COMMONWEALTH OF AUSTRALIA

DEPARTMENT OF NATIONAL DEVELOPMENT

BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS

REPORT No. 125

# Reconnaissance Geology and Petrography of the Ngalia Basin, N.T.

BY

P. J. COOK AND I. F. SCOTT



*Issued under the Authority of the Hon. David Fairbairn*
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MINISTER: THE HON. DAVID FAIRBAIRN, D.F.C., M.P.

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# INTRODUCTION

The Ngalia Basin was mapped in reconnaissance by P.J. Cook of the Bureau of Mineral Resources, who spent 5 weeks in the area in 1962 while on the staff of the Resident Geologist's Office, Alice Springs, and 2 weeks in 1964 when he was accompanied by J. Perry and K. Edworthy of the BMR and J. Rivereau of the Institut Français du Pétrole.

I.F. Scott of the Australian Mineral Development Laboratories is responsible for the petrographic descriptions, except for the descriptions of some granitic and gneissic rocks from the Yuendumu area by W.R. Morgan of the BMR, as indicated in the text.

J.C. Rivereau prepared photogeological maps of the basin (Rivereau, 1965).

## Location and Access

The Ngalia Basin, which is about 200 miles long and up to 50 miles wide, covers an area of about 7000 square miles in the southern part of the Northern Territory to the north-west of Alice Springs. It lies approximately between latitudes 22°10'S. and 22°55'S. and between longitudes 130°00'E. and 133°30'E. The western margin is poorly exposed.

The Stuart Highway passes through the eastern end of the area. A formed earth road links Yuendumu Aboriginal Reserve with the Stuart Highway and Alice Springs, and there are several station tracks on the northern and southern margins of the basin. Roads used by geophysical survey crews cross the central part of the basin south of Yuendumu. Access to the western end of the basin is poor.

There are permanent settlements at Yuendumu Aboriginal Reserve, Vaughan Springs, Newhaven, Mount Allan, and Napperby homesteads, and Aileron.

Potable water is available at the inhabited homesteads, but is scarce elsewhere, particularly in the western half of the basin.

## Previous Investigations

Tindale (1933) used the name Hann Range/Uldiarra Hill/Crown Hill series for the succession in the Ngalia Basin. The Mount Doreen Mineral Field was visited by Keik (1941).

There are several unpublished reports (Ryan, 1956; Jones & Quinlan, 1958; Quinlan, 1958; Wiebenga et al., 1959) on the hydrology of the Yuendumu Aboriginal Reserve.

The sediments are briefly mentioned by Quinlan (1962), and Cook (1963, unpubl.) prepared a geological map of Yuendumu Aboriginal Reserve on the northern margin of the basin.

# STRATIGRAPHY

A generalized geological map of the Ngalia Basin and a composite stratigraphic column are given in Figure 1.

Informal stratigraphic names have been used for all rock units as the Ngalia Basin is to be systematically mapped in the near future by the Bureau of Mineral Resources.

## PRECAMBRIAN BASEMENT

The metamorphic and igneous basement rocks, which underlie the Ngalia Basin succession on the southern and northern margins, include schist, gneiss, migmatite, quartzite, amphibolite, gneissic granite, and 'granite'. Pegmatites are common, and there are dolerite(?) dykes in some areas.

### Metamorphic Rocks

Gneiss and schist are the most abundant metamorphic rocks. The schist is generally biotite schist and commonly has a pronounced east-west foliation. The gneiss is predominantly a mica-quartz gneiss; it is generally coarse-grained and has a moderate foliation roughly parallel to the foliation in the schist.

Specimen No. R11346, from north-east of Yuendumu Settlement, is a sillimanite-plagioclase-biotite-quartz gneiss. It consists of a mosaic of intergrown unstrained quartz grains, about 1.25 mm across, segregations of biotite, sillimanite, and plagioclase up to 5 mm across, and subordinate single grains of andesine about 1 mm in diameter; the andesine is altered to sericite along its margins and along cracks.

The segregations consist of small brown biotite flakes, fibrous aggregates and acicular crystals of sillimanite which in places is altered to sericite, and fine-grained plagioclase. A few small subpoikiloblastic grains of andalusite may be found in the segregations. Accessory zircon was noted. The estimated mineralogical composition is: quartz, 70 percent; biotite, 15 percent; plagioclase, 10 percent; sillimanite, 5 percent (WRM). The sillimanite may have been formed by contact metamorphism.

Phyllite(?) occurs in some areas, e.g. specimen No. 65.660048 from about 20 miles west of Napperby homestead. The rock fractures along joints and other irregular planes which correspond approximately to the orientation of the sericite flakes. It is a sericitized siltstone. It is shot through with quartz veins, and cross-fractures filled with clay which appear to follow earlier narrow veins. The rock consists of silt-size quartz grains and at least 5 percent sericite in very fine, preferentially oriented flecks, evenly scattered through the rock. A few fine opaque grains are also present.

A fine-grained sheared quartzo-feldspathic rock (No. 65.660049) crops out just below the contact of the basement and the Ngalia Basin sediments at Mount Wedge. The rock has been recrystallized and partly replaced by sericite, biotite, and iron oxides. The quartz forms an irregular, embayed, interconnected network of mosaics strongly aligned in a preferred orientation. Only remnants of plagioclase remain. It is uncertain whether the parent rock was sandstone or granite, but the biotite-rich layers may be related to the original bedding.

Quartzites are common in the basement. They are generally white or pale brown, fine-grained, strongly jointed and fractured, and up to 500 feet thick. They generally dip steeply and commonly trend parallel to the schistosity and gneissosity in the country rock. The contacts with the surrounding metamorphic rocks are sharp. Many of the quartzites can be traced for long distances.

