstone, shale, dolomite, and limestone, with volcanics prominent towards the base, and are well developed near the Gulf of Carpentaria, after which the system is named. More than 8 500 m of arenite and carbonate sedimentary rocks are part of the sequence in the McArthur Basin, which is referred to as the type sequence of the Carpentarian System.

In the South Nicholson Basin over 6 000 m of mud, silt, and glauconitic sand accumulated. This sequence is equivalent to the upper part of the sequence deposited in the McArthur Basin.

In the Musgrave Complex highly feldspathized and granitic quartzite and gneiss of granulite facies (1 600 and 1 300 m.y. old), associated with large-scale intrusions of granite, charnockite, and pegmatite, are separated by a major thrust from gneiss of amphibolite facies (1 200 m.y. old) intruded by coarse porphyritic granite, even-grained granite, and quartfeldspar porphyry (1 170 m.y. old).

Adelaidean sediments were laid down in the Arafura and Victoria River Basins and possibly over the Granites-Tanami Complex and constitute the basal formations of the Ngalia, Georgina, and Amadeus Basins.

In the Victoria River Basin, over 2 000 m of quartz sandstone, siltstone, and dolomite are separated by a major north-northeasterly fault from a possibly older sequence, almost entirely of sandstone and more than 3 600 m thick.

In the Arafura Basin more than 1350 m of terrigenous stable shelf sediments consisting of quartz sandstone and shale lie unconformably on older units of the McArthur Basin.

An unnamed basin between the Granites-Tanami Complex and the Wiso Basin contains over 5 000 m of sandstone, conglomerate, shale, siltstone, and stromatolitic chert. They rest with strong angular unconformity on probably lower Carpentarian granite and Archaean-Lower Proterozoic basement (Granites-Tanami Complex). The sedimentary rocks form structural domes and basins separated by irregularly deformed areas. Dips range from gentle to very steep. The rocks of the basin are overlain unconformably in the north and east by flat-lying Cambrian volcanic rocks and sedimentary rocks of the Wiso Basin.

In the Ngalia Basin, an intracratonic depression within the Arunta Complex, much of the sequence is concealed by superficial Cainozoic deposits up to 180 m thick. A maximum thickness of sediments of 6 500 m has been indicated in the western part of the basin by aeromagnetic studies and confirmed by seismic surveys. The basal formations of the basin consist of quartzite, with interbeds of siltstone and fine sandstone in its lower part, overlain by sandstone, siltstone, tillite, and dolomite.

The Georgina Basin, northeast of the Arunta Complex, also contains Adelaidean sediments. A glacigene unit at the base consists of siltstone with some striated boulders up to 1 m in diameter, quartz sandstone, and dolomite. A sequence of shale, quartz sandstone, siltstone, and dolomite 1 500 m thick overlies the glacigene unit. The sequence was derived in part from the Arunta Complex and contains Cambrian fossils near its top.

The Amadeus Basin, which is bounded on the north by the Arunta Complex and on the south by the Musgrave Complex, contains about 2 500 m of Precambrian quartzite and carbonate rock overlain by sandstone, siltstone, shale, limestone, dolomite, and glacigene sediments equivalent to those in the Georgina Basin.

PALAEOZOIC

Basic volcanics up to 1 000 m thick (Antrim Plateau Volcanics) flooded across much of the northwestern part of the Northern Territory and northeastern Western Australia soon after the beginning of the Cambrian. They are overlain by Middle Cambrian marine limestone, shale, and sandstone of the Daly River Basin and by Middle Cambrian interbedded shale and thin bedded limestone and Devonian sandstone of the Ord River Basin. Breaks in sedimentation from Silurian to Middle Devonian were caused by uplift and erosion without deformation; the Northern Territory during that time was mostly land, probably with moderate relief. In the Bonaparte Gulf Basin a carbonate and arenite sequence was laid down on the basic volcanics in the Devonian and Carboniferous followed by a paralic sequence in the Permo-Triassic. In the Georgina Basin, Middle Cambrian carbonate rocks are widespread, but Upper Cambrian, Ordovician, and Devonian freshwater sequences are restricted to the southern part of the basin. The northwestern margin of the basin is obscured by Mesozoic sediments. Cambrian and Middle Ordovician sedimentary rocks consist predominantly of carbonate rocks; the Middle Ordovician sequence mainly of sandstone and siltstone; and Devonian formations of sandstone. In the Wiso Basin the oldest rocks are dolomite, limestone, and dolomitic siltstone of lower Middle Cambrian age. In a trough in the southern half of the basin, Lower to Middle Ordovician dolomite and sandstone are overlain unconformably by Devonian sandstone. The relation between the Cambrian and Ordovician rocks is unknown. Tentative structural and stratigraphic comparisons with the neighbouring Georgina Basin and consideration of the geophysical evidence indicate that thicknesses of sedimentary rocks in the trough may be of the order of 3 000 m or more.

