Petrology of the Late Proterozoic(?)- Early Cambrian Arumbera Sandstone and the Late Proterozoic Quandong Conglomerate, East-Central Amadeus Basin, Central Australia

Johnnie O. Phillips
Utah State University

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PETROLOGY OF THE LATE PROTEROZOIC(?) - EARLY CAMBRIAN ARUMBERA SANDSTONE AND THE LATE PROTEROZOIC QUANDONG CONGLOMERATE, EAST-CENTRAL AMADEUS BASIN, CENTRAL AUSTRALIA

by

Johnnie O. Phillips, Jr.

A thesis submitted in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

in

Geology

Approved:

Utah State University
Logan, Utah

1986
DEDICATION


TO MY PARENTS, JOHNNIE AND BETTY PHILLIPS, WHO SHARED THEIR LIVES WITH ME, I OWE MUCH. THEIR SUPPORT AND ENCOURAGEMENT THROUGH THIS TASK WAS SO PRECIOUS. THANKS MOM AND DAD FOR WHAT YOU HAVE GIVEN TO ME. GOD BLESS YOU! I LOVE YOU!

YVONNIE, JODY, TONYA, AMANDA, AND ELISABETH THANK YA'LL VERY MUCH! I LOVE YOU!!
... hide thy face from my sins, and blot out all mine iniquities. Create in me a clean heart, O God; and renew a right spirit within me. Cast me not away from thy presence; and take not thy Holy Spirit from me. Restore unto me the joy of thy salvation; and uphold me with thy free Spirit. Then will I teach transgressors thy ways; and sinners shall be converted unto thee. Deliver me from bloodguiltiness, O God, thou God of my salvation; and my tongue shall sing aloud of thy righteousness. O Lord, open thou my lips; and my mouth shall show forth thy praise. For thou desirest not sacrifice, else would I give it: thou delightest not in burnt offering. The sacrifices of God are a broken spirit: a broken and a contrite heart, O God, thou wilt not despise...

Ps. 51: 9-18
ACKNOWLEDGEMENTS

Dr. Robert Q. Oaks Jr. provided much encouragement, assistance, guidance, and significant insights through his comments, ideas, manuscript improvements, and long hours of laboring throughout the entirety of this project. He also arranged for the author's participation in this Amadeus Basin research. For all of these, a special word of thanks and appreciation is offered. Drs. Peter T. Kolesar and W. David Liddell served as committee members, and supplied many suggestions which improved the manuscript.

Magellan Petroleum Corporation supported the project by providing travel and field expenses, supplying field transportation and a field assistant, and making available to the author aerial photographs of the field area and many published and unpublished reports. They also covered expenses for thin section preparation and X-ray diffraction of the samples for this thesis, and for much of the cost for the manuscript preparation. The Department of Geology of Utah State University also provided financial support, during the preparation of the report, from a Department Assistance Grant received from Magellan Petroleum Corporation. Mr. Dennis H. Benbow suggested the project. He and Mr. Roy M. Hopkins, of Magellan Petroleum Corporation made much of the above mentioned support possible.

John Cullen, Neville B. Johns, Robert Liddle, Peter Kotz, Leon Amadio, James Deckelman, Ruth Sliep, and Mark Ferrell provided friendship, assistance, and hospitality while the author was in Alice Springs. A special note of thanks goes to John Cullen and Ruth Gardner.
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ABSTRACT

Petrology of the Late Proterozoic(?) - Early Cambrian Arumbera Sandstone and Late Proterozoic Quandong Conglomerate, East-central Amadeus Basin, Central Australia

by

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Utah State University, 1986

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Department: Geology

Throughout the James Ranges and Gardiner Range the Arumbera Sandstone forms prominent strike ridges with distinctive dark reddish slopes and pale red to orange-white cliffs. Because of their lithologic and stratigraphic similarities, the names Eninta and "Quandong" for these units should be suppressed in favor of the name of Arumbera Sandstone, which has precedence. The stratigraphic and lithologic differences observed between the Quandong Conglomerate in the type locality and the Arumbera Sandstone in the study area suggest that these units are not equivalent. Similarites with the Areyonga Formation suggest the Quandong Conglomerate could be part of the Areyonga Formation.

Lithofacies 1a, 1d, and 2b, and Unit 3 of the Arumbera and its equivalents are typically recessive arkoses, subarkose, and mudrocks. They are interpreted as nearshore-marine to coastal deltaic deposits which include intertonguing tidal-flat, tidal-channel, and beach-
sediments. Lithofacies 1b and 2a consist of cliff-forming arkoses, subarkoses, and lithic arkoses. Lithofacies 2c is also resistant, and consists of orthoconglomerates and conglomeratic sandstones. Lithofacies 1c is moderately resistant, and consists of paraconglomerates, conglomeratic sandstones, and mudrocks. It and lithofacies 2c contain pebbles and small cobbles of chert, quartzite, vein quartz, silicified ooids, and limestone, dolostone, shale, and sandstone. These four lithofacies are interpreted as braidplain and fluvial sheet sands.

In the east-central part of the Amadeus Basin the Arumbera Sandstone probably was deposited in a coastal environment as a sequence of deltaic sediments that was dominated by fluvial processes. The Arumbera Sandstone appears to be the molasse derived from the Late Proterozoic and Early Cambrian Petermann Ranges orogeny. Source rocks include sedimentary, low- to middle-rank metamorphic, and plutonic granites. Grain mineralogy and weathering characteristics suggest a hot, semiarid climate during deposition of the Arumbera.

The Arumbera Sandstone and Quandong Conglomerate contain fair to good porosity and permeability, and petrographic evidence shows meso-genetic generation of secondary porosity. Previous and present burial depths are adequate for the generation of petroleum. The presence of suitable underlying source rocks, overlying salt of the Chandler for a seal, and stratigraphic and structural traps suggest a good potential for petroleum. Production of dry gas from the lower part of the Arumbera at Dingo field, north of Deep Well Homestead, confirms the petroleum potential of this formation.
INTRODUCTION

General Statement

This report summarizes a detailed study of the stratigraphy, environments of deposition, and diagenesis of the Arumbera Sandstone and its equivalents, the Eninta Sandstone, and "Quandong Conglomerate," and also the Quandong Conglomerate (Fig. 1). The study area is located in the Amadeus Basin, Northern Territory, in Central Australia (Figs. 2-7).

The "Quandong Conglomerate" mapped in the James Range 'B' anticline appears unrelated to the Quandong Conglomerate at the type locality near Tempe Downs Homestead, based on field observations and stratigraphic relationships reported herein. For this reason, hereinafter the lithologic sequence measured in the James Range 'B' anticline will be called "Quandong Conglomerate," and the sequence measured near Tempe Downs Homestead will be called Quandong Conglomerate. Several sections of the unit mapped as the Areyonga Formation by the Australian Bureau of Mineral Resources, Geology, and Geophysics (BMR) were measured in the Petermann Creek anticline, and in the Deception Creek anticline (here named), near Tempe Downs Homestead (Appendices E & F; Figs. 3, 4). Those Areyonga sections measured near Tempe Downs and Deception Creek are considered in this report to be located within the Deception Creek anticline. These descriptions were included for comparison with the Quandong Conglomerate and the Inindia Formation to see if the Areyonga might be correlative with one or both of these units.
Location and General Geologic Setting

The study area lies in the east-central portion of the Amadeus Basin (Figs. 2, 3). The Amadeus Basin is a large intracratonic depression located in the southern part of the Northern Territory and the easternmost part of West Australia (Fig. 2). It includes largely unmetamorphosed to slightly metamorphosed Proterozoic, Cambrian, Ordovician, possibly Silurian, and Devonian lithified sediments unconformably beneath Tertiary and Quaternary sediments (Wells et al., 1967a). The major folding within the Amadeus Basin occurred first during the Petermann Ranges orogeny (latest Proterozoic) and later during the Alice Springs orogeny (Late Devonian). Thinning of Paleozoic sediments over the crests of several anticlines shows that these structures formed during Early Paleozoic sedimentation (Wells et al., 1967a), possibly due to passive salt tectonics. The eastern Arumbera outcrops of this study are shown on the Rodinga 1:250,000 scale geologic map (Cook, 1972). East and northeast of this area the Arumbera has been investigated in detail by Keith T. Conrad (1981). The central and western outcrops of the Arumbera are shown on the Henbury 1:250,000 scale (Cook, 1968a; Ranford et al., 1965), Hermannsburg 1:250,000 scale (Prichard and Quinlan, 1962), and Mt. Liebig 1:250,000 scale (Ranford, 1969) geologic maps. Outcrops of the Quandong Conglomerate are shown on the Henbury 1:250,000 scale geologic map.
Purposes of the Investigation

The purposes of this investigation are: (1) to evaluate the lateral stratigraphic relationships among the Arumbera Sandstone, Eninta Sandstone, the "Quandong Conglomerate," and the Quandong Conglomerate; (2) to determine the environments of deposition of these formations; (3) to determine areal extents and variations in thickness of these formations; (4) to determine the possible source areas for these formations; (5) to identify the rock units overlying and underlying these formations and to determine the nature of their contacts; (6) to determine mineralogy, average grain size, sorting, original grain roundness, grain shape, and porosity (type and amount) of these formations by petrographic methods; (7) to reconstruct the diagenetic sequences of these formations from petrographic study; (8) to reconstruct the paleogeography of the east-central Amadeus Basin during the time of deposition of these formations; (9) to evaluate evidence bearing on the possible correlation of the Arumbera Sandstone, Eninta Sandstone, "Quandong Conglomerate," and Quandong Conglomerate; (10) to evaluate the nature of any structural highs in this study area and possibly determine if any were growth structures during the time of deposition of the Arumbera Sandstone, Eninta Sandstone, "Quandong Conglomerate," and Quandong Conglomerate; and, thus (11) to extend Conrad's (1981) investigation of the Arumbera Sandstone in the northeastern part of the Amadeus Basin to the east-central part of the basin.
Field Methods

Field work was done during the Australian Winter. The field season extended from July 1 through September 20, 1982. From published geologic maps, aerial photos, and personal reconnaissance, exposures of the Arumbera Sandstone, Eninta Sandstone, "Quandong Conglomerate," Quandong Conglomerate, and Areyonga Formation were selected for detailed measurement. Criteria considered for selecting section locations included: completeness of the total unit, good exposures of the formations, outcrops of underlying and overlying units, distance from other measured sections (to provide good coverage of available exposures), and accessibility. Because outcrops of the Eninta, "Quandong," Quandong, and Areyonga are on tribal Aboriginal lands, special permission to enter and/or cross these regions was necessary. This was also considered when selecting locations for sections. The number of sections measured also was limited by a fixed time factor.

Three complete stratigraphic sections of the Arumbera Sandstone, seven complete stratigraphic sections of the Eninta Sandstone, one partial (but nearly complete) stratigraphic section of the "Quandong Conglomerate," two partial (probably very nearly complete) sections of the Quandong Conglomerate, and three complete or very nearly complete stratigraphic sections of the Areyonga Formation were measured and described (Table 1; Appendices E and F).

Measurement of the stratigraphic sections followed techniques described by Kottlowski (1965). Two Jacob staffs, an Abney hand level, and a thirty-, fifty-, or sixty-meter tape were used. Descriptions of the rock units followed procedures used by Conrad (1981) for his
investigation of the Arumbera Sandstone in the northeastern part of the Amadeus Basin. A Brunton compass was used to measure strikes and dips of bedding surfaces, cross-stratification, parting lineations, and slicken-sides. Dips for cross-stratification were measured with a protractor. Data gathered on cross-stratification included: set thickness, grouped or solitary type, lithology, dip angle and direction, strike direction, relationships at upper and lower contacts, and general classification based on Allen (1963a, 1965a), Allen and Banks (1972), Campbell (1966, 1967, 1971, 1976), Campbell and Oaks (1973), and Reineck and Wunderlich (1968).

Other observations recorded during the field investigations included: (1) names and map locations for each stratigraphic section measured and described; (2) sketch of the topographic profile, with station and sample sites located, for each of the stratigraphic sections; (3) date, field conditions, and names of those assisting in measuring each section; (4) the nature of the upper and lower contacts of the formations and the contacts between lithofacies within each formation; (5) general description of the formations overlying and underlying the measured formations; (6) lithologies and average grain sizes (after Wentworth, 1922, and Lundegard and Samuels, 1980); (7) mineralogy of each rock type; (8) weathered and unweathered colors (rock-color chart, Goddard, 1979); (9) inorganic and biogenic sedimentary structures (Conybeare and Crook, 1968, and Seilacher, 1964); (10) porosity-permeability field test (described by Oaks, 1982, oral communication); (11) tectonic structural relations or features; (12) section location for each sample collected for thin-section analysis; (13) descriptions of bedding contacts and bed forms (after Allen, 1963a, 1963b, 1965a,
1965b; Allen and Banks, 1972; Campbell, 1966, 1967; and Conybeare and Crook, 1968); and (14) paleocurrent directions (measured scour directions).

For covered or concealed intervals, pits were dug in an attempt to determine the lithology. At some locations, lateral traverses of up to 100 m in length along strike were used to determine lithologies of the recessive units. Over 200 samples were collected at regular intervals of about 10 m at sections chosen as being representative for each unit studied. Samples also were taken where major changes take place between lithofacies. Fifty-one samples were chosen for thin-section and X-ray analyses. These samples were selected to characterize different lithologies observed in field investigations, for purposes of comparisons of units and subunits among stratigraphic sections and among formations. This coverage was constrained by limitations placed by time and by objectives of the thesis problem, which required coverage of the various lithologies encountered in the four units studied, and by the need for correlations of units and/or subunits at a level of detail similar to that utilized by Conrad (1981) in his thesis area.

After measurement and description of the stratigraphic sections, isopachous maps (Figs. 5-12), paleocurrent directions (Figs. 13-21), fence diagrams (Figs. 22, 23) and graphic summaries (Appendix E) of the sections were drafted. From these, correlations among the Arumbera Sandstone, Eninta Sandstone, and "Quandong Conglomerate" were made, plus probable correlations of units and lithofacies (or subunits) within each formation. The units and subunits (or lithofacies) are directly correlative with units of the Arumbera Sandstone defined by Conrad (1981). Together with the thin-section analysis, the results also were used to
determine the possible depositional environments and provenance, and to
determine whether anticlines within the study area formed passively
during and following deposition, or resulted from compression during the
Alice Springs orogeny. The data are presented in the Appendices.

**Laboratory Methods**

Fifty-one samples were selected for thin-section analysis. Eleven
samples were selected from the Arumbera Sandstone, thirty from the
Eninta Sandstone, five from the "Quandong Conglomerate," and five from
the Quandong Conglomerate. Because of the lithologic similarity of the
lithofacies of the Eninta, "Quandong," and Arumbera, and because of the
dissimilarity in composition, color, and vertical sequence of sedimen-
tary structures of the "type" Quandong, the latter unit was not regarded
as equivalent to the other units. For this reason, and because vertical
and lateral changes, observed in the field within each lithofacies are
slight, the fifty-one samples are believed to afford adequate representa-
tion and comparisons of these formations. Selection of the samples was
based on the following criteria:

1. The emphasis of this study was on the Eninta Sandstone. Seventeen
of the thirty samples of the Eninta were selected from the strati-
graphic section deemed most representative (Pattalindama Gap section).
This section was chosen for a rather comprehensive study because it lies
east of a tectonic high where most of the Eninta was removed by post-
depositional erosion. The Pattalindama Gap section lies nearer to the
Arumbera study area of Conrad (1981) than the area west of the tectonic
high, and the section also is closer to the "Quandong" and Arumbera of
this study. Also, little or no previous field investigation had been conducted in this portion of the Gardiner Range anticline. Furthermore, this section showed two coarsening-upwards cycles typical of the Eninta in several other sections. The other thirteen samples of the Eninta were chosen at other stratigraphic sections in the Gardiner Range anticline. They were chosen for comparison of the various lithofacies encountered within the formation, especially lithofacies lb.

2. The eleven Arumbera samples were collected from the stratigraphic section deemed most representative (Billabong Bore West section). The samples were selected to represent each of the major subunits (lithofacies) of the Arumbera Sandstone. The section was chosen because it was very near the center of the exposed Arumbera of this study area, and it offered the best exposed and thickest section.

3. Five samples were chosen from the "Quandong Conglomerate" measured and described in the core of the James Range 'B' anticline (Tidenvale section). Representative samples were selected from each lithofacies.

4. Five samples were collected from the Quandong Conglomerate at the Tempe Downs North section. Because the Quandong is dissimilar to the Eninta, Arumbera, and the "Quandong;" samples were selected below the top at intervals proportional to the intervals for samples selected from the "Quandong Conglomerate." This was done to achieve an approximate comparison between the two units.

Thin sections were cut perpendicular to bedding. Each was stained with sodium cobaltinitrite for potassium feldspar by the method described by Bailey and Stevens (1960). Each thin section was impregnated initially with blue-stained epoxy. This aided in the analysis of porosi-
ty. Thin sections were cut to standard thickness and stained by Roberts Rock Laboratory, Monterey, California. Rock chips from many of these samples were prepared and used for X-ray analysis.

An Olympus binocular polarizing microscope, model BH-2, with a mechanical stage and other accessories was used to examine the prepared thin sections. Observations were recorded for a minimum of 310 points randomly selected at regular grid intersections for each of the fifty-one thin sections. This particular number of points was chosen in order to provide uniformly distributed sampling across the area of each thin-section. For moderately sorted sandstones, this should ensure a count of at least 200 grains. Because Conrad (1981) counted 200 grains in his investigation of the Arumbera, the two studies are comparable. Observations and measurements recorded at each point included: (1) mineralogy of the original grain, matrix, or cement and its replacement product if alteration has occurred (after Schmidt and McDonald, 1979a, 1979b; Scholle, 1979); (2) grain size (longest diameter, see Friedman, 1958; Folk, 1974; and Folk and Ward, 1957); (3) original grain shape; (4) original grain roundness; (5) quartz types (Blatt and Christie, 1963; and Basu et al., 1975); (6) grain overgrowths; (7) grain inclusions; (8) porosity type; (9) microsedimentary structures; (10) diagenetic, replacement, or alteration products and features; and (11) extinction angles for any plagioclase feldspars with albite twins.

X-ray diffractograms were made for thirty-three rock chips selected from the fifty-one samples used for thin-section analysis. All samples of siltstone and very fine-grained sandstones were selected, plus representatives of the remaining sandstone samples. X-ray diffraction of these samples aided in the identification of clay minerals and clay-
sized particles observed in thin-section analysis. A bulk sample finer than 250 mesh (sieve size) was prepared for each sample by pulverizing a rock chip with a mortar and pestle. Samples were scanned from $2^\circ \ 20$ to $31^\circ \ 20$ at a rate of $2^\circ \ 20$ per minute on a Siemens Krystaloflex-4 diffractometer. Both Vaseline-mounted and wet-slurry-mounted samples were X-rayed in order to determine the mineralogy. Samples prepared by the slurry method also were X-rayed following glycolation at $60^\circ \mathrm{C}$ and again after heating to $550^\circ \mathrm{C}$ when these procedures were needed for identification of the clay minerals.

**Quantitative Methods**

Following examinations of thin sections, the data were processed using various analytical techniques. Composition of each sample was determined from calculations of the percentages of each grain type, relative to the total number of grains, and the proportion of grains, matrix, cement, and porosity that compose the sample (Tables 2-5). Next the relative percentage of each original constituent was determined. Secondary porosity resulting from dissolution of feldspars and micas was included in the mineralogy used to classify each sandstone. Each sample was plotted using Folk's 1974 classification scheme (Figs. 24-26). A four-variable plot of the quartz population was made for each sample using the classification of Basu (1976) and Basu et al. (1975), (Figs. 27-30). The original mineralogical data also were used to evaluate provenance by means of triangular plots (Dickinson and Suczek, 1979; Figs. 31-42).
The graphic mean grain size (phi mean, M\text{z}), inclusive graphic standard deviation (sorting, \sigma_i), kurtosis (K_G), and inclusive graphic skewness (SK_i) of Folk and Ward (1957) were calculated for each thin section. The median and coarsest 1% were also determined for each sample. Data for these calculations and plots were corrected by converting the thin-section grain sizes to sieve-equivalent grain sizes by means of the conversion graph designed by Friedman (1958). In 15 thin sections, grain sizes greater than -1 phi constituted more than 5% of the sample. For these samples corrected sieve-sizes were extrapolated by extending Friedman's correction graph. Because Friedman only worked with well-sorted sands finer than -1 phi, his conversion graph is only known to be valid for grains finer than or equal to -1 phi. However, his results show a linear conversion factor. If one assumes this linear factor continues into the coarser sand grains, then the extrapolated equivalent sieve sizes are acceptable for these coarser grain sizes. The grain-size data, converted to sieve equivalents, were used to construct C-M diagrams (Figs. 43-45; after Passega, 1957, 1964), cumulative-frequency probability curves (Figs. 46-56), and frequency-distribution histograms (Figs. 57-60), and for each thin section (Appendix D).

Names of Sedimentary Rocks

"Mudrocks" are indurated sedimentary rocks composed of more than 50% silt and clay, less than 33% carbonate, and less than 25% gravel. Mud is a mixture of silt and clay with more than 33% of each. "Clay-shale," "mud-shale," and "silt-shale," refer to thinly laminated or fissile mudrocks composed dominantly of clay, mud, or silt, respectively.
Claystone, "mudstone," and "siltstone" are indurated non-fissile mudrocks composed dominantly of clay, mud, and silt respectively. "Conglomerate" is an indurated sedimentary rock that contains over 25% gravel. "Orthoconglomerates" contain less than 15% matrix, whereas "paraconglomerates" contain more (Pettijohn, 1975). "Orthoconglomerates" are oligomict (cherty) or ortho-quartzitic if metastable components form less than 15% of the clasts, or are polymict, if greater than 15%. Paraconglomerates have laminated matrixes, or are diamictites if not laminated. "Sandstone" is an indurated sedimentary rock composed of more than 50% sand and less than 25% gravel. "Conglomeratic sandstone" is a sandstone that contains 5 to 25% gravel. Sandstones are classified by composition (QFR of Folk, 1974). "Carbonates" are indurated rocks consisting predominantly of calcite and dolomite, with less than 33% terrigenous mud (marl), less than 50% mud plus sand, and less than 25% terrigenous gravel. "Limestone" is a carbonate rock wherein calcite forms more than 50% of the carbonate. "Dolostone" is a carbonate rock wherein dolomite forms more than 50% of the carbonate.

**Stratigraphic Terminology**

The term "facies" refers to the distinct lateral changes in characteristics of a definite stratigraphic unit (after Gressly, 1838, p. 10-12, 20-25, from Gary et al., 1974). An individual facies represents the sum of all primary lithologic and paleontologic characteristics from which the origin and environment of formation may be inferred. A facies has distinctive lithologic characters (after Gary et al., 1974). "Litho-
"facies" refers to a laterally mappable subdivision of a stratigraphic unit. A "unit" consists of one or more mappable lithofacies, and is distinguished primarily by its topographic expression and the lateral continuity of grouped facies. "Subunit" refers to individual lithofacies mapped within a unit. A "formation" is a mappable unit or a mappable group of units. A "member" is a division of a formation characterized by separate or distinct lithofacies.

Syndepositional inorganic sedimentary structures are those formed by mechanical processes during deposition (after Pettijohn, 1957, p. 158, Table 34). They are distinguished from diagenetic and organic structures by their mode of origin. Types of syndepositional structures are described in Conybeare and Crook (1968) and Nagtegaal (1965).

Campbell's (1967) definition of "bed" as an informal time-stratigraphic unit of limited areal extent, of a relatively short time span, and bounded by nearly synchronous depositional surfaces (bedding surfaces) was applied in this study. The term "lamina" describes small-scale stratification similar to a bed, but with these exceptions: (1) it is uniform in composition and texture, (2) its internal laying is not megascopic, (3) it typically has a much smaller areal extent than a "bed," and (4) it is formed during a shorter period of time than the bed which encloses it (Campbell, 1967, p. 19). Cross-stratification used in this report follow descriptions and usages by McKee and Weir (1953), Allen (1963a, 1970), and Conybeare and Crook (1968). The usage and descriptions of Reineck and Singh (1975) and Conybeare and Crook (1968), for primary inorganic structures, were also applied in this study.
PREVIOUS WORK

In the 1860's and 1870's, exploration of the region was sporadic, but provided the earliest general geological information of the region. The first geologist known to visit the area was C. Chewings in 1886. Chewings (1914, 1928, 1931, and 1935) published several papers on the geology of the region. Mawson and Madigan (1930) first used the term "Pataoortta Series" for the sequence from the "middle" quartzite (Arumbera Sandstone) to the base of the upper "Pacoota Quartzite." Chewings (1931) altered the spelling, and Madigan (1932a, 1932b) assigned the Petaoortta Series to rocks between his numbers three and four quartzites. Possibly the number three quartzite was included in this series. Prichard and Quinlan (1960) named Madigan's number three quartzite the Arumbera Greywacke. The name was taken from Arumbera Creek, which flows northwest from the MacDonnell Ranges east of Haast Bluff to join Derwent Creek in the western part of the Burt Plain. Their type section was measured 5 km (3 miles) west of Ellery Creek (Prichard and Quinlan, 1960). Later Wells et al. (1967a) renamed the Arumbera Greywacke the Arumbera Sandstone. Hopkins (1964), Wells et al., (1967a), and Conrad (1981) divided the Arumbera Sandstone into four units. Daily (1972) and Cowie and Glaessner (1975) proposed a possible revision based on a presumed unconformity between Units 2 and 3. However, no physical evidence for an unconformity between Units 2 and 3 was found by Conrad (1981) or during the present study. Conrad (1981) presented an extensive summarization of the descriptions and interpretations given to the Arumbera Sandstone from previous studies, and documented the results of
his own detailed study of the Arumbera in the northeastern Amadeus Basin.

The Eninta Sandstone was first defined in the Gardiner Range by Wells et al. (1962) as the Arumbera Greywacke. It was later changed to the Eninta Sandstone Member, the basal unit of the Pertaoorrta Formation, by Wells et al. (1963) because sandstones above the Tempe Formation resembled sandstones in the upper part of the Arumbera. The type locality of the Eninta lies 6.5 km (4 miles) west of Katapata Gap in the Gardiner Range. The name is derived from Eninta Creek, which lies 22 km (14 miles) east-northeast of Tempe Downs Homestead. Ranford et al. (1966) raised the Eninta to formational status because the younger Petermann Sandstone resembles the Arumbera. Those authors introduced the names Eninta because of the possibility that the Tempe might be a marine tongue within the Arumbera. At the MLR 2 section, located on the Mt. Liebig 1:250,000 scale geologic map, Ranford (1969) listed 370 m (1200 feet) for maximum thickness of the Eninta. Their site is located at the Katapata Gap section of this report. This section has become the reference locality for the Eninta Sandstone. Ranford and Cook (1964) measured a thickness of 100 m (310 feet) of the Eninta Sandstone at BMR section HyR 3, located on the Henbury 1:250,000 scale geologic map (Cook, 1968a). Their site lies approximately 1 km west of the Areyonga section of this report, where 86 m was measured (Table 1). Williams (1967) suggested the name "Eninta" be dropped in favor of the name "Arumbera Sandstone" because he found the Chandler Formation just above the Eninta in the basal part of the unit mapped as the Tempe Formation in the Gardiner Range. He divided the Eninta into six informal units and recognized the pre-Eninta topographic high near Katapata Gap where the Eninta is thinnest. Williams also
pointed out that, west of Katapata Gap, there are rapid facies changes which are very local in extent. He described the Eninta as a molasse sequence of both marine and non-marine, paralic or deltaic deposits.

The Quandong Conglomerate was defined by Ranford et al. (1966). Originally, Ranford and Cook (1964) considered it the basal member of the Pertaoorrta Formation. The name is derived from Quandong Creek, which lies about 10 km (6 miles) east of the type locality. The type locality, which was not measured previously, lies 10 km (6 miles) northeast of Tempe Downs Homestead. Wells et al. (1970) described the Quandong Conglomerate at its type locality as an unfossiliferous basal conglomerate which changes in thickness and lithology through short distances. They estimated the maximum thickness as 155 m (500 feet). They also regarded the Quandong as lying conformably beneath the lower Middle Cambrian Tempe Formation and considered it to be Lower Cambrian in age. Wells et al. (1970) listed three locations where the Quandong Conglomerate is exposed: (1) Tempe Downs (type locality), (2) core of the James Range 'B' anticline, and (3) a small eroded anticline between the Petermann Creek and Parana Hill anticlines (White Horse anticline). Field investigations in these areas for this report suggest that the Quandong mapped at the type locality is part of the Areyonga Formation. A section measured by Oaks (1984, oral communication) and an earlier traverse by the author through the core of the White Horse anticline found the Chandler unconformably overlying the Loves Creek Member of the Bitter Springs, and no Quandong or "Quandong."

From previous geologic mapping and stratigraphic investigations (Prichard and Quinlan, 1960; Wells et al., 1962; Ranford and Cook, 1964; Ranford et al., 1966; Wells et al., 1967a; Wells et al., 1967b; Williams,
1967; and Conrad, 1981), the Arumbera Sandstone and the Eninta Sandstone were interpreted as transitional-marine to deltaic and fluvial arkoses to subarkoses of Proterozoic to Early Cambrian age. The Quandong Conglomerate was considered to be a basal conglomerate and conglomeratic sandstone of similar age. In all previous references cited, the writers have considered the Arumbera Sandstone, Eninta Sandstone, and Quandong Conglomerate as lateral equivalents. Wells et al. (1967a) suggested possible correlation of these formations with the Mount Currie Conglomerate and the Arkose at Ayers Rock. These two rock units crop out southwest of this study area. Together these units form a belt of outcrops which extend across the eastern two-thirds of the Amadeus Basin. Outcrops mapped as the Eninta Sandstone on the Lake Amadeus 1:250,000 scale geologic map area by Wells et al. (1963) were later considered to belonging to the Tempe Formation by Ranford and Cook (1964) and Cook (1968b).
COMPARISONS AND RESULTS

Results from this investigation indicate that the Arumbera Sandstone, Eninta Sandstone, and "Quandong Conglomerate" are the same formation. Therefore, future discussions of these three units will be referred to as the Arumbera Sandstone. The Eninta will be referred to as the Arumbera Sandstone in the Gardiner Range, whereas the "Quandong" will be referred to as the Arumbera Sandstone in the James Ranges 'B' anticline. Because the Quandong Conglomerate in the Tempe Downs area is unlike the Arumbera Sandstone it will be discussed separately. These conclusions are based on the following results:

(1) Measured stratigraphic sections in the Gardiner Range and James Ranges 'B' anticline show that the Eninta Sandstone and "Quandong Conglomerate" consist of the two lower units of the Arumbera Sandstone. The source material was from sedimentary, metamorphic, plutonic, and minor volcanic rocks of the Petermann Ranges and Olia Chain for the Arumbera, Eninta, and "Quandong."

(2) Characteristics and stratigraphic position of the Quandong Conglomerate present at two stratigraphic sections measured near Tempe Downs Homestead show deposition of the Quandong predates the Arumbera and its equivalents. Orthoconglomerates strikingly similar to those described at the type locality of the Quandong are present in the Areyonga along the western flank of the Deception Creek anticline, near Illamurta Native Settlement. These field observations suggest the Quandong is not correlative with the Arumbera, but is a member of the Areyonga Formation. More evidence to support this conclusion includes
compositional differences, relative abundances of feldspars, and variations in abundances of the lithic rock fragments (see QFR, QmFLt, and CFP plots). Mineralogy of the lithic fragments suggests that the metamorphic rock fragments are of lower rank than for the Arumbera, Eninta, and "Quandong." Also, a greater proportion of the Quandong lithic fragments are sedimentary rock fragments than typically present in the Arumbera type deposits. Feldspar content is significantly lower for the Quandong than for Arumbera deposits. No microcline was observed, and both orthoclase and plagioclase are noticeably lower than for any of the Arumbera, Eninta, or "Quandong" thin sections studied.