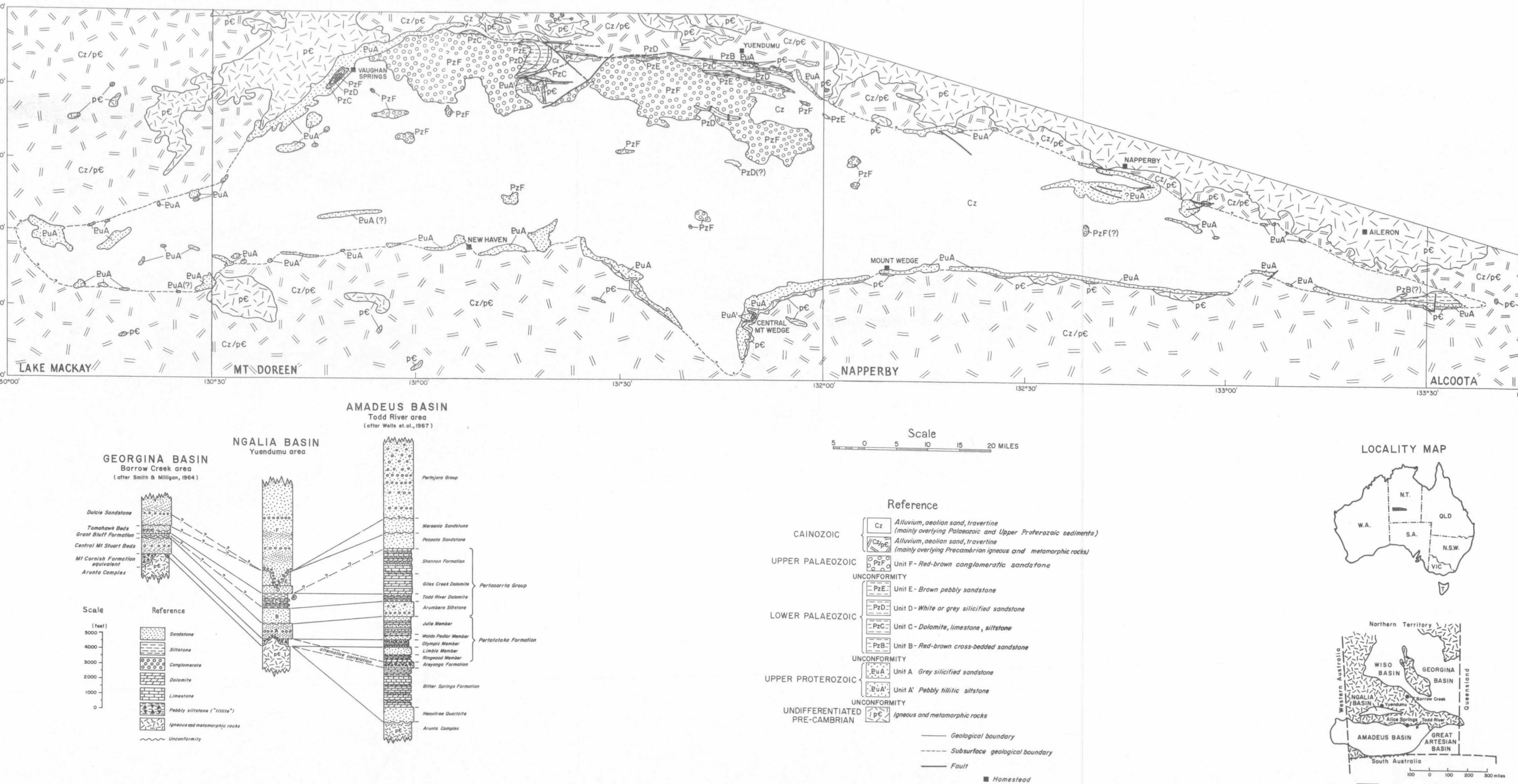


Fig. 1 Ngalia Basin, Northern Territory, scale 16 miles to 1 inch.

Specimen No. 65.660011 (Pl. 1, fig. 2) is a typical cataclastic quartzite which crops out about 4 miles west of the Siddley Range. It is composed essentially of quartz, with a few grains of zircon; the quartz shows severe strain extinction, and the lensoid grains are commonly preferentially oriented. All the quartz grains have sutured boundaries and the interstices are filled with fine recrystallized quartz. The fine-grained irregular cross-cutting band is probably the remnants of a vein.

Specimen No. 65.660014A, from 50 to 100 feet below the top of the metamorphic rocks at Central Mount Wedge, is an altered quartzo-feldspathic sandstone. Sand grains are generally subordinate, and the main constituents are sericite, muscovite, biotite, chlorite, and clay minerals. Only occasional remnants of the original feldspar remain. One quartz-rich area consists of subrounded mosaics of quartz set in a matrix composed mainly of sericite and opaque minerals. Along the boundary of the quartz-rich area there is an accumulation or vein(?) of chlorite with cross-cutting biotite.

Igneous Rocks

The metamorphic rocks have been intruded by granitic bodies.

The granitic rocks are generally coarse-grained, with phenocrysts of feldspar up to 3 inches long. Dark ovate xenoliths, up to several feet across, are present in places. Some of the phenocrysts and xenoliths have a poor lineation. The granites are particularly well exposed in the northern halves of the Mount Doreen and Napperby 1:250,000 Sheet areas.

The Napperby Granite is probably the largest intrusion. At Day Creek, about 11 miles east of Napperby homestead, it is a very coarse-grained biotite granite (No. 65.660049) which has been slightly sheared and crushed. In the shear zones the quartz has been granulated and the biotite flakes reoriented. Perthitic microcline is more abundant than sodic plagioclase; the plagioclase commonly has a rim of myrmekite adjacent to potash feldspar. Quartz forms 30 to 40 percent of the rock, and mafic minerals 10 to 15 percent. Many quartz grains have sutured boundaries and shadowy extinction. Biotite and opaque minerals are commonly associated; zircon and apatite occur as accessories.

In the northern part of the Yuendumu Aboriginal Reserve, near Rock Hill, Cook (1963, unpubl.) distinguished four granitic bodies. The largest is the Rock Hill Granite (Kiek, 1941) which is 2 to 3 miles wide and about 20 miles long. Specimen No. R11340 of Rock Hill Granite, a granulated biotite quartz diorite from about 10 miles north of Yuendumu Settlement, is creamish grey mottled with black, coarse-grained, and porphyritic; the phenocrysts range up to 2 inches long. The average grainsize of the groundmass is 4 mm. The texture is hypidiomorphic, but has been modified by granulation, presumably due to shearing. Some of the granulated zones have a granoblastic texture due to the recrystallization of the granulated material. Quartz (40 percent) forms anhedral grains with strong strain shadows, and is commonly granulated. Plagioclase (40 percent) is subhedral to tabular, and is slightly sericitized. It is slightly fractured and the margins are granulated in places. Brown biotite (15 percent) forms large anhedral to tabular books which are slightly to moderately distorted. The microcline perthite (5 percent) is interstitial and partly granulated. A little muscovite is present in association with the biotite. The accessories include apatite, zircon, iron oxide, epidote, and garnet (WRM).

Xenoliths are common in the Rock Hill Granite. One specimen (No. R11341), from the south-east corner of the granite, consists of biotite-plagioclase-microcline-quartz gneiss. The groundmass has an average grainsize of 0.4 mm, and the porphyroblasts range up to 1.5 mm long. The texture is granoblastic, foliated, and porphyroblastic. The grains, including the porphyroblasts, are elongated parallel to the foliation. Quartz

(50 percent) is granoblastic and strained; microcline perthite (40 percent) is granoblastic to poikiloblastic, and also forms the porphyroblasts. The plagioclase (5 percent) is probably andesine; it is subtabular to granoblastic, and somewhat sericitized; some of the muscovite may represent completely altered plagioclase. Myrmekite has been developed in the plagioclase adjacent to microcline.

The brown biotite (5 percent) is subpoikiloblastic. Iron oxide is associated with the biotite; other accessory minerals include apatite and zircon (WRM).

The granoblastic and gneissic texture of the xenolith suggests that it is a fragment of country rock rather than a cognate xenolith. Some of the microcline may have been introduced metasomatically.

Muscovite-biotite trondhjemite (No. R11344), with a uniformly fine-grained texture, crops out over an area of about 4 square miles, 13 miles west of Yuendumu Settlement. The rock is creamish grey and coarse-grained. The texture is xenomorphic-granular and porphyritic; the average grainsize of the groundmass is 2.5 mm, and the phenocrysts range up to 5.5 mm across. The marginal granoblastic intergrowths around the grains are probably due to recrystallization. The quartz (45 percent) occurs in aggregates; some of it is only slightly strained, but some of the plagioclase crystals are fractured. This is unusual, as where the plagioclase is fractured the quartz is commonly strained and granulated, and it is possible that the quartz has been recrystallized after the fracturing of the rock. Oligoclase (50 percent) forms subtabular crystals with irregular intergrown margins. The brown biotite (2 percent) occurs as anhedral to tabular flakes. The microcline perthite (2 percent) is interstitial, and the muscovite (1 percent) flakes are subhedral. Accessory zircon and apatite are present (WRM).

Six miles north-east of Yuendumu Settlement, a small body of granulated, recrystallized, and greisenized muscovite-biotite granite crops out over an area of about 2 square miles. The rock is creamish grey speckled with black, and is medium-grained and porphyritic. The feldspar phenocrysts range up to about 8 mm long, and are commonly associated with coarse-grained muscovite, which suggests that the rock has been greisenized. The rock has a grainsize of about 0.4 mm, and the texture is similar to that of the granulated and recrystallized rock (No. R11343) described below. A large area of coarse intergrown muscovite and quartz probably represents a greisenized feldspar phenocryst; the quartz and muscovite are only slightly distorted and the greisenization probably took place after the granulation of the rock. The estimated mineralogical composition is: microcline perthite, 45 percent; quartz, 35 percent; oligoclase, 15 percent; biotite, 3 percent; muscovite, 2 percent; and accessory zircon (WRM).

