A GUIDE TO THE GEOLOGY AND LANDFORMS OF CENTRAL AUSTRALIA

by

R B Thompson

NORTHERN TERRITORY GEOLOGICAL SURVEY

DEPARTMENT OF MINES AND ENERGY
NORTHERN TERRITORY GEOLOGICAL SURVEY

A GUIDE TO
THE GEOLOGY AND LANDFORMS
OF CENTRAL AUSTRALIA

BY
R.B. THOMPSON

Alice Springs 1995
## CONTENTS

**INTRODUCTION**  
1

**GEOLOGY**  
5

- Igneous Rocks  
5
- Sedimentary Rocks  
8
- Metamorphic Rocks  
12
- Faults and Folds  
16
- Fossils  
20
- Gemstones  
25
  - Pegmatite Minerals  
28
- Astrogeology  
29

**LANDFORMS**  
33

- Mountains  
33
- Geomorphology  
36
- Weathering  
37
  - Climate and weathering  
37
  - Weathering  
40
  - Differential weathering  
44
  - Duricrusts  
45
  - Weathering of metamorphic rocks  
48
  - Weathering of igneous rocks  
49
- Erosion  
52
- Dunes  
53
- Drainage  
53

**GEOLOGICAL HISTORY**  
57

<table>
<thead>
<tr>
<th>Era</th>
<th>Time Period</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Formation of the Earth</td>
<td>4550 Ma</td>
<td>57</td>
</tr>
<tr>
<td>Proterozoic</td>
<td>2500 - 570 Ma</td>
<td>57</td>
</tr>
</tbody>
</table>
  - Early & Middle Proterozoic | 2500 - 1000 Ma     | 57   |
  - Amadeus Sea            | 850 - 750 Ma           | 68   |
  - Glacial Period         | 750 and 625 Ma         | 69   |
  - Petermann Orogeny      | 600 Ma                 | 72   |
| Phanerozoic              | 570 - 0 Ma             | 76   |
  - Cambrian               | 570 - 510 Ma           | 76   |
  - Ordovician             | 510 - 435 Ma           | 77   |
  - Silurian               | 435 - 410 Ma           | 77   |
  - Devonian - Carboniferous | 410 - 290 Ma     | 77   |
  - Alice Springs Orogeny  | 350 - 320 Ma           | 80   |
  - Permian                | 290 - 250 Ma           | 81   |
  - Mesozoic               | 250 - 65 Ma            | 81   |
  - Ngalia Basin           |                        | 83   |
  - Wiso Basin             |                        | 84   |
  - Georgina Basin         |                        | 84   |
  - Tertiary               | 65 - 1.6 Ma            | 88   |
GEOLOGICAL FEATURES OF INTEREST IN
CENTRAL AUSTRALIA

Alice Springs Telegraph Station 93
Arltunga 93
Ayers Rock and the Olgas 93
Central Mount Stuart 97
Chambers Pillar 97
Corroboree Rock 100
Devils Marbles 100
Ellery Creek Big Hole 101
Gosse Bluff 104
Heavitree Gap Railway Cutting 105
Henbury meteorite Craters 105
Jessie and Emily Gaps 105
Kings Canyon 106
Mount Conner 108
Ormiston Gorge 108
Palm Valley 109
Rainbow Valley 109
Ross River Section 111
Ruby Gap 112
Simpsons Gap 112
Standley Chasm 113
Trephina Gorge 113

ACKNOWLEDGEMENTS 114
GLOSSARY 115
REFERENCES 123
INDEX 130

FIGURES
1. Geography and 1:250 000 map sheets in central Australia 2
2. Map of structural and depositional areas in central Australia 3
3. Distribution of igneous, metamorphic and sedimentary rocks 6
4. Diagram of common structural elements 17
5. Fossil Development in central Australia 19
6. Development of Gosse Bluff 31
7. Contour map of central Australia 34
8. Diagrammatic map of ranges and mountains in central Australia 35
<table>
<thead>
<tr>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>9. Map of Landform Divisions in central Australia</td>
</tr>
<tr>
<td>10. Geology of north central Australia</td>
</tr>
<tr>
<td>11. Palaeogeography - 1870 - 1860 Ma and 1820 - 1750 Ma</td>
</tr>
<tr>
<td>12. Metamorphism in the central Arunta Inlier</td>
</tr>
<tr>
<td>13. Geology of the Amadeus Basin</td>
</tr>
<tr>
<td>14. Palaeogeography - 850 - 800 Ma &amp; 750 - 700 Ma</td>
</tr>
<tr>
<td>15. Palaeogeography - 570 - 550 Ma &amp; 545 - 541 Ma</td>
</tr>
<tr>
<td>16. Palaeogeography - 500 - 490 Ma &amp; 490 - 480 Ma</td>
</tr>
<tr>
<td>17. Palaeogeography - 375 - 360 Ma &amp; 350 - 325 Ma</td>
</tr>
<tr>
<td>18. Palaeogeography - 300 - 280 Ma &amp; 120 - 110 Ma</td>
</tr>
<tr>
<td>19. Palaeogeography - 100 - 30 Ma &amp; 20 - 5 Ma</td>
</tr>
<tr>
<td>20. Described localities of geological interest</td>
</tr>
<tr>
<td>21. Ayers Rock weathering</td>
</tr>
<tr>
<td>22. Development of the Devils Marbles</td>
</tr>
<tr>
<td>23. Ellery Creek geology &amp; cross section</td>
</tr>
<tr>
<td>24. Kings Canyon geology</td>
</tr>
</tbody>
</table>

PLATES

<table>
<thead>
<tr>
<th>Plate</th>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Igneous rocks common in central Australia</td>
<td>7</td>
</tr>
<tr>
<td>2.</td>
<td>A range of sedimentary rocks found in central Australia</td>
<td>10</td>
</tr>
<tr>
<td>3.</td>
<td>Landforms developed in sediments</td>
<td>11</td>
</tr>
<tr>
<td>4.</td>
<td>Metamorphic rock types occurring in the Arunta Inlier</td>
<td>15</td>
</tr>
<tr>
<td>5.</td>
<td>Fold and thrust structures in central Australia</td>
<td>18</td>
</tr>
<tr>
<td>6.</td>
<td>Adelaidean and Cambrian trace fossils</td>
<td>22</td>
</tr>
<tr>
<td>7.</td>
<td>Cambrian and Ordovician fossils</td>
<td>23</td>
</tr>
<tr>
<td>8.</td>
<td>Minerals from regional igneous and metamorphic rocks</td>
<td>27</td>
</tr>
<tr>
<td>9.</td>
<td>Craters and impact features of Gosse Bluff and Henbury</td>
<td>30</td>
</tr>
<tr>
<td>10.</td>
<td>Bedding surfaces and landforms</td>
<td>39</td>
</tr>
<tr>
<td>11.</td>
<td>Scenery in the southern landform divisions</td>
<td>42</td>
</tr>
<tr>
<td>12.</td>
<td>Scenery in the central and northern landform divisions</td>
<td>43</td>
</tr>
</tbody>
</table>
13 Weathering of the surface 46
14 Hard crusts and cavities 47
15 The differential resistance to weathering 50
16 Corestones and granites 51
17 Landforms in deeply weathered terrain 54
18 Landforms developed on metamorphic rocks 55
19 Salt lakes and sand dunes 58
20 Remnants of Pre-Tertiary landforms 90
21 Late Tertiary erosional landforms 91
22 Weathering and erosion features on Ayers Rock, Uluru National Park 98
23 Landforms and sedimentary features of the Olgas, Uluru National Park 99
24 Landforms and sedimentary features in Kings Canyon National Park 110

TABLES
1. Geological time scale in relation to geological events in central Australia 4
2. Correlation of metamorphic grades and mineral assemblages 14
3. Early and middle Proterozoic geological correlations 60
4. Adelaidean geological correlations 73
5. Palaeozoic geological correlations 79
INTRODUCTION

In arid country such as central Australia, the generally red rocky landscape is accentuated by the sparse vegetation, blue skies and strong sunlight. Long sinuous mountains of layered rocks rise to an even height and stretch across the country. Alternating valleys and ridges reflect the softness or hardness of the underlying rocks. The link between landforms, which concern the shapes and texture of the land, and geology is so noticeable that an increasing number of visitors and residents have become interested in learning more about how the region evolved. This booklet, which has been written to satisfy this interest, has been developed from lectures given to the public over the last ten years and replaces the long-out-of print "A Layman’s guide to the Geology of Central Australia" written by D. R. Woolley in 1964.

The geological history of the region, which includes both Alice Springs and Tennant Creek, is developed with particular reference to places commonly seen by visitors. The history is condensed from a large number of reports and studies by the Bureau of Mineral Resources, Canberra, the Northern Territory Geological Survey and university researchers, and those referred to are listed at the back of this booklet. Geological maps at a scale of 1:250 000 cover the region and the included maps have been generalised from these. The chapter on fossils was written by P. Haines, of the Northern Territory Geological Survey.

Landforms result from the interaction over time between a changing climate, which determines the availability of water and the range of temperature, gravity and the condition of the rock at the surface. When the sky and vegetation cover are added to the landform the whole view becomes the scenery or landscape.

The discussion of the landforms is mainly based on personal observation and the examples given, are mostly places a visitor might see. The works of Mabbutt (1977) and Twidale (1968) have been used to augment the commentary. To simplify the reference to areas in central Australia, Figures 1 and 2 are included to illustrate the structural divisions of the area. The Amadeus, Georgina, Ngalia and Wiso basins are areas where accumulations of sediments have been preserved, and the basins are separated by upstanding belts of Early Proterozoic metamorphosed rocks such as the Arunta-Granites-Tanami Inlier, the Davenport-Tennant Creek Inlier, and the Petermann Province. Table 1 is a geological calendar of past events. The geology to be seen in parks and reserves has been emphasised and please note that geological hammers must not be used in these areas.
Figure 1  The geography and 1:250 000 mapsheets in central Australia
Figure 2  Map of structural and depositional areas in central Australia
<table>
<thead>
<tr>
<th>Millions of EON years ago</th>
<th>EON</th>
<th>PERIOD</th>
<th>MAJOR GEOLOGICAL EVENTS</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Central Australia</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.6</td>
<td>CEN</td>
<td>Quarternary</td>
<td>Henbury meteorites</td>
</tr>
<tr>
<td></td>
<td>OZO</td>
<td>Tertiary</td>
<td>Diprotodon fossils</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>crocodiles, reed swamps</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Waste Formation</td>
</tr>
<tr>
<td></td>
<td>65</td>
<td></td>
<td>Tertiary weathering</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>surface silcrete and</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>laterite formation</td>
</tr>
<tr>
<td>135</td>
<td>MES</td>
<td>Cretaceous</td>
<td>erosion</td>
</tr>
<tr>
<td></td>
<td>OZO</td>
<td></td>
<td>Gosse Bluff crater</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>last inundation</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Rumbalara Shale</td>
</tr>
<tr>
<td>205</td>
<td>MES</td>
<td>Jurassic</td>
<td>Hooray Sandstone</td>
</tr>
<tr>
<td></td>
<td>OZO</td>
<td></td>
<td>marine molluscs</td>
</tr>
<tr>
<td></td>
<td>250</td>
<td>Triassic</td>
<td>ignito, glaciation</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Crown Point Formm.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>290</td>
<td>Carboniferous</td>
<td>Brewer Conglomerate</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Alice Springs Orogeny</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Herrmansburg Sst.</td>
</tr>
<tr>
<td>355</td>
<td>DEV</td>
<td>Devonian</td>
<td>inundation</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Mercie Sandstone</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Dulice Sandstone</td>
</tr>
<tr>
<td>410</td>
<td>SIL</td>
<td>Silurian</td>
<td>erosion - no</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>sediments preserved</td>
</tr>
<tr>
<td>435</td>
<td>ORD</td>
<td>Ordovician</td>
<td>Larapinta Seaway</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>trilobites, inundations</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Georgina Wiso Amadeus</td>
</tr>
<tr>
<td>510</td>
<td>CAM</td>
<td>Cambrian</td>
<td>main inundation Wiso</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Georgina Basin</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Arumbeera Sandstone</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Mt Currie Conglomerate</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Petermann Orogeny</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Central Mt Stuart Formm</td>
</tr>
<tr>
<td>570</td>
<td>PRE</td>
<td>&quot;Adelaidian&quot;</td>
<td>jellyfish glaciation</td>
</tr>
<tr>
<td>675</td>
<td></td>
<td></td>
<td>glaciation</td>
</tr>
<tr>
<td>750</td>
<td></td>
<td></td>
<td>stromatolites</td>
</tr>
<tr>
<td>900</td>
<td></td>
<td></td>
<td>flooding of central Aust.</td>
</tr>
<tr>
<td>1000</td>
<td></td>
<td></td>
<td>Heavitree Quartzite</td>
</tr>
<tr>
<td>1600</td>
<td>CAM</td>
<td>&quot;Carpentarian&quot;</td>
<td>metamorphism</td>
</tr>
<tr>
<td>1650</td>
<td></td>
<td></td>
<td>metamorphism</td>
</tr>
<tr>
<td>1800</td>
<td></td>
<td></td>
<td>volcanoes</td>
</tr>
<tr>
<td>2500</td>
<td></td>
<td></td>
<td>oldest sedimentation</td>
</tr>
<tr>
<td>3400</td>
<td></td>
<td></td>
<td>in central Australia</td>
</tr>
<tr>
<td>4300</td>
<td></td>
<td></td>
<td>stromatolites</td>
</tr>
<tr>
<td>4500</td>
<td></td>
<td></td>
<td>continents and oceans</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Earth and planets</td>
</tr>
</tbody>
</table>

Table 1 Geological Time Scale related to geological events in central Australia
GEOLOGY

IGNEOUS ROCKS

Igneous rocks have crystallised from a hot liquid or melt. Plutonic igneous rocks cooled very slowly at depths in the crust of the earth where the temperature of the surrounding rock was similar to that of the melt. Large mineral crystals developed. Whenever the molten rock reached the surface during a volcanic eruption, cooling was so rapid that large crystals did not have time to grow and a magnifying glass may be needed to see the crystal boundaries in lavas. The crystals, can be seen to have grown in a definite order. The first formed, developed better crystal forms and faces as their growth in a liquid was unimpeded. The later formed crystals had to grow in the space remaining. Dyke rocks injected into sheet-like cracks in the host rock tend to have an intermediate mineral grain size between the two extremes.

Igneous rocks are also classified by their composition. Silica rich igneous rocks are white or light coloured, contain abundant quartz (silica) and feldspar minerals and are called “acid” by geologists. Granites composed of characteristic grey or white quartz, pink or white potassium feldspar, and black or white mica are the predominant acid plutonic rocks in central Australia (Plate 1a). Pegmatites are a very coarsely crystalline igneous rock containing similar minerals to granite (Plate 1b). Intrusion, often as dykes, normally occurs as a late event in the history of a granite intrusion (Plate 1e). Igneous rocks with less quartz, plagioclase feldspar and more dark minerals such as hornblende, pyroxene and olivine all enriched in iron and magnesia, are called “basic” or “mafic” by geologists. These rocks are dark coloured, basalts and dolerites being the commonest examples in central Australia (Plate 1c).

Where the once deeply buried granite outcrops at the surface, the area is generally sufficiently large to influence the scenery with rounded hills and scattered core stones being a feature (Plates 1d, 16c - e). Much of the Alice Springs Telegraph Station Historical Reserve is underlain by the Alice Springs Granite. The Devils Marbles Granite, Kulgera Granite, Yuendumu Granite and the Tennant Creek Granite can all be seen from main highways. Most of the central Australian granites crystallised between 1860-1500 Ma*. Where dolerite dykes are numerous and display parallel outcrops, the group is called a “swarm”. The Kulgera Dyke Swarm and Stuart Dyke Swarm around Alice Springs were both intruded at about the same time and both are quarryed, the rocks of the former being used as ballast beneath the railway track.

Nearly all the lavas in central Australia are old and have been metamorphosed to some extent. The Davenport Province was a volcanic centre 1820-1770 Ma when basalts, andesites and feldspar-rich volcanics were extruded. Basalts also occur in the Mount Doreen region. Rhyolites extruded about 1808 Ma occur in the Mount Winnecke Formation in the Tanami Desert region (Page and others 1976). Even older are the Bernborough Volcanics extruded about 1860 Ma (Blake and Page 1988), and of unknown age are the basalts and rhyolites found in the Division I metamorphic rocks in the Arunta Inlier (Shaw and others 1979).

* Ma an abbreviation for million years ago.
Figure 3  Distribution of igneous, metamorphic and sedimentary rocks.
Plate 1 Igneous rocks common in central Australia. Granite, dolerite and pegmatite
The boulders of black volcanic rock which can be seen in the conglomerates in the Olgas (Plate 23d), are cobbles of the Mount Harris Basalt which was extruded about 1200 Ma, and is now exposed in Bloods Range (Forman 1966). The Early Cambrian Antrim Plateau Volcanics which exhibit all the features of lavas such as discernible flow sheets and preserved gas bubble cavities, can only be seen in central Australia as deeply weathered relics in the Tanami Desert region. These basalts, which flooded huge areas as far north as Darwin, emanated from fissures rather than volcanoes and are the youngest volcanic event in the region.

Volcanic rocks are sometimes associated with the earlier phases of a mountain building event (orogeny) and granite emplacement occurs early in the waning phase, when the temperatures are falling. Basalts solidify about 1200-1000°C whereas granites normally crystallise 10 - 15 km below the surface at about 800-450°C depending on the composition. Volcanic rocks and granite intrusions are not associated with the Petermann and Alice Springs Orogenies.

SEDIMENTARY ROCKS

The weathered and eroded products of rocks exposed in an older landscape become the next generation of sediments after their movement down hill is complete. Sediments are usually transported by water, some settle in the sea and so are called marine. If the water never reaches the sea, as in modern central Australia, the sediments come to rest in floodouts or spread as fans where mountain rivers discharge onto a plain. Sediments deposited on the land are called terrestrial.

Sediments may be described as claystone, mudstone, siltstone, shale, sandstone, grit or conglomerate as the size of the included particles of broken rock (clasts) increases from one thousandth of a millimetre (in clay) to over one metre (in some conglomerates) in diameter. The dominant component of the clasts may be added to the name of the rock such as quartz sandstone. Most limestones are a mass of crystals of calcium carbonate deposited from sea water and do not readily fit the size description. Many marine clastic sediments contain calcium carbonate as a cement and it is common to find fine grained clastic sediments interbedded with limestones (Plate 2a-d). Dolomites contain magnesium carbonate.

The transport of weathered clasts, namely erosion, may be a rough trip with angular fragments tumbling down slopes and progressively breaking up. In streams, the tumbling action grinds the rocks against one another. The harder rocks become better rounded as they go further. The soft material may be ground away to sand or a powder which is more easily transportable by water currents. The rounded cobbles in the Brewer Conglomerate, Hermannsburg Sandstone, the Mount Currie Conglomerate and the Tertiary gravels to be seen along Namatjira Drive are examples (Plates 2e, 21d, 23d). Sediments with two distinct sizes of clasts, called tillites, are deposited by melting glaciers (Plate 2f).

The velocity of the flowing water determines the size of the particles it can carry in suspension or rolling along the stream bed. A swift flow carries a big load including larger clasts. As the flow slackens the load is progressively dumped with the larger clasts dropping first.
Where a flooded river carrying sediment enters the sea, the freshwater velocity will gradually fall to zero and the sediment load will sink to the bottom of the sea with the largest and heaviest clasts sinking fastest. The layer of new sediment will be widely and evenly spread over the seafloor and will have the coarsest clasts on the bottom and clast size will decrease towards the top of the layer or bed. This is a normal size distribution in beds deposited in this way and this feature can be used to determine the top and bottom and original attitude of beds in disturbed sediments.

In shallow parts of a sea, storm waves, tides and currents can disturb the regular size sorting in soft recently deposited sediments. In shallow water, ripple marks caused by currents can develop and these may be preserved, as well as the tracks of feeding creatures and sometimes the fossilised creatures themselves may still remain. In Ellery Creek, trilobite tracks and worm tubes are well preserved in a ripple marked Pacoota Sandstone. Mud crack casts also in the same sandstone are evidence that some beds were exposed by the tide and dried out sufficiently for the muddy surface to crack (Plate 10e).

A major flood may carry enough sediment to form a bed. However if the land rises slightly relative to sea level, erosion will initially accelerate producing an increased sediment load with a higher proportion of larger clasts in the rivers emptying into the sea. In time, the effect of the uplift is progressively eliminated by erosion and both the size of the sediment load and the size of the clasts of sediment will decrease, resulting in increasingly finer grained beds. This sequence is called a sedimentary cycle and in some rock formations has been repeated many times (Plate 3b).

The coarser part of the bed, when compressed into rock by the accumulating weight of successive beds settling on the sea floor, tends to become the hardest and most resistant. On a weathered surface, the cyclical deposition of alternating hard and soft beds is exhibited as parallel ridges and furrows (Plate 3c). Soft beds such as shales are generally covered with soil except in cliffs protected by a hard bed or in river banks (Plate 3a).

If sediments are deposited on land (terrestrial) they are most commonly sands or scree off a cliff. Lacustrine sediments comprise sands and muds dropped by rivers when the water velocity approached zero on entering a lake. In a desert, the sediment load may be dropped in a floodout. There, or in an alluvial fan growing near a river discharging on to a plain, the water often follows a different channel for each new flood. Consequently the continuity of layers of sand and mud deposited earlier is partly destroyed by successive depositional events, cross cutting older patterns, and a new layering in a different attitude is established. The cross bedded Crown Point Formation, so well exposed in Colsons Pillar (Plate 2a) is an excellent example of this type of terrestrial deposit.

Conglomerates are sediments composed of pebbles, cobbles and boulders together with a range of finer material between the larger clasts which have been dropped by rivers close to the foot of the hills that were being eroded. Heavy boulders are only transported by the rivers when the flow is fast enough to carry
Plate 2  A range of sedimentary rocks found in central Australia.
a Cliff are maintained in the soft horizontally bedded shales of the Finke Group by the erosion of floodwater in the Finke River. Horseshoe Bend.

b Cyclical deposition in the Carmichael Sandstone. Merenier Sandstone caps the cliffs. George Gill Range.

c Dipping sandstone beds in the Pertatataka Formation give a stepped profile to the landscape. South of the Ross Highway.

d Sandy limestone beds with a very steep dip, protrude through thin soil covering shales. Julie Formation, Namatjira Drive.

Plate 3 Landforms developed in sediments.
them and the load is dumped in semi-conical shaped fans where the water velocity lessened as the rivers disgorged on to a plain or into the sea. The Mount Currie Conglomerate is a surviving remnant of alluvial fans developed at the foot of the now almost disappeared Petermann Ranges (Plate 23d). The Hermannsburg Sandstone and the Brewer Conglomerates are fan deposits bordering mountains formed during Devonian and Carboniferous uplifts on the site of the MacDonnell Ranges (Plate 2e).

On the sea floor, the uppermost layer of sediment is soft and the particles have no cohesion. As successive layers of sediment are slowly accumulated on the bottom, the weight of the increasing load of overlying sediments will squeeze the water out of the sediments beneath. If the sea floor sinks deeper under the added weight, the temperature may rise slightly and the previously loose grains will adhere together to become rock. Sometimes there are minor mineral changes within the sediment and sometimes a material such as calcium carbonate may recrystallise effectively cementing the grains together. This process is called lithification or diagenesis and is the normal change which converts loose grains into a coherent rock.

Volcanoes, when they erupt, eject huge quantities of ash into the air which may fall on land or in the sea and become a sediment. Any volcanic material deposited on land as ash or tuff, which is coarser, is at first unconsolidated and may be eroded by water to be redeposited beneath the sea. The Davenport Ranges were a major volcanic centre about 1800 Ma and the Hatches Creek Group of sediments which comprise the ranges contain many beds of volcanic origin.

Besides the clastic or detrital products of erosion, some rock waste is soluble and is transported by water in solution to be deposited as a chemical precipitate, such as limestone (Plate 2c) or as salt in salt lakes (Plate 19 b, c). Normally the salts remain in solution and go out to sea. Fossil reefs, and the detritus derived from them, are composed of calcium carbonate which has been extracted from the seawater by living corals and deposited as a skeleton on which the corals can grow. Where a loose mass of coral has become cemented, coralline limestone is the product.

Other elements such as iron and manganese may precipitate out of solution in special environments. The iron rich horizon in the Warramunga Group, which can be seen both north and south of Tennant Creek as low elongated black hills, was precipitated from solutions.

METAMORPHIC ROCKS

About half central Australia is underlain by metamorphic rocks (Figure 3). The Arunta Inlier and Petermann Province are examples of higher grade granulite or amphibolite metamorphism, whereas in the Granites region, the Davenport Ranges and the Tennant Creek Inlier, the lower amphibolite or greenschist grade of metamorphism occurs. A metamorphic grade or facies describes an achieved environment of temperature and pressure in which an association of minerals crystallise dependent on the rock composition. Metamorphism is also the
response of the pre-existing sedimentary, igneous, or metamorphic rocks to changed conditions of temperature and pressure caused by a tectonic or mountain building event. Groups of new minerals crystallise in a recognised order within quite well defined limits of temperature, pressure and composition (facies) (Table 2).

Limestones, rocks composed predominantly of calcium carbonate, when metamorphosed, become marbles. Sediments containing quartz together with a minor proportion of calcium carbonate, metamorphose to rocks called calcisilicates which are commonly green because of the formation of epidote.

Materials, selected to equate with rock compositions, can be subjected to measured temperatures and pressures in the laboratory to simulate metamorphic conditions. The new minerals formed can be identified and matched with naturally occurring mineral suites, thus natural temperature-pressure conditions can be established experimentally. The short duration of laboratory experiments produce very small crystals. However when natural rocks of the appropriate composition are held at the optimum temperature and pressure for a long time, well formed larger sized crystals will develop. If, in addition, some are transparent then they may be classed as semiprecious gemstones. Garnet, iolite, kyanite, epidote, sphene, labradorite, diopside and corundum are examples found in central Australia.

Most of the best formed crystals are found in the Harts Range portion of the Arunta Inlier and are in the amphibolite facies grade of metamorphism. However many of the rocks in the central zone were metamorphosed initially to the higher temperature granulite facies and later reheated to lower temperatures and pressures when amphibolite facies minerals developed during a later metamorphism. This metamorphism to a lower grade is called retrograde.

Most of the metamorphic rocks in the central zone of the Arunta Inlier were probably formed at about 25 kilometres below the surface at a temperature in excess of 850°C about 1800 million years ago (Warren 1983). Retrogression, while the rocks were still deeply buried and had cooled to 600-700°C, occurred some time later. This phase is now exposed as linear schist zones. Gneisses and calcisilicates are the representative rock types (Plate 4a - c). The granulites, characterised by pyroxene minerals, were probably formed at slightly higher temperatures at much the same depth.