In the Amadeus Basin during the Cambrian thick conglomerate and arkose were deposited in the southwest, and sand, shale, and some marine sediments to the northeast. The basal sandstone in the northeast was succeeded by 2 000 m of carbonate rocks, lutite, and evaporite deposits which were followed by penesaline and marine stromatolitic carbonate rocks. Only minor facies changes occur across the central zone. Ordovician sandstone, shale, and minor carbonate rocks overlie the basal formations conformably in the north and unconformably in the south. The maximum thickness of Ordovician sandstone and siltstone on the northern margin of the basin is about 2 500 m. Broad vertical movements started in the Silurian. Devonian sandstone up to 900 m thick, partly shallow marine and partly fluvial and aeolian, crops out throughout the basin. A major upheaval was followed by late Devonian molasse-like fluvial and lacustrine sedimentation which persisted into the early Carboniferous, and by a major orogeny in the Carboniferous. These sedimentary rocks are over 3 000 m thick on the northern margin of the basin and are unconformably overlain by Permian glacials.

In the Ngalia Basin, Cambrian dolomite, siltstone, and minor sandstone are over 300 m thick, Ordovician sandstone about 1 000 m thick, and Carboniferous sandstone 2 000 m thick.

MESOZOIC

Mesozoic rocks are found over most of the northern part of the Northern Territory and in the southeast on the western fringe of the Eromanga Basin, whose sediments overlap the succession in the Amadeus Basin. In the north, Lower Cretaceous marine and non-marine rocks crop out, mainly as isolated residual mesas, or as broad flat tablelands. They consist of conglomerate, sandstone, siltstone, and claystone, strongly lateritized, and are no more than about 60 m thick on the mainland, though they are considerably thicker and slightly inclined on Melville and Bathurst Islands. They have not been folded, but in a few places are cut by minor faults. In the southeast, the Eromanga Basin sequence consists of up to 1 500 m of flat-lying to very gently folded Lower Jurassic to Upper Cretaceous fluvial and shallow marine sedimentary rocks. These rocks in places form highly weathered residuals separated by large tracts of fluvial and aeolian sand cover. Basement to the Eromanga Basin includes the Upper Proterozoic sequences of the Amadeus and Georgina Basins, possible Devonian sedimentary rocks, and Permo-Triassic sedimentary rocks of the Pedirka Basin.

CAINOZOIC

During the Cainozoic, older rocks have been deeply weathered, and laterite and soil profiles have developed. Along stream courses and in low-lying coastal areas, alluvial detritus, sand, colluvial rubble, and in small areas marine sediments accumulated. In some places in central Australia a few hundred metres of valley fill includes Mesozoic and overlying Tertiary sediments within the large salt lakes.

## Structure

The older metamorphic and igneous complexes and thick flysch-like deposits accumulating in extensive troughs of intracratonic geosynclines were strongly deformed between 2 200 and 1 900 million years ago. These orogenic domains in the Northern Territory are the Rum Jungle, Granites-Tanami, Arnhem, Litchfield, Arunta, and Musgrave Complexes, the Halls Creek Group and Murphy Metamorphics, and the Pine Creek and Warramunga Geosynclines.

Late to post-orogenic events accompanied by moderate deformation between 1 900 and 1 750 million years ago include the deposition of molasse-like sequences with abundant plutonic and volcanic rocks and rare metamorphism. Rocks of these transitional domains unconformably overlie the immediately preceding orogenic domain and in the Northern Territory are associated with the Pine Creek and Warramunga Geosynclines; in some places to the north and northeast they are represented by post-orogenic granites.

Deformation following cratonization involved the deposition in the Northern Territory of parts of three succeeding platform cover domains, each represented by its own group of sedimentary basins with rare plutons and associated basaltic sheets: from earliest Carpentarian to early Adelaidean the Ashburton and Davenport Geosynclines, the McArthur and South Nicholson Basins, and the unnamed basin of the North Australian Platform Cover; from early Adelaidean to Permian the Victoria River, Arafura, Amadeus, Ngalia, Daly River, Georgina, Wiso, Ord, and Bonaparte Gulf Basins of the Central Australian Platform Cover; from earliest Permian to Upper Cretaceous the Bonaparte Gulf Basin (offshore part only), and Pedirka and Eromanga Basins of the Trans Australian Platform Cover. Development in each group is similar and broadly contemporaneous, and the deposits overlie unconformably the immediately preceding sequences of the orogenic domains and associated transitional domains and spread across older basement rocks.