Specimen No. R11343, which probably represents the north-west corner of the same granitic body, is a sheared and recrystallized biotite adamellite. The rock is pink-cream, mottled with black. It has been extensively granulated, and the granulated zones are commonly recrystallized and have a granoblastic texture. The grainsize in the granulated zones is about 0.5 mm, with relict grains up to 3 mm across. The foliation or banding is due to the granulation, and the grains are somewhat elongated parallel to the banding. Quartz (35 percent) is strained and granulated. Microcline perthite (40 percent) and plagioclase (25 percent) form microfractured porphyroclasts which have been granulated and recrystallized. Brown biotite (1 percent) forms clusters of small flakes aligned parallel to the banding. The biotite is associated with epidote and leucoxene; other accessory minerals include zircon and apatite (WRM).

To the north-west of Yuendumu Settlement there are several small outcrops of hornblende-biotite adamellite. The rock (No. R11345) is white, heavily speckled with black. It is coarse-grained and has a gneissic foliation. The texture is hypidiomorphic-granular, and the margins of grains are partly recrystallized. Mica tends to be lineated. The rock has an average grainsize of 2 mm. Quartz (35 percent) is interstitial to poikilitic and is somewhat strained. The plagioclase (35 percent) is tabular and is generally only slightly sericitized, but in some crystals the cores are strongly sericitized. Microcline perthite (15 percent) is interstitial to poikilitic. Brown biotite (10 percent) forms strings of coarse lineated flakes associated with epidote. The green hornblende (5 percent) forms subprismatic crystals which are commonly partly altered to biotite. The accessory minerals include apatite, sphene, and zircon (WRM).

Morgan concluded that ... 'The mica "granites" could well be members of a related series of intrusive rocks ranging from mafic-rich to leucocratic types; such intrusive series are quite common - several examples are summarized by Buddington (1959), and more recently, ideas on their genesis were reviewed by Vance (1961). The important feature of the mica "granite" specimens is that they all show signs of granulation followed by some recrystallization of the granulated material. These suggest movement followed by reheating. The movement may have been tectonic; on the other hand the movements could have resulted from intrusion of related material into almost completely solidified rock that is represented by these granulated specimens; heating of this by the newly injected magma would cause the granoblastic textures to develop. This process is described very clearly by Waters & Krauskopf (1941) in the Colville Batholith, U.S.A. The hornblende-biotite adamellite has a foliation that is probably a primary igneous flow structure - however, this can only be confirmed in the field by plotting the foliation in relation to the adamellite margin. The other textural characters in the rocks suggest that it is of igneous rather than metamorphic origin'.

About half-way along the road between Yuendumu Settlement and Vaughan Springs homestead the basal sediments overlie weathered granite. The rock (No. 65. 660041A) has been severely sericitized. Remnants of biotite are present in the sericite-muscovite groundmass in the interstices between large angular fragments of quartz. The biotite is usually twisted and buckled, and partly altered to white mica and iron oxides (Pl. 1, fig. 4).

The weathered granite nearby has been injected by a tourmaline-bearing pegmatite (No. 65.660041B) composed mainly of quartz and potash feldspar. A few needles of rutile and a little green mica are also present. The shadowy mosaic extinction in the major constituents indicates that the rock has been partly crushed.

## SEDIMENTARY ROCKS

### Unit $A^1$

Unit $A^1$ is probably the oldest unit in the Ngalia Basin succession. It crops out at the base of the succession at Central Mount Wedge and near the road about half-way between Yuendumu Settlement and Vaughan Springs homestead. At both localities it unconformably overlies the Precambrian basement and is conformably overlain by Unit A sandstone.

At Central Mount Wedge, the unit was apparently deposited on an irregular surface and is 100 to 200 feet thick. It consists of poorly sorted conglomerate and conglomeratic siltstone with minor sandstone. The siltstone is poorly bedded and tillitic. It contains fairly well rounded boulders up to 18 inches across, but no striae were seen.

In a conglomerate from Central Mount Wedge (No. 65.660013A) the clasts range from rock fragments about 1 cm long to interstitial grains of fine sand size. The components range from rounded to angular. The larger fragments consist of quartz and quartz mosaics with interspersed sericite and minor biotite. Other quartz mosaics contain euhedral secondary opaque grains. Some of the fragments, which were probably originally quartz-feldspar mosaics, have been almost completely replaced by sericite, biotite, and minor chlorite(?). The remainder of the rock consists almost exclusively of fine to coarse sand-sized particles of quartz set in a sericitic matrix. A few flakes of biotite and muscovite are present, and occasional grains of zircon, green tourmaline, and iron oxides. The uniformity of the coarse fragments and their association with fine-grained opaque minerals, rutilated quartz (with biotite), and zircon indicate some degree of sorting.

Similar coarse poorly sorted sediments also crop out near the top of a prominent escarpment on the Yuendumu/Vaughan Springs road, where I.P. Youles (pers. comm.) has found striated pebbles. The tillitic sediments are only about 25 feet thick; the section is as follows:

Strongly silicified sandstone of Unit A (No. 65.660044).

| Thickness (ft) | |
|---|---|
| 20 | Pebble and cobble conglomerate, grading into breccia (No. 65.660043) |
| 3 | Red or red-brown pebble siltstone or mudstone (Nos 65.660042A,B) |
| 1- 3 | Basal conglomerate, Pebbles, cobbles, and boulders, up to 2 feet in diameter, of silicified sandstone, vein quartz, and metaquartzite. The clasts are generally poorly rounded. Overlies strongly weathered granite (Nos 65.660041A,B). |

In the pebbly siltstone (No. 65.660042A) the angular quartz grains range from the maximum size in the coarse sand range down to the siltstone matrix. The quartz fragments form up to 20 percent of the rock and are very poorly sorted (Pl. 2, fig. 1). The matrix consists mainly of quartz and muscovite with a liberal dusting of red and partly opaque hematitic material. Minor amounts of clay-size material are present in the interstices, but the grains are more commonly welded together or cemented by interstitial iron oxide.

Specimen No. 65.660042B is a pebbly mudstone. The largest fragments are at the maximum of the pebble size range. They are subrounded to angular, completely unsorted, and range down to the silt-sized matrix containing 30 to 40 percent of fragments. A little muscovite is present, but the matrix consists mainly of quartz with interstitial sericite and clay. A little hematitic material occurs in a narrow half-inch band in this particular specimen. Although the rock is layered there is no evidence of graded bedding. The poor sorting, the angularity of the fragments, and the general texture give this rock and specimen No. 65.660042A a tillitic aspect, but as the fragments consist almost entirely of quartz, the rocks can possibly be classified as tilloids (Pettijohn, 1957). Specimen No. 65.660043 is a quartz conglomerate with fragments of quartz grading from cobbles to silt grains. The rock is poorly sorted, and consists of fragments larger than coarse sand, and medium and finer sand-size grains, set in a sericite-clay cement with a few silt-size quartz grains. Clastic fragments form 60 to 70 percent of the rock; the remainder consists of sericite and occasional aggregates of muscovite. A subrounded cobble of quartzite was the only type of clast, other than quartz, recorded. The constituents are generally poorly rounded or angular.

On the southern flank of the Stuart Bluff Range near Mount Hammond, the silicified sandstone of Unit A is underlain by a 1-foot bed containing large composite grains of quartz about 3 mm in diameter, potash feldspar, and muscovite; and individual large rounded grains of altered microcline, and subrounded grains of quartz. The larger fragments of microcline have been almost completely replaced by opaline material or clay. The matrix consists of rounded to angular grains of fine to medium-grained quartz sand cemented by sericite, clay, and minor chlorite(?). Some of the muscovite has been formed by the recrystallization of sericite, but some of the severely altered flakes appear to be detrital. Occasional interstitial grains of potash feldspar are present.

The rock represents probably slightly reworked granitic material, and in places it is difficult to distinguish the boundary of the underlying weathered granite. It may be the lateral equivalent of Unit $A^1$ or the basal conglomerate of Unit A.

The age of Unit $A^1$ cannot be established, but its tillitic nature and its unconformable position below known Cambrian sediments strongly suggest that it is Adelaidean (Upper Proterozoic).

Unit A

Unit A comprises sandstone with minor siltstone and some conglomeratic bands. It conformably overlies the Unit $A^1$ and is unconformably overlain by Unit B near Yuendumu.