Mountain building events which cause metamorphism, usually produce mountain ranges and initiate a new cycle of active erosion. In the case of the Central Province of the Arunta Inlier, the metamorphic minerals cooled at depth and do not appear to have risen to higher levels in the crust until about 1450 Ma (Warren 1983). The Alice Springs Orogeny (320 Ma) elevated them further. Once active erosion is initiated, the huge load of overlying rock is progressively removed, so the underlying rocks tend to rise up to rejuvenate the erosion. Eventually the rocks once deeply buried reach the surface. If during this process blocks of rock break or slide against one another to relieve stresses, faulting occurs and in extreme cases mylonites are formed. Mylonites are composed of minerals pulverised by pressure and movement (Plate 4d).
<table>
<thead>
<tr>
<th>GRADE</th>
<th>LOW</th>
<th>MEDIUM</th>
<th>HIGH</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rock Temperature</td>
<td>250 - 400°C</td>
<td>400 - 600°C</td>
<td>600 - 700°C</td>
</tr>
<tr>
<td>Pressure, Depth of burial</td>
<td>10 - 15Km</td>
<td>15 - 22Km</td>
<td>25 - 32Km</td>
</tr>
</tbody>
</table>

**ORIGINAL ROCK**

**Major contained elements expressed as oxides, minor element oxides**

<table>
<thead>
<tr>
<th>SANDSTONE</th>
<th>quartzite</th>
<th>quartzite</th>
<th>quartzite</th>
</tr>
</thead>
<tbody>
<tr>
<td>SiO₂</td>
<td>SiO₂</td>
<td>SiO₂</td>
<td>increasing recrystallisation</td>
</tr>
<tr>
<td>ARKOSE</td>
<td>schist</td>
<td>schist</td>
<td>schist/gneiss</td>
</tr>
<tr>
<td>SiO₂ Al₂O₃</td>
<td>quartz</td>
<td>quartz</td>
<td></td>
</tr>
<tr>
<td>Na₂O, K₂O</td>
<td>feldspar</td>
<td>feldspar</td>
<td>feldspar</td>
</tr>
<tr>
<td>CaO</td>
<td>muscovite</td>
<td>scapolite</td>
<td>sillimanite</td>
</tr>
</tbody>
</table>

| LIMESTONE                   | recrystallised     | marble           | marble            |
| CaO, CO₂                    | limestone          |                  |                  |

| DOLOMITE                    | recrystallised     | marble           | marble            |
| CaO, MgO                    | dolomite           | tremolite        | wollastonite      |
| + SiO₂                      | talc               | diopside         | forsterite        |

| BASALTS & DOLERITES         | low                | amphibolite      | high              |
| SiO₂, MgO                   | chlorite           | actinolite       | granulite         |
| CaO, FeO                    | albite             | hornblende       | garnet            |
|                             | epidote            | garnet           | garnet            |

| GRANITE                     |                    |                  |                   |
| SiO₂, K₂O, Al₂O₃            |                    |                  |                   |

| PELITE (Mudstone)           | greenschist        | low amphibolite  | amphibolite       |
|                            | facies muscovite   | facies muscovite | schist facies     |
| SiO₂, Al₂O₃                | biotite feldspar   | biotite feldspar | muscovite         |
| FeO, MgO                   | epidote albite     | epidote albite   | biotite feldspar  |
| Fe₂O₃, K₂O                 |                    |                  | garnet            |
| CaO                        |                    |                  | garnet            |
|                             |                    |                  | garnet            |

Table 2 A generalised correlation between rocks and their derived metamorphic mineral suites and the metamorphic environment
Plate 4  Metamorphic rock types occurring in the Arunta Inlier.
In general if regionally metamorphosed rocks become heated to 650-700°C, partial melting of the rock commences. Where this has happened, elongated lenses of rock looking like granite can be seen to have separated out from the remaining gneissic rock (Plate 4e). These rocks are called migmatites and are a characteristic of the Ormiston metamorphic event, about 1076 Ma, which affected rocks along the central southern margin of the Arunta Inlier (Marjoribanks and Black 1974). Migmatites can be seen in the road cuttings on the Stuart Highway 15 kilometres north of the Alice Springs and in Simpsons Gap National Park. Migmatites also occur in the Central Province of the Arunta Inlier and can be seen south of the Harts Range police station.

Local heating and melting at deeper levels in the central Harts Range, generated pods of a quartz or feldspar-rich rock which have migrated upwards along joints to crystallise slowly in a cooler environment, as pegmatites. This probably happened during the Alice Springs Orogeny (Stewart and others 1984). The pegmatites are now seen as conspicuous white veins or dykes of coarsely crystalline quartz or quartz-with- feldspar cross-cutting the grain of the country. Some are the host to the mica which was mined there from the end of the last century until 1958 (Plate 1e).

In the Kulgera portion of the Petermann region along the southern margin of the Territory, pelitic rocks and acid volcanic rocks which crystallised about 1550 Ma, were later metamorphosed to the amphibolite facies about 1200 Ma (Camacho 1989). A phase of granite intrusion around Kulgera followed almost contemporaneously (Camacho 1990).

In the Petermann Ranges, metamorphic grades vary from greenschist and lower amphibolite in the northeast to granulite south of the Olia Chain. The Olia Gneiss in the north was metamorphosed about 1150 Ma before the later deposition of the Dean Quartzite and metamorphosed again about 600 Ma during the Petermann Orogeny (Duncan personal communication 1991).

The metamorphic grade in the Davenport Ranges and the Tennant Creek Inlier reached greenschist facies grade twice, once about 1815 Ma and later 1650 Ma during a mountain building event, which extensively folded the Hatches Creek Group (Blake and Page 1988).

The Granites-Tanami region has a greenschist grade of metamorphism (Blake and others 1979). At the greenschist grade of regional metamorphism pressures were lower and temperatures were about 450 - 500°C. Original sedimentary textures, such as cross bedding in quartzite, may still be preserved at this grade of metamorphism.

FAULTS AND FOLDS

Differences in attitude of the layers or bedding in sedimentary rocks are evident as one drives around in central Australia. At Simpsons Gap, the Heavitree Quartzite dips north. At Honeymoon Gap 10 kilometres to the south, the quartzite dips south (Plate 10c). The quartzite in the two gaps was once connected as a
huge arch. Erosion along Larapinta Valley has now removed all the connecting quartzite which had been folded into a huge anticlinal fold.

A dip is the direction water would flow in if poured onto a bedding surface of folded sediments. The strike of a bed is the direction of the line of contact between the bedding surface and a horizontal plane. In a pool, the water surface provides a convenient horizontal reference (Figure 4). Dip and strike are the terms used by geologists to describe the attitude of bedded rocks and other surfaces.

Huge forces are needed to bend or fold rocks and these are generated during mountain building periods or orogenies. Around Alice Springs pressures generated during the Alice Springs Orogeny (450 - 410 Ma) pushed the MacDonnell Ranges southwards towards the Amadeus Basin causing the sediments in the Basin to yield by crumpling into a series of corrugated folds. The fold troughs extend east-west separated by long winding east-west ridges with a resistant bed forming the summit of the ridges or steps on a slope (Plate 5b). This is a characteristic landform in the Basin. The folded quartzite at Ellery Creek Big Hole perhaps conveys some impression of the enormity of the force expended (Plate 5a).

Further north in the Arunta Inlier, a much older period of folding (about 1800 Ma) affected the rocks which were then deeply buried and metamorphosed. Now the deeply buried rocks are at the surface, steep dips can be seen in the metamorphic rock layers which equate to original sedimentary bedding (Plate 18a).

**Figure 4** Common geological structural elements
a Overturned fold in Heavitree Quartzite. Ellery Creek Big Hole National Park.

b Syncline in Ordovician sediments. Ross River Gorge.

c Anticline in Bitter Springs Formation. Ormiston National Park.

d Two thrust sheets of Heavitree Quartzite overlie flat lying folds of brown Bitter Springs Formation. Gorge in Ruby Gap Nature Park.

Plate 5  Fold and thrust structures to be seen in central Australia.
**Figure 5** Fossil development in central Australia
Strong and more brittle rocks, such as the Heavitree Quartzite, are found to be less folded than weaker rocks such as the adjacent Bitter Springs Formation, which contains shales and gypsum. In the cliffs in Ruby Gorge, slabs of quartzite separated by zones of intensely folded Bitter Springs Formation can be seen (Plate 5d). Near Ormiston Gorge the more brittle Heavitree Quartzite has been faulted whereas the Bitter Springs has been folded (Plate 5c).

Folding may cause slipping to occur between individual beds. In the Heavitree Quartzite at Honeymoon Gap, small scale movements between beds has generated sufficient frictional heat to melt the quartzite on the slip plane and produce a striated glassy surface called a slickensided surface (Plate 10f).

Faults are formed when rocks break and yield along a plane or zone to relieve stress. The movement may be metres or kilometres. On the ground the sideways displacement of a bedding horizon may indicate a fault, the plane of which is rarely exposed. The line of the Heavitree Quartzite outcrop is displaced west of Stanley Chasm. In metamorphic terrain, faulting may separate different rock types. A thrust is an almost flat lying fault plane along which there has been considerable movement. It is believed that the rocks above the Woodroffe Thrust plane have been pushed up to 25 kilometres northwards.

FOSSILS

What is a Fossil?

A fossil can be defined as any remains, trace or imprint of an animal or plant that has been preserved in the Earth’s crust since some past geological or prehistoric time. Loosely speaking it is any evidence of past life. Fossils can include the complete organism (e.g. mammoths frozen in ice), but more commonly they comprise only the hard parts (e.g. bones and shells) of organisms which have often been altered or replaced by some new mineral during fossilisation. Tracks and burrows of ancient organisms where none of the animal is preserved are called trace fossils as are the prints of leaves and the casts of soft bodied animals. Stromatolites are examples of organically produced sedimentary structures.

Fossils in Central Australia:

Central Australia is well represented by fossils from a number of different geological periods. These will be discussed period by period beginning with the oldest. A table of geological periods is given in (Figure 5).

Precambrian Eon:

During most of the Precambrian Eon, life was restricted to microscopic single-celled algae and bacteria. These are sometimes preserved in fine grained siliceous sediments called chert, but can be seen only when very thin slabs of the rock are examined under a microscope. Some of the oldest in the world have been found in 3,500 million year old sediments from northwestern Western Australia. In central Australia, similar, but more advanced microfossils have been found in 800 million year old cherts from the Bitter Springs Formation. Some of these
micro-organisms lived in large mat-like colonies, the sticky surface of which was capable of trapping the sediment to produce multiple - layered structures known as stromatolites. As the stromatolite grew, the colony often divided into small units, each growing upward as a separate column to form a composite dome shaped structure up to a metre high. Trace fossil stromatolites are common in the Bitter Springs Formation and other limestone bearing formations of Precambrian and Cambrian age in central Australia (Plate 6e,f). Today stromatolites are rare, being found only in very saline water (e.g. Shark Bay, W.A.) where the high salt content excludes grazing organisms.

The first animal life appears in the fossil record very close to the end of the Precambrian Era (about 600 million years ago). All were soft-bodied and include such things as jellyfish and worms. Such organisms require exceptional conditions for preservation and are thus rare on a global scale. However they may be common locally, the most famous site being in the Flinders Ranges in South Australia. Fossils of jellyfish and other organisms have been found in the lower part of the Arumbera Sandstone near Alice Springs and in the Central Mount Stuart Formation near Mount Skinner and other areas north of Alice Springs (Plate 6a - d).

Cambrian Period:

At the beginning of the Cambrian Period there was a relatively sudden global increase in the abundance and diversification of animal life sometimes referred to as the “Cambrian explosion”. The first animals with hard shells appeared at this time, but during the Early Cambrian Period soft-bodied animals still dominated. Their existence is indicated not by body fossils, but by an abundance of trace fossils (tracks and burrows)(Plate 6c, d). Such trace fossils are common in the upper part of the Arumbera Sandstone, and are best seen along the Ross River south of the homestead. The first shelly fossils to become common were the archaeocyatha. These were a now extinct group of filter-feeding organisms that had a lifestyle similar to that of a sponge. They lived in great abundance for a geologically short period of time. Their cup-shaped calcareous skeletons often formed small reefs on the sea floor. Fossil archaeocyatha can be found in the Todd River Dolomite which overlies the Arumbera Sandstone at Ross River. Other common Cambrian fossils include trilobites (extinct crustacean - like animals that had a hard segmented calcified skeleton), brachiopods (lamp shells) and gastropods (snails)(Plate 7a, b). One of the best trilobite localities occurs in the Arthur Creek Formation along the Sandover Highway about 55km east from the Ammaroo turnoff (Stidolph and others 1988).

Ordovician Period:

During most of the Ordovician Period, much of central Australia was under a shallow sea and most rocks of this age contain marine fossils. The sandstones (Pacoota Sandstone, Stairway Sandstone, Carmichael Sandstone) often contain abundant trace fossils ranging from vertical worm tubes to tracks and burrows of trilobites. Some layers also contain trilobites, brachiopods, gastropods, nautiloids (related to the modern nautilus) and bivalves (two-shelled molluscs such as clams). The Stairway Sandstone contains the oldest fossil fish recorded from the Southern Hemisphere. These fossils consist of boney plates that would not be
Plate 6  Adelaidean and Cambrian trace fossils from central Australia.
Plate 7  Cambrian and Ordovician fossils from central Australia.
readily recognised as fossil fish. In the Horn Valley Siltstone and the Stokes Siltstone a well preserved fossil fauna can be found, the most notable are large nautiloids (Plate 7c). These had long straight conical shells with numerous gas chambers for buoyancy. At one end was a living chamber in which the soft parts of the squid-like animal resided. Some reached over a metre in length, but most specimens collected consist only of broken fragments. A few species have coiled shells which became much commoner in later geological periods. The Horn Valley Siltstone also contains abundant trilobites (usually fragmentary), brachiopods, gastropods and bivalves, as well as rare graptolites (Plate 7d - f). Graptolites are extinct marine colonial organisms that collectively secreted a light skeleton of organic material that was capable of floating. They are usually preserved as flattened ferns or leaf-like films of carbon. The most accessible collecting site for the Horn Valley Siltstone occurs just north of the Maloney Creek Bridge on the Stuart Highway 120 km south of Alice Springs. Fossils are exposed in a drainage ditch along the eastern side of the road.

Devonian Period:

Devonian sediments are widespread in central Australia but as most were deposited on land in fluvial, dune and lake environments they contain few fossils. Fossil freshwater fish are sometimes found in the Parke Siltstone of the Amadeus Basin and the Dulcie Sandstone of the Georgina Basin. Faint impressions of leaves and some plant remains are preserved in the Mount Eclipse Sandstone (White 1983).

Mesozoic Era:

Mesozoic marine sediments occur in the Kulgera and Finke areas south of Alice Springs and underlie much of the Simpson Desert. Similar aged rocks in South Australia have yielded many marine fossils including opalised shells and bones. Opalised bones of extinct marine reptiles such as the plesiosaur have been found at Coober Pedy and Andamooka. The few fossils of this age found in the Territory are of fossilised wood in the Hooray Sandstone (Smith 1972).

Tertiary Period:

During the middle and late Tertiary period, the land surface in central Australia was similar to that of today but the climate was generally much wetter. This was the period when Australia separated from Antarctica and moved to its present position. Many of the low lying areas were filled by lakes. Some of these old lake deposits contain fossils of fresh-water molluscs. Fossil plants including petrified wood, reed and leaf impressions have also been found. One of the most important finds has been the discovery of fossil vertebrate bones near Alcoota Station. The fossils include extinct crocodiles, emu-like birds, kangaroos and diprotodons (extinct giant marsupials)(Woodburne 1967).
GEMSTONES

Some crystals are considered to be semi-precious minerals, or when transparent, semi-precious gemstones. Many are metamorphic minerals which can be found in the Arunta Inlier.

**Almandine garnet** $\text{Fe}_3\text{Al}_2(\text{SiO}_4)_3$ is red, sometimes transparent and a very common metamorphic mineral throughout the central province of the Arunta Inlier. Almandine commonly develops in pelitic rocks, muds and clays which contain aluminium and iron minerals required for its formation when they are subjected to amphibolite grade metamorphism (Table 2)(Plate 8d, g). Some crystals are zoned, like growth rings in a tree, with the zones reflecting changing conditions. Almandine with the best developed crystal faces occurs in biotite or chlorite schists in retrograde zones.

**Grossular garnet** $\text{Ca}_3\text{Al}_2(\text{SiO}_4)_3$ can occur in zones along a contact where limestones have been intruded by igneous rocks, usually granites. Some fluids from the granite have reacted with the limestones to produce grossular, epidote and other minerals. This type of deposit is called a skarn. Well formed yellow opaque grossular crystals occur in a skarn in the Jervois area.

**Hessonite garnet** $\text{Ca}_3\text{Al}_2(\text{SiO}_4)_3$ a variety of grossular is formed in zones where silty limestones and quartz sandstones or feldspathic quartz sandstones are intermixed and metamorphosed to temperatures above 400°C. Calcium from the limestones, aluminium from the silt or the felspar, and quartz from the sandstones combine to form sometimes transparent colourless, yellow or orange garnets in a quartz matrix.

**Aluminium silicate** $\text{Al}_2\text{SiO}_5$ occurs in three different crystalline forms, kyanite, andalusite, sillimanite. The prevailing temperature and pressure at the time of formation determines which mineral develops. These have been measured when the minerals have been grown in a laboratory. Thus the temperatures and pressures which once prevailed in natural metamorphic rocks can be estimated by identifying the minerals present. The estimation of the pressure and temperature in a metamorphic rock from the study of the minerals present is called geobarometry and geothermometry respectively.

**Kyanite** $\text{Al}_2\text{SiO}_5$ commonly crystallises in blue, white, pale green or colourless elongated crystals with a rectangular cross section. Sometimes the colourless crystals have an internal blue stripe parallel to their lengths. Kyanite forms in zones rich in aluminium and quartz, usually derived from pelitic rocks. Kyanite is also commonly found developed in black biotite, and is considered to indicate that a temperature of about 600°C and a pressure of more than 4 kilobars prevailed. Five kilobars equates to a depth of burial of between 15 to 20 kilometres (Plate 8c).

**Andalusite** $\text{Al}_2\text{SiO}_5$ will develop in place of kyanite if the pressure is lower and the temperature is about 550°C. Transparent andalusite has not been described from central Australia but the mineral is common.
Sillimanite $\text{Al}_2\text{SiO}_5$ requires higher pressures and temperatures than the other minerals with the same composition and will develop in place of kyanite if the temperature is higher, above $600^\circ$C and the pressure is moderate to high, about 3 - 4 kilobars. Well developed fibrous crystals are common in the higher grade amphibolite facies and in some retrograded rocks it can be seen wrapped around garnet crystals. Transparent sillimanite has been reported in needle sized crystals (Plate 8h).

Feldspar $\text{KAlSi}_3\text{O}_8$ is a common metamorphic mineral particularly in gneiss where it forms the pale eyes in a black foliated biotite-rich matrix. Coloured off-white, buff or rarely pink it crystallises about 400 - 500°C in the amphibolite grade. **Plagioclase** $(\text{Na, Ca})(\text{Al, Si})\text{AlSi}_2\text{O}_8$ is also included in the feldspar group of minerals and the white, sometimes transparent, sodium-rich plagioclase, **albite**, $\text{NaAlSi}_3\text{O}_8$ occurs with epidote where igneous rocks have been metamorphosed. Feldspar after quartz is the most important rock forming mineral occurring in igneous, metamorphic and sedimentary rocks (Plate 8b). Transparent varieties are gemstones, see moonstone.

Iolite $(\text{Mg, Fe})_2\text{Al}_4\text{Si}_4\text{O}_{18}$, the blue transparent variety of cordierite is of interest and is found with fibrous pale brown **anthophyllite** $(\text{Mg, Fe})_7\text{Si}_8\text{O}_{22}(\text{OH})_2$ in pods in black biotite mica. It formed at about $600^\circ$C and at a pressure of 5 kilobars. Crystal faces rarely develop. In the same locality but not mixed with the iolite, blue kyanite occurs in black biotite.

Yellow-green **epidote** $\text{Ca}_2(\text{Al, Fe})_3(\text{SiO}_4)_3(\text{OH})$ occurs either as granular or crystalline masses in scattered localities in the central Arunta zone. Larger crystals of epidote have been found in some localities where volcanic or limestone rich rocks were once deposited and metamorphosed to the amphibolite grade (Plate 8e). The accompanying blue-green amphibolite, calcite, feldspar, almandine, and occasional **sphene** $\text{CaTiSiO}_5$ are all minerals of this facies which probably formed at about $550^\circ$C from a lime rich mudstone. Locally, gem quality crystals of epidote may be found and more rarely green or brown sphene. Small white **feldspar** crystals (Plate 4b) with well developed crystal faces occur in the same locality with pink, yellow, brown or colourless **calcite** $\text{CaCO}_3$ in cleavage rhombs. Well formed **quartz** $\text{SiO}_2$ crystals have been found in carbonate horizons (Plate 8a).

**Staurolite** $(\text{Fe, Mg})_2\text{Al}_9(\text{Si, Al})_4\text{O}_{22}(\text{OH})_2$ will develop in a slightly more iron-rich pelitic rock if metamorphosed to the lower amphibolite grade at about $550^\circ$C. Garnet may develop as well. Andalusite forms first and as the temperature increases it can react with chlorite to form staurolite and cordierite or garnet. Small semi-transparent crystals of staurolite in biotite have been found but most of the crystals found are black and opaque.

**Corundum** $\text{Al}_2\text{O}_3$ can develop if the pelitic sediments locally contain very little silica and the temperature and pressure associated with the amphibolite facies of metamorphism has been reached. Stumpy hexagonal crystals or pink or white granular corundum has been found in biotite. Ruby coloured corundum which
Plate 8  Minerals from regional igneous and metamorphic rocks.
developed in the area known as the Ruby Mine in Harts Range is a metamorphic mineral produced by the reaction of anorthosites with basic rock. Anorthosites are igneous rocks rich in calcium, aluminium and silica and these elements have reacted with the iron and magnesia of the basic and ultra basic rocks to produce micaceous *vermiculite* (Mg,Fe₃Al₃(Si₄O₁₀)(OH)₂·4H₂O and corundum crystals some of which have developed as hexagonal plates, on the anorthosite side of the contact (McColl and Warren 1979, Lawrence and others, 1987).

**Sunstone** KAlSi₃O₈ is found in iron-rich quartz feldspar gneisses metamorphosed to upper amphibolite grade. It is microcline feldspar with very thin translucent flakes of *hematite* Fe₂O₃ developed on the cleavage planes within the crystal. The microcline may be pink or transparent (Brown and Bracewell 1984).

**Moonstone** KAlSi₃O₈ is a variety of whitish to colourless feldspar which is translucent to transparent and may occur as “eyes” in a gneiss. Some translucent albite NaAlSi₃O₈ also occurs and has a similar appearance.

**Pegmatite minerals**

The minerals developed in pegmatite dykes may be considered to be igneous as they have crystallised from molten rock even though the pegmatite materials have been sweated out of a deeply metamorphosed rock.

**Tourmaline** (Na,Li,Ca)(Fe,Mg,Mn,Al)₃Al₆(OH)₄(BO₃)₂Si₂O₁₈ in black prismatic crystals with curved striated faces is a common mineral in pegmatites and also in granites throughout the region. Transparent green, blue and pink varieties are very rare (Plate 8f).

**Beryl** Al₂Be₃(Si₆O₁₈) or its blue variety aquamarine, is found in some of the pegmatites in the Arunta Inlier, particularly where muscovite and biotite have also developed. Transparent green, yellow or blue material is rare, white opaque hexagonal crystals may be locally common and some may grow to 0.3 metre in length. Beryl also occurs in pegmatites in the Barrow Creek and Kulgera granites.

**Apatite** Ca₅(F,Cl,OH)(PO₄)₂ another hexagonal prismatic green mineral appears to have been quite common in some pegmatites. The mineral is softer than beryl and appears to weather out of its quartz host if exposed at the surface. Empty hexagonal pits in a quartz pegmatite probably mean that apatite crystals were once present. Transparent green apatite has been found in a range of hues although most material is granular and opaque.

The Mud Tank gem field, is celebrated for its soil cover containing some large zircon crystals, apatite and magnetite, all of which have weathered out from an unusual igneous calcium carbonate rich intrusion called a carbonatite. Intruded as a molten rock about 732 Ma. (Black and Gulson 1978) it now outcrops in four pods extending over 4 kilometres. Calcium carbonate with some green amphibole minerals and vermiculite comprise the main bodies, and apatite or magnetite occur in zones or veins.
Zircon ZrSiO₄ is found as single crystals in magnetite Fe₃O₄ or in veins. Both are found within the Mud Tank carbonatite which occurs in central Harts Range. Zircon crystals are very resistant and are one of nature’s great survivors. Valued as gemstones, zircons are recovered from the soil by sieving and washing. Some crystals have an uncracked portion large enough to be facetted into a gemstone. Zircons coloured purple, red, pink, colourless to yellow or pale brown are a feature of the Mud Tank occurrence (Plate 8g). Minute zircons also occur in granites and are used to establish the date of crystallisation.

Quartz SiO₂ is the commonest mineral in almost all surface rocks in central Australia. It may occur as grains or clasts in sediments, or as crystals in igneous or metamorphic rocks (Plate 8a). Well developed crystals are rare as they require open cavities in which to grow from percolating solutions after metamorphism. Impurities in quartz give rise to a variety of colours.

Traces of iron in crystalline quartz cause the mauve or purple colours of amethyst, the yellow of citrine or the black of smoky quartz. Massive (non-crystalline) quartz when coloured pink, plum or lavender by traces of manganese is called rose quartz and traces of nickel give rise to green chrysoprase. Iron gives the red and yellow colours to opaque jasper and translucent carnelian. Agate is a minutefibrinous variety of quartz deposited in various coloured transparent or opaque bands. A brown or white variety of quartz containing water is called potch of which opal is a multicoloured variety.

Rutilated quartz is transparent colourless quartz containing golden hair like needles of rutile crystals. White milky quartz is a very common crystalline or non-crystalline opaque form of quartz without impurities.

ASTROGEOLOGY

The Henbury, Boxhole and Huckitta meteorite impact sites, Gosse Bluff comet impact structure, Kelly West Astrobleme and scattered tektites along the southern margin of central Australia are all features caused by extraterrestrial activity.

Henbury

At the Henbury conservation reserve 120 km south of Alice Springs, a cluster of thirteen craters from one meteorite shower occur within a square kilometre. There, the craters, up to 183 metres in diameter, with surrounding ramparts up to 6.1 metres above the plain are classified as explosive. The rampart material was pushed aside by the almost instantaneous release of huge compressive forces generated when several tonnes of iron meteorite travelling about 15 kilometres a second were stopped in less than 10 metres (Plate 9b). The extreme impact stress caused the formation of some glassy minerals, only found in such an environment (Milton 1968,1976b). The meteorites are thought to have hit the earth within the last 10,000 years. The iron to nickel ratio of 12 to 1 in the meteorite was found when the site was first investigated (Alderman 1931). A 44 kg fragment is on display in the Alice Springs Museum (Plate 9c).
a Aerial view of Gosse Bluff crater caused by a comet or meteorite.

b View of a single crater in the cluster of thirteen at Henbury.

c Meteorite fragment from Henbury.

d Shatter cone from Gosse Bluff Specimen 100 mm across.

e Horsetail fracture patterns on sandstone caused by shock of impact.

Plate 9  Craters and impact features at Gosse Bluff and Henbury.
GOSSE BLUFF GEOLOGICAL MAP AND CROSS SECTION

Probable diameter of original crater

Land surface 130 million years ago

Present land surface

Scale $V_H = 1$

QUATERNARY (<2 Ma)  
Soil and sand

LATE DEVONIAN (370 - 350 Ma)  
Sandstone, conglomerate

DEVONIAN (370 Ma)  
Mereenie Sandstone

CAMBRIAN - ORDOVICIAN (500 - 450 Ma)  
Sandstone, siltstone, limestone

LATE PROTEROZOIC - CAMBRIAN (800 - 500 Ma)  
Sandstone, siltstone, shale, limestone

Brecciated rock

Road unsealed

Watercourse

Geological boundary

Fault

Aboriginal Land Boundary

Ma million years old

Figure 6
Gosse Bluff

Gosse Bluff is the relic of a large crater formed when a speeding body, possibly a comet about 600 metres in diameter, crashed about 130 Ma. However as nothing remained of the original body, a meteorite could equally well have caused the same effects. The flat bedded rocks at the point of impact were so compressed, that when the forward momentum of the comet had been expended, the stored compressive energy in the rock caused them to rebound, pivoting upwards and generating a huge crater and ramparts up to 20 kilometres in diameter.