(3) Measured stratigraphic sections in the Gardiner Range and James Ranges show that the Chandler Formation disconformably overlies the Arumbera, Eninta, and "Quandong" along a low-angle regional unconformity. In the eastern part of the study area, the contact is sharp, whereas in the Gardiner Range it is sharp to gradational. Just west of the Tempe Downs South section, an oval outcrop of contorted Chandler limestone lies above the Quandong and suggests a possible detachment surface associated with Chandler flowage. For the Arumbera and its equivalents the base of the overlying Chandler Formation is defined where silt-sized proportion of the sediments is predominant over the sand-sized proportion. The upper contact of the Arumbera is sharp to gradational (through 20 m or less), and probably is marked by a low-angle regional unconformity along which the Todd River Dolomite and Unit 4 and the upper part of Unit 3 of the Arumbera are absent. The upper contact of the Eninta is topographically sharp, but texturally and mineralogical it is gradational through as much as 20 m, but generally less than 10 m. This is generally defined topographically at the base of
the prominent dipslope. The upper contact of the "Quandong" is sharp and possibly a low-angle regional unconformity. Here the Chandler Formation lies directly on the uppermost sandstone of lithofacies 2a.

(4) In the eastern James Ranges, the lower contact of the Arumbera with the Pertatataka Formation is sharp and probably marked by a low-angle regional unconformity. The Pertatataka Formation is thin, and overlies the Areyonga Formation. In the Gardiner Range, the Eninta overlies the Julie Formation locally, but steps downsection successively eastward onto the underlying Pertatataka, Areyonga, and Bitter Springs formations along an angular unconformity that probably postdates the Julie. In the central part of the Gardiner Range, the contact with the underlying Julie Formation is sharp and marked by a change in dip of 10° to 20° across the contact. From field observations and aerial photos, a progressive downcutting through these same formations may also occur westward from the Missionary View section, although not as rapidly as in the east. The probable underlying formation of the "Quandong" is the Areyonga or Bitter Springs based on Finke No. 1 and James Ranges 'A' No. 1 well reports. The lower contact of the Quandong is concealed at the sections measured, although there is a small outcrop of Loves Creek below a thin covered interval at the base of the Tempe Downs North section.

(5) Lateral variations in thickness of the separate units of the Arumbera and its equivalents probably are due primarily to differential rates of subsidence during deposition and syndepositional tectonics (Figs. 22, 23). Based on lithologic and thickness data, differential subsidence probably took place during deposition of the Arumbera in the James Ranges (Fig. 22). No pronounced growth structures were defined in
the eastern James Ranges, but a distinct high just to the northwest is shown on the isopachous map (Fig. 5). The Arumbera Sandstone in the eastern James Ranges thins both to the east and to the west of the Billabong Bore West section. The formation thickens northeastward in Conrad's (1981) study area. A minimum thickness of 86 m was measured at the Areyonga section, and at least 58 m was measured at the Tidenvale section. A maximum thickness of 423 m was measured at the Katapata Gap section. Based on lithology and stratigraphy, the "Quandong" either lies in an area which was a structural high during the time of the Arumbera deposition or later post-depositional erosion reduced the "Quandong" to its present thickness.

(6) The Quandong is 168 m thick at the Tempe Downs North section, yet 500 m south its outcrops thin to 130 m at the Tempe Downs South section. These are the only reported outcrops of the Quandong Conglomerate.

(7) Measured stratigraphic sections in the Gardiner Range show the existence of two sub-basins in that area during deposition of the Pertatataka, Julie, and Arumbera formations, and possibly the Chandler Formation. These sub-basins were separated by a structural high near Pattalindama Gap and Areyonga Native Settlement, which grew episodically during the deposition of these formations. The shape and orientation of this high is unclear, but rapid thinning and abrupt lateral pinchout of beds toward the area of the Areyonga section and Pattalindama Gap suggest an active growth structure. Seismic evidence suggests that it did not extend very far northward (Oaks, 1985, oral communication). Growth of this structure perhaps initiated as early as Areyonga deposition. Pinchout of the Julie Formation, thinning of the Pertatataka Formation,
and thinning of both Units 1 and 2 of the Eninta over this region demonstrate its activity during their deposition (Fig. 23).

(8) From well reports (Wells et al., 1970) and field investigations by Oaks (oral communication, 1984), McNaughton (1973, 1974), McNaughton and Huckaba (1978, 1980), and Conrad (1981), a Central Ridge (Fig. 4) trends west-northwest to east-southeast just south of the Gardiner Range. Eninta and Arumbera sediments pinch out onto this structural high, and are absent across its crest and in most of the area farther south.

(9) Unit 1 of the Arumbera, Eninta, and "Quandong," a recessive, basal unit, is a sequence of pale red ('brick red'), fine- to medium-bedded, fine- to medium-grained muddy arkoses and subarkoses with common mudrocks. It has a minimum thickness of 56 m at the Billabong Bore East and Walkabout sections and a maximum thickness of 240 m at the Katapata Gap section. Unit 1 is divisible into four lithofacies. Lithofacies 1a, the basal part of the unit, consists of recessive, mostly concealed, pale red to reddish brown, thin-bedded, fine-grained arkoses and subarkoses with common mudrocks and local rare carbonates. Lithofacies 1b forms a moderately resistant bench or small ridge within lithofacies 1a, and is comprised of grayish orange pink, medium-bedded, medium- to coarse-grained subarkoses. Lithofacies 1c forms a moderately resistant bench, and is comprised of pale red to reddish brown, medium-bedded, para- and orthoconglomerates and conglomeratic sandstones with pebbles of chert, quartzite, vein quartz, limestone, dolostone, sandstone, and shale. Lithofacies 1d, the recessive upper part of Unit 1, is comprised of pale red to moderate red, fine- to medium-bedded, fine- to medium-grained arkoses and subarkoses with common mudrocks.
(10) Unit 2 forms the main strike ridge of the Arumbera, Eninta, and "Quandong." It is divisible into three lithofacies. Lithofacies 2a, the basal part of the unit, consists of cliff-forming, white to pinkish gray, medium-bedded, fine- to medium-grained subarkoses and arkoses. The middle part, lithofacies 2b, is a sequence of moderately resistant, moderate to pale red, fine- to medium-bedded, fine- to medium-grained arkoses and subarkoses. Lithofacies 2a and 2b intertongue in the Gardiner Range. Lithofacies 2c forms a prominent dipslope. It is comprised of moderate red ('maroon'), medium- to thick-bedded orthoconglomerates and conglomeratic sandstones. Lithofacies 2c is absent in the Gardiner Range and James Ranges 'B' anticline, due either to non-deposition or postdepositional erosion. Framework grains of lithofacies 2c include pebbles and cobbles of chert, quartzite, vein quartz, and sandstone. In the James Ranges and Gardiner Range, Unit 2 has a minimum thickness of 27 m at the Areyonga section and a maximum thickness of 230 m at the Missionary View section.

(11) Unit 3 consists of recessive, pale red to reddish brown, thin- to medium-bedded, very fine- to medium-grained arkoses and subarkoses with siltstones and mudrocks. In the James Ranges, Unit 3 has a minimum thickness of 28 m at the Walkabout section and a maximum thickness of 35 m at the Billabong Bore East section. It is absent in the James Ranges 'B' anticline and in the Gardiner Range. Unit 4 pinches out southward in the Deep Well Range, and is absent in the area studied.

(12) The Quandong is divisible into three lithofacies. Lithofacies A₁, the recessive, basal part of the Quandong, is comprised of pale orange to pale reddish purple, medium-bedded, fine- to coarse-grained, subarkoses based on field observation. Lithofacies A₂ forms local cliffs
and a prominent dipslope. It is comprised of resistant, very pale orange, medium- to thick-bedded orthoconglomerates and conglomeratic sandstones with pebbles and small cobbles of chert, quartzite, and vein quartz. Sandstones of this lithofacies are fine- to coarse-grained lithic arkoses, feldspathic litharenites, and subarkoses. Lithofacies A$_3$, the uppermost part of the Quandong, is comprised of recessive, pale orange, thin-bedded, very fine-grained sandstones with common mudrocks. It is mostly silicified and chert-replaced siltstone.

(13) In the Arumbera (percentages listed in the following order: total of all Arumbera samples, Arumbera in the eastern James Ranges, Eninta, "Quandong") quartz (65%, 71%, 63%, 64%) is the most common framework grain, with lesser amounts of orthoclase (11%, 8%, 13%, 12%), chert (8%, 7%, 9%, 6%), other lithics (5%, 4%, 6%, 6%; primarily granite and schist), plagioclase (4%, 3%, 5%, 6%), and microcline (2%, 4%, 1%, 6%). Common accessory minerals are muscovite, biotite, zircon, tourmaline, and magnetite. Minor accessory minerals include rutile, pyrite, epidote, ilmenite/leucoxene, and augite. Most grains are subrounded, and the sandstones are moderately well sorted with little skewness. Matrix is generally hematite and kaolinite with minor illite. Cementing agents are syntaxial overgrowths of quartz (major) and feldspar (minor), hematite (common), kaolinite (common), carbonate (local), and chert (rare).

(14) Quartz (70%) is the most common framework grain in the Quandong Conglomerate. Other framework grains are chert (14%), orthoclase (7%), other lithics (6%, primarily schist), and plagioclase (<1%). Common accessory minerals include muscovite, zircon, tourmaline, rutile, sphene, magnetite, pyrite, and ilmenite/leucoxene. Most grains are rounded to subrounded, and the sandstones are generally poorly sorted to
moderately sorted and moderately skewed. Matrix is generally kaolinite with minor illite and hematite. Cementing agents are syntaxial quartz overgrowths (abundant), chert (minor), kaolinite (common), and hematite (rare).

(15) No fossils were observed in the Arumbera, Eninta, and Quandong. However, shallow vertical burrows were found in the Areyonga Formation at the Tempe Downs Central section and in the upper part of lithofacies 2a of the "Quandong." Also, in lithofacies 2a of the "Quandong" the bedding has locally undergone bioturbation.

(16) Porosity (percentages listed in the following order: total of all Arumbera samples, Arumbera in the eastern James Ranges, Eninta, "Quandong") of the Arumbera (9%, 10%, 8%, 5%) is mostly secondary in origin and formed by dissolution primarily of feldspars. Most of the original porosity probably was destroyed during deep burial, which exceeded 4000 m at the Ooraminna No. 1 well (McNaughton and Huckaba, 1978). Evidence of secondary porosity includes dissolution of grains, cement, and matrix; elongated pores; inhomogeneity in packing; floating grains; and micro-fractures.

(17) Porosity for the Quandong averages 15%. The porosity is mostly secondary. Original porosity probably was mostly destroyed during deep burial. Evidence of secondary porosity includes dissolution of grains, matrix, and cement; elongated pores, inhomogeneity in packing; floating grains; and micro-fractures.

(18) Diagenetic alteration has significantly changed the character of the Arumbera, Eninta, and "Quandong" sediments. The probable sequence of diagenetic events is: (a) mechanical compaction; (b) local replacement by iron oxides; (c) formation of 'dust rims' and clay coats (Fe(?)-
chlorite, hematite, and/or illite); (d) syntaxial tourmaline overgrowth; (e) syntaxial feldspar overgrowths; (f) syntaxial quartz overgrowths; (g) formation of authigenic clay minerals; (h) fracturing; (i) calcite and/or dolomite cement; (j) pyrite cement; (k) alteration of iron-bearing minerals to hematite (initial alteration may have begun during the mechanical compaction stage which helped to supply iron oxide for the 'dust rims'); (l) alteration and disolution of feldspars; (m) development of secondary porosity; (n) pore-filling kaolinite and hematite; (o) pore-filling microcrystalline quartz (originally probably precipitated as opal); (p) expansion fractures (probably related to unloading and uplift); and (q) calcite (calcrete) cement. Steps a-d and possibly part of e are eogenetic, steps e-m are mesogenetic, and steps n-q are telogenetic.

(19) Eogenetic events for the Quandong include steps a and c listed above for the Arumbera. Mesogenetic events for the Quandong include steps f, h, i, l, and m listed for the Arumbera. Steps n and o listed for the Arumbera are the telogenetic stages present in the diagenetic sequence for the Quandong.

(20) Arumbera Units 1 and 2 of Hopkins (1964), Wells et al. (1967a) and Conrad (1981) are clearly present in the Eninta in the Gardiner Range. However, rapid lateral facies changes within Units 1 and 2 make it difficult to utilize Conrad's (1981) subdivision of these units into successive subunits. The complex interfingering of the facies of the Eninta in the Gardiner Range (Fig. 23) is similar to complex intertonguing within the lower two units of the Arumbera in the western MacDonnell Ranges (Hamp, 1985) and in the Nummery area east of Conrad's area of study (Oaks, 1985, oral communication). At least three factors
may have caused more complex and cyclic depositional patterns in the Eninta than for the Arumbera Sandstone in the northeastern part of the Amadeus Basin: (1) deposition of the Eninta within the Gardiner Range may have been nearer to the source area; (2) a persistent structural high, running eastward through the central part of the Amadeus Basin, appears to be onlapped by the Eninta Sandstone, whereas the Arumbera studied by Conrad (1981) appears to lie farther north of this "Central Ridge" (McNaughton and Huckaba, 1980; Oaks, 1983; Fig. 4); and (3) a passive, vertical growth structure across the axis of the Gardiner Range anticline, near Areyonga, was a positive feature during deposition of Unit 1 of the Eninta and again following deposition of Unit 2, prior to the Chandler. This vertical growth structure influenced directions during deposition of the Eninta (Fig. 23).
Pre- Arumbera and Pre-Quandong Stratigraphy

General Statement

Units that stratigraphically underlie the Arumbera Sandstone, Eninta Sandstone, "Quandong Conglomerate," and Quandong Conglomerate will be reviewed in this section. Descriptions of contacts will be discussed under the field description. The term Arumbera Sandstone will include the Arumbera Sandstone, Eninta Sandstone, and "Quandong Conglomerate" (James Range 'B' anticline). The term Quandong Conglomerate will be restricted to outcrops near Tempe Downs Homestead at the type locality.

The Arumbera Sandstone is underlain by the Julie, Pertatataka, Areyonga, and Bitter Springs formations. In the area studied, each of these formations lies unconformably beneath the Arumbera Sandstone. In the unnamed east-west strike ridge in the southern part of the James Ranges southwest of Deep Well Homestead, the Arumbera Sandstone is underlain by the Pertatataka Shale. At the Billabong Bore West section, outcrops of the Areyonga Formation, overlying the Loves Creek Member of the Bitter Springs Formation, were present below a rather thin sequence of Pertatataka shales and fine-grained sandstones. At other measured sections in this strike ridge, only a thick covered interval is present, which is probably Pertatataka based on the green (and red) silt-shale float in creek beds and limited exposures found in shallow dug pits. The contact between the Arumbera Sandstone and the underlying Pertatataka Shale is generally concealed. The coarser material of the Arumbera
generally marks a major change in sedimentation from fissile shales which characterize the upper Pertatataka Shale. The nature of this transition ranges from a sharp erosional contact to a more gradational change through 1 to 3 m, which is marked by a coarser grain size above the contact. Elsewhere, throughout most of the area studied by Conrad (1981), sandstone, shale, and dolostone of the Julie Formation overlie and intertongue with the Pertatataka, and the upper dolostone subunit intertongues upwards with the Arumbera.

In the central part of the Gardiner Range, the underlying formations are equivalent to those present below the Arumbera Sandstone in the northeast part of the Amadeus Basin (cf. Oaks, 1983). These include the Cyclops Member of the Pertatataka Shale and the overlying Julie Formation. In the eastern part of the Gardiner Range anticline, the Pertatataka pinches out, probably due to pre-Arumbera erosion (Fig. 23). In the east, the Eninta rests unconformably on the underlying Areyonga and Bitter Springs formations (Fig. 23; Ranford and Cook, 1964). In the central part of the Gardiner Range, where the Eninta rests on the Julie Formation, there is a decrease of 10° to 20° in dip of the beds of the two formations across the contact. Near the western end of the anticline, where the Julie is absent, the Eninta lies unconformably on the underlying Pertatataka Shale.

The pre-Arumbera units beneath the "Quandong" in the James Range 'B' anticline are not exposed. But from Finke No. 1 and James Ranges 'A' No. 1 well reports, the "Quandong" is probably underlain by the Areyonga Formation or possibly the Bitter Springs Formation.

The Loves Creek Member of the Bitter Springs Formation underlies the Quandong Conglomerate at the Tempe Downs North section, but at the
Tempe Downs South section the Quandong is underlain by a thick covered interval above the Areyonga Formation. At the Tempe Downs North section, beds of the Quandong and Areyonga dip in opposite directions, and are separated by the Bitter Springs. Thus, the contact with the Bitter Springs probably represents a detachment surface or, less likely, an angular unconformity. Possibly the Quandong Conglomerate represents a part of the Areyonga Formation.

**Bitter Springs Formation**

**Name**

The Bitter Springs Formation originally was defined by Joklik (1955) as the Bitter Springs Limestone. This was later amended to its present name by Ranford et al. (1966) based on its content of siltstone, shale, dolostone, sandstone, and subsurface salt and anhydrite, in addition to limestone. Wells et al. (1967a) subdivided the Bitter Springs into the Gillen and Loves Creek members based on the unpublished work of Banks (1964). The Loves Creek Member underlies the Pertatataka Shale. In the eastern part of the Gardiner Range it unconformably underlies the Eninta Sandstone. Elsewhere in the Gardiner Range it underlies the Pertatataka Shale or Areyonga Formation. Also, near Tempe Downs Homestead, it underlies the Areyonga Formation and also the Quandong Conglomerate.

**Character**

The Bitter Springs Formation consists of brecciated dolomitic lime-
stone and calcareous dolostone. Its Loves Creek Member consists of medium-red calcareous siltstones with light yellow spots, and pale bluish-green dolostones and dolomitic limestones which often weather tan, pink, or golden brown with local white bleach spots. The dolostones and dolomitic limestones are micritic to fine-crystalline and generally are thin bedded. Gray chert lenses and nodules are present in the beds. The darker beds give a foetid odor from freshly broken surfaces. At the West Gardiner Range section, a concealed interval, 300 m wide, of possible siltstone and shale separate the Bitter Springs from the overlying Eninta. The lower part of this zone may contain the upper part beds of the Loves Creek Member. At the Tempe Downs North section, the Loves Creek contains stromatolites within intensely folded and/or brecciated beds. Here the Loves Creek forms a small rounded ridge with scarce exposures.

**Distribution**

The Bitter Springs Formation is distributed throughout the Amadeus Basin, and is best exposed along the northern margin and in the north-east (Wells et al., 1967a). In the Gardiner Range anticline the thickness of the Loves Creek Member exceeds 400 m (Oaks, 1985, oral communication).

**Age**

Wells et al. (1967a) regarded the Bitter Springs Formation as early to middle Late Proterozoic in age with provisional isotopic ages suggesting a possible Adelaidean age. An apparent maximum age of 1.17 B.Y
was determined on samples from the Bitter Springs taken from the Mt. Charlotte No. 1 well (Wells et al., 1970).

**Areyonga Formation**

**Name**

The Areyonga Formation was first defined by Prichard and Quinlan (1962). The type section was established at Ellery Creek, 82 km west of Alice Springs. The name comes from outcrops present near the Areyonga Native Settlement in the Gardiner Range. Wells et al. (1970) recognized two members.

**Character**

The Areyonga Formation is composed of sandstone, conglomeratic sandstone, orthoconglomerate, paraconglomerate, limestone, dolomitic limestone, and mudrocks (Oaks, 1983, p. L-18,19). The limestones and dolomitic limestones are pale blue to light bluish-green, fine-crystalline to micritic, and thin bedded. Locally, the beds are contorted or brecciated. Lenses and nodules of black to gray chert are present throughout the carbonate beds, which form recessive slopes. Unweathered colors of the sandstones, conglomeratic sandstones, and ortho- and paraconglomerates commonly are grayish orange pink (10R 8/2) to reddish brown (10R 4/6). The sandstones and sandy groundmass of the orthoconglomerates are poorly sorted, fine- to coarse-grained. The lenticular-shaped nature of the beds makes it difficult to correlate beds laterally. Beds weather massively, but generally are actually
medium-bedded with scour-filled bedding contacts. Clasts include: chert, dolostone, sandstone, and quartzite. Packets of sandy beds form two prominent strike ridges containing and separated by recessive intervals. At the Petermann Creek anticline section, a cherty unit is present in the lowest outcrops. The cherty unit consists of interbedded chert, chert breccia, calcareous siltstones, and calcareous sandstones. A similar cherty zone is present in a covered interval just below outcrops of the Quandong at the Tempe Downs North section (Appendices E & F).

Distribution

Wells et al. (1970) reported that exposures of the Areyonga are limited to the north-central and northeastern parts of the Amadeus Basin. Ranford et al. (1966) reported that the Areyonga Formation crops out in the cores of the Gardiner Range, Walker Creek, Petermann Creek, and Parana Hill anticlines. They estimated a thickness of 155 m near the Areyonga Native Settlement. Measured sections in the eastern and western limits of Areyonga outcrops in the Gardiner Range slightly exceed 200 m (Oaks, 1985, oral communication). Measured outcrops of the Areyonga in the Petermann Creek anticline and Deception Creek structure have respective thicknesses of 341 m and 228 m.

Age

Wells et al. (1970) considered the Areyonga Formation to be Late Proterozoic in age based on its stratigraphic position above the dated Bitter Springs Formation and below the dated Pertatataka Shale.
**Pertatataka Shale**

**Name**

The Pertatataka Series of Chewings (1935) included all units between the Bitter Springs and Arumbera formations. The Pertatataka Shale was defined by Prichard and Quinlan (1960, pp. 1, 18). Wells et al. (1967a) subdivided the Pertatataka into six members in the northeastern Amadeus Basin. These are the Ringwood, Limbla, Olympic, Waldo Pedlar, "Pioneer," Cyclops, and Julie members. Preiss et al. (1978) redefined the usage to restrict the Pertatataka to the shale sequence above the "Pioneer" Formation and below the Julie Formation. Oaks (1983) cited evidence that the Olympic and Waldo Pedlar underlie the redefined Pertatataka Shale, but that the "Pioneer" and Cyclops are part of it. The reference section is 5 km (3.5 miles) west of Ellery Creek.

**Character**

The Pertatataka Shale is a sequence of predominantly olive gray (5Y 5/2) and grayish green (5GY 6/1), thin bedded siltstones and shales with minor feldspathic, fine-grained sandstones. The unit exhibits parallel, lenticular-shaped, and wavy bedding, and locally is micaceous. Locally, current ripples are present. Mu and nu cross-stratification are present plus local load deformation. The Pertatataka is a recessive sequence, and the outcrops that are found in the Gardiner Range often resemble the descriptions of the "bookie beds" of the Cyclops Member (Wells et al., 1967b).
Distribution

The Pertatataka Shale is distributed throughout the northeastern and north-central parts of the Amadeus Basin (Wells et al., 1970). Wells et al. (1967a) reported that the Areyonga Formation underlies the Pertatataka, below the Arumbera ridge in the eastern James Ranges. In the Gardiner Range the Pertatataka is overlain unconformably by the Eninta Sandstone or overlain by the Julie Formation. The Pertatataka Shale is absent in the southeastern part of the Gardiner Range anticline, and field measurements by the author in the western part of the anticline suggest it may greatly diminish in thickness or thin to a feather edge farther westward in the subsurface. The Areyonga Formation appears to underlie conformably the Pertatataka Shale through most of the eastern Gardiner Range anticline. However, toward its western end, at the West Gardiner Range section, the Pertatataka rests on the Bitter Springs Formation. This basal contact is concealed, but may be a low-angle regional unconformity that appears to be conformable at individual outcrops. An overstep of the Arumbera, from the Julie onto the Pertatataka, southwestward within the Deep Well Range supports the interpretation of a low-angle regional unconformity (Oaks, 1985, oral communication). The Pertatataka Shale has an estimated maximum thickness of 300 m in the Gardiner Range (Wells et al., 1970).

Age

Wells et al. (1970) regarded the age of the Pertatataka Shale as Late Proterozoic. This is based on: (1) its stratigraphic position below Unit 1 of the "Arumbera Sandstone" (rare simple burrows), which is
interpreted as Late Proterozoic; (2) two radiometric age dates of $760 \pm 33$ M.Y. and $822 \pm 8$ M.Y. from well cuttings from shales assigned to the Pertatataka in Ooraminna No. 1 well and Mt. Charlotte No. 1 well, respectively (Wells et al., 1967b); and (3) a maximum radiometric age date of 1.17 B.Y. from the underlying Bitter Springs Formation (Wells et al., 1967b).

### Julie Formation

#### Name

Wells et al. (1967a) defined the Julie as a member of the Pertatataka Formation. Preiss et al. (1978) upgraded this unit to formational status. A type section was designated near the Ross River Chalet.

#### Character

The Julie Formation is composed of mudstone, dolomitic limestone, limestone, calcareous sandstone, and intraformational conglomeratic limestone. Unweathered colors are dominantly yellow gray (5Y 7/2) to bluish gray. The terrigenous rocks are generally fissile to thin-bedded and lenticular-shaped to wavy parallel. Locally, carbonate beds are brecciated. The carbonates are micritic to fine-crystalline. There are scattered pink to gray chert nodules (up to 2 cm in diameter) and chert lenses (up to 10 cm long). Locally, lenses of silicified ooids are present. A slight foetid odor is given from freshly broken surfaces of many carbonates in the lower part. The intraformational conglomerates
contain subrounded chert pebbles (up to 2 cm in diameter), and are present near the contact with the "Arumbera Sandstone." The upper Julie forms a rounded, low-lying strike-ridge which is covered by Spinifex. Laterally, where this subunit thins, the upper Julie becomes more recessive and concealed.

Distribution

The Julie Formation is distributed throughout most of the north-eastern and north-central parts of the Amadeus Basin (Wells et al., 1970). In the Gardiner Range it is unconformably overlain by the Eninta Sandstone. The Julie Formation conformably overlies the Pertatataka Shale in the central Gardiner Range. However, the Julie pinches out just west of the Missionary View section and is absent east of the Areyonga section. The only thickness of the Julie Formation measured for this report was at the Missionary View section, where the thickness is 12 m. The estimated maximum thickness of the Julie Formation in the Gardiner Range is less than 100 m.

Age

The Julie Formation is considered Upper Proterozoic based on its stratigraphic position below the Arumbera Sandstone and its equivalents, and above the dated Pertatataka and Bitter Springs formations (Wells et al., 1967b; Wells et al., 1970).
POST-ARUMBERA AND POST-QUANDONG
CONGLOMERATE STRATIGRAPHY

General Statement

Units that stratigraphically overlie the Arumbera Sandstone (Arumbera Sandstone, Eninta Sandstone, and "Quandong Conglomerate") and the Quandong Conglomerate will be reviewed in this section. Descriptions of contacts will be discussed under field descriptions.

The Arumbera Sandstone is overlain by the Chandler Formation, a shallow-marine unit containing carbonates, mudrocks, and evaporites in the subsurface (Wells et al., 1967a). In the Gardiner Range the overlying unit is mapped as the Tempe Formation. Following deposition of the Arumbera and tectonic uplift and erosion of part of Unit 2 (and possibly Units 3 and 4), deposition resumed with dominantly fine-grained terrigenous deposits and then carbonates. At the base of the sediments mapped as the Tempe Formation is a thin unit composed of foetid carbonates that form low steps. Therefore, the lower part of the previously mapped Tempe Formation in the Gardiner Range is considered Chandler Formation, and the Tempe Formation begins above the uppermost limestone bed of the Chandler. In the James Range 'B' anticline the carbonates overlying the Arumbera Sandstone were previously mapped as the Jay Creek Limestone. However, they resemble the Chandler Formation rather than the upper Shannon Formation typically mapped as Jay Creek in the western MacDonnell Ranges (Oaks, 1985, oral communication). Williams (1967) was first to recognize that this unit is the Chandler Formation, which
defines the highest possible "Arumbera" deposition. However, because the transition from sandstone to mudrock is gradual (through as much as 20 m locally), the contact between the Eninta Sandstone and the overlying Chandler Formation (or Tempe Formation where the Chandler is absent) was selected where the proportion of sandstone becomes less than siltstone and shale. This typically occurs at the top of a prominent dipslope which marks the end of dominantly sandstone or conglomeratic sandstone deposits. Both the Chandler and Tempe formations are shallow-marine deposits.

In the eastern James Ranges, the Chandler Formation has a sharp to gradational contact with the underlying Arumbera. In the east, the change occurs through less than 1 m, whereas in the central and western parts a gradual change (through 10-20 m) in the proportion of sand to mudrock takes place. In the James Range 'B' anticline a very sharp contact separates sandstones of the Arumbera and carbonates of the overlying Chandler Formation.

Along the western flank of the Deception Creek anticline, the Chandler Formation and undifferentiated Cambrian deposits unconformably overlie the Quandong Conglomerate. The only exposed limestone of the Chandler crops out, laterally, west of the Tempe Downs South section. This contact is concealed. Here and elsewhere, where the contact is concealed, it was picked at the uppermost exposed conglomeratic sandstone or sandstone bed, generally at the top of a dipslope. At the Tempe Downs North section, the contact was picked at the top of a zone of chert-cemented and chert-replaced siltstones and fine-grained sandstones, 2 m thick. The replacement along this contact, together with the sharp scour beneath this zone, suggest that an unconformity exists between the
Quandong and the overlying red sandstones of undifferentiated Cambrian deposits (mapped by Ranford and Cook, 1964). These red sandstones may represent the lower Tempe Formation.

**Undifferentiated Cambrian Deposits**

**Name**

The name Pertaoorrrta Series was amended by Madigan (1932a) from the name Pataoorrrta Series applied by Mawson and Madigan (1930). Prichard and Quinlan (1962) based the Pertaoorrrta Group on outcrops in the area of the Hermannsburg 1:250,000 geologic map (Wells et al., 1970).

**Character**

The Pertaoorrrta Group consists of a wide variety of lithologies. However in the vicinity of the Tempe Downs North section, the unnamed Cambrian deposits are comprised primarily of very fine- to fine-grained sandstones and mudrocks. Here the unweathered colors vary from pale yellow brown (10YR 6/2) to moderate reddish brown (10R 4/6). The mudrocks are fissile and the sandstones thin- to medium-bedded with local convolute bedding. Mu, nu, and lambda cross-stratification dominate in sandstones in the lower part, whereas omikron, alpha, beta, and gamma cross-stratification dominate in the upper part. The sandstones are micaceous, calcareous, and feldspathic. The undifferentiated Cambrian lithologies present in this vicinity generally form a recessive valley with local, low-lying strike ridges of sandstones.
Distribution

The undifferentiated Cambrian sediments are present in outcrops north of Tempe Downs Homestead, at Parana Hill and Wild Horse anticlines, and mapped as Winnall near Rogers Pass, to the southeast (Oaks, 1985, oral communication) as well as elsewhere in the Amadeus Basin. Laterally along strike, the Chandler Formation underlies this unit locally, whereas at the Tempe Downs North section this unit overlies the Quandong Conglomerate.