Unit A forms prominent scarps on both the southern and northern margins of the basin, such as Central Mount Wedge, the Siddley Range, the Stuart Bluff Range, and the Hann Range in the south, and some of the ridges of the Truer Range in the north. It forms the capping of many of the mesas in the Lake Mackay Sheet area in the western part of the basin, and it may underlie the entire basin.

The unit appears to thin out to the north and east. In the Vaughan Springs area, and possibly also near Central Mount Wedge, it is at least 1000 feet thick, but near Yuendumu it is only 300 to 400 feet thick.

Unit A consists mainly of grey or grey-brown fine to coarse-grained thin to thick-bedded strongly silicified sandstone; cross-bedding, ripple marks, mud-pellet markings, and flow and slump casts are common. A few of the sandstones are white, clean, and friable, but most of them are strongly resistant to weathering and form prominent ridges.

Conglomeratic bands are present in places. One band occurs 150 to 200 feet above the base of the unit in the Stuart Bluff Range; it is 30 to 40 feet thick and contains well rounded cobbles of metaquartzite and minor vein quartz up to 4 inches in diameter. There is generally a coarse poorly sorted subangular conglomerate at the base of the unit, and some minor silty interbeds in places.

The age of Unit A is uncertain; its stratigraphic position above the Upper Proterozoic(?) tillitic horizon and below Cambrian sediments, and its marked lithological affinity with the Upper Proterozoic sediments in the Amadeus and Georgina Basins, suggest that it is Upper Proterozoic.

Several specimens were collected at various levels above the base of the unit in the Stuart Bluff Range near Mount Hammond. Specimen No. 65.660002 from 6 inches above the base is a poorly sorted orthoquartzite. It contains over 95 percent quartz and has an interstitial clayey cement in places. Occasional secondary silica overgrowths have been formed on the quartz grains. Most of the fine to medium quartz grains have shadowy extinction, probably because of load strain in the rock. Some of the grains, especially the larger ones, are well rounded, but most are subrounded to subangular. Some of the elongate grains have a preferential alignment. A little iron oxide, rutile(?), and muscovite were observed. The porosity of the rock is low.

A second specimen (No. 65.660003), from 15 feet above the base of the unit, is a poorly sorted orthoquartzite similar to specimen No. 65.660002. The porosity may be slightly higher, and none of the constituents have a preferred orientation. Grains are mainly medium to fine sand size.

Specimen No. 65.660004, from 100 feet above the base of the unit, is a poorly sorted fine to medium-grained orthoquartzite similar to specimens Nos 65.660003 and 65.660002. The proportion of interstitial clay is slightly higher (about 5 percent). The grains are commonly well packed, but are less compressed than in the other specimens, and individual grains show less strain. A little zircon and amphibole are present.

Specimen No. 65.660005, from 150 feet above the base of the unit, is a quartzose conglomerate with pebbles of quartz up to 3.0 cm in diameter. There is a complete range of sizes down to the well rounded grains of quartz in the matrix. The medium to coarse sand-size grains commonly have silica overgrowths (Pl. 1, fig. 1) and about 10 percent of the interstices are filled with clay and sericite. The clasts include relatively unstrained quartz and strained sutured composite metamorphic quartzite.

Specimen No. 65.660006, from 170 feet above the base of the unit, is a much finer-grained conglomerate than specimen No. 65.660005, and the largest grains are less than 5 mm in diameter. Most of the grains are angular to subrounded medium to coarse sand-size particles; they are commonly strained and loosely packed in a matrix of clay, sericite, and a little muscovite which forms 20 to 25 percent of the rock. A little tourmaline, rutile, and dusty opaque hematite(?) are also present. The fine hematite is probably responsible for the red colour of the rock.

In the Siddeley Range, Unit A is strongly silicified; tension fractures are common, and in places quartz veins up to 10 cm thick cut the silicified sandstone. The rock (No. 65.660007) from the base of the formation is an orthoquartzite composed almost entirely of quartz with 1 to 2 percent of sericite and muscovite. The micaceous flakes are confined to grain boundaries, which are usually sutured and cemented by secondary overgrowths. The rock is fairly well sorted with only occasional larger grains in the medium-grained sandy host. The confining pressure on the rock has resulted in the development of shadowy extinction and sutured grain boundaries. A little fine iron oxide is also present.

The quartzites of Unit A on the northern and southern margins of the Ngalia Basin are similar. Specimen No. 65.6600016A, from about 3 miles south-east of Yuendumu Settlement, is a poorly sorted fine to coarse-grained orthoquartzite cemented by limonite and sericite. Most of the grains consist of subrounded to rounded quartz with undulose extinction. Some of the grains have been fractured to form a mosaic. A little zircon, tourmaline, and muscovite are present.

Specimen No. 65.6600016B, from the base of the unit in the same locality, is a siliceous conglomerate. It consists of angular and subordinate rounded fragments of quartz or quartz mosaics, up to 1.5 cm in diameter, set in a hematitic and siliceous matrix. The hematite, which gives the rock its deep red colour, is usually confined to grain boundaries in association with the siliceous cement. The sand grains in the matrix are medium to coarse-grained and commonly well rounded. Occasional flakes of muscovite are present, and rounded blebs of opaque material are not uncommon in the interstices in the larger rock fragments.

Specimen No. 65.6600044, from about half-way along the Yuendumu/Vaughan Springs road and about 50 feet above the base of the unit, is a poorly sorted pure orthoquartzite. The quartz grains, which range from fine to medium sand size, are generally rounded to well rounded and cemented by quartz overgrowths. Many of the grains have undulose extinction. The porosity of the rock is low.

Three specimens (Nos 65.660037A, B, and C) were collected from the southern limb of the Vaughan Springs Syncline, where Unit A is well exposed. Specimen No. 65.660037A, from near the base of the unit, is a friable orthoquartzite composed mainly of grains of medium sand size. The grains are well sorted and are generally lightly packed. The quartz is subrounded to rounded and the grains commonly have undulose extinction. The only impurity present is a little iron hydroxide or oxide.

Specimen No. 65.660037B, from the middle of Unit A, is a fine to medium-grained orthoquartzite composed almost entirely of tightly packed quartz grains with a little sericite along the grain boundaries. The grains are rarely rounded and commonly exhibit undulose extinction. A little zircon and iron oxide are also present.

Specimen No. 65.660037C, from a thin lutaceous interbed near the top of Unit A, is a sericitized silty claystone. Over 90 percent of the rock consists of clay or clay-sized particles. The sericite flakes are probably oriented parallel to the bedding. A few grains of sand-sized quartz are present.

The irregular layers of clay or clay and quartz cutting the rock roughly parallel to the bedding were probably formed by movements in the rock before it was consolidated.

Unit A also crops out near Napperby homestead, where a strongly folded thrust cuts across the beds. Three specimens (Nos 65.660048A, B, and C) were collected from about 3 miles west of Napperby homestead.

Specimen No. 65.660048A is a typical Unit A sandstone which has not been affected by the thrusting. It is a porous rock composed mainly of poorly sorted fine sand grains, and subordinate medium sand grains. Rounded grains are rare, and the irregular grains are commonly sutured and highly indented (Pl. 2, fig. 4). The grains exhibit shadowy extinction. The interstices between the quartz grains are partly or completely filled with fine granulated quartz, clay, and dusty iron oxide. Overgrowths on the quartz grains are not common. A little zircon is present.

Specimen No. 65.660048B, from the thrust zone, appears to be a crushed and clayey equivalent of specimen No. 65.660048A. The quartz-rich zones contain sheared-out grains with sutured boundaries and shadowy extinction. A little muscovite, tourmaline, and iron oxide are present in the quartzite zones. The rock also contains irregular patches composed of clay and quartz or mainly clay. Stringers of sericite and muscovite are present in the sheared zones. The abundant iron oxides in the clayey zones impart a mottled appearance to the rock. The iron oxide in the clay commonly forms tiny spherical blebs. The sheared and quartz-rich zones are irregularly distributed, and both are cut by clay-filled fractures.