The crater one sees today is at least 2000 metres below the original surface on which the body crashed 130 Ma. It is an upstanding ring of resistant Mereenie Sandstone and a sandstone member of the Parke Siltstone (Plate 9a, Figure 6). A circular zone of contrasting colour 20 kilometres in diameter, centred on the crater, can be seen clearly on a satellite image and this is interpreted as being the zone of shattered rock and probable extent of the original crater. Ejecta from the impact is exposed on Mount Pyroclast. Within the exposed modern crater, well developed “horsetail” or cone shaped crack patterns can be seen on the sandstones (Plate 9d). Intense and almost instantaneous stress formed these “shatter cones” whose apices point towards the zone of maximum stress (Milton and others 1972, Milton 1976a).

Boxhole

This single crater about 200 metres in diameter is so similar to the craters at Henbury that it is considered to be part of the same shower. The composition of iron meteorite fragments found matches those from Henbury.

Huckitta

Some scaly iron debris remains at this site which has no visible crater. The meteorite is a stony-iron variety and consists of nearly equal proportions of metallic iron and olivine. Most of the meteorite remains are in the Adelaide museum (Madigan 1939).

Kelly West Astrobleme

A poorly preserved crater about 2 km in diameter occurs about 35 kilometres southwest of Tennant Creek. Shatter cone structures were found in presumed Hatches Creek Group quartzites. Cambrian sediments were found within the crater margin. It was concluded that the impact occurred between 550 Ma and 1850 Ma (Mendum & Tonkin 1976).

Tektites

Tektites are orbicular pellets of black glassy material with the chemical composition of terrestrial rocks. Their origin is uncertain although it has been suggested that they are splash material caused by a big meteorite hitting earth and instantly melting some rock around the crash site. Their shapes appear to be controlled by airflow perhaps whilst they were cooling and in flight. Tektites are found in several discrete regions over the earth, the southern boundary of the Northern Territory being one of them.

-32-
LANDFORMS

Scenery is everything in a view of a landscape, landforms are the landscape foundations without vegetation and in central Australia are an expression of the underlying geology and the climate both past and present. In the last several million years the climate has been becoming drier and weathering and erosion have been actively attacking all the high ground to reduce it to a plain. Fortunately the end result has not yet been achieved and mountains still exist, Mt Zeil rising to 1510m. The mountainous centre of Australia is surrounded by dune covered plains (Figure 7).

MOUNTAINS

The mountains of central Australia are a scenic feature, often not anticipated by visitors. Although they do not rise much more than 1500 metres, and many are 300 metres or less above the plains, the mountains and the rocks comprising them are very visible with little vegetation on the slopes or on the flat plains from which they rise abruptly. Foothills are conspicuously scarce in the central Australian landscape. Cliffs in the mountains are common but the crest lines are subdued often reflecting an old erosion level.

During the Early to Middle Tertiary, a 65 million year period, there were no big earth movements in central Australia and the climate was wet and humid. Weathering and erosion were more active than at present and all the pre-existing topography was levelled to a vast plain with gentle rises around the sites of the present day mountains, some of which rose above the plain. The continued wet climate promoted deep leaching beneath the plain, the Tertiary erosion surface, and the precipitation of silica and iron on the surface as an extensive duricrust.

Scattered relicts of duricrust on hill tops confirm the extent and level of the Tertiary erosion surface which, in general, has set the upper limit to the height of the present topography. The base level of the hills is controlled by erosion which has carved out most of the landscape in central Australia only in the last 20 million years.

Cone-shaped hills are a distinctive feature of many central Australian landscapes developed in both metamorphic and sedimentary terrains. It is believed that the cone shape may be an indication that the Early to Middle Tertiary erosion surface had previously existed at some level above the summit of the cone.

The intense folding caused by the Alice Springs Orogeny has left many of the sediments of the Amadeus Basin with steep to near vertical dips and a predominant east-west strike. Consequently long winding east-west ridges with a resistant bed forming the summit ridge are an important landform. Cliffs have developed on the scarp slope and dip slopes are common where the slope coincides with the bedding plane (Plate 10a-d). Weathering and erosion have accentuated the differences between hard and soft rocks so that thin hard vertically dipping beds now outcrop as rock faces on hill slopes or as free standing walls of rock trending along strike across the countryside. Many can be seen from the Namatjira Drive near Ellery Creek (Plate 3d).
Figure 7  Contour map of central Australia

-34-
Figure 8  Diagram of ranges and mountains in central Australia
Ridges of folded sandstones of the Hatches Creek Group form the higher ground in the Davenport Ranges and a contorted ridge pattern has developed which contrasts with the linear landforms of the Amadeus Basin.

The quartz-rich metamorphic rocks such as the quartzofeldspathic gneisses or granulites tend to form the mountain ridges in the Arunta Inlier (Plate 18c). The hard quartzite of the Chewings Range has become a most spectacular mountain. Veined quartz or pegmatite will tend to form a ridge capping or the summit of a cone shaped hill (Plate 15d). Generally the main ridges in the Arunta Inlier and the Amadeus Basin are oriented east-west, a response to the Alice Springs Orogeny.

Figure 8 shows the orientation of the ranges in central Australia. The northwest to southeast trend in the north of the central Australian region compares with the east-west trend in the south. The differing directions relate to the Middle Proterozoic folding in the north and the Alice Springs Orogeny in the south.

GEOMORPHOLOGY

Almost all the ranges south of the Arunta Inlier have been carved out of a flat laterised and silicified plain which had developed over the southern half of the region during the Early and Middle Tertiary about 65-20 Ma when the climate was wetter. The old plain level is preserved as silcrete surfaces capping hills and was between 50 and 200 metres above the present plain level with a very gentle dip southwards to merge with the modern plain level south of the Territory. Beneath the silcrete and local laterite, a soft leached and bleached zone developed which was up to 50 metres thick. The erosion which excavated this vast quantity of material between the past and present surfaces was initiated by minor faulting and the subsidence of the Lake Eyre region about 20 Ma causing downcutting. Much of the resistant silcrete capping collapsed when erosion removed the already soft bleached horizon from below. Remnants of this white bleached layer can be seen at Chambers Pillar, Rainbow Valley and in many of the surviving mesas on the edge of the Simpson Desert (Plate 11b).

Figure 9 shows central Australia divided into regions which have had a similar geomorphological history and where similar scenery exists. The undermined Tertiary plain has become the southern desert on the geomorphological map.

Hills on the Henbury Erldunda plain are all subdued except where some Tertiary duricrust remains protecting the underlying leached sediments (Plate 11c).

Weathering and erosion in the last 20 million years have etched out the softer beds, such as shales, in the folded sediments of the northern Amadeus Basin to produce a landscape dominated by sandstone ridges. This landform comprises the Folded Central Ranges division and contains a conspicuous number of cone-shaped hills, which may have been one consequence of the break-up of the erosion surface. Colsons Pillar, a perfect cone-shaped hill, still has a "top knot" of Tertiary duricrust from the old landsurface, to protect the soft sediments beneath. This landform would probably have persisted after the duricrust had completely gone. (Plate 11b, d, 17b).
Mountains in the MacDonnell Ranges and Harts Ranges in the Crystalline Central Ranges division have an east-west grain reflecting the dominant structural and sedimentary strike directions. The quartz-rich metamorphic rocks and the poorly jointed granulites of the Strangways Range comprise the high ground (Plate 12d).

However, the landform developed in the flat-lying Palaezoic sediments under the Tertiary erosion surface on Lucy Creek Plateau has no derived grain (Plate 12e).

The northern plains contain many extensive areas of laterite developed during the Tertiary. It appears that the rejuvenated erosion in the last 20 million years has had little effect north of the MacDonnell Ranges. Extensive laterite can be seen immediately to the east of the Stuart Highway along the Arltunga scenic drive 50 kilometres north of Alice Springs.

The northern uplands comprise the highlands around the Davenport Ranges and Tennant Creek. The tops of many of these hills are bevelled as they also rise to the Ashburton surface which developed in Late Proterozoic to Cambrian times, 600-550 Ma. (Hays 1967, Stewart and others 1986)(Plate 12c). The flat-topped low sandstone ranges in the northern plains are evidence of a Tertiary erosion surface called the Tennant Creek surface (Hays 1967)(Plate 12a, b).

WEATHERING

Weathering is the process of rock degradation that weakens the original fabric of the rock. The constituent grains of the original material lose cohesion or are chemically altered to weaker minerals. The rock may swell due to the chemical alteration to become softer and lose strength.

Erosion is the process of the removal of the degraded rock. Water, gravity and wind all assist in this process, which in general, ceases when all the hills have been reduced to a plain and no slopes remain down which gravity can promote the movement of waste material.

Climate and weathering

The moderately arid climate of central Australia has an average annual rainfall of 275 mm (11 inches), a high evaporation rate of approximately 3000 mm a year, predominantly cloudless days and plentiful sunshine. The latter two factors cause air temperature variations of 20 -25 °C in a day, and the radiant heat absorbed by day and radiated at night cause the ground and rock temperatures to vary up to 40°C or more, in 24 hours.

These extremes of temperature and the dryness, restrict the natural growth of plants to well separated individuals, which are specially adapted to existing in drought prone environments. The vegetation, as seen from ground level, often looks so plentiful that the term desert doesn’t seem appropriate. However, when viewed from above, the dominant red soils can be seen and the true distribution of the sparse vegetation appreciated. River courses and other places where
Figure 9  Map of landform divisions in central Australia
a The scarp slope of the Heavitree Quartzite in the MacDonnell Range tends to be a cliff. Burts Bluff Gneiss outcrops below on the level Larapinta Plain.

b Bevelled crest and dip slopes on Mount Gillen Range. Low ground at the base of slope is underlain by soft shales and limestones of the Bitter Springs Formation.

c Tree covered dip slope; bare cliff scarp. Honeymoon Gap.

d Bare dip slopes blackened by algae Heavitree Quartzite, MacDonnell Range.

e Cast of mud cracks in Pacoota Sandstone.

f Slickensides on Heavitree Quartzite. Honeymoon Gap.

g Ripple marks on a bed of Heavitree Quartzite.

Plate 10 Bedding surfaces and landforms
moisture is available to plants, stand out as well vegetated strips winding across
the plains or as lines of trees along a watercourse in the hills.

Most landforms and types of weathering typical of a middle latitude desert can
be seen in central Australia. Notable are escarpments, bare rocky hills rising
abruptly from flat valley floors, piedmont slopes, rock-strewn surfaces, and sand
dunes. Geologically, the area is a vast flatlith continental shield of Proterozoic
metamorphic rocks covered by a comparatively thin and patchy veneer of folded
sedimentary cover rocks. Thicker sedimentary successions have been preserved
in downwarps in the Proterozoic surface. In an arid climate, weathering and
erosional rates are slow compared with areas in tropical or temperate climates,
where rain water, an important weathering and erosional agent, is more plentiful.
As a result, small differences in rock hardness or resistance to weathering
become large differences in the scenery. Valleys develop over soft rocks such as
siltstones; upstanding sinuous ridges develop over hard sandstones (Plate 15a-c).
Heavitree Quartzite caps Mount Gillen in the MacDonnell Ranges and Mount
Sonder. Mount Zeil composed of the Chewing Range Quartzite is even more
spectacular (Plates 12a, b, 18a).

The smaller differences in hardness of beds within a unit may be selectively
exploited by the weathering to produce smaller scale ridges or furrows on slopes,
and where the rock can be seen, colour banding may also reflect slight differences
in composition in individual beds (Plates 9a, b, 13a).

Weathering

As water is a most important contributor to rock breakdown in the weathering
process, weathering in an arid climate is very slow. Indeed the conspicuous
visibility of rock faces, scarps and rock-strewn slopes is due to the weathering
rate being slower than the erosion or removal rate of the degraded rock. In a
wetter and more humid climate, the more plentiful degraded rock breaks down to
a soil before it reaches the foot of a slope, thus delaying the runoff of rain water.
A long contact between rock and water further promotes the breakdown of rock
giving rise ultimately, to more rounded, soil covered hills.

Many of the rock surfaces in an arid landscape have a network of small shallow
 cracks extending inwards from the surface for about 5 centimetres. It is not
certain whether these cracks are caused by repeated heating and cooling of the
rock, or by the relief from pressure by removal of the overlying rocks.

Rainwater enters these cracks and begins reacting with the component mineral
gains or the cement holding the rock together. The reaction is very, very slow
and is intermittent as the rainwater in the cracks will quite quickly be drawn back
to the surface by capillary action, and subsequently evaporates. Slow though this
process may be, it causes the rock in the outer surface layer to alter, leaching
some minerals and hydrating or oxidising others. The layer may swell slightly,
and if iron minerals are being dissolved from the core of the rock, they may
precipitate on the surface developing a hard crust with weaker rock beneath.
Eventually, the weathered crust will split off from the parent rock and slide away
if the slope is steep enough (Plate 13a). The underlying surface is surprisingly
smooth. These weathered sheets or scales are commonest on igneous and
metamorphic rocks although they do develop in sediments and can be seen on the surface of Ayers Rock (Plates 13c, d, 18c). In some coarse grained and possibly more porous rocks the thickness of the weathering crust may be one to two metres and generally a hardened crust develops on the upper surface. Spectacular scenery develops as large blocks fret around their bases before collapsing and occasionally a huge block can be seen supported by a slender pillar (Plate 14c).

Gnammas are shallow pits which have developed on level rock surfaces by the enlargement of small cracks. Here, the water collecting in the pits has promoted weathering and any degraded rock products are removed by wind or water (Plate 13b). The noted honeycomb textured surface so well developed at Rainbow Valley has formed in a somewhat, similar way. There the Hermannsburg Sandstone, where it was just beneath the Tertiary erosion level, was slightly leached and kaolinised. The cement holding the sand grains was leached by seeping rain water, so that the weathered rock collapsed and produced holes in place of the small cracks. Any moisture in the base of the pit will be shaded from the sun and persist there longer, further corroding the surrounding rock and deepening the pit (Plate 14a-d). The weathered rock is removed by rain wash and wind. The “Brain” a series of irregular pits and hollows on the eastern side of Ayers Rock has formed in the same general way (Plate 22b). Iron oxides have dissolved out of the higher part of the Rock and redeposited, as the water containing the dissolved iron evaporated near the surface or on its way down the rock face. A harder iron-rich crust has developed to protect Ayers Rock (Figure 18). Many igneous and metamorphic rocks which contain small quantities of iron-rich minerals also develop a rusty iron weathering crust.

Small shallow caves can be seen in many cliff faces in central Australia and these have developed in the same way as the smaller hollows. Intersecting joints or a group of closely subparallel joints can often be identified as the cause of moisture penetration and consequent cave development. However, because of their depth, the moisture which contributes to their continual deepening by weathering, will survive evaporation longer due to the greater shade inside. Animals often occupy these caves and help to excavate the fretted rock waste, either deliberately by burrowing, or by scattering material in their efforts to seek shelter from the sun.

The potency of water as a weathering agent may be enhanced if carbon dioxide, a gas in the air, is dissolved in the rainwater to form a weak acid. Such rainwater can dissolve limestone and in so doing etch shallow grooves in the exposed rock as it slowly trickles down a surface. The grooves are called “karren” and can be seen on the grey rocks at the side of the road into Ellery Creek Big Hole or along the Ross Highway (Plate 2c). This process of dissolution of limestone can go much further and a major crack can become widened to a valley if there is a good flow of water and sufficient time. Sinkholes also develop by the dissolution of limestone around a natural drainage pipe to the water table.

The lime or calcium carbonate dissolved out of limestones will eventually end up in ground water or in the sea. Where mineral charged water evaporates at the surface, the calcium carbonate will crystallise out as a white deposit called calcrite. Look inside a kettle in central Australia and see the white deposit. The salt lakes of the Amadeus Basin and the Ngalia Basin are evaporite deposits,
a Southerly dipping Cambrian Pertaorrra Group sediments in the Ross River Syncline. Folded central ranges division of Figure 9.

b Leached rock beneath the duricrust of the Tertiary weathering surface, in mesas scattered in the western Simpson Desert.

c Subdued hills developed on the Carboniferous sandstones beneath the completely eroded Tertiary weathering surface. Rldunda plain division of Figure 9.

d Flat lying beds of Hermannsburg Sandstone in the Waterhouse Range. Folded central ranges division of Figure 9. Palm Valley National Park.

Plate 11 Scenery in the southern landform division shown in Figure 9.
a  Low sandstone rises in the Tanami Desert. Northern plains division.
b  Flat-topped Gardiner Range is evidence of an ancient land surface.

c  Mount Strezlecki composed of Hatches Creek Group sandstone is in the Northern uplands division. Note the bevelled summit.

d  Harts Range in the Crystalline central ranges division. Ridges indicate bands of more resistant metamorphic rock which may relate to the original sediment.

e  Flat lying Cambrian sediments of the Georgina Basin succession in the Lucy Creek Plateau. Hukitta.

Plate 12  Scenery in the central and northern landform divisions of Figure 9.
mainly of gypsum, from mineral-charged water. The generally warm temperature in central Australia promotes the speed of chemical reaction and conversely, quickly evaporates the water which is the medium in which the reactions can occur, halting the reaction (Plate 19b, c).

Any factor, which increases the time that water is available to react with rock, promotes weathering. The debris at the base of a slope will tend to hold the run off water, so that weathering will continue its degrading reactions there when the higher slopes have drained and are dry.

This base of slope weathering is largely responsible for the abrupt change of slope at the foot of hills, so common in arid environments. This enhanced weathering corrodes and cuts back the bed rocks at the base, thus maintaining the abrupt change in slope, as well as degrading the fallen debris to an easily transportable size so that it will be removed as fast as it arrives.

Soil and the plants which grow in degraded rock retard the erosion and promote weathering. The roots hold the loose mineral grains and prevent wind or water carrying away the surface material. Roots also expel acids to promote the breakdown of mineral grains. Generally soils on the slopes in central Australia are thin and mostly confined to pockets. On the plains, the soils are thicker with a larger proportion of fine grains which tend to dry out to a hard crust. When wet they lose almost all strength. If the soil loses the finest material, it loses cohesion and dune sand results.

The Tafoni or shallow caves around the foot of Ayers Rock are thought to have been initiated when the sand level around the base of the rock was a few metres higher than at present and the water draining off the rock was held around the base as ground water in the sand. The ground water corroded the foot wall, which, when the sand and water level fell, became exposed and was eroded to a shallow cave. The overhanging lip is caused by the iron and silica salts, leached from above, precipitating close to the rock surface and strengthening it. This effect may be likened to icing on a cake (Figure 21, Plate 22d, e).

**Differential weathering**

The hardness of rocks and their resistance to weathering has an exaggerated influence on the scenery in an arid climate. Quartz is the most resistant of the common minerals and quartz rich rocks almost invariably form the higher ground. Feldspars and dark coloured minerals such as amphiboles, pyroxenes and micas found in igneous rocks are less resistant to attack particularly by water. An extreme example of differential weathering resistance can be seen at Birthday Gap, where two dolerite dykes, intruded into and cross-cutting a quartzite ridge, have weathered away so much more quickly than the quartzite that there are two parallel sided cuttings through the quartzite ridge. The Hugh River flows through one cutting, a weathered basalt can be seen on the floor of the other. Standley Chasm is another excavated dolerite passage through a quartzite ridge. In sedimentary rocks, the mineral grains have already been through one cycle of weathering and erosion, and they have either survived, such as quartz, or the grains are already degraded rock or secondary minerals. In sediments it is the material cementing the grains that usually loses strength first when exposed to
weathering. The Mercenie Sandstone which once was free flowing quartz sand, will weather to free flowing quartz dune sand. Only the cement will have gone.

The strongly banded appearance of the sediments and a corresponding ridge and furrow pattern to be seen on slopes is due to often repeated changes in the environment which occurred at the time of deposition (Plate 3b). Slight differences in sea level, storms, or change in the source of sediment are factors which give rise to these changes. On the flanks and top of Ayers Rock the surface is conspicuously ridged and furrowed, and it relates to small compositional differences and hardnesses in individual beds in the predominant arkose, a much finer grained facies of the Mount Currie Conglomerate (Plate 22a).

The landforms developed on well bedded sedimentary rocks will reflect the differences in rock hardness of the individual layers and the attitude or dip of the beds. Resistant beds in a sequence of dipping sediments tend to form a stepped profile and hard beds cap cliffs on the scarp face (Plate 3c, 10a-c). On the alternate slope the resistant bed will form the upper surface of the slope called the dip slope or sometimes flat iron. The dip slopes are very conspicuous on the southern side of the MacDonnell Range as seen from the Ross Highway (Plate 10d). Flat irons are well developed as north dipping surfaces on the Central Mount Stuart Formation in the Stuart Bluff Range. If the beds are vertical, the differences in weathering can be very clearly seen from above or on aerial photographs. Indeed, some spectacular scenery has developed where there are vertical beds probably because slight differences in the constitution of each bed are accentuated. This can be seen very clearly from the lookout 10 kilometres east of Ellery Creek. Opposite the Ellery Creek turnoff along the Glen Helen road, harder beds of the vertically dipping Julie Formation outcrops as a low wall of limestone standing up above the general ground surface.

Examples of flat lying resistant sediments forming the top of cliffs are Mount Conner, which has a classical table top profile, the Kings Canyon plateau, where the Mereenie Sandstone forms a resistant cap over the Carmichael Sandstone and Stokes Siltstone, and the 20 metre thick basal quartzite of the Central Mount Stuart Formation, which caps the cliffs above a granite behind Barrow Creek racecourse (Plate 3b).

Where no great differences in hardness exist, a landscape of gently rounded ridges and domes may result as can be seen over the Brewer Conglomerate (Figure 23) or around the Tylers Pass Lookout.

**Duricrusts**

The layer formed on a weathering soil surface by the deposition of silica, iron oxides or calcium carbonate is called a duricrust and constitutes silcrete, ferricrete or calcrete respectively. A silcrete duricrust commonly develops on a mature level peneplain, where there is little or no sediment movement, during an extended period of weathering in a wet warmish climate.

Pervasive rainwater slowly penetrates the bedrock, dissolving or altering minerals to produce, over time, a deeply leached and bleached zone up to 70 metres thick. Chambers Pillar and Rainbow Valley are examples of this bleached
Plate 13  Weathering of the surface.

a  Flaky weathering on Barrow Creek Granite. Barrow Creek.

b  Gnamma (hollow) developed on Oorobra Arkose. Oorobra.

c  Smooth well drained slopes are a long lived landform. Kulgera.

d  Smooth gneiss surface exposed where weathered crust has been stripped.

e  Onion skin weathering in gneiss.

f  Scar on Ayers Rock where lightning strikes caused stripping.


c Weathering undermining the iron-rich thick Tertiary crust. Rainbow Valley.

d Honeycomb textured pit weathering in leached sandstone. Rainbow Valley.

e White rock from the core and typical reddened crust. Mereenie Sandstone.

f Microcolonial fungi growing on quartz and fixing iron salts on the surface.

Plate 14 Hard crusts and cavities.
Dissolved silica in the ground-water has been drawn to the surface by capillary effects and was deposited there as silcrete. Many of the flat topped hills so common in the country between the MacDonnell Ranges and the Northern Territory - South Australian border are capped with silcrete and the summits are a remnant of the duricrust which developed over the long period of wet climate weathering 60-20 million years ago. The duricrust may be regarded as a fossil land surface. Silcrete cap-rocks can conveniently be seen along the roadside about 2 kilometres east of Emily Gap National Park, where a group of hills with sloping cap-rock surfaces give an indication of the profile of the MacDonnell Range as it was about 20 million years ago (Plate 21b). The Stuart Highway, 3 kilometres south of Kulgera passes over a hill which has a thick development of porcellanitic silcrete on its eastern half.

Another variety of tough quartz indurated soil can become a preserved surface which again is a relic of former weathering conditions. It is called "grey billy". The Bacon Ranges, a kilometre south of the Henbury Meteorite Craters are capped with "grey billy".

If the climate and weathering conditions are more tropical, an iron-rich laterite layer, ferricrete can form on the surface. Relics of such a weathering surface of Early Tertiary age (65 million years ago) can be seen along the Gardens Road through the Hale River Basin. There, black masses of hematite form mounds along the roadside and black hematite granules cover the red soil.

Calcrete, another common duricrust in central Australia involves calcium carbonate being leached from below and being precipitated at the surface. Arid climates promote calcrete formation which is widely scattered in small outcrops except around salt lakes where continuous beds have developed.

Around Tennant Creek and on the northern plains many ridge crests have flat tops attributable to former long lived plain landsurface. Surfaces with ferricrete (Tennent Creek) are considered to have developed in the mid Tertiary (60-20 Ma) like the surface south of Alice Springs, but in a more tropical northern climate (Hays 1967). Residuals of a higher and older surface (Ashburton) are seen particularly in the Davenport, Short and Ashburton ranges and relate to a pre-Cretaceous (135 Ma) and possibly pre-Cambrian (570 Ma) erosion surface (Stewart and others 1986) (Plate 12c). In the Hatches Creek Group northeast of Barrow Creek a "U"-shaped valley, typical of glacial erosion, was filled with Central Mount Stuart Formation sediments and modern erosion has now almost completely removed these. It is likely, the re-emerged landform visible today originally existed about 600 Ma (Plate 20a) (Haines and others, 1991).

**Weathering of Metamorphic rocks**

The differences in hardness have a similar effect on the rate of weathering of metamorphic rocks as in sediments. Quartz-rich metamorphic rocks tend to be resistant, those containing micas are weaker. Many of the metamorphic rocks were sediments before they were heated under pressure by burial and so the bulk composition of a layer in a metamorphic rock will be much the same as that of the original bed of sediments (Plate 18a, b). Pressure applied to the sediments during metamorphism has often imparted a foliation to the metamorphic rocks.
The weathered metamorphic rocks tend to part along these foliation surfaces in a similar way to sediments parting along bedding surfaces and from a distance the two may look similar. Metamorphic rocks also tend, in central Australia, to be locally heavily jointed. The net effect on the scenery is that the country will have an uneven grouping of disjointed ridges which compares with long, almost unbroken lines of ridges developed in the sediments (Plate 12d). On the smaller scale the well foliated metamorphic schists can give rise to slaty outcrops with a multitude of parallel cleavages and the surrounding debris will also be very platy (Plate 4a, b).

Gneisses are metamorphic rocks in which the foliation or cleavage planes are not well developed (Plate 4c). Crystal growth, largely of quartz and feldspar, has interrupted the planar structure imparted by mica in schists, and the rock does not tend to break easily into parallel sided slabs. Likewise the scenery developed over gneisses tends to be more rounded and lumpy, although gneiss bands rich in quartz will form higher ground than those bands richer in mica. Many gneisses have a dark and light small scale banding due to mineral separation and this appears to have no directional effect on the weathering. Not uncommonly, weathered crust can be found flaking off gneisses as the weathering penetrates surface cracks and degrades the underlying layer to a surprisingly smooth surface (Plate 13d). Local surface hardening is quite common. The remains of detached crusts scattered over bare rock surfaces can be seen and is a result of this type of weathering. On steep slopes, bare rock faces can be seen, with the crusts forming a scree of slabs below, which may be vegetated (Plate 13c). Granulites, generally, are the least jointed of the metamorphic rocks and produce topography similar to granites. The migmatites north of Alice Springs are also very poorly jointed and give rise to rounded undulating country with a thin stony soil cover.

Weathering of igneous rocks

The weathering of igneous rocks such as granite and dolerites produce a different and distinctive scenery. The large rounded core stones of the Devils Marbles (Plate 16a) or the Devils Pebbles are probably well known, but they are certainly not unique. Granite, which is composed mainly of quartz and feldspar with some mica, crystallised from a molten mass to solidify into large rounded or elongated bodies several kilometers in diameter. Generally, a right-angled pattern of joint planes or cracks developed in the rock mass during cooling and it is into these cracks that water has seeped to initiate weathering. Eventually, the weathering will convert the granite on either side of the cracks into a kaolin-rich clay containing quartz grains. This soft degraded rock, if on a slope, washes out of the cracks exposing the unaffected and rounded core stones, hence the Marbles. The weathering rate of the corestones decreases significantly once the surfaces are free from the clay which holds the corroding water.