Rocks of the Pine Creek Geosyncline were folded along axes generally trending between 300° and 360°; the trend of the fold axes follows the trend of the margins of the geosyncline, but was locally modified by basement inliers. High-angle reverse and normal faulting accompanied the folding and was mainly parallel to the fold axes. Regional metamorphism of the sediments was generally very low-grade. The dolerite sills emplaced both before and after folding were metamorphosed to greenschist and amphibolite facies. Rocks of the Warramunga Geosyncline are intersected by a major northwest-trending shear zone. To the south and west of this zone folds have east-west axes and the dips average about 60°; to the east and north folding is generally more open and the dips are from 30° to 45°.

The McArthur Basin is characterized by a trough in the axial part of the basin, flanked by platforms to the west and the east. During Carpentarian time, uplift and erosion of the margin of the basin interrupted sedimentation. A local positive block separates this basin from the South Nicholson Basin. Deposition was continuous only in the median part of the McArthur Basin, with rapid subsidence between two north-trending hinge-lines. Minor folding and faulting in the early Adelaidean brought deposition in both McArthur and South Nicholson Basins to a close.

The Bonaparte Gulf Basin is a simple and fairly symmetrical structure and the morphology of its offshore surface corresponds with the depth to magnetic basement. The major structural elements are step faults and block faults, and folds are rare. The basin began to subside in the early Cambrian at approximately the same time as the Ord and Daly River Basins. Widespread mild vertical movements took place in late Devonian, early Carboniferous, Triassic, and early Cretaceous times and warping in the Tertiary. Sediments, generally undisturbed over most of the Victoria River Basin, have a gentle regional dip to the northwest, but they are deformed close to a large north-northeast thrust fault, with the basin succession on the northwest side of the fault forming a belt of relatively highly deformed rocks. Deformation is predominantly by faulting. Folds are generally broad with bedding dips rarely greater than 45°; vertical bedding is common near the major fault, where some strata are overturned.

In the Georgina Basin faulting predominates over foldings, and most of the visible folds are related to the faulting. Faults which affected the Middle Cambrian sedimentary rocks along the northern margin of the basin tend west-southwest, parallel to other fault systems in the basement to the north. In the southern part of the basin some mild fault movements have affected the Middle Cambrian sedimentary rocks. Faulting predominates in the post-Devonian tectonism in the western and southwestern parts of the basin, and the major structures are parallel faults. They trend parallel to the major northwesterly trend in the Precambrian crystalline rocks and to the major faults in them. These major faults have produced two major asymmetrical synclines in the basin, with steep dips on the southwestern flanks flattening out rapidly to the northeast.

Conditions in the Upper Cambrian, at least in the southeast part of the Wiso Basin, were similar to those in the Georgina Basin. Uplift of part, if not all, of the Wiso Basin and erosion of Ordovician (and perhaps Cambrian in the west) rocks resulted from the increasing tectonic activity during the Cambrian and Ordovician Periods. The south of the basin subsided during the late Devonian. Tectonic activity culminated in the latest Devonian and appears to have been concentrated in the southern part of the basin. Faulting in this area probably delineated the present-day outline of the southern margin of the basin.

Several unconformities have been recognized in the Ngalia Basin succession, which is not as complete as that in the Amadeus Basin although it is considered that deposition began in both regions at about the same time. Faulting has been related to the epeirogenic movements which gave rise to the observed unconformities. A major disturbance occurred during the

Carboniferous, when the sedimentation ceased. This event was almost certainly equivalent to the orogeny which affected the Amadeus Basin, and resulted in the folding and overthrusting of rocks in the northern Ngalia Basin, while the southern equivalents were merely tilted and block faulted. Regional anticlinoria of metamorphosed basement rocks separate the Amadeus Basin from the Ngalia Basin and Georgina Basin.

The Amadeus Basin is a downwarp lying between the anticlinoria. Nappe structures, involving both basement rocks and sedimentary cover rocks, occur on the southwestern, northern, and northeastern margins of the basin. All the nappes front towards the basin. The sedimentary rocks of the Amadeus Basin are strongly folded. There are two major unconformities: a folded unconformity in the late Adelaidean, and another in the Carboniferous. Major thrusts occur within the anticlinoria of basement rocks north and south of the Amadeus Basin. Where they cut the Proterozoic strata on the northern margin of the basin, displacements of a few thousand metres are suspected. Throughout the Northern Territory, Mesozoic sedimentary rocks are mostly flat-lying or have been gently warped during the Cretaceous and the Cainozoic.