Specimen No. 65.660048C is a white silicified sandstone from 2 to 3 feet above the thrust zone. It is a medium-grained pure orthoquartzite in which most of the grains have been severely fractured and crushed. Crush zones are present, but only one pocket of clay with associated iron oxides was observed. Occasional grains of zircon and tourmaline were also noted.

Unit B

Unit B is a sandstone sequence which unconformably overlies Unit A and is overlain apparently conformably by Unit C. It has been identified only on the northern margin of the basin near Yuendumu Settlement, but it is absent in the Vaughan Springs Syncline. South of Yuendumu, the unit forms low strike ridges, and is about 1000 feet thick. Unit B consists of pale brown or grey sandstone which weathers red-brown. It is fine to coarse-grained, pebbly in places, poorly rounded, poorly sorted, thin-bedded, cross-bedded in places, friable, and poorly exposed. Specimen No. 65.660019B, from about 2 miles south of Yuendumu Settlement, is a porous comparatively well sorted and medium-grained cherty sandstone. About half of the elastic fragments consist of rounded to angular quartz grains. Detrital grains of chert are common, and a little chalcedony, and fragments of sericitized fine sandstone and schist, and occasional flakes of muscovite are also present.

The interstitial matrix includes limonitic cement, clay, chlorite, and sericite, and a few grains of rutile, zircon, and iron oxide.

Unit B is unfossiliferous and the age is uncertain. As it is overlain apparently conformably by Unit C, which contains Cambrian fossils, and overlies sediments which are probably Upper Proterozoic with strong angular unconformity, it is possibly Cambrian.

Unit C

Unit C is a fossiliferous carbonate-lutite sequence. It overlies Unit B apparently conformably and is overlain apparently conformably by Unit D. In places, it is unconformably overlain by Unit F. Unit C crops out sporadically as far east as Yuendumu Settlement and as far west as Vaughan Springs, and in both areas it is about 1000 feet thick. The dolomite of Unit C is well exposed south of Yuendumu Settlement. It is grey, pink, or yellow, and weathers dark grey; thin-bedded, strongly silicified, and brecciated in places; and generally only moderately to poorly exposed in low rounded hills.

Travertine forms a thin veneer on the outcrop in places. Large irregular masses of barite occur in the dolomite 3 miles west of White Point Bore on Yuendumu Aboriginal Reserve, and specks possibly of galena were also noted. Cuprite and malachite also occur south of Yuendumu Settlement and elsewhere.

Specimen No. 65.660020, from near the middle of Unit C south of Yuendumu Settlement, is a quartz-bearing dolomite. Most of the quartz crystals are subhedral and occur in a vein which has been partly replaced by dolomite. A few grains of partly replaced quartz also occur in the body of the rock. None of the grains appear to be detrital and the rock consists of a fine to medium-grained crystalline aggregate.

Specimen No. 65.660033 is a fine-grained dolomite from about half-way between Yuendumu Settlement and Vaughan Springs. The rock is transected by numerous irregular veins of quartz, recrystallized dolomite, calcite, and barite. Some of the veins are partly filled with opaque minerals. Barite is also associated with irregular quartz mosaics which are commonly partly replaced by dolomite. The quartz mosaics may be remnants of veins.

Specimen No. 65.660038 from Vaughan Springs Syncline is a fine-grained dolomite containing micro-interbeds of silty and sandy detritus. The interbeds, which form about 5 percent of the rock, consist mainly of quartz, biotite(?), and muscovite, with subordinate potash feldspar and plagioclase, and a little carbonate detritus and a few fragments of chert(?). The dark brown opaque dendritic stains parallel to the bedding and another plane in the rock are probably manganiferous. Siltstone and subordinate silty sandstone are probably common in Unit C but they are rarely exposed. Good exposures of the Unit C lutite occur about 3 miles west of White Point Bore, where about 300 feet of siltstone with minor sandstone crops out. Siltstone is best developed near the top of the unit, but occurs throughout. The siltstone is purple, purple-brown, fissile, thinly bedded to laminate, and rich in muscovite.

Specimen No. 65.660024A, from about 300 feet below the top of Unit C, is a porous micaceous clayey siltstone with distinct graded bedding.

Only occasional quartz grains of fine sand size are present. Muscovite flakes form over 10 percent of the rock; most of them are oriented parallel to the bedding planes, and the rock is consequently fissile. Sericite is common, and a little chlorite is also present. The reddish brown colour of the rock is due to finely disseminated hematite.

The minor interbeds of sandstone are red-brown, commonly silty, poorly sorted, thin-bedded, slumped, and ripple-marked, with some cross-bedding. Like the siltstone, the sandstone is micaceous.

Specimen No. 65.660024B, from 3 miles west of White Point Bore about 300 feet below the top of Unit C, is a micaceous feldspathic sandstone. Fine to medium-grained quartz predominates, with subordinate potash feldspar and fragments of chert. The muscovite and biotite flakes have been almost completely replaced by iron oxide. The cement includes silica, hematite, and minor clay and sericite. The silica forms overgrowths on the subangular to subrounded grains of quartz. A little tourmaline, zircon, and glauconite(?) are present.

The first fossil in Unit C was found by D. Woolley, Resident Geologist, Alice Springs, in the upper part of the unit about 3 miles west of White Point Bore. It has been identified by A.A. Öpik as a Protichnites; it is a track probably produced by a large trilobite such as an asaphid and is probably of Lower Palaeozoic age. Lower Cambrian fossils have been also found in the Unit C siltstone by A.W. Lindner and N.W. Hamilton of American Overseas Petroleum Ltd; they have been identified by A.A. Öpik as Helcionella sp. and the fossil tracks Rusophycus and Protichnites.

Unit D

Unit D consists mainly of sandstone, with minor siltstone. It overlies Unit C apparently conformably and is probably conformably overlain by Unit F. It crops out sporadically for about 100 miles across the Mount Doreen Sheet area on the northern margin of the basin. It is generally well exposed, and forms prominent strike ridges in places. The unit is about 500 feet thick.

The sandstone is white, grey-white, or pale brown, fine-grained, well sorted, thinly to thickly bedded, and cross-bedded in places. Mud-pellet markings are common near Penhalls Bore in Yuendumu Aboriginal Reserve. Most of the sandstone is strongly silicified.

Specimen No. 65.660021A, from just south of Penhalls Bore, is a typical weathered Unit D sandstone with mud-pellet markings. It is a well sorted fine to medium-grained orthoquartzite. The quartz grains have generally been welded by pressure-solution and there are few voids. Most of the grains are strained. Minor amounts of clay are present in small bands; occasional grains of zircon and chert are also present.

Specimen No. 65.660021B, from the same locality, is a strongly silicified sandstone similar to specimen No. 65.660021A. It is a pure medium-grained well sorted orthoquartzite; there are no chert fragments, but a few grains of tourmaline were noted. Many of the original quartz grains were well rounded, but pressure-solution and the formation of quartz overgrowths has almost obliterated the original boundaries.

Unit D is well exposed about half-way along the Yuendumu/Vaughan Springs road, and some of the sandstone (No. 65.660034A) can be described as glauconite(?) orthoquartzite. The rock is generally cemented by quartz overgrowths, but minor amounts of interstitial clay and sericite are present. A little barite occurs as detrital(?) grains and interstitially.

The rock is well sorted and medium-grained. The quartz overgrowths are mostly deposited on well rounded to subrounded grains. The glauconite(?) grains are commonly well rounded and similar in size to the quartz grains. A little tourmaline, muscovite, and iron oxide are also present.

Specimen No. 65.660034B, from the same locality, is a finer-grained equivalent of specimen No. 65.660034A. The mineralogical composition is similar, except for the presence of a few grains of zircon and potash feldspar.