Consideration of the weathering of a cube-like shape will show that the surface area of the attacked body will tend to decrease until it has a minimum surface area which is the spherical form. Thus spheres, domes, and rounded profiles very commonly develop in granites, igneous rocks and any other rock which is uniformly hard in all directions (Plates 1d, 16b, 23b). The scenery over granite masses is generally rounded with a coarse rubble of corestones scattered over the
a The outcrop of soft shales has preferentially weathered to form a valley between sandstone beds. Ross River Syncline.


c Heavitree Quartzite stands above Bitter Springs Formation limestone.

d Vein quartz capping hill in the Entire Valley.

e Feldspar crystals upstanding in the granite gneiss Telegraph Station.

Plate 15 The differential resistance to weathering.
Corestones and jointing in the Devils Marbles Granite.

Corestones weather to a sphere in cross jointed rock.

Surviving granite corestones on Jinka Plain. Corestones survive when corroding moisture can disperse quickly.

Surviving corestones on a granite slope. Rain has washed away all the fine debris to a level valley floor. Kulgera.

Well jointed Barrow Creek Granite underlies uneven country cluttered with heaps of corestones. Cliff top is a hard sandstone. Central Mount Stuart Formation.

Plate 16  Corestones and granites.
surface. Commonly, a heap of core stones remain on the crest of a granite dome and are called a tor. Even when a granite mass has weathered to a flat coarse-sand-covered plain, core stones may be found on the surface as on the Jinka Plain (Plate 16c-e). There vertical quartz veins up to 5 metres thick have cut this particular granite, and the quartz has been so much more resistant to weathering than the granite, that now the plain is crossed by long quartz walls standing 10 to 20 metres above the plain. Around Kulgera, the granites are not well jointed and the weathering has rarely broken the exposed mass into corestones. Instead some granites form an unbroken dome from the sandplain on one side to the sand plain of the other (Plate 13c). Weathering is by shallow flaking of crusts with some gnmmas developed on the flattened areas (Plate 13a, b).

Dolerite, a dark grey rock, which occurs near Alice Springs and Kulgera is a basic igneous dyke rock. It has no banding, but is commonly well jointed into small blocks which weather to well rounded cobbles. A rusty surface commonly develops on these boulders as dolerites contain some minerals rich in iron. Dolerite is intermediate in its resistance to weathering. It is much weaker than quartzite but stronger than gneisses. Where dykes of the Stuart Dyke Swarm intrude the Burt Bluff Gneiss, they form low north-south ridges. One such ridge cuts across Larapinta Drive 25 kilometres west of Alice Springs.

EROSION

In this discussion of weathering and landforms, little has been written so far about erosion or the transport of the degraded rock. The scarcity of rain is a feature of an arid climate and yet, it is the most important agent for removing the weathered rock, and even in central Australia it has the capability of removing waste faster than it is produced. This tends to eliminate deep piles of debris at the foot of slopes and maintains the abrupt change of slope between hill and piedmont (Mabbutt 1977). Rain in central Australia tends to fall heavily, and when it comes, the poor vegetation cover does little to protect the soil from being washed away. The impervious nature of the soil surface permits little water to soak in. As a result the runoff water carries a maximum soil load. The normally dry river beds in central Australia are all full of sand and silt dumped when the peak flood flow wanes quickly and the water dries up again. Flood water loses its final velocity in the floodouts in the sandy plains and there drops its remaining load, clogging the present stream channel so that the water may follow a new course during each flood. The sediments deposited in a distant floodout are generally fine grained and may be scattered by the wind. In the process, the dust gets blown away and the remaining fine sand forms dunes. Willy-willies are quite destructive over dry soil plains, where gravity has ceased to drive the erosion. These whirl-winds, although only affecting a small soil area, can be seen continuously wandering over the surface as a twisting column of red soil during very hot weather.

"Bad land-type" erosion, in which numerous stream channels can be seen to have actively cut back into soft soils, are generally the results of changes in the environment or the drainage. Vehicle tracks, cattle pads and the dying back of vegetation during droughts, are factors which promote this type of erosion, which
is not too prevalent in central Australia. Gullying, however is common and is a serious problem.

An example of almost instantaneous erosion is the displacement of weathered crusts or blocks of rock. The electrical energy of the lightning probably vapourises moisture in cracks or pores as it passes through the rock and generates high pressure steam. This blasts off a crust of rock leaving a shallow furrow marking the passage of the lightning as can be seen on Ayers Rock. The furrows are particularly noticeable between the breaks in the hand chain along the climbing route up Ayers Rock (Plate 13f).

DUNES

No description of the scenery of central Australia would be complete without mention of the sand dunes which are to be found on the floors of all the wide valleys and plains. Dune fields tend to form in arid or semi-arid shield areas, where there is an abundance of fine grained detritus and particularly if it is rich in quartz grains. The plains of central Australia fully meet these criteria as besides granites, there are many quartz rich sediments and metamorphic rocks presently being eroded. Ephemeral rivers deliver this sediment load to floodouts where wind removes the finest particles as dust in storms and scatters the remainder to form dunes. The dunes are predominately longitudinal in form and parallel to the prevailing wind directions. Their position appears to be stable as many are well vegetated with bushes and in places stands of desert oaks have developed (Plate 19a, d). The Simpson Desert has probably the best development of longitudinal dunes which are spaced about 500 metres apart and are up to 15 metres high (Mabbutt 1984). The interdunal flats have a silt layer, which may cover calcere and hold water after heavy rain. The predominant dune directions have been plotted on the topographic map (Figure 7) and it can be seen that the trend in the Simpson Desert is northwest - southeast whereas southwest of Tennant Creek and to the west of Lake Amadeus the trend is roughly east-west.

One climbing dune, resting against the MacDonnell Ranges can be seen 3 kilometres east of Jessie Gap where it is being quarried for fine sand.

DRAINAGE

Most water courses in central Australia appear dry. However there are a few semi permanent waterholes, generally in rocky and shaded stretches of the valley and most rivers have a seepage flow buried in the sand and gravel.

None of the river courses in central Australia reach the sea and most terminate within the central Australian map area. Most rivers terminate in floodouts. Small catchments in flattish areas may drain into playa lakes which fill and dry out.

The direction and pattern of the drainage in the hilly parts of central Australia is controlled by the slope and also strongly influenced by the relative strengths of the outcropping rock as well as discrete lines of weakness such as fault and joint

b  The topknot of silcrete protects the kaolinised Umbura Shales and the De Souza Sandstone. Colsons Pillar.

c  A relic of silcrete from the Tertiary weathering surface being actively undermined by erosion of the soft bleached layer. Rainbow Valley Nature Park.

d  A cave formed where the bleached layer was excavated from beneath a silcrete capping. Huckitta.

Plate 17  Landforms in deeply weathered terrain.
a Stepped profile developed in the metamorphic rocks of the western Harts Range is suggestive of a sedimentary origin for the original sequence.

b Weathering has penetrated the gneiss and mafic layers of the Mount Riddock Amphibolite along the cleavage planes to generate this landscape. Central Harts Range, south of the Police Station.

c Soil formation is inhibited by rapid drainage on these slopes of gneiss that look like granite. Central Harts Range.

Plate 18 Landforms developed on metamorphic rocks.
zones. The pattern of straight stretches and right angled bends in the drainage of the Kings Canyon plateau is characteristic of control by jointing in flat lying strata. One has only to look at the river pattern on a geological map to see how well the rivers follow the outcrops of soft strata such as siltstones and volcanic rocks.

The downhill flow of water may be interrupted by a hard bed such as quartzite, and there, other weaknesses caused by joint zones, fault zones or cross cutting dykes may be exploited, and excavated. The river may spill over into another valley as has happened in some places upstream of the Heavitree Quartzite, a barrier across all the southward flowing streams draining the MacDonnell Ranges. Another example of river capture which is presently occurring, is the capture of the Marshall River by the Plenty River.

Where the rivers cross a plain, the controlling gradient may be so flat that the course meanders within a broad channel with a maze of subchannels. As the rivers only flow in times of flood, the water is always carrying a maximum load of sediment, not all of which reaches the floodout. As a consequence, the channels are always shallow, wide, often meandering and almost overfilled with sand, except where rocky bars constrain the depth or width.

A river pattern, such as a meandering course developed by a mature river across a flat plain, may be incised into a terrain even though different hardinesses and attitudes of the underlying strata can be expected to significantly redirect the meandering course. The south-easterly flowing Finke River follows such a meandering course through the Waterhouse Range, and it is presumed that this course is a relic from the time when it meandered southeast across the Tertiary erosion surface from highlands in the MacDonnell Ranges.

The Finke River started incising its meanders into the sediments of the Amadeus Basin during the Miocene about 15Ma. The rejuvenation of the downcutting was promoted by some uplift and the sinking of the Lake Eyre region which became a natural sink. All the rivers flowing from the southern MacDonnell Ranges acquired a distinctive south-easterly course to reach this topographic low (Figure 7). Several sets of unused meanders incised to differing depths can be recognised (Plate 20c) and the course changes may have happened when the whole valley was choked with alluvium and the river was not constrained by a pre-existing course (Haines personal communication 1989).

It is noticeable that the highest mountains in the region are composed of one of the hardest rocks, the Chewings Range Quartzite. These mountains are also the source of the Finke River, the longest river in central Australia.

Floodout is a Northern Territory term for an ephemeral site at the downstream end of a flowing river where the water spreads out onto the plain. There the water flow slows down as it sinks into the sandy plain and any sediments suspended in the water are deposited. The water itself either evaporates or sinks through the sandy plain to add to the groundwater.
GEOLOGICAL HISTORY

FORMATION OF THE EARTH about 4550 Ma.

The earth and the moon are believed to have condensed shortly before 4500 million years ago from a cold cloud of gas and dust, perhaps the product of an exploding star. This age was confirmed when men brought back samples of rock from the moon’s surface which differs from the earth’s by remaining unchanged since its origin. The earth has a hot molten core and solid pulsating crust. Huge forces have acted on the earth’s crust, squeezing parts thus causing them to rise up and become mountains, stretching other parts causing the surface to sink and probably become covered by sea. Since the earth’s solidification, the whole surface has been recycled by being dragged down into the hot depths and there, melted to a liquid, and then squeezed back up again to the near surface as igneous rocks such as granites or erupted over the surface as volcanic rocks. If the burial was less deep then wholesale mineralogical rearrangement in the crustal rocks occurred during a process called metamorphism.

In contrast, the moon has a cold centre and once it solidified about 4500 Ma, internal forces did not exist to cause the recycling of the surface rocks. The oldest rocks on the earth’s surface have been dated at 3900 Ma, thus establishing the age of the oldest known solidification event.

In central Australia, the oldest rocks for which an age can be estimated are sands, silts, clays and volcanic rocks which formed a landscape in the Arunta area about 1900-1840 Ma. They are estimated to have been derived from a crust which crystallised sometime in the period 2200-2000 Ma (Windrim and others 1983; Warren and others 1989). That is at the beginning of the second half of the world’s history. No record of the first half exists in central Australia (Table 1).

The geological history of central Australia has been pieced together using many methods. Firstly by considering the order of deposition. The older rocks lie under the younger rocks. Igneous rocks are an exception and the younger rocks have an intrusive or cross cutting relationship to the older rocks. Secondly, if fossils can be found in sedimentary rocks and identified as being part of a community which lived during a known period, the age of the host rocks can be determined. Thirdly, if the amount of natural change from one suitable isotope to another can be determined, the time since crystallisation or recrystallisation can be established. For example, uranium decays to lead in zircon crystals at a known steady rate. Measurement of the proportion of lead derived from uranium enables an age since crystallisation, in millions of years, to be determined.

PROTEROZOIC 2500-570 Ma

Early and Middle Proterozoic 2500 - 1000 Ma

The different metamorphic histories interpreted in the separated Arunta, Petermann, Tennant Creek and Granites-Tanami Inliers where incomplete rock
a  Sand-dunes spreading over an eroded level surface on shales of Devonian-Carboniferous age of the Finke Group. Horseshoe Bend, Finke River.

b  Aerial view of Lake Lewis, one of the ephemeral salt lakes in the Ngalia Basin.

c  Polygonal cracks on salt crust. Lake near Mount Ebenezer.

d  Sand-dunes with wind ripple marks. Simpson Desert near Chambers Pillar.

Plate 19  Salt lakes and sand-dunes.
sequences of this period are exposed, has complicated the assemblage of a history of the region. Dates of crystallisation of igneous rocks as determined by zircon crystal analysis and estimates of the dates of metamorphic events using rubidium-strontium analysis have provided a timeframe for events and have enabled cross-correlation between the inliers (Table 3)(Ethridge and others 1987).

The Warramunga Group of rocks outcrop around Tennant Creek and are the oldest dated rocks in central Australia. They consist of greywackes, siltstones and shales with some felsic volcanics. Gold mineralisation is found in the included hematitic chert beds. Isotopic uranium-lead determinations made on minute quantities of zircon crystals collected from a rhyodacitic igneous rock within the Warramunga Group gave a date of crystallisation of 1880-1870 Ma (Blake and Page 1988).

The geological environment at that time was probably changing rapidly with mountains emerging particularly to the north of Tennant Creek and sediments derived from erosion transported into a sea over the site of present day Tennant Creek. There was local volcanic activity throughout the period. The Barramundi Orogeny 1880-1850 Ma (Page 1988) was then the driving force affecting most of northern Australia. Metamorphism to lower greenschist facies together with the first period of folding seen in the Warramunga rocks was probably generated by this orogeny. The Whippet Sandstone, a possible erosional product of the mountain building and the Bernborough Volcanics, dated about 1870 Ma (Black 1984) are local members and can possibly be placed in the upper part of the Warramunga Group in the Tennant Creek area.

The Tennant Creek Granite, about 1864 Ma, and the Cabbage Gum Granite, about 1846 Ma, (Black 1984) both intrude the Warramunga Group and with the Bernborough Volcanics are likely products of a vast north Australian igneous event which occurred towards the close of the Barramundi Orogeny (Wyborn 1988).

In the Granites–Tanami province of the Arunta Inlier, the Mount Charles Beds and the Killi Killi Beds of the Tanami Complex are correlatives of the Warramunga Group. Lithologically, both are a suite of inter-beded greywackes, siltstones and shales with included cherts, silicified siltstones, some jaspillites and carbonates (Blake and others 1979).

In a detailed study of the Halls Creek orogen by Page and Hancock (1988) the uranium-lead method was used to determine dates on zircon crystals in volcanics and pegmatites. They showed that the deposition of the Halls Creek Group, the metamorphism, and later eruption of Whitewater volcanics was completed between 1860 and 1850 Ma. The Killi Killi Beds and the Mount Charles Beds are correlated with the Halls Creek Group (Blake and others 1979) and were probably deposited about 1860 Ma and metamorphosed shortly afterwards. The Mt Charles Beds, like the Warramunga Group, is the host to gold mineralisation, and both are intruded by granites, respectively the Granites Granite dated at about 1780 Ma (Page and others 1976) and the Tennant Creek Granite dated at about 1870 Ma (Black 1984). Both are also accompanied by volcanics and sandstones, namely the Mount Winnecke Formation about 1808 Ma and the Supplejack or
Table 3  Correlation of Early and Middle Proterozoic rocks in central Australia
Pargee sandstones in the Granites-Tanami Province (Page and others, 1976) and the Epenarra Volcanics and the Hatches Creek Group 1820-1770 Ma in the Davenport province, (Blake and Page 1988). The Birrindudu Group of sandstones were deposited to the north, south and west of Tanami between 1700 and 1500 Ma and correlate with the McArthur River Group (Blake and others 1979).

Some quartz-rich lavas and tuffaceous sandstones were deposited in the Mount Webb area and then intruded by the Mount Webb Granite (about 1526 Ma). Erosion continued in the Tanami region until about 1100 Ma when the planed off surface was inundated by a shallow sea and the Wade Creek Sandstone was deposited. There was probably another break in deposition about 1050 Ma when the Ormiston Event was occurring further south (Blake and others 1979).

Returning to the history of the Tennant Creek-Davenport Inlier, a period of erosion followed the intrusion of the Tennant Creek Granite about 1870 Ma, and before the commencement of the deposition of the Hatches Creek Group about 1860 Ma. Gradual sinking of the depositional platform provided a resting place for the accumulating load of Hatches Creek Group sediments by maintaining a shallow marine or fluvial environment. Sands and silts freely mixed with both mafic and felsic volcanic debris was deposited in a shallow sea. The total thickness of the sediments of the Hatches Creek Group is over 10 kilometres, and time of cooling of one of the older lavas (Epenarra Volcanics) in the sequence is about 1860 Ma (Page 1988).

Rocks of the Hatches Creek Group were folded, regionally metamorphosed to the lower greenschist facies and later intruded by Devils Marbles and Elkedra granites which crystallised about 1660 Ma (Black 1984).

To the north of Tennant Creek, the Tomkinson Creek Beds, a sequence of predominantly quartz sandstones outcrops on either side of the Stuart Highway, and are correlated with the middle and upper parts of the Hatches Creek Group (Blake and Page 1988).

An unbroken cover of Palaeozoic and Mesozoic rocks over the Wiso Basin has effectively hidden the history of Proterozoic sedimentation in that area which is thought, on the basis of the airborne magnetic surveys, to include volcanic sequences perhaps similar to the Hatches Creek Group and a thin Adelaidean sequence (Questa 1989).

The geological history of the Arunta Inlier is more difficult to unravel as several high grade metamorphic events coupled with mountain building orogenies, have almost completely altered the rocks and their constituent minerals. However the bulk chemical and elemental composition of layers has remained essentially unchanged over time, and using this evidence, it has been possible to correlate groups of rocks, particularly metamorphosed volcanics, in the Arunta Inlier with volcanic rocks in the Tennant Creek Inlier.

A system of divisions and provinces was introduced to facilitate understanding the large number of metamorphic rock groupings found in the Arunta, as major faults divide the whole Inlier into blocks (Figures 10, 12). Three divisions, each
Figure 10  Geology of north central Australia
Figure 11  Palaeogeography 1870-1860 Ma and 1820-1750 Ma
of a recognisable group of lithologies are used to divide the metamorphic rock mass into relatively older, intermediate, and younger rocks within a single province. In general Division I rocks contain felsic and mafic volcanics and younger shales and calcareous rocks, Division II are pelitic and calcareous sediments and Division III are mature quartzites and pelites. Rarely can an unconformity be seen between divisions. Within a province the rocks of Division II are younger than those of Division I but it does not mean that they are of the same general age as adjacent Division II rocks in another province (Stewart and others 1984).

Felsic and minor mafic volcanics and other sediments including limestones were deposited in an east-west rift-bounded sea with a sinking floor, and this setting appears to have been the original depositional environment of the Division I rocks in the Central Province (Warren 1983)(Figure 11). Later these rocks were metamorphosed to granulite facies about 1820 Ma (Iyer and others 1976; Windrim and McCulloch 1983; Black and others 1983). The most easily accessible Division I rocks in the Central Province are located in the Strangways Range, in the eastern part of a lens shaped outcrop area extending from Jervois 500 km west to Mount Rennie. The Central Province is now characterised by felsic and mafic granulites, quartz and felspathic gneisses, metamorphosed gabbros, anorthosites and some marbles. Local later retrograde metamorphism to amphibolite facies has occurred. Collectively these rocks are considered to be the oldest in the Central Province. The high temperature (850-920°C) of metamorphism and pressure, 8 ± 1 kilobars, may be related to deep burial with the probability that they are the oldest rocks in the province (Warren 1983) (Figure 12). Directly comparable rocks are not found in the Tennant Creek sequence, although there is a chemical similarity between the Strangways quartzo-felspathic gneisses, the Tennant Creek Granites intruded about 1870 Ma (Black 1984) and the granites of the Barramundi Orogeny, 1885-1860 Ma (Page 1988; Wyborn 1988).

Division II rocks of the Arunta Inlier have a widespread distribution principally to the north of the Division I rocks, but also to the east and west. Amphibolite grade metamorphism distinguishes the Division II rocks from the higher grade granulites of Division I, in the Central and Southern Provinces. Before metamorphism, the Division II material of the Central Province is thought to have been a mass of layered quartz rich volcanics with tonalites and some granites, intruded by minor volumes of mafic rocks. Included in the original sequence were limestones, quartzites and shales. Division II rocks of the Arunta are correlated with the Warramunga Group which have a lower metamorphic grade (Stewart and others 1984).

Two metamorphic events in the Reynolds Range in the centre of the Arunta Inlier were dated at 1820 and 1760 Ma. Metamorphism occurred at 1760 and 1730 Ma in the eastern Arunta Inlier (Cooper and others 1988). In the Northern Province, Division II rocks were affected by the 1820 Ma event. They are correlated with the Warramunga Group with a date of deposition about 1870 Ma (Blake and Page 1988). The Lander Rock Beds in Division II are very widespread in the northwestern part of the Arunta Inlier and generally exhibit low pressure chlorite grade metamorphism. Locally they are metamorphosed to a very low pressure
granulite facies in the Mount Stafford area and yet still retain discernible bedding. Division III rocks of the northern province such as the predominately quartz rich Reynolds Range Group, are correlated with the Hatches Creek Group and were deposited between 1820 and 1770 Ma (Warren and others 1989).

Division II rocks in the east and west of the Central Province of the Arunta Inlier were not affected by the 1800-1820 Ma metamorphism and are presumed to have been deposited between the 1760 and 1730 Ma metamorphic events, if the history in the eastern Arunta is similar to that of Central Province (Freeman and others 1986, Cooper and others 1988). Amphibolite facies metamorphism is characteristic of Division II and was the peak metamorphic grade reached in the 1730 Ma event (Black 1980).

Division II rocks of the Southern Province are mainly exposed in an elongated zone between the Division I rocks and the southern margin of the Arunta Inlier (Figure 12). One or two small scattered outcrops have been identified further north. Now mostly consisting of quartzites and quartz felspathic gneisses, these rocks were deposited some time before 1660 Ma as they are intruded by the Alice Springs Granite, or other granites of the same age (Shaw and others 1975). Their metamorphism to lower amphibolite facies was probably achieved about 1670 Ma as a group of rubidium-strontium metamorphic age determinations also applicable to the eastern Arunta Inlier, the Reynolds Range, the Davenport Ranges cluster around the 1670 Ma (Warren and others 1989). The Alice Springs Granite, Elkedra Granite and the Devils Marbles Granite were probably intruded at the same time, collectively named the Aileron event (Black and others 1983).

Quartzites and quartz-rich rocks are very resistant to weathering and erosion and consequently, Division III rocks composed largely of these rocks, comprise much of the high ground in the southern Arunta Inlier and give rise to spectacular scenery. In particular the quartz rich Chewings Range Quartzite of Division III is interpreted as a mature sediment derived from a granite terrain. An unconformity between the Division II and Division III rocks has been found 8 kilometres west of Alice Springs.

The intrusion of the alkaline igneous Mordor Complex about 1200 Ma was perhaps the precursor of a temperature rise which affected the Southern Province of the Arunta Inlier between 1100 and 1000 Ma (Langworthy and Black 1978). Migmatite development is characteristic of this metamorphism which affected the Division III rocks and the Alice Springs Granite, and was called the Ormiston Event by Marjoribanks and Black (1974). The Gum Tree Granite intrusion (1000 Ma) was probably associated with this event (Allen and Black 1979). The intrusion of the Stuart Dyke Swarm into north-south striking fractures in the Southern Province, about 897 Ma, was perhaps the last spasm of the Ormiston Event (Black and others 1980). Examples can be seen on top of Anzac Hill, and at Wigley’s Waterhole, among other places. Nowhere do they intrude any of sediments of the Amadeus basin and so all those sediments must be younger. The intrusion of the Mud Tank carbonatite and associated peralkaline bodies about 732 Ma appears to have been an isolated event (Black and Gulson 1978).

The last major event with a maximum affect in both the southern Arunta Inlier and the northern Amadeus Basin sediments was the widespread Alice Springs
Figure 12  Metamorphism in the central Arunta Inlier
Orogeny, 350-310 Ma with a climax about 315 Ma (Shaw and others 1984). Major uplift in the central Arunta Inlier of about 3 kilometres (Warren 1983, Cooper and others 1988), accompanied by large scale thrusting from the north, caused the development of complex nappe folds generally along the zone which now separates the Arunta Inlier from the Amadeus Basin. The remnants of these nappes and thrust sheets can be seen at Ruby Gorge, Arltunga, Blatherskite Range, Ormiston Gorge and Mount Sonder. Narrow fault zones, throughout the Arunta were reactivated during this period resulting in the development of mylonites, rocks ground finely along a fault plane and recemented. The pegmatite dykes of the Harts Range were intruded during this period (Shaw and others 1984).

The Musgrave-Petermann Inlier, which includes the Kulgera area straddles the South Australian-Northern Territory boundary and abuts the southern margin of the Amadeus Basin. Although the Proterozoic history of the Inlier has resemblances to the history described to the north of the Amadeus Basin, there are major differences. The oldest period of sedimentation before 1800 Ma did not appear to include volcanics. The initial metamorphism, the Kimban orogenic movement occurred between 1800 and 1650 Ma and developed amphibolite grade assemblages. Rocks of this period are confined to the South Australian and Western Australian part of the Ranges (Plumb 1985).

The Kimban orogenic movement (1800-1650 Ma) was followed by metamorphism which produced layered and massive granulites about 1560 Ma and about 1330 Ma respectively. None of the rocks of this period are known to occur in the Northern Territory. A regional metamorphism about 1100 Ma generated the Olia Gneiss from the Pottoyu Granite intruded between 1125 -1160 Ma (Plumb 1985). The Mount Harris Basalt and the Bloods Range Beds, the oldest recognisable sediments in the Northern Territory part of the Petermann Inlier, include sandstone, siltstone, shale, conglomerate, and limestone together with basic and acid volcanics all of which have been partly or wholly metamorphosed during the Petermann Orogeny to quartzite, slate, phyllite, schist, amphibolite (600 Ma).

Extreme pressure generated about this time caused an uplifted part of the southern Musgrave inlier to be thrust horizontally northwards up to 20 kilometres over the northern block. The Woodroffe Thrust is the name of this huge feature which extends about 300 kilometres in an east west direction and lies mainly in South Australia. Mylonites and pseudotachylites, which are partly stress-melted rocks, characterise the thrust plane (Ludbrook 1980).

In the Kulgera area, numerous shallowly dipping dolerite dykes were intruded into the granites and gneisses about 1054 Ma. The Kulgera Granites were intruded about 1163 Ma into schists and gneisses, derived from a pile of acid volcanic sediment deposited about 1550 Ma. The schists and gneisses were subjected to granulite grade metamorphism in the 50 million years prior to the intrusion of the granites. (Camacho 1990). The whole of the rock mass outcropping around Kulgera is considered to be part of an upper overthrust sheet (Camacho 1989). The Dean Quartzite was deposited about 850-800 Ma as the oldest sediment in the Amadeus Basin succession in the Kulgera region.
Between 1660 Ma and 880 Ma, the whole of central Australia appears to have been land, sometimes mountainous. Any sediments similar to the McArthur Group or the Limbunya Group in the Birrindudu Basin which may have been deposited in central Australia during this period have been completely removed (Blake and Page 1988).