Age

The Pertaoorrta Group ranges in age from lowermost Cambrian (or possibly Late Proterozoic) to middle Late Cambrian based on its stratigraphic position above the dated Pertatataka Shale (760 ± 33 M.Y. and 822 ± 8 M.Y.) and below the dated Pacoota Sandstone (eight faunal assemblages dated by Joyce G. Tomlinson; Wells et al., 1970).

Tempe Formation

Name

The Tempe Formation was originally distinguished as a member of the Pertaoorrta Formation by Wells et al. (1965). Later, Ranford et al. (1966) raised the Tempe to formational status. The reference locality is in the Gardiner Range near the Areyonga Native Settlement.
Character

The Tempe Formation is composed of interbedded siltstone, shale, mudrock, and calcareous fine-grained sandstone. In the Gardiner Range these lithologies are dominantly grayish red to reddish brown on unweathered surfaces. The Tempe Formation contains fissile shales and up to medium-bedded sandstones which exhibit wavy parallel bedding. Mu, nu, kappa, and lambda are the major cross-stratifications present in the thin- to medium-bedded sandstones. Locally the sandstones are well cemented by silica. In the Gardiner Range the Tempe Formation forms a recessive valley. Outcrops are rare because the beds often are not resistant.

Distribution

Ranford et al. (1966) reported that the Tempe Formation has been mapped in the Gardiner Range, Walker Creek, Petermann Creek, and Parana Hill anticlines, and in several unnamed anticlines within the east-central part of the Amadeus Basin. They reported that the Tempe Formation has not been recognized east of Longitude 132° 30' E or south of Latitude 24° 30' S. Ranford et al. (1966) reported a measured thickness of 235 m for the Tempe Formation at the BMR's HvR-3 section, 1 km west of the Areyonga section of this report. The Tempe Formation is conformably overlain by the Illara Sandstone which forms a prominent strike ridge. A sharp contact is present between the Tempe Formation and the underlying Chandler Formation. It is picked at the top of the uppermost limestone bed of the Chandler.
Age

The upper part of the Tempe Formation at the Petermann Creek and Parana Hill anticlines yielded brachiopods, trilobites, hyolithids, and gastropods which Joyce G. Tomlinson considered to be lower Middle Cambrian (Wells et al., 1970, p. 53).

Chandler Formation

Name

The Chandler Limestone was defined by Ranford et al. (1966). Outcrops just above the Quandong Conglomerate, about 10 km northeast of Tempe Downs Homestead were designated as the type area. Oaks (1983) proposed that the name be changed to Chandler Formation based on the heterogeneous nature of the unit, and Jackson et al. (1984, Fig. 3) and Deckelman (1985) have adopted this recommendation.

Character

The Chandler Formation in outcrop consists of thin benches or low-lying ridges of carbonates separated by covered intervals. The outcrops are generally laterally discontinuous. The limestones and dolomitic limestones of the lower member are light gray (5YR 7/0), pale orange (10YR 8/2), and medium dark gray (N-4), laminated, and fine-crystalline. These carbonates contain numerous gray to black lenses and nodules of chert. The beds are folded or contorted, and locally brecciated. Freshly broken surfaces commonly yield a foetid odor. Wells et al. (1967a)
suggested that the covered part of the unit consists of red-brown shales and evaporites. Salt and anhydrite are present in the subsurface. The upper member apparently does not extend southward or westward from Conrad's (1981) area into the area of the present study.

**Distribution**

The Chandler Formation is distributed through much of the north-eastern and east-central parts of the Amadeus Basin (Wells et al., 1970). In the Gardiner Range, it forms a thin unit beneath the Tempe Formation. Here the Chandler appears to have a gradational contact with the Eninta Sandstone, whereas in the James Ranges 'B' anticline and the eastern James Ranges the contact varies from sharp to gradational. The lower member of the Chandler Formation overlies the Arumbera Sandstone at each of the measured stratigraphic sections in the study area. It also overlies the Arumbera in the southeastern part of the Deep Well Range, but overlies the Todd River Dolomite where Unit 4 of the Arumbera wedges in farther to the northeast (Conrad, 1981). Locally it overlies the Quandong Conglomerate either along a detachment surface or unconformably. Here the contact is distinguished by contorted limestone bedding resting on a covered interval.

In the Gardiner Range, the Chandler Formation is thickest and best exposed at the Katapata Gap and Pine Point sections. There, 5 and 12 m, respectively, above the Eninta, the first limestone beds are exposed. Eastward, at the Areyonga and Pattalindama Gap sections, the covered interval increased only slightly to 20 and 16 m, respectively. At the easternmost section, Namatjiras, the distance above the Eninta to the
lowest exposed limestone bed of the Chandler increases to 94 m. Exposures and thicknesses of the carbonate tongue are greatly diminished at these last three sections, but apparently offset by an increase in the underlying mudrock. At these locations, the Chandler is exposed only locally, generally within gullies. From the Katapata Gap section, the mudrock unit of the lower Chandler thickens considerably westward. At the Missionary View section, 9 km west of the Katapata Gap section, 82 m of mudrocks lie between the Eninta and the lowest exposed limestone bed of the Chandler Formation. At the West Gardiner Range section, limestones of the Chandler are separated from the Eninta by 200 m of mudrocks. This section represents the probable maximum total thickness of the Chandler Formation within the Gardiner Range. The thickest exposed carbonate sequence of the Chandler is 20 m, at the Katapata Gap section. Because outcrops are rare, actual thicknesses of the Chandler Formation at the measured sections were estimated by measuring to the base of the lowest exposed carbonate bed. Usually this was the only exposed carbonate bed.

Thickness of the lower mudstone subunit is difficult to determine because of the considerable internal deformation caused by post-depositional flowage and possibly by solution of evaporites (Oaks, 1983, p. L-86).

Age

The Chandler Formation is considered Early Cambrian in age on the basis of its stratigraphic position below the Tempe Formation and above the Arumbera Sandstone (Wells et al., 1970). Ranford et al. (1966)
included early Middle Cambrian along with Early Cambrian as the possible age of the Chandler Formation. Tribolites and hyolithids (including Biconulites), present in the upper subunit of the Chandler in the Purple Range, are considered Middle Cambrian in age by J. D. Gorter (Oaks, 1983, p. L-85).

Jay Creek Limestone (Chandler Limestone)

Name

The Jay Creek Limestone was defined by Prichard and Quinlan (1962). A reference locality was not designated in previous works. Field investigations showed that the carbonate sequence mapped as Jay Creek Limestone in the core of the James Range 'B' anticline (Ranford et al., 1966) resembles the Chandler Formation. For this reason the carbonate sequence above the "Quandong Conglomerate" at this location will be considered the Chandler Formation hereafter in this report.

Character

The Chandler Formation (Jay Creek Limestone) in the James Range 'B' anticline is a pale yellow brown (10YR 6/2), laminated to thin-bedded, fine-crystalline to micritic, limestone and dolomitic limestone. It contains thin, dark gray to black chert lenses. A foetid odor is given from freshly broken surfaces. Locally the beds are contorted or brecciated. Generally cryptalgalaminae and domes are the only fossil traces present. The carbonate beds form low-lying strike ridges and a recessive valley. Siltstones and shales are also associated with the concealed valley.
STRATIGRAPHY OF THE ARUMBERA SANDSTONE

General Statement

The Arumbera is dominantly red, feldspathic to arkosic, fine- to medium-grained sandstones. Nearly all of the beds are composed of terrigenous material. Locally, thin beds of carbonate and gypsum are present in Units 2 and 3 of the formation. In the eastern James Ranges, the Arumbera Sandstone forms an east-west trending strike ridge. From 197 m in the east, at the Billabong Bore East section, the Arumbera thickens westward to 267 m at the Billong Bore West section and then thins to 176 m at the Walkabout section (Fig. 5; Table 1). In the Gardiner Range, the Arumbera Sandstone thins considerably in the area southeast of the Areyonga Native Settlement between the Pine Point and Pattalindama Gap sections. Figure 6 and Table 1 show that the Arumbera thickens rapidly westward from 86 m, at the Areyonga section, to 320 m at the Pine Point section and 423 m at the Katapata Gap section, and then thins to 303 m at the West Gardiner Range section. East of the Areyonga section the Arumbera thickens rapidly to 250 m at the Pattalindama Gap and Namatjiras sections.

In the present area of study of the Arumbera, only the lower three of Conrad's (1981) four units are present. Unit 1 is an informal name for a recessive sequence of interbedded sandstones, siltstones, mudstones, and silt-shales, with minor beds of dolomitic and/or calcareous sandstone, carbonate, and gypsum. Unit 1 characteristically forms gentle slopes beneath cliff-forming sandstones of Subunit 2a. Unit 1 is herein divided
into four lithofacies (1a, 1b, 1c, and 1d). Lithofacies 1a characteristically forms a gentle slope below the step-forming conglomeratic lithofacies 1c. Lithofacies 1b, encountered only in the Gardiner Range at the Pine Point and Katapata Gap sections, forms a lens of sandstone and conglomeratic sandstone within lithofacies 1a. It may correlate with the basal conglomerate at the Billabong Bore East section in the eastern James Ranges and at the Bloodwood Bore section of Conrad (1981). Lithofacies 1b characteristically forms a low strike ridge. Lithofacies 1c is a step-forming conglomeratic unit located near the base of the prominent strike ridge. It overlies lithofacies 1a and underlies lithofacies 1d. Lithofacies 1c was present only in the Gardiner Range. Typically this lithofacies is rather thin. Lithofacies 1d characteristically forms moderate slopes within gentler slopes beneath the cliff-forming conglomeratic sandstones of lithofacies 2a. Locally thin tongues of lithofacies 2a are present within lithofacies 1d (Fig. 23).

Unit 2 is an informal name for a sequence of ridge-forming sandstones, recessive mudrocks, and conglomerates. Unit 2 has been subdivided into three lithofacies. Lithofacies 2a consists of cliff-forming sandstones that comprise the lower part of the unit. Lithofacies 2c is characterized by the upper orthoconglomeratic beds which form prominent dipslopes. Lithofacies 2b separates these two subunits and commonly intertongues with lithofacies 2c. This middle subunit generally forms slightly recessive areas along ridge crests in the eastern part of the James Ranges. These lithofacies correspond to Subunits 2a, 2b and 2c, respectively, of the Arumbera (Conrad, 1981), although these lithofacies are repeated vertically (Figs. 22, 23). Subunit 2c of Conrad (1981) appears to be minor or absent in the Gardiner Range.
Lithofacies 1c of the Eninta most nearly resembles Conrad's Subunit 2c. If lithofacies 1c were equivalent to Conrad's Subunit 2c, then lithofacies 2a, of this report, might be the correlative of the rest of Unit 4. However, essentially all other characteristics, suggest that lithofacies 2a is correlative with Conrad's (1981) Subunit 2a of the Arumbera, and that lithofacies 2c is essentially absent in the James Ranges 'B' anticline and the Gardiner Range.

Unit 1 unconformably overlies the Julie, Pertatataka, Areyonga, and Bitter Springs formations. Lithofacies 1a forms the basal deposits of the Arumbera Sandstone of the Gardiner Range. Within the region of the structural high between the Pattalindama Gap and Pine Point sections, lithofacies 1a is absent. There, lithofacies 1a, 1b, and 1c pinch out, probably by onlap, and lithofacies 1d locally forms the basal deposits of the Eninta (Fig. 23). In the James Ranges only lithofacies 1d and possibly 1b are present. In the eastern James Ranges lithofacies 1d and possibly 1b, at the Billabong Bore East section, unconformably overlie the Pertatataka Formation. In the James Ranges 'B' anticline the base of Unit 1 is not exposed. However, from nearby well reports it appears that lithofacies 1d rests unconformably on top of either the Areyonga or Bitter Springs Formation.

Unit 3 is an informal name for a recessive sequence of interbedded sandstones, siltstones, mudstones, and silt-shales. Unit 3 characteristically forms the gentle, recessive slopes above the prominent dip-slopes of lithofacies 2c.
Unit 1

Lower and Upper Contacts

Unit 1 is characterized by recessive sandstones, siltstones, and mudstones. In the eastern James Ranges the contact between Unit 1 and the underlying Pertatataka Formation is sharp. Probably it is a low-angle regional unconformity. Greenish-gray silty shales and siltstones of the Pertatataka underlie a thin lenticular, calcareous sandstone at the Billabong Bore East section. Here sandstone beds fill scours in the underlying shales of the Pertatataka. At the Walkabout section, the contact is concealed. However, about 150 meters laterally along strike to the west, a sharp color change was found at the contact. Below the contact, greenish-gray shale and siltstone are present, whereas, above the contact, moderate red to bluish-white siltstone and very fine-grained sandstone are present. There is a change in dip across the contact also. Beds of the underlying Pertatataka dip about 20° steeper than beds of the overlying Arumbera. However, beds within the Arumbera tend to increase in dip upsection, through about 75 m, until the dips are nearly those of the Pertatataka. The greatest changes in dip in Unit 1 tend to be in the silty and shaly intervals. At the Billabong Bore West section, the lower contact is gradational through 10 m. It is picked where calcareous cement diminishes and the color changes from the typical gray to greenish-gray micaceous mudrocks and very fine-grained sandstones of the Pertatataka to red and reddish-gray fine-grained sandstones of the Arumbera.

In the Gardiner Range, at the Pine Point, Katapata Gap, and
Missionary View sections, the contact between Unit 1 and the underlying Julie Formation is an angular unconformity. Light gray, thin-bedded dolomitic limestones of the Julie Formation underlie thin-bedded siltstones and sandstones of lithofacies 1a. Along the contact, the strike of the beds for the two units is similar, but dips in the Julie are 10° to 20° steeper than those in the overlying Arumbera. At the Katapata Gap section, the contact is sharp, and marked by scours and a color change from gray limestone and greenish-gray, very fine-grained sandstones to reddish brown fine-grained sandstones.

At the Pattalindama Gap section, an angular unconformity was observed. Here the pale red ("brick" red) sandstones, siltstones, and mudstones of lithofacies 1a fill scours in the olive gray beds of the Pertatataka, which dip 22° steeper. At the Areyonga section, this unconformity is marked by red conglomeratic sandstones of lithofacies 1c filling scours in the underlying silver gray siltstones of the Pertatataka. At the West Gardiner Range section, the contact between Unit 1 and the underlying Pertatataka is concealed. Here the contact was picked 12 m below the base of the lowest conglomerate bed of lithofacies 1c. This covered interval forms a gentle slope underlain by 12 m of red siltstones and very fine-grained sandstones found in dug pits. These are considered a part of lithofacies 1a. Below this interval, a wide covered valley is present.

Eastward in the Gardiner Range, the surface of unconformity at the base of Unit 1 cuts successively farther downsection (Fig. 23). At the Namatjiras section, beds of lithofacies 1a dip 41° to the south, whereas those of the underlying Areyonga are overturned and dip steeply to the north. East of this section, the Eninta rests unconformably on the
In the Gardiner Range, lithofacies 1a was present at all measured sections except the Areyonga section. Its upper contact is sharp and erosional, wherein conglomeratic beds of lithofacies 1c fill scours into it. Lithologies of lithofacies 1a form a recessive slope and valley.

Lithofacies 1b was found only at the Katapata Gap, Pine Point, and possibly the Billabong Bore East sections. It is a tongue of sandstones and conglomeratic sandstones with a sharp base cutting into lithofacies 1a. It pinches out laterally, and its upper contact grades into lithofacies 1a through one to two meters. Lithofacies 1b forms a low-lying strike ridge bounded both above and below by recessive, gentle slopes of lithofacies 1a.

Lithofacies 1c, present only in the Gardiner Range, has a very sharp erosional contact with the underlying lithofacies 1a (and, locally, with the Pertatataka). Lithofacies 1c is characterized by bench-forming conglomeratic sandstones and paraconglomerates. Lithofacies 1c consists of paraconglomerates cyclically interbedded with silty to muddy, very fine-grained sandstones. The upper contact of lithofacies 1c grades into lithofacies 1d through 1 to 5 m.

Lithofacies 1d conformably overlies lithofacies 1c in the Gardiner Range. In the eastern James Ranges it unconformably overlies the Pertatataka Formation and at the James Ranges 'B' anticline its base is not exposed but probably unconformably overlies either the Areyonga or Bitter Springs Formation. At the Missionary View, Pattalindama Gap, and Namatjiras sections, lenses of lithofacies 2a are present within lithofacies 1d. The upper contact of Unit 1 (and lithofacies 1d) is here defined as the base of the persistent cliff-forming sandstones of litho-
facies 2a which extend laterally throughout the James Ranges and Gardiner Range.

The persistent cliff-forming sandstones and conglomeratic sandstones of lithofacies 2a define the upper contact of Unit 1. These overlying sandstones and conglomeratic sandstones can be traced laterally on aerial photographs. The contact is sharp, and marked by shallow scours. These scours are filled by cliff-forming sandstones of lithofacies 2a. There is a sharp change from the recessive, pale red, mostly thin-bedded, micaceous, fine-grained sandstones and siltstones of Unit 1 to the medium- to thick-bedded sandstones and/or orthoconglomerates of Unit 2. This is an easily recognizable contact. At all sections the contact was also distinguished by changes in the unweathered colors. Siltstones and fine-grained sandstones of the underlying Unit 1 are generally moderate red, whereas the fine- to coarse-grained sandstones of the overlying lithofacies 2a are mostly light gray to grayish orange.

Weathered and Unweathered Colors

Unit 1 characteristically appears "brick" red from a distance. It has small white spots or thin white bands, visible from a short distance. The presence of iron oxide as matrix and/or cement probably accounts for the red to reddish brown colors of these sandstones and siltstones. Common unweathered colors of lithofacies 1a include dark reddish brown (10R 5/4), pale red (5R 6/2 and 10R 6/2), and pale reddish brown (10R 5/4). Weathered colors are similar, but lighter in value. They include light brown (5YR 6/4), pale reddish brown (10R 5/4), and grayish red (5R 4/2).
Lithofacies lb typically has unweathered colors which include yellow gray (5Y 7/2) and grayish orange pink (5YR 7/2 and 10R 8/2). Common weathered colors of lithofacies lb include pale reddish purple (5RP 6/2), light brown (5YR 6/4), and moderate reddish orange (10R 6/6).

Unweathered colors for lithofacies lc tend to be moderate red (5R 5/4), dark reddish brown (10R 3/4), and gray reddish purple (5RP 4/2). It predominantly weathers grayish red (5R 4/2), dusky red (5R 3/4), and moderate reddish brown (10R 4/6).

Unweathered and weathered colors of lithofacies ld are similar to those of lithofacies la. The unweathered colors typically are pale reddish brown (10R 5/4), grayish red (5R 4/2), dark reddish brown (10R 3/4), and pale red (5R 6/2). The common weathered colors for lithofacies ld include moderate reddish brown (10R 4/6), moderate brown (5YR 4/4), grayish red (5R 4/2), dark reddish brown (10R 3/4), pale reddish brown (10R 5/4), and light brown (5YR 6/4).

**Lithology and Grain Size**

Unit 1 contains interbedded sandstones, siltstones, mudstones, and silt-shales with local beds of carbonates and gypsum (Appendices E, F). The sandstones are generally thin- to medium-bedded and fine- to medium-grained, moderately sorted to muddy subarkoses and arkoses. Locally, they are micaceous and contain scattered granules or pebbles. Most of these fragments are chert with minor quartzite and vein quartz. Quartz, primarily in the form of overgrowths, is the chief cementing agent. Pore-filling sparry calcite is present locally, and together with iron oxide is a minor cement throughout the unit. Thin mudrocks, siltstones,
and shales are present at all measured sections. At the Billabong Bore East section, dolomitic sandstone and silty dolostone are interbedded with siltstone, sandstone, shale, and mudrock.

A conglomeratic marker bed, lithofacies lc, is present at all sections in the Gardiner Range. A medium- to coarse-grained sandstone lens lies near the base at the Billabong Bore East, Katapata Gap, and Pine Point sections.

Lithofacies la is characterized by interbedded, very fine- to fine-grained arkoses and subarkoses, and mudrocks. Most are micaceous, calcareous, and cemented by silica. Scattered mud pebbles are present locally within the sandstones. Most of the sandstones are poorly to moderately sorted. Many possess a muddy matrix disseminated with iron oxides, which form a cement, diagenetic residue, or matrix. Locally, thin beds of fine-crystalline to micritic dolostone are present. The proportion of sandstones tends to increase upsection. Much of lithofacies la is friable.

Lithofacies lb is composed primarily of medium- to coarse-grained subarkoses, conglomeratic subarkoses, and orthoconglomerates. This lithofacies contains only traces of mica and rare glauconite, and is calcareous locally. The sandstones consist of well- to moderately well-sorted, rounded grains. The orthoconglomerates and conglomeratic sandstones contain granule-sized clasts of rounded quartzite, vein quartz, and minor chert. Lithofacies lb coarsens upwards. At the Pine Point section, medium-grained sandstones are present at the base, whereas a granular orthoconglomerate lies at the top, with beds in between progressively increasing in average grain size upward. At the Katapata Gap section, beds of fine- to medium-grained sandstone with local siltstones
grade upward into medium- to coarse-grained sandstones.

Lithofacies 1c is composed of poorly sorted epiclastic polymict paraconglomerates, conglomeratic litharenites or feldspathic litharenites, and orthoconglomerates, with interbeds of muddy, very fine- to medium-grained sandstones. The paraconglomerates range from clast supported to matrix supported. The matrix consists of mud and fine- to medium-grained sand. The clasts consist of subangular to rounded chert, dolostone, limestone, sandstone, siltstone, silicified ooids, quartzite, vein quartz, and shale. The maximum recorded pebble size is 5 cm (Fig. 61).

Lithofacies 1d is characterized by moderately sorted fine- to medium-grained arkoses and subarkoses, with minor interbedded siltstones. The sandstones typically are micaceous, and contain traces of glauconite. Iron oxides and clay minerals comprise rare matrix. Clay partings can be found locally in this lithofacies. Scattered mud pebbles lie at the base of the sandstones locally.

Lateral Variations in Thickness

Conrad (1981) measured 115 m for Unit 1 at the Bloodwood section. Unit 1 thins to 56 m at the Billabong Bore East section, increases to 72 m thick at the Billabong Bore West section, thins to 44 m westward at the BMR Mt. Peachy section, and is 56 m thick farther west at the Walkabout section (Fig. 8; Table 1). Unit 1 reaches a maximum thickness of 240 m at the Katapata Gap section. From this section, it thins to the west and east (Table 1; Fig. 9). Westward, at the Missionary View and West Gardiner Range sections, Unit 1 is 162 m and 128 m thick,
respectively. Eastward, at the Pine Point and Areyonga sections, the thickness of Unit 1 is 217 m and 59 m, respectively. At the Pattalindama Gap section, Unit 1 has a thickness of 109 m, and, farther east at the Namatjiras section, its thickness is 86 m. In the James Ranges 'B' anticline, Unit 1 has a minimum thickness of 13 m.

In the Gardiner Range lithofacies 1a reaches its greatest thicknesses of 129 m and 122 m, respectively, at the Pine Point and Katapata Gap sections. Westward, lithofacies 1a is 27 m thick at the Missionary View section. It is concealed at the West Gardiner Range section, but a thickness of 12 m is estimated based on dug pits. Eastward, lithofacies 1a is absent at the Areyonga section and lithofacies 1a is only 13 m and 10 m thick, respectively, at the Pattalindama Gap and Namatjiras sections.

Lithofacies 1b is present only at the Billabong Bore East, Pine Point, and Katapata Gap sections, where it is only 9 m, 12 m, and 9 m thick, respectively. Lithofacies 1b may correlate laterally with the basal conglomeratic sandstone recognized at Conrad's Bloodwood section and at other sections measured farther east by Oaks (Conrad, 1981, Table 8). This basal sandstone is not present at the other measured sections of this report, but is about 4 m thick at Mt. Peachy Bore (Oaks, 1984, oral communication). Oaks (1983, p. L-73) suggested that this basal sandstone is likely the productive interval in the Dingo gas field.

Lithofacies 1c retains a fairly constant thickness through the Gardiner Range, although the paraconglomerates which characterize it diminish considerably in thickness at several of the measured sections. The maximum measured thickness of 17 m is at the Katapata Gap section. Elsewhere the thickness of this lithofacies ranges from 7 m, at the Missionary View section, to 11 m at the Pattalindama Gap section.
Although the lithofacies is distinguished by its conglomeratic beds, siltstones and very fine-grained sandstones are actually more abundant. The prominent appearance of the conglomeratic beds usually masks this characteristic of lithofacies 1c.

Lithofacies 1d is present throughout the James Ranges and Gardiner Range. It reaches a maximum thickness of 127 m at the Missionary View section. Westward it decreases to 105 m at the West Gardiner Range section. Eastward, it decreases to 50 m at the Areyonga section, then thickens to 85 m and 65 m for the Pattalindama Gap and Namatjiras sections, respectively. In the eastern James Ranges it reaches a maximum thickness of 72 m at the Billabong Bore West section.

Paleocurrent Directions

Rose diagrams illustrating paleocurrent directions of the Arumbera Sandstone are shown in Figures 13-20. Most paleocurrent patterns in Unit 1 are bimodal or polymodal. The general trend of paleocurrents for Unit 1 is to the north, northeast, east, and southeast.

The composite of Unit 1 paleocurrent patterns in the eastern James Ranges has a vector mean of 142° and a 95% confidence interval (C.I.) of 89° to 195°. A composite of all Unit 1 paleocurrent patterns in the Gardiner Range has a vector mean of 56° with a 95% confidence interval (C.I.) of 7° to 105°.

A composite of lithofacies 1c paleocurrents (35 measurements) has a vector mean direction of 42° with a 95% C.I. of 352° to 92°. The composite vector mean for lithofacies 1b (3 measurements) is 62° with a 95% C.I. of 25° to 99°. The composite vector mean for lithofacies 1d
(198 measurements) is 65° and the 95% C.I. is 9° to 107°. No paleo­
current directions were measured in lithofacies la.

The Katapata Gap, Pine Point, and Areylinga sections have a
significant southeasterly mode in their paleocurrent patterns for litho­
facies ld, whereas for lithofacies lc only the Pine Point and Areylinga
sections possess a southeasterly mode. In both lithofacies the rose
diagrams for each section show a secondary or primary mode toward the
north, northeast, or east.

Primary Inorganic Sedimentary Structures

Primary inorganic sedimentary structures present in lithofacies la
include: (1) laminated to thin beds (average: 7 cm, range: 1-10 cm);
(2) planar parallel to wavy parallel bedding; (3) local lenticular­
shaped bedding; (4) mu and nu major cross-stratification (less than 7 cm
thick lamina sets); (5) local lambda, kappa, omikron, alpha, beta, and
gamma cross-stratification; (6) planar parallel laminae (0.5-4.0 mm
thick); (7) wavy continuous and discontinuous laminae (0.5-3.0 mm
thick); (8) current ripples; and (9) parting lineations.

Primary inorganic sedimentary structures observed in lithofacies lb
include: (1) medium beds (average: 20 cm, range: 10-23 cm); (2) wavy
parallel to lenticular-shaped bedding; (3) alpha, beta, and xi major
cross-stratification (7-10 cm thick lamina sets); (4) minor mu and nu
cross-stratification; (5) planar parallel laminae (1-10 mm thick);
(6) cross laminae (3-12 mm thick); (7) wavy discontinuous laminae
(3-12 mm thick); and (8) current ripples.

Primary inorganic sedimentary structures observed in lithofacies lc
include: (1) thin to thick beds, mostly medium beds; (average: 25 cm, range: 4-30 cm); (2) lenticular-shaped bedding with local wedging channels; (3) scour into the underlying lithofacies; (4) local, normally graded bedding (paraconglomerate to conglomeratic sandstone to sandstone and/or siltstone); (5) pi and omikron with lesser alpha, beta, and gamma cross-stratification; (6) minor mu, nu, kappa, and lambda cross-stratification; (7) paraconglomerates are often non-laminated whereas the sandstones are generally laminated; (8) planar parallel and cross laminae (0.5-6.0 mm thick); (9) wavy discontinuous laminae (0.5-4.0 mm thick); (10) lithoclasts decrease in amount and size upward in lithofacies 1c; (11) local fining-upward sequences; and (12) local rounded clay pebbles (up to 2 cm in diameter).

Primary inorganic sedimentary structures present in lithofacies 1d include: (1) thin to medium beds (average: 20 cm, range: 1-26 cm); (2) planar parallel bedding with local wavy parallel bedding; (3) alpha, beta, and gamma major cross-stratification (7-15 cm thick lamina sets); (4) local intervals 2 to 5 m thick with xi cross-stratification dominant; (5) mu, nu, kappa, and lambda cross-stratification; (6) scattered clay partings; (7) local mud-pebble orthoconglomerate (1-3 cm thick); (8) planar parallel laminae (0.3-8.0 mm thick); (9) cross laminae (2.0-6.0 mm thick); (10) wavy discontinuous laminae (0.3-6.0 mm thick); (11) dunes (megaripples) which are often stacked in-phase (up to 1 m in wavelength and 50 cm in height); (12) climbing ripples (often superimposed on the dunes); (13) current ripples (locally stacked in-phase); (14) planar parallel laminae (many represent high flow regime based on their association with parting lineations and other high flow regime structures); (15) rare flaser bedding; (16) local herringbone cross-
stratification; (17) local desiccation shrinkage cracks; (18) rare lenticular-shaped bedding with wedging channels (generally less than 10 m in lateral extent); (19) local Liesegang banding; (20) parting lineations; (21) load deformation; (22) convolute bedding; (23) load casts; (24) slumped bedding and cross-stratification; (25) local scoured bedding contacts; (26) ball-and-pillow structures; and (27) local water-escape structures.

Biogenic Structures

No biogenic structures were observed in Unit 1.

Porosity and Permeability

Porosity and permeability of Unit 1 are generally poor to moderate, except for the basal sandstones of lithofacies 1b where porosity of 10 to 15% is present. Elsewhere, generally, only a trace is present (Appendix E). In contrast, weathered surfaces generally exhibit good porosity due to grain dissolution and fracture porosity developed along bedding planes.

Field tests of lithofacies 1a indicate only a trace to 3% porosity at all measured sections except in the upper 4 m at the Pattalindama Gap section where 12% porosity was estimated. Lithofacies 1c exhibited poor porosity and permeability at all sections except the Areyonga and Pine Point sections where porosities of 10 to 12%, respectively, were estimated. Intense and deep surficial weathering probably increased the porosities at these two sections.

Lithofacies 1d generally shows poor to moderate porosity and
permeability. An interval 15 m thick near the top of lithofacies ld at the West Gardiner Range section, an interval 20 m thick in the central part of lithofacies ld at the Pine Point section, and the lower 20 m of lithofacies ld at the Areyonga section are the only intervals exhibiting porosities of 10 to 12% (Appendix E).

**Unit 2**

**Internal and Upper Contacts**

Unit 2 is overlain by Unit 3 in the eastern James Ranges and by the Chandler Formation in the James Ranges 'B' anticline and Gardiner Range. The upper contact is sharp. Unit 2 forms cliffs and dipslopes, whereas Units 1 and 3, and the Chandler generally are recessive in nature. Decreases in the average grain size and average thickness of the beds also occur at the upper contact of Unit 2.