In the Vaughan Springs Syncline, the sandstone of Unit D is similar to that south of Yuendumu Settlement; no glauconite was seen. Specimen No. 65.660039A, from near the base of the unit, is a fairly well sorted fine-grained orthoquartzite. The rock is completely cemented by quartz overgrowths on rounded grains of quartz. Shadowy extinction in the quartz grains is common. Rounded aggregates of clay, similar in size to the quartz fragments, form about 5 percent of the rock. A little zircon, tourmaline, and iron oxide are present.

Specimen No. 65.660039B, from near the top of the unit, is similar to specimen No. 65.660039A, except for the presence of minor amounts of limonitic clayey(?) cement, and a little muscovite. The rock is not so well sorted as specimen No. 65.660039A, although most of the grains are of fine sand size. The finer grains tend to occur in bands, but the bands are irregularly distributed. The bands make the rock fissile.

The prominent ridge of grey silicified sandstone about 8 miles south-east of Yuendumu Settlement is possibly composed of Unit D. Specimen No. 65.660045A, from near the top of the ridge, is a poorly sorted protoquartzite composed of well rounded quartz grains, ranging from 0.5 to 1.5 mm across, set in a matrix of fine sand-size quartz (Pl. 2, fig. 2). The finer grains are subrounded to rounded, and are cemented by interstitial clay and a little very fine quartz. Narrow quartz overgrowths are also present. The interstitial material forms 10 to 15 percent of the rock. The clastic fragments include 95 percent quartz and a few rounded grains of quartzite and aggregates of clay. A little tourmaline and iron oxide are also present.

No fossils have been found in Unit D, but its conformable position above Cambrian sediments suggests that it is probably Cambrian or Ordovician in age.

Unit E

Unit E is composed predominantly of sandstone. It conformably overlies Unit D and is unconformably overlain by Unit F. It crops out on the northern margin of the basin, near Yuendumu Settlement, and has a maximum thickness of about 1000 feet.

Unit E consists of pale brown or grey sandstone, which weathers grey-brown. The sandstone is generally moderately sorted, thin to thickly bedded, commonly cross-bedded, and slumped. The sandstone is similar to those of Units B and F.

Specimen No. 65.660022A, from south of Penhalls Bore on Yuendumu Aboriginal Reserve, is a medium-grained protoquartzite composed of quartz, chert, and fragments of sericitized fine-grained sandstone and sericite schist. Clay occurs as detrital grains and in the matrix. The quartz grains, which were originally rounded, are commonly cemented by overgrowths. A little iron oxide and tourmaline are also present. Specimen No. 65.660022B from the same locality is a fine-grained equivalent of specimen No. 65.660022A. It contains a few grains of zircon.

Specimen No. 65.660027, near the top of Unit E 6 miles south-west of Yuendumu Settlement, is a poorly sorted orthoquartzite with over 95 percent quartz. The grain-size ranges from clay to coarse sand size; the larger quartz grains are rounded, but the finer interstitial material is usually angular and commonly has sutured grain boundaries. Interstitial quartz is the main constituent of the matrix; some of the quartz has been welded by pressure-solution. A little interstitial clay, zircon, tourmaline, muscovite, sericite, and iron oxide are also present.

An extremely poorly sorted lithic greywacke (No. 65.660046), which crops out about 8 miles south-east of Yuendumu Settlement, probably also belongs to Unit E. Quartz grains form about 60 percent of the rock; they are angular to subrounded and of fine to medium sand size. The rock also contains chert, sericite schist, quartzite, muscovite flakes, and aggregates of clay. Some of the mica flakes are probably oriented parallel to the bedding planes. Clusters of quartz grains have been welded together by pressure-solution, but the cement is generally red hematitic material which makes the rock friable.

No fossils have been found in Unit E. Its stratigraphic position above Cambrian sediments and below a major unconformity suggests that it is of Lower Palaeozoic age.

Unit F

Unit F is composed predominantly of sandstone, and unconformably overlies Units E, D, and C. The top is an erosional surface. It crops out over a considerable area, particularly in the prominent hills and ranges south and south-west of Yuendumu Settlement. It forms several mesas in the central part of the basin. Unit F is estimated from the air-photographs to be about 7000 feet thick. A few possible fossil tracks have been noted about 4 miles west of White Point Bore. Unit F is perhaps Upper Palaeozoic in age.

The sandstone is pale brown or red-brown, poorly sorted, pebbly and conglomeratic in part, micaceous in part, kaolinitic, friable, thin to massively bedded, and cross-bedded. Ripple marks, mud-pellet markings, mud cracks, slump rolls, and load casts are present in places. There are a few silty interbeds. The direction of the currents as indicated by the cross-beds in the central part of the basin suggests that the main source area was to the south-west.

Specimen No. 65.660026, from 3 to 4 miles west of White Point Bore, is a typical well bedded protoquartzite from near the base of Unit F. The rock is very poorly sorted. The grains range from fine to medium sand size; they are cemented by quartz overgrowths and by clay, sericite, or limonite. The grains are generally irregular. Flakes of muscovite, grains of chert, fragments of sericitized fine sandstone, and occasional aggregates of clay are also present, but they form less than 10 percent of the rock. Iron oxides or hydroxides form nearly 5 percent of the rock. A little tourmaline and zircon are present.

Specimen No. 65.660028, from near the base of Unit F, 7 miles south-west of Yuendumu Settlement, is a porous cherty subgreywacke. The rock is poorly sorted, and ranges from fine to medium in grainsize. Quartz grains form at least 50 percent of the rock; the remainder consists of cherty fragments, clay aggregates, sericitized fine quartzite or schist, and 10 to 15 percent of clay cement with some sericite. A little rutile, muscovite, and iron oxide are also present.

Specimen No. 65.660030, from an isolated outcrop about 8 miles south of Kerridy Waterhole, is a medium-grained protoquartzite. It is better sorted than specimen No. 65.660028, and contains at least 75 percent of quartz. Chert fragments, clay aggregates, and partly sericitized schistose(?) rock fragments form the remainder of the rock. Many of the grains were originally rounded, but they have been silicified by quartz overgrowths and the rock has a low porosity. A few grains of rutile, tourmaline, muscovite, and iron oxide were noted.

Specimen No. 65.660031A probably represents a horizon near the top of Unit F in the middle of the basin about 30 miles south of Yuendumu Settlement; it is a well sorted subgreywacke or protoquartzite. It contains medium to fine grains of quartz and numerous fragments of chert, sericitized quartzite, clay, schist, and muscovite flakes. Clay cement is more common than in specimen No. 65.660030, but silica overgrowths are less abundant. Most of the grains were coated with a thin layer of iron oxide or hydroxide prior to cementation. Iron oxides form 5 to 10 percent of the rock; a little tourmaline and rutile are also present.

Specimen No. 65.660036 is a poorly sorted protoquartzite from 500 to 1000 feet above the base of Unit F about half-way along and just north of the Yuendumu/Vaughan Springs road. It is composed of irregular quartz grains, fragments of chert, sericitized silt, and claystone, and aggregates of sericite and clay. Most grains are of fine to medium sand sizes; a few are coarser. The quartz grains are cemented by overgrowths, and by sericite, clay, and limonitic material. Occasional flakes of biotite and muscovite and a few grains of zircon are also present.

Specimen No. 65.660040, from about 50 feet above the base of Unit F in the core of the Vaughan Springs Syncline, is a porous cherty subgreywacke containing about 70 percent quartz, interstitial clay and detrital aggregates of clay, muscovite flakes, and minor schistose fragments. A little tourmaline, iron oxide, and zircon are also present. The rock is fine to medium-grained, and poorly sorted, and contains few rounded grains. Adjacent quartz grains may be welded together, but quartz overgrowths are uncommon. Clay is the only other cement. In places, conglomerates occur at the base of and within Unit F. The basal conglomerate is 2 to 3 feet thick, 4 miles west of White Point Bore. It consists of well rounded clasts up to 4 inches in diameter, and is composed mainly of vein quartz, metaquartzite, and silicified sandstone. There are also a few fragments of the underlying Unit C siltstone.