**Amadeus Sea (850-750 Ma)**

After about 850-800 Ma, there was a shallow marine inundation of a vast flat desert covering most of central Australia. The date is very imprecisely known, being younger than the Stuart Dyke Swarm (897 Ma) and older than the Sturtian glaciation 750 Ma (Black and others 1980). Shallow-water very quartz rich uniform sandstones were deposited as the oldest and essentially unmetamorphosed sediments. They are now preserved in the western Georgina, Amadeus, Ngalia and Birrindudu Basins. There is little doubt that the deposit blanketed almost the whole region including the Arunta Inlier. The Tennant Creek Inlier and the Davenport Ranges area may have remained as rocky islands in this vast shallow sea with very wide sandy beaches and foreshore (Figure 14).

Shore line, tidal, fluvial and braided stream environments of deposition, have all been invoked to interpret these sandstones. The Heavitree Quartzite, Dean Quartzite, Vaughan Springs Quartzite, Yackah Beds and possibly the Amesbury Quartzite are all names for separated outcrops of the same rock unit (Haines and others 1991)(Table 4). For the convenience of the reader, the Amadeus Basin history will be described first and the history of the other basins compared. (Figure 13, Table 5). Ellery Creek has cut a valley through the outcrops of nearly all the rocks occurring in the Amadeus Basin and as it is convenient to see them there, they will be described as they occur there. The Heavitree Quartzite, however, can be seen conveniently west of Jessie Gap near Alice Springs. There original sedimentary structures such as ripple marks and cross bedding have been preserved on the steeply dipping bedding surfaces (Plate 10g). Thin shale beds are found at the base of the Heavitree Quartzite in some localities, most notably at the northern end of the railway cutting at Heavitree Gap where an unconformity is well exposed (Clarke 1976). At Arltunga a basal conglomerate can also be seen.

Four cycles of deposition are recognised which probably reflect three marine incursions (Clarke 1976). The quartz sandstone has been compressed to a quartzite, a rock in which the quartz grains in the rock have been slightly recrystallised to become interlocking.

The Heavitree Quartzite is a very hard rock and it forms well defined upstanding ridges, resisting erosion better than the surrounding beds. Those living in Alice Springs are familiar with the reddened rock which forms the cliffs capping Mount Gillen, the Blatherskite Range and the steep sided valleys at Simpson Gap, Heavitree Gap, Emily Gap and Jessie Gap (Plate 10a, b). The upstanding ridges of Heavitree Quartzite were so distinctive that the first geologists in the area used them as a “marker horizon” to enable the geological structure of the area to be unravelled. The Heavitree Quartzite outcrops along the northern margin of the Amadeus Basin for 300 km in an east-west direction from Kintore in the west to Tommy’s Gap in the east.
The shallow sea, with a thickness of about 300 metres of sands on its floor at the end of the Heavitree Quartzite time, became shallower still and probably consisted of shallow tidal lagoons. Very fine muds and sands settled in this sea and at times the lagoons dried up depositing beds of gypsum and halite(salt). In some places colonies of blue-green algae grew in the shallow water forming a series of mounds which may or may not have been exposed at low tide. The algal mounds called stromatolites, are a primitive life form which still exists in Shark Bay in Western Australia where the sea water is very salty (Plate 6e,f). The stromatolite consists of a thin flat layer of tissue with short upward growing filaments or hairs which wave in the sea water to obtain food. The hairs periodically die trapping fine-mud and then another layer of tissue grows on top of the dead layer. Gradually mounds or columns consisting of fine laminae of mud grew upwards and later hardened to rock (Figure 14).

The resulting limestones accompanied by mudstone, rare volcanic rocks and gypsum and halite beds form the Bitter Springs Formation and Corroboree Rock east of Alice Springs is a good example of this formation. Limestones of the Bitter Springs Formation crop out immediately north of the Ross River Highway where, the grey, sometimes grooved, slabby rocks, stand out above the spinnifex and can be seen from the highway (Plate 2c).

The Bitter Springs Formation is not a very strong rock, particularly when compared with the Heavitree Quartzite. Consequently these rocks became very crumpled and intensely folded during the Alice Springs Orogeny which occurred about 500 million years after its deposition. This crumpling can be seen at Ormiston Gorge, Ellery Creek, along the road to Arltunga and in Ruby Gap (Plate 5d). Deep within the Amadeus Basin the gypsum and salt beds of the Bitter Springs Formation behaved as a soft slip surface separating the sediments above from the more rigid quartzite and metamorphic basement below. It also squeezed into the cores of anticlines and locally forced its way through other rocks to the surface (diapirs).

Glacial Period (750 & 625 Ma)

A climate change occurred about 750 million years ago. Cold weather affected the whole world and rocks of glacial derivation have been found on all the continents. A particularly well preserved sequence of these glacial beds has been studied in South Australia where the glaciations about 750 Ma have been grouped in an episode called Sturtian. In central Australia the climate change brought to an end the deposition of the gypatherous Bitter Springs Formation, a facies normally associated with warm weather. About the same time some regional tilting occurred (Areyonga Movement) but water depths remained much the same in the Amadeus Basin. The Areyonga Formation is composed of glacial debris, conglomerates, sandstones and dolomitic limestone. The type section (best example) can be seen in Ellery Creek National Park (Preiss and others 1978). There pebbles of varying sizes are set in a very fine grained rock matrix which is derived from rock ground to a powder by moving glaciers. Some large blocks of conspicuous pink feldspar granite are also included in this rock which is called a tillite or a diamicrite. Some of the pebbles are recognisable Heavitree Quartzite or Bitter Springs dolomites indicating that hills of those beds were close by and were eroded by glaciers (Plate 2f, Figure 14).
Figure 13  Geology of the Amadeus Basin
It is believed that the Areongta Formation in Ellery Creek was deposited from streams fed by melting glaciers, dropping their load of pebbles and rock flour. Some of the harder pebbles have scratch marks on them which were obtained when the pebbles were held at the bottom of a glacier and scraped over the rocks of a valley floor. The southern or upper beds of the tillite are sandy and the topmost bed comprises a distinctive thin dolomite bed. Other outcrops of tillite derived from this Sturtian glaciation are scattered over a wide area in central Australia and include the Naburla Formation preserved in the Ngalia Basin and the Mount Cornish Formation in the Georgina Basin (Preiss and others 1978).

The Sturtian ice age was followed by the deposition of the Aralka Formation. It is typically a shale with some dolomitic limestone deposited in a calm sea. It does not outcrop at Ellery Creek. However further to the east along the northern margin of the Amadeus Basin, the formation is up to 1020 m thick. In the southern part of the Amadeus Basin, rocks of the same age are probably included in the Inindia Formation (Preiss and others 1978).

A second major ice age, the Marinoan, affected Australia approximately 125 million years later and beds of this age are preserved in central Australia. The Pioneer Sandstone exposed in Ellery Creek is an example. Beautiful cross-beds with a herring bone pattern have developed. The coarse sands are outwash material dumped by melting glaciers which were active further north. The uppermost (southernmost) part of the creek outcrop contains two lenses of pink dolomite containing pencil-thick stromatolite columns. The dolomite and stromatolites indicate that a shallow sea existed there at that time. The Pioneer Sandstone outcrops near Areongta and as far east as Mount Ringwood where there is a facies change and the unit becomes coarser. A different name, Olympic Formation, reflects this facies change (Preiss and others 1978).

The shallow sea in the Amadeus Basin became much deeper and this change in the depositional environment is reflected by the change to fine-grained sediments. Thick beds of red brown shale of the Pertatataka Formation which can be seen in the Ellery Creek section, overlie the glacial deposits in the northern Amadeus Basin, and are very widely distributed. In the southern parts of the basin they are called the Winnall Beds. The sea later shallowed and limestones of the Julie Formation were deposited. The limestone thickens eastwards from 30 metres at Ellery Creek to 300 metres at Ross River. The difference in thickness may in part be related to two interconnected basins of deposition called the Carmichael and Oroaminna sub-basins, both north of a central submarine rise within the Amadeus Basin. A marine connection southeastwards to the Adelaide Geosyncline appears to have existed then. The deposition of the Julie Formation was terminated by the Petermann Orogeny about 600 million years ago (Wells and others 1970).

**The Petermann Orogeny (600 Ma)**

The Petermann Orogeny was a major mountain building event effecting the southern margin of the shallow Amadeus sea. High mountains were pushed up by north-south squeezing pressures.
Table 4 Correlation of Adelaidean rocks in central Australia
Figure 14  Palaeogeography 850-800 Ma and 750-700 Ma
Figure 15  Palaeogeography 570-550 Ma and 545-541 Ma.
Upper Proterozoic rocks such as the Inindia Beds and the Winnall Beds which had been deposited in the southern sub-basin of the Amadeus sea were tightly folded. The underlying gypsiferous Bitter Springs Formation, which has very low strength, flowed to zones where lower pressure prevailed and acted as a slide surface between the sediments above and the more rigid Heavitree Quartzite or Dean Quartzite which is presumed to lie beneath. Sedimentation in the southern part of the Amadeus sea ceased during the Orogeny.

**PHANEROZOIC (570 - 0 Ma)**

**Cambrian (570-510 Ma)**

As soon as the Petermann Orogeny had pushed up mountain ranges along southern margins of the Amadeus sea, weathering and erosion began producing a plentiful supply of sediments. The shoreline bordering the newly formed highlands was moved seawards as thick fans of detritus from the uplifted mountains, and over-loaded river deltas, spread further and further northwards and eastwards.

The Mount Currie Conglomerate is the name of this detrital formation and it is preserved in an east west zone along the foot of the formerly more extensive Petermann Ranges. Mount Olga is the well known outcrop of the conglomeratic facies of this formation and Ayers Rock, further from the sediment source is the equally well known outcrop of the finer grained arkosic facies of the same formation (Figure 15, Plate 22a).

In the Mount Olga area, the evidence of progressive stripping of the Proterozoic rocks off the Petermann Range can be seen. First removed, and now at the bottom of the pile, are blocks of Dean Quartzite amongst a matrix of debris from the Pinyinna Beds which are correlated with the Bitter Springs Formation. In the middle levels are layers of volcanic rocks which may be equated with the Mount Harris Basalt. The upper-most levels contain boulders of Olia Gneiss and granites from the more deeply buried parts of the Petermann Ranges. A total thickness of 6000 metres of conglomerate is estimated (Wells and others, 1970).

During the Early Cambrian period, 570-550 Ma, the pre-existing shallow Amadeus sea continued to receive sediments, from the south and west with grain size decreasing northwards and eastwards and the thickness decreasing eastward. The Arumbera Sandstone, the sandy equivalent of the Mt Currie Conglomerate was deposited over a very wide area (Figure 13). During the succeeding sedimentation, the two northerly sub-basins within the Amadeus sea, which were probably connected to an ocean to the east appear to have continued to influence the sedimentation, with predominantly calcareous deposits forming in the eastern basin and the more sandy beds in the west (Figure 15). The rocks typical of the eastern basin can be seen in the Ross River gorge and those typical of the western basin in the Ellery Creek gorge. During the Middle Cambrian Ordian period 545-540 Ma, there was a major sea level rise and large parts of the previously dry Georgina, Wiso and Ngalia basins were flooded after a long period of erosion (Wells & Moss 1983; Kennewell & Huleatt 1980; Smith 1972)(Figure 15). In the late Cambrian, the seas shallowed and limestones were deposited in the east Amadeus and Georgina basins. In the Wiso Basin, the sea appears to have
retreated after depositing the Ordian Montejinni Limestone, except in the Lander Trough area (Table 5)(Kennelwell & Huleatt 1980).

**Ordovician (510 - 435 Ma)**

During the late Cambrian and Early Ordovician period, the Pacoota Sandstone (505-487 Ma), the oldest unit in the Larapinta Group, was deposited in the Amadeus sea which was still very shallow. The sandstone has beds of worm tubes, preserved ripple marks, tracks of trilobites, as well as mud cracks (Plate 10e, g) which are the most compelling evidence of slight emergence of the sea floor above sea level. The sediments, well sorted quartz sandstones were probably derived from the west (Nicol and others 1988). The porosity of the Pacoota Sandstone is most important as this unit is the reservoir rock for the petroleum accumulations found in the Amadeus Basin (Figure 16).

Overlying the Pacoota Sandstone, the Horn Valley Siltstone represents a slight deepening of the Amadeus sea particularly to the north away from the hills in the south, a remnant from the Petermann Orogeny. Grey siltstones were deposited in the deeper parts of the basin whereas limestones were deposited where the sea was shallow around its margins. The sea was alive with living creatures, including trilobites, brachiopods, nautiloids, graptolites, gastropods, and the remains of the harder parts of these animals have been preserved as fossils. The soft parts of the bodies, in time were converted by pressure and low temperature to oil and gas. The Horn Valley Siltstone was deposited about 485 Ma (Figure 13)(Plate 7c-f).

The sea became shallower and the widespread Stairway Sandstone was deposited over the whole Amadeus sea area. Evidence of further oscillations in the depth of the sea, never deep, and the changes in sediment supply is preserved, as the Stokes Siltstone was deposited in a salt lake environment and the Carmichael Sandstone displays textures found in shallow water. A cyclical depositional environment prevailed (Plate 3b). The Stokes Siltstone (475 Ma) and the overlying Carmichael Sandstone form, respectively, the floor and lower slopes of the cliffs around the Kings Canyon in the George Gill Range.

**Silurian (435 - 410 Ma)**

Deposition ceased and the Amadeus sea retreated at the end of the Ordovician period about 462 Ma. Localised regional uplift called the Rodingan Movement, caused the newly deposited sediments in the eastern Amadeus sea to be elevated above sea level after which erosion removed a wedge of sediment. Varying thicknesses of the Larapinta Group were removed west of Ross River and in Ellery Creek, whereas in Kings Canyon the succession remained complete.

**Devonian-Carboniferous (410 - 290 Ma)**

Erosion levelled the Amadeus Basin area and most of central Australia to a flat low lying plain covered with dune sands, with scattered ephemeral lakes and river systems mainly to the north. A desert climate prevailed (Wells and others 1970). Clean white marine, dune and fluvial sands make up the Mereenie Sandstone and were deposited probably during the Devonian period, at about 360 Ma (Figure 17). These rocks are best seen at Kings Canyon. Towards the close
Figure 16  Palaeogeography 500-490 Ma and 490-480 Ma
Table 5  Correlation of Palaeozoic rocks in central Australia
of the Mereenie period a shallow sea in the southern part of the Amadeus Basin inundated the whole of the Mereenie deposition area. The Arunta Inlier may have been pushed up by the Rodingan Movement to form a divide between the Amadeus and Georgina Basins at the commencement of the Mereenie Sandstone period. This divide had been levelled by the time the sea partly submerged the dune covered plain in the Devonian Period reconnecting the Amadeus and Georgina seas (Wells and others 1970).

The short lived partial inundation of the Mereenie peneplain dunefield was terminated by uplift which acted as a forerunner of the gentle Pernjara Movement during the late Devonian.

The Parke Siltstone, the oldest member of the Pernjara Group, was deposited in a shallow depression in the western arm of the Amadeus Basin and a lacustrine environment. This can be interpreted from the fossils found (Wells and others 1970, Young and others 1988).

A further uplift or a series of uplifts, particularly active along the north central margin of the Amadeus Basin, was perhaps a precursor to the Alice Springs Orogeny and reactivated erosion. The Hermannsburg Sandstone, the immediate product of this uplift, was deposited to the south as a thick wedge of alluvial fans and as more distant sandy floodout deposits. These can now be seen in the Finke Gorge and in Palm Valley. Conglomerates, and silts containing recognisable fragments of all the older sediments found in the northern Amadeus Basin, are exposed in the Ellery Creek section (Plate 2e, Figure 23).

Early Carboniferous (350 Ma) plant remains have been recognised in the Hermannsburg Sandstone which is thought to have been deposited in the late Devonian to Early Carboniferous time (Wells and others 1970).

**Alice Springs Orogeny (340 - 310 Ma, 315 Ma peak)**

In Early Carboniferous time, the Alice Springs Orogeny, a major mountain building event, affected the whole of the northern margin of the Amadeus Basin with the greatest amplitudes occurring over the Arunta basement region east and west of Alice Springs. Pressure from the north, faulted the basement and folded all the Palaeozoic and Proterozoic sediments in the Amadeus Basin (Shaw and others 1984)(Plate 5a - d). The folds generally have an east-west axis.

The newly uplifted mountains provided coarse detritus that built very thick conglomerate fans extending southwards from the site of the MacDonnell Ranges over the partly eroded Hermannsburg Sandstone. The conglomerates, the youngest rocks in the Pernjara Group, are named the Brewer Conglomerates and under the Brewer Plain are over 3000 metres thick (Wells and others 1970). However they are best seen at Ellery Creek and Goyder Pass. A dry climate prevailed at the time. The Brewer Conglomerate is directly comparable with the style of formation of the Mount Currie Conglomerate which was deposited at the foot of the Petermann Ranges 300 million years earlier, and are now exposed in Mount Olga (Figure 18).

In the south-eastern part of the Amadeus Basin, the Finke Group, also a series of conglomerates, sandstones and shales, interfinger with the Pernjara Group
which outcrop in the northern half of the Amadeus Basin. The coarseness and angularity of the conglomerates in the south confirms that some local uplift and faulting was occurring at about 380 Ma the time of the Pernjara Movement (Wells and others 1970). The Black Hills appear to be a relict of this uplifted ridge and the reduction of grain size within a single bed, as the distance increases away from these hills, has been observed in bore holes beneath the Pedirka Basin. This trend confirms that the Black Hills area was most probably the source of the Finke Group (Youngs 1976). It is noteworthy that the overall grain size decreases in the younger formations of the Finke Group as the height of Black Hills area was decreased by erosion and the energy of transport diminished. The Idracowra Sandstone, which disconformably overlies the Horseshoe Bend Shale, thickens eastwards, perhaps indicating a different source area to the south or northwest of the Pedirka Basin which may have been elevated by the Alice Springs Orogeny (Youngs 1978, Plate 3a).

Permian (290 - 250 Ma)

Most of the Amadeus Basin area was above sea level and eroding during this period. The southeastern part was the exception and up to 200 metres of terrestrial glacial debris is preserved together with some sandstones. Conspicuous very well rounded quartzite boulders are characteristic of the glacial Crown Point Formation, which lies unconformably above the Idracowra Sandstone (Wells and others 1970). It may be argued that these rocks should be included in the succession of the Pedirka Basin which represents another hollow in the Proterozoic surface, to the east of the Amadeus Basin where a thickness of Permian sediments has been preserved (Figure 2). The basin contains older buried Palaeozoic sediments only known from drill holes bored in search of petroleum. The Crown Point Formation is the only Permian formation that outcrops in central Australia. Both this and the coal bearing Purni Formation extend widely beneath the Simpson Desert, and the latter formation is important as a possible source of petroleum. The coal it contains is too deeply buried to be considered economic at present, although considerable effort has been expended to find petroleum or gas which may have been derived from the coal. Similar beds of the same age in the adjoining Cooper Basin are petroleum producing (Youngs 1976).

Mesozoic (250 -65 Ma)

In central Australia, the sediments deposited in the Eromanga Basin, almost completely overlap the Pedirka Basin sediments (Figure 2). As most of the area is part of the Simpson Desert, exposures are poor and most information has been gained from bores.

There are no known Triassic (250-205 Ma) sediments in central Australia, which was then a stable land surface. Coal formed in some small basins in South Australia.

In southern central Australia the freshwater Algebuckina Sandstone of Jurassic (205-135 Ma) age has been found in drill cores bored beneath the Simpson Desert and is separated from the underlying Purni Formation by a major erosional unconformity.
Figure 17  Palaeogeography 375-360 Ma and 350-325 Ma
Isolated outcrops of Jurassic sandstone called De Souza (Hooray) Sandstone occur in both the Amadeus Basin and the Georgina Basin. Leaves of plants preserved in the sandstones have enabled the age of deposition to be determined. The stable central Australian land surface does not appear to have been noticeably affected by the tectonism connected with Australia breaking away from the Gondwanaland supercontinent at about 160 Ma. However at about 135 Ma, there was a marine incursion which submerged most of the Northern Territory except the Arunta, Tennant Creek and Petermann provinces and most of the western Amadeus Basin. In the eastern most part of the Amadeus Basin, the Rumbalara Shale, up to 300 metres thick, is preserved as the youngest marine sediment in central Australia (Figure 18).

Ngalia Basin

The Ngalia Basin, a lens shaped depression in the Arunta Inlier with a faulted northern boundary has had an almost identical depositional history to that of the northern Amadeus Basin. The similarity of sediments is suggestive that at the commencement of the Late Proterozoic sedimentation, about 850 Ma, both areas were part of a flat plain which was inundated by a small sealevel rise. The Heavitree Quartzite and the Vaughan Springs Quartzite are almost identical and the similarity of the sedimentation in the two areas continued until the end of the Marinoan glaciation, 625 Ma (Table 4).

The Mount Doreen Formation in the Ngalia Basin contains glacial deposits of diamicrite with pink dolomite above (Wells and Moss 1983). Still further north, conglomerates of glacial origin occur beneath the Central Mount Stuart Formation.

As there are no sediments preserved in the Ngalia Basin area correlating with the marine deposition of the Pertatataka Formation and Julie Formation in the Amadeus Sea, it is concluded that the area was above sea level and eroding between 625 and 600 Ma. The Petermann Orogeny (about 600 Ma) may have already started to cause minor uplift (Figure 14).

At the beginning of the Cambrian period the Ngalia Basin area was still just above sea level as the lower beds in the Yuendumu Sandstone are of lacustrine origin. However the Ordian (Middle Cambrian, 550 Ma) beds are marine as the flooding of the Georgina and Wiso Basins reached the Ngalia area (Wells and Moss 1983) and with the Amadeus Basin area formed a single inland sea channel called the Larapintine seaway (Figure 15).

The very shallow-marine sandstones of the Djangamara Formation correlate very closely with the Ordovician Pacoota Sandstone.

During most of the Devonian Period the whole of central Australia was covered with sand dunes and fluvial deposits. In the Amadeus Basin the environment was initially lacustrine and was flooded later by a shallow sea during the close of Mereenie Sandstone time. The same environmental history appears to apply to the Dulcie Sandstone of the Georgina Basin and the Lake Surprise Sandstone in the Wiso Basin (Kennewell & Huleatt 1980; Wells and others 1970). In the Ngalia Basin, no direct equivalent of the Mereenie Sandstone is preserved.
Mount Eclipse Sandstone is a terrestrial or lacustrine sediment derived from the mountains pushed up by the Alice Springs Orogeny. Plant fossils indicate a late Devonian or earliest Carboniferous age 350-300 Ma (Wells & Moss 1983).

**Wiso Basin**

An earliest Middle Cambrian (Ordian) inundation about 550 Ma which affected almost the whole of central Australia provided a shallow water depositional environment. In the Wiso Basin, the oldest sediment, namely the Montijenni Limestone, was deposited on an eroded level surface on the Earliest Cambrian Antrim Plateau Volcanics or on Proterozoic rocks. In the southern part of the Basin there are likely to be Hatches Creek Group or Central Mount Stuart Formation rocks underlying the Palaeozoic succession.

In the Wiso Basin, the sea shallowed even more and a drying shoreline environment existed when the Lothan Hill Sandstone was deposited about 500 Ma.

The Point Wakefield Beds in the Wiso Basin are the preserved response to another regional inundation. The region was so flat at the time of deposition that sediments were in short supply and the beds are thin and commonly fine grained (Kennewell and Huleatt 1980). The Sandover Beds of a similar age in the Georgina Basin are thicker and the mainly calcareous beds of the Shannon Formation are the Amadeus Basin correlatives (Table 5).

The term “basin” used here may be misleading as it refers to geographical area of preserved sediments rather than depositional hollow. The environment of deposition in all three basins was a shallow and occasionally drying sea called the Larapintine seaway. World wide sea level changes affected the channel which extend from Western Australia across the southern part of the Territory to the deep ocean of the Tasman Sea (Nicholl and others 1988)(Figure 16).

In the Wiso Basin the, fossiliferous Hanson River Beds overlying the Point Wakefield Beds contain sandstones, mudstones and limestones deposited during another sequence of regional sea level rise between 490 and 460 Ma.

A study of fossil populations has enabled correlations to be made between the Tomahawk, Coolibah, Nora, Carlo, and Mithaka beds in the Georgina Basin and the Early Ordovician Pacoota Sandstone, Horn Valley Siltstone, Stairway Sandstone and Stokes Siltstone of the Amadeus Basin (Kennewell & Huleatt 1980). Fossils in these beds are plentiful and include trilobites, gastropods and cephalopods. In common with the Amadeus Basin there was no deposition anywhere in central Australia during the Silurian (Table 5). The Lake Surprise Sandstone is a relic of some later deposition, the age of which is uncertain, and it is tentatively correlated with the Mereenie and Dulcie Sandstones (400-350 Ma) (Kennewell and Huleatt 1980).

**Georgina Basin**

The Proterozoic succession of the Georgina Basin is preserved in an east-west trough lying along the northern edge of the Arunta Inlier and now exposed in the folded mountains north of Jervois on the Huckitta mapsheet (Figure 1, Table 4).
Sediments derived from both the Sturtian and Mariano glaciations are preserved as the Mount Cornish Formation and the Oorabro Arkose respectively. Still further north, conglomerates of glacial origin occur beneath the Central Mount Stuart Beds around Barrow Creek. There U-shaped valleys, typical of glacial activity, can be seen to have been cut into quartzite of the Hatches Creek Group. The glacial valleys have now been almost completely exhumed except for a veneer of Central Mount Stuart Beds still clinging to the valley walls. The landscape now, must closely resemble the landscape of 600 Ma, the major differences being that the ice and glaciers of the Mariano glaciation are missing and plants and trees are growing now (Haines and others 1991)(Plate 20a).

Glacially eroded U-shaped valleys are evidence that highlands existed near Barrow Creek during the Mariano glacial period (625 Ma). The Central Mount Stuart Formation lying unconformably above this eroded surface indicates that inundation, accompanied by faulting in that area, occurred shortly after the glaciation (Haines and others 1991).

Sedimentation continued until the onset of the Cambrian Period with the deposition of sandstones and shales of the Mopunga Group which are exposed in the Mopunga Range. The sandstones of the Mount Baldwin Formation are similar to the Arumbera Sandstones (600-550 Ma) of the Amadeus Basin.

The Palaeozoic history of the Georgina Basin generally commenced with the Early Middle Cambrian (Ordian 550 Ma) flooding of the whole Basin and the deposition of fossiliferous marine sediments (Figure 2). Trilobites and archaeocyathids were abundant locally (Stidolph and others 1988). The first inundation extended furthest to the north and the shores of the many short-lived seas contracted southwards with successive flooding events. Sediments from about five inundations which occurred before the Middle Ordovician (475 Ma) have been recognised (Stidolph and others 1988)(Figure 15).

Thereafter the basin was level with no deposition during the Silurian (435-410 Ma). The Dulcie Sandstone and the Cravens Peake Beds are Devonian in age. The former contains fossilised fish scales and both appear to be remnants of scattered freshwater deposition (Long and others 1988; Young 1987). The joint effects of the almost simultaneous Alice Springs Orogeny and the Kanimbian Orogeny of eastern Australia, caused extensive faulting, particularly in the southern part of the Georgina Basin. A subsequent long period of erosion planed off any hills caused by the faulting.

The Permian glaciation, at about 280 Ma, left deposits of gravels and clays, some of which are now exposed in the Tarlton Range and on hills on the Tobermorey and Hay River mapsheets (Smith 1972)(Figure 1).

The whole basin was again extensively flooded by a shallow sea in Early Cretaceous times (135 Ma) with the resultant deposition of siltstones and sandstones equivalent in age to the Mullaman Beds of the Wiso Basin and elsewhere in northern Australia (Smith 1972). In the channel country on either side of the Georgina River, flatlying Cretaceous sediments, which were non-marine, form scattered mesas often capped with a Tertiary duricrust. They have
Figure 18 Palaeogeography 300-280 Ma and 120-110 Ma
Figure 19  Palaeogeography 100-30 Ma and 20-5 Ma
eroded to a landform similar to the western Simpson Desert (Plate 11b). However, alluvial plains substitute for the sand dunes of the Simpson Desert.