## Palaeontology

Substantial numbers of faunal assemblages are known in the Northern Territory, but many localities have yet to be studied in detail.

Few of the primitive forms of life left recognizable traces in Proterozoic rocks. Stromatolites (algae) are common from the Lower Proterozoic sequence of the Pine Creek Geosyncline and the Carpentarian sequence of the McArthur Basin, where also large oncolites (also presumed to be algae) have been found. Some forms were also identified in the Adelaidean sequence of the Amadeus Basin, where microfossils including bacterium-like organisms, blue-green algae, and fungi have also been recognized. Skolithos (trace fossils: burrows) occur in the late Adelaidean sequence of the Arafura Basin.

Lower Cambrian archaeocyathids, algae, and sponges are found in rocks of the southern part of the Northern Territory. Middle Cambrian trilobites occur in the Bonaparte Gulf, Ord, Daly River, and Georgina Basins. Ordovician graptolites occur in the Georgina, Amadeus, and Bonaparte Gulf Basins. Lower Ordovician nautiloids occur in the Georgina and Amadeus Basins as well as trilobites, brachiopods, and conodonts. Upper Devonian brachiopods and plant fossils, Permian brachiopods, marine molluscs, and land plants have been described from the Bonaparte Gulf Basin. Lower Cretaceous ammonites were collected near Darwin. Tertiary marine sediments contain polyzoans, foraminifera, pelecypods, gastropods, echinoderms, and many other forms of marine animal life. Vertebrates are well represented by fish, reptiles, sharks' teeth, birds, and marsupials.

## Economics

Remoteness from potential markets hampered the mineral development of the Northern Territory in the past. Most of the economic deposits of gold, copper, silver, lead, zinc, tin, tungsten, and uranium in a mineral province between Katherine and Darwin are in Proterozoic rocks and, with the possible exception of the uranium deposits, are related to granite intrusions. In the mineral province in and around Tennant Creek, gold-copper mineralization is possibly associated with igneous Proterozoic rocks. Between the Barkly Tableland and the southwestern coast of the Gulf of Carpentaria a large zinc-lead deposit has been found in pyritic shale at McArthur River; but the ore is fully disseminated, and problems of beneficiation have not been solved as yet.

Mining in the Katherine-Darwin metalliferous province commenced before the turn of the century. Further prospecting was stimulated in 1949 and again in 1970 by uranium discoveries. Uranium reserves have not yet been fully delineated, but the recent discoveries indicate that Australia will become one of the world's leading uranium producers. Copper, gold, and bismuth are produced from a group of mines near Tennant Creek, where some of the deposits were originally worked for gold only. Large-scale copper mining began in 1952, and more copper-gold deposits have since been discovered. At the Warrego mine a 5-million ton orebody is being developed for production.

Bauxite deposits are known at Gove Peninsula and Marchinbar Island on the western side of the Gulf of Carpentaria. Proved reserves at Gove Peninsula are about 250 million tons; reserves at Marchinbar are very much smaller. Small lateritic nickel deposits are known in the south-west of the Territory, near the border with Western Australia and South Australia. Several manganese deposits are present on Groote Eylandt in the Gulf of Carpentaria. They occur as flat-lying or gently dipping seams of pisolitic ore, mixed with lower-grade manganiferous material. Proven reserves exceed 50 million tons, and large-scale production began in 1966.

Coal seams have been intersected in boreholes and oil exploration wells in Lower Permian rocks between the mouths of the Fitzmaurice and Daly Rivers on the eastern coast of the Joseph Bonaparte Gulf. Low-grade lignite has been found in the Santa Teresa area 70 km southeast of Alice Springs. At Mereenie and Palm Valley, west of Alice Springs, gas and oil fields have been discovered in Cambrian-Ordovician rocks of the Amadeus Basin; proven gas reserves are estimated at $1.57 \times 10^{12}$ cubic feet; and proven oil reserves at Mereenie at 60 million barrels. Exploration for oil and gas is continuing, particularly in the offshore Bonaparte Gulf Basin.

Large deposits of phosphate rock occur as beds up to 20 m thick, but mostly thinner, in lower Middle Cambrian rocks around the northwestern margins of the Georgina Basin and in Ordovician rocks of the Amadeus Basin; however, their low grade and distance from a market make them uneconomic at present.

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