Conglomerate is particularly well developed in Unit F about 2 miles south of Smiths Gift Bore on the western margin of the Napperby Sheet area. The conglomeratic bands range up to 6 feet thick, and are composed of well rounded pebbles, cobbles, and boulders up to 1 foot in diameter. Most of the phenoclasts consist of vein quartz, silicified sandstone, and metaquartzite set in a poorly sorted sandstone matrix. Sandstone also occurs in the conglomerate: specimen No. 65.660047A is a porous protoquartzite. The quartz grains are mostly of fine sand size and are usually angular to subrounded. Quartz overgrowths are not common. The rock has been tightly welded by pressure-solution. A few fragments of chert and grains of tourmaline, zircon, rutile, and iron oxide also occur. The heavy minerals are commonly segregated in narrow bands. The rock has a slightly reddish colour due to the presence of a little hematitic material.

Specimen No. 65.660047B, from the same locality, is loosely packed orthoquartzite. The quartz grains are poorly sorted and range from the fine to medium sand size. Angular to subrounded grains are common. The rock is cemented by thin coatings of opal on the large and small grains, but it does not fill the interstices completely (Pl. 2, fig. 3), and consequently the rock is porous, even where the interstices are partly filled with grains of silt. The red weathered surface of the rock is indurated by opaline silica, but an inch below the surface it is friable.

CORRELATION WITH THE GEORGINA AND AMADEUS BASINS (Fig. 1)

Unit $A^1$ is tillitic and is similar to the Mount Cornish Formation (Smith, 1964) in the Georgina Basin. In the Amadeus Basin, there are two tillitic horizons, the Areyonga Formation and the Olympic Member of the Pertatataka Formation (Wells et al., 1967): Unit $A^1$ can probably be correlated with the Olympic Member, and with the Marinoan tillite in the Adelaide Geosyncline rather than with the Sturtian tillite.

Unit A can be correlated with the Central Mount Stuart Beds of the Barrow Creek area because the two units are similar in lithology and are both underlain by a tillitic horizon (K.G. Smith, pers. comm.). Unit A can also be correlated for similar reasons with the Pertatataka Formation or its arenitic equivalent, the Winnall Beds (Ranford et al., 1966).

Unit B. The red-brown sandstone of Unit B is similar in lithology and occupies a similar stratigraphic position to the Grants Bluff Formation in the Georgina Basin and the Arumbera Sandstone in the Amadeus Basin. The presence of Helcionella sp. (Smith & Milligan, 1964) in the upper part of Grants Bluff Formation suggests that only the lower half of the formation in the Barrow Creek area should be correlated with Unit B.

Unit C. The Lower Cambrian age and the calcareous lithology of Unit C suggest that it should be correlated with the Todd River Dolomite in the Amadeus Basin (Wells et al., 1967) and with the Mount Baldwin Formation (Smith, 1964) in the Georgina Basin. The presence of Helcionella sp. suggests that the upper part of the Grants Bluff Formation in the Barrow Creek area is the time equivalent of the Mount Baldwin Formation and also of Unit C.

Unit D. Although there is no angular unconformity between Units C and D, there is probably a major time break between the two units. Unit D may be Upper Cambrian or Ordovician, and it is correlated on lithological grounds with the Tomahawk Beds of the Barrow Creek area in the Georgina Basin (Smith & Milligan, 1964) and possibly with the Pacoota Sandstone of the Larapinta Group in the Amadeus Basin.

Unit E may be equivalent to part of the Tomahawk Beds and Larapinta Group, but it is considered unlikely to be equivalent to the Mereenie Sandstone in the Amadeus Basin.

The lithology of Unit F and the pronounced unconformity with the underlying units suggest that it can be correlated with the Upper Devonian/Carboniferous Pertnjara Group, particularly the Hermannsburg Sandstone, in the Amadeus Basin (Wells et al., 1967; Tomlinson, 1967). It is probably also equivalent to the upper part of the Dulcie Sandstone in the Georgina Basin.

## STRUCTURE

The Ngalia Basin has been affected by at least three important tectonic episodes: they are represented by the unconformity between Unit A and the basement complex, the unconformity at the base of Unit B, and the unconformity at the base of Unit F. They may correspond to the three main orogenies in the Amadeus Basin, which have been referred to by Forman et al. (1967) as the Arunta Orogeny (Upper Proterozoic), the Petermann Ranges Orogeny (late Upper Proterozoic), and the Alice Springs Orogeny (Devonian-Carboniferous).

Unit F is also strongly folded in many parts of the basin, and it may be a continental synorogenic formation similar to the Pertnjara Group.

The movements in the Ngalia Basin resulted in uplift, folding, and faulting of unknown magnitude. Some of the folds in Unit F to the south of Yuendumu Settlement are of the Jura type, perhaps because an incompetent formation is present (possibly Unit C). Nettleton (1965) considers that the presence of salt may be the cause of seismic anomalies south of Yuendumu Settlement. He also considers that the northerly decrease in the Bouguer anomaly values across the same area is caused by the northerly slope of the floor of the Ngalia Basin to an axis situated near the outcropping northern margin.

The aeromagnetic survey (Hartman, 1963) has indicated that the sediments are about 17,000 feet thick south of Yuendumu Settlement. There also appears to be a complex horst or group of horsts in the same area. Hartman has described one feature (Anomaly 1-8) as possibly due to a small igneous plug which corresponds to basement cropping out about half-way along the Yuendumu/Vaughan Springs road.

There is a large negative gravity anomaly of -100 milligals where the basement crops out to the north of Napperby homestead (Flavelle, 1966). Farther north, in the Reynolds Range area, the air-photographs suggest that there is a complex infolding of the sediments and basement which corresponds to a gravity ridge, and the structure may be similar to that on the northern margin of the Amadeus Basin.

On the northern margin of the Ngalia Basin in the Napperby Sheet area, the basement may have been thrust over the sediments. Three miles west of Napperby homestead, where there is probably a folded thrust involving Unit A, the sediments dip beneath the granitic basement. The known outcrops of sedimentary rocks in the southern half of the Napperby Sheet area correspond to a steep north-dipping gradient. There is no correlation between the boundaries of the Ngalia Basin as indicated by outcrop and the Bouguer anomaly map; this may be due to the influence of a large body of granite on the gravity gradient, or to complex overfolding or overthrusting of the basement into the Upper Proterozoic and Palaeozoic sediments. In the Yuendumu area, the northern boundary of the basin appears to be a normal fault.

The structural history of the Ngalia Basin is probably complex, and is possibly similar to that of the Amadeus Basin.

## GEOLOGICAL HISTORY

The main events may be summarized as follows:

1. Arenites and lutites were deposited in the Precambrian.

2. The arenite-lutite sequence was regionally metamorphosed to schist, phyllite, and metaquartzite (Lower Proterozoic).

3. Large igneous bodies such as the Rock Hill Granite and the Napperby Granite were injected (Lower Proterozoic).

4. During the Upper Proterozoic, the area was probably above sea level for a long period, and was eroded and peneplaned.

5. Marine or continental glacial sediments were deposited in parts of the area (Unit $A^{1}$) during the Upper Proterozoic.

6. A thick sequence of marine sandstone with some conglomerate and lutites was deposited over the entire basin, probably in a shallow sea (Unit A), in the Upper Proterozoic.

7. There were major earth movements and folding of the sediments, which possibly also affected the basement, in the Upper Proterozoic Lower Cambrian. The area was raised above sea level and subsequently eroded.

8. Shallow sea returned in the Lower Cambrian, and Units B, C, D, and E were deposited in the Cambrian-Ordovician. There were possibly breaks in sedimentation during this interval.

9. A thick sequence of coarse continental deposits (Unit F) was deposited during a major orogeny in the Devonian-Carboniferous. The sediments were strongly folded and possibly faulted, and the basement rocks were possibly also affected.