**Tertiary (65 - 1.6 Ma)**

The geological history of central Australia during the Tertiary period was initially one of widespread erosion and deposition in hollows. Many of the deposits were removed by later erosion. The Early Tertiary history is difficult to piece together as there are few exposures of sediments of this age and even fewer which can be dated using non-marine fossils such as plant pollens (Figure 19).

One feature of the landscape in the Alice Springs region is the remarkably level surface to which the summits of many hills rise, and this level represents the Late Cretaceous and Early to Mid-Tertiary land surface. This feature can best be appreciated by standing on the top of the MacDonnell Ranges near Mount Gillen, and on this elevated surface noticing the similarity in height of surrounding hill tops (Plate 21a). The remnant of the Tertiary erosion surface on Mount Gillen is expressed as a bevellng of the crest, a feature not noticeable from below (Mabbutt 1962) (Plate 10b). This Tertiary erosion surface, as it was 70-20 million years ago, was not completely flat and taller peaks undoubtedly stood as hills above it, while some plains lay below it. Hill slopes were more gentle in those days, and this can be appreciated if one looks east along Ross River Highway where the upper surface of duricrust capped hills defines a gentle slope to the top of the MacDonnell Ranges (Plate 21b) and contrasts with the much steeper present day slopes.

The climate of central Australia about 65 million years ago was wet and probably less extreme than today. Australia at that time had only just started to separate from Antarctica and the latitude of Alice Springs would have been about 45 degrees south rather than the 24 degrees south at present. Southern Tasmania is 45 degrees south and is recognised as a wet place (Ludbrook 1980).

As Australia moved northwards away from Antarctica, the mean temperatures increased as the direct influence of the ice caps receded. Much of the land was forested and remained wet. However, towards the end of the Eocene period (53-37 Ma), it is thought that the Antarctic ice cap melted due to a general rise in temperatures. In central Australia, pollen found in a bore hole near Napperby came from plants which lived in marshy environments and were preserved in lakes. A humid climate with possible dry seasons is interpreted for central Australia in the Middle Eocene (Kemp 1978).

Another climate change occurred during the Oligocene (37-20 Ma), when the Antarctic ice cap reformed and eventually extended down to the Antarctic sea. Central Australia now at latitude 30-40 degrees south, was probably cooler but still wet. Silcrete and later ferricrete profiles have a widespread distribution in central Australia. The time of formation is not well constrained and could have occurred during the Oligocene-Miocene (38-16 Ma) (Ludbrook 1980). The ferruginisation may have occurred first in some areas (Wells and others 1970). Wood and leaf impressions have been found in a silicified sandstone near Ormiston Gorge and petrified wood was found in the Waterhouse Range. The dating is uncertain.

-88-
Mount Etingambra and a small group of low hills in the south Simpson Desert close to the Northern Territory–South Australian border and situated on the McDills Anticline, contains beds of sandstone, siltstone and conglomerates totalling 1.2 metres thick (Wells and others 1970). The beds were deposited after the major silicification and are possibly late Oligocene in age. This outcrop is similar to many small occurrences of Tertiary sediments widely scattered in or around the Amadeus Basin.

During the Miocene period 16 to 7 million years ago the interpretation of the history in central Australia is more certain. The climate continued to be wet. Earlier east-west faulting and regional uplift had rejuvenated erosion and promoted the dissection of the very stable Tertiary erosion surface. The Lake Eyre region sank lowering the base level and promoted the erosion by undercutting and removing the thick bleached zone (Ludbrook 1980). Hollows, some fault-bounded, became sediment traps. The boulder beds to be seen in the road cuttings along Namatjira Drive 60-80 kilometres to the west of Alice Springs are the product of this erosion and the size and roundness of the quartzite and silcrete boulders suggests that water was not in short supply (Plate 21d, Figure 13). The Ellery lookout itself, would have been the valley floor about 10 million years ago (Plate 21c). In the Miocene, hollows became lakes and swamps in which some plant matter was preserved as thin layers of lignite. From an analysis of the preserved pollen it is deduced that reed swamps existed in a landscape of forests and grassy plains which enjoyed a cooler drier climate (Kemp 1978). Elsewhere in Australia, rain forests were the dominant vegetation cover. Lignite has been found at depths of up to 90 metres by drilling into the Tertiary sediments at Ti Tree, Hale River Basin, Paddy's Plain, Tempe Downs, Alice Springs farm area, near Santa Teresa and Ayers Rock (Wyche 1983).

The Waite Basin, a depression north of the Strangways Range, has a floor of Tertiary laterite overlying the eroded Arunta rocks. Above the laterite, Late Miocene erosional debris deposited as siltstones and limestones in a lake or river environment, contain a rich fossil assemblage, the only one of this age found in central Australia. Bones and teeth of Diprotodon, an extinct wombat, freshwater crocodiles, wallabies and kangaroos are evidence of a thriving fauna living in much wetter conditions, about 7 Ma (Woodburne 1967).

Since that time central Australia has become drier and since the Pleistocene glaciation 1 Ma to 40,000 years ago it has become warmer.

The rivers west of Alice Springs were studied in 1967 by Mabbutt who came to the conclusion that the Hugh River, Ellery Creek and the Finke River have followed the same general course for about 100 million years. During the Late Cretaceous to Early Tertiary erosion period, they flowed southward through shallow valleys which cut through the Heavitree Quartzite at the sites of the present gorges. Tributaries of these rivers flowed parallel to the “grain” or strike of the country, most commonly through valleys carved in the softer siltstones, shales and limestones (Mabbutt 1967). The tributary valley floors were preferentially filled with resistant Heavitree and Chewings Range Quartzite boulders. The limestone, shale, sandstone and schist boulders in the river systems were quickly degraded to sand and silt and did not survive the transport.
a The 'U' shaped valley is typical of glacial erosion. A thin veneer of Central Mount Stuart Formation clings to the valley walls. Near Barrow Creek.

b The flat Ashburton surface forms the upper limit to the height of the modern hills. Looking south towards Tennant Creek.

c The dry valley not used by the modern river is a remnant of an old course. Finke River, Palm Valley National Park.

Plate 20 Remnants of Pre-Tertiary erosion surfaces.
The flat top of the Blatherskite Range was once part of the Tertiary weathering surface which developed between 60 Ma and 20 Ma in central Australia.

The preserved brown duricrust of the Tertiary weathering surface slopes up to a bevelled crest on the MacDonnell Range. Recent erosion exposed dip slopes.

Flat topped spurs (terrace) is a relic of a Tertiary valley floor. Note the white leached rock in breakaway beneath old floor level. Ellery Lookout. Namatjira Dr.

Well rounded cobbles deposited in the Late Tertiary (15 Ma) unconformably cover an uneven eroded surface of vertically dipping shales. Ellery Lookout.

Plate 21 Late Tertiary erosional landforms.
The Late Tertiary rejuvenation which appears to have caused the rivers to cut narrow deep channels up to 100 metres below the floors of the early Tertiary shallow valleys. It has also caused marked northward downcutting of the Finke and Hugh Rivers, and Ellery Creek so that they now flow between the highest peaks in the West MacDonnell Ranges and have captured the flow from earlier east-west strike valleys. In the Finke Gorge, at least two sets of incised meanders can be seen, and these were formed when the river bed level was higher (Plate 20c).

The sinking of the country to the southeast of the Territory was also responsible for the development of the conspicuous change in drainage direction from south to southeast (Figure 7). The eastward trend commences south of the main mountain ranges.
GEOLOGICAL FEATURES OF INTEREST IN CENTRAL AUSTRALIA.

Alice Springs Telegraph Station  CCNT Historical Reserve
The Todd River has cut a comparatively narrow valley through the Alice Springs Granite and the Telegraph Station was built in a local widening of the valley where there was a spring. The scenery around the Telegraph Station is characteristic of a granite terrain with rounded boulder-strewn hills, bare flaking rock surfaces and pockets of a gritty quartz-rich soil. Upstream at Wigleys Waterhole, north-south trending dolerite dykes of the Stuart Dyke Swarm can be seen cutting the Charles River Gneiss.

Arltunga  CCNT Historical Reserve
The lumpy but gentle scenery developed over the Early Proterozoic metamorphic rocks (1800 Ma) in the northern and western parts of the Reserve, contrast with the steep slopes developed on the almost white and much more resistant Late Proterozoic Haevitree Quartzite (850-800 Ma) in the east. In the metamorphic rocks, mainly well foliated schists and gneisses, increasing quartz content can be directly related to the higher ground or ridges. White quartz veins, some of which contain gold, are so much more resistant to weathering than the metamorphic rocks, that many rises have a quartz vein in their summit and a mantle of white quartz boulders covering the slopes. The slabby nature of the gneiss can be seen in boulders protruding through the thin soil and the early miners selected the parallel sided blocks when building their stone walled houses. The Haevitree Quartzite overlies the metamorphic rocks in the east and a basal conglomerate separates the two units. Locally, the deformation in the area was so intense that the rounded conglomerate boulders have been dragged out into elongated and pointed sausage-shape pebbles.

Ayers Rock and the Olgas*  ANPWS Uluru National Park
Ayers Rock stands 340 metres above its surrounding sand plains and the rounded hills grouped around Mount Olga rise to 600 metres above the plain (Figure 21).

Both are remnants of a landscape more than 100 million years old and their uppermost layers were part of that much more extensive landsurface.

Since then all the enveloping rock has been weathered away and the general level of the landscape lowered, with the notable exception of Ayers Rock and the Olgas which stand out and are called "bornhardts" by geomorphologists (Twidale and Bourne 1978). Indeed, by the Palaeocene, 65 Ma, the erosion had lowered the level of the surrounding uneven countryside to about 90 metres below present plain level before some slight warping halted the downcutting (Freeman 1986).

*Localities listed as geological heritage sites (Fortowski and others 1988)
Figure 20 Map showing localities of geological interest in central Australia
Figure 21  Ayers Rock weathering and development
The accumulation of sediments recommenced with muds containing plant remains being trapped in lakes formed around the foot of Ayers Rock when the climate was wetter. The plants recognisable in these muds are similar to those known to have been living in Victoria and South Australia 65 million years ago (Twidale & Harris 1977). Later sands subsequently buried these deposits which were discovered when drilling for water.

Both Ayers Rock and the Olgas are composed of the Mount Currie Conglomerate, a sediment derived from high mountains, which were formed by the Peterrmann Orogeny, a mountain building event 600 Ma, in the neighbourhood of the present day Peterrmann Ranges. The coarsest debris, eroded off the new mountains, was deposited as conglomerates in thick alluvial fans where mountain rivers disgorged their sediment load onto a plain. The boulders in these conglomerates consist of granite, gneiss and basalt similar to rocks now found in the Peterrmann Ranges (Plate 23d).

The bedding in the Olga is nearly horizontal with a slight dip to the southwest (Figure 21, Plate 23a). Ayers Rock is composed of a coarse quartz sandstone in which feldspar comprises about 25 percent. The sandstone is regarded as the fine-grained equivalent of the conglomerates in the Olgas, the diminished grain size being attributed to the extra distance from the source.

Folding of the Mount Currie Conglomerate occurred during the Alice Springs Orogeny, a mountain building event 340-310 Ma, and the cross section (Figure 21) illustrates this. The bedding attitude in the Olgas has changed little since deposition whereas in Ayers Rock, situated on a limb of an antclinal fold close to the axis, it is vertical (Plate 22a). The prominent jointing to be seen in the Olgas developed during that orogeny (Plate 23c), as well as the unseen jointing which, it is concluded, bounds the single block of Mount Currie Conglomerate, called Ayers Rock. Multiple joints away from the Rock are thought to be the cause of the enveloping Mount Currie Conglomerate eroding away leaving Ayers Rock as a huge unhonited core stone (Twidale and Bourne 1978).

Many examples of the processes of weathering and erosion can be seen at Ayers Rock, including some which are tending to preserve the rock. On the flattish top of the Rock, the slight differences in hardness of individual beds have given rise to the low wave-like ridges across the surface and down the flanks (Plate 22a). Also on the top there are shallow hollows called gnammas which trap rain water to prolonge the weathering of the surrounding rock (Plate 13b). Figure 21 illustrates the water flow over and through the fabric of the Rock, and the consequent dissolution of iron-rich minerals from the top and their deposition on the lower faces, thus building up a tougher surface crust.

The Brain, a honeycomb pattern of pits on the eastern flank of Ayers Rock is an area where the protective crust development has been broken. It is probable that shallow random cracks, perhaps caused by the successive heating and cooling of the northern surface in the area of the Brain, has provided access to rainwater which in turn has caused the weathering of the subsurface zone. The process is intermittent and only proceeds until the water dries up. Eventually, the degraded rock around the cracks is soft enough to be washed out by the rain or blown away by the wind. A pitted texture appears on the surface (Plate 22b).
The weathering of the lower flanks is minimal as the water run off is very rapid. Iron mineral deposition on the crust is active near the bottom. There rib-like iron-rich deposits have been left by dripping water (Plate 22d). Run-off water is held in the loose sand surrounding the Rock and is tapped by wells to supply drinking water. The contained water is also actively weathering the buried flanks of the Rock and this tends to maintain the steepness of the slopes. The shallow caves, tafoni, along the base of the northern side and at Maggie Springs, developed where the foot-wall was corroded and weathered when the plain level was a few metres higher. Now that the sand plain has fallen to its present level, erosion and fretting have removed the weathered rock to produce caves and the overhanging lip is a testimony to the extra toughness of the crust (Plate 22e).

Small localised joints, parallel to and beneath the surface, but different from those causing the “Brain”, are thought to have formed when the pressure of all the enveloping rock, which once buried Ayers Rock and the surrounding desert, was removed. The elastic outward expansion of the compressed rock is enough to cause these joints, one of which can be seen on the northern face where a shaft of rock has separated from the main body and is called “the digging stick” or “kangaroo tail” (Twidale & Harris 1977)(Plate 22c). Another unusual erosional feature which can be seen at Ayers Rock is the irregular surface stripping along a zone through which lightning has travelled over the presumably wet surface (Plate 13 f). This effect is commonest between breaks in the hand chain which appears to act as a conductor.

In the Olgas, the joint planes have been widened by weathering and erosion to narrow steep-sided valleys. Here the weathering and erosion are most active at the base of the slope where moisture collects, thus maintaining the steepness of the landform (Plate 23b). The rounded summits of the hills are the natural product of weathering and erosion of material which contains no directional differences in toughness to cause another shape to develop. A cube of rock if exposed on all sides will weather to a sphere, a shape which has a minimum surface area for its volume (Plate 16b). Other examples are the Devils Marbles, the granite domes of Kulgera and the beehives of Kings Canyon (Plates 1d, 16a, 24a, c).

Central Mount Stuart*  CCNT Historical Reserve

An excellent view of the horizontally bedded Central Mount Stuart Formation exposed on the steep slopes of the dome shaped Central Mount Stuart, can be seen from the Reserve. The alternating ribs of harder rock exposed on the slopes contrasts with the layers of poor outcrop and is indicative of cyclical deposition.

Chambers Pillar*  CCNT Historical Reserve

Chambers Pillar, like Colsons Pillar, Rainbow Valley, and many of the mesas around the western margin of the Simpson Desert, is a remnant of rock which once extended up to the Tertiary erosion surface, a deeply weathered plain. That
a Vertical ridges and furrows on the flanks of Ayers Rock relate to slight differences in the hardness of the vertically dipping beds. Maggie Springs, Ayers Rock.

b Weathered pits have developed on the slope where unprotected by crust.

c Jointing caused by unloading has developed parallel to the surface.

d Trickling water on the slope has left iron and silica rich rib-like deposits.

e Tafoni. Caves developed at the base of slope. Ayers Rock.

Plate 22 Weathering and erosional features on Ayers Rock, Uluru National Park.
a The gentle easterly dip of the conglomerate beds can be clearly seen as well as the vertical jointing. Viewed from west of Mount Olga.

b Weathering and erosion has domed the tops of the widely spaced joint bounded blocks. The Olgas, Uluru National Park.

c Stone covered piedmont platform at base of cliff of conglomerate.

d Granite and basalt boulders in the Mount Currie Conglomerate. Olgas.

Plate 23 Landforms and sedimentary features in the Olgas, Uluru National Park.
plain, developed when a wet climate prevailed 80 - 20 Ma, was eventually covered by a hard siliceous duricrust which included some ferricrete, up to 5 metres thick. Beneath the duricrust, white bleached and degraded rock extends down for about 30 metres. Rejuvenated erosion, caused by down warping in the Lake Eyre region about 20 Ma, started the break up the plain by undercutting and removing the soft bleached layer, and causing the collapse of the duricrust. Chambers Pillar is a remnant of Santo Sandstone conformably overlying Horseshoe Bend Shale, both units in the Finke Group. The top is protected by the duricrust. Brown iron staining of the upper part of the pillar indicated that the duricrust contained both silica and iron minerals and the steep walls of the pillar are in places joint-controlled. The Hermannsburg Sandstone seen in Rainbow Valley is approximately the same age as the Finke Group rocks (about 340 Ma) (Plate 11b and front cover).

**Corroboree Rock CCNT Conservation Reserve**

Corroboree Rock is an upstanding remnant of vertically bedded Bitter Springs Formation dolomite (800 Ma) which crops out as a belt of dark grey rocks along the southern margin of the MacDonnell Ranges. The bedding attitude was changed from horizontal to vertical during the Alice Springs Orogeny (340 - 320 Ma). The ring of low ground around the rock is an erosional feature which makes the rock look like a natural obelisk.

At the base of the rock, dark grey and light grey streaky blobs in the dolomite can be matched with the “dalmation rock” outcrop in the same Bitter Springs Formation in Ellery Creek 150 kilometres to the west.

**Devils Marbles** CCNT Conservation Reserve

The huge rounded granite boulders, up to 6 metres in diameter, are scattered over a saucer shaped surface depression about 5 kilometres wide and surrounded by hills made up of rocks of the Hatches Creek Group. These boulders, which have fascinated explorers and visitors are the residual core stones of a granite that once filled the depression and now underlies it.

Figure 22 illustrates the formation of the “Marble” corestones from regularly jointed granite (Plate 16a). Moisture entered the joints and converted the adjacent feldspar and mica to kaolin and sericite, both soft minerals. These were washed away removing the support for the corestones with the consequence that they collapsed or became perched in sometimes seemingly unstable positions.

The granite is medium to coarse grained, pale pink in colour and composed of quartz, large white microcline crystals, biotite and muscovite with a little plagioclase. The Devils Marbles Granite was probably intruded about 1640 Ma, and is very similar in composition and age to the Elkedra Granite (Blake and others 1987).
Ellery Creek Big Hole*  CCNT Nature Park

An almost complete sequence of sediments deposited in the northern Amadeus Basin between 850 Ma and 310 Ma is exposed along the banks of Ellery Creek. To be able to see such a complete geological succession in such a short distance is exceptional. The bedding is steep to vertical and the strike is perpendicular to the creek bed so that during a drive of about eight kilometres downstream a thickness of about 6000 metres of sediments can be inspected (Figure 23).

At Ellery Creek Big Hole, the upstream and northern end of the section, a waterhole has developed in the narrow gorge through the upstanding range of reddened Heavitree Quartzite (850 - 800 Ma). The gorge may lie along a north-south fault line which has slightly displaced the quartzite. On either side of the waterhole, an overturned fold in the Heavitree Quartzite can be seen (Plate 5a).

Southwards, the younger shales and dolomitic limestones of the Bitter Springs Formation (800 - 760 Ma) form the lower irregular country dominated by grey strike ridges. In one ridge slope west of the car park, a characteristic crumpled fold in the Bitter Springs Formation has developed as a consequence of the unit being very weak compared with the Heavitree Quartzite below (north) and the Areyonga Formation above (south). The behaviour of the Bitter Springs Formation when compressed can be likened to soft cheese in a sandwich which, when squeezed, flows and crumples.

Stromatolites flourished in the very shallow seas in Bitter Springs time and can be seen in boulders in the creek bed or in the west bank. “Dalmation rock”, a mixture of pale and dark grey dolomite blobs, is exposed in a ridge 80 metres east of the access road. The rock was formed by inter-mixing of unconsolidated layered sediments. “Karren” or solution grooves, caused by rain water trickling down the limestone blocks and slowly etching a channel in the rock, can be seen by the road side.

Further south and 50 metres east of the access track, a pale grey textureless fine-grained rock containing rounded boulders of pink granite is an outcrop of the glacial Areyonga Formation(750 Ma). The boulders, some quite large, are called erratics and may have been carried many kilometres in glaciers before being dropped when the ice melted. Scratch marks can be found on some boulders. The pebble beds to the south are outwash deposits of glacial debris released by the melting ice (Plate 2f).

The younger Pioneer Sandstone, a product of a younger glaciation (625 Ma) is well exposed in Ellery Creek as a rock bar of intensely cross-bedded sandstone. Pencil thick stromatolite columns occur in a pink dolomite which fringes the southern margin of this outcrop indicating a marine incursion. The sea became deeper and the red brown flaky shales of the Pertatataka Formation (620 - 600 Ma) can be seen exposed in the river bed about 100 metres further downstream. Green zones within the shales indicate that chemically reducing conditions existed.

The remainder of the succession lies downstream to the south of the main highway and is on Aboriginal Land for which a permit to enter is required. It is
Figure 22  Development of the Devils Marbles corestones
Figure 23  Geology of Ellery Creek and cross-section
briefly described here for the benefit of those who obtain a permit. A full description is included in A Field Guide to Geological Localities in the Alice Springs Region (Freeman and others 1987). Immediately south of the highway opposite the park entrance a two metre high wall of limestone in the Julie Formation can be seen. The shales in the Formation are soft and do not outcrop.

Figure 23 illustrates the different weathering patterns developed over a range of sediments. Strike ridges are conspicuous over the Heavitree, Arumbera, Pacoota, Stairway and Mereenie Sandstones. Bedding is poorly developed in the Brewer Conglomerate exposed in the south and a markedly different landform has developed. The Figure can also be used as an aid to identifying the rock formations in the river banks.

A kilometre further south the Arumbera Sandstone outcrops in the river and on the west side of the gravel terrace a green malachite stained rock is evidence of some detrital copper in the sandstone. The Arumbera Sandstones were deposited at the same time as the Mount Currie Conglomerate (600-550 Ma).

Further south, in the Pacoota Sandstone (490 Ma), ripple-marked bedding surfaces, sand-filled mud crack polygons, trilobite tracks, and layers of worm tubes can be seen. All these features signify a very shallow sea water environment which occasionally dried up (Plate 10e, g).

Horn Valley is a short tributary valley on the east side of Ellery Creek in which the Horn Valley Siltstone outcrops. Fragments of fossilised trilobites, gastropods and cephalopods can be found in the stream bed together with slabs of limestone which also form part of the Horn Valley Siltstone (Plate 7c, d, f).

Southwards between the Horn Valley Siltstone and the typically red brown Mereenie Sandstone, is the pale Stairway Sandstone (450 Ma). Looking south from the entrance to Horn Valley towards the red cliffs of Mereenie Sandstone, it can be seen that a pale coloured wedge of Stairway Sandstone widens westwards. The surface between the two units is an unconformity and represents a break in deposition of perhaps 80 million years.

Downstream of the cross-bedded Mereenie Sandstone and around a dog leg in the river course, the sandstones and conglomerates of the Hermannsberg Sandstone Formation (350 - 320 Ma) outcrop (Plate 2e). Rock fragments of all the older rocks present upstream can be found in this formation, including fossils derived from the Horn Valley Siltstone. The southern-most outcrop, and youngest rocks in the succession, are the thick, coarse boulder beds of the Brewer Conglomerate, a direct sedimentation product of the hills pushed up by the Alice Springs Orogeny (310 Ma).

**Gosse Bluff * CCNT Scientific Reserve**

Gosse Bluff impact crater is 100 kilometres west of Alice Springs and is described in the chapter on Astrogeology.
Heavitree Gap Railway Cutting*  Alice Springs town

A small excavation on the west side of the railway line at the base of the northern hill slope in Heavitree Gap contains an excellent exposure of an unconformity between the Heavitree Quartzite and the Early Proterozoic Sadadeen Range gneiss, one of the metamorphic rocks of the Arunta Inlier.

The underlying gneiss, which looks rather like a granite, and was metamorphosed about 1750 Ma, is separated by an uneven southward dipping unconformity from the overlying, 9 metre thick siltstone bed, the oldest member of the Heavitree Quartzite. The siltstone and the overlying quartzite are the oldest (about 850 Ma) of the preserved sediments deposited by a shallow sea which flooded much of central Australia after a long period of erosion. Small shallow semi-circular breaks in the southward dipping bedding of the siltstone are filled with sandstone and are most likely small sand-filled wash out channels.

The overlying sandstone members of the Heavitree Quartzite can be seen more closely by walking southward along the side of the railway line. Shallow-water and shoreline textures such as cross bedding and ripple marks are exposed. A conspicuous pattern of concentric millimetre thick zones of alternating light brown and dark brown colours, called Liesegang rings, can be seen in fallen sandstone blocks in which the true bedding can be identified by layers of pebbles.

Henbury Meteorite Craters *  CCNT Reserve

A cluster of 13 meteorite craters can be seen in the Reserve which is about one kilometre north of Bacon Range. The geology is described in the chapter on Astrogeology.

Jessie and Emily Gaps  CCNT Nature Park

Jessie and Emily Creeks, which give their names to the gaps, have widened the north-south vertical joint planes through the steeply southward dipping Heavitree Quartzite. Minor quartz veining and plentiful slickensided surfaces suggest that faulting may have affected the quartzite during the Alice Springs Orogeny when the attitude of the quartzite was changed from horizontal to a very steep dip southwards.

The heat developed when blocks under pressure slide against one another, even over centimetre distances, is sufficient to form a shiny veneer from melted silica on striated slip surfaces. Slickensides is the name given to the shiny striated fault surfaces which rarely have a common orientation (Plate 10f). Quartz-filled tear and tension joints can be seen on the water-polished sandstone near river level. Ripple marked bedding planes can be seen on the Heavitree Quartzite to the west of the entrance to Jessie Gap. About 3 kilometres east of Jessie Gap, a wedge of dune sand blown into a sheltered spot at the foot of the ranges survived recent erosion.

-105-
Kings Canyon*  CCNT Watarrka National Park

Kings Canyon is a valley with both sides capped by joint controlled cliffs of red coloured flat lying Mereenie Sandstone, deposited about 360 Ma. Below the cliffs, the slope is less steep and is underlain by the softer Carmichael Sandstone, deposited about 440 Ma. Between the Mereenie and the Carmichael Sandstone is a thin layer of purple shale or mudstone, which represents deposits laid down when the environment was changing from shallow marine (Carmichael) to an inland dune field in which there were rivers and lakes (Mereenie). The outcrop of the mudstone bed coincides with the change in slope and the dip is almost horizontal (Plate 2 b). The flat ground, which is commonly sand covered around the foot of the George Gill Range is underlain by the soft Stokes Siltstone. It has weathered to base level and outcrops poorly (Figure 24).

On the walk up to the plateau, ripple marks on some of the sandstone steps, can be seen. The same patterns can be seen on modern beaches, leading to the conclusion that a similar shallow-sea environment prevailed in Carmichael times (440 Ma).

Jointing has played a dominant role in forming the scenery at Kings Canyon. The cliff faces above the main valley are joint faces. The Garden of Eden Valley is set at right angles to the Canyon and is a joint plane which has been enlarged by weathering and erosion (Plate 24c). The "Beehives", dome-like rock masses, have developed from large rectangular jointed blocks of Mereenie Sandstone, in which weathering and erosion have widened the joints and so produced hemispherical forms with minimum surface areas (Plate 24a). The process has some similarity to the formation of core stones in a jointed granite. The regular jointing has mainly affected the Mereenie Sandstone, perhaps because it was more brittle. The underlying soft shale layer appears to have yielded plastically and prevented much of the stress which caused the jointing from being transmitted through to the Carmichael Sandstone below.