The contact between lithofacies 2a and lithofacies 2b is marked by a decrease in the average grain size and by a change in the unweathered colors. The contact is gradational through 2 to 5 m, and was picked where mudrocks begin to dominate upward. Rocks of lithofacies 2b show a return to reddish unweathered colors. There is also a change in topographic expression. Rocks of lithofacies 2b tend to form recessive areas along the ridge crest, whereas sandstones of lithofacies 2a tend to be prominently exposed in the cliffs below. lithofacies 2b is also characterized by interbeds of dolomitic sandstones and rare silty dolostones, along with an increase in the proportion of mudrocks, whereas these lithofacies are rare in lithofacies 2a.
A tongue of lithofacies 2a lies above lithofacies 2b at the Namatjiras, Pattalindama Gap, Katapata Gap, Missionary View, and West Gardiner Range sections. A gradational contact exists between the top of lithofacies 2a and the base of lithofacies 2b, whereas a sharp contact exists between the base of lithofacies 2a and the top of lithofacies 2b.

The contact between lithofacies 2b and 2c is typically sharp between beds but the lithofacies intertongue. Orthoconglomerates of lithofacies 2c fill scours into the underlying sandstones and siltstones of lithofacies 2b at most contacts. However, beds in the upper part of lithofacies 2b at the Billabong Bore West section intertongue with beds of lithofacies 2c. Here the contact of lithofacies 2c was picked at the base of the lowest conglomeratic sandstone. Lithofacies 2c is generally distinct due to its conglomeratic nature. These orthoconglomerates often form prominent steps in a long dipslope, whereas members of lithofacies 2b are typically recessive. Lenses of lithofacies 2c are present in the upper half of lithofacies 2b at the Walkabout and Billabong Bore West sections, and appear to be represented in the strip log of the BMR Mt. Peachy section (Wells et al., 1967b). At the Billabong Bore East section no lenses of lithofacies 2c were present within lithofacies 2b. Conrad (1981) reported no lithofacies 2b at his Bloodwood section.

The contact between lithofacies 2c and the overlying Unit 3 is gradational through 5 to 20 m as thicker intervals of mudrocks separate resistant ledges of orthoconglomerates. There is a pronounced change in lithology and topographic expression across this boundary. The basal part of Unit 3 is recessive sandstone and siltstone, whereas lithofacies 2c forms a prominent dipslope comprised of steps of conglomeratic sandstones and pebbly orthoconglomerates. The contact is picked at the top
of the uppermost "purple" or "maroon" conglomerate bed of lithofacies 2c at the Billabong Bore East and Walkabout sections. Here the contact is distinct and sharp. At the Billabong Bore West section, Unit 3 contains a lens of lithofacies 2c conglomerate. Here the contact was picked at the top of the conglomeratic sequence that formed a prominent strike ridge and dipslope. The higher conglomeratic lens, included in Unit 3, is recessive and forms a gentle slope. The underlying fine-grained sandstone beds grade upward into this thin sequence of orthoconglomerates through 2 to 3 m.

Where Unit 2 is overlain by the Chandler Formation, the contact appears conformable and often gradational locally, but probably represents a low-angle regional unconformity (Oaks, 1985, oral communication). The contact between Unit 2 and the Chandler Formation was picked where the proportion of siltstones became greater than the proportion of sandstones. Above the contact, lithologies of the lower part of the Chandler Formation are dominated by siltstones, shales, and mudrocks. Below the contact, Unit 2 is dominantly sandstones but contains minor interbedded siltstones. At the measured sections where lithofacies 2b marks the upper limits of Arumbera deposition, the amount of siltstones increases upward within lithofacies 2b relative to the amount of sandstones, and the contact with the Chandler appears to be gradational. Where lithofacies 2a represents the highest Arumbera deposits, the contact is sharp. Usually at these locations a resistant conglomeratic sandstone marks the uppermost bed of the Arumbera Sandstone. Usually this contact between the Arumbera Sandstone and the Chandler Formation lies at the base of a prominent dipslope at the top of Unit 2. At the Katapata Gap and Pine Point sections the limestone
beds in the Chandler are best exposed. There they lie 5 and 12 m, respectively, above the contact with the Arumbera Sandstone. Eastward, at the Areyonga and Pattalindama Gap sections, the first exposed limestone beds are 20 m and 16 m, respectively, above the highest sandstone bed of the Arumbera. At the easternmost section, Namatjiras, the distance above the Arumbera-Chandler contact to the first exposed limestone increases to 94 m. At the Missionary View section this interval is 82 m, but increases considerably to an estimated 200 m at the West Gardiner Range section. Because limestone outcrops of Chandler are rare, minimum thicknesses of the Chandler Formation were estimated using the measured distance to the first exposed limestone (usually this was the only exposed limestone).

Weathered and Unweathered Colors

Within Unit 2, lithofacies 2a is generally lighter in color than lithofacies 2b. Lithofacies 2a is characterized by grayish orange pink (5YR 7/2), light olive gray (5R 5/2), and grayish purple (5P 4/2) unweathered colors. Its weathered colors tends to be light brown (5YR 5/6 to 5YR 6/4). Unweathered colors for lithofacies 2b tend to be dusky red (5R 3/4), grayish red (5R 4/2), dark reddish brown (10R 6/6), and moderate red (5R 5/4). Rocks of lithofacies 2b generally weather pale red (5R 6/2), light brown (10R 5/4), moderate reddish brown (10R4/6), or dark reddish brown (10R 3/4). Rocks of lithofacies 2c have unweathered colors of grayish red purple (5RP 4/2), pale red (5R 6/2), and grayish red (10R 4/2). These generally weather pale reddish brown (10R 5/4), very dusky red purple (5RP 2/2), or light brown (5YR 5/6).
The colors of lithofacies 2c are distinctive, and commonly are designated informally as purple or maroon. Manganese stains are present along some bedding planes locally at the Billabong Bore West section in lithofacies 2a and 2c.

**Lithology and Grain size**

Lithofacies 2a consists of fine- to coarse-grained sandstones, conglomeratic sandstones, and orthoconglomerates (Appendices E, F). The sandstones are subarkosic to arkosic, and are mostly fine- to medium-grained. Lithofacies 2c is dominated by orthoconglomerates and conglomeratic sandstones. The orthoconglomerates and conglomeratic sandstones have a very fine- to coarse-grained sandy groundmass (mostly fine- to medium-grained). Lithoclasts range from granule- to pebble-sized, and are up to 8 cm in diameter (Fig. 62). Subangular to subrounded chert is the most common lithoclast. Other lithoclasts found are subrounded to rounded quartzite, vein quartz, and shale pebbles. Locally, lenses of well sorted, well rounded, granular orthoconglomerates are present in lithofacies 2a. Lithologies of lithofacies 2a and 2c are well cemented by silica, as overgrowths and mosaics.

Lithofacies 2b is composed of very fine- to medium-grained, poorly to moderately well sorted arkoses. Locally, siltstones, mudstones, limestones, and dolostones are interbedded with the sandstones. Locally, beds of lithofacies 2b are slightly calcareous and micaceous. Most beds of this lithofacies are cemented by silica and iron oxides. At the Billabong Bore West section, thin lenses of gyspum are present in lithofacies 2b, and thin intervals of conglomeratic sandstone may be present.
locally. The conglomeratic sandstone is poorly sorted, and the clasts are mostly granules.

**Lateral Variations in Thickness**

In the James Ranges, Unit 2 reaches its maximum thickness of 166 m at the Billabong Bore West section. From this section it thins both to the west and to the east. At the BMR Mt. Peachy section it has a thickness of 119 m, and continues to thin westward to 91 m and 45 m at the Walkabout and Tidenvale sections, respectively. Unit 2 thins eastward to 106 m at the Billabong Bore East section and 110 m at Conrad's (1981) Bloodwood Bore section (Fig. 10; Table 1).

Unit 2 reaches its maximum thickness of 230 m at the Missionary View section in the Gardiner Range (Fig. 23; Table 1). To the west, at the West Gardiner Range section, it thins to 175 m. Eastward it decreases to 183 m, 103 m, and 27 m at the Katapata Gap, Pine Point, and Areyonga sections, respectively. Eastward from the Areyonga section, Unit 2 increases in thickness to 141 m and 164 m at the Pattalindama Gap and Namatjiras sections, respectively. Thinning between the Pine Point and Pattalindama Gap sections is significant.

In the eastern James Ranges, lithofacies 2a has a maximum thickness of 38 m at the Billabong Bore West and BMR Mt. Peachy sections. Lithofacies 2a thins westward to 9 m at the Walkabout section. Eastward it thins to 18 m at the Billabong Bore East section. To the northeast, at Conrad's (1981) Bloodwood Bore East section, lithofacies 2a has a thickness of 29 m.

Lithofacies 2a has a maximum total thickness of 84 m at the
Namatjiras section. At the Missionary View section, lithofacies 2a totals 82 m. Elsewhere the total thickness of lithofacies 2a ranges from 62 m at the West Gardiner Range section to 11 m at the Pine Point section. At the two sections where the greatest thicknesses of lithofacies 2a are present, lenses of lithofacies 2a are present within lithofacies 1d and 2b. At the Pine Point and Areyonga sections, where the thicknesses of lithofacies 2a are least, no lenses of lithofacies 2a are present within lithofacies 1d or 2b. Figure 23 suggests that the tongue of lithofacies 2a within lithofacies 2b was present but subsequently eroded prior to the deposition of the Chandler.

Lithofacies 2b and 2c intertongue at the Walkabout and Billabong Bore West sections (Fig. 22). At the Walkabout section, lithofacies 2b has a combined thickness of 63 m, whereas lithofacies 2c has a combined thickness of 20 m. At the Billabong Bore West section, lithofacies 2b has a combined thickness of 111 m, whereas lithofacies 2c has a combined thickness of 17 m. At the Billabong Bore East section, these two lithofacies do not intertongue. The thickness for lithofacies 2b at this section is 64 m, whereas lithofacies 2c has a thickness of 24 m. To the northeast, Conrad (1981) did not recognize any lithofacies 2b at his Bloodwood Bore section, where lithofacies 2c has a thickness of 81 m. It appears that lithofacies 2b pinches out eastward in this area.

Lithofacies 2b reaches a maximum measured thickness of 148 m at the Missionary View section. Eastward at the Katapata Gap, Pine Point, and Areyonga sections, its total thickness decreases to 124 m, 92 m, and 12 m, respectively. Farther eastward, at the Pattalindama Gap and Namatjiras sections, lithofacies 2b increases to 120 m and 80 m, respectively. Westward at the West Gardiner Range section, its thickness
is 113 m. A very sharp decrease in thickness takes place between Pattalindama Gap and the Areyonga sections (Fig. 23).

**Paleocurrent Directions**

Rose diagrams illustrating paleocurrent directions for Unit 2 are shown in Figures 14-16 and 18-19. A moderate to strong unimodal pattern exists in lithofacies 2a and 2c at Billabong Bore East and in lithofacies 2a at Walkabout.

For paleocurrents of lithofacies 2a, the Pine Point pattern has a primary mode to the east-southeast, whereas the Namatjiras pattern has modes to the north, northeast, east, and west. The remaining sections have a primary modal direction to the north or northeast with a secondary mode to the east or southeast.

All sections where paleocurrents of lithofacies 2b were measured show a primary modal direction to the north or northeast. The Namatjiras section has an additional primary mode to the northwest, whereas the remaining sections have a secondary modal direction to the east or southeast.

A composite of all Unit 2 paleocurrent directions in the Gardiner Range has a vector mean of 40° with a 95% level C.I. of 354° to 86°. Here, both composites of lithofacies 2a and 2b have vector means of 40°. Lithofacies 2a has a 95% level C.I. of 355° to 80° and lithofacies 2b has a 95% level C.I. of 353° to 87°.

The composite of paleocurrent directions in the eastern James Ranges of lithofacies 2a has a vector mean of 152° and a 95% level C. I. of 94° to 210°, whereas the composite of lithofacies 2b has a vector mean
of 106° and a 95% level C. I. of 38° to 174°. For lithofacies 2c the
composite of paleocurrents has a vector mean of 153° and a 95% level
C. I. of 97° to 209°. A composite of all paleocurrents of Unit 2 has a
mean vector of 149° with a 95% level C. I. of 86° to 212°. The vector
mean for the lithofacies 2a at the Tidenvale section is 99° with a 95%
level C. I. of 32° to 166°.

**Primary Inorganic Sedimentary Structures**

Primary inorganic sedimentary structures observed in lithofacies
2a include: (1) thin to thick beds (average: 60 cm, range: 4-100 cm),
mostly medium beds; (2) lenticular-shaped bedding with local wedging
channels with 10-20 m in lateral extents; (3) pi major cross-stratifi­
cation (10-30 cm thick lamina sets); (4) local omikron, alpha, beta, and
gamma cross-stratification (10-25 cm thick lamina sets); (5) rare xi,
kappa, lambda, mu, and nu cross-stratification; (6) scour-filled bedding
contacts; (7) local normally graded beds wherein orthoconglomerates
grade upward into sandstones; (8) mud pebbles and casts of mud pebbles
(up to 6 cm in diameter); (9) local lenses of well sorted, rounded,
granular orthoconglomerate; (10) local parting lineations; (11) local
clay partings; (12) planar parallel laminae (2-8 mm thick); (13) cross
laminae (3-15 mm thick); (14) brush marks; (15) local load deformation;
(16) rare slumped bedding and cross-stratification; (17) rare convolute
bedding; (18) minor ball-and-pillow structures; (19) current ripple
marks; (20) local bedding surfaces with symmetric ripples with
wavelengths of 2 cm; (21) local dunes (probably subaqueous) with
wavelengths up to 52 cm and heights up to 30 cm; (22) local climbing
ripples; (23) local clay partings; (24) local herringbone cross-
stratification at the Billabong Bore East section; and (25) load casts.
The Walkabout section exhibited an overall fining-upward sequence.

Primary inorganic sedimentary structures present in lithofacies
2b include: (1) thin to medium beds (average: 30 cm, range: 1-50 cm);
(2) common parallel laminae; (3) mostly planar parallel bedding with
local wavy parallel and lenticular-shaped bedding; (4) local scour-
filled bedding contacts; (5) parting lineations; (6) alpha, beta, and
gamma major large-scale cross-stratification (7-13 cm thick lamina
sets); (7) minor pi and omikron large-scale cross-stratification (7-
13 cm thick lamina sets); (8) lambda and kappa major small-scale cross-
stratification; (9) minor mu and nu cross-stratification; (10) xi cross-
stratification common locally; (11) common dunes (megaripples) with
wavelengths of 1-2 m and heights up to 40 cm; (12) climbing ripples
(often superimposed on the dunes); (13) vertical sequences of planar
parallel laminae (base) --> megaripple --> planar parallel laminae -->
convolute bedding or slumped solitary type cross-stratification -->
planar parallel laminae (top); (14) current ripples; (15) local mud-
pebble orthoconglomerate in basal parts of beds (up to 3 cm thick) and
locally just above beds with convolute bedding; (16) mud pebbles and
casts of mud pebbles (up to 5 cm in diameter); (17) scattered clay
partings; (18) wavy discontinuous and continuous parallel laminae
(1-7 mm thick); (19) high-velocity planar parallel laminae and parting
lineations; (20) homogeneous cross laminae (1-9 mm thick); (21) planar
parallel laminae (0.5-10 mm thick); (22) sets of ripples and dunes which
are stacked with their troughs and crests in-phase; (23) minor flaser
bedding; (24) local traces of glauconite; (25) load deformation;
(26) slumped bedding and cross-stratification; (27) load casts; (28) water-escape structures; (29) ball-and-pillow structures; and (30) convolute bedding.

Primary inorganic structures observed in lithofacies 2c include:
(1) medium to thick beds (average: 50 cm, range: 10 to 90 cm), (2) scour-filled bedding contacts; (3) wedging channels and lenticular-shaped bedding; (4) channels with lateral extents of 10 to 15 m; (5) alpha, beta, and gamma major cross-stratification, with lesser xi and pi cross-stratification; (6) pebbles and casts of mudrocks up to 6 cm in diameter; (7) load deformation; (8) local slumped bedding and cross-stratification; and (9) local ball-and-pillow structures. At the Billabong Bore West section, lithoclasts within the conglomerate beds tend to increase in size and abundance upsection. Locally, there are several fining-upward sequences within conglomeratic bedsets of lithofacies 2c.

**Biogenic Structures**

In the James Ranges 'B' anticline, local beds within lithofacies 2a have been subjected to mixing, possibly from organic activity. This activity resulted in the local destruction of primary inorganic sedimentary structures. Minor traces of simple vertical burrows were also observed. At the Pattalindama Gap section, questionable shallow vertical burrows 1-2 cm deep were observed in the uppermost 2 m of the Eninta. This interval belongs to a lens of lithofacies 2a. Also, within the upper tongue of lithofacies 2a at the Katapata Gap section, similar problematic structures were observed. Perhaps they are associated to the
weathering out of clay pellets.

At the Billabong Bore West section possible vertical burrows were found in lithofacies 2b. There, unbranched shallow vertical tubes 1 cm in diameter are present. Possibly they are water-escape tubes.

**Porosity and Permeability**

Overall, porosity and permeability of Unit 2 are greater than those of Unit 1. However, intervals of good porosity and permeability are generally minor.

In the eastern James Ranges, lithofacies 2a porosities and permeabilities increase toward the east. At the Walkabout section they are poor in lithofacies 2a, whereas, at the Billabong Bore East section, they are moderate to good. Between these two sections, the porosity and permeability of lithofacies 2a are poor to moderate.

In the James Ranges 'B' anticline, lithofacies 2a contains two intervals (total of 12 m) near the middle that exhibit good porosity (>10%). Here the remaining beds demonstrate poor to moderate porosity (trace to 10%).

In the eastern James Ranges, the best porosities and permeabilities in lithofacies 2b were found in the west, just below the upper tongue of orthoconglomerate of lithofacies 2c. Sandstones totalling 12 to 45 m thick in the three sections measured showed good porosity and permeability in lithofacies 2b. Lithofacies 2c generally exhibits poor porosity and permeability at all sections because it is well cemented by silica.

In the Gardiner Range, the cliff-forming lower part of lithofacies 2a, contains mostly good porosity and permeability. This is the most
consistent zone exhibiting good field-test results for porosity and permeability. Otherwise only local intervals showing good readings were measured in Unit 2.

At the Namatjiras section, an interval of good porosity (>10%) 25 m thick extends from the base of the lower lithofacies 2a into the lower part of lithofacies 2b. Elsewhere at this section, lithofacies 2b has moderate to good porosity (5 to 10%) between 135-150 m and 175-200 m above the base of the Eninta. The remaining porosities of Unit 2 at this section were poor to moderate (trace to 5%). At the Pattalindama Gap section, good porosity (>10%) was found within the lower part of lithofacies 2a and also in the tongue of lithofacies 2a at the top of the Eninta (Fig. 21). Within lithofacies 2b at this section, good porosity was measured between 170-185 m, and moderate porosity (4-9%) was found between 155-160 m and 222-227 m. The remaining parts of Unit 2 at this section have poor porosity.

Unit 2 at the Areyonga section shows good porosity and permeability throughout the unit except for the 70-77 m interval. At the Pine Point section, good porosity was found only in lithofacies 2b between 252-260 m. Here lithofacies 2a has only poor to fair porosity. Most of the remaining parts of lithofacies 2b have moderate porosity (5 to 10%), although some portions are poor (Appendix E). At the Katapata Gap section no intervals of good porosity were found, and the average porosity for Unit 2 was only 4 to 5%. At the Missionary View section, good porosity within lithofacies 2b was found between 275-298 m. Moderate porosity (5 to 10%) was found in lithofacies 2b between 220-255 m and 315-340 m. Elsewhere at this section, the porosity is poor to fair. At the West Gardiner Range section, good porosity was measured in
lithofacies 2a between 120-140 m and between 280-291 m, and at the following intervals within lithofacies 2b: 193-197 m, 208-217 m, 235-241 m, 280-291 m, and 294-303 m. The interval between 162-192 m exhibits moderate porosity. The remaining intervals of Unit 2 at this section have poor to fair porosity (trace to 5%).

Unit 3

Upper Contact

Unit 3 is overlain by the lower member of the Chandler Formation at all stratigraphic sections. This contact is often concealed. Although probably sharp, it is possible that the upper contact is gradational. At the Walkabout and Billabong Bore West sections, a covered interval 75 m and 50 m thick, respectively, separates exposures of Unit 3 and the overlying Chandler Limestone. Here the contact was picked at the base of the gentle slope formed by the uppermost exposed beds of Unit 3. Shallow pits dug in the covered interval failed to reach bedrock. Probably this interval is composed of mudrocks interbedded with carbonate beds of the Chandler. At the Billabong Bore West section, the contact was followed 400 m laterally along strike to a sharp exposed contact. At the Billabong Bore East section, the contact between Unit 3 and the overlying Chandler Formation is sharp. Here sandstones of the Arumbera and limestones of the Chandler lie within 0.5 m of each other. A covered interval 50 m thick overlies this contact. Above the covered interval, limestone beds are exposed. Because Unit 4 of the Arumbera and all of the Todd River Dolomite are absent, the contact probably is a low-angle
Weathered and Unweathered Colors

Sandstones and siltstones of Unit 3 generally weather light brown (5YR 5/6 or 5YR 6/4) or pale yellow brown (10YR 6/2). On fresh unweathered surfaces, they are pale red (5R 6/2), grayish orange pink (10R 8/2), and grayish red (10R 4/2). The conglomeratic sandstones at the Billabong Bore West section have an unweathered color of pale brown (5YR 5/2), and weather grayish red (5R 4/2).

Lithology and Grain Size

Unit 3 is comprised of interbedded sandstones and siltstones with minor orthoconglomerates and conglomeratic sandstones. The sandstones are very fine- to fine-grained arkoses and lithic felsarenites. Locally, they are micaceous and/or calcareous. Sorting is poor to moderately good. The orthoconglomerates and conglomeratic sandstones generally contain 10 to 30% granule-size clasts in a fine- to coarse-grained sandy groundmass. Subangular chert fragments range up to 1 cm in diameter. Other clasts, mostly quartzite and vein quartz, are subrounded to well-rounded, and range up to 0.5 cm in diameter.

Lateral Variations in Thickness

Unit 3 exhibits a fairly uniform thickness in the study area (Fig. 12). The maximum thickness of 41 m is at the BMR Mt. Peachy section. Unit 3 is 28 m and 29 m thick at the Walkabout and Billabong Bore West
sections, respectively, and 35 m thick at the Billabong Bore East section. Conrad (1981) measured 36 m of Unit 3 at his Bloodwood Bore section. Apparently there is a gradual lateral thickening to the northeast, where Unit 4 is present and post-depositional erosion was less. The BMR's Mt. Peachy section may be a local area of lesser post-depositional erosion of Unit 3, because the unit thins westward from this location, and eastward to the Billabong Bore sections.

**Paleocurrent Directions**

Only one paleocurrent direction was taken in Unit 3. Measured at the Billabong Bore East section, it was 138°. Most of Unit 3 was concealed or highly weathered, which prevented the collection of paleocurrent data.

**Primary Inorganic Sedimentary Structures**

Primary inorganic sedimentary structures observed in Unit 3 include: (1) thin to medium beds (average: 15 cm, range: 1 to 26 cm); (2) wavy irregular to lenticular bedding with minor parallel bedding; (3) common shallow scours; (4) local parting lineations; (5) mu and nu cross-stratification in sandstone and siltstone beds; (6) pi cross-stratification in conglomeratic beds; (7) scattered mud pebbles and casts of mud pebbles that reach 7 cm in diameter in the conglomerate beds; (8) local current ripples; and (9) local load deformation.
Biogenic Structures

No biogenic structures were observed in Unit 3. Elsewhere, Conrad (1981) and Hamp (in prep.) have found rare to common trails and burrows in Unit 3. Oaks (1984, oral communication) found abundant trails and burrows in Unit 3 just west of Jay Creek Native Settlement in the MacDonnell Ranges.

Porosity and Permeability

Porosity and permeability in Unit 3 are generally poor. At the Billabong Bore East and Walkabout sections, good porosity and permeability are present in an interval 8 m thick near the top of Unit 3 (Appendix E). At both of the Billabong Bore sections an interval near the base of Unit 3 exhibits moderate porosity and permeability. These results may be due to weathering near the present surface, because fresh, unweathered samples could not be obtained for this interval. Porosity and permeability in Unit 3 in the subsurface may be less. Besides weathering, the only observed porosity within Unit 3 was due to fracturing, microfracturing, and separation along bedding planes and laminae.
QUANDONG CONGLOMERATE

General Statement

The Quandong Conglomerate forms a horseshoe-shaped ridge on the western end of the Deception Creek anticline. The Quandong is 168 m thick on the north limb of this prominent ridge, whereas its thickness is 130 m on the southern limb, 500 m to the south. The lenticular-shaped bedding of this unit makes it very difficult to correlate beds laterally. However, the orthoconglomerates and conglomeratic sandstones that form the ridge crest contain abundant cross-stratification, whereas the orthoconglomerates above and below it rarely exhibit cross-stratification. An unmeasured but traversed unit of the Quandong on the eastern end of the Deception Creek anticline showed similar cross-stratification at the highest ridge crest.

The Quandong Conglomerate is divided into three lithofacies. Lithofacies A1 is an informal name for recessive sandstones and minor granular orthoconglomerate lenses. These beds characteristically form the gentle slopes beneath the prominent ridge-forming members of lithofacies A2. A covered interval underlies lithofacies A1. Beneath the covered interval, laterally along strike, a cherty sequence overlies beds of the Bitter Springs Formation.

Lithofacies A2 is an informal name for the prominent ridge-forming sequence of thick-bedded to massive orthoconglomerates interfingered with thick-bedded conglomeratic sandstones, granular orthoconglomerates, and sandstones. Both the upper and lower contacts of this lithofacies
are sharp and erosional. The contact with lithofacies A3 is at the base of the prominent dipslope on the upper orthoconglomerates of lithofacies A2. Both the upper and lower contacts of lithofacies A2 are marked by a change in topographic expression.

Lithofacies A3 is an informal name for recessive chert-replaced and chert-cemented siltstones, shales, and very fine- to fine-grained sandstones. This lithofacies and its upper contact are often concealed. However, at the Tempe Downs North section, lithofacies A3 is exposed and shows a very sharp erosional contact with the underlying lithofacies A2 and a scour-filled contact with the overlying siltstones and very fine-grained sandstones of the undifferentiated Cambrian deposits. The nature of lithofacies A3 suggests that it may represent a weathered surface exposed prior to Chandler deposition or Tertiary silcrete replacement which follows the upper Quandong contact.

Stratigraphy and lithology of the Areyonga Formation in the Deception Creek anticline and in the Petermann Creek anticline suggest that the Quandong may be correlative with the Areyonga. The Quandong Conglomerate does not possess features characteristic of the Arumbera Sandstone. Features it shares with the Areyonga Formation are: (1) the presence of many silica-filled fractures; (2) typically quite friable; (3) dominantly orange pink color which weathers white; (4) basal granular orthoconglomerates with well rounded granules and laterally wedging pinchouts; (5) honeycomb-type weathering; (6) beds of chert and/or silicified mudstone both above the uppermost orthoconglomerate beds and below the basal orthoconglomerate beds; and (7) directly overlies the Bitter Springs Formation with possible unconformity. Other features which the Quandong exhibits but that are not associated with
the Arumbera Sandstone are: (1) The Chandler overlying the Quandong is highly contorted. The map pattern suggests southward thrusting of the Quandong along a frontal ramp surface that climbs southward from the Bitter Springs through the Quandong (Areyonga) (Oaks, 1982, oral communication). (2) In the north part of the curving ridge, red sandstones of the Pertaoorta rest unconformably on the cherty mudstones at the top of the Quandong. (3) Below the lowest orthoconglomerates of the Quandong are dark colored chert beds which in turn rest unconformably on the Bitter Springs Formation. (4) No red sandstones or siltstones resembling the Arumbera are present underlying or within the Quandong; and (5) the orthoconglomerates of the Arumbera Sandstone appear to have, based on field observations, greater amounts of chert lithoclasts and less quartzite lithoclasts than the orthoconglomerates of the Quandong.

The basal contact of the Quandong Conglomerate is concealed but Oaks (1985, oral communication) found the contact of the Areyonga Formation with the underlying Inindia Formation to be sharp west of Stockyard Creek. The Areyonga in the Petermann Creek anticline overlies a unit of conglomeratic sandstone that is discontinuous laterally. This underlying unit is similar to the Areyonga Formation present in the Gardiner Range and other localities with similar features (Oaks, 1982, oral communication). At the Petermann Creek anticline this lower Areyonga member overlies outcrops of the Loves Creek Member of the Bitter Springs Formation. The Upper Areyonga consists of moderate reddish orange (10R 6/6) sandstones, conglomeratic sandstones, and conglomerates. At the Petermann Creek anticline section, a basal cherty sequence composed of interbedded cherts, chert breccia, calcareous siltstones, and calcareous sandstones is present. A similar cherty zone is
present below the Quandong at the Tempe Downs North section. At each location, the chert unit forms a recessive valley or gentle slope.

**Lower, Internal, and Upper Contacts**

The contact between the Quandong Conglomerate and the underlying Bitter Springs Formation is nearly always concealed. At the Tempe Downs North section, the covered interval includes a cherty sequence overlying a small interval of Bitter Springs dolostones. At the Tempe Downs South section, a large covered interval separates beds of the Quandong and the underlying Areyonga Formation. At both sections the lower contact is picked at the base of the lowest exposed orthoconglomerate or conglomeratic sandstone bed. Typically this bed is present at the base of a prominent ridge. At an unmeasured traverse of the Areyonga, in the eastern part of the Deception Creek anticline, near Illamurta Native Settlement, deposits similar to the Quandong form the conformable upper part of a ridge mapped as the Areyonga Formation.

The contact with the overlying undifferentiated Cambrian deposits and Chandler Formation is generally concealed. However, at the Tempe Downs North section, beds of the Quandong form a prominent dipslope whereas the overlying sandstones and siltstones of the undifferentiated Cambrian deposits form a recessive valley with local low-lying strike ridges. The contact is picked at the top of chert-replaced and chert-cemented mudstones and fine-grained sandstones 2 m thick. Because it may represent an ancient weathering surface, it is included with the Quandong Conglomerate. At the Tempe Downs South section, the upper contact is picked at the top of the uppermost exposed conglomeratic
sandstone. Quaternary alluvium covers the beds above this exposure. West of this section, limestones of the Chandler Formation are exposed. They are separated from the underlying Quandong by a covered interval. The contorted bedding of these limestones suggests an unconformable contact or a décollement by Chandler flowage.

Contacts between the lithofacies are defined primarily by lithology changes. Lithofacies A₁ and A₃ consist of recessive sandstones and siltstones. They are separated by lithofacies A₂ which is the prominent ridge-forming sequence dominated by lenticular orthoconglomerate beds.

**Weathered and Unweathered Colors**

Lithofacies A₁ generally is very pale orange (10YR 8/2) to moderate orange pink (5YR 8/2) on weathered surfaces. Its unweathered colors range from pale reddish purple (5RP 6/2) to pale pink (5RP 8/2). Lithofacies A₂ is characterized by light brown (5YR 5/6 to 5YR 6/4) weathered colors. Unweathered colors are dominantly very pale orange (10R 8/2) at the Tempe Downs North section and grayish pink (5R 8/2), moderate orange pink (10R 7/4), and pale red (10R 6/2) at the Tempe Downs South section. Lithofacies A₃ weathers white or light brown (5YR 6/4). Its unweathered colors are dominantly very pale orange (10YR 8/2) and pale pink (5RP 8/2).

**Lithology and Grain Size**

Lithofacies A₁ is composed of fine- to coarse-grained sandstones with occasional interbeds of granular orthoconglomerates. The sandstones are poorly to moderately sorted, poorly cemented subarkoses.

Lithofacies A₂ consists of orthoconglomerates with interbeds of
granular orthoconglomerates, conglomeratic sandstones, and sandstones. The sandstones and groundmass are fine- to coarse-grained. The lithoclasts of the orthoconglomerates and conglomeratic sandstones range from granule- to cobble-size (up to 8 cm in diameter). They consist of subequal amounts of quartzite and chert, with minor vein quartz. The quartzite and vein quartz tend to be subrounded to well rounded, whereas the chert fragments tend to be subangular to rounded. Most lithoclasts are gravel sized. The granular orthoconglomerates consist mostly of well rounded quartzite and vein quartz. They nearly always form lenses which pinch out laterally. Mud pebbles and casts of mud pebbles, up to 7 cm in diameter, are scattered throughout this lithofacies. The sandstones are poorly sorted to moderately sorted subarkoses to lithic arkoses which are generally poorly cemented by silica and calcite.

Lithofacies A3 is composed of chert-replaced and chert-cemented siltstones, shales, and very fine- to fine-grained sandstones. This lithofacies is well cemented. The sandstones, which are very minor, are arkosic.

**Lateral Variations in Thickness**

The Quandong Conglomerate shows considerable lateral variations in thickness. At the Tempe Downs North section, lithofacies A2 is 147 m thick, whereas 500 m south at the Tempe Downs South section it is 130 m thick. Lithofacies A1 and A3 are present only at the Tempe Downs North section. Here they are 19 m and 2 m thick, respectively. Exposures of the Quandong are absent between the Tempe Downs North section and the eastern end of the Deception Creek anticline. Near the Illamurta Native
Settlement, sediments resembling the Quandong form the upper 49 m of a section of Areyonga about 155 m thick (Oaks, 1985, oral communication).

**Paleocurrent Directions**

Rose diagrams illustrating paleocurrent directions are bimodal, but contrast in their directions (Fig. 21). The two primary modal directions for the Tempe Downs South section are north and east. For the Tempe Downs North section, they are south-southeast and west-southwest. The northern section also contains a secondary modal direction to the northeast. Measurements were made on omikron cross-stratification that probably represented different longitudinal or transverse bars in a braided stream system. A composite of these two paleocurrent patterns has a vector mean of 140° and a 95% level C.I. of 62° to 218°.

**Primary Inorganic Sedimentary Structures**

Primary inorganic sedimentary structures observed in lithofacies A1 include: (1) thin to medium beds (average: 15 cm, range: 7-18 cm); (2) lenticular-shaped bedding; and (3) planar parallel laminae.

Primary inorganic sedimentary structures observed in lithofacies A2 include: (1) medium to thick beds (average: 40 cm, range: 12-65 cm); (2) lenticular-shaped bedding with wedging cut-and-fill channels; (3) pi and omikron dominant cross-stratification; (4) minor xi, alpha, beta, and gamma cross-stratification; (5) scour-filled bedding contacts; (6) rare parting lineations; (7) scattered mud pebbles and casts of mud pebbles up to 7 cm in diameter; (8) local purplish black manganese staining; (9) massive weathering; and (10) rare slumped bedding.
Primary inorganic sedimentary structures observed in lithofacies A3 include: (1) thin beds (average: 5 cm, range: 1-6 cm); (2) wavy discontinuous laminae; and (3) planar parallel laminae.

**Biogenic Structures**

No biogenic structures were observed in the Quandong Conglomerate.

**Porosity and Permeability**

Field measurements indicate that the Quandong Conglomerate has moderate to good porosity and permeability. At the Tempe Downs South section, porosities greater than 10% are present throughout the section except at two intervals which totaled 17 m. Porosity is dominantly moderate at the Tempe Downs North section. Here, except for two small intervals of poor to fair porosity (less than 5%), the porosity ranged from 5 to 10%. Three intervals, totaling 57 m, had porosities greater than 10%.
Petrography of the Arumbera Sandstone

Unit 1

General Statement

Sandstones of lithofacies 1a, 1b, and 1d of Unit 1 are arkoses and subarkoses (Figs. 24-26). The conglomeratic sandstones of lithofacies 1c are litharenites and feldspathic litharenites. The sandstones of Unit 1 are poorly sorted to well sorted, whereas the conglomeratic sandstones (lithofacies 1c) are very poorly sorted to poorly sorted. Average grain size for sandstones of Unit 1 range from coarse silt to medium sand. For the conglomeratic sandstones, average grain size ranges from coarse sand to very coarse sand. Syntaxial overgrowths of quartz and rarely of feldspar, and cementation by iron oxides (predominantly hematite and very rare limonite), calcite, chert, and authigenic clays were observed in thin sections point-counted for Unit 1. These samples also contain 1 to 22% orthoclase, 0 to 9% plagioclase, 0 to 7% microcline, 0 to 55% chert, 0 to 17% lithic grains, and trace to 23% accessory minerals. Porosity varies from 1 to 13%.

Detailed mineralogy of the point-counted thin-section is summarized in Tables 2-5. Statistical parameters are presented in Tables 3 and 5. A detailed diagenetic sequence is listed in Table 9. A cumulative-frequency probability curve (after Friedman, 1958) and a histogram with class intervals of 0.5 phi are presented in Figures 46-55, and 57-60. The following description is based primarily on detailed point counts of
thin sections 1-4, 6-7, 18, 20, 25-30, 35, and 51 from Unit 1.

Grain Mineralogy

Quartz is the most common grain type in sandstones of Unit 1. It averages 59%, and ranges between 18% and 90%. Nonundulant grains (extinction angle less than or equal to 5°) comprise 65%, undulant grains, 22%, polycrystalline grains with 2-3 crystals, 4%, and polycrystalline grains with greater than 3 crystals, 9% of the quartz fraction. Inclusions in quartz grains consist of bubble trains, random bubbles or vacuoles, muscovite microlites, needle-shaped rutile, platy to rod-shaped tourmaline, zircon, biotite, and chlorite. These are present in minor amounts as a whole, but individual quartz grains may be rich in one or more of these inclusions. No attempt was made to quantify their occurrence. Thin section 18 contains one euhedral quartz grain which may be of volcanic origin. Some grains exhibit Boehm lamellae.

In sandstones of lithofacies la, quartz averages 69% (range: 53 to 84%) of the grains. Nonundulant grains average 67%, undulant grains, 25%, polycrystalline grains with 2-3 crystals, 2%, and polycrystalline grains with greater than 3 crystals, 6% of the quartz fraction. In lithofacies lb, quartz comprises 84% of the grains. Nonundulant grains comprise 67%, undulant grains 23%, polycrystalline grains with 2-3 crystals, 5%, and polycrystalline grains with more than 3 crystals, 5% of the quartz fraction. For the conglomeratic sandstones of lithofacies 1c, quartz grains average 31% (range: 18 to 37%) of the total grains. Nonundulant grains average 65%, undulant grains, 18%, polycrystalline grains with 2-3 crystals, 4%, and polycrystalline grains with more than
3 crystals, 12% of the quartz fraction. The percent of quartz grains in sandstones of lithofacies 1d averages 71% (range: 52 to 90%) of the grains. Nonundulant grains average 63%, undulant grains, 23%, polycrystalline grains with 2-3 crystals, 5%, and polycrystalline grains with greater than 3 crystals, 9% of the quartz fraction.

Chert averages 1% (range: 0 to 5%) of the grains of sandstones of lithofacies 1a, 1b, and 1d. Conglomeratic sandstones of lithofacies 1c average 45% chert (range: 32 to 55%). Lithofacies 1c contains pebbles of chert which account for the high percentage of chert in thin sections of these samples. The chert, composed primarily of microcrystalline quartz and minor macrocrystalline quartz and radial-fibrous chalcedony, contains small relict inclusions of calcite, possible dolomite rhombs, and/or pyrite cubes. Numerous relict silicified carbonate structures such as ooids, pellets, and possible algal structures are also preserved in cherts in Unit 1, primarily in lithofacies 1c. These suggest a carbonate sedimentary source for the chert.

Total feldspars in Unit 1 average 15% (range: 1 to 26%) of the grains. Of this, 9% is orthoclase, 4%, plagioclase, and 2%, microcline. The orthoclase is both fresh and partially to completely altered to kaolinite and/or hematite. Locally some orthoclase grains have undergone partial or complete dissolution. Much of the untwinned plagioclase is partially or completely sericitized, whereas the twinned plagioclase appears mostly fresh. Most microcline grains exhibit grid twinning, and most are unaltered. Five grains of plagioclase in lithofacies 1c and three grains in lithofacies 1d contain albite-twins suitable for composition determination using the Michel-Levy method (after Kerr, 1977). In thin section 18, four grains were measured. Their compositions
are An9 (albite), An10 (albite), An12 (oligoclase), and An14 (oligoclase), respectively. In thin section 27 the composition is An13 (oligoclase) for the sole suitable plagioclase grain. Two lithofacies 1d grains are in thin section 25. Their respective compositions are An2 (albite) and An7 (albite). A twinned plagioclase grain in thin section 51 had an albite composition of An7.

Total feldspars in lithofacies 1a average 17% (range: 11 to 22%) of the grains. Of this, 12% is orthoclase, 4%, plagioclase, and 1%, microcline. For lithofacies 1b, the percent feldspars in thin section 29 is 8% of the grains, of which 7% is orthoclase and 1%, plagioclase. Feldspars in the conglomeratic sandstones of lithofacies 1c average 9% (range: 1 to 18%) of the grains, of which 4% is orthoclase, 3%, plagioclase, and 2%, microcline. For lithofacies 1d, the feldspars average 18% (range: 4 to 26%) of the grains, of which 12% is orthoclase, 4%, plagioclase, and 2%, microcline.

Other lithics average 7% (range: 0 to 17%) of the grains in samples from Unit 1. These consist predominantly of sedimentary rock fragments (sandstone, limestone, dolostone, shale, silicified ooids, and siltstone) with lesser amounts of metamorphic (primarily schist and quartzite with minor gneiss and slate) and granitic (primarily orthoclase and quartz, but also minor microcline and quartz, quartz and magnetite, amphibole and quartz, plagioclase and quartz, and graphic granite) rock fragments. Rare acidic volcanic rock fragments are also present. In lithofacies 1a, lithics average 2% (range: 0 to 4%) of the grains. In lithofacies 1b they comprise 5% of the grains of thin section 29. Conglomerates and conglomeratic sandstones of lithofacies 1c show the highest proportion of lithics and are largely responsible for the high average of lithic
grains in Unit 1. Lithics average 13% (range: 10 to 17%) of the grains in lithofacies 1c. For lithofacies 1d, the lithics average 5% (range: 2 to 9%) of the grains.

Accessory minerals average 5% (range: 0 to 23%) of the grains. They include: (1) muscovite (0 to 12%), (2) biotite (0 to 10%), (3) ilmenite/leucoxene (trace), (4) chlorite (rare trace), (5) pyrite (rare trace), and (6) heavy minerals (0 to 5%). The heavy minerals consist of magnetite, tourmaline, zircon, and rutile. For lithofacies 1a, accessory minerals average 11% with a range between 1% and 23%. Accessory minerals comprise 2% (range: 0 to 4%) of the grains, in lithofacies 1b and in lithofacies 1c. For lithofacies 1d, accessory minerals average 4% (range: trace to 10%) of the grains. The high percentages of accessory minerals in lithofacies 1a are due to large amounts of micas present in thin sections 28 and 30, probably a correlative of the rather fine grain size (coarse silt).

Framework grains form an average of 67% (range: 30 to 84%) of the rock in Unit 1. For lithofacies 1a the average is 52% (range: 30 to 72%). Framework grains comprise 83% of the sample of lithofacies 1b. In lithofacies 1c they average 68% (range: 49 to 84%) of the rock. In lithofacies 1d, framework grains average 74% (range: 69 to 80%) of the rock.

Pettijohn et al. (1972) reported that modern sands often have porosities of 50% or more, whereas closest packing of spheres of uniform diameter has a porosity of 25%. Clay minerals in lithofacies 1a can not be entirely authigenic because, in most cases, they were also an initial matrix constituent. However, if the iron oxides and other cements are assumed authigenic, and if secondary porosity is ignored, the average
minimum initial porosity of lithofacies la samples after compaction, was 16% (range: 11 to 26%). For lithofacies lb, lc, and ld, clay minerals and iron oxides are assumed to be entirely authigenic. If secondary porosity is ignored, the minimum initial porosity after compaction, for lithofacies lb was 7%. For lithofacies lc, it averages 28% (range: 11 to 50%), and for lithofacies ld, it averages 18% (range: 12 to 23%). Using the above assumptions, the average minimum initial porosity for Unit 1 following compaction was 20% with a range between 7 and 50%. This suggests that considerable mechanical compaction and/or pressure solution occurred prior to or during cementation. Grain-to-grain contacts are common and suggest that postdepositional destruction of initial porosity by compaction and pressure solution reduced the original porosity from between 20 and 25% to about 12% prior to (or during) cementation.

**Grain Size, Sorting, Skewness, and Kurtosis**

The mean grain size of Unit 1 is 1.81 phi (0.28 mm), and the range is -0.94 phi (1.90 mm) to 4.07 phi (0.06 mm). The mean grain size for lithofacies la is 3.42 phi (0.09 mm), whereas the range is 2.50 phi (0.18 mm) to 4.07 phi (0.06 mm). For lithofacies lb the mean grain size of one sample is 1.80 phi (0.28 mm). The mean grain size for the conglomeratic sandstones of lithofacies lc is -0.16 phi (1.10 mm), with a range between -0.94 phi (1.93 mm) and 0.66 phi (0.64 mm). Lithofacies ld has a mean grain size of 2.37 phi (0.20 mm), and the range is 1.40 phi (0.38 mm) to 3.17 phi (0.11 mm). The median grain size for Unit 1 thin sections averages 1.84 phi (0.28 mm), whereas the median
grain sizes for lithofacies 1a, 1b, 1c, and 1d are 3.48 phi (0.09 mm), 1.80 phi (0.28 mm), -0.08 phi (1.06 mm), and 2.35 phi (0.19 mm), respectively. The coarsest 1% for Unit 1 averages -0.05 phi (1.03 mm). For lithofacies 1a, 1b, 1c, and 1d the respective averages of the coarsest 1% are 1.78 phi (0.29 mm), 0.22 phi (0.86 mm), -2.91 phi (7.13 mm), and 1.06 phi (0.48 mm). The average median size for Unit 1 is medium sand, whereas the coarsest 1% is very coarse sand. For lithofacies 1a, 1b, 1c, and 1d the average medians are very fine sand, medium sand, very coarse sand, and fine sand, respectively; whereas their coarsest 1% is medium sand, coarse sand, pebble-size gravel, and coarse sand, respectively. The average size of feldspars is slightly less than that of the quartz (Table 4).

Thin sections 2 and 3 of lithofacies 1a and thin section 35 of lithofacies 1d are composed chiefly of fine sand and very fine sand, respectively, whereas thin sections 28 and 30 are composed chiefly of coarse silt. Thin section 29 (lithofacies 1b) and thin section 51 (lithofacies 1d) are composed chiefly of medium sand. Lithofacies 1c conglomeratic sandstones average very coarse to coarse sand. Thin sections 18 and 27 average coarse sand, whereas thin sections 1, 20, and 26 average very coarse sand. The larger grain sizes of lithofacies 1c are affected by the presence of numerous pebble-sized grains. Thin sections 4, 7, 25, and 35 of lithofacies 1d are composed chiefly of fine sand, whereas thin section 6 is chiefly very fine sand. Thin section 51 is chiefly medium sand.

Sorting (phi units) in Unit 1 averages 1.06 (poorly sorted) with a range of 0.43 (well sorted) to 2.20 (very poorly sorted). Sorting for the sandstones of Unit 1 averages 0.64 (moderately well sorted) with a
range of 0.43 (well sorted) to 1.16 (poorly sorted). For lithofacies 1a the sorting averages 0.72 (moderately sorted). The sorting for lithofacies 1b is 0.55 (moderately well sorted). For lithofacies 1c the sorting averages 1.97 (poorly sorted) with a range of 1.66 (poorly sorted) to 2.20 (very poorly sorted). Poor sorting of lithofacies 1c reflects the predominance of conglomeratic sandstones that are poorly sorted even in a cursory field examination. For lithofacies 1d the sorting averages 0.61 with a range of 0.53 to 0.69 (all moderately well sorted).

Skewness, the symmetry of the frequency distribution, averages +0.01 (near-symmetrical) with a range of -0.47 (strongly coarse-skewed) to +0.47 (strongly fine-skewed). For the sandstone samples of Unit 1, skewness averages +0.02 (near-symmetrical) with a range of -0.35 (strongly coarse-skewed) to +0.23 (fine-skewed). Skewness for lithofacies 1a averages -0.05 (near-symmetrical) with a range between -0.35 (strongly coarse-skewed) and +0.20 (fine-skewed). Lithofacies 1b has a skewness of +0.03 (near-symmetrical). Skewness for lithofacies 1c averages -0.02 (near-symmetrical) with a range of -0.47 (strongly coarse-skewed) to +0.47 (strongly fine-skewed). The skewness of lithofacies 1d averages +0.06 (near-symmetrical) with a range of -0.19 (coarse-skewed) to +0.23 (fine-skewed).

Kurtosis for Unit 1 averages 0.91 (mesokurtic) with a range of 0.54 (very platykurtic) to 1.25 (leptokurtic). For the sandstone samples of Unit 1, kurtosis averages 1.01 (mesokurtic) with a range of 0.85 (platykurtic) to 1.25 (leptokurtic). Kurtosis of lithofacies 1a averages 0.87 (platykurtic) with a range of 0.85 (platykurtic) to 0.90 (mesokurtic). Kurtosis in lithofacies 1b is 1.25 (leptokurtic). Kurtosis of litho-
facies lc averages 0.69 (platykurtic) with a range of 0.54 (very platykurtic) to 0.82 (platykurtic). Finally, kurtosis of lithofacies ld averages 1.07 (mesokurtic) with a range of 0.95 (mesokurtic) to 1.18 (leptokurtic).

Grain Angularity and Equantness

Dust rims of iron oxide and/or clay minerals, present on most grains, allow recognition of original grain shape even where syntaxial overgrowths are present. Using the scale of Powers (1953), the average grain roundness (angularity) is determined as 12% well rounded to rounded, 42% subrounded, 34% subangular, and 12% angular to very angular. The average grain roundness of lithofacies la is 12% well rounded to rounded, 36% subrounded, 32% subangular, and 20% angular to very angular. For lithofacies lb grain roundness is 24% well rounded to rounded, 28% subrounded, 27% subangular, and 21% angular to very angular. The average grain roundness for the conglomeratic sandstones of lithofacies le is 10% well rounded to rounded, 44% subrounded, 37% subangular, and 9% angular to very angular. For lithofacies ld the average grain roundness is 11% well rounded to rounded, 48% subrounded, 34% subangular, and 7% angular to very angular. Roundness values demonstrate a trend from more angular grains at the base (lithofacies la) to more rounded grains upsection (lithofacies ld). The totals for well rounded to subrounded for lithofacies la, lb, lc, and ld average 48%, 52%, 54%, and 59%, respectively.

Determination of grain equantness by comparison of maximum and minimum diameters of grains in Unit 1 revealed 59% equant, 38% sub-
equant, and 3% bladed. The grain shapes of lithofacies la average 57% equant, 35% subequant, and 8% bladed. For lithofacies lb the grain shapes are 57% equant, 43% subequant, and less than 1% bladed. The grain shapes of lithofacies lc average 58% equant, 41% subequant, and 1% bladed. For lithofacies ld the average grain shapes are 62% equant, 36% subequant, and 2% bladed. There is a slight tendency for the grains to be more equant in shape going upsection. In lithofacies la and lb 57% are equant, whereas in lithofacies lc and ld 58% and 62% are equant, respectively.

Table 4 compares the roundness (angularity) and shape (equantness) of the quartz, feldspar, and chert grains. These data show significantly higher roundness for quartz grains than for feldspar grains in lithofacies lb, lc, and ld, whereas in lithofacies la roundness is about the same. No significant difference can be distinguished in equantness between quartz and feldspar grains in Unit 1.

Classification of Sandstones, Conglomerates and Conglomeratic Sandstones

The sandstone classification outlined by Folk (1974) is used for rock types in the Arumbera Sandstone and Quandong Conglomerate. The standard QFR (Quartz-Feldspar-Rock Fragments) ternary diagrams for the Arumbera are shown in Figures 24-26. For this report, secondary porosity derived from dissolution of grains was considered as the original grain.

Table 2 gives the classification parameters (corrected for dissolution that produced secondary porosity; after Folk, 1974) for point-counted thin sections. Thin sections 28 and 30 are arkoses, whereas thin sections 2 and 3 are subarkoses for sandstones of lithofacies la. Thin
section 29 (lithofacies 1b) is a subarkose. The paraconglomerates, orthoconglomerates, and conglomeratic sandstone samples of lithofacies 1c plot in the litharenite field (thin sections 1, 20, and 26) and in the feldspathic litharenite field (thin sections 18 and 27). The conglomerates of lithofacies 1c are primarily paraconglomerates with minor orthoconglomerates. Thin sections 6, 7, 25, and 35 are arkoses, whereas thin section 4 and 51 are subarkoses (lithofacies 1d).

Cement, Matrix, and Porosity

Cement ranges from 5% to 48% of the whole rock in Unit 1, with an average of 15% (Table 3). Syntaxial quartz overgrowths comprise 5% (range: <1 to 10%), whereas the remaining cement consists of 1% chert (range: 0 to 12%); 5% carbonate (primarily calcite with minor dolomite) (range: 0 to 38%); 4% iron oxides (range: 0 to 14%); and traces of syntaxial feldspar overgrowths and authigenic clays. Authigenic clays, chlorite and/or illite, are present, often as radial-fibrous coatings of grains.

In lithofacies 1a, cement averages 12% (range: 7 to 20%) of the whole rock. Syntaxial quartz overgrowths comprise 4% (range: trace to 10%). Carbonates (primarily calcite with minor dolomite) comprise 4% (range: 0 to 15%). Iron-oxide cements (primarily hematite with rare limonite) average 2% (range: 1 to 2%).

For lithofacies 1b, cement forms 5% of the whole rock, and is entirely in the form of syntaxial quartz overgrowths. Cement in lithofacies 1c averages 24% (range: 10 to 48%). Carbonates (primarily calcite with minor dolomite) average 13% (range: 0 to 38%), whereas syntaxial
quartz overgrowths average 4% (range: <1 to 9%). Chert averages 3% (range: 0 to 12%), and iron oxides comprise 4% (range: 1 to 10%). Traces of authigenic clays and syntaxial feldspar overgrowths are also present as cement in lithofacies 1c. For lithofacies 1d, cement ranges from 10 to 16%, with an average of 13%. Syntaxial quartz overgrowths comprise 7% (range: 2 to 10%), whereas iron oxides average 5% (range: trace to 14%). Traces of authigenic clays as cement and syntaxial feldspar overgrowths are also present.

Percent of matrix ranges from trace amounts to 59% in Unit 1, and averages 11% of the whole rock. Clay minerals (kaolinite and/or illite) and iron oxides (hematite or rare limonite) form the bulk of the matrix. In lithofacies 1a, matrix averages 31% (range: 4 to 59%). For lithofacies 1b, matrix is approximately 1%. In lithofacies 1c, matrix averages 3% (range: 1 to 6%) of the whole rock. For lithofacies 1d, the matrix averages 6% (range: 1 to 11%).

Porosity averages 6% of the whole rock with a range of 1 to 13%. Of the total porosity, 89% is judged to be secondary porosity. Types of secondary porosity recognized (in order of decreasing importance) are: complete to partial dissolution of grains, matrix, and cement; molds of grains; fractures; and inhomogeneity of packing. The balance of the total porosity is judged to be relict original porosity.

In lithofacies 1a, porosity averages 6% and ranges from 3 to 13% of the whole rock. Of the total porosity, 88% is judged to be secondary porosity. For lithofacies 1b, porosity is 12% in the thin section examined. Of the total porosity, 87% is recognized as secondary in origin. In lithofacies 1c, porosity averages 4% (range: 1 to 8%). Of the total porosity, 91% is judged to be secondary porosity. For lithofacies
ld, porosity averages 8% (range: 3 to 11%). Of the total porosity, 89% is recognized as secondary in origin.

**X-ray Analysis of Samples**

Ten samples of Unit 1 (thin sections 1, 3, 20, 25-30, and 35) were prepared for X-ray analysis. The mineralogy determined thereby includes quartz, kaolinite, illite, chlorite, and bayerite, with local palygorskite, smectite, and sillimanite (Table 9).

**Unit 2**

**General Statement**

Sandstones of Unit 2 are arkoses, subarkoses, feldspathic litharenites, and lithic arkoses (Figs. 24-26). They are well sorted to poorly sorted, cemented by syntaxial overgrowths of quartz and feldspar, by iron oxide, by carbonate (calcite with minor dolomite), by chert, and by authigenic clay minerals. Sandstones of Unit 2 contain abundant quartz (44 to 88% of grains), orthoclase (5 to 31% of grains), plagioclase (<1 to 15% of grains), microcline (0 to 15% of grains), other lithics (1 to 7% of grains), chert (0 to 39% of grains), and accessory minerals (trace to 7% of grains). Porosity varies from 1 to 14%. This description is based on analyses of thin sections 5, 8-17, 19, 21-24, 31-43, and 44-50 from Unit 2 (Tables 2-5).
Grain Mineralogy

Quartz is the most common grain type in the sandstones of Unit 2. It averages 68% of the grains and ranges between 44 and 88%. Nonundulant grains (extinction angle less than or equal to 5°) comprise 64%, undulant grains average 23%, polycrystalline grains with 2-3 crystals average 4%, and polycrystalline grains with greater than 3 crystals average 9% of the quartz fraction in Unit 2. Quartz is significantly less abundant in chert-rich lithofacies 2c than in lithofacies 2a and 2b. Inclusions are present in minor amounts in the quartz grains. They consist of bubble trains, random bubbles or vacuoles, muscovite microlites, tourmaline, zircon, rutile needles, chlorite, epidote, and sillimanite. Some grains exhibit Boehm lamellae, whereas several others possess hair-like fractures.

In lithofacies 2a, quartz averages 72%, and ranges between 60 and 88% of the grains. Nonundulant quartz grains comprise 59%, undulant grains, 26%, polycrystalline grains with 2-3 crystals, 4%, and polycrystalline grains with greater than 3 crystals, 11% of the quartz fraction.

In lithofacies 2b, quartz averages 68%, and ranges between 53 and 87% of the grains. Nonundulant quartz grains comprise 70%, undulant grains, 20%, polycrystalline grains with 2-3 crystals, 3%, and polycrystalline grains with more than 3 crystals, 7% of the quartz fraction in lithofacies 2b.

In lithofacies 2c quartz averages 46% and ranges between 44 and 49% of the grains. Nonundulant quartz grains comprise 57%, undulant grains, 24%, polycrystalline grains with 2-3 crystals, 4%, and polycrystalline
grains with more than 3 crystals, 15% of the quartz fraction in lithofacies 2c

Chert averages 5% (range: 0 to 39%) of the grains in Unit 2. Some of the chert grains contain relict carbonate structures such as ooids or pellets, small relict inclusions of carbonate, or relict molds of dolomite rhombs or pyrite cubes. Microcrystalline quartz is the major chert type, but radial-fibrous chalcedony and macrocrystalline quartz are also present. In lithofacies 2a, chert grains average 3%, with a range between 1 and 12% of the total grains. In lithofacies 2b, chert grains average 1%, with a range of 0 to 4% of the total grains. Lithofacies 2c contains numerous pebbles of chert, and averages 37% chert.

Feldspars for Unit 2 average 21% (range: 8 to 37%) of the grains, of which 13% is orthoclase, 5%, plagioclase, and 3%, microcline. One perthite grain was observed in thin section 24. Orthoclase grains range from fresh to partially or nearly completely altered. Alteration includes replacement by hematite and/or clay minerals, primarily kaolinite. Some orthoclase grains are partially or completely dissolved. Much of the plagioclase is untwinned and often sericitized to some degree. The twinned plagioclase grains primarily exhibit albite twinning, but minor Carlsbad twinning is observed. Six grains of plagioclase in lithofacies 2b with albite twinning were measured by the Michel-Levy method. Two grains were found in thin section 21. Their respective compositions were An26 (oligoclase) and An10 (albite). Thin sections 12, 19, 47, and 48 contained one suitable plagioclase each for composition determination. Their respective compositions were An7 (albite), An8 (albite), An14 (oligoclase), and An14 (oligoclase). Grains of microcline exhibit grid twinning, and are commonly unaltered. Feldspars are more
abundant in the marine lithofacies than in the fluvial lithofacies.

In lithofacies 2a, total feldspar grains average 17% with a range of 8 to 27% of the total grains. Of the grains, 12% are orthoclase, 3% are plagioclase, and 3% microcline. In lithofacies 2b, total feldspar grains average 24% (range: 11 to 37%) of the grains, of which 15% is orthoclase, 6%, plagioclase, and 3%, microcline. In lithofacies 2c, total feldspar grains average 11% with a range of 8 to 14% of the total grains. Of the grains, 6% are orthoclase, 3% are microcline, and 2% are plagioclase.

Other lithic grains average 4% (range: 1 to 8%) of the total grains in Unit 2. Metamorphic rock fragments (primarily schist with minor gneiss) are the most numerous types. Granitic rock fragments are primarily orthoclase and quartz with minor microcline and quartz, amphibole and quartz, plagioclase and quartz, and graphic granite. Sedimentary rock fragments are shale, siltstone, sandstone, and silicified ooids. Both rock types are common. Acidic volcanic rock fragments are rare. In lithofacies 2a and 2c other lithics average 5% (range: 2 to 7%) of the grains, whereas in lithofacies 2b other lithics average 4% (range: 1 to 7%) of the grains.

Accessory minerals average 2% (range: 0 to 6%) of the grains in Unit 2. They include: (1) muscovite (0 to 4%), (2) biotite (0 to 4%), (3) augite (trace), (4) ilmenite/leucoxene (trace), (5) pyrite (trace), (6) chlorite (trace), (7) epidote (trace), and (8) heavy minerals (0 to 3% of the grains). The assemblage of heavy minerals includes rounded to well-rounded tourmaline, zircon, rutile, and magnetite. In lithofacies 2a, accessory minerals average 2% (range: 0 to 5%) of the grains, whereas in lithofacies 2b they average 3% (range: 1 to 6%) of the grains. In
lithofacies 2c accessory minerals average less than 1% of the grains.

Framework grains average 75% (range: 65 to 82%) of sandstones in Unit 2. Assuming an authigenic origin for clay minerals and iron oxide, and if secondary porosity is ignored, the average minimum initial porosity was 22% (range: 12 to 31%) after compaction. Smashed ductile grains and an abundance of grain-to-grain contacts and sutured grain contacts indicate considerable mechanical compaction and pressure solution prior to cementation.

Framework grains for lithofacies 2a average 77% (range: 73 to 82%) of the rock. The average minimum initial porosity was 19% (range: 12 to 25%). For lithofacies 2b, framework grains average 73% (range: 65 to 82%) of the rock. The minimum initial porosity averages 24% (range: 12 to 31%). Framework grains for lithofacies 2c average 76% (range: 75 to 76%). The average minimum initial porosity was 20%.

**Grain Size, Sorting, Skewness, and Kurtosis**

The mean grain size of Unit 2 is 2.02 phi (0.25 mm), whereas the range is 0.41 phi (0.75 mm) to 3.25 phi (0.10 mm). Unit 2 is composed of very fine sand, fine sand, medium sand, and coarse sand. The mean grain size for lithofacies 2a is 2.05 phi (0.24 mm) with a range from 0.88 phi (0.54 mm) to 2.64 phi (0.16 mm). It is composed of fine to coarse sand. The mean grain size for lithofacies 2b is 2.19 phi (0.22 mm) with a range from 0.64 phi (0.64 mm) to 3.25 phi (0.10 mm). It is composed of very fine to medium sand. The mean grain size for lithofacies 2c is 0.54 phi (0.69 mm) with a range from 0.41 phi (0.75 mm) to 0.66 phi (0.63 mm). The mean grain size for lithofacies 2a and 2b is fine sand, whereas for
lithofacies 2c it is coarse sand.

The average median grain size ($\varnothing_{50}$) for Unit 2 is 2.03 phi (0.25 mm), and the average coarsest 1% is 0.24 phi (0.85 mm). For lithofacies 2a, the average median grain size is 2.07 phi (0.24 mm) and the average coarsest 1% is 0.22 phi (0.86 mm), whereas for lithofacies 2b they are 2.17 phi (0.22 mm) and 0.52 phi (0.70 mm), respectively. For lithofacies 2c, the average median grain size is 0.84 phi (0.56 mm) and the average coarsest 1% is -1.76 phi (3.40 mm). The median grain size for Unit 2 is fine sand and the coarsest 1% is coarse sand.

Sorting (phi units) in Unit 2 averages 0.66 (moderately well sorted), with a range of 0.44 (well sorted) to 1.26 (poorly sorted). For lithofacies 2a sorting averages 0.65 (moderately well sorted) and ranges between 0.46 (moderately well sorted) and 1.26 (poorly sorted). In lithofacies 2b sorting averages 0.58 (moderately well sorted) with a range of 0.44 (well sorted) to 0.86 (moderately sorted). In lithofacies 2c sorting averages 1.34 (poorly sorted) with a range of 1.07 (poorly sorted) to 1.64 (very poorly sorted).

Skewness averages +0.03 (near-symmetrical) with a range of -0.44 (coarse-skewed) to +0.29 (fine-skewed) for Unit 2. In lithofacies 2a the skewness averages -0.02 (near-symmetrical) with a range of -0.28 (coarse-skewed) to +0.19 (fine-skewed). The skewness for lithofacies 2b averages +0.09 (near-symmetrical) with a range of -0.08 (near-symmetrical) to +0.29 (fine-skewed). The skewness for lithofacies 2c averages -0.19 (coarse-skewed) with a range of -0.44 (coarse-skewed) to 0.06 (near-symmetrical).

Kurtosis averages 1.08 (mesokurtic) with a range between 0.70 (mesokurtic) and 1.58 (very leptokurtic) for Unit 2. In lithofacies 2a
kurtosis averages 1.10 (mesokurtic), and ranges between 0.70 (mesokurtic) and 1.58 (very leptokurtic). For lithofacies 2b kurtosis averages 1.07 (mesokurtic), with a range of 0.70 (mesokurtic) to 1.37 (leptokurtic). For lithofacies 2c kurtosis averages 1.02 (mesokurtic) with a range of 0.92 (mesokurtic) to 1.12 (leptokurtic).

Grain Angularity and Equantness

Average roundness (angularity) of grains in Unit 2 is 9% well rounded to rounded, 42% subrounded, 38% subangular, and 11% angular to very angular. In lithofacies 2a the average roundness of grains is 9% well rounded to rounded, 42% subrounded, 36% subangular, and 13% angular to very angular. For lithofacies 2b the average roundness of grains is 9% well rounded to rounded, 41% subrounded, 39% subangular, and 11% angular to very angular. For lithofacies 2c the average roundness of grains is 13% well rounded to rounded, 43% subrounded, 35% subangular, and 9% angular to very angular. The data presented in Table 4 show a significantly greater degree of roundness for quartz grains (average: 57% subrounded to well rounded, range: 34 to 86%) than for feldspar grains (average: 29% subrounded to well rounded, range: 0 to 61%). Only thin sections 24, 32 and 33 show no significant difference between the roundness of quartz and feldspar grains.

Average grain shapes in Unit 2 are as follows: 58% equant, 40% subequant, and 2% bladed. For lithofacies 2a the grain shapes average 60% equant, 38% subequant, and 2% bladed. In lithofacies 2b they average 58% equant, 40% subequant, and 2% bladed. In lithofacies 2c they average 50% equant and 50% subequant. For Unit 2 the quartz grains tend to be
slightly more equant (average: 62%) than feldspar grains (average: 51%). However, in thin sections 9 and 23 (lithofacies 2b) and thin sections 5, 17, 24, and 31 (lithofacies 2a) a greater percentage of feldspar grains are equant.

Classification of Sandstones

As shown in Figures 24-26, sandstones of Unit 2 are arkoses, subarkoses, and lithic arkoses. For lithofacies 2a, thin sections 24 and 33 are lithic arkoses, whereas thin sections 5, 8, 31, 32, and 34 are arkoses. Thin sections 17, 22, and 50 are subarkoses. All of the thin sections (9-16, 23, 45, 48, and 49) of lithofacies 2b are arkoses except thin section 47 which is a subarkose. Thin sections 44 and 46 of lithofacies 2c plot in the feldspathic litharenite field. QFR data for these thin sections are given in Table 2.

Cement, Matrix, and Porosity

Cement averages 12% of sandstones (range: 6 to 22%) of Unit 2. Syntaxial quartz overgrowths are most common, and average 9%. Other cementing agents include hematite (2%), authigenic clay minerals (1%), chert (<1%), and syntaxial feldspar overgrowths (trace). In sandstones of lithofacies 2a, cement averages 10% (range: 6 to 18%). Cementing agents include syntaxial quartz overgrowths (7%), hematite (2%), authigenic clay minerals (1%), chert (<1%), and syntaxial feldspar overgrowths (trace). Cement averages 14% of sandstones in lithofacies 2b (range: 6 to 22%). Cementing agents include syntaxial quartz overgrowths (10%), hematite (3%), authigenic clay minerals (1%), chert (trace), and syntaxial feldspar
overgrowths (trace). In sandstones of lithofacies 2c, cement averages 8% (range: 6 to 10%). Cementing agents include syntaxial quartz overgrowths (6%), hematite (1%), authigenic clay minerals (<1%), chert (<1%), calcite (trace), and syntaxial feldspar overgrowths (trace).

Matrix ranges from 0 to 11% of sandstones in Unit 2 (average: 3%). In lithofacies 2a matrix averages 3% (range: 0 to 8%). Matrix in lithofacies 2b and 2c averages 4%, with a range between less than 1% and 11%. Iron oxide, as either hematite or rarely limonite, together with clay minerals, usually kaolinite and illite, form the bulk of the matrix in Unit 2. They occur in subequal amounts. Glauconite, chlorite, and clinozoisite are rare matrix materials in this unit.

Porosity averages 10% (range: 1 to 14%). Of the total porosity, 84% was judged to be secondary. Types of secondary porosity encountered (in order of decreasing importance) included: complete to partial dissolution of grains, matrix, and original cement; molds of grains; inhomogeneity of packing; and fractures. The balance of the total porosity is considered relict original. In lithofacies 2a porosity averages 9% and ranges between 1 and 14%. Porosity in lithofacies 2b averages 10% with a range of 3 to 14%. In lithofacies 2c porosity averages 12% with a range of 10 to 14%.

**X-ray Analysis of Samples**

Seventeen samples (thin sections 5, 8-10, 14, 17, 21-22, 24, 31, 33, 41, 42, 44-45, and 48-50) were prepared for X-ray analysis. Common mineralogy determined by this analysis includes quartz, feldspar, kaolinite, illite, chlorite, and bayerite (Table 8).
Unit 3

General Statement

Two of the three point-counted samples of Unit 3 are lithic arkoses whereas the other is a subarkose (Fig. 24). Sandstones of Unit 3 are moderately well sorted overall, but range from well sorted to moderately well sorted (Tables 3, 5). They are cemented by syntaxial quartz overgrowths, chert, iron oxide, calcite, and authigenic clay minerals (Table 3). They contain 6 to 10% orthoclase, 2 to 5% microcline, 1 to 3% plagioclase, 1 to 7% chert, 4 to 5% lithic grains, and 4 to less than 1% muscovite, biotite, and heavy minerals. Porosity varies from 8 to 11%. The following descriptions are based on examinations of thin sections 41, 42, and 43.

Grain Mineralogy

Quartz is the most common grain type of the sandstones in Unit 3. It averages 74% of the grains, and ranges between 71 and 77% (Table 3). Nonundulant quartz grains comprise 63%, undulant grains, 23%, polycrystalline grains with 2-3 crystals, 4%, and polycrystalline grains with more than 3 crystals, 10% of the quartz fraction (Table 2). Inclusions in the quartz grains include: (1) bubble trains, (2) random bubbles or vacuoles, (3) rutile, (4) zircon, (5) muscovite microlites, (6) tourmaline, and (7) biotite.

Chert averages 5% (range: 1 to 7%) of the grains. Some grains contain small, relict inclusions of carbonate (calcite and possible dolomite rhombs). Microcrystalline quartz is the primary chert type,
but radial-fibrous chalcedony and macrocrystalline quartz types are also present.

Total feldspars average 15% (range: 11 to 17%) of the grains, of which 9% is orthoclase, 4% microcline, and 2% plagioclase. Orthoclase ranges from fresh to altered. Replacement by hematite and/or clay minerals (primarily kaolinite) are the alteration products. Several of the orthoclase grains are partially or nearly completely dissolved. Much of the plagioclase is untwinned and/or partially to completely sericitized. The twinned varieties of plagioclase include albite and Carlsbad types. Microcline, with grid twinning, is usually fresh and unaltered. Albite twins in one plagioclase grain in thin section 42 were measured using the Michel-Levy method. Its composition is An_{10}; albite.

Lithics average 4% (range: 4 to 5%) of the grains. Common lithic grains are sedimentary (mudstones and siltstones with rare silicified ooids); granitic rock fragments with orthoclase and quartz, but also minor fragments with microcline and quartz, and one graphic granite; and schistose metamorphic rock fragments. Acidic volcanic rock fragments are rare.

Accessory minerals average 2% of the grains. They include muscovite, biotite, magnetite, and tourmaline, with traces of rutile, pyrite, and zircon.

Framework grains form an average of 78% (range: 76 to 82%) of the rock. Assuming clay minerals and iron oxides are authigenic, and if secondary porosity is ignored, the average minimum initial porosity was 15% (range: 13 to 17%) after compaction. Squashed ductile grains, sutured grain contacts, and numerous grain-to-grain contacts also suggest that considerable mechanical compaction and pressure solution account for the decrease in primary porosity prior to or during cementation.
Grain Size, Sorting, Skewness, and Kurtosis

The mean grain size of Unit 3 (Tables 2, 4) is 1.88 phi (0.27 mm), whereas the range is 1.36 phi (0.39 mm) to 2.87 phi (0.13 mm). The mean size of the samples ranges from fine sand to medium sand. The average median grain size (Ø50) for the three thin sections point-counted for Unit 3 is 1.88 phi (0.27 mm). The coarsest 1% for these three samples averages 0.56 phi (0.77 mm). The median is medium sand, whereas the coarsest 1% is coarse sand.

Sorting (phi units) for the thin sections point-counted in Unit 3 averages +0.58 (moderately well sorted). Its range is +0.47 (well sorted) to +0.71 (moderately well sorted). Skewness averages -0.06 (near-symmetrical), with a range of -0.10 (near-symmetrical) to +0.02 (near-symmetrical). Kurtosis averages +0.98 (mesokurtic). Its range is +0.84 (platykurtic) to +1.06 (mesokurtic).

Grain Angularity and Equantness

Grains in Unit 3 average 12% well rounded to rounded, 52% subrounded, 27% subangular, and 9% angular to very angular (Table 2). Quartz and chert grains have significantly greater roundnesses (68% and 72% average subrounded to well rounded, respectively with ranges of 65 to 70% and 52 to 100%, respectively) than the feldspar grains (47% average subrounded to well rounded, range 41 to 53%).

Grains in Unit 3 average 59% equant, 40% subequant, and 1% bladed (Table 2). The quartz grains are significantly more equant (67% average) than the feldspar grains (46% average) (Table 4).
Classification of Sandstones

As shown in Figure 24, thin sections 42 and 43 are lithic arkoses, whereas thin section 41 is a subarkose.

Cement, Matrix, and Porosity

Cement as a percent of the whole rock averages 10%, with a range of 7 to 14%. Syntaxial quartz overgrowths are the most common, and average 8%. Lesser amounts of iron oxides (1%), chert (1%), calcite (less than 1%), and authigenic clays (less than 1%) are present.

Percent of matrix ranges from 1 to 6%. Iron oxides average 1%, and are predominantly hematite with very rare limonite. Clay minerals average 2%, and are primarily kaolinite and illite.

Porosity ranges from 8 to 11%, and averages 9%. Secondary porosity is judged to form 79% of the total. Types of secondary porosity observed (in order of decreasing importance) include: complete to partial dissolution of grains, matrix, and cement; molds of grains; and inhomogeneity in packing. The balance of the total porosity, about 2%, is considered relict original.

X-ray Analysis of Samples

Mineralogy determined by X-ray analysis of two samples of Unit 3 (thin sections 41 and 42) includes quartz, kaolinite, illite, chlorite, and bayerite (Table 8).
PETROGRAPHY OF THE QUANDONG CONGLOMERATE

Lithofacies A2

General Statement

Sandstones of the Quandong Conglomerate are lithic arkoses, subarkoses, and feldspathic litharenites (Fig. 26). They are moderately well sorted to very poorly sorted, consist of very fine sand to coarse sand, and are cemented by syntaxial quartz overgrowths, chert, and minor authigenic clay minerals. Iron oxide is a cement. Grains consist of 60 to 80% quartz, 1 to 35% chert, 6 to 12% orthoclase, 0 to 1% plagioclase, 3 to 9% other lithics, and trace to 4% accessory minerals. Tables 2-4 show the detailed mineralogy of point-counted thin sections.

Grain Mineralogy

Quartz is the most common grain type in the Quandong Conglomerate. It averages 72%, and ranges between 60 and 83% of the grains. Nonundulant grains (extinction angle less than or equal to 5°) average 51%, undulant grains, 26%, polycrystalline grains with 2-3 crystals, 6%, and polycrystalline grains with greater than 3 crystals, 17% of the quartz fraction in the Quandong. Inclusions in the quartz grains consist of bubble trains, random bubbles or vacuoles, tourmaline, zircon, muscovite microlites, biotite, and rutile needles. Some quartz grains possess Boehm lamellae.

Chert averages 14%, and ranges between 1 to 35% of the grains. The
chert grains are composed predominantly of microcrystalline quartz with minor macrocrystalline quartz and radial-fibrous chalcedony. Some grains contain small relict inclusions of calcite, possible relict molds of dolomite rhombs, or relict algal-, pellet-, and/or ooid structures. These features suggest a carbonate sedimentary source.

Feldspars average 8% (range: 5 to 13%) of the grains, of which 7% is orthoclase and 1% is plagioclase. Most of the orthoclase is slightly or nearly completely altered to clay minerals (primarily kaolinite) and/or very minor hematite. Some of the orthoclase grains have undergone partial or complete dissolution. Much of the plagioclase is sericitized to some degree.

Other lithics average 6%, and range between 3 and 9% of the grains. These consist primarily of metamorphic (schist and gneiss) and sedimentary (shale, siltstone, sandstone, and silicified ooids) rock fragments. Volcanic and granitic rock fragments (orthoclase and quartz with rare microcline and quartz) are rare.

Accessory minerals average 2% (range: trace to 4%) of the grains. They include: (1) muscovite (range: 0 to 1%), (2) biotite (range: 0 to 1%), (3) sphene (trace), (4) ilmenite/leucoxene (trace), (5) pyrite (trace), and (6) heavy minerals (range: trace to 3%). Heavy minerals include magnetite, zircon, tourmaline, and minor rutile.

Framework grains form an average of 76% (range: 70 to 82%) of the rock. Assuming the clay minerals and the iron oxide are authigenic, and if secondary porosity is ignored, the average minimum initial porosity of the samples after compaction was 11% (range: 4 to 24%). The abundant grain-to-grain contacts also suggest considerable mechanical compaction of the grains prior to or during cementation.
Grain Size, Sorting, Skewness, and Kurtosis

The mean grain size of the Quandong samples is 1.77 phi (0.29 mm), whereas the range is 0.80 phi (0.57 mm) to 3.10 phi (0.12 mm). Thin section 36 is composed chiefly of very fine sand, thin section 38 is composed chiefly of fine sand, thin sections 39 and 40 are composed chiefly of medium sand, and thin section 37 is composed primarily of coarse sand. The average median grain size for the samples is 2.10 phi (0.23 mm) and the coarsest 1% averages -0.74 phi (1.65 mm), which are fine sand and very coarse sand, respectively.

Sorting (phi units) averages +1.21 (poorly sorted), with a range of +0.56 (moderately well sorted) to +2.05 (very poorly sorted). Skewness averages -0.27 (coarse-skewed) with a range of +0.15 (fine-skewed) to -0.53 (strongly coarse-skewed). Kurtosis averages +1.00 (mesokurtic). It ranges between +0.55 (very platykurtic) to +1.41 (leptokurtic).

Grain Angularity and Equantness

The grains average 17% well rounded to rounded, 42% subrounded, 24% subangular, and 17% angular to very angular (Tables 3, 4). There are considerable differences in grain angularity and grain shapes between quartz and chert compared to feldspar in the Quandong. Quartz averages 61% (range: 50 to 71%) subrounded to well rounded, and chert averages 88% (range: 71 to 100%) subrounded to well rounded, whereas feldspar averages 10% (range: 6 to 15%) subrounded to well rounded. Quartz grains average 64% (range: 58 to 71%) equant, and chert grains average 65% (range: 37 to 100%) equant, whereas feldspar grains average 34% (range:
15 to 50%) equant. The Quandong samples show 58% equant grains, 41% subequant grains, and 1% bladed grains.

**Classification of Sandstones**

Thin section 36 is a subarkose, thin sections 37-39 are lithic arkoses, and thin section 40 is a feldspathic litharenite (Fig. 26).

**Cement, Matrix, and Porosity**

Cement for the Quandong samples averages 6% of the rock, and ranges from 3 to 14%. Syntaxial quartz overgrowths comprise 4%, chert, less than 1%, authigenic clay minerals, less than 1%, and iron oxide, 2% of the rock. The iron oxides (hematite with very rare limonite), present only in thin section 36, comprise 14% of the rock, of which 57% (8% of the rock) was judged to be cement. This one sample accounts for the abnormally high average of iron oxide for the Quandong samples. The authigenic clays consist of kaolinite and/or illite and possible traces of chlorite.

Matrix ranges from 0 to 10% of the rock, with an average of 3%. Overall, clay minerals, probably illite and kaolinite with rare chlorite, form the bulk of the matrix. In thin section 36 iron oxides, as hematite and possibly very rare limonite, form the bulk of the matrix.

Porosity averages 15% of the rock, with a range of 3 to 20%. Of the total porosity, 90% is judged to be secondary in origin based on the criteria of Schmidt and McDonald (1979a, b). Types of secondary porosity recognized (in order of decreasing importance) are: complete to partial dissolution of grains, matrix, and cement; molds of grains; inhom-
geneity in packing; and fractures. The balance of the total porosity is considered relict original.

X-ray Analysis of Samples

Three samples (thin sections 37-39) were prepared for X-ray analysis. The minerals determined include quartz, kaolinite, illite, and chlorite (Table 8).
DIAGENESIS

General Statement

Diagenesis is defined by many geologists as "... processes occurring between deposition and metamorphism ..." (Larsen and Chilingar, 1983, p. 2). Pettijohn et al. (1972) included all physical and chemical processes which affect the sediment after deposition up to the lowest grade of metamorphism. The diagenetic changes form a record of the post-depositional history. Knowledge of which authigenic minerals are present, how they are distributed, and the sequence in which they formed, aids in understanding the origins of porosity and permeability and in predicting types of porosity expected in the subsurface, and thereby, reservoir potential. The diagenetic terms proposed by Choquette and Pray (1970) will be used in this report.

Authigenic Cement and Matrix

The nine cements recognized in the Arumbera Sandstone and Quandong Conglomerate, are discussed here.

Quartz- Authigenic quartz is present in most of the samples, chiefly as syntaxial overgrowths. Quartz cementation has greatly reduced porosities and permeabilities. This, together with mechanical compaction, accounts for most of the loss of primary porosity. Quartz cement has greatly reduced primary pore networks in all sandstones, so that only minor isolated voids or microporosity persist. Some grains were recognized as
having several stages of syntaxial overgrowths that followed deposition (thin sections 2, 4, 7, 9, 13, 14, 22, 24, 29, 35, 36, 38, 43, 46, and 49; Austin, 1974).

**Carbonate**—Calcite and dolomite cement is a minor constituent in the samples studied. Nearly all carbonate has been eliminated by later dissolution and replacement by iron oxides and authigenic clays. However, there are, carbonate relics which suggest possible early cementation by calcite and/or dolomite (thin sections 1-6, 12, 18-21, 26-28, 30, 35, 37-40, 42-43, 46-47, and 49-51). Calcite cement has replaced grains of quartz, chert, feldspar, and early silica cement. Possible molds of dolomite rhombs have replaced earlier quartz cement in thin sections 1, 20, 21, 26, 28, 30, 46, 47, and 49. A second period of calcite replacement occurred locally as the final stage (thin sections 35, 46, and 49) in the diagenetic sequence (Table 9). During this diagenetic stage calcite has replaced chert cement.

**Clay Minerals**—Clay minerals play a significant role in cementation and modification of porosity. They are present in several forms. Detrital clays are generally very minor and most are identified as illite and kaolinite with rare chloride (Table 8). Authigenic clay minerals, illite and (?)Fe-chlorite, form dust rims and minor clay coats on framework grains, primarily quartz and feldspars. Galloway (1975) made the distinction between clay coats (parallel alignment) and clay rims (perpendicular, radiating). He suggested clay coats inhibit development of quartz overgrowths whereas clay rims do not. Dust rims are common at the bases of quartz overgrowths in the units studied, and obviously did not inhibit quartz overgrowths. Therefore, if Galloway is correct, these are mostly clay rims rather than clay coats. Locally, quartz grains with
thick clay coatings are present. These lack syntaxial overgrowths and therefore the dust rims are considered to be clay coats. Authigenic clays also fill pore centers. Kaolinite and minor illite form crystals radiating into pore spaces or more rarely, the clay coats described above. Often identification is hindered by the presence of iron oxide which is associated with the kaolinite and illite. Areas having the size and shape of grains, and partially or completely filled by kaolinite are probably replacement of orthoclase. Locally the kaolinite is stacked to form a vermicular texture.

**K-Feldspar-** Overgrowths of orthoclase in optical continuity are present, but rare, in most thin sections of the Arumbera Sandstone but are absent in the thin sections of the Quandong. Overgrowths of orthoclase predate the quartz cement. Possible source material for the overgrowths may have resulted from leaching of other feldspars present in adjacent formations or from alteration of clay minerals and other unstable minerals during the mesogenetic stage or even the eogenetic stage. In most cases these overgrowths have been partially or completely leached, or altered to kaolinite.

**Chert-** Only minor chert cement was observed in 20 thin sections total. The samples in which chert is present could represent surficial Tertiary silica cementation ("grey billy" or silcrete). This is a local cement present only in samples taken from ridges where this telogenetic Tertiary chert has not been eroded. Chert has also replaced feldspar and earlier quartz and carbonate cements.

**Opal-** Opal is a rare cement. It was observed as trace amounts in thin sections 8, 38, 39, and 45. It formed during the telogenetic phase, and probably is related to the Tertiary "grey billy." Possibly the opal is
the parent form of the microcrystalline chert.

Tourmaline- Tourmaline overgrowths were found on two grains in thin sections 19 and 41. They probably formed early during the eogenetic stage.

Pyrite- Pore-filling pyrite was observed in three samples of Arumbera (thin sections 45, 49, and 51). Pyrite cement may have formed in local reducing microenvironment during deposition. However, it probably formed during the maturation and migration of petroleum. In most cases only relics are observed because most of the pyrite has been altered to iron oxides.

Iron Oxides- Iron oxides (primarily hematite, with rare limonite and magnetite) form a major proportion of the cement and minor amounts of the matrix. They are generally associated with clay minerals, as pore-fill and as coatings around grains. The hematite cement in some instances may have resulted from the alteration of pyrite, magnetite, and other iron-bearing grains such as biotite, amphiboles, and some clay minerals.

**Mechanical Compaction**

Throughout the early and middle diagenetic stages, compaction apparently played a vital role in reduction of primary porosity. Abundant contacts of grains, sutured grain-to-grain contacts, and flattened and squashed grains were noted in the thin sections. Early diagenetic compaction is represented by fractures that cut only the grains and not the overgrowths (No. 1, Table 9). A later stage of compaction is represented by fractures which cut both grains and cement (No. 6, Table 9). Bohem lamellae in some of the quartz grains also suggest significant
mechanical compaction.

**Replacement and Solution**

The most common replacement reactions involve hematite. However, in many instances the parent material that the hematite replaced could not be determined. In other cases it was difficult to determine if the hematite were detrital or replacement. Hematite is often associated with clays in the replaced and/or altered feldspars. At other times it is a replacement of former iron-bearing matrix or grains. Minor amounts of hematite were found as dust rims on quartz grains, particularly those containing several stages of syntaxial overgrowths. At other sites hematite is mixed with the clay minerals in clay coatings on grains. Subsurface cores show that hematite probably has been present in the Arumbera from the time of deposition (Oaks, 1982, oral communication). The amount of hematite probably has increased or remained about the same throughout the diagenetic history, chiefly as a result of replacement. This also is suggested by the rather low amounts of iron-bearing minerals and rock fragments present in the samples.

Chert and carbonate are other replacement minerals. In some samples chert replaces both grains and cement. Dolomite replaces grains, quartz cement, and chert cement in several samples. It generally formed as coarse-crystalline spar or rhomb-shaped crystals. Some replacement of grains and cement by calcite also occurred. Most replacement occurred in the mesogenetic stage. Possibly minor amounts formed in the telogenetic stage.

The major alteration involves the feldspar grains. Many grains were
completely replaced by kaolinite. Others exhibit partial dissolution and replacement. In some cases the alteration of the K-feldspars to kaolinite was associated with the formation of iron oxides. Most kaolinization of K-feldspar appears to be post-depositional because overgrowths as well as K-feldspar grains are similarly altered. The plagioclase feldspars exhibit local sericitization and vacuolization (primarily derived from weathering but locally they are igneous in origin). These alterations were both pre- and post-depositional. Some grains are completely sericitized, and probably would not survive transport by traction. Others, only partially sericitized, suggest the possibility that some of the plagioclase grains may be reworked.

**Secondary Porosity**

Criteria for the recognition of secondary porosity were described by Schmidt and McDonald (1979a, b). The most common type of secondary porosity observed in the thin sections studied is the dissolution of feldspar grains. The textural relationships, kaolinization, outlines of relic grains, and traces of feldspars suggest that secondary pores are formed by the direct dissolution of feldspar and by the partial dissolution of their alteration products. Feldspar dissolution has occurred to various degrees in these samples. It ranges from total dissolution of the grain with a partial collapse of surrounding grains into the vacated space to only partially embayed feldspar grains. Evidence of feldspar dissolution includes: (1) pore space the size and shape of a grain, which is partially filled with authigenic kaolinite; (2) free-standing undissolved coatings of authigenic clay minerals and iron oxides around
a pore; (3) floating grains of quartz; (4) oversize pores, some with relics of feldspar, kaolinite, or both, (5) honeycomb texture of feldspar grains; and (6) scarcity of feldspar grains in some of the samples. Some solution of quartz grains may have taken place. The best evidence for this are local embayments of quartz grains next to open pore spaces. Dissolution of quartz appears to be of minor significance in the development of secondary porosity.

Dissolution of other grains and their replacement products probably also occurred to a minor degree. Evidence to support this includes: (1) some pore space is bladed in shape and resembles mica grains; and (2) several chert grains exhibit partial dissolution along their borders, internally, or both.

**Diagenetic Sequence for the Arumbera Sandstone**

A detailed diagenetic history for each Arumbera thin section is presented in Table 9. Although not all diagenetic events may be recognized in each individual thin section, a composite sequence of diagenetic alterations of the Arumbera has been determined.

Eogenetic changes in the Arumbera include: (a) mechanical compaction as evidenced by squashed ductile grains, sutured grain-to-grain contacts, and numerous grain-to-grain contacts. Then (b) the formation of dust rims or clay coats of (?)Fe-chlorite, illite, and iron oxides, all of which are absent or minor at grain-to-grain contacts. A possible source for the iron oxides may be the mechanical breakdown and chemical degradation of iron-bearing detrital grains such as biotite, magnetite, and hornblende (Walker, 1967; Turner and Archer, 1977). Only
minor amounts of biotite and magnetite persist in the Arumbera
(Tables 3, 8).

The formation of (c) tourmaline overgrowths and (d) K-feldspar
overgrowths may be either late eogenetic or early mesogenetic. Little
has been published on the origin of tourmaline overgrowths.

Overgrowths of K-feldspar may be similar to those described by Odom
et al. (1979) for the St. Peter Sandstone. Authigenic K-feldspar prob­
abley precipitated from pore fluids rich in potassium, aluminum, and
silica where the ions may have been supplied by saline pore fluids
released during the compaction of underlying shales and carbonates.

Mesogenetic features observed include: (e) pressure solution
of quartz and feldspar grains; (f) syntaxial overgrowths on quartz;
(g) pore-filling calcite cement and dolomite rhombs; and (h) the
formation of secondary porosity by dissolution. These are probably
associated with deep burial. McNaughton and Huckaba (1978) reported a
maximum loading depth of 4000 to 4250 meters for the Arumbera in the
Ooraminna area. It is clear that syntaxial feldspar overgrowths predate
syntaxial quartz overgrowths because the euhedral to subhedral feldspar
overgrowths are rimmed by anhedral quartz overgrowths or pore-filling
quartz cement. Pressure solution of quartz grains may have been the
major source of silica for the quartz overgrowths. The addition of
silica from an external source may be necessary to account for the
entire amount of silica cement. However, James (Oaks, 1985, oral commun­
ication) suggested that the silica can come from pressure solution of
the very fine-grained quartz arenites interbeds. The abundance of dust
rims in the fine-grained to medium-grained sandstones in the Arumbera
suggests that pressure solution in these sandstones may have been
hindered by the development of these authigenic clay minerals. Potassium, aluminum, and silica may have been released during the compaction and dewatering of the underlying Pertatataka Shale, shales within the Arumbera Sandstone, or possibly shales in the overlying Chandler Formation. Additional silica may have been released by degradation of smectite in these shales during deep burial (Land and Dutton, 1978).

Calcite cementation (i) possibly followed maximum burial when subsidence rate diminished or uplift with unloading by erosion occurred. Dolomite rhombs are present within the silica cement apparently replaced the silica. Pressure solution, including the formation of stylolites, of carbonates in the overlying Chandler Formation and underlying Julie Formation may have provided the necessary CaCO$_3$ and MgCaCO$_3$.

Carbonate cementation was followed by an episode of (j) dissolution of both feldspars and cements (K-feldspar, calcite, and very minor quartz) probably by decarboxylation and decarbonatization. Evidence for dissolved cements (calcite, dolomite, silica, and K-feldspar) and possibly matrix includes: (1) scattered areas of undissolved, corroded silica and calcite cement, (2) quartz overgrowths embayed by pore space, (3) floating grains, (4) very elongate, thin pore spaces the size and shape of nearby micas, and (5) areas containing both close-packed, well-cemented grains near loosely packed, poorly cemented grains.

In three samples of the Arumbera, (k) minor pyrite precipitated in the newly formed secondary porosity. The pyrite may be related to the generation of hydrogen sulfide during organic maturation (Land and Dutton, 1978). It generally indicates a reducing environment.

Alteration of K-feldspars to clay minerals (l) took place during and/or following dissolution of grains and cement. Kaolinite, with minor
illite, collected in the grain location and is associated with the
development of secondary porosity.

In thin sections 46 and 47 the development of (m) pseudo-matrix by
clay minerals was found. In thin section 46 it occurred prior to the
development of feldspar overgrowths, whereas in thin section 47 it took
place following the alteration of the feldspars to kaolinite.

Telogenetic events observed in the Arumbera include the formation
of (n) pore-filling kaolinite and possibly illite, and (o) chert replace­
ment of grains and cement, and as pore-filling; (p) fractures that cut
across the chert cementation; (q) formation of pore-filling opal; and
(r) calcite as pore-filling and replacement of chert cement. Locally
vermicular "worms" of stacked kaolinite plates are present. Conrad
(1981) also observed these in the Arumbera in his study area. Odem et
al. (1979) reported that a similar form of kaolinite in the St. Peter
Sandstone formed in association with fresh, possibly meteoric, pore
water. The pore-filling chert is probably related to the formation of
Tertiary silcrete (Conrad, 1981). This cement originally may have been
opal, but has recrystallized to microcrystalline and minor macrocrystal­
line quartz and chalcedony. This later stage of calcite replacement
probably is Tertiary calcrete.

**Diagenetic Sequence of the Quandong Conglomerate**

Eogenetic events observed in the Quandong Conglomerate include:
(a) mechanical compaction as evidenced by the many grain-to-grain
contacts and minor sutured grain-tp-grain contacts; then (b) the minor
to rare development of dust rims of illite, (?)Fe-chlorite, and very rare iron oxides. Possibly included in this event is an early period of authigenic clay mineral precipitation as pseudo-matrix.

Mesogenetic events include: (c) syntaxial quartz overgrowths, followed by (d) microfractures (cross quartz grains and their overgrowths), and (e) minor cementation by calcite. Textural evidence (two stages of quartz overgrowths separated by two distinct periods of formation of dust rims) suggests two episodes of cementation by quartz. Then (f) alteration of K-feldspars to kaolinite, and other unstable grains to authigenic clays. Next, (g) dissolution, perhaps due to decarboxylation and decarbonatization of K-feldspars and calcite, formed secondary porosity.

The telogenetic events include: (h) the additional formation of pore-filling kaolinite and (i) later minor pore-filling chert, originally probably as opal that (j) recrystallized to microcrystalline, macrocrystalline quartz, and chalcedony.
Cumulative-frequency probability (CFP) curves and weight-percent histograms (WPH) based on size intervals of 0.5 phi were constructed for each of the 51 thin sections point counted (Figs. 46-60). These were constructed after converting thin-section data into equivalent sieve-size data (see Friedman, 1958). Grain sizes were coarser than Friedman's (1958) conversion chart in 20 samples. Because his conversion scale is linear, a linear extrapolation was made for grains coarser than -1.0 phi. The minimum grain size present was finer than 4 phi, whereas most were within 1 phi class of his maximum phi size. Conrad (1981, p. 92-94) presented additional limitations, as well as curve characteristics for the CFP curves. James and Oaks (1977, p. 1504) provided a concise summary of general characteristics of CFP curves.

The relation of grain-size distributions to depositional processes is based on the assumption that straight-line, log-normal segments of the CFP curves represent separate grain populations characteristic of transport by traction, intermittent suspension, and viscous suspension (Visher, 1969; Visher et al., 1971). From his study of size analyses of individual laminae in modern sediments, Visher developed general empirical characteristics for fluvial, intertidal, backshore, and near-shore marine environments. Visher recognized two major changes in slope for the CFP curves, one near +2.0 phi (fine to medium sand) and the
other near +3.5 phi (silt/sand boundary). They probably represent the transition from traction to transport by intermittent suspension and then to true suspension, respectively. Positions of the two primary changes in slope will vary slightly depending on such depositional factors as current velocities, flow separation, flow regime, and fluid density (James and Oaks, 1977, p. 1505).

**Arumbera Sandstone**

The CFP curves for the Arumbera can be divided into three major curve types. Type I curves (thin sections 1, 3, 13, 18, 20, 24, 26, 27, 44, 46, and 48 are bimodal or polymodal with at least two log-normal segments that resemble, in their steepness, populations transported by intermittent suspension. These segments are separated by a less steep (more poorly sorted) transition zone (Figs. 46-54, 57, 58). The modes are subequal in height and generally less than 2 phi intervals apart. Type I curves, as a whole, have the poorest sorting.

Thin section 13 possibly represents a transition between type I and type III curves. This sample contains a significantly smaller population transported by traction, about 3%, than the other type I samples studied. The remaining type I curves have traction populations of 15 to 75%. All type I curves have suspension-transported populations of 1 to 4%. The suspension populations are mostly coarse silt size with lesser amounts of very fine sand. The traction population is primarily gravel and very coarse sand with minor fine to coarse sand.

Type II curves (thin sections 2, 5, 6, 12, 16, 17, 21, 23, 32, 34, 42, 43, 45, 50, and 51 are nearly unimodal, and have a coarse-grained
tail. Steepness of the log-normal segments suggest that transport was primarily by intermittent suspension.

Thin sections 6, 12, 16, and 21 contain minor traction populations (range: 1 to 15%). Except for thin sections 2 and 17, type II samples possess fine populations transported by suspension (range: 1 to 7%). Most traction populations are medium to coarse sand with minor very coarse sand and fine gravel. The suspension populations are typically coarse silt with lesser amounts of very fine sand. Type II curves are dominated by steep log-normal populations probably transported by intermittent suspension. These populations constitute 85 to 99% of the total.

Thin sections 33 and 42 may represent a transition between type I and type II curves. Thin sections 7-9, 19, 22, 29, 31, and 50 on the other hand may represent a transition between type II and type III curves. These curves are nearly symmetrical about a single mode or possess a slight fine population. Thin sections 8, 9, 19, and 29 have minor populations transported by traction (range: 0.5 to 3%). All of these transitional curves possess minor populations transported in viscous suspension (range: 0.5 to 7%). These curves have steep log-normal segments which probably represent grains transported by intermittent suspension. The traction populations are typically coarse to very coarse sand with minor gravel, whereas the suspension populations are primarily very fine sand to coarse silt. Coarse populations show a break in slope at approximately +2.0 to +1.0 phi.

Type III curves (thin sections 4, 10, 11, 14, 15, 25, 28, 30, 35, 41, 47, and 49) are nearly unimodal with a fine-grained tail. Steepness of the log-normal segments suggests that transport was primarily by intermittent suspension. Most type III curves appear to have minor slope
breaks, within medium to coarse sand sizes, that may indicate small populations transported by traction. They also exhibit minor slope breaks, within coarse silt and very fine sand sizes, that may reflect populations transported by viscous suspension.

The CFP curves demonstrate that transport of fine to coarse sands in marine lithofacies of the Arumbera was dominated by intermittent suspension with only very minor transport by traction and viscous suspension. As Conrad (1981) pointed out, these findings are consistent with subaqueous deposition of current ripples, oscillation ripples, sand waves, dunes, and parallel laminae by weak to strong currents in the lower flow regime. Thin sections of the fluvial lithofacies 1c and 2c possess the best traction "tails."

There are several possible explanations for these differences in curve types. One possibility is that each type represents sediments deposited in different subaqueous environments. Eight fluvial and three marine samples exhibited type I CFP curves. Five fluvial and ten marine samples exhibited type II CFP curves. Twelve marine samples exhibited type III CFP curves. Other factors may be differences in velocity of currents, orientation of the thin section perpendicular to bedding (and laminae), and, although unlikely in the fluvial units, possibly the effects of burrowing. Finally, there may have been fluctuations in sediment sizes as uplift, erosion, and drainage diversions caused changes in the source rocks or the transporting agents.
The CFP curves for the Quandong Conglomerate are primarily type I curves (Figs. 56, 60). Four thin sections (37, 38, 39, and 40) are bimodal to polymodal, with log-normal segments of one or more intermittent suspension populations separated by less steep (more poorly sorted) transition zones. Modes are subequal in height and are separated by 0.5 to 5.0 phi intervals. Thin section 38 has indistinct transition zones. Type I curves are very poorly sorted to moderately sorted. There is one type II curve, thin section 36. It exhibits two steep log-normal populations that resemble intermittent-suspension populations, and has a minor population of fines transported by viscous suspension, about 1%, of coarse silt. A traction segment may be present, but is not clearly expressed for this sample, and is indistinct in thin section 38. The other three type I curves exhibit a traction population of 1 to 14%. Two of the Type I curves have suspension populations of coarse silt to very fine sand that constitute less than 0.5% of the sample. The traction populations range from medium sand to fine gravel.

A considerable difference in sorting is present between the intermittent suspension populations of the fluvial Quandong samples and those of the fluvial lithofacies 1c of the Arumbera. Quandong CFP curves are steeper for these populations (see Figs. 50, 56), whereas the five samples of lithofacies 1c of the Arumbera, from five different sections, are remarkably similar. Greater similarity exists between the Quandong CFP curves and those of fluvial lithofacies 2a and 2c of the Arumbera (Figs. 47, 52). The Arumbera in the James Ranges 'B' anticline (Fig. 55) also appears dissimilar to the fluvial Arumbera and Quandong samples in
their finer median grain sizes.

The CFP curves demonstrate that for several of the Quandong samples (37, 39, and 40) a significant traction population occurs along with the dominant intermittent suspension population. This is noteworthy as a supplement to sedimentary structures for interpretation of the depositional environment of the Quandong. The coarse traction populations are consistent with the interpretation of deposition under fluvial conditions with strong or possibly moderate currents.
PROVENANCE

General Statement

According to Basu (1976), provenance can be defined for the terrigenous rocks by means of four variables: relief, climate, types of source rocks, and location (distance) of source rocks. Evidence for these variables were gathered by careful observations of the variety and packing relationships of grains encountered during detailed point counts of each thin section. Integration of these data with paleocurrent data enables inferences about source rocks and the regional tectonic setting. Comparison of these ancient sandstones with Holocene sands of known parentage also permits further inferences about provenance(s) of the Arumbera Sandstone and Quandong Conglomerate.

Studies by Basu et al. (1975), Basu (1976), and Mack and Suttner (1977) have supplied appropriate data concerning the effects climate, grain size, and source rocks play on recent sands. Other reports (Blatt and Christie, 1963; Blatt, 1967; Pettijohn et al. 1972; and Folk, 1974) suggest that general inferences regarding provenance can be made from the types and relative proportions of quartz varieties. Basu et al. (1975) published a classification of quartz types using first-cycle, medium-grained sandstones. By differentiating nonundulant, undulant, polycrystalline (2-3 crystal units), and polycrystalline (more than 3 crystal units) types of quartz they established a scheme for differentiating among plutonic, middle- and upper-rank metamorphic, and low-rank metamorphic source rocks from plots of modern and ancient sands.
and sandstones of known or inferred provenance.

When compared with data for first-cycle sands derived from Holocene source rocks (Basu, 1976), quartz types in the Arumbera (Table 2) show subequal amounts of nonundulant quartz, much greater undulant quartz, fewer polycrystalline (2-3 crystal units) quartz, and slightly more polycrystalline (more than 3 crystal units) quartz. Overall the Arumbera demonstrates fewer total polycrystalline grains than the sands studied by Basu (1976). These results are similar to those observed by Conrad (1981) in his study area of the Arumbera. Conrad listed three reasons that may explain the increase of the undulant quartz population in the Arumbera compared to Basu's (1976) data: (1) post-depositional straining during folding and faulting associated with the Alice Springs orogeny (some of the quartz grains observed in this study possess Boehm lamella which probably resulted from post-depositional strain); (2) a possible second-cycle or multicycle sedimentary source with fewer polycrystalline quartz grains due to breakage; or (3) a high-grade metamorphic source with a high percentage of undulant quartz.

The small population of polycrystalline grains may have resulted from destruction during transport. Blatt (1967) demonstrated that polycrystalline grains are less durable during transport than monocrystalline quartz grains.

Ten Arumbera thin sections (8, 11, 12, 24, 29, 42, 43, 45, 50, and 51) are medium-grained sandstones. Because thin sections 10 (2.08 phi mean), 15 (2.06 phi mean), 17 (0.88 phi mean), 25 (2.09 phi mean), 47 (2.07 phi mean) and 49 (2.08 phi mean) are only slightly finer or coarser than medium sand, they also were plotted in the classification diamond (Figs. 27-30) developed by Basu et al. (1975). Basu et al.
(1975) stressed the importance of using only medium sand because:
(1) the fields are based on data from medium sands; (2) recognition of
undulose grains decreases with decreasing grain size; and (3) the number
of polycrystalline grains relative to monocrystalline grains decreases
with decreasing grain size.

Fourteen of the sixteen samples plot in the middle- and upper-rank
metamorphic fields. Thin section 11 (lithofacies 2b) plots on the bound­
dary separating the plutonic and the middle- and upper-rank metamorphic
fields. Thin section 51 (Unit 1) plots near the boundary between low­
rank and middle- and upper-rank metamorphic provenances. The remaining
Arumbera thin sections, which are either too fine-grained or too coarse­
grained, plot in the middle- and upper-rank metamorphic source rock
field. Although these samples fall outside the size criterion of Basu et
al. (1975) for source-rock determination, they are plotted for compar­
ison with samples taken from the Quandong Conglomerate.

The four-variable quartz plot of Basu et al. (1975) suggests
the Arumbera sediments were derived primarily from middle- to upper-rank
metamorphic terrain. This provenance is confirmed by the presence of
metamorphic rock fragments (quartzite and schist), granitic rock frag­
ments, and magnetite grains. If the tectonic strain from the Alice
Springs orogeny increased the undulant quartz population, then perhaps
several samples had a felsic plutonic source. Thin section 51 suggests a
possible lower- to middle-rank metamorphic source. It also suggests,
when compared to medium-grained samples of Units 2 and 3, progressive
unroofing in the source area.

In the James Ranges 'B' anticline, thin sections 34 and 35 are
fine-grained (means of 2.37 phi and 2.34 phi, respectively) but are the
closest samples to the medium sand size. They plot in the middle- and upper-rank metamorphic field (Fig. 30).

Two Quandong thin sections (39 and 40) are medium grained. Thin section 38 (2.07 phi) is only slightly finer than the medium sand, and so was also plotted in the diagram. Thin sections 39 and 40 fall near the center of the middle- and upper-rank metamorphic field, whereas thin section 38 falls near the boundary for low-rank metamorphic source rocks (Fig. 30). The remaining Quandong thin sections (36 and 37) were also plotted for the purpose of comparing with the Arumbera Sandstone. The five Quandong samples suggest possible unroofing in the source area, because their plots move from the low-rank metamorphic source rock field toward the plutonic source rock field upsection.

A composite of the quartz types from each of the areas studied shows that the Arumbera in the James Ranges and Gardiner Range are very similar. In the eastern James Ranges, Arumbera quartz types average 59% nonundulant, 28% undulant, and 13% polycrystalline, whereas in the James Ranges 'B' anticline the Arumbera quartz types average 58% nonundulant, 27% undulant, and 15% polycrystalline. In the Gardiner Range, the Arumbera quartz types average 67% nonundulant, 20% undulant, and 13% polycrystalline. The Quandong quartz types average 50% nonundulant, 27% undulant, and 23% polycrystalline. The Quandong is considerably lower in nonundulatory quartz and higher in polycrystalline quartz than the Arumbera. This difference indicates either a different provenance or a shorter distance of transport from the source.
Cobbles, pebbles, and sand-sized framework grains present in the various Arumbera lithofacies are useful for provenance information. Pebbles in lithofacies 1c and 2c consist of chert, quartzite, vein quartz, granitic rock fragments, limestone rock fragments, dolostone rock fragments, shale rock fragments, and sandstone rock fragments. They range up to 7 cm in diameter in the James Ranges and up to 5 cm in diameter in the Gardiner Range.

Chert pebbles are common. Some of these contain relict ooids, pellets, and possible algal structures. They may have been derived from the Bitter Springs Formation (Conrad, 1981). In thin sections, chert grains contain small relict inclusions of carbonate, relict rhombs of dolomite, and relict casts of pyrite cubes. These preserved relics of carbonate rocks provide evidence that carbonate sedimentary rocks were present in the source area during deposition of lithofacies 1c and 2c. Microcrystalline quartz is the dominant chert type, but radial-fibrous chalcedony and macrocrystalline varieties are also present. Chalcedony is a common replacement in sedimentary rocks and in felsic volcanic rocks (Scholle, 1979). Chert grains were present in all of the Arumbera thin sections except thin sections 10, 21, 28, 30, and 51. In lithofacies 1a, 1b, and 1d chert averages less than 1% of the grains. In lithofacies 2a and 2b chert averages 3% and 1% of the total grains, respectively. In lithofacies 1c and 2c chert averages 45% and 37% of the total grains, respectively. In Unit 3 chert averages 5% of the grains. The high values for lithofacies 1c and 2c result from the large number and size of chert pebbles in these samples.
Quartzite pebbles were recognized by the granoblastic texture in hand samples and by their granular, interlocked nature in thin sections. Conrad (1981) believed they resembled the Heavytree Quartzite, the oldest Upper Proterozoic sedimentary formation in the Amadeus Basin. A sedimentary or metasedimentary source is indicated by the quartzite pebbles.

Vein quartz is rare, and granules generally are the maximum grain size. It is recognized by the milky to smoky color and noticeable lack of interlocked grain boundaries. Pegmatites are probably the chief source of the vein quartz. However, the generally well rounded to rounded nature suggests that the vein quartz may also be reworked from older sediments.

Pebbles of granitic rock fragments are present but rare. They were observed only in lithofacies 2c. They indicate a felsic plutonic source.

Pebbles of sandstone fragments are rare. They represent reworking of previously deposited terrigenous rocks, which must have been present in the source area.

Rock fragments of limestone, dolstone, and silicified-ooids are common in lithofacies 1c. They indicate a sedimentary rock source. The Bitter Springs and Julie formations are possible source units for these rock fragments.

Shale rock fragments also indicate a sedimentary source. They are rare in lithofacies 1c, but their presence, along with sandstone rock fragments, suggest the reworking of older terrigenous sedimentary rocks such as the Heavitree Quartzite, Areyonga, and Pertatataka.

Feldspars are common as sand-sized grains in the Arumbera. Orthoclase averages 11% of the grains, plagioclase averages 4%, and micro-
cline averages 2%. Folk (1974) reported that orthoclase and microcline generally dominate in sediments, with sodic plagioclase a minor constituent and calcic plagioclase almost lacking. He reported that nearly all sand-sized feldspar ultimately comes from a felsic plutonic or high-grade metamorphic sources, with granites and gneisses supplying most. Others (Pettijohn et al., 1972; Basu, 1976; and Mack and Suttner, 1977) also have considered feldspar useful as an indicator of provenance, especially paleoclimate. The two important parameters used as indicators are: (1) comparative grain sizes and shapes of quartz and feldspar, and (2) degree of alteration of feldspars. Because of their cleavages and greater vulnerability to chemical attack, feldspars break into smaller fragments more easily than quartz. Table 4 shows the grain relationships among quartz, feldspar, and chert. The feldspars are slightly coarser than the quartz in most thin sections, and nearly the same size in others, and finer than the chert in most of the thin sections. Angularity of feldspars is considerably higher than for quartz and chert. Only moderate abrasion of feldspars, prior to deposition, can be inferred from these comparisons.

Most orthoclase grains are fresh in thin sections, but many grains are partially to completely replaced by kaolinite and/or hematite, or partially to completely dissolved. The alteration of the orthoclase grains probably resulted primarily from diagenetic chemical weathering. The presence of altered K-feldspar overgrowths on several altered and unaltered grains indicates that most K-feldspar alteration followed deposition, whereas the presence of unaltered feldspar overgrowths on partially altered grains suggests that some weathering may have taken place prior to deposition.
Microcline ranges from subequal to five times less abundant than orthoclase in the Arumbera (Table 3). Several perthite grains are also present. Blatt et al. (1972, p. 264) reported that in plutonic rocks microcline is twice as abundant as orthoclase. Basu et al. (1975) suggested recognition of microcline in thin section is hindered because not all have grid (cross-hatch) twinning and because preferential breakage along composition planes may leave finer fragments untwinned. The apparent deficiency of microcline relative to orthoclase may result from scarcity in the source area (most grains of microcline are unaltered), or a lack of recognition during point counting (Conrad, 1981).

Plagioclase grains are either twinned or untwinned, with the untwinned varieties most common. Albite twins are the most common. Compositions of An2 and An7-10 were determined for some albite-twinned plagioclase grains. These are albite, a common mineral in granite, gneiss, schist, diorite, phonolite, and trachyte (Merrill, 1906). Compositions of An12-14 and An26 were determined for additional plagioclase grains. These are oligoclase, a common mineral in monzonites, granodiorites, and medium-grade metamorphic rocks (Berry and Mason, 1959, p. 489-490). The plagioclase commonly is sericitized, which can result from chemical weathering or hydrothermal alteration. Plagioclase grains with distinct, unaltered grain boundaries, which are heavily sericitized, may not have been able to survive transport. For these grains, alteration probably followed deposition. Grains that are only partially sericitized could have been altered either before or after deposition. Minor vacuolization (bubbles) was encountered in several of the plagioclase grains. It results from diagenetic chemical weathering or from hydrothermal alteration (Folk, 1974, p. 84).
Lithic rock fragments in the Arumbera are primarily granitic. Metamorphic and sedimentary rock fragments are common but present in smaller amounts. Some graphic granite is present. However, most of the granitic rock fragments consist of orthoclase and quartz, although fragments with microcline and quartz are present. One granite fragment composed of amphibole and quartz was observed. The sedimentary rock fragments are predominantly terrigenous shales, siltstones, and sandstones. Schistose metamorphic rock fragments are common. They consist primarily of elongate crenulate grains of quartz and muscovite. Felsic volcanic rock fragments are rare.

The heavy-mineral population in the Arumbera consists predominantly of ultrastable tourmaline, zircon, and minor rutile. Stable rounded magnetite grains are rather common. Minor to trace amounts of epidote, pyrite, ilmenite/leucoxene, and augite are present. Two tourmaline grains contained syntaxial tourmaline overgrowths. The ultrastable population of heavy minerals is typically well rounded, which suggests a recycled sedimentary source (Folk, 1974, p. 95-96).

First-cycle sediments in a semiarid environment favor rock fragments, feldspar, and accessory minerals, whereas first-cycle sediments in a humid climate should be relatively enriched in monocrystalline and polycrystalline quartz (Basu, 1976; and Mack and Suttner, 1977). Blatt et al. (1972) reported that in felsic plutonic and metamorphic rocks, feldspars are generally three times as abundant as quartz. The high-grading of quartz relative to feldspar in the Arumbera may reflect climatic controls (Crook, 1968) or it may represent the recycling of sands from the Heavytree, Bitter Springs, Areyonga, Pertatataka, and Julie formations (Conrad, 1981). When plotted on the time-intensity
feldspar chart of Folk (1974, p. 85), the high-grading of quartz relative to feldspar suggests a warm to hot semiarid to humid climate if most of the quartz and feldspar are first-cycle. Alternatively, the high degree of roundness of the quartz (and chert and ZTR) suggest that part of the quartz may be an admixture from recycled sedimentary rocks. The iron oxide in the Arumbera suggests hot temperatures at the site of deposition (Walker, 1967). Probably a hot climate can be inferred for both the provenance and depositional site during deposition of the Arumbera. Possibly semiarid, conditions can be inferred for the provence of the Arumbera based on the high-grading of quartz relative to feldspar, the rarity of accessory minerals (particularly ZTR), and the low number of rock fragments. Conrad (1981) suggested that the arkosic nature of the Arumbera Sandstone implies a tectonically active source area with rugged relief. Paleocurrents, an increase in the ratio of quartz to feldspar to the northeast, and the decline in the number and maximum size of rock fragments to the northeast suggest a source area west-southwest of the present James Ranges, with transportation possibly by aggrading braided streams. Some sediments may have endured moderate to prolonged periods of chemical weathering during temporary storage during transport. Downcurrent paleocurrent directions suggest an east to southeast flow direction for the Arumbera in the eastern James Ranges (Figs. 13-16) and east to northeast flow direction in the Gardiner Range (Figs. 17-20). Source areas must have been farther west-southwest, perhaps in the area of the present Pettermann Ranges and Olia Chain. Oaks (1983) suggested the Newland Ranges as a possible source, although paleocurrent directions to the northeast for the Arumbera in the Gardiner Range and James Ranges 'B' anticline (Figs. 15, 17-20) do not support that interpretation.
The character of sedimentary provenance has been related to plate-tectonic settings for sandstone composition by using a QFL (quartz-feldspar-lithics) plot and three auxiliary plots which compare quartz, feldspar, and lithic types (Dickinson and Suczek, 1979). Modal compositions of framework grains were recalculated as volumetric proportions into the following grain categories (after Graham et al., 1976):

1. stable quartz grains (Q), which include both monocrystalline quartz grains (Qm) and polycrystalline quartz grains (Qp);
2. monocrystalline feldspar grains (F) which include plagioclase (P) and K-feldspars (K);
3. unstable polycrystalline lithic fragments (L), which include volcanic and metavolcanic types (Lv) and sedimentary and metasedimentary types (Ls). The total of the lithic fragments (Lt) equals the sum of unstable lithics (L) plus stable quartzose lithic fragments (Qp).

Extraneous constituents, such as heavy minerals and calcareous grains, are disregarded in this scheme. The four ternary plots are: (1) QFL, (2) QmFLt, (3) QpLvLs, and (4) QmPK. Dickinson and Suczek (1979) classified the provenances into three general groups: (1) continental block (shields, platforms, or faulted basement rock), (2) magmatic arcs (active arc orogens of island arcs or active continental margins), and (3) recycled orogens (subduction zones, collisions orogens, or foreland fold-thrust belts).

QFL (Figs. 31-33) and QmFLt (Figs. 34-36) plots suggest the Arumbera sandstones were derived from uplifted basement in continental-block provenances. Such a tectonic setting is characterized by high relief and rapid erosion of the uplifted source that commonly yields arkosic sands. More lithic sands may reflect partial derivation from sedimentary and/or metamorphic envelopes that can partially or complete-
ly cover basement gneisses and granites in the uplifted area. Key tectonic settings may include incipient rift belts, continental blocks, and zones of wrench tectonics within continental interiors (Dickinson and Suczek, 1979). However, Conrad (1981) suggested the tectonic regime of the Petermann Ranges orogeny (Forman and Shaw, 1973), does not fit any of these three key settings, but instead may resemble deformation in the Colorado Rockies. A similar clustering of QFL data points is reported by Basu (1976, Fig. 7) for first-cycle, fine- and medium-grained Holocene fluval sands derived from the granitic rocks of the Appalachians. The QpLvLs and QmPK diagrams for the Arumbera reflect the dominance of plutonic over volcanic detritus, show the high K/P ratio and the high Q/F ratio, and demonstrate that the sands consist of fairly stable and mature grains probably derived from the foreland fold-thrust belt within a continental block.

Wells et al. (1967a) reported the probable source area for the Arumbera sediments includes the Petermann Ranges and other associated regions of uplift along the southern margin of the Amadeus Basin. This uplift occurred during the Late Proterozoic Petermann Ranges orogeny. It was described by Forman and Shaw (1973) as an intracratonic orogeny which formed extensive northward displaced nappes. Relative northward movement of Precambrian cratonic basement during thrusting produced features similar to those of the foreland fold-thrust belts described by Dickinson and Suczek (1979). These highland belts shed sediment into the foreland basins and shield the basins from sediment sources located in the volcanic arc. Conrad (1981) suggested a more recent analogy for the Arumbera might be the Cenozoic of the High Plains, especially the Ogallala Formation, which is derived from exposed basement blocks in the
central Rocky Mountains uplifted vertically during the Laramide orogeny. The QFL plots suggest a progressive decrease in mineralogic maturity during deposition of the Arumbera. A migration of fields for each unit away from the Q-pole through time appears to be present, but the relation is not as distinct in the Gardiner Range as in the eastern James Ranges. Perhaps proximity to the Central Ridge caused greater dilution by sedimentary sources in the Gardiner Range than in the eastern James Ranges (cf. mud flows of lithofacies 1c, Figs. 33 and 36, probably derived locally). Lithofacies 2b appears to be the least mature in its mineralogy, whereas lithofacies 2c and Units 1 and 3 are equal or slightly more mature. The QmPK plot also suggests a slight decrease in mineralogic maturity through time.

Several factors may have influenced the lack of a clear-cut decrease in mineralogic maturity of the units through time. Periods of storage prior to final deposition could vary for sediments of the different units. This would affect the length of time for chemical weathering prior to final deposition. Harrell and Blatt (1978) believed chemical weathering is more important than mechanical durability in determining survival potential during transport in aggraded streams. Bradley (1970) and Breyer and Bart (1978) showed that storage and chemical attack are minimized for streams at grade or degrading. Climatic changes or changes in the source area could also cause changes in mineralogic maturity. However, the overall pattern of decreasing maturity supports progressive unroofing of the source area during deposition of the Arumbera.

Framework-grain mineralogy demonstrates a diverse source area composed of sedimentary carbonates (chert with relict carbonate inclusions),
terrigenous rock fragments (shale, siltstone, and minor sandstone),
felsic plutonic rocks (granitic rock fragments), high- to middle-grade
metamorphic rocks (schists and quartzite), and very minor felsic volcanics. Grain mineralogy demonstrates a slight difference in the predomi-
nant source rocks. In the Gardiner Range, metamorphic rock fragments
(schists and gneiss) are the dominant types, whereas in the eastern
James Ranges the Arumbera contains subequal amounts of the dominant
sedimentary and granitic rock fragments. The observance of very similar
graphic granite and rock fragments with silicified ooids further sup-
ports the interpretation that the Arumbera in the Gardiner Range and
James Ranges had the same or very similar source areas. A granite with
microperthite and quartz in a micrographic texture was reported 11 km
(6 miles) southwest of Mount Harris (Forman and Shaw, 1973). Silicified
oooids are common in the underlying Julie and Loves Creek, and these two
units may have served as source rocks for similar rock fragments in the
Arumbera sandstones. The degree of feldspar weathering, and iron oxides
at the site of deposition of the Arumbera suggest a hot, semiarid climate
at the source. Higher angularity of framework grains of sands of this
study as compared to Conrad's (1981) study area may reflect deposition
nearer the source. The source area may have been 400 to 600 km distant
(Conrad, 1981). However, lithofacies 2c is absent in the Gardiner Range,
at outcrops and well west of the eastern James Ranges, at Jay Creek (R.
Q. Oaks, 1985, oral communication) and in the MacDonnell Ranges farther
west (Hamp, 1985). Therefore a source for part of the Arumbera Sandstone
in the eastern James Ranges and in the area studied by Conrad may
have been to the south-southwest in the Newland Ranges Ridge (Oaks,
1983), a distance of perhaps 150 to 200 km prior to thrust faulting.
Provenance of the Quandong Conglomerate

Cobbles, pebbles, and sand-sized framework grains are present in the Quandong Conglomerate. Descriptions of their features and provenance will be noted where they differ from those previously described. Otherwise, the reader is referred to the section on Arumbera provenance for those details. Cobbles and pebbles in the Quandong include quartzite, chert, and vein quartz. The chert and quartzite range up to 7 cm in diameter and are subangular to subrounded. The vein quartz ranges up to 3 cm in diameter, but consists primarily of subrounded to rounded granules.

Feldspars are common as sand-sized grains, and are less abundant than those in the Arumbera. Microcline, present in the Arumbera, was not observed in the Quandong. Also, the content of plagioclase (average: 1% of the grains) is strikingly low when compared to the Arumbera. Orthoclase (average: 7% of the grains) also is somewhat less in the Quandong. Nearly all of the orthoclase has been altered to or replaced by kaolinite and/or partially or completely dissolved. Plagioclase grains are partially to completely sericitized. Some feldspar alteration appears to be pre-depositional based on altered feldspar grains with unaltered overgrowths. However, most appears to postdate deposition as shown by the intense weathering and alteration of both grain and overgrowth. In all cases, the pre- and post-depositional alteration of feldspars appears much more severe than in the Arumbera. The deficiency in microcline may have resulted from scarcity in the source area. The overall deficiency in feldspar may indicate that the primary source consisted principally of sedimentary rocks. This supports the interpretation that
the Quandong predates the Petermann Ranges orogeny and is older than the Arumbera.

Lithic rock fragments found in the Quandong are predominantly metamorphic. Sedimentary rock fragments are half as common as the metamorphics. They are primarily cherts (some silicified ooids), shales, sandstones, and minor siltstones. Felsic volcanic and granitic rock fragments are minor. Both are less than half as common as the sedimentary rock fragments. The volcanic rock fragments are slightly more abundant than the granitics. No graphic granite was found in the Quandong samples.

The heavy-mineral population consists primarily of ultrastable zircon, tourmaline, and minor rutile. Stable sphene and magnetite are present in minor amounts. Pyrite and ilmenite (with leucoxene alteration) are rare constituents. The ultrastable and stable constituents are often rounded to well rounded, which suggests a recycled sedimentary source (Folk, 1974).

The high proportion of quartz relative to feldspar in the Quandong is more striking than for the Arumbera. This may reflect climatic control or, much more likely, may represent a greater proportion of recycled sands from older formations. When plotted on the time-intensity feldspar chart of Folk (1974, p. 85), the high proportion of quartz relative to feldspar suggests a warm to hot, humid to semiarid climate if most of the quartz and feldspars are first cycle. The presence of hematite cement in the lower Quandong suggests hot temperatures at the site of deposition (Walker, 1967). However, hematite cement was not observed in the upper four samples. Intensity of feldspar weathering favors a humid climate. The subarkosic composition of the samples might be due to a transition from a source area of moderate relief to a
tectonically active source area with high relief. The relative high-grading of quartz to feldspar and high-grading of polycrystalline quartz to monocrystalline quartz, and the greater of metamorphic, sedimentary, and felsic-volcanic rock fragments in the Quandong relative to the Arumbera, suggest that most of the Quandong was recycled from older sedimentary rocks, and that granitic plutons were not widely exposed in the source area. Perhaps the major source rocks for the Quandong Conglomerate were the Dean Quartzite and Heavitree Quartzite. The Arumbera on the other hand represents deposits derived from a similar area at a time when granitic basement rocks were widely exposed and a smaller contribution was received from sedimentary and felsic-volcanic source rocks. The Quandong sediments probably were transported in graded or aggrading streams, perhaps with prolonged periods of storage and chemical weathering prior to final deposition. The intensity and variability of weathering of feldspars together with their common absence, and the lack of mafic minerals support this conclusion. If the Quandong is derived mostly from recycled sediments, then storage and harsh chemical weathering during transport perhaps would not be needed. Also, post-depositional leaching of such heavily weathered grains may account for much of the absence of the feldspars. Possible source area(s) may have been to the north-northwest of the Deception Creek anticline. Possible source rocks include the Dean Quartzite, Heavitree Quartzite, Bitter Springs, Winnall, and Inindia formations, as well as underlying granitic and metamorphic basement rocks.

Data (Table 6) derived from point counts of the five Quandong thin sections are plotted on ternary provenance diagrams (Dickinson and Suczek 1979). QFL (Fig. 34) and QmFLt (Fig. 37) plots suggest the
Quandong sediments may have been derived from a foreland uplift in a recycled-orogen provenance and, to a lesser degree, from uplifted basement in a continental-block provenance. A tectonic setting of a foreland uplift in a recycled-orogen provenance involves recycled sedimentary sands derived from within fold-thrust belts. Such sands typically contain moderately high amounts of quartz and low amounts of feldspar. The tectonic setting for a basement-uplift provenance is described for the Arumbera and will not be repeated here. The QpLvLs (Fig. 40) and QmPK (Fig. 43) plots demonstrate a high K/P ratio and a high Q/F(P+K) ratio. They show a rather high mineralogic maturity and stability for the Quandong sediments, a dominance of sedimentary over volcanic detritus, and a dominance of plutonic over volcanic detritus.

Much of the material for the Quandong probably was derived by earlier erosion of Precambrian sedimentary and metasedimentary rocks prior to the uplift and thrusting along the present southern margin of the Amadeus Basin. Conrad (1981) proposed the Cenozoic deposits of the High Plains as a more recent analogy for the Arumbera. This recent model may also be appropriate for the Quandong. Prior to high basement uplifts during the Petermann Ranges orogeny, apparently less basement was exposed, or basement source rocks lay farther away, and the Proterozoic sedimentary cover was the dominant source during Quandong deposition.

The degree of alteration of feldspars of the Quandong suggest a warm to hot, humid to semiarid climate at the source. A slightly greater roundness of the Quandong framework grains, as compared to Arumbera framework grains, may reflect different primary source rocks or areas, a greater distance of the Quandong from the source, more harsh conditions of transport, or more severe chemical weathering in a different climate.
Whichever choice is made, the underlying conclusion is that Quandong deposition took place at a different time, probably earlier, than Arumbera, or else involved a different source area. Because of present proximity of these units, and a southerly to westerly source for the Arumbera (which source would be closer to the Quandong), a different source area likely implies a different time of deposition.
INFERRED DEPOSITIONAL ENVIRONMENTS

Arumbera Sandstone

The red arkosic sequence of the Arumbera has been interpreted as a fluvial-deltaic complex by Conrad (1981) and by "others" cited by Wells et al. (1970). Results from the present study suggest the Arumbera is a remnant, the lower part of a coastal deltaic deposit. Coastal marine sedimentation dominated in Units 1 and 3, whereas fluvial processes dominated in Unit 2. So far the Arumbera has yielded no megascopic body fossils. The absence of vascular terrestrial vegetation during the Proterozoic and Early Paleozoic probably produced fluvial environments with few modern analogues (Schumm, 1968; Long, 1978; Van de Graaff, 1972). Schumm (1968) believed this absence of vascular vegetation resulted in a dominance of braided streams, wherein sediments are transported primarily as bed load. Abundant syndepositional load deformation in the Arumbera suggests a saturated environment at shallow depths. The sediments likely were subjected to frequent floods with high and variable discharges and near maximum bedloads. Sedimentation probably occurred in both the upper and lower flow regimes, as suggested by vertical sequences of plane beds, subaqueous dunes, and current ripples, with small gravel at the base and fine sand at the top.

The Arumbera is divided into eight "packets" of terrigenous sediments. Lithofacies 1a and 1d and Unit 3 are interpreted as shallow-water, tidal-influenced marine environments. Lithofacies 1b is interpreted as a distributary-mouth bar, whereas lithofacies 1c is regarded
as a thin sequence of debrisflow. Lithofacies 2a and 2c are interpreted as fluvial sheet sandstones and braided-channel deposits. Lithofacies 2b is interpreted as coastal floodplain sheet sands deposited by braided distributaries. Campbell (1976) described sheet sandstones as the most favorable setting for trapping oil. Features pertinent to those interpretations of the various lithofacies of the Arumbera Sandstone are listed in the section for field descriptions.

Lithofacies 1a and 1d and Unit 3 are interpreted as tidal-dominated coastal-marine deltaic deposits. The predominance of thin parallel beds, along with abundant shallow-water sedimentary structures such as oscillation ripples, the dominance of mu and nu cross-stratification, lenses of carbonate, thin gypsum beds, desiccation mudcracks, and local flaser bedding support this interpretation (after Ginsburg, 1975; Johnson, 1975; Sellwood, 1975). Paleocurrent patterns are bimodal or polymodal, which is consistent with a tidal-influenced environment. Local subenvironments included tidal channels, beaches, and microtidal to mesotidal flats. Lithofacies 1a is dominated by quiet, shallow-water fine-grained sandstones and mudstones. The lower part of lithofacies 1a is considered prodelta deposits. As progradation of the delta lobe or front continued, subsidence either slowed or was locally overcome by the rapid influx of fluvial sediments.

The first fluvial deposit is lithofacies 1b, interpreted as a distributary-mouth bar. At the Katapata Gap and Pine Point sections lithofacies 1b forms a lens of medium- to coarse-grained sandstones with scours and lenticular-shaped beds. Granular orthoconglomerates are typically present near the top of the lithofacies. No correlation between clast size and bed thickness was observed. Lithofacies 1b was
deposited and probably reworked in an active environment. Local xi cross-stratification, with common omikron cross-stratification and current-ripple cross laminae support this interpretation. Overall coarsening upward of the lithofacies, followed by a thin carbonate bed or mudrock at the base of the overlyiong lithofacies 1a, suggest a prograding distributary-mouth bar that was abandoned abruptly, perhaps due to alvusion upstream.

Subsequent deposition of lithofacies 1a with local carbonates, overlying lithofacies 1b, represents a slight transgression of the sea followed by a period of subequal sedimentation and subsidence in a quiet, shallow-water environment. These later conditions are reflected by dominance of very fine-grained sandstones and mudrocks.

The overlying lithofacies 1c consists of debrisflow paraconglomerates up to 1 m thick that form a deposit 7 to 11 m thick throughout the Gardiner Range. Paraconglomerates and minor orthoconglomerates of lithofacies 1c comprise laterally extensive beds. These beds rarely show basal erosional surfaces. Thus, they resemble high-viscosity flows. each is overlain by a thin bed of siltstone or fine-grained sandstone with parallel laminae or low-angle cross-stratification. These fine-grained beds are interpreted as the waning flood stage or high stages of flood-water known to follow debrisflows. Reading (1978) and Steel (1974) reported similar features for mudflow and debrisflow deposits. Thin-sections of samples of lithofacies 1c, taken from five of the seven Gardiner Range sections, indicate a very similar mineralogic composition and maturity (Tables 2, 3). Grain-size analyses of the five samples are quite similar, and distinct from all other samples studied. They resemble modern debrisflows and mudflows with their convex-up CFP curves and
very poor sorting (Oaks, 1985, oral communication). Lithofacies 1c forms an excellent marker in the Gardiner Range, and is probably approximately coeval through its extent. The size of lithoclasts is greater where lithofacies 1c is thickest (Fig. 61). Steel (1974) attributed similar associations to debrisflow deposits.

The subsequent deposition of lithofacies 1d was dominated by tidal-flat environments. Lithofacies 1d differs from lithofacies 1a in that fine- to medium-grained sandstones rather than mudstones dominate, and sedimentary structures indicate higher energy flow conditions. In lithofacies 1a flaser bedding and thin, parallel beds are common, whereas in lithofacies 1d slumped bedding and cross-stratification, parting lineations, and thin- to medium-thick beds are common. Sedimentation also reflects a stronger fluvial influence in lithofacies 1d than in lithofacies 1a, although tidal dominance appears to have continued. In lithofacies 1d, subenvironments such as beach, microtidal to mesotidal flats, and tidal channel are common, and are interlayered with thin tongues of fluvial sheet sands.

Lithofacies 2a and 2c are interpreted as deposits of fluvial distributary channels and stream-mouth bars. The longitudinal and transverse bars which characterise braided streams may be partly preserved in lithofacies 2a and 2c as cross-laminated trough beds (pi cross-stratification). Fining-upward sequences observed are characteristic of point bars (meandering streams) as well as of braided stream deposits. Rare occurrence of lateral-accretion surfaces suggests low-sinuosity, which is typical of braided streams. The dominantly planar cross-stratification is a common characteristic of fluvial sheet sands. Beds with trough (pi) cross-stratified conglomeratic sandstones and mud-pebble conglomer-
ates with erosional bases indicate prolonged unidirectional flow. These 
beds are typically overlain by parallel-bedded mudrocks and fine-grained 
sandstones. Such a series of deposits is interpreted as a succession 
from channel-lag deposits (formed during initial channel erosion in the 
deepest part of the river) to migrating channel bar or subaqueous dunes 
followed vertically by shallow-water, channel fills deposited during 
channel abandonment or possibly deposition on a floodplain. Load defor­
mation within the lower and middle parts of such vertical sequences may 
reflect high discharge and sudden deposition of saturated bed load or 
the coarser part of intermittent suspension load under the shear stress 
of unidirectional currents. Mud-pebble conglomerates in the basal parts 
of beds can result from ephemeral flow in cases of "healing" or 
"stranding" of a braid channel during periods of low discharges 
(Reading, 1978). In vertical section the Arumbera deposits are very 
similar to those described by Conrad (1981) and by Campbell (1976) for 
fluvial sheet sandstones. The Arumbera fluvial-channel systems range in 
width from 5 to 20 km (Figs. 22, 23) and in thickness from 9 to 38 m.

Lithofacies 2b and Unit 3 are interpreted as complex, shallow-
water, tidal-influenced marine deposits. Common vertical sequences found 
in lithofacies 2b include: (1) syndepositional load deformation of bed­
ding and cross-stratification ---> high velocity laminae (HVL) ---> planar cross-stratified beds or convolute bedding ---> HVL --->; and 
(2) subaqueous dunes with superimposed climbing ripples ---> planar 
parallel bedding (lower flow regime) ---> convolute bedding or HVL 
(represented by parting lineations). Sedimentary structures in litho­
facies 2b that are indicative of beaches include xi cross-stratifica­
tion, truncated wave-ripple laminae, and planar parallel laminae with
local heavy-mineral concentrations.

Progradation during deposition of lithofacies 2b and the lower part of Unit 3 was occasionally interrupted by periods during which the braid channel migrated laterally and braid sheet sands encountered tidal-influenced, shallow-marine environments. The abundance of soft sediment load deformation within the sheet sands of lithofacies 2b, together with the intertonguing of lithofacies 2a, are highly supportive of a fluvial-dominated deltaic system for Unit 2. Vertical sequences listed above suggest that sedimentation occurred in lower to upper flow regime conditions.

Rhythmically repeated interbedding of planar parallel mudrocks and fine- to medium-grained sandstones in Unit 2 may represent sediment-laden incursions of braided sheet sands into a deltaic floodplain. Channel abandonment or avulsion may have caused the pre-existing delta lobe to have been abandoned to coastal and shallow-water marine processes. This created at least local reworking of the sediments into tidal-flat and beach deposits with local tidal channels. As subsidence continued, fluvial dominance reoccurred when distributary channels migrated over the region and once again caused progradation of the delta lobe.

Deposits in the abandoned parts of the delta are generally characterized by relatively slow rates of sedimentation (Walker, 1979). However, reactivation of braid channels into the vicinity could erode much of the vertically accreted sediments. Thus, theoretically, a stacked sequence of fluvial sheet sands could form in the proximal parts of a delta. The rarity of tidal-flat features is supportive of a fluvial-dominance during deposition of Unit 2. The abundance of syn-depositional load deformation structures and the lack of fossils and
trace fossils in Unit 2 adds support to this interpretation. Conrad (1981) found trace fossils in lithofacies 2b farther northeast. Here a tidal-dominated deltaic deposit is inferred for the Arumbera. The presence of trace fossils here is consistent with the interpretation for that study area.

Sandstones in Unit 3 contain subaqueous dunes, slumped strata, and high velocity planar parallel laminae that suggest episodes of deposition in the upper part of the lower flow regime, and perhaps the lower part of the upper flow regime. These alternate with clay drapes, small-scale current ripples, and mudrock partings that suggest episodes of deposition in the middle and lower parts of the lower flow regime. These combined features strongly suggest rapid fluctuation of energy, which is consistent with a tidal-flat setting for Unit 3.

The complex succession of seven episodes of alternating dominance of fluvial conditions and shallow-marine conditions described by Conrad (1981) for the Arumbera Sandstone in the northeastern part of the Amadeus Basin is more complete than for the Arumbera Sandstone in the Gardiner Range. Units 3 and 4, and at least some of the upper part of Unit 2 either were not deposited or, more likely, were uplifted and eroded prior to deposition of the Chandler in the present area of the Gardiner Range and James Ranges 'B' anticline.

Evidence supportive of a deltaic origin for the Arumbera Sandstone includes: (1) facies of fluvial and near-shore marine deposits are present in vertical, cyclic succession with lateral intertonguing and pinchouts; (2) trace fossils are absence or very rare in the shallow-marine deposits, which may reflect unfavorable conditions such as periodic influx of fresh to brackish water, whereas Conrad (1981)
reported a progressive increase in number and variety of trace fossils northward in Units 1 and 3 and lithofacies 2b; (3) local graded bedding and fining-upward cycles filling scours are repeated in lithofacies 2a and 2c; (4) thicker deposits of all units in the central portion of the eastern James Ranges and in the central portion of the Gardiner Range with thinning to the east and west from these locations; (5) a wedge-shaped marine tongue separating fluvial sheet sands of lithofacies 2c (Fig. 22; Elliott, 1978a, b) suggests shifting positions of distributaries to form successive deltaic lobes; (6) interfingering of lithofacies 2a with 2b, and 2b with 2c and Unit 3 may represent prograding distributary-channel systems wherein channel deposits were replaced by nearshore marine deposits as distributaries migrated laterally, possibly rapidly, due to avulsion; and (7) thin beach deposits interbedded with tidal flat deposits and the abundance of mudrocks in lithofacies 1a suggest gradual subsidence, quiescence in the source area, cut off of coarse size grades, and/or protracted submergence during this time. All other evidence, including abundant syndepositional load deformation structures, suggests relatively rapid progradation during Arumbera deposition. During this time, fluvial sheet sands were deposited by a migrating and coalescing braided stream system. Locally, nearshore, tidal-dominated marine processes reshaped the remaining material delivered by distributary channels into associated beach and tidal-flat deposits.

A growth structure in the vicinity of Pattalindama Gap divided the region into two sub-basins. Evidence from lithology and stratigraphy (Fig. 23) suggest this high existed throughout deposition of the Arumbera and the underlying Julie in the Gardiner Range, and influenced the growth of the delta system.
The correlation of Units 1 and 2 of the Arumbera Sandstone in the Gardiner Range and in the eastern James Ranges with the Arumbera in the northeastern part of the Amadeus Basin (Conrad, 1981) is striking, although fluvial conditions were more predominant in Units 1 and 2 in the Gardiner Range. Tidally-dominated processes were progressively more common towards the northeast. In the Gardiner Range, low-sinuous, braided-stream deposits dominate in Unit 2, whereas in Conrad's (1981) study area more lenses of tidal-influenced sediments are present in Unit 2. Also an overlying lithofacies 2c was not found in the James Ranges 'B' anticline and in the Gardiner Range. These variations, together with minor mineralogical differences (Tables 2, 3) suggest differences in source areas, distance to source rocks, and/or variation in abrasion and weathering of feldspars and quartz during transport, deposition, and diagenesis. It is likely that the site of deposition in the Gardiner Range was closer to the source area than that of the Arumbera in the eastern James Ranges and thus contains more proximal deposits. Deposition in the Gardiner Range was affected by periodic uplift and erosion, centered on the area near Pattalindama Gap, especially during the early part of deposition of Unit 1 and at some time following deposition of Unit 2, whereas, to the northeast, subsidence and sedimentation were more or less continuous for all four units of the Arumbera and for the overlying Todd River Dolomite. Differences between deposits of Unit 2 in these two regions may reflect the nature of their respective sub-basins. Perhaps due to proximity to the Central Ridge of the Arumbera in the Gardiner Range, localized uplift was more frequent, so that erosion or nondeposition has resulted in a less complete stratigraphic section in the Gardiner Range than in the northeastern Amadeus Basin.
Quandong Conglomerate

The pale orange lithic arkoses and subarkoses of the Quandong were interpreted by Wells et al. (1970) as a "basal conglomerate". Preiss et al. (1978) interpreted two Late Proterozoic (Adelaidean) episodes of glaciation in central Australia. The older episode is represented by presumed periglacial deposits (Walter and Bauld, 1983) of the Areyonga. The younger episode is represented by the Olympic and Pioneer. Salient characteristics observed in this study support a braidplain interpretation for the depositional setting of the Quandong. This model is based on grain-size characteristics, sedimentary structures, bedmates, and geometry of the conglomerates. The absence of terrestrial vascular vegetation during the Proterozoic and Early Paleozoic was favorable for braided fluvial environments.

The Quandong probably consists of alluvium possibly deposited by multiple, low-sinuous and relatively unstable braided channels. The sediments were probably deposited by frequent floods with high and variable discharges and, in some cases, large amounts of bedload (Fig. 56). The degree and variability of weathering is most pertinent with the low content of feldspars, their high degree and variability of weathering, their small grain-size, high equantness, and moderately high angularity support the interpretation of mechanical attrition and suggest that extended periods of storage of the sediments occurred prior to final deposition. During storage phases, the feldspars and other unstable mineral assemblages probably were subjected to chemical weathering.

The Quandong is divided into three lithofacies, $A_1$, $A_2$, and $A_3$. Lithofacies $A_1$ is interpreted as horizontally stratified (Sh) and trough
cross-stratified (St) braided alluvial sands that represent intermediate to proximal braidplain deposition. Locally, transitional planar cross-stratified lenses of granular orthoconglomerates and coarse-grained sandstones are present. These probably represent conditions of high sediment transport associated with flood discharge.

Lithofacies A2 is interpreted as proximal braidplain deposition. Sublithofacies consist of Gm, Gp, Sh, Sp, and St stratification (after Miall, 1977; as modified by Miall, 1978a, b, 1984 and Rust, 1978), which are typical of proximal braidplain deposits. Rust and Koster (1984) suggested that alluvial conglomerates are indicators of high terrestrial relief. Wilson (1973) pointed out that alluvial conglomerates are also indicative of climatic extremes. The production of large lithic fragments is maximized on steep slopes in semiarid or periglacial/alpine settings. Alluvial fans may be tributary to braided rivers and enter them at right angles, or may be transitional downslope to a braidplain that may enter the sea directly (Rust and Koster, 1984). Braided rivers and braidplains have two-dimensional depositional surfaces whose slopes are lower than alluvial fans (Allen, 1975). Proximal braidplains form in response to major glacial or tectonic event (Rust and Koster, 1984). Both tectonic uplift (Souths Range Movement) and presumed glaciation (striated dropstones in Areyonga in the Petermann Creek anticline, Oaks, 1985, oral communication) immediately preceded or were ongoing during deposition of the Areyonga and Quandong. Rust and Koster (1984) also reported that stratification types and increases in grain size are specific responses to major floods rather than separate tectonic events.

In lithofacies A2, the omikron cross-stratified Gp interval 8 m thick probably represents the middle and upper parts of a diagonal or
traverse bar which evolved from gravel sheets and channel-lag deposits. Modification of these deposits during falling-water stage is reflected by the vertical transition of Gm sublithofacies to Gp, Sp, or Sh sublithofacies. Leckie and Walker (1982) reported that braidplains may also form in coastal environments. Perhaps in the Quandong a coastal braidplain deposit is suggested by rare xi cross-stratification present in lithofacies A2.

The proximal-braidplain models of Miall (1977, 1978b), Rust (1978), and Rust and Koster (1984) is dominated by imbricate, horizontally stratified gravel (sublithofacies Gm), with minor amounts of planar cross-stratified gravel (sublithofacies Gp) and sand sublithofacies Sp and Sh. These same characteristics are present in the two measured sections of the Quandong.

Lithofacies A3 is interpreted as a possible paleosol or ancient weathering surface. Replacement of sandstones and mudstones by microcrystalline and macrocrystalline quartz may represent a period of subaerial and/or subaqueous erosion and weathering and marks an unconformity. An alternative possibility is that silicification has taken place at a thrusting horizon, just below Chandler or undifferentiated Cambrian deposits.
CONCLUSIONS

The conclusions of this report are:

(1) Based on their stratigraphic position and the characteristics of their members, the Eninta Sandstone and "Quandong Conglomerate" consist of Units 1 and 2 of the Arumbera Sandstone. Units 3 and 4 and the upper part of Unit 2 are absent. Either they were not deposited or they were removed by erosion prior to deposition of the overlying Chandler Formation. Therefore the name Arumbera should be reinstated for the deposits in the Gardiner Range, as originally proposed by Williams (1967); and the "Quandong Conglomerate" be renamed the Arumbera Sandstone.

(2) The Quandong Conglomerate probably represents an earlier episode of erosion that pre-dated the Petermann Ranges orogeny and the Arumbera Sandstone. Characteristics of the Quandong are more similar to the Areyonga Formation than to the Arumbera Sandstone. Therefore it is regarded as a possible member of the Areyonga.

(3) Braided streams in a semiarid, hot climate transported sediments for the Arumbera Sandstone from the source area where high uplifts exposed the Precambrian source rocks. Petrographic evidence suggests grains were derived from recycled sedimentary rocks, from felsic plutonic source rocks, and from medium- to high-grade metamorphic source rocks exposed during the Souths Range movement and/or more likely during the Petermann Ranges orogeny. Older units that may have supplied material to the Arumbera included basement plutonics, Dean Quartzite, Heavitree Quartzite, Bitter Springs, Winnall, Ininidia, Areyonga, and
Pertatataka. Distributary channels distributed the sediments as a prograding deltaic sequence dominated by fluvial processes.

(4) The provence analysis together with sedimentary structures for the Quandong sediments support the interpretation for deposition by aggrading to graded braided streams in a humid to semiarid, temperate to cool climate. Sediments were derived chiefly from low-rank metamorphic and sedimentary rocks, with minor plutonic and volcanic rocks in a moderately high to high source area(s).

(5) Unit 1 is considered to be tidal-dominated deltaic deposits. Lithofacies la, and ld, and Unit 3 are interpreted as a complex system of coastal to nearshore-marine environments, including tidal flats, beaches, tidal channels, estuarine, and marine bars. Lithofacies lb and lc are interpreted as channel-lag, bar, and/or debrisflow deposits of fluvial sheet sandstones.

(6) Unit 2 is considered to be fluvial-dominated deltaic deposits. Lithofacies 2a and 2c are interpreted as fluvial sheet sands with scours filled by channel-lag deposits. Lithofacies 2b is interpreted to be coastal floodplain sheet sands deposited by braided distributaries.

(7) Lithofacies A₁ and A₂ of the Quandong Conglomerate are interpreted as coalescing braided-stream deposits of a proximal braidplain. Lithofacies A₁ (Gp, Sh, and St sublithofacies) is regarded as flood-plain-, overbank-, and crevasse-splay deposits. Lithofacies A₂ (Gm and Gp sublithofacies) is interpreted as proximal-braidplain deposits which include channel-lag, channel-gravel, and channel-bar deposits. Lithofacies A₃ resembles an ancient weathering surface, probably a silcrete. Alternatively, the Quandong may have been deposited as a distal channel deposit on an alluvial fan.
Both the Arumbera Sandstone and the Quandong Conglomerate are potential petroleum reservoir rock units. Shows of petroleum were reported from several wells and production of dry gas at the Dingo field probably are from the basal part of the Arumbera. Mudrocks within the Arumbera, and mudrocks and evaporites in the overlying Chandler could form suitable reservoir seals for both the Arumbera and Quandong. In addition, local stratigraphic and structural traps are possible in the subsurface, especially against the Central Ridge (here the Arumbera is known to pinchout). Suitable source rocks are present in the Bitter Springs Formation below, and in the Chandler Formation above the Arumbera and the Quandong. Appreciable porosity and permeability are present within lithofacies 1b, 2a, and 2b, and locally, within lithofacies 1d of the Arumbera. The Quandong contains very good porosity (15% average) and permeability. The secondary porosities of the Arumbera and Quandong demonstrate the necessary depth and time of burial that accumulation of petroleum from organic maturation requires.
REFERENCES


APPENDICES
Appendix A

Maps and Stratigraphic Cross Sections
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Figure 1. Stratigraphic nomenclature chart for the Amadeus Basin (from Jackson et al., 1984).

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Figure 2. Index map of the Amadeus Basin (after Wells et al., 1970). The study area shown in Figures 3 and 4 is outlined by bold lines. Conrad's (1981) study area is outlined by dashed lines.
Figure 3. Index map showing outcrops studied of the Arumbera Sandstone, Eninta Sandstone, and "Quandong Conglomerate." Also shown are outcrops studied of the Quandong Conglomerate and Areyonga Formation.

--- Outline of the Amadeus Basin (from Wells et al., 1970)
A Arumbera Sandstone in the eastern part of the James Ranges southwest of Deep Well Homestead
B "Quandong Conglomerate" in the James Range 'B' anticline
C Eninta Sandstone in the Gardiner Range anticline
D Quandong Conglomerate & Areyonga Formation in the Deception Creek structure
E Areyonga Formation in the Petermann Creek anticline
Figure 4. Study area showing outcrops of the Arumbera Sandstone and location of the Central Ridge. Also shown are the locations of the stratigraphic sections measured or traversed for this study.
Figure 5. Isopachous map showing total thickness of the Arumbera Sandstone in the James Ranges. Contour interval is 50 meters. Outcrops are shown in black. Data for measured sections are given in Table 1. Letters denote measured sections of this report (A = Billabong Bore East, B = Billabong Bore West, C = Walkabout, and D = Tidenvale), whereas numbers denote sections measured by others (1 = BMR'S Mt. Peachy and 2 = Conrad's Bloodwood Bore).
Figure 6. Isopachous map showing total thickness of the Arumbera Sandstone in the Gardiner Range. Contour Interval is 50 meters. Outcrops are shown in black. Data for measured sections are given in Table 1.
Figure 7. Isopachous map showing total thickness of the Areyonga Formation in the Tempe Downs study area. Contour Interval is 50 meters. Outcrops are shown in black.
Figure 8. Isopachous map showing thickness of Unit 1 of the Arumbera Sandstone in the James Ranges. Contour Interval is 50 meters. Letters denote measured sections of this report (A = Billabong Bore East, B = Billabong Bore West, C = Walkabout, and D = Tidenvale), whereas numbers denote sections measured by others (1 = BMR'S Mt. Peachy and 2 = Conrad's Bloodwood Bore).
Figure 9. Isopachous map showing thickness of Unit 1 of the Arumbera Sandstone in the Gardiner Range. Contour Interval is 50 meters.
Figure 10. Isopachous map showing thickness of Unit 2 of the Arumbera Sandstone in the James Ranges. Contour Interval is 50 meters. Letters denote measured sections of this report (A = Billabong Bore East, B = Billabong Bore West, C = Walkabout, and D = Tidenvale), whