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GEOLOGY OF THE NORTHWEST SECTION OF THE KULGERA 1:250,000 SHEET:

ANGAS, WESTERN EBENEZER, AND NORTHWESTERN SENTINEL BORE 1:100,000 SHEETS

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ABSTRACT

This report describes the mapping of the northwestern Kulgera 1:250,000 sheet, an area comprised of Proterozoic to Devonian sedimentary rocks of the Amadeus Basin, and Cainozoic sedimentary rocks, sediments, and duricrusts.

The southern margin of the Amadeus Basin is here represented by a compressed and incomplete section consisting of Bitter Springs Formation, Inindia Beds, Winnall Beds, Larapinta Group (Stairway Sandstone, Stokes Siltstone, Carmichael Sandstone), Mereenie Sandstone, and Finke Group (Langra Formation and Horseshoe Bend Shale). Unconformities observably exist beneath the Larapinta Group and the Finke Group. The pre-Devonian rocks of the Amadeus Basin have been affected by several tectonic events, most notably the Devonian Alice Springs Orogeny, during which the rocks were folded into narrow, east-west trending folds, with associated south-over-north faulting.

Cainozoic units cover the majority of the map area. These include alluvial and colluvial sediments of presumed Tertiary age; undated silcrete and ferricrete; and Quaternary calcrete, talus, alluvial sediments, playa sediments, and sand. Quaternary erosion has stripped some areas, leaving only remnants of the Cainozoic deposit.

The calcretes are the main aquifer and are of economic importance in this area of no surface water flow. The playa sediments are prospective for zeolites and a number of magnesium and/or potassium sulphate salts.

INTRODUCTION

This report describes the mapping of those sections of the Kulgera 1:250,000 sheet which are covered by the ANGAS 1:100,000 sheet, the western section of the EBENEZER 1:100,000 sheet, and a small portion of the northwestern section of the SENTINEL BORE 1:100,000 sheet. Mapping occurred from 1987-88, and was based on 1:50,000 scale colour aerial photographs (flown in 1986 by the NT Department of Lands, negative numbers NTc971, NTc996, NTc997, and NTc998). A drilling program was carried out in 1988. Raw data (drill logs, thin-section descriptions, etc.) are compiled in the Kulgera Data Record (Library File, Northern Territory Department of Mines and Energy, Alice Springs), and other reports are referred to in the relevant sections.

## LOCATION AND ACCESS

The map area is that northwestern section of the *Kulgera 1:250,000 map sheet which extends from the northwest corner (latitude 25 00, longitude 132 00), southwards to the level of Bankin Bore, and eastwards to the level of Murphy's Range (in the south) and 5km east of the end of the Basedow Range (in the north). The map area covers all of ANGUS, half of EBENEZER, and a small portion of SENTINEL BORE 1:100,000 sheets. The map area covers the Imanpa Community and parts of the following Pastoral Leases: Angas Downs, Mt. Ebenezer, Lyndavale, and Curtin Springs. Access to the area is via the sealed Lasseter Highway, with a major formed road from the Lasseter Highway to Wallara passing through Angas Downs. Graded bore tracks generally provide good access within pastoral leases, although access in the playa lake area can be difficult.

## CLIMATE

The climate in the area is semi-arid, with long hot summers and relatively mild winters. At Curtin Springs, the closest Meteorological Recording Station, the average yearly rainfall is 233 mm; rain may fall at any time of the year but the highest average falls have been recorded from December to March (data from 1953 to 1989). The average daily maximum and minimum temperatures in January are 37.1-21.4'C; and for July the average temperatures are 19.6-3.0'C.

## PHYSIOGRAPHY AND VEGETATION

The map area can be divided into uplands, lowlands, sand plains, and playa chains and calcretes.

The uplands consist of the east-west belt of Amadeus Basin outcrop in the north of the map area, including the Kernot and Basedow Ranges. The folded and faulted rocks produce relatively sharp relief: 230 m above the surrounding plains at Kernot Range, and 200 m above the plains at Mt. Ebenezer in the Basedow Range. The rocks of the uplands form dipslopes of shallow to medium grade, with steep to scarped scarp slopes. They are vegetated with sparse to thick communities of eucalypts, mulga, hardy shrubs and grasses

Lowlands are clayey or sandy flat areas around the ranges. The lowlands are often areas where recent erosion has taken place, and they may be covered by scattered fragments of calcrete or silcrete, or desert-varnished gravel (gibber, buckshot gravel). They are sparsely vegetated with grasses, mulga, corkwood, or shrubs. Mesas of ?Tertiary sediments protected by duricrusts occur both in the lowlands near the ranges, and flanking the ranges themselves.

Sandy plains occur either as dune fields, with longitudinal-type dunes forming here in reticulate patterns and vegetated by hardy shrubs and spinifex, or (in the northwest) desert oaks and spinifex; or as sheetflood plains, vegetated by thick arcuate groves of mulga trees.

The topographically lowest points in the map area are occupied by a chain of playa lakes which is the southeasterly extension of the groundwater discharge zone that includes Lake Amadeus. The playas are flat expanses ranging in size from a few hundred metres to kilometers. Playa surfaces may be dry or wet; the may be covered in mud, gypsum, or grey to white halite. Playa margins are sandy and vegetated by samphires or saltbush. Calcrete scarps up to 4 m high are often distributed around playa margins; these are part of broad flat calcrete plateaus which are associated with the playas. The calcretes are thinly vegetated by mulga and other trees, and characteristically by a low (<20 cm high) plant with greyish leaves.

Aside from short channels carrying runoff from the highlands, there is no surface drainage in the map area.

## REGIONAL GEOLOGICAL SETTING

The Amadeus Basin is a large intracratonic structure about 800 km long (east-west) and about 300 km wide (north-south), which extends into Western Australia. Within its area is preserved about 14 km of Proterozoic and Palaeozoic sediments. The overall sequence of the Basin records several episodes of sedimentation, with several periods of diastrophism being evidenced by unconformities. Accordingly, the Basin margins changed with each depositional cycle, and therefore the present margins do not correspond to former depositional markers. The present day limits of the Basin are attributed to major orogenic periods: the southern margin to the Late Proterozoic or Early Cambrian Petermann Orogeny, and the northern to the Devonian Alice Springs Orogeny. The Amadeus sequence in the *Kulgera 1:250,000 sheet forms the south-eastern edge of the Basin.

Cainozoic sediments, sedimentary rocks, and duricrusts unconformably overlie and/or replace rocks of the Amadeus Basin. The distribution of some of these units (especially playa sediments and calcretes) is related to the previous climatic and groundwater history in the area.

## STRATIGRAPHY

Where different observations are made for the individual 1:100,000 sheets, the relevant paragraphs will be headed in *lower case italics* with the sheet name..

### Upper Proterozoic

Bitter Springs Formation *(Angas)*

Name derivation: The Bitter Springs Formation was defined by Joklik (1955) and revised by Wells et al. (1967). The type locality is at Bitter Springs, and Wells et al.(1967) have selected a reference section at Ellery Creek.

Distribution: The Bitter Springs Formation occurs only sparsely on *Angas*, with three larger (2-5km long) and two smaller (<1km) outcrops extending in a belt along the northern sheet area.

Thickness: Outcrop is poor; bedding inclination and degree of structural influence on outcrop is not visible. The only outcrop that is in contact with other units at top and bottom (site 1044, 6 km south-southwest from Angas Downs) is approximately 150 m wide, perpendicular to strike. The largest outcrop (site 1310, 10km west of Angas Downs) is 1 km wide, perpendicular to strike.

Airphoto expression: Appears as low broad ridges, greyish in colour; similar to calcrete.

Outcrop style: Outcrop is generally heavily masked by well-developed calcrete. Fragments of Bitter Springs Formation are found amongst the calcrete rubble, but are generally < 10% of surface rubble.

Lithology: Only the limestones of the Bitter Springs Formation were seen. These occur as 5-10 cm chunks of limestone, pale green, pale to dark grey, or black; massive, laminated, or bedded; and occasionally cherty. Thin section S1111A (from site 1111, 6 km southeast of Angas Downs) consisted of 100% recrystallized dolomite.

Relationship: The Bitter Springs Formation is stratigraphically beneath the Inindia Beds (Wells et al., 1970). Outcrop of both units is poor, and no evidence for their conformity/unconformity is visible in *Angas*. The two smaller outcrops (6km southwest and 6km southeast of Angas Downs homestead) are situated between outcrops of the Inindia Beds on the north, and Larapinta Group to the south. This indicates angular unconformity between the Bitter Springs Formation and the Larapinta Group and suggests some pre-Ordovician tectonism.

Inindia Beds

Name derivation: The Inindia Beds were described by Ranford et al. (1966) but were not formally defined as a formation. The original reference areas listed in Ranford et al. are amended in Wells et al. (1970), to: the northern slopes of Mount Connor for the upper part of the formation, and the area 12 miles northeast of Curtain Springs homestead for the lower part (both on the Ayers Rock 1:250 000 sheet).

Distribution: Outcrops of the Inindia Beds occur along the northern section of the map area, in the belt consisting of the Kernot and Basedow Ranges, and the scattered outcrops between the Ranges. A small outcrop occurs approximately 25 km southwest of the Mount Ebenezer homestead, in the Murphys Range area, and Inindia Beds also occur in the southwest of the area, near Mount Connor.

Thickness: Total thicknesses of outcrops of the Inindia Beds are generally not determinable, since outcrops: (a) show only a top or a bottom contact, if any; (b) are generally too poor to show bedding; and (c) where beds are present, they often show a high degree of folding (e.g. site 1051, just north of the sheet boundary, 12 km west-northwest of Angus Downs homestead). *Angas:* The largest outcrop where bedding shows little folding is the somewhat atypical range of hills 20 km southeast of Angus Downs homestead, near Boundary Bore. This outcrop is 1.5 km wide (perpendicular to strike, at its widest point), giving an approximate thickness of 750 m (average dip 30°).

*Ebenezer:* Only one outcrop of the Inindia Beds shows contacts on both sides: site 1105, in the Murphys Range. This outcrop is 300m wide, giving a thickness of approximately 120m (dip of 28° in the adjoining Winnall Beds). However, this outcrop is bounded on both sides by younger units (the Winnall Beds and the Stairway Sandstone). This indicates that at least some of the lower Inindia Beds are missing. A narrow band of Inindia Beds sandstone is exposed to the north of the Basedow Range. It is 600 m wide perpendicular to strike at its widest point (site 1375), giving a rough thickness of 300 m (dip of 29° at site 1077, 2 km to the east). Shales and siltstone of the Inindia Beds are overlain by Quaternary talus from the Basedow Range, and it is likely that the Inindia Beds extend southwards for a further 300-500 m, giving an estimated thickness of 500-600 m at site 1375.