The Alice Springs Orogeny (340-310 Ma) was the folding event which stressed the rocks of Kings Canyon and also produced a very shallow east-west striking syncline centered along George Gill Range. Seen from the entrance road to the park, the structure appears as an elongated mesa bordered by cliffs capped with Mereenie Sandstone. Although iron-free and white in the interior, the Mereenie Sandstone is characteristically reddened on the surface by iron oxides and iron silicates. The colouration is believed to be due to an iron-rich dust blown onto the surface and then chemically fixed to the sandgrains on the surface zone by a form of fungi which thrive on iron, silica and ephemeral rainwater (Stanley and others 1983)(Plate 14e, f).

The Mereenie Sandstone formed mainly in a sand dune environment and the cross beds, so well exposed in the Beehives, are relics of the sand dune slopes. Wind in a dune environment tends to concentrate the size of sand grains it can move along the ground. The lightest and finest blow away as dust and the heavier cannot be moved by wind. A porous sandstone of uniformly sized grains results. If a jar is filled with similar sized marbles, quite a lot of water can be added to fill the open spaces. A uniform grainsized sandstone, such as the Mereenie Sandstone, has a similar texture and this is why this unit is the most important
Figure 24  Geology of Kings Canyon
water-bearing rock formation in central Australia. It is the source of most water used in Alice Springs.

In Kings Canyon, rainwater collecting in the synclinal trough of Mereenie Sandstone on top of the hill is prevented from percolating downward by the impervious shale bed between the Mereenie and Carmichael Sandstones. The Garden of Eden Valley, an enlarged joint in Mereenie Sandstone, cuts the ground water table and thus stored water gets tapped and slowly trickles out of the sandstone to water the lush vegetation (Figure 24).

Weathered pits and the development of an iron-rich crust can be seen on the Canyon cliff face, if one climbs down the Garden of Eden Valley to the head of the waterfall. There vertical streaks of the rusty coloured deposit have precipitated from rainwater trickling down the cliff faces and evaporating as it flowed down (Plate 24d, e).

**Mount Conner**  
**Pastoral lease**

Mount Conner is a spectacular mesa rising over 300 metres above the plain and is usually seen from the Lasseter Highway. The flat capping rock is a hard resistant sandstone unit of the Winnall Beds. Below is a softer sandstone of the Late Proterozoic Winnall Beds which forms the steep slopes. Two circular ridges of Inindia Sandstone surround the mesa and large scale cross bedding is very noticeable even from a distance. Tillite, a glacial deposit, has been recognised between the two sandstones and was probably deposited during the Sturtian glaciation (750 Ma).

**Ormiston Gorge**  
**CCNT National Park**

Heavitree Quartzite, exposed in the spectacular vertical cliff on the western side of Ormiston Gorge and upstream of the waterhole, has an exaggerated thickness. There, the upper part of the cliff is a flat lying upper limb of the Ormiston fold containing horizontally bedded Heavitree Quartzite. Below the horizontal Ormiston Thrust separates the upper limb from the near vertical or overturned Heavitree Quartzite underneath.

Ormiston Pound, about 1km upstream of the waterhole, is surrounded by both Heavitree Quartzite and Chewings Range Quartzite which have been thrust aside by the intrusion of the Ormiston Pound granite. This granite has weathered and eroded away much more quickly than the quartzites, and it now forms the sunken floor of the Pound.

On the ridge north of the visitor centre and below the main quartzite hills an anticline in tightly folded beds of the Bitter Springs Formation is well exposed (Plate 8c).

Mount Sonder is also part of the Ormiston Thrust system. The top is formed of a pale coloured slab of Heavitree Quartzite. Below this and clearly separated by a thrust plain on the southeast face are the Arunta metamorphic rocks.
Palm Valley*  CCNT Finke Gorge National Park

In the Krichauff Range, erosion has removed all the sediments overlying the Hermannsburg Sandstone, thereby exposing a very gently folded surface. Along the northern margin of this range and south of Hermannsburg, an important broad east-west striking anticline, crosscut by the Finke River, has been mapped. This structure has trapped natural gas in the deeply buried Ordovician Pocoota Sandstone.

The adjacent and complementary syncline, 15 kilometres to the south in the Hermannsburg Sandstone, is a natural surface and groundwater collecting basin, drained by Palm Valley creek. Over the last 20 million years, erosion by the creek into the floor of this natural trough, has carved the steep sided valleys, the amphitheatre, and another Corroboree Rock. Jointing is widely spaced and has influenced the river directions. The level of downcutting in Palm Valley has been influenced by the bed level of the larger Finke River which also has a history of downcutting and course changes during the same time span (Plate 11d).

The Hermannsburg Sandstone has some porosity and behaves as a natural reservoir for water which is slowly released at the bottom of the syncline where Palm Valley creek cuts deeply into the Sandstone. The huge water storage has provided a permanent water source through all droughts to feed the creek and sustain the unique surviving flora characteristic of a wetter climate in the past.

The pitted surface of the cliffs has developed where moisture has entered small cracks and weathered the surrounding rock to the extent that wind and rainwater has removed it. The rock in the cliffs may have been partly weathered but not eroded during the Tertiary when it was probably within the zone of leaching beneath the Tertiary erosion surface and duricrust layer.

The winding Finke Gorge leading to Palm Valley has been incised into the gently folded sediments of the Hermannsburg and Mercenie Sandstone Formations. Dry and unused ancient channels of the Finke can be seen (Plate 20c).

Rainbow Valley*  CCNT Nature Park

Spectacular red, yellow and white cliffs, controlled by joint faces developed in weathered Hermannsburg Sandstone are one of the features in the Rainbow Valley Nature Park. The colouration was developed during the long period of deep tropical weathering which affected central Australia between 80 and 20 Ma. At that time, all the hills in the Rainbow Valley area were just beneath a vast level plain in which a deep leaching profile had developed. Uppermost, and now largely removed by erosion, was a silica rich or iron rich duricrust. Below were deeply leached and bleached sandstones out of which evaporating ground water had dissolved some of the iron and silica salts. Iron minerals redeposited in the upper capping zone has slightly strengthened and coloured the rocks (Plate 17a).

Except for remnants beneath the hills, the whole of the bleached zone in this region has been completely eroded largely by undercutting and transported to the dune field of the Simpson Desert. Chambers Pillar is another survivor
Plate 24  Landforms and sedimentary features in the Kings Canyon National Park.
of the bleached zone as are many other mesa shaped hills southeast of Alice Springs (Plate 11b).

The honeycomb textured surface, another feature of Rainbow Valley has developed where modern rainwater has penetrated about 50-100 mm into minute surface cracks or pits into the already partly weathered sandstone. There, the water has further degraded the rock, particularly the cement between the sandgrains to the extent that water or wind can remove the loosened grains to enlarge cracks resulting in a pitted surface (Plate 14b, d). The pits tend to coincide with the original bedding layers in the sandstone. Cross bedding is very well exposed in the base of the cliffs to the south of the picnic area (Plate 14 b). The development of little caves and tunnels beneath a honeycomb trellis supports the view that surface deposition of iron minerals has strengthened the surface (Plate 14a).

Ross River Section* Pastoral lease and N’Dhala Gorge Nature Park

Ross River is 160 kilometres east of Ellery Creek and the exposures in the gorge of the Amadeus Basin sequence provide an opportunity to compare changes in lithology in beds of the same age with the Ellery Creek exposures. In general, the rocks younger than Cambrian to be seen in the Ross River gorge contain more limestones and siltstones than the more sandy rocks of a similar age exposed in Ellery Creek.

The Proterozoic part of the north-south section is exposed in low hills on either side of a tributary creek flowing into the Ross River and situated north of the Ross River tourist homestead. This creek flows through pastoral land (permission required). The Heavitree Quartzite is exposed in the mountains at the north end of the section. Conformably above and lying to the south in the dipping sequence, the Bitter Springs Formation is exposed in the grey hills on both sides of the valley. There plentiful traces of stromatolite can be seen as mounds up to 3 metres across. Preserved layers of gypsum are indicative of the evaporite depositional environment.

The sandy units within the Pioneer Sandstone and the Pertatataka Formation crop out as east-west striking ridges further south, and the shale beds form the low ground.

The Julie Formation at Ross River is thick and forms hills of limestone immediately south of the homestead and they form the northern-most cliffs of the Ross River gorge. In Ellery Creek, the Julie Formation is represented by a thin low ridge opposite the turnoff into the park.

The Arumbera Sandstone rests conformably on the southward dipping Julie Formation and is 340 metres thick. A deltaic depositional environment is interpreted from the sedimentary structures developed during the latest Proterozoic and earliest Cambrian time (600-550 Ma) (Lindsay 1986). Some of the oldest shelly fossils ever found occur here.
The Todd River Dolomite, Giles Creek Dolomite, Shannon Formation and Goyder Formation are all very shallow water carbonate deposits. They outcrop successively downstream. The Pacoota Sandstone crops out in the hills to the west of the river and contains trilobites, brachiopods, nautiloids and lamellibranchs (Kennard, 1986). The change in dip of the beds exposed in the cliff, marks the axis of the Ross River syncline (Plate 5b).

The younger N'Dhala Member is exposed in the N'Dhala Gorge Nature Park. It contains rare Devonian fish plates and rests unconformably on the Pacoota Sandstone (Owen 1986; Young 1987).

A more detailed description of the section has been published in the field excursion guide to the 12th International Sedimentological Congress held in Canberra 1986 (Kennard 1986).

Ruby Gap*  CCNT Nature Park

The most spectacular geological feature in Ruby Gap Park is the southern gorge, cut by the Hale River through a pile of nappes and thrust sheets of the Arltunga Nappe system.

In the gorge, two upper horizontal thrust sheets of pale Heavitree Quartzite are separated by thrust planes from one another and from the brownish underlying intensely drag-folded younger Bitter Springs Formation (Plate 5d).

The Heavitree Quartzite is hard, strong and rigid and has yielded to compressional north-south stresses during the Alice Springs Orogeny by forming thick competent slices bounded by horizontal thrust planes.

The Bitter Springs Formation comprised of dolomite, shale and some gypsum beds, is very weak compared with the quartzite, and it has folded in a most spectacular manner as it yielded plastically to the stress.

The resultant flat-lying, recumbent folds in the brown Bitter Springs dolomite can be seen in the cliffs of the gorge close to the river level, and the bedding planes can be traced along both limbs of the folds.

Simpsons Gap*  CCNT National Park

The narrow gorge cut by Roe Creek through the Rungutjirba ridge of Heavitree Quartzite, probably follows a pre-existing joint trend and some dramatic scenery has resulted. The northward dip of the bedding in the quartzite has been locally folded to an overturned position which can be matched with the outcrop in Ellery Creek Big Hole.

The northward dipping quartzite at Simpsons Gap and the southward dipping Heavitree Quartzite on Mount Gillen, are remnants of a huge arch (anticline) of quartzite which once extended over the Larapinta Valley. Weathering and erosion during the last 300 million years have now removed all but the remnant abutments. The rocks exposed in Rocky Gap, 5 km northwest of the Ranger's
station are quite different. Fresh water-worn granite, cut by narrow zones of foliation and mylonitization are intersected by thin dolerite dykes. All are features of the Proterozoic basement (Plate 4d).

**Standley Chasm*** **Scenic reserve open to the public**

At Standley Chasm, one of the dolerite dykes of the Stuart Dyke Swarm which intruded the Early Proterozoic Chewings Range Quartzite and gneisses, has been almost completely eroded away by the river to form a deep vertical-sided scenic gorge. North-south aligned dolerite dykes of the Stuart Dyke Swarm can also be seen intruding the Early Proterozoic Burt Bluff Gneiss of the southern Arunta Inlier along Larapinta Drive 25 km west of Alice Springs on the way to Standley Chasm. Here the dolerite resists weathering better than the gneiss and forms a ridge.

**Trephina Gorge*** **CCNT Nature Park**

The gorge cuts through Heavitree Quartzite and probably lies along a fault plane. In the hills to the north of the gorge the Arunta metamorphic rocks can be seen to be lying above the younger Bitter Springs Formation and separated from it by a almost horizontal thrust plane. The normal sequence of younger rocks over older rocks was disturbed during the Alice Springs Orogeny by the faulting and thrusting. However the Bitter Springs Formation rests on top of the older Heavitree Quartzite (Offe and Shaw 1983).
ACKNOWLEDGEMENTS

The help and encouragement received from many people in Alice Springs is gratefully acknowledged. Particular thanks for all the checking, suggestions and support are due to Dr C.A. Mulder, Dr R.G. Warren and Dr P.W. Haines who also kindly contributed the section on fossils. The enthusiasm of M.J. Freeman, now with the West Australian Geological Survey, for disseminating information is recognised with thanks and some of his locality descriptions and photographs have been included. The author would like to thank the drafting section and especially Vivi Kotsonis who prepared most of the figures. The computer skills of Kay Pisani and Lyn Page, whose helpful comments improved the text, were greatly appreciated. Without the continuing support of my wife this guide would not have been printed.

The aerial photographs used in Figures 23 and 24 are Crown copyright and have been reproduced by permission of the General Manager, Australian Surveying and Land Information Group, Department of Administrative Services, Canberra. Plate 23a has been reproduced by permission of the Surveyor General, Northern Territory Department of Lands and Housing, Darwin.

The use of slides taken by the following photographers is gratefully acknowledged.

Plates 9a, 13f, 15a, 20c, 23d, 24c  M.J. Freeman
Plates 6a, b, c, d, 7c, d, e, f  P. Haines
Plates 6e, f, 7a, b  A. Wally
Plate 20b  N.C. Donnellan
Front cover  G.B.R. Thompson

All other photographs were taken by the author.
GLOSSARY

abrasion a term to describe the wearing away of rock by the grinding action of other moving particles carried in wind, water or ice.

acid rocks a geological description of an igneous rock containing predominantly white or light coloured minerals, mainly quartz and orthoclase. SiO₂ more than 60%. Opposite basic rocks.

actinolite green mineral Ca₂(Mg,Fe)₅(Si₄O₁₁)₂(OH)₂.

agate banded, in part transparent chalcedonic quartz, SiO₂, any colour.

alkaline describes an igneous rock containing more sodium and potassium than is required for feldspar formation.

almandine variety of red garnet Fe₃Al₂(SiO₄)₃.

alluvium; alluvial sediment transported and recently deposited from flowing water. A poorly sorted unconsolidated sediment found in river valleys, on flood plains or in an estuary.

alteration a change in the mineralogical composition of any rock or mineral. Alteration by normal chemical weathering of minerals may involve the addition of ions from molecules of water, carbon dioxide or oxygen. Metamorphic alteration caused by changes of temperature and pressure may also involve elemental migration between minerals.

Amadeus Basin a major geologic unit shaped as a vast elongated east west depression containing late Proterozoic and Palaeozoic sediments.

amphibolite a metamorphic rock rich in amphibole with a black or dark green appearance with white feldspar specks.

andalusite a metamorphic mineral Al₂SiO₅.

andesite a lava containing hornblende or biotite with predominant feldspar, some of which can be in larger crystals called phenocrysts.

anticline an upward arch-shaped fold with beds in the normal stratigraphic order. Opposite, syncline (Figure 4, Plate 5c).

apatite a hexagonal phosphate mineral Ca₅(F,Cl,OH)(PO₄)₃ in igneous and metamorphic rocks.

aquamarine a hexagonal blue mineral Al₂Be₃(SiO₃)₆. A variety of beryl.

aquifer a porous layer of rock in which water can occur and through which it can flow.

arkose a coarse-grained sandstone containing more than 15% feldspar. Example Ayers Rock.

Arunta Inlier a vast belt of metamorphic rocks in central Australia characterised by several metamorphic episodes, the first of which occurred about 1800 Ma. Syn: Arunta Orogen, Arunta Block.

augite a black or greenish mineral, common in basic rocks Ca(Mg,Fe,Al)(Al,Si)₂O₆.

axis of a fold, the central line around which the beds were folded as in a trough or arch.

basal the lowest part of a unit or sequence.

basalt a basic lava; commonly almost black. Example Antrim Plateau Basalt.

basement the oldest, and commonly metamorphosed, underlying rock group in a geological sequence.
basic a geological term for rocks containing less than 50% SiO₂ and enriched in iron and magnesia. Colour grey to black.

basin a lower area which sank as sediments were deposited leading to their preservation.

bed the smallest layer or unit of sediment laid down during a single depositional event and separated by distinguishable surfaces from beds above and below.

bedding plane a surface parallel to the layer of sediment and generally parallel to the original surface on which the sediment was deposited (Plate 2d).

beryl a hexagonal green, blue, or yellow semiprecious mineral Al₂Be₆(SiO₃)₆.

biotite a very common pseudo-hexagonal dark mica mineral with a perfect diametric (basal) cleavage to give paper thin flakes, K(Mg,Fe)₃(Al,Fe)Si₃O₁₀(OH)₂.

block a mass of rock generally fault-bounded which may be elevated or depressed.

bornhardt an isolated upstanding steep-sided hill or group of hills with rounded crests which has survived as a residual from an older, higher land surface.

calcareous rich in calcium carbonate.

calcite a white mineral, CaCO₃, calcium carbonate, a major constituent of limestone and a cement in calcareous rocks.

calcrete calcium carbonate deposited at or near surface from dissolved material: calcareous duricrust.

Cambrian geological period in Palaeozoic Era (570-510 Ma).

capillary action the effect of surface tension on a fluid, usually water, when enclosed in a thin tube. The water can rise upwards against gravity.

cast the preserved shape of the outside of a fossil in more durable rock. If sand covers mud cracks or worm trails, a cast or mould will form on the underside of the sand and will probably survive better than the mud when lithified.

clasts particles of broken rocks or minerals of any size which together constitute a sediment.

cleavage the tendency of a rock to crack along parallel planes generated by metamorphism or deformation. In minerals the cleavage is a tendency to crack parallel to a crystal or mineralogical plane. Example mica.

conformable describes a parallel non-crosscutting contact between two beds or units where there has been no change in the attitude of the depositional environment.

coral marine organism capable of building a calcium carbonate skeleton into reefs.

coralline, composed of fragments of coral skeletons. Rock generally of calcium carbonate.

Cretaceous geological period in Mesozoic era (approx. 135-65 Ma).

crop out describes rocks which are visible at the surface.

cross beds bedding planes developed at an angle to the main bedding plane in an active shallow water or dune depositional environment (Plate 2a, 14b, 24b).

crust the outermost layer of the Earth 35 to 60 km thick beneath continents.

crust a weathered layer, often ferruginised on the surface of rocks (Plate 14 a-d).
**dalmatian rock** a streaky dolomite rock with blobs of dark or light grey colour.

**degradation** a term to describe the weathering of rock or soil to a softer, weaker fine-grained material in which the original textures may no longer be retained. Includes erosion when applied to a landscape.

**detritus** rock material of any size removed by mechanical means or disintegrated from bed rock.

**Devonian** a geological period in the Palaeozoic era (410-355 Ma).

**diamictite** a sediment containing a wide range of clast sizes and is normally deposited on land.

**diapir** a dome like structure caused by the upward movement of underlying beds of plastic material usually salt or gypsum.

**diopside** a greenish contact-metamorphic and igneous mineral CaMg(SiO₃)₂.

**dip** the direction water would flow down an inclined bedding surface (Figure 4).

**diprotodon** an extinct wombat like animal which lived 7 Ma.

**dipslope** a hillslope along the bedding surface and generally formed on a hard band or unit (Plate 10b. - d).

**disgorge** the water from one valley or river system pouring out into another river or onto a plain.

**dissecting** the downcutting by renewed erosion of pre-existing planes or slopes with the formation of valleys and gullies or the almost total removal of a layer.

**dolerite** a dark medium grained igneous rock composed of plagioclase and pyroxene and occurring as intrusive bodies such as dykes (Plate 1c).

**dolomite** rock or mineral composed largely of magnesium and calcium carbonate CaMg(CO₃)₂.

**duricrust** a resistant surface crust enriched in silica (sillcrete) or iron (ferricrete) or lime (calcrete) material precipitated from rising ground water (Plate 17a, c).

**dyke** an intrusive parallel-sided igneous body.

**Eocene** geological epoch in the Tertiary period (53-36.5 Ma).

**ejectamenta** material violently scattered by a meteorite impact or volcanic eruption.

**ephemeral** a short lived event such as a desert stream flowing briefly after a rain storm.

**epidote** a yellow-green or dark green mineral Ca₂(AlFe)₂Si₃O₁₂(OH) (Plate 8e) commonly found in low grade regionally metamorphosed calcareous rocks.

**erosion** the removal of weathered or unweathered particles of rock by wind, ice or water including transportation in solution.

**erratic** a boulder carried and dropped by moving ice. Commonly of a very different composition from its host rock.

**escarpment** a cliff separating two general ground levels (Plate 10a).

**evaporite** a rock formed from soluble minerals which remain after the water has evaporated. Found in shallow seas, lakes or lagoons which have dried up (Plate 19b, c).

**exposure** part of a rock visible above the soil cover.

**extrusive** molten rock squeezed out at the surface as a lava.
event group of geological happenings generally tectonic at about the same time such as metamorphism, intrusions, orogeny.

facies metamorphic facies, a suite of minerals characteristic of a particular environment of temperature, pressure and composition.

facies sedimentary facies, a group of sedimentary rocks characteristic of a particular environment existing at the time of deposition.

feldspar potassium feldspar KAlSi3O8 together with plagioclase are collectively called feldspars. A most important group of white rock forming minerals found in granites, pegmatites, metamorphic rocks and sediments (Plate 8b).

felsic a composition rich in light coloured minerals such as quartz, muscovite and particularly feldspar.

ferricrete a surface layer impregnated by iron oxides, duricrust (Plate 17a, c).

fissure a narrow crack in rock or soil.

flatiron dipslopes on hills broken by valleys (Plate 10d).

fluvial belonging to a river or stream environment.

fold, folding describes the bending of rock by stress. Wave like structures result (Plate 5a - c).

foliation parallel planes in a rock texture caused by stress. A parallelism of minerals in metamorphic rocks (Plate 4a, b).

forsterite a magnesian variety of olivine, common in metamorphic dolomite, Mg2SiO4.

furrowed an overall flattish surface marked by shallow parallel grooves, similar to a ploughed field.

gabbro a dark coloured basic plutonic igneous rock containing labradorite, augite with orthopyroxene and sometimes olivine and a little quartz.

garnet a common metamorphic mineral commonly red with 12 crystal faces (Plate 8g).

g geomorphology the study of the landforms of the earth’s surface and its development.

gnamma a shallow plate-shaped depression on a flattish rock surface caused by the weathering effect of standing water (Plate 13b).

gneiss a regionally strongly metamorphosed rock with a crude foliation caused by zones of granular feldspar, quartz, mica and schistose (Plate 4c).

Gondwanaland a supercontinent comprising Australia, Africa, South America and India which started breaking up about 195 Ma. Australia parted from Antarctica 65 Ma.

grain grainsize, the size of the component particles or crystals in a rock.

grain a parallelism of ridges, valleys or rivers to be seen in the landform.

granite igneous rock composed of feldspar 50%, quartz 30% with plagioclase, muscovite and biotite.

granulite uniformly grainsized high grade metamorphic rock commonly containing pyroxene.

greybilly a silicified soil or rock, silcrete; see also duricrust.

greywacke a poorly sorted marine sandstone deposited on a rapidly sinking sea floor.
gypsum a common white evaporite mineral CaSO₄·2H₂O.

hydrate the addition of water to the molecular composition of minerals.

igneous rock, one which has solidified from a hot liquid. Volcanic rocks, granite.

indurate a process of impregnation of rock by solution resulting in hardening of the rock.

inlier a large outcrop of older rock often with the same evolutionary history surrounded by younger rock e.g. Tennant Creek Inlier.

iolite a blue/mauve gem variety of cordierite (Mg,Fe)₂Al₄Si₅O₁₈.

inselberg a steep sided, and often domed hill or group of hills standing alone above a plain. Example Ayers Rock.

isotope a form of an element with the normal number of protons but with differing numbers of neutrons in the nucleus.

intrusive igneous rocks squeezed when hot and molten into fractures in older rocks.

interstitial occupying a position between crystals, rock grains or clasts.

jasper a variety of amorphous silica containing iron oxides which give it a red or yellow colour. Jasplite is a fine-grained rock mainly composed of jasper.

joint a planar break in a rock with no discernible movement along the joint.

Jurassic a geological period lasting from 205-135 Ma.

karren the solution grooves developed in limestone by trickling rain water.

kyanite Al₂SiO₅ a four sided prismatic mineral blue, bluegreen or white in colour (Plate 8c).

lacustrine formed in a lake environment.

laterite a red weathered iron-impregnated soil often with iron oxide pellets. Ferricrete is an advanced development of laterite duricrust.

lava a rock squeezed out of a volcano or fissure as a molten liquid which flowed until solidification on cooling.

leached removal of material by slow dissolution and transport in moving groundwater (Plate 17 a)

limestone a rock containing more than 50% calcium carbonate CaCO₃. Dolomite CaMg(CO₃)₂ is commonly associated with limestone (Plate 2c).

lithologic pertaining to the mineral content of rocks.

lithification the conversion of loose sediments into strong solid rock.

mafic a term to describe rocks rich in iron and magnesian minerals and low in silica.

mature sediments are enriched in quartz and resistant minerals and free from clays and weathering products as a groundmass.

Ma abbreviation for million years ago.

matrix the material surrounding or hosting the principal constituents.

mesa an isolated hill with a flat top and bounded by cliffs (Plate 11b).
melt the hot liquid from which igneous rocks crystallise. Formed by the melting of pre-existing solid rock.

metamorphism metamorphic changes in texture and mineral composition of a rock caused by a changed environment of temperature, pressure and stress often developed during a mountain building event.

mica a hexagonal rock-forming mineral of metamorphic and igneous rocks. CLEaves to paper thin flakes. Detrital mica occurs in sediments.

migmatisation the melting out of granitic material from metamorphic rocks when the temperature rises sufficiently (Plate 4e).

Miocene an epoch in the Tertiary period, 23-5 Ma.

mylonite a rock of streaky appearance with the original mineral constituents ground to a microcrystallite mass by movement (Plate 4d).

ochre an earthy very fine grained rock composed largely of yellow, red or brown oxides of iron.

Oligocene an epoch in the Tertiary period, 36.5-23 Ma.

orbicular a texture in rocks comprising many spheres.

Ordovician a geological period 510-435 Ma.

orogeny all the processes including metamorphism involved in a mountain building event eg Alice Springs Orogeny.

outcrop rock visible at the surface of the earth’s crust.

oxidising the process of oxygen reacting with minerals. Rust is oxidised iron.

paralic the coastal environment on the landward side of a shore line.

Palaeozoic geological era 570-250 Ma.


pelagic a deep-water marine sedimentary environment.

pelite a very fine-grained sediment or mudstone. Includes metamorphosed muds with a minor carbonate content.

pelitic describing a rock composed of the finest grain sized particles mainly clays or a metamorphic derivative of the same rock type.

pegmatite a very coarse grained intrusive igneous rock occurring as dykes and veins (Plate 1b).

peneplain an almost flat plain resulting from prolonged weathering and erosion. A mature landform.

Permian a geological period 290-250 Ma.

phyllite a flaky metamorphic rock rich in sericite and chlorite.

piedmont the platform at the base of an erosional hill slope.

plagioclase a group of minerals (Na, Ca)(Al, Si)AlSi3O8 within the feldspar group. Sodium end-member NaAlSi3O8 albite (Ab); calcium end-member CaAl2Si2O8 anorthite (An). Mixtures 70% Ab oligoclase, 50% Ab andesine, 70% An labradorite, 90% An bytonite. Important rock forming mineral.
platy a rock fragment or mineral with a much larger length than thickness.

playa a bare, flat, low lying clay or sand covered area prone to flooding.

Pleistocene an epoch in the Tertiary period 1.6 Ma-10,000 years ago.

Pliocene an epoch in the Tertiary period 5.1-1.6 Ma.

plutonic describes igneous rocks crystallized from a melt at great depth in the crust.

porcellanite a very uniform white silica-rich rock with appearance of porcelain.

porphyry an igneous rock with conspicuous large crystals.

precipitate the process of material settling down out of water and the chemical process of dissolved material separating from the fluid as crystals.

Proterozoic a geological era 2500-570 Ma.

province a subdivision of an Inlier eg central Arunta province.

pseudotachylite a dark fine-grained rock produced by almost instantaneous brecciation in a shear zone.

quartz the commonest mineral in the earths crust, SiO₂, silica.

quartzite a quartz-rich sandstone with many grains cemented by quartz or partly recrystallised to an interlocking crystal mass. May be caused by metamorphism. Example Heavitree Quartzite (Plate 5a).

radiant heat is transmitted as electro magnetic waves.

regional metamorphism mineralogical and structural changes generated by an orogeny. Example the Arunta Inlier affected by the Strangways Event.

recessive describes rocks which weather and erode easily and commonly form lower ground with poor outcrop (Plate 15a).

rejuvenated the resumption of a process, such as weathering, faulting, erosion and uplift.

relic, relict a pre-existing texture or feature surviving a change in conditions.

retrograde metamorphism a change from a higher to a lower metamorphic grade caused by reheating to a peak temperature and pressure lower than the original metamorphism.

rhomb a three dimensional shape with parallel faces not meeting at right angles.

ryholite porphyritic lava containing quartz, plagioclase and biotite.

rhythmic banding a sequence of alternating fine-grained and coarse-grained beds in a unit, caused by minor environmental changes (Plate 3b).

rift a depression bounded by parallel faults generally in a continental environment e.g. rift valley.

rubidium - strontium an age determination method using the radioactive decay of strontium 87 to rubidium 87, gives a date of crystallisation or metamorphism.

sandstone a sediment with a majority of the grains of sand size (1/16 - 2 mm) and cemented by finer material. Quartz is generally the commonest constituent.

scarp an abrupt change in slope from gentle to near vertical. A line of cliffs.

schist a well foliated metamorphic rock characterised by parallel mica flakes which promote the flaky nature of the rock (Plate 4b).
scree broken rock fallen from and accumulated at the foot of a cliff.

**sedimentary rock** a rock composed of transported particles of rock which have settled and solidified. Also solidified chemical precipitates.

**shale** laminated very fine-grained, sedimentary rock formed from mud or clay. Mudstone similar and un laminated (Plate 2).

**shear plane** the plane of movement between two masses of rock.

**shield** a very large exposed deeply eroded mass of old rocks, usually of sub-continent size.

**silicify** an induration resulting from an increased silica content.

**silcrete** a near surface sediment indurated by silica, silicious duricrust.

**siltstone** a fine grained sedimentary rock with a grain size between sandstone and mudstone or shale (Plate 2d).

Silurian a geological period of time between 435-410 Ma.

**skarn** an impure metamorphosed limestone formed from the heat from adjacent plutonic intrusives, usually granites.

**slaty, slate** a fine grained metamorphic rock with very well developed lamellar cleavage. Usually formed from shale (Plate 4a).

**slickenside** a polished rock surface, often striated, indicating the direction of local rock movement. (Plate 10 f).

**striated** subparallel scratch marks or shallow furrows.

**strike** the line made by the bedding plane cutting a horizontal surface.

**stromatolite** a laminated organo-sedimentary structure produced by sediment trapping organisms (Plate 6e, f).

**syncline** a trough shaped fold (Plate 5b).

**tectonic** describing the structural effects of stress and upheaval on the structure of the rocks. Includes crustal movement, faulting, folding, deformation and mountain building.

**terrain** a part of the landscape.

**tillite** rock composed of sediment derived from glacial erosion commonly contains pebbles and rock flour.

**tonalite** a plutonic rock containing predominant plagioclase feldspar with quartz, orthoclase, biotite and hornblende.

**tor** an isolated pile of rocks near the summit of a domed hill usually in granite.

**Triassic** a geological period 250-205 Ma.

**trilobite** an arthropod with 2-20 pairs of legs and with some similarity to a centipede except it was marine (Plate 7a).

**ultrabasic rocks** dark igneous rocks rich in iron and magnesia and with less than 45% SiO₂. Olivine, pyroxene common minerals.

**zircon** a colourless, pink or brown tetragonal mineral ZrSiO₄. Minute crystals occur as an accessory in granites and some other igneous rocks. Used by geologists for uranium-lead dating (Plate 8g).

-122-
REFERENCES


-124-


-126-


-128-


-129-
<table>
<thead>
<tr>
<th>Entry</th>
<th>Page(s)</th>
<th>Index</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aileron Event</td>
<td>45, 60, 65</td>
<td>Areyonga Formation 10, 69, 72, 73 101, 103</td>
</tr>
<tr>
<td>Algebuckina Sandstone</td>
<td>81, 83</td>
<td>Arrinhrunga Formation 10, 22, 79</td>
</tr>
<tr>
<td>Alice Springs Granite</td>
<td>5, 65, 93</td>
<td>Artleunga 37, 67, 68, 69, 93, 112</td>
</tr>
<tr>
<td>Alice Springs Orogeny</td>
<td>8, 13, 16, 17, 33, 36, 37, 67, 68, 80*, 81, 84, 85, 100, 104, 105,106, 113</td>
<td>Arthur Creek Formation 21, 79 Arumbera Sandstone 21, 73, 76, 79, 85, 104, 111</td>
</tr>
<tr>
<td>Alice Springs Telegraph Station Historical Reserve</td>
<td>5, 50**, 93</td>
<td>Arunta Inlier 5, 12, 13, 16, 17, 25, 26, 28, 37, 57, 59, 61, 64, 84, 89, 104, 105, 113</td>
</tr>
<tr>
<td>almandine</td>
<td>25</td>
<td></td>
</tr>
<tr>
<td>Amadeus Basin</td>
<td>1, 3***, 17, 24, 33, 36, 37, 38, 41, 53, 56, 65, 67, 68, 70, 71, 72, 73, 74, 75, 76, 77, 78, 79, 80, 81, 82, 83, 89, 101</td>
<td>Ashburton Surface 37, 48, 90 Ayers Rock 35, 41, 44, 45, 46, 53, 76, 89, 93, 96, 97, 98</td>
</tr>
<tr>
<td>Amesbury Quartzite</td>
<td>68, 73</td>
<td>Bacon Range 35, 48, 105</td>
</tr>
<tr>
<td>Ammaroo</td>
<td>21, 23</td>
<td>Barrow Creek 21, 28, 46, 51, 59, 85</td>
</tr>
<tr>
<td>andalusite</td>
<td>14, 25</td>
<td></td>
</tr>
<tr>
<td>anthophyllite</td>
<td>26</td>
<td>Barramundi Orogeny 59, 64</td>
</tr>
<tr>
<td>Antrim Plateau Volcanics</td>
<td>8, 79, 84</td>
<td>Bernborough Volcanics 5, 59</td>
</tr>
<tr>
<td>Anzac Hill</td>
<td>65</td>
<td>beryl 28</td>
</tr>
<tr>
<td>apatite</td>
<td>28</td>
<td>Birrindudu Group 61, 68</td>
</tr>
<tr>
<td>Aralka Formation</td>
<td>72, 73, 103</td>
<td>Bitter Springs Formation 18, 20, 21, 39, 50, 69, 73, 76, 100, 101, 103, 111, 112, 113</td>
</tr>
<tr>
<td>archaeocyathia</td>
<td>21, 85</td>
<td>bivalve 21, 24</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Black Hills 81</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Blatherskite Range 67, 68</td>
</tr>
</tbody>
</table>

* Italics - paragraph on entry  
** Bold - shown in plates  
*** Underlined - shown in figure/table
<table>
<thead>
<tr>
<th>Geographic Feature</th>
<th>References</th>
<th>Rock Type</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bloods Range</td>
<td>8, 60, 67</td>
<td>De Souza Sandstone</td>
<td>54, 83</td>
</tr>
<tr>
<td>Boxhole</td>
<td>29, 32</td>
<td>Dean Quartzite</td>
<td>60, 67, 68, 76</td>
</tr>
<tr>
<td>brachiopods</td>
<td>19, 21, 23, 24, 77, 112</td>
<td>Devils Marbles</td>
<td>49, 51, 60, 65, 97, 100</td>
</tr>
<tr>
<td>Brewer Conglomerate</td>
<td>8, 11, 12, 45, 80, 103, 104</td>
<td>Devils Marbles Granite</td>
<td>61, 100, 102</td>
</tr>
<tr>
<td>Burt Bluff Gneiss</td>
<td>39, 52, 113</td>
<td>Diprotodon</td>
<td>24, 89</td>
</tr>
<tr>
<td>calcrete</td>
<td>48</td>
<td>Djamagarr Formation</td>
<td>79, 83</td>
</tr>
<tr>
<td>Carlo Formation</td>
<td>84</td>
<td>dolerite</td>
<td>7, 52, 67, 113</td>
</tr>
<tr>
<td>Central Mount Stuart Formation</td>
<td>22, 45, 48, 51, 73, 83, 84, 85, 97</td>
<td>Ellery Creek</td>
<td>17, 18, 33, 41, 45, 68, 69, 72, 76, 77, 80, 89, 92, 100, 101, 103, 104, 111, 112</td>
</tr>
<tr>
<td>Chambers Pillar</td>
<td>36, 45, 58, 97, 100, 109, front cover</td>
<td>Elkedra Granite</td>
<td>60, 61, 65, 100</td>
</tr>
<tr>
<td>Charles River Gneiss</td>
<td>15, 93</td>
<td>Epernarr Volcanics</td>
<td>61</td>
</tr>
<tr>
<td>Chewings Range Quartzite</td>
<td>40, 56, 65, 89, 108, 113</td>
<td>epidote</td>
<td>13, 14, 25, 27</td>
</tr>
<tr>
<td>Colsons Pillar</td>
<td>36, 54, 97</td>
<td>Eul Fluid</td>
<td>36, 38, 42</td>
</tr>
<tr>
<td>Coolibah Formation</td>
<td>84</td>
<td>Eromanga Basin</td>
<td>81</td>
</tr>
<tr>
<td>Corroboree Rock</td>
<td>69, 100, 109</td>
<td>feldspar</td>
<td>5, 7, 14, 15, 16, 25, 27, 44, 49, 50, 69, 96</td>
</tr>
<tr>
<td>corundum</td>
<td>13, 26</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cravens Peak Beds</td>
<td>85</td>
<td>Fish</td>
<td>21, 112</td>
</tr>
<tr>
<td>Crown Point Formation</td>
<td>81</td>
<td>Finkle Group</td>
<td>58, 80, 100</td>
</tr>
<tr>
<td>Davenport Ranges</td>
<td>12, 16, 35, 37, 38, 48, 61, 65, 68</td>
<td>Fish</td>
<td>21, 112</td>
</tr>
<tr>
<td>Crow Point Formation</td>
<td>81</td>
<td>Finkle River</td>
<td>34, 56, 58, 80, 89, 92, 109</td>
</tr>
<tr>
<td>Garden of Eden</td>
<td>107, 108, 110</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Location</td>
<td>Pages</td>
<td>Other Location</td>
<td>Pages</td>
</tr>
<tr>
<td>-------------------------</td>
<td>-------</td>
<td>------------------------------</td>
<td>-------</td>
</tr>
<tr>
<td>Gardiner Range</td>
<td>35, 43</td>
<td>Hatches Creek Group</td>
<td>16, 32, 36, 43, 48, 60, 61, 65, 84, 85, 100</td>
</tr>
<tr>
<td>garnet</td>
<td>13, 14, 25, 26, 27</td>
<td>Hay River</td>
<td>85</td>
</tr>
<tr>
<td>gastropods</td>
<td>19, 21, 24, 77, 84, 104</td>
<td>Heavitree Quartzite</td>
<td>16, 18, 20, 39, 40, 50, 56, 60, 68, 69, 73, 76, 83, 89, 93, 101, 103, 104, 105, 108, 111, 112, 113</td>
</tr>
<tr>
<td>George Gill Range</td>
<td>11, 35, 77, 106</td>
<td>Georgina Basin</td>
<td>24, 68, 76, 83, 84, 85</td>
</tr>
<tr>
<td>Giles Creek Dolomite</td>
<td>79, 111</td>
<td>Henbury</td>
<td>29, 30, 48, 105</td>
</tr>
<tr>
<td>glaciers</td>
<td>8, 69, 72, 85, 101, 108</td>
<td>Hermannsburg Sandstone</td>
<td>12, 42, 47, 80, 103, 104, 109</td>
</tr>
<tr>
<td>gnammas</td>
<td>41, 46, 52, 95, 96</td>
<td>Honeymoon Gap</td>
<td>15, 16, 20, 39</td>
</tr>
<tr>
<td>Gosse Bluff</td>
<td>29, 30, 31, 32, 104</td>
<td>Hooray Sandstone</td>
<td>24, 83</td>
</tr>
<tr>
<td>Goyder Formation</td>
<td>79, 103, 112</td>
<td>Horn Valley Siltstone</td>
<td>23, 24, 77, 79, 84, 103, 104</td>
</tr>
<tr>
<td>Granites</td>
<td>59, 60</td>
<td>Horsehoe Bend Shale</td>
<td>11, 58, 81, 100</td>
</tr>
<tr>
<td>Granites-Tanami</td>
<td>12, 16, 57, 59, 61</td>
<td>Huckitta</td>
<td>22, 32, 43, 50, 54, 84</td>
</tr>
<tr>
<td>granulites</td>
<td>13, 14, 37, 49, 60, 67</td>
<td>Hugh River</td>
<td>44, 89, 92, 103</td>
</tr>
<tr>
<td>graptolites</td>
<td>18, 24, 27</td>
<td>Idracowra Sandstone</td>
<td>81</td>
</tr>
<tr>
<td>grey billy</td>
<td>48</td>
<td>Inindia Beds</td>
<td>72, 76, 108</td>
</tr>
<tr>
<td>gypsum</td>
<td>20, 44, 69, 111</td>
<td>iolite</td>
<td>13, 26</td>
</tr>
<tr>
<td>Hale River</td>
<td>48, 89, 112</td>
<td>jellyfish</td>
<td>18, 21, 22</td>
</tr>
<tr>
<td>Hanson River Beds</td>
<td>79, 84</td>
<td>Jervois</td>
<td>25, 84</td>
</tr>
<tr>
<td>Harts Range</td>
<td>13, 15, 16, 27, 29, 37, 38, 43, 55, 67</td>
<td>Jessie Gap</td>
<td>53, 62, 105</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Jinka</td>
<td>51, 52</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Julie Formation</td>
<td>11, 45, 72, 73, 83, 103, 111</td>
</tr>
<tr>
<td>Location</td>
<td>Coordinates</td>
<td>Formation/Formation Group</td>
<td>Page Numbers</td>
</tr>
<tr>
<td>----------------------------------</td>
<td>-------------</td>
<td>---------------------------</td>
<td>--------------</td>
</tr>
<tr>
<td>kaolin</td>
<td>49, 54</td>
<td>Maloney Creek</td>
<td>24</td>
</tr>
<tr>
<td>karren</td>
<td>41, 101</td>
<td>marble</td>
<td>13</td>
</tr>
<tr>
<td>Kelly West Astoblemere</td>
<td>29, 32</td>
<td>Marinoan Glaciation</td>
<td>72, 83, 84</td>
</tr>
<tr>
<td>Kings Canyon</td>
<td>45, 56, 77, 80, 99, 106, 107, 108</td>
<td>McArthur River Group</td>
<td>61, 68</td>
</tr>
<tr>
<td>Killi Killi Beds</td>
<td>59, 60</td>
<td>Mereenie Sandstone</td>
<td>11, 32, 45, 47, 77, 79, 80, 83, 84, 103, 104, 106, 107, 108, 109, 110</td>
</tr>
<tr>
<td>Krichauff Range</td>
<td>109</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Kulgera</td>
<td>16, 24, 28, 46, 51, 52, 67</td>
<td>meteorite</td>
<td>29</td>
</tr>
<tr>
<td>Kulgera Dyke Swarm</td>
<td>5</td>
<td>Mithaka Beds</td>
<td>84</td>
</tr>
<tr>
<td>Kulgera Granite</td>
<td>5, 16, 51, 60, 67, 97</td>
<td>migmatite</td>
<td>15, 16, 49, 65</td>
</tr>
<tr>
<td>kyanite</td>
<td>13, 25, 27</td>
<td>Montijenni Limestone</td>
<td>77, 79, 84</td>
</tr>
<tr>
<td>Lake Amadeus</td>
<td>53</td>
<td>Mopunga Group</td>
<td>85</td>
</tr>
<tr>
<td>Lake Lewis</td>
<td>58</td>
<td>Mordor</td>
<td>60, 65</td>
</tr>
<tr>
<td>Lake Surprise Sandstone</td>
<td>79, 83, 84</td>
<td>Mount Baldwin Formation</td>
<td>73, 79, 85</td>
</tr>
<tr>
<td>Lander Rock Beds</td>
<td>60, 64</td>
<td>Mount Charles Beds</td>
<td>59, 60</td>
</tr>
<tr>
<td>Landform divisions</td>
<td>38</td>
<td>Mount Conner</td>
<td>45, 108</td>
</tr>
<tr>
<td>Larapinta Drive</td>
<td>15, 16, 39, 52, 113</td>
<td>Mount Cornish Formation</td>
<td>73, 85</td>
</tr>
<tr>
<td>Larapinta Group</td>
<td>77, 103</td>
<td>Mount Currie Congostrater</td>
<td>45, 76, 95, 104</td>
</tr>
<tr>
<td>Limbununya Group</td>
<td>68</td>
<td>Mount Doreen Formation</td>
<td>73, 83</td>
</tr>
<tr>
<td>Lothan Hill Sandstone</td>
<td>84</td>
<td>Mount Eclipse Sandstone</td>
<td>24, 79, 84</td>
</tr>
<tr>
<td>Lucy Creek</td>
<td>37, 43</td>
<td>Mount Etingambra</td>
<td>35, 89</td>
</tr>
<tr>
<td>MacDonnell Ranges</td>
<td>12, 17, 37, 39, 40, 45, 48, 53, 56, 88, 92, 100</td>
<td>Mount Gillen</td>
<td>39, 40, 68, 88, 112</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Mount Harris Basalt</td>
<td>60, 67, 76</td>
</tr>
<tr>
<td>Location</td>
<td>Page Numbers</td>
<td>Description</td>
<td>Page Numbers</td>
</tr>
<tr>
<td>--------------------------------</td>
<td>--------------</td>
<td>-------------------------------</td>
<td>--------------</td>
</tr>
<tr>
<td>Mount Olga</td>
<td>35, 76, 80, 93, 96</td>
<td>Oorabra Arkose</td>
<td>46, 73, 85</td>
</tr>
<tr>
<td>Mount Pyroclast</td>
<td>31, 32</td>
<td>Ormiston Gorge</td>
<td>16, 18, 20, 65, 67, 69, 88, 108</td>
</tr>
<tr>
<td>Mount Rennie</td>
<td>64</td>
<td>Ormiston Event</td>
<td>16, 60, 61, 65</td>
</tr>
<tr>
<td>Mount Riddock Amphibolite</td>
<td>27, 55</td>
<td>Pacoota Sandstone</td>
<td>9, 21, 39, 77, 79, 83, 84, 103, 104, 109, 112</td>
</tr>
<tr>
<td>Mount Ringwood</td>
<td>72</td>
<td>Palm Valley</td>
<td>42, 80, 109</td>
</tr>
<tr>
<td>Mount Skinner</td>
<td>21</td>
<td>Parget Sandstone</td>
<td>61</td>
</tr>
<tr>
<td>Mount Sonder</td>
<td>40, 67, 108</td>
<td>Parke Siltstone</td>
<td>32, 80</td>
</tr>
<tr>
<td>Mount Stafford</td>
<td>60, 65</td>
<td>Pedirka Basin</td>
<td>81</td>
</tr>
<tr>
<td>Mount Webb Granite</td>
<td>61</td>
<td>Pertatatka Formation</td>
<td>11, 72, 83, 101, 103, 111</td>
</tr>
<tr>
<td>Mount Winnecke Formation</td>
<td>59</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mount Zeil</td>
<td>33, 40</td>
<td>Pertnjara Group</td>
<td>79, 80, 81, 103</td>
</tr>
<tr>
<td>mud cracks</td>
<td>39, 77</td>
<td>Petermann Orogeny</td>
<td>16, 67, 72, 76, 80, 83, 96</td>
</tr>
<tr>
<td>mud tank</td>
<td>27, 65</td>
<td>Petermann region</td>
<td>1, 8, 12, 16, 67, 76, 80, 83, 96</td>
</tr>
<tr>
<td>Mullaman Beds</td>
<td>85</td>
<td></td>
<td></td>
</tr>
<tr>
<td>mylonite</td>
<td>13, 15, 67, 113</td>
<td>Pioneer Sandstone</td>
<td>72, 73, 101, 103, 111</td>
</tr>
<tr>
<td>Namatjira Drive</td>
<td>8, 11, 33, 64, 89</td>
<td>Point Wakefield Beds</td>
<td>79, 84</td>
</tr>
<tr>
<td>Napperby</td>
<td>88</td>
<td>Pottoyu Granite</td>
<td>67</td>
</tr>
<tr>
<td>Namburla Formation</td>
<td>72, 73</td>
<td></td>
<td></td>
</tr>
<tr>
<td>nautiloids</td>
<td>19, 21, 23, 24, 77, 112</td>
<td>Purni Formation</td>
<td>81, 83</td>
</tr>
<tr>
<td></td>
<td></td>
<td>pyroxene</td>
<td>13, 14, 44</td>
</tr>
<tr>
<td>Ngalia Basin</td>
<td>1, 3, 41, 58, 68, 72, 76, 83, 84</td>
<td>Rainbow Valley</td>
<td>36, 41, 45, 47, 48, 54, 97, 100, 109, 111</td>
</tr>
<tr>
<td>Nora Formation</td>
<td>79, 84</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Olia Gneiss</td>
<td>16, 67, 76</td>
<td>Ranges</td>
<td>35</td>
</tr>
<tr>
<td>Olympic Formation</td>
<td>72</td>
<td>Reynolds Range</td>
<td>7, 38, 60, 64, 65</td>
</tr>
</tbody>
</table>

-134-
<table>
<thead>
<tr>
<th>Place</th>
<th>Numbers</th>
<th>Feature</th>
<th>Numbers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rodingan Movement</td>
<td>77, 80</td>
<td>stromatolite</td>
<td>18, 21, 22, 69, 72, 101, 111</td>
</tr>
<tr>
<td>Ross River</td>
<td>18, 21, 42, 50, 72, 76, 77, 111</td>
<td>Stuart Dyke Swarm</td>
<td>52, 65, 93, 113</td>
</tr>
<tr>
<td>Ross Highway</td>
<td>10, 11, 41, 45, 69, 88</td>
<td>Sturtian glaciation</td>
<td>69, 72, 84, 108</td>
</tr>
<tr>
<td>Ruby Gorge, Ruby Gap</td>
<td>18, 20, 67, 69, 112</td>
<td>sunstone</td>
<td>28</td>
</tr>
<tr>
<td>Rumbalara Shale</td>
<td>83</td>
<td>Supplejack Sandstone</td>
<td>59, 60</td>
</tr>
<tr>
<td>Sadadeen Range gneiss</td>
<td>105</td>
<td>Tafoni</td>
<td>44, 47, 95, 97, 98</td>
</tr>
<tr>
<td>salt lakes</td>
<td>12, 41, 58</td>
<td>Tanami</td>
<td>43, 59, 61</td>
</tr>
<tr>
<td>Sandover Beds</td>
<td>84</td>
<td>Tarlton Range</td>
<td>85</td>
</tr>
<tr>
<td>Santo Sandstone</td>
<td>100</td>
<td>tektites</td>
<td>29, 32</td>
</tr>
<tr>
<td>Shannon Formation</td>
<td>79, 84, 111</td>
<td>Tempe Downs</td>
<td>89</td>
</tr>
<tr>
<td>sillimanite</td>
<td>14, 25, 27</td>
<td>Tennant Creek</td>
<td>12, 16, 32, 48, 53, 57, 61, 68, 83</td>
</tr>
<tr>
<td>Simpson Desert</td>
<td>24, 36, 38, 42, 53, 58, 81, 85, 88, 89, 97, 109</td>
<td>Tennant Creek Granite</td>
<td>59, 60, 61, 64</td>
</tr>
<tr>
<td>Simpsons Gap National Park</td>
<td>16, 36, 68, 112</td>
<td>Tertiary erosion surface</td>
<td>33, 36, 41, 42, 47, 48, 54, 56, 89, 97, 109</td>
</tr>
<tr>
<td>slickensides</td>
<td>20</td>
<td>Ti Tree</td>
<td>89</td>
</tr>
<tr>
<td>sphene</td>
<td>13, 26</td>
<td>Tobermorey</td>
<td>85</td>
</tr>
<tr>
<td>Stairway Sandstone</td>
<td>21, 79, 84, 103, 104</td>
<td>Todd River Dolomite</td>
<td>79, 111</td>
</tr>
<tr>
<td>Stanley Chasm</td>
<td>44, 113</td>
<td>Tomahawk Beds</td>
<td>79, 84</td>
</tr>
<tr>
<td>staurolite</td>
<td>14, 26</td>
<td>Tompkinson Creek Beds</td>
<td>60, 61</td>
</tr>
<tr>
<td>Stokes Siltstone</td>
<td>23, 77, 79, 84, 106</td>
<td>tourmaline</td>
<td>28</td>
</tr>
<tr>
<td>Strangways Range</td>
<td>37, 60, 64, 89</td>
<td>Trephina Gorge</td>
<td>113</td>
</tr>
</tbody>
</table>

-135-
<table>
<thead>
<tr>
<th>geological feature</th>
<th>references</th>
</tr>
</thead>
<tbody>
<tr>
<td>Umbeara Shale</td>
<td>54</td>
</tr>
<tr>
<td>Vaughan Springs Quartzite</td>
<td>60, 68, 73, 83</td>
</tr>
<tr>
<td>volcanic rock</td>
<td>12, 56, 59, 61, 64, 67</td>
</tr>
<tr>
<td>Wade Creek Sandstone</td>
<td>61</td>
</tr>
<tr>
<td>Waite Formation</td>
<td>89</td>
</tr>
<tr>
<td>Warramunga Group</td>
<td>12, 59, 64</td>
</tr>
<tr>
<td>Waterhouse Range</td>
<td>35, 42, 56, 88</td>
</tr>
<tr>
<td>Whippet Sandstone</td>
<td>59</td>
</tr>
<tr>
<td>Wigleys Waterhole</td>
<td>65, 93</td>
</tr>
<tr>
<td>Winnall Beds</td>
<td>72, 76, 108</td>
</tr>
<tr>
<td>Wiso Basin</td>
<td>61, 76, 83, 84, 85</td>
</tr>
<tr>
<td>Woodroffe Thrust</td>
<td>20</td>
</tr>
<tr>
<td>worm-tubes</td>
<td>9, 21, 22</td>
</tr>
<tr>
<td>Yackah Beds</td>
<td>68, 73</td>
</tr>
<tr>
<td>Yuendumu Sandstone</td>
<td>73, 79, 83</td>
</tr>
<tr>
<td>zircon</td>
<td>27, 29, 57, 59</td>
</tr>
</tbody>
</table>