10. The region remained a continental area throughout the Mesozoic and Cainozoic.

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PLATE 1

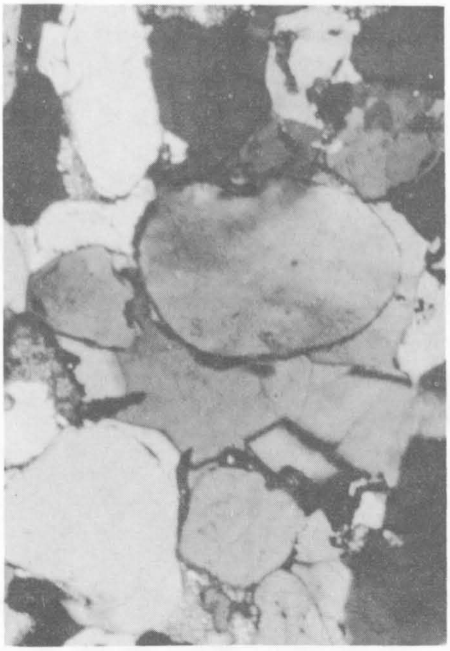

FIG. 1. Quartz overgrowths on rounded quartz grains. Specimen No. 65.660005. Crossed nicols, x 40.

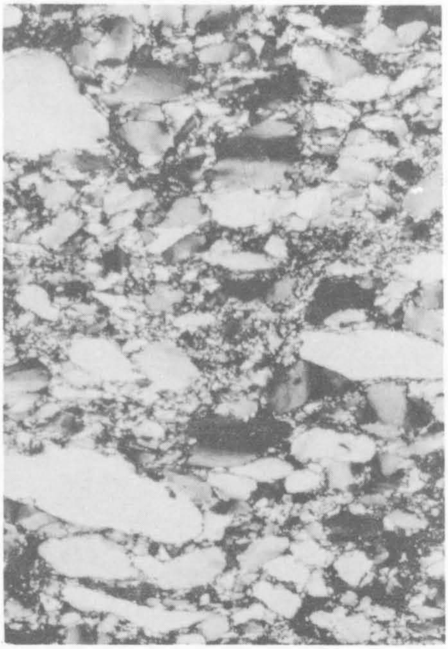

FIG. 2. Cataclastic quartzite. Specimen No. 65.660011. Crossed nicols, x 40.

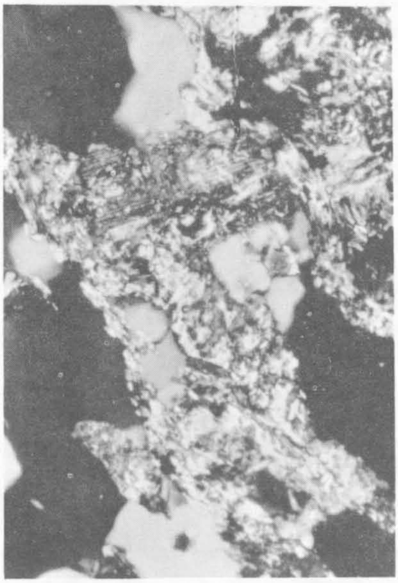

FIG. 3. Sericite, biotite, and iron oxides replacing plagioclase. Specimen No. 65.660015. Crossed nicols, x 100.

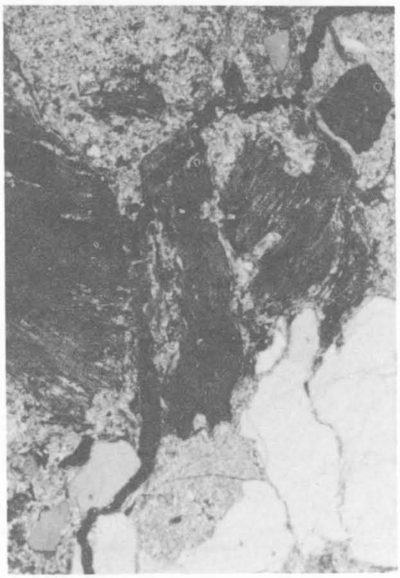

FIG. 4. Twisted biotite altering to white mica and iron oxides. Specimen No. 65. 660041A. Crossed nicols, x 25.

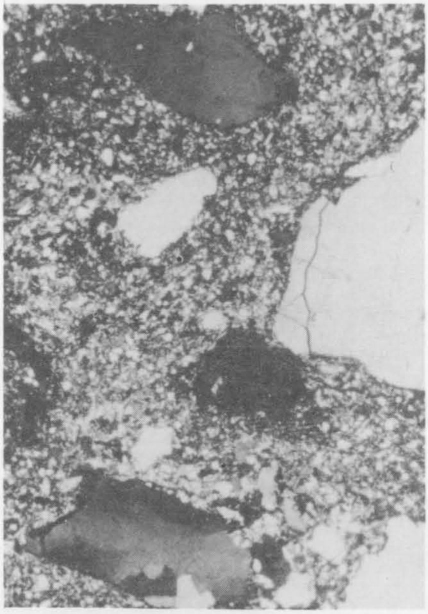

FIG. 1. Poorly sorted pebbly siltstone with a 'tilloid' texture. Specimen No. 65.660042A. Crossed nicols, x 25.

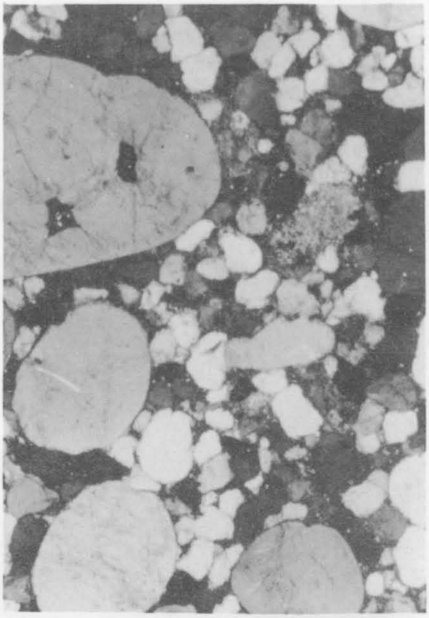

FIG. 2. Poorly sorted, well rounded quartz grains in a protoquartzite. Specimen No. 65.660045A. Crossed nicols, x 25.

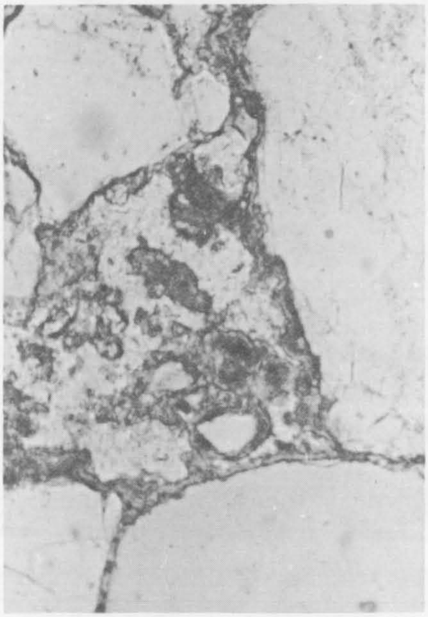

FIG. 3. Opal cement forming thin coatings on quartz grains. Specimen No. 65.660047B. Ordinary light, x 100.

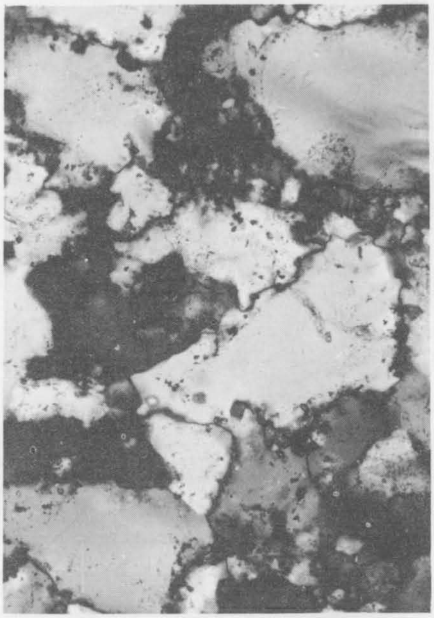

FIG. 4. Irregular quartz grains sutured together. Specimen No. 65.660048A. Crossed nicols, x 100.