Airphoto expression: The most widespread airphoto expression of this unit is as groups of irregular low mounds, grey to very dark grey where large amounts of jasper or chert are present. White blazes are common where shale crops out, generally along eroding scarps of overlying protective sandstone, talus, or duricrust. Sandstones are occasionally well-enough developed to show as distinct grey ridges, sometimes with definite scarps, and often showing contorted folding on a scale of 100-300 m. Outcrops are often associated with, and may merge into, greyish calcrete patches.

Outcrop style: The wide range of lithologies in the Inindia Beds (see below) is reflected in variable outcrop styles. As a broad generalization, outcrop is poor to very poor.
Finegrained rocks (claystone, siltstone, shale) are visible in scarps where overlain by protective rock layers, or rare outcrops poking through a pavement of harder rock rubble, or where fragments are brought up in rabbit burrows.
The most common outcrop style is as low knolls and rises of rock rubble (cherts, jaspers, sandstones, ironstones etc.). Occasionally remnants of bedding may be seen as discernable trendlines in the rubble. Rubble trails off into common gibber pavements, making the map distinction between gibber and outcrop slightly arbitrary.
The best outcrop in the unit occurs with the various quartz sandstones, which often form strike-ridges. Such ridges are usually 1-5 m high, but where the sandstone is thick the ridges may be much higher (e.g. the range of hills near Boundary Bore, 20 km southeast

of Angus Downs homestead, which is approximately 80 m high).

Lithologies: The Inindia Beds contain a large number of rock types, and these show rapid variation, both laterally and vertically. The poor nature of the outcrop makes it difficult to assign the various rock types to any stratigraphic order, and therefore lithotypes are listed below in decreasing order of outcrop abundance:

1. Quartz sandstones: a highly variable group, with grain sizes ranging from very fine to coarse. The sandstones may be kaolinitic, arkosic, or show thin heavy mineral layers, but are most commonly pure quartz. They are usually well-cemented, but range from friable totally silicified. Bedding (when visible) ranges from laminar to up to 1 m thick. Crossbedding is not common, but does occur in some of the coarser sandstones, where it is often fairly distinctive: the crossbeds tend to be much less regular in appearance than those of other crossbedded units (e.g. Oc, Os). Thin section S1050, from one such crossbedded sandstone, consists of 100% quartz, well rounded clasts strongly compressed together showing pressure solution at grain boundaries.

   One sandstone which appears to be characteristic of, and reasonably common in, the Inindia Beds has been given the field name of "speckle sandstone". This rock is silicified, medium-grained and well sorted, white to pale grey with small black flecks along the weathered surface. On the fresh surface, the black flecks correspond to pale brown clasts which in thin-section can be seen to be fine-grained magnetite converted to haematite (section S1092). The fresh surface may also show a sugary sparkle. The speckle sandstone is found as ridges, as rubble, and as conglomerate clasts.

2. Ironstones: brick-red to black quartz sandstones up to medium grain size, heavily impregnated with iron oxides; and occasional shaley (finegrained) ironstones. Thin section S1052A is a medium-grained silicified quartz sandstone with 30% Fe oxide cement. The ironstones are found as rubble on low knolls, often in associa-

tion with jasper.

3. Jasper and chert: pale to dark red jasper or jasper breccia and white, grey, clear, or banded chert or chert breccia, sometimes very vuggy, are the most distinctive rocks of the Inindia Beds. These are always found as rubble; the nearest thing to in-situ outcrops are the cherts and jaspers between the two sandstone ridges near Boundary Bore (20 km southeast of Angus Downs homestead). Chert and jasper are often found in association with ironstone or sandstone rubble, and rare outcrops of pale siltstones are visible beneath the protective layer of rubble.

4. Conglomerate cobbles: in a number of outcrops (e.g. 1120, 1121 11 km northwest of Angas Downs homestead, 1126 24 km west-northwest of ditto) the sandstone rubble was clearly water worn; clasts were well rounded (though sometimes mixed with more angular clasts), had a high degree of sphericity, and in one case exhibited clear chatter-marks.

   Clast size ranges to 40 cm in diameter, and clasts were most often Inindia Beds sandstone, with some vein quartz or iron-stained sandstone. Distribution of these rounded cobbles matched folded Inindia Bed trends visible on airphotos, and the cobbles are clearly not the result of Cainozoic sediment redistribution. No matrix survived the weathering process, suggesting a friable or fine-grained or arkosic nature; a small outcrop of finegrained arkose was found at site 1120.

5. Finegrained rocks: white, ochre yellow, pale green, or purple siltstone or claystone was rarely visible, generally cropping out where protected from weathering. Bedding is generally not exposed but may be finely laminated or disrupted; outcrop may be fractured into cm-scale rectangular blocks. Because of the easily weathered nature of these rocks, it is suggested that they (land thus the whole unit) may have a wider distribution than is implied by surface outcrop. *Ebenezer:* A green poorly sorted siltstone in Murphys Range (25 km southwest of Mt Ebenezer homestead) shows sand-, grit-, and pebble-sized clasts floating in matrix, and clasts include rounded vein quartz and granite.

6. Limestone: at sites 1036 and 1053(8 km south-southwest and 13 km northwest of Angas Downs homestead), some rubble of dolomitic limestone or interbedded limestone and siltstone are seen. Dolomite is described in the Inindia Beds elsewhere (Wells et al., 1970); however these sites are both in heavily disrupted areas and the limestone may also be infolded or faulted Bitter Springs Formation.

N.T.G.S. stratigraphic drillholee 88K3, east of Mt. Connor, intersected approximately 25m of Inindia Beds at the base of the hole. These consisted of dark grey well lithified shale containing up to 35% fine quartz clasts, with occasional interbeds of pink or grey dolomite (thin-sections K3-3 and K3-4).

Structure: *Angas:* Outcrop of the Inindia Beds shows open to tight folding on a kilometer scale. Much of the folding is probably of Alice Springs Orogeny age, since it involves Ordovician rocks as well as the Inindia Beds (e.g. the areas 12 km west-northwest, or 13.5 km southeast of Angus Downs homestead). Angular unconformity beneath the Stairway Sandstone (site 1108, 4 km south of Angus Downs homestead) indicates pre-Ordovician tectonism. *Ebenezer:*Although folding on an outcrop (macroscopic) scale is present in the Angas 1:100 000 sheet, outcrop trends do not show folding in the Ebenezer 1:100 000 sheet. Only one outcrop shows folds expressed in measured dip (site 1090, 11 km north of Mt. Ebenezer homestead). However, the outcrop near site 1105 in Murphys Range (25km southwest of Mt. Ebenezer homestead) is bounded on either side by younger units (the Winnall Beds and the Stairway Sandstone). This indicates that after the deposition of the Winnall Beds, sufficient folding took place to overturn the rocks and expose the base of the Inindia Beds to erosion. The Ordovician Stairway Sandstone was subsequently deposited on the unconformity surface. *Sentinel Bore:* The outcrops appear to form a minor anticline associated with, and on the eastern edge of, the syncline forming

Mt. Connor. In drillhole 88K3, dips ranged from 30-45°, and the more competent siltstone was frequently intensely folded and transposed, and brecciated as a result.

Relationships: the Inindia Beds overlie the Bitter Springs Formation and are overlaid by the Winnall Beds. Both contacts are unconformable (Wells et al., 1970) but no clear relationships are seen in the map area. The Inindia Beds are unconformable beneath the Stairway Sandstone (site 1108, 4 km south of Angus Downs homestead and site 1090, 11 km north of Mt. Ebenezer Homestead.).

Correlations: the Inindia Beds are suggested to be comtemporaneous with the Areyonga Formation in Wells et al., 1970.

Comments: The Inindia Beds are suggested to be glacial towards the top in Wells et al. (1970). The poorly sorted green siltstone which contains a granite cobble (at Murphys Range, site 1100) may be a tillite with an erratic. The bands of conglomeratic rubble might be interpreted as the remains of tillitic diamicitite.
The presence of the speckle sandstone both as beds, and as reworked cobbles, may suggest a significant time break within the Inindia Beds. This may be a point for consideration if this unit is ever formalized to Formation status.

<u>Winnall Beds</u> Puw
Name derivation: The Winnall Beds were described by Randford et al. (1966) and named after the Winnall Ridge.

Distribution: Rocks of the Winnall Beds form the Kernot and Basedow Ranges, and some small outcrops also occur in Murphy's Range, 25 km southwest of the Mt. Ebenezer homestead.

Thickness: *Angas:* Kernot Range is 2 km wide at its widest point measured perpendicular to strike, giving a thickness of 1000 m (dip 30°). It should be noted that the basal micaceous unit, seen in the Basedow Range, is not present in the Kernot Range. *Ebenezer:* The Basedow Range outcrop of the Winnall Beds is 1250 m wide at its widest point perpendicular to strike, giving a thickness of 530 m. A further 250 m of section, covered by scree, separates the lowermost Winnall Beds outcrop from the uppermost Inindia Beds outcrop, and the lower boundary will be somewhere in this covered interval. A fault running along the south of the Basedow Range has removed some of the upper section of the unit.

Airphoto expression: The lower micaceous beds form greyish gentle slopes, bare and poorly vegetated, on which bedding trends can often be seen. The more strongly outcropping upper beds form reddish strike-ridges, often showing prominent cliffs.

Outcrop style: In the lower micaceous beds, outcrop is usually poor: soil mixed with loose, not-quite-in-situ small rectangular blocks. Steeper slopes or gullies may show quite good outcrop, however. The upper beds of this unit crop out as well-defined beds, sometimes fractured into rubble or rubbly pavements. The more highly silicified and/or thickly bedded sections fracture sub-conchoidally, giving rounded rubble or beds whose broken ends are rounded.

Lithologies: Broadly, the Winnall Beds are pale coloured moderately well silicified quartz sandstones. The unit can be divided into three subunits: the basal micaceous, the main ridge forming, and the minor ridge-forming.

The basal micaceous subunit crops out on the north of the Basedow Range. It is a fissile finegrained micaceous quartz sandstone, usually purple or purple-brown, but occasionally grey, pale green, or white. Beds are thin and regular (0.5-5 cm) with rare thick pods (?channels). Occasional low-angle crossbeds, 1-2 m ball-and-pillow structures, and linear symmetrical ripples can be seen. To the northeast of the Basedow Range (site 1088), beds (2-50 cm) of a medium-coarse sandstone with pebble-conglomerate layers crop out near the contact with the Stairway Sandstone; these beds must be close to the base of the Winnall Beds.

A slightly thicker bedded (to 20 cm, with crossbeds) fine sandstone at the base of the Kernot Range is probably a continuation of the same subunit, but it is much diminished compared to the Basedow Range outcrop,

The main ridge-forming subunit forms the highest part of the Kernot and Basedow Ranges, including the main cliff-forming beds. This subunit consists of fine to medium grained silicified quartz sandstone or quartzites, occasionally slightly kaolinitic. The sandstones are weathered to grey, orange, or purple-brown, and are white, grey, pale orange, pale purple or purple on a fresh surface. Beds may often be thick and structureless. However, current streaming lineations, flat oval clay galls, and long slightly asymmetric wave ripples are the most common sedimentary structures; slump folds, raindrop impressions, low-angle crossbeds, and rare burrows ($\leq$ 1 cm diameter, horizontal or oblique) also occurred. A good exposure of nearshore wave ripples exists at site 1071 (3 km northwest of Imanpa Community), where a gully cuts through many beds, each bearing good ripple marks. In the traverse south from site 1012, fine quartz sandstone in 0.5-1 m cliff-forming beds surmounted the basal siltstone; these are topped by silicified medium-grained quartz sandstones in 20 cm beds; then massive thickly bedded ($\leq$ 1 m) structureless silicified sandstone / quartzite to the crest, and down the dipslope.

The minor ridge-forming unit consists of 4-6 smaller ridges to the south of the main Kernot Range. These consist of repeated thickening-upwards sequences of fine sandstone, from laminated (1-2 mm) beds passing up to more thickly bedded (5-30 cm) often massive or blocky sandstone. This subunit has clay galls, current-streaming lineations, 2 m ball-and-pillow structures, low-angle crossbeds, ripples, flute casts, and irregular (?bioturbated) bed tops.

Structure: *Angas:* In the west of the Kernot Range, beds trending NW-SE kink sharply and trend NNW-SSE (see trend-lines on compilation sheets). Measured dips echo this change (e.g. site 1025, 25 km east-southeast of Angas Downs homestead). Outcrop dies away very suddenly along a straight line on this western edge of the range, and it is suggested that there may be concealed fault along this area. *Ebenezer:* The Winnall Beds are folded into a syncline in the main Basedow Range (sites 1066 to 1096, 2.5 km north-east to 9 km west-northwest from Imanpa Community), and folding can be seen in the lower-lying eastern and western extensions from the main range. The southern limb of the syncline has been removed by a fault extending along the southern margin of the Range. Outcrop is usually non-existent to very poor along the fault contact, often consisting of disrupted, calcrete-encrusted shales beneath the overlying Stairway Sandstone. At site 1073 and the gully west of site 1073 (1.5 km north of Imanpa Community) outcrops of the Stairway Sandstone show sharp changes in orientation across the fault.

Relationships: The Winnall Beds overlie the Inindia Beds, unconformably according to Wells et al. (1970) although no contact with measureable exposure is seen in the map area. The Winnall Beds are overlaid by the Stairway Sandstone. No direct contact is exposed, but air-photo trends show the contact to be unconformable. The Winnall Beds are in faulted contact with the Stairway Sandstone along the southern margin of the Basedow Range. At site 1073, on the western side of the main gully and north of the fault, a conglomerate unconformably overlies the Winnall Beds; the matrix is a finegrained kaolinitic sandstone which resembles the Stairway Sandstone.

Correlations: The Winnall Beds are correlated with the Pertatataka Formation in Wells et al. (1970).

Comments: To the north at West Bore, and to the east in a belt extending up to the Basedow Range, the Inindia Beds are consistently in direct contact with the Stairway Sandstone. It therefore is interesting to find such well-developed units of the Winnall Beds so close: it suggests that the pre-Ordovician erosion surface has stripped off most of the Winnall Beds at other sites.

<u>Ordovician</u>

<u>Larapinta Group</u>

Nomenclature: The name Larapinta Series was first used by Tate (1896), and the present group and constituent formations were defined by Prichard and Quinlan (1962) with amendations by Wells et al. (1965) (Wells et al., 1970).

Distribution: "The Larapinta Group is sporadically distributed throughout much of the Amadeus Basin, and is particularly well-developed in the northern half." (Wells et al., 1970). In the map area, the Larapinta Group is found throughout the belt of outcrop stretching along the north (the Ranges and associated outcrops), and in Murphy's Range to the south.

Age: The Larapinta Group ranges in age from the late Upper Cambrian at the base of the Pacoota Sandstone, to Upper Ordovician (Wells et al., 1970). Ages are based on a range of fossils found in the group's formations.

Constituent formations: The Larapinta Group consists of the Pacoota Sandstone, the Horn Valley Siltstone, the Stairway Sandstone, the Stokes Siltstone, and the Carmichael Sandstone. Of these, only the latter three are present in the map area.

Thickness: The maximum thickness of the Larapinta Group is 2350 m, at the Idirriki Range, 400 km west of Alice Springs (Wells et al., 1970). The Group thins consistently towards the south, and in the map area the maximum thickness of outcrop is 350 m.

Structure: Units of the Larapinta Group are locally faulted, gently folded, and occasionally tightly folded. Structure will be more fully described in the individual formation sections.

Relationships: The Larapinta Group is unconformable over the Winnall Beds and the Inindia Beds, and is unconformably overlain by the Finke Group.

<u>Stairway Sandstone</u> Os

Name derivation: The Stairway Sandstone was defined by Prichard and Quinlan (1962) and the name was amended by Wells et al. (1965).

Distribution: *Angas:* Outcrop of the Stairway Sandstone occurs along the southern margins of the Kernot and Basedow Ranges, and in the linear belts of outcrop between the ranges. Another isolated outcrop occurs amongst the salt lakes on the western edge of the sheet, near the Lasseter Highway. *Ebenezer:* The Stairway Sandstone crops out principally along the southern margin of the Basedow Range. Small outcrops also occur to the east of the Range, and in the Murphy's Range.

Thickness: Although the Stairway Sandstone is up to 560 m thick in the northern Amadeus Basin (Wells et al.,1970), the unit thins consistently to the south and in *Angas,* the maximum thickness is approximately 100 m. *Ebenezer:* This unit has a maximum thickness of 160 m in Murphy's Range. Outcrop south of the fault in the main Basedow Range tends to be much thinner: approximately 75 m .

Airphoto expression: The Stairway Sandstone forms long narrow ridges, grey or greyish-red in colour, sometimes with white blazes on the scarpslope side of the ridge. Occasional prominent scarps can be seen along the ridges, and lines of trees or scrub growing along bedding planes commonly form dark lines visible on air photos. In some places (notably west of Angus Downs homestead), two sandstones separated by a recessive ?siltstone form a distinctive double ridge, resembling railroad tracks.

Outcrop style: Sandstones of this unit crop out as low to medium sized (.1-15 m) ridges, shedding abundant scree over topographically lower recessive units. These ridges may be broad and flat, with little in-situ outcrop; or outcrop may be well exposed with well-defined dipslope and scarp-slope. Outcrops of sandstones may also be poor and rubbly, especially near faults. Siltstones/claystones in this unit are recessive and crop out poorly.

Lithologies: Finegrained rocks such as siltstone or friable highly kaolinitic fine sandstone do occur in the Stairway Sandstone, but their outcrop is poor. They are sometimes visible beneath scarps or in gullies, and are evidenced by covered intervals within the sequence. When visible, the finegrained rocks are white or purple, weathering to a mottled orange, black, and white.

Sandstones form the main outcrops in this unit, and these fall into two groups: the crossbedded coarser sandstones and the silicified finer sandstones.

The crossbedded coarser sandstones are generally medium to coarse-grained with distinctive scatterings of grit or pebbles on bed surfaces. The quartz clasts are well-sorted, well-rounded and sometimes show a bimodal grainsize population. Grainsize can vary within an outcrop, with coarser patches, pebble conglomerate layers, or coarse lag deposits at crossbed bases. Planar, trough, and some ?festoon crossbedding are common, as are ripple marks and ripple cross-lamination. Good outcrops of this type occur at *(Angas)* site 1091, 21 km southeast of Angas Downs Homestead, or sites 1005 and 1097 in the Basedow Range, 20.5 and 23 km east-southeast of the homestead; *(Ebenezer),* site 1167 and at site 1100 (17.5 km northeast and 25 km southwest of Mount Ebenezer homestead). These sandstones are not as common in *Ebenezer* as they are in *Angas*.

The silicified finer sandstones are usually white or pale orange weathering to dark orange, purple-brown, or grey. They are fine to medium grained and are generally well-silicified; some rocks are friable and some display a sparkly, sugary texture. Bedding tends to be variable between 1-50 cm. The unit is characterised by the abundance of trace fossils and sedimentary structures it contains: disrupted, bioturbated bed tops are very common, as are Skolithos (pipe-rock); intraclast horizons, showing flat oval hollows where phosphatic clasts have weathered out of the sandstone are also frequent; others include Diplocrateriaon, Cruziana,, various tubules and pellets, flute marks, and "dingo paws" (Wells et al. 19661).

The phosphatic beds consist of tan to light brown 1-3 cm oval phosphatic intraclasts in a matrix of silicified sandstone. On exposed surfaces, the phosphates have usually weathered out, leaving flat oval cavities. Phosphate clasts usually constitute less than 20% of any one horizon. Thin-section S1004D shows <5% collophane as clasts and intergranular staining, in >95% fine quartz sandstone, well-cemented with quartz overgrowths.

Structure: The Stairway Sandstone crops out in a consistent belt along the south of the Basedow Range. Beneath the Stairway Sandstone, the Winnall Beds crop out; the straight-line nature of the contact, and some of the folding (?drag-folding) of the Winnall Beds, suggests that this boundary may be a fault. Slickensides are very common in this unit near the suggested fault, but are not common elsewhere (except in proximity to other local faults). Outcrops at and near site 1073 (2 km north of Imanpa Community) show mesoscopic (10-30 m) fault blocks of Stairway Sandstone, which show sharp changes in bedding trend and heavy fracturing. The fault seems to occur at or near the base of the Stairway Sandstone, and is approximately bedding-parallel. The contact (fault) between the Stairway Sandstone and the Winnall Beds is usually hidden by scree, suggesting a recessive bed. At site 1068 (2.5 km northeast of Imanpa Community), siltstone covered by calcrete in a messy, disrupted outcrop is exposed in a gully. At site 1005 (20.5 km southeast of Angas Downs homestead), the contact is exposed in a rabbit warren and gully near a scarp of coarser crossbedded sandstone. The contact consists of a pervasive calcrete, rather messy-looking and weathering to mottled white, orange, and black, cementing and masking fragments of the rock units above and below.

Elsewhere, the Stairway Sandstone crops out as long straight beds or lines of rubble which are often disrupted and offset (on a scale of metres) by local faults. Slickensides are common near these faulted areas, increasing towards the fault. Sandstones near faults may often be fractured into thin rectangles, coarse lenses, or rhomboids.

Relationships: The Stairway Sandstone is unconformable over the Inindia Beds, and in faulted contact with and unconformable over the Winnall Beds. At site 1073 (2 km north of Imanpa Community), a conglomerate unconformably overlies the Winnall Beds, at the western edge of the northern gully. The moderately rounded boulders and cobbles appear to be from the Winnall Beds, but the white friable kaolinitic sandstone matrix is more similar to the Stairway Sandstone; this outcrop may be in-situ basal conglomerate of the Stairway Sandstone. The Stairway Sandstone is overlain by the Stokes Siltstone, and this relationship is noted as conformable in Wells et al., (1970). Outcrop of the Stokes Siltstone in the map area is too poor to directly observe any relationships but in air-photograph the two units certainly appear conformable.

Mineralisation: Phosphorite appears locally as intraclasts (≤20%, more commonly ~5%) in silicified sandstone. Phosphorite horizons do not appear to be very thick (<2m) or laterally persistent.

Stokes Siltstone Ot

Name derivation: The Stokes Formation was defined in 1962 by Prichard and Quinlan, but as defined it also included the Carmichael Sandstone. Wells et al (1970) redefined and renamed the Stokes Siltstone.

Distribution: Small outcrops occur south of the Kernot and Basedow Ranges, in the belt of outcrop between the ranges, and west of Angas Downs homestead. An unusually good outcrop occurs in the Murphys Range (25 km southwest of Mount Ebenezer homestead).

Thickness: Although the unit is over 660 m thick at the type area, it thins towards the south and in *Angas* the maximum true thickness shown by outcrop is 260 m (site 1023, just south of the Kernot Range). A more typical thickness is closer to 180 m (including both outcrop and associated recessive section). In *Ebenezer,* the maximum true thickness is approximately 90 m, in Murphys Range (site 1100).

Airphoto expression: *Angas:* As outcrop is usually poor to non-existent in the map sheet (and also as noted by Wells et al., 1970), the presence of the unit is usually indicated by a shallow valley of Cainozoic sediments, between two more strongly outcropping units (usually the Stairway and Carmichael Sandstones). When the basal dolomites are exposed, they appear on air photos as narrow bands of even-textured light grey (very dissimilar to calcrete grey) within a broader valley of Cainozoic sediments. *Ebenezer:* Outcrop of this unit is usually very poor and it most frequently shows as white blazes in scarps or gullys of the talus shed by the Basedow Range. Beds in Murphys Range show as narrow grey linear bands.

Outcrop style: Outcrop is generally very poor. The dolomites crop out as low (<1m) broad ridges, mostly covered in calcrete but with floating rubble of limestone. Claystones may be visible in gullies, but are generally only seen in fragments lying amongst Cainoizoic sediments, brought up in rabbit warrens, or exposed by human activity. The occasional more resistant sandstone may be exposed as a low bed or as rubble.

Lithology: The most distinctive unit of the Stokes Siltstone is the near-basal dolomite, which is microcrystalline, even-textured, grey, microkarstic, and marked by ?worm trails and occasional mudcracks. The dolomites are often thinly bedded (5-20 cm) and may be associated with silty dolomites or shaley interbeds. Kaolinitic fine sandstones and siltstones may be white, brown, or purple; crossbedding, bioturbation, clay galls, Skolithos, and Diplocrateriaon may rarely be seen. Thin-section S1041 contained 100% equant dolomite crystals, with a rind of calcite and quartz calcrete.

Relationships: The Stokes Siltstone is reported to be conformable between the Stairway and the Carmichael Sandstones in Wells et al.(1970). No direct relationships are observable due to the poor outcrop, however airphoto evidence indicates conformability. At some sites, the Stokes Silstone appears to directly overlie the Inindia Beds (sites 1330 and 1045, 5 km south and 7 km southwest of Angas Downs homestead), however it is possible that thin Stairway Sandstone may be subcropping at these areas.

<u>Carmichael Sandstone</u> Oc

Name derivation: The Carmichael Sandstone is defined and named in Wells et al.,1970. The type-section is in the George Gill Range.

Distribution: The Carmichael Sandstone occurs on the northeastern edge of *Angas,* and in the belt of outcrop that stretches between the Kernot and Basedow Ranges. *Ebenezer:* The Carmichael Sandstone occurs in isolated outcrops in this map sheet: three 4 km to the north of the Basedow Range, three just to the south of the range, and one long outcrop in Murphy's Range, 25 km southwest of Mount Ebenezer homestead.

Thickness: *Angas:* The broadest outcrop is that 10.5 km west of Angas Downs homestead, however that outcrop is heavily folded. The broadest unfolded outcrop (site 1151) gives a true thickness of 140 m. *Ebenezer:* The broadest outcrop is the curved hill south of the Basedow Range (in the centre of Imanpa Community). This outcrop gives a maximum true thickness of 300 m, however it is disrupted by folding and faulting and the figure may not be accurate. In Murphys Range true thickness as shown by outcrop is 40 m.

Airphoto expression: The Carmichael Sandstone shows as narrow but generally prominent ridges. They are red-brown in colour and are often distinctively striped by lines of vegetation growing along bedding planes. The ridges to the north of the Basedow Range are hidden from view (on the ground and in the air photos) by sand dunes.

Outcrop style: This unit can form prominent hills and strikeridges, up to 50 m high; it also may form low ridges of poor or rubbly outcrop. Because of the prevalence of crossbedding, rubbly disrupted outcrop is more common than might be expected. Outcrop is usually a distinctive red-brown colour, and outcrops of this unit are more prone to be covered in drifts of red sand than any other pre-Cainozoic unit.

Lithologies: The Carmichael Sandstone is a uniform slightly kaolinitic friable quartz sandstone, fine to medium-fine grained. Outcrops commonly exhibit planar crossbedding. Crossbeds may either weather out as separate forsets, or appear as mm- or cm-scale layering within the 10 cm to 1 m beds. The most characteristic colour is a dark red-brown (fresh and weathered surfaces); however colours range from white to orange or purple, and a white blaze of more highly kaolinitic sandstone can sometimes be seen. Occasional symmetrical ripple marks are preserved. Dark, thin layers seen at the base of some crossbed forsets may be heavy mineral layers. Thin-section S1061 shows quartz and some weathered feldspar grains, cemented by both quartz overgrowths and iron oxides; the iron oxides tended to be concentrated in 2-3 mm layers.

Structure: *Angas:* The Carmichael Sandstone is occasionally displaced (on a scale of metres) by local faulting, (e.g. the outcrops 8 km southwest of Angas Downs homestead). A small section of outcrop is overturned at site 1112 (9 km southeast of Angas Downs homestead), and outcrop is heavily folded 10.5 km west of Angas Downs homestead. Slickensides are common near both folds and faults. *Ebenezer:* The rocks of this unit become slickensided and sometimes fractured near folds and faults. The most massive outcrop of the Carmichael Sandstone, the semicircular hill at Imanpa Community (sites 1060, 1061) is both folded and faulted. Its circular shape is mimiced by other outcrops nearby (Oc to the west, Pzm to the north and southwest). The Mereenie Sandstone to the north (sites 1062, 1064) is out of stratigraphic sequence (since Stairway Sandstone occurs further north again). The outcrop pattern and stratigraphic reversal in this area indicates some sort of structure (possibly diapiric?) hidden beneath the Cainozoic.

Relationships: The Carmichael Sandstone is conformable over the Stokes Siltstone and unconformable beneath the Mereenie Sandstone (Wells et al., 1970). Outcrop is poor and no direct relationships are observed, however airphoto trends are consistent with the relationships as described above.

Remarks: A strong resemblance exists between the Carmichael Sandstone and the Mereenie Sandstone. Differentiating characteristics include crossbed direction and bimodal size distribution of frosted grains (M. Owen, B.M.R., pers. comm. 1987). However, outcrop is frequently too poor to examine the former, while the latter may not always be present. In this map sheet, dubious outcrop was assigned according to colour and general "feel"; and thus not all outcrops are expected to be correct.

Siluro-Devonian

Mereenie Sandstone Pzm

Name derivation: The Mereenie Sandstone was first described in the George Gill Range by Chewings (1894). Madigan (1932) and Prichard and Quinlan (1962) gave the unit its present name.

*Angas:* only one outcrop exists in *Angas:* site 1298, 30 km southwest of Angas Downs homestead. It gives a true thickness of 55 m, and shows on the airphoto as a narrow strike-ridge, the same colour as the surrounding sand. It has a fragmented rubbly outcrop with occasional recognizable crossbeds. The rock is a slightly kaolinitic quartz sandstone, pale brown with several white areas, and both hand specimen and thin-section S1298 show a bimodal grainsize population. The outcrop has been assigned to the Mereenie on the basis of this bimodality. The Mereenie Sandstone unconformably overlies the Carmichael Sandstone (Wells et al., 1970). Here the Carmichael Sandstone does not crop out between the Stairway Sandstone to the south and this outcrop; it may be masked by sand or be missing altogether.

*Ebenezer:*

Distribution: Outcrops of the Mereenie Sandstone occur at Imanpa Community, 5 km southwest of the Community, and one tiny outcrop (masked by a sand dune) 6 km northeast of Mount Ebenezer homestead.

Thickness: At site 1402, the true thickness as shown by the outcrop is (100m x sine 12) m.

Airphoto expression: The outcrops in Imanpa Community (sites 1062, 1064) are strongly outcropping red-brown hills with white blazes on their sides. They are partially masked by Cainozoic sediments. The outcrops to the southwest of the Community (sites 1137, 1138, 1139, 1402) are poor and only visible as lineations, with the exception of one grey strike-ridge (site 1139).

Outcrop style: As with the Carmichael Sandstone, the prevalence of crossbeds often results in a disrupted and rubbly outcrop. Sites 1062, 1064 are strongly outcropping; these are both thick and somewhat protected by Cainozoic units.

Lithology: The Mereenie Sandstone is a kaolinitic finegrained quartz sandstone commonly displaying crossbeds, either as observable foreset units (e.g. the 3 m crossbeds at site 1139) or as cm-scale layering within isolated rubble. The rock may be red-brown, similar to the Carmichael Sandstone, but in this map sheet it tends to contain more pale colours: white and grey are common, and other colours include pink, orange, and dark red-brown. The rocks may contain a bimodal size population of rounded and frosted grains, which is typical of the lower Mereenie where it overlies the Carmichael Sandstone (M. Owens, B.M.R., pers. comm. 1987).

Structure: These outcrops of the Mereenie Sandstone are folded into semicircular hills or low ridges. In addition, sites 1062 and 1064 are between outcrops of the Carmichael Sandstone to the south and the Stairway Sandstone to the north; they are out of stratigraphic order. There are strong indications of some sort of structure (possibly diapiric?) hidden beneath the Cainozoic.

Relationships: The Mereenie Sandstone unconformably overlies the Carmichael Sandstone (Wells et al., 1970). No direct relationships are observable on this sheet, either in outcrop or on the air photo.

Comment: The Carmichael and Mereenie Sandstones are hard to differentiate (see Carmichael Sandstone, Comment). These outcrops all posses the bimodal grainsizes and/or the rounding and frosting which are characteristic of the Mereenie Sandstone. Other outcrops lacking these features may have been wrongly identified as Carmichael Sandstone.

Devonian

Finke Group

Nomenclature: Chewings (1914) used the term "Finke River Sandstone or series" to describe sediments cropping out in the Finke River area. The name Finke Group is defined in Wells et al. (1970).

Distribution: The Finke Group has a somewhat limited distribution and occurs in the southeast of the Amadeus Basin. It crops out on the Finke and Kulgera 1:250 000 sheets and Wells et al. (1970) state that it underlies large areas of Permian and Mesozoic rocks in the McDills and Hale River 1:250 000 sheets.

Age: The Finke Group interfingers with and correlates with the Late Devonian to ?Carbonigerous Pertnjara Group (Wells et al. 1970). Palynological identification of samples from teh Langra Formation and the Horseshoe Bend Shale from NTGS stratigraphic hole K3 (*Sentinel Bore* 1:100 000 sheet) indicates an age of late Givetian to early Frasnian; that is close to the Middle / Late Devonian Boundary (Dettmann and Playford, 1989, in the Kulgera Data Record).

Constituent Formations: The Finke Group consists of the Polly Conglomerate, the Langra Formation, the Horseshoe Bend Shale, and the Idracowra Sandstone, from oldest to youngest. Of these, only the Horseshoe Bend Shale crops out on the map area, with the Langra Formation probably occurring as subcrop.

Thickness: The Finke Group is 460 m thick in outcrop and 915 m thick in the McDills No. 1 well (Wells et al. 1970). In NTGS stratigraphic hole K3 the section from base to the

Cainozoic unconformity is 215 m. No thickness can be determined elsewhere in the map area due to the poor outcrop.

Structure: The Finke Group is essentially flat-lying in the map areat. However, trend-lines of shallowy subcropping Horseshoe Bend Shale which show on air-photos of some playa lakes indicate gentle dome-and-basin folds and some minor faulting. Dips in the core from NTGS stratigraphic hole K3 range from 0-30°; however crossbedding is fairly common throughout the core, and the higher dips are probably depositional rather than structural. The dip of 10° seems to be fairly consistant.

Correlations: The palynoflora described from both the Langra Formation and the Horse-shoe Bend Sahle in the NTGS stratigraphic hole K3 suggests correlation with the Parke Siltstone, the basal formation of the Pertnjara Group (Dettmann and Playford, in the Kulgera data record).

Relationships: The Finke Group unconformably overlies Precambrian basement and Ama-deus Basin units, and is unconformable under the Permian and the Mesozoic on the Finke 1:250 000 sheet (Wells et al. 1970). In hole K3, the Finke Group is unconformable on the Inindia Beds and is overlain by Cainozoic sediments which are replaced by Quaterna-ry calcrete (Kulgera Data Record). Given the wide distribution of this group on the Kulgera 1:250 000 sheet, it probably also unconformably overlies the Ordovician Larapin-ta Group.

Remarks: The 1965 edition of the Kulgera 1:250 000 sheet shows significant outcrop of the Mesozoic (the Rumbalara Shale and the De Souze Sandstone). In view of the dating done on the NTGS stratigraphic hole K3, these outcrops are now considered to be Finke Group.

<u>Langra Formation</u> Dn

Name derivation: The Langra Formation is named after Langra Well in the Finke River (Polly Corner - Horseshoe Bend area) and is defined in Wells et al. 1966.

Distribution: The Langra Formation does not crop out in the map area, but occurs as subcrop. In NTGS stratigraphic hole K3, the Langra Formation occurs from approximately 137 m, down to its erosional base at 235 m. In view of this significant thickness, and the position of this drillhole on the far wetern edge of the Kulgera 1:250 000 sheet, it is suggested that the Langra Formation may occur as subcrop throughout much of the sheet.

Thickness: The Langra Formation is approximately 100 m thick in drill hole K3.

Lithologies: At the base, 6 m of interbedded fine conglomerate, coarse sandstone, and fine sandstone shows some resemblance to the underlying Inindia Beds in colour and clast composition. This is overlain by 45 m of fine to medium-fine sandstone, white to pale brown, containing well sorted and well rounded clasts of quartz and feldspar; occasionally clayey. Thin section K3-12 (depth 188.5 m) showed quartz (40%), plagioclase (almost totally weathered to clays, 30%) and K-feldspar (30%), with thin rims of calcite around the grains and occasional patches of calcite filling intergranular spaces.
Overlying the sandstones, from 183-137 m, is a sequence of sandstones as above, interbedded (on a sclae of 0.5-1.5 m) with brown, green, or grey shales and wackes. These may show disrupted bedding, load casts, and scours; biotite is common along partings. The top of the formation is placed at the top of the last major sandstone bed in this sequence (137.35-139.35 m).

Structure: Dips in the core vary from 0-30°; the core commonly shows crossbedding, and the higher dips are probably attributable to this. Dip due to folding is more likely to be on the order of 0-10°.

Relationships: The Langra Formation unconformably overlies the Inindia Beds and is gradiational upwards into the Horseshoe Bend Shale.

Correlations: See Finke Group, Correlations.

Horseshoe Bend Shale Dh

Name derivation: The Horseshoe Bend Shale is defined by Wells et al. (1966), with the reference area at Horseshoe Bend on the Finke River.

Distribution: The Shale occurs broadly through the central and southern sections of *Angas* and *Ebenezer*. No outcrop or shallow subrop of shale was noted north of the major outcrop belt (the Kernot and Basedow Ranges, and the outcrops stretching between them ). The Horseshoe Bend Shale does not crop out in *Sentinel Bore* but occurs as subcrop. In the NTGS stratigraphic hole K3, the shale occurs between the depths of 15 m and approximately 137 m. In view of this significant thickness, and the position of this drillhole on the far western edge of the Kulger 1:250 000 sheet, it is suggested that the shale may occur as subcrop throughout much of the sheet.

Thickness: This unit is 122 m thick in NTGS stratigraphic hole K3.

Airphoto expression: *Angas:* The Horseshoe Bend Shale is usually masked by calcrete, sand, or both; or by playa lake sediments. On some playa lakes where sediments are thin, or where differing porosities of shale beds influence surface evaporite deposition, bedding trends are visible on airphotos. *Ebenezer:*The Horseshoe Bend Shale appears as dark brownish-grey low irregular mounds with common white blazes in the flat plains south of Mount Ebenezer homestead. These outcrops are associated with, and partially masked by, various duricrusts. The distinction between outcrop and gibber is a fine one; much of what appears to be outcrop may also be gibber transported from a local source by sheetflood. In the playa-lake belt, outcrop is almost totally masked by calcrete and / or sand.

Outcrop style: The Horseshoe Bend Shale crops out very poorly, and is best seen in gullies, or scarps where it is protected by overlying sediments or duricrusts. It is frequently masked by these overlying units, which include calcrete and sand in the playa lake belt, and silcrete, talus, and Tertiary sediments in the area south of the Basedow Range. The shale is frequently fractured into small blocks, which readily disperse to form gibber pavements. In areas unprotected by overlying units, "outcrop" may consist of a gibber pavement with rare patches of in-situ shale emerging 1-2 cm above the pavement. The darker-coloured shales (Fe-impregnated?) are most likely to form such pavements.

Lithologies: *Angas:*The Horseshoe Bend Shale occurs as shale (often micaceous) or occasionally siltstone, with rare white quartzose fine sandstone interbeds. It is typically mottled brown and kakhi green, but may also be pale green, purple, ochre yellow or white. The shale is also found at shallow depths (0-50 cm) beneath the playa lake sediments, wehre it appears as blocky, sometimes hard or stiff clays that break into chips when dug; this grades upwards into wetter and less dense playa muds. Shale in scarps may be damp, with halite efflorescense; dried shale surfaces may show loose dessication cracking in the disaggregated clays. *Ebenezer:* The Horseshoe Bend Shale contains shale, siltstone, and fine sandstone. The shale is probably most abundant but it shows the poorest degree of outcrop. Typically it is red-brown and grey-green; other commonly occurring colours are ochre yellow, white, and purple. Fe-oxide impregnated shales may be a dark purple-brown or black. In good outcrop, soft-sediment deformation structures, Leisegang rings, and micaceous partings can be seen. *Sentinel Bore:* This formation is charcterised by red-brown and green shales sometimes grey or tan, often showing biotite or less commonly muscovite along partings. The shale may occur as 1-5 m beds on its own, or may be slightly silty or sandy (clay wacke or sandy wacke in the drilling log, Kulgera Data Record). Most commonly, it is thinly interbedded ( on a scale of 1-20 mm) with white fine sandstone. Load casts, soft sediment deformation, microfaults, mudcracks, and ripple cross-lamination occur throughout. Occasional vugs may be filled with calcite and / or euhedral transparent gypsum crystals. Occasional beds (1-4 m) of siltstone or fine sandstone also occur. Thin-section K3-13 (depth 136.6 m) of an interbedded shale and sandstone interval, shows micacous shale with some quartz clasts, alternating with calcite-cemented micaceous sandstone similar to the sandstone of the underlying Langra Formation.

Structure: The Horseshoe Bend Shale is essentially flat-lying, however trends discernable on airphotos show gently dome-and-basin folding and minor local faulting. In NTGS stratigraphic hole K3, dips of up to 30' probably reflect depositional conditions; an estimated 0-10' dip is given for the structural component of bedding inclination.

Relationships: The Horseshoe Bend Shale is gradational downwards into the Langra Formation in K3, and the boundary in this core is placed at the base of the lowermost major interbedded shale, siltstone, and sandstone (137 m). The Shale is overlain by calcrete replacing Cainozoic sediments; calcrete has formed around shale chips (regolith) at the top of the shale (15 m).

Correlations: See Finke Group, Correlation.

Cainozoic

?Tertiary

Tertiary sediments Ts

Distribution: isolated outcrops of ?Tertiary sediments occur both north and south of the main outcrop belt (Kernot to Basedow Ranges). Tertiary sediment outcrops are small and are generally found near or flanking pre-Devonian outcrops. Rare isolated outcrops also occur, in the area 0 - 6 km south of Mount Ebenezer homestead, and some outcrops are revealed in a dissected area bordering a playa lake 15 km southwest of Mount Ebenezer homestead.

Thickness: The sediments are essentially flat-lying with neither exposed bottom nor preserved top, so true thickness is hard to estimate. The highest hill with Ts outcrop is site 1333 (16 km southeast of Angas Downs homestead) is approximately 10 m high; scree around the base disguises the extent of underlying Inindia Beds. Visible thickness in

*Ebenezer* ranged from 0.5-3.0 m.

Airphoto expression: Tertiary sediments are often one of the components of mesas (old land surfaces) attached to or near strongly outcropping older rocks. However, the steeply sided flat-topped character of these old land remnants probably owes more to the duricrust which usually caps these sediments. The sediments on their own have very little photo expression, except occasionally as low rises covering, and blurring the outcrop trends of, older outcrop. White blazes may occur on scarp faces.

Outcrop style: Outcrop is often poor; the sediments are best seen in gullies or scarps, or in freshly-broken surfaces of partially silicified horizons. The "valley fill" unit often occurs as dark brown cliff faces, highly fractured and crumbly. The fine sandstone unit may also occur this way. The ?Eocene unit is generally only seen as remnant pebbles lying on the ground, except where silicified.

Lithologies: The "Tertiary sediments" unit is a basket classification containing many disparate sediment occurrences. Lithologies are discussed according to 1:100,000 sheet.

*Angas:*Two types of Tertiary sediments are found on *Angas*: the fine sandstone unit and the ?Eocene unit.

The fine sandstone unit consists of white quartzone fine sandstone, sometimes silty or kaolinitic, sometimes friable, and commonly partially silcified. This unit may be more widespread in a fully silcified form; that is, it may form the host for some of the silcretes. This unit is somewhat more cohesive and lithified than other Tertiary sediments; the possiblity exists that rather than being Tertiary, it may be the Devonian Langra Formation lapping on to pre-existing topographic highs. this unit is also found in the Ebenzer 1:100 000 sheet.

The ?Eocene unit contains small (0.5 - 3 cm) pebbles, generally well-rounded and often exhibiting an unusually high degree of polish. The pebbles include vein quartz, Amadeus

Basin sandstones, and and silcrete. This unit is most often partially or wholly replaced by silcrete, which replaces the (unknown) matrix and leaves the pebbles to weather out and be found on the ground surface. It is possible that where this unit is mapped wih the matrix preserved, the pebbles are not so evident and it is mapped as something else (e.g. the fine sandstone unit). Thin-section S1152 shows silcrete pebbles in a silicifed quartz siltstone / sandstone matrix. This unit also occurs in *Ebenezer*.

*Ebenezer:* Four types of sediment occur on *Ebenezer*. Of these, the most common three (no.'s 1-3 below) sometimes resemble each other closely and may be different aspects of the same sedimentation event, or be otherwise related. Outcrop is too poor and isolated to draw definite inferences.

(1) The fine sandstone unit consists of white fine-grained quartz sandstone, silty or kaolinitic, rarely up to medium-grained. It is usually capped by silicrete and is often partially silicified, it is probably a common host for siliccret although relict sedimentary featrues are not usually visible in the silcretes. It generally appears more cohesive than other Tertiary sediments, although it sometimes occurs in messy-looking brown scarps, similar to the "valley fill" unit. In at least one site (1075, 10 km northwest of Mt Ebenzer homestead) the sediment is full of root tubules. Where best consolidated the sandstone resembles some Amadeus Basin sandstones, although its outcrop pattern (flat-lying rather than a narrow belt of dipping rocks) preculdes it being Ordovician or earlier. However, some outcrops marked Ts may in fact be the edges of the Langra Formation lapping on to the Basedow Range. This unit also occurs in the Angas 1:100 000 sheet.

(2) The "valley fill" unit (field name only) crops out as distinctive red-brown cliffs of rotten crumbly fractured material. The rock is stained red-brown to brown or black. Fresh surfaces are very hard to find, as the rock is so pervasively broken, but when visible they show whitish siltstone or medium to coarse sandstone in a silty matrix. Root tubules may be present.

(3) The ?Eocene unit is characterised by small (0.5 - 3 cm) pebbles, generally well-

rounded and often exhibiting an unusually high degree of polish. The pebbles include vein quartz, silcrete, and Amadeus Basin rocks. This unit ismost often partially or wholly replaced by silcrete, which replaces the matrix and leaves the pebbles to weather out and be found on the ground surface. In some places, the matrix appears to be, or be similar to, the fine sandstone unit. This unit also occurs on the Angas 1:100 000 sheet.

(4) The gastropod marl found at site 2200 (25 km south of Mt Ebenzer homestead) crops out in a gully, and is topographically between two horizons of the chalcedonic calcrete Qc. This finegrained rock may originally have been a mudstone or a marl, and is now at least partially replaced by calcrete. A course sandstone occurs above the marl.

Correlations: It has been suggested that the ?Eocene unit may correlate with the Eocene Eyre Formation in South Australia which also possesses characteristic highly polished pebbles (M.J.Freeman, pers. comm. 1987).

The gastropods in the marl at site 2200 are probably *Rivisessor sp.* of Micocene age (N.H. Ludbrook, S.A. Dept. of Mines and Energy, pers. comm. 1987). Dr.Ludbrook suggests that the marl containing the gastropods is an equivalent of those sediments deposited in a regressive Miocene lake system (Ambrose and Flint 1981), including limestones in the Billa Kalina area and the Etadunna Formation.

Remarks: The presence of silcrete pebbles in a silcretized sediment is clear evidence of at least two episodes of silcrete formation in the area.

These sediments have not been dated; they are assigned to the Tertiary by convention and by virtue of their position as relict land surfaces.

Undetermined

Talus and scree Czt

Distribution: talus fans and their dissected remnants flank the Kernot and Basedow

Ranges, the strongly outcropping Inindia Beds to the south of the Basedow Range, and small outcrops in the Murphy's Range area to the south..

Thickness: Although the talus fans may be as much as ~ 20 m high close to the source of the sediment, the common occurence of thin lines of outcrop poking up through the talus suggests that the fan may often be less than 3 m thick. The talus fans overlie Amadeus Basin rocks and protect them from erosion.

Airphoto expresssion: The talus fans form moderately dark brown slopes, sometimes partially covered by red sand. The fans slope up towards high outcrop (e.g. the Basedow Range); they may join onto the outcrop, or be isolated from it by modern drainage. To the east of Imanpa community, the fans have been dissected and eroded down to irregular low hills. The dark colour remains, but the drainage patterns and landform shape are quite different from the fans to the west. (See Remarks)

Outcrop style and lighology: The talus fans consist of slightly rounded pebbles and cobbles of local rock in a sandy clayey matrix. The pebbles often show a degree of desert varnish. Finer sediments on the surface may be washed away, leaving a rough rocky pavement. The fans are generally flat slopes which may merge with the downhill Cainozoic unit, or may terminate in definate convex slope breaks.

Relationships: *Angas:*The talus fans overlie Amadeus Basin rocks, and where shallowly subcropping, these rocks may show through. The fans are frequently capped silcrete; and at site 1116, southeast of Kernot Range, Winnall Beds talus is cemented by ferricrete. *Ebenezer:* The talus fans overlie Amadeus Basin rocks. They are commonly capped by silcrete; at one site (1098, 7 km west-northwest of Imanpa community) the silcrete clearly cements the talus, but generally the silcrete shows no relict features and may well have replaced some later sediment. Quaternary calcrete commonly lies beneath the surface of the talus fans; it is exposed in gullies or scarps. In the eastern eroded section, the fans have been stripped down to such a level that calcrete scarps cap the talus.

Ferricrete Czf

*Angas:* Small occurrences of ferricrete are found at sites 1116, 1304 and 1306, all just southeast of the end of the Kernot Range. The ferricretes are approximately 3 m thick; their grading downwrds into parent rock makes thickness determinations slightly arbitrary. The largest outcrop shows on the airphoto as a flat duricrust surface with an unusual dark-red tone; smaller outcrops do not show on the photo. At site 1116, dark iron-oxides cement Cainozoic talus of Winnall Bed origin; at site 1304 the ferricrete overprints Carmichael Sandstone. Here, rubbly outcrop of Carmichael Sandstone becomes more and more iron-stained towards the hilltop, and the hill is crowned by highly polished angular ironstone rubble.

Another small occurrence at site 1319, 16 km west of Angas Downs homestead, appears to show in thin section that a patchily silcretized Tertiary sediment was replaced by ironoxides. However, this small outcrop was found amongst the poorly outcropping Inindia Beds, which contain both cherts and ironstones; it may not be Cainozoic at all. The late stage chalcedony filling pore spaces in thin-section S1319 is probably relted to nearby Quaternary calcretes (q.u.).

*Ebenezer:*Small isolated patches of ferricrete occur along the south of the Basedow Range east of Imanpa Community, south of Mt Ebenezer homestead, and in the dissected playa margin 15 km southwest of Mt Ebenezer. These ferricretes are generally too small to be visible on air-photos although their presence may be indicated by a dark red-brown tone. They crop out as hills or scarps of often glossy rubble; or amongst hills or scarps formed by the dominant Cainozoic unit. they consist of finegrained ironstones, ferruginised sandstone, or iron-oxide cemented silcrete breccia.

Relationships: Iron oxides are seen staining or replacing: the Horseshoe Bend Shale (sites 1063, 1079, 1182, 1387; 11 km northwest, 1 km east, 15 km southwest, 7 km north-east of Mt Ebenzer homestead respectively); Inindia Beds shale (site 1382, 10 km north of Mt Ebenezer); and Tertiary sediments (sites 1079, 1180, 1372; 1 km east, 15 km southwest, and 8 km northwest of Mt Ebenezer homestead).

The ferricrete is almost always found in close association with silcretes, either laterally (site 1382, 10 km north of Mt Ebenzer homestead) or vertically (site 1387, 8 km north-east of ditto). The ferricretes may appear to predate the silcrete breccia is cemented by iron oxides. At site 1182, the Horseshoe Bend Shale appears to be replaced by both silcrete and ferricrete in different areas. The question is complicated by the presence of two generations of silcrete in the area (see Tertiary sediments, Remarks); and there may also be more than one generation of ferricrete. In view of the close association between the silcretes and ferricretes, it is also a strong possiblity that they form synchronously under differing local conditions.

Silcrete Czs

Distribution: There are major occurrences of silcrete on the northern and southern flanks of the Kernot and Basedow Ranges. Smaller more isolated outcrops occur north, east, and south of the Basedow Range, in the outcrop 10 to 20 km west-northwest of Angas Downs homestead, in the outcrop belt between the Kernot and Basedow Ranges, in the Murphy's Range area, and in the area just south of Mt. Ebenezer homestead.

Thickness: Outcrops on hill-crests appeared to be 1 - 2 m thick; greater thicknesses may have been concealed by the ground surface.

Airphoto expression: in many cases, silcrete occurrences were small and did not show on air photographs. Larger outcrops showed as low mounds or gently flat slopes, often greyish or a darker red-brown than nearby Qs. Where close to high outcrop (such as the Basedow Range) they occur as flat slopes well above the present-day ground surface (mesas); distally (such as the outcrops near Mt Ebenzer homestead) they form low irregular hills. White blazes on the scarps of mesas are often casued by underlying calcrete, but many also be formed by white silcrete scree.

Outcrop style: *Angas:* The silcrete occurs as rubble or as pavements of large boulders (≤ 1 m ), generally on hill crests. It often displays a coarse columnar texture; this texture may also be displayed in associated partially silcified rocks. It is also frequently massive; and candle-dripping textures and closely allied pebbly / nodular textures are also found.

*Ebenezer:* Although in the distal outcrops (near Mt Ebenezer homestead) the silcrete may occur at or just below ground level, the most common form of outcrop is as rubble on hillcrests and flat mesa slopes. The rubble varies from cobbles to boulders up to 1 m in diameter; rarely thick silcrete pavements may also be found. Silcrete rubble may show signs of localized transport (faint to moderate rounding) but the deposits are generally in situ.

The silcretes display variety of surface textures. Massive silcretes are common, as are pebbly conglomeratic textures; in some sites along the south of the Basedow Range (e.g. site 1064 near Imanpa Community) pebbly textures at scarp bases graded up to massive textures. in thin-section 1365A, a typical pebbly silcrete, the pebbles appear to be nodules of more complete silicification, rather than any primary sedimentary feature. Columnar texture is also found in silcrete scarp faces; this ranges from coarse, poorly defined texture to very fine columns (0.3 - 1 cm wide, 20 cm high). Candlewax and dogstooth structures also occur. The silcretes were occassionally vuggy.

Lithologies: The silcrete (also referred to as "grey billy" in earlier editions of the map sheet) is white, cream, or pale grey, often stained orange or dark red-brown by iron oxides. It is generally fine-grained and may contain clear quartz crystals (products of silcification, or remnant clasts) which give it a sugary appearance. It fractures sub-conchoidally. Where host rocks (particularly Tertiary sediments) are only partially silicified, the features described above may be seen as an outside rind, with original sedimentary textures remaining within; or silicification may be patchy.

Rarely, variations in silcrete lighology are seen. Extremely fine-grained billy resembles noraml billy but the textrue is homogenous and very fine; it shows a more strongly conchoidal fracture. This is referred to as porcellinite; both porcellinite and billy can occur together in the same outcrop. Some porcellinites show a brecciated or psuedo-brecciated texture, with angualr opaque blocks apparently floating in a clear matrix. Thin-section S 1048, one such porcellinite shows virtually 100% microquartz, with rare relict sedimentary quartz clasts.

Although usually pale, silcrete often weathers to orange-brown. Light to heavy staining by ironoxides is common; such staining may be outside only, inside only, or throughout the fabric of the silcrete. Rarely silcretes appear to be cemented by ferricretes. Terrazo-type silcrete also occurs rarely. This very finegrained silcrete often shows bright colours (white, red-brown, and ochre yellow) and often shows a brecciated or psuedo-brecciated texture.

Relationships: *Angas:* The Cainozoic silcrete is seen forming on Tertiary sediments, and on fine sandstones / siltstones of the Inindia Beds and (rarely) the Stokes Siltsone. No pattern was seen which lined host rock to silcrete type.

*Ebenezer:* Silcrete is most commonly hosted by Tertiary sediments; this is evidenced by associated partially silicified rocks, and by the occurrence within silcretes of rounded highly polished pebbles. Often, the total thickness of Tertiary sediment will be silicified, leaving a silcrete sitting directly on other rock. This may confuse the question of what has hosted the silcrete. Silcretes are also formed on or hosted by talus (Czt), Horseshoe Bend Shale, Stairway Sandstone, and Inindia Beds. No pattern was seen which linked host rock to silcrete type.

Silcretes are commonly stained by iron oxides, and the rare outcrops of ferricrete are invariably assocated with silcretes.

Outcrop and thin-section evidence seems to support both silcrete predating and postdating the ferricrete; it is a strong possiblity that they are synchronous (see Ferricrete, Relationships). Thin-sections S1356B and S1356C show silcrete with pore-filling chalcedony; iron oxide stains line vugs, post-dating the chalcedony. If the chalcedony is related to the calcrete Qc, which is possible considering the close association between Czs and Qc at that site, then some very late movement ofiron oxides is indicated.

The presence of calcrete beneath the silcrete should not be taken to indicate younger age for the silcrete; the law of superposition does not apply to duricrusts.

Correlations: Amongst the most common clues to the host rock of a silcrete is when highly polished pebbles of the ?Eocene unit of the Tertiary sediments are found scattered around (or in) a silcrete outcrop. Thses pebbles commonly include waterworn silcrete pebbles, indicating that at least 2 episodes of silcretization happened in this area. If the presence of these pebbles does indicate correlation of the Tertiary sediment with the Eocene Eyre Formation (M.J.Freeman, pers. comm. 1987), then the silcrete must be post-Eocene.

Autochthonous soils over subcrop Cz/s

Thin Cainozoic sediment deposits cover shallowly subcropping Amadeus Basin rocks. These sediments represent areas where the shallowness of the subcrop has (a) allowed contribution of local material to the makeup of the overlying sediments, and (b) prevented the establishment of a widespread functioning land system. On airphotos, subcrop trends are often clearly visible through a disorganized-looking and patchy ground surface. Pale portions of the airphoto tone reflect sand, scalded areas, claypans, minor calcretes, and local alluvium; dark areas reflect patches of gibber. These areas are frequently poorly vegetated, and may be cut by erosion gullies.

Quaternary

Calcrete Qc

Distribution: Calcretes occur widely throughout the map area, as patches extending in east-west belts amongst the outcrop in the north, and along the playa-lake belt to the south. Much outcrop is concealed by overlying sands (Qs).

Age: Previously, calcretes on the Kulgera 1:250 000 sheet had been divided into Quaternary calcretes and Tertiary limestones, on the basis of absence or presence of silicification (chalcedonic layers) within the calcretes. The presence of chalcedony was taken to indicate that a pre-existing limestone had been partially replaced during Tertiary silcrete formation (Wells et al. 1966). Recent thin-section work has indicated that the calcrete and chalcedony were precipitated simultaneously; and dating by electron-spin resonance in the same study has indicated ages of 22-27 000 ybp for vadose calcretes (see Environment of deposition, below) and 34-75 000 ybp for phreatic calcretes (Jacobson et al. 1988). These studies were done on calcretes in the Curtin Springs area, adjoining *Angas*.

Thickness: Calcrete scarps around playa lakes reach heights of up to 6 m, although underlying Horseshoe Bend Shale (hidden by scree) may account for up to 4 m of that height. Observed thicknesses of calcretes ranged from 0.5 - 3 m; cored drillholes K1 - K5 intersected up to 20 m of calcrete or calcareous earths (Kulgera Data Record).

Airphoto expression: Calcrete outcrops form low flat areas, high gently undulating uplands, or (around playa lakes) flat-topped benches with steep scarp slopes. They are grey in colour; the colour may be partially masked by red sands, or it may be quite strong and distinct. They grey colour is often mottled and vermiform (again, depending on the partially overlying sands). Small white blazes are common and are characteristic; these are rabbit warrens bringing fresh calcrete to the ground surface (the rabbits preferentially nest in calcrete areas). Calcretes are associated with subsidence dolines: areas where water ponding has caused dissolution of the underlying calcrete and subsidence of the ground. This encourages further water ponding, and so on. These dolines are shallow depressions, usually roughly circular, supporting unusually dense vegetation. The vegetation is generally mallee gums (*Eucalyptus spp.)* rather than the common mulga scrub (*Acacia aneura*). In some areas, calcretes have been dissected and eroded down, leaving isolated relicts and a disorganized-looking ground surface (the areas referred to with a subscript s on the compliation sheets). On airphotos, these areas are characterized by a less grey tone, or by many irregular white blazes (scalds). There are commonly sand dunes within these areas, but the sand dunes also are irregular, lacking the regular longitudinal or reticulate forms seen in sand dunes in Qs.

Outcrop style: Calcretes generally crop out as rubble, ranging from small (2 - 5 cm) pisolites and nodules (usually the remnants of a calcrete, found in an eroded area, subscript-s on the complilation sheets) through larger rounded nodules, up to large (10 - 30 cm) angular chunks. They may occur sparsely or densely. Thick tough laminar pavements are also common, and these often display solution pipes. At scarp edges, calcretes may form masses of closely-packed nodules; or laminar pavements may resemble bedding. Where veins and networks of chalcedony cut through the calcrete, the calcrete is preferentially weathered out, leaving vuggy, orange to black, very rugged surface. In eroded (subscript-s) areas, small calcrete nodules are scattered on the low ground surface, and remnant 1 - 2 m high hillocks of massive calcrete stand isolated at intervals of several hundred metres. These hillocks are crowned andmasked by sand dunes; the calcrete pavements are often only visible as you walk up the dune. The area just south of the Lasseter Highway, opposite the Imanpa turnoff, is a good example of this.

Lithologies: The calcretes display a variety of types, although in thin-section they seem to consist fairly consistently of finegrained calcite in nodular, spherically or amorphous textures, with larger sparry calcite crystals in veins and vugs. In two sections, the major mineral was dolomite rather than calcite. In hand-specimen, the most notable and characteristic type of calcrete is a dense, microcrystalline limestone, very homogenous and fine in texture, showing a splintery or sometimes subconchoidal fracture. It is commonly brownish pink in colour, although white, cream, tan, and dark purple-brown also occur. Chalcedony veins (0.1 - 10 cm) may occur within this type of calcrete; they do not appear to occur in association with any other calcrete type. Microcrystalline limestones may infrequently contain varying amounts of sand. Typical examples include samples S1008, S1032J, S1109, and S1195B.

A variety of less dense calcretes occur, often as nodules, laminar calcretes, or cemented-pisolite calcretes (where pisolites or nodules are re-cemented into pavements by later calcite; a reworked section of the calcrete horizon). These calcretes show various degrees of included sand; they frequently also contain desert-varnished pebbles (rounded, glossy, red-black pebbles); the calcite matrix is usually coarser than the microcrystalline limestones. The microcrystalline limestones may be associated with these less dense calcretes, as nodule cores or pisolite elements.

A powdery, chalky, white, non-dense calcrete commonly coats other calcrete types, and contributes largely to the messy and indeterminate appearance of many scarp faces. It is likely to be a recent weathering feature.

Of particular interest are the grey calcretes that rarely occur throughout the sheet area. These range from pale grey to black. They almost invariably occur as rubble (no matter how good the surrounding outcrop) in a well-defined circular patch. Four or five such patches will occur within a 50 m area, then there will be no further occurrence for kilometres. Two such grey calcretes, cemented-pisolite types, (S1221 and S1082D) show that the grey colour is diagenetic rather than primary; however the chalky calcrete coating it was white as usual. X-Ray diffraction analysis (samples S1109B, S1216A) showed no unusual mineral components (e.f. a control S1216B, a typical microcrystalline limestone).

Environment of deposition: Two types of calcrete are included in this unit: an earlier phreatic calcrete (34-75 000 ybp) and a later vadose calcrete (22-27 000 ybp) (A. V. Arakel, pers. comm.). The phreatic calcrete formed beneath the water table, along palaeodrainages and basin axes. It is historically connected with the playa lake chain; the source of its water is the whole catchment area. The vadose calcrete formed in the zone of evaporation above the water table; the water source was local vertical water movement through the soil profile (see Carlisle 1978).

Although the two calcretes have different ages, origins, and economic implications, no attempt is made to separate them on the map. The vadose calcrete commonly overprints the phreatic, and definite distinction can often only be made on the basis of thin-section; impractical on this scale. Generally speaking, most calcrete outcrop in the map area will have a phreatic component.

Relationships: Calcretes replace Cainozoic sediments; they overlie the Horseshoe Bend Shale throughout the map sheet.

Correlations: Limestones with chalcedonic layers or cappings are common in the inland sections of Australia, (for example, see Grimes, 1984). These are often stated to be Tertiary; it is possible that many or most of them may in fact be Quaternary. The closest equivalent in South Australia may be the Mount Willoughby Limestone, although no work has been done during this mapping program to establish a connection.

Economic significance: The Quaternary calcretes and the sediments they replace are the only reliable aquifers on the Kulgera 1:250 000 map sheet. Specifically, the phreatic calcretes carry generally good supplies of good water; the vadose calcretes may carry little water or poor quality water. This is especially important since there is no significant surface drainage in the map area. Rainwater infiltrates directly into the aquifer; surface runoff is localized and sporadic. As well as the obvious importance to the cattle and roadhouse industries, the calcrete aquifer carries water to the playa lake system, which is potentially economic for exotic evaporates.

<u>Talus and colluvium</u> Qt

Gentle slopes of locally-derived rock rubble, sand, and clay descend from the Kernot and Basedow Ranges. These talus fans are not cut or dissected by modern day drainage (i.e. they are not relict surfaces); they are usually topographically lower than nearby Czt talus fans.

<u>Playa sediments</u> Qp

Distribution: A chain of playa lakes extends in an east-west belt across the centre of the map area. This chain starts in the Curtin Springs area (west to northwest of the most westerly playa on the Angas sheet) and extends eastwards into the Finke 1:250 000 sheet.

Thickness: Playa sediments have not been drilled in the map area. Hand sampling showed some playas with less than 15 cm of sediment overlying shale, and the several lakes had sediments to ≥ 1 m (the limit of sampling depth) (Wakelin-King, 1989). Thicknesses were highly variable from lake to lake and showed no particular pattern.

Airphoto expression: The playa lakes form flat-floored depressions with (generally) clearly defined edges. The playa sediments are dark grey (muds) with whitish streaks or patches (evaporates, chiefly halite), and some tan-brown patches (evaporates, chiefly gypsum). In some lakes, the banding of the colours reveals the bedding trends of the underlying Horseshoe Bend Shale.

Lithologies: The sediments in the playas consist of muds, unusually brown but sometimes mottled with green; evaporate crystals within the muds, unusually gypsum as small (≤ 1 mm) crystals which gives a sparkle to the muds; and evaporate crystals above the muds as a precipitated or effloresced crust of halite and other highly soluble minerals. A range of evaporate minerals is present, including magnesium and potassium sulphates and chlorides; full descriptions of mineral occurrences can be found in Wakelin-King 1989.

The playa muds often grade down into wetted Horseshoe Bend Shale, which occurs as damp stiff muds which break into chips when dug. Where shale was encountered during hand sampling, the area is marked on the compilation sheets as Qp / Dh.

Relationships: Playa sediments overlie, and are partially formed from, the Horseshoe Bend Shale. The shale also crops out under calcrete scarps along the edges of many playas. The calcretes act as aquifers and feed water into the playa lakes; this is the playas' major source of water.

Mineralisation: The playas are potentially economic for exotic evaporates (Wakelin-King, 1989); these evaporites are part of the present-day groundwater system and are therefore likely to be harvestable (that is, the deposit is probably renewable). Zeolites occur in the Curtin Springs area (Arakel, 1987) which suggests the possibility of zeolite potential on the Angas 1:100 000 sheet. These zeolites are probably related to palaeohydrological systems, and so are likely to be non-renewable.

Gypsiferous sands Qpg

Gypsiferous sands occur as benches around many of the playa lakes, or broader areas bordering playas or their rare associated watercourses. These sands are notably paler than Qs sands in airphotos, being light tan in colour. In outcrop, the sands are composed of small ($\leq$ 1 mm) gypsum crystals, mixed with varying amounts of clays, red quartz sand from the surrounding Qs, and occasionally calcite fragments from local calcretes. Rarely nodules of greenish celestite ($Sr\ SO_4$) are found up to 1 m deep in the gypseous sands. The sands are light brown, pale brown, to white where nearly pure. They feel less dense than quartz sand, and more "sticky". Gypcretes may also be found in these areas: pale frey duricrusts, irregularly outcropping, soft enough to be scratched by a finger nail, and showing microkarstic weathering. Sample S1233 (gypseous sand) showed gypsum with trace quartz and bassanite in X-ray diffraction analysis.

Gypseous sands at playa margins originate as precipitates from phreatic groundwater and may be later altered in the vadose zone (Jacobson et al. 1988). Wind-blown gypsum from the playa floor being deposited at the playa edge (lunettes) does not appear to be a major factor here, although this process has been seen to occur (Wakelin-King, 1989, site S2190).

Sheetflood plains Qr

Sandy sheetflood plains occur mainly in the northern half of *Angas* and in the western half of *Ebenezer,* either in their own right or combined with Qs. In air photo, they are red-sand colour, with distinctive swirling or arcuate patterns of vegetation. On the ground they form flat sand sheets populated by alternate thick groves and sparsely populated areas of mulga scrub (Acacia aneura). The sand is the red-stained, sometimes clayey, quartz sand, typical of the presently or previously mobile desert sands of Central Australia.

Although this distinctive airphoto pattern has in the past been described in terms of its lithology (e.g. "red-earth soil", Freeman, 1986), it may be more accurate to think of it in terms of its processes as a land system. In these areas, rainwater falling on the flat ground surface moves along the surface as sheetflood, pushing plant debris and seeds into arc-shaped mounds (Perry et al. 1962). Germination in these mounds gives the arcuate pattern seen on the airphotos. Qr is often found in the flat swales between sand dunes in the combined Qs, Qr areas.

Patches of gibber also occur sporadically within Qr. These stony pavements consist of dark red-brown, often highly polished, rounded pebbles to cobbles; they appear dark grey on airphotos.

<u>Sand</u> Qs

Sand dunefields and fields of sheet sands cover wide areas in the map area. Sand dunes can be over 10 m high; depth of sand below the surface is unknown, but is likely to be thin. In many places the sand sheet is visibly just a thin veneer over calcretes. On airphotos, the sand is a distinctive red colour. Dunes (where present) belong to the "longitudinal dune" type (Mabbut 1977). Although broadly longitudinal, however, the majority of dunes display a reticulate pattern on a narrower scale; so they may resemble a chain rather than a straight line. This is particularly marked where nearby outcrop interrupts airflow. The sand is the red-stained, sometimes clayey quartz sand which is typical of the presently or previously mobile desert sands of Central Australia.

Patches of gibber are also included in Qs. These pebble- to cobble-sized rounded rocks may be loosely scattered on the ground surface, or they may be closely packed to form a pavement. Where gibber patches are extensive, they appear dark grey on airphotos.

Gibber rocks are always iron-stained, and are usually a glossy dark red-brown to black. Sources of gibber include Amadeus Basin ironstones and quartzites, the Horseshoe Bend Shale, and silcretes.

Alluvium Qa

Significant surface drainage is absent in *Angas* and rare in *Ebenezer*; most water movement occurs beneath the ground in calcrete aquifers. Most surface water courses are erosional rather than depositional (e.g. the gullies found in many eroded areas, see Czt, Remarks) and are therefore not associated with deposited alluvium. Exceptions to this are Karinga Creek and the larger watercourses draining the eroded area south of the Basedow Range. These are depositing a significant although minor amount of thin sandy sediments immediately bordering the water courses.

STRUCTURE

An outcrop of Inindia Beds in the Murphys Range area is overlaid by younger units on either side; all three beds are roughly parallel in dip. This indicates that the Inindia and Winnall beds were overturned when the overlying Stairway Sandstone was deposited, suggesting some significant pre-Ordovician tectonism.

The Winnall beds in the Basedow Range are folded into a syncline, of which the southern limb is now faulted away. The fault runs along the southern margin of the Range, and is bedding-parallel to the Stairway Sandstone, which overlies it. Seismic sections (Weaks Petroleum) indicate shallow south-over-north thrusting, which must have been post-Ordivician at least. The Kernot Range is also minorly faulted along its southwest edge. Folding occurs throughout the rocks of the northern outcrop belt, including some very tight folding with major stratigraphic displacement west of Angas Downs homestead (especially 8 km northwest of the homestead; see Angas 1 compilation sheet.).

The Middle to Late Devonian Finke Group is mildly folded and faulted, but is essentially flat-lying. This lack of structure indicates that the affects of the Alice Springs Orogeny were not strong south of the Basedow Range.

## GEOLOGICAL HISTORY

Deposition of the Bitter Springs Formation in the late Proterozoic was followed by the deposition of the Winnall Beds and the laterally variable Inindia Beds. Tectonism followed, resulting in some folding, and uplift and erosion during which much of the Winnall Beds were removed. Thin units of the Larapinta Group were laid down in the Ordovician. Folding and south-over-north faulting occurred during the Alice Springs Orogeny. South of the main outcrop belt, the sandstones and shales of the Finke Group were laid down in the late Givetian-early Frasnian (i.e., close to the Middle/Late Devonian Boundary, ~360 million years), after the majority of the folding in this area had taken place.

No further deposition or tectonism is recorded in the map area until the Cainozoic. In the ?Tertiary, local fluvial and colluvial systems deposited a variey of sediments. Two are of note:

1. A ?fluvial fine sandstone which is characterised by rounded and highly polished pebbles of a previously existing silcrete, and resembles the Eocene Eyre Formation of South Australia.. This sandstone is generally replaced by a subsequent silcrete.
2. A marl, now replaced by calcrete, contains gastropods of possible Miocene age, and may be a correlative of palaeolake deposits such as the Etadunna Formation.

Silcretes and ferricretes of undetermined age relaced the Tertiary sediments, and were then uplifted and eroded into remnant landforms.

During the Quaternary, lakes in the Central Australian groundwater discharge zone (including Lake Amadeus and the playa lakes in *Angas*) received groundwaters from a wide catchment. Zeolites developed in lake sediments. Chalcedonic calcretes precipitated from the phreatic groundwater, most recently 34-75000 years before present. During a subsequent pluvial phase, the expanded freshwater lakes overflowed to a creek system (east of the map area), and localised erosion stripped calcretes and sediments in some areas. As the climate dried out again, the playas shrank to their present form, the groundwaters developed their present chemistry, and sand sheets and dunes assumed their rpesent form.

## ECONOMIC GEOLOGY

Sampling of the playa lake chain has shown that it is potentially economic for exotic evaporites, particularly potassium and magnesium sulphates and chlorides (Wakelin-King, 1989). Some potential for zeolites may also exist.

The Quaternary calcretes, in their role as aquifers, also exert a strong influence on the economy of the area. Surface watercourses are very rare, and the pastoral and hospitality industries in the area rely heavily on subsurface waters.

Phosphatic pebbles are present in the Stairway Sandstone, but in this area they are sparse and the unit itself is thin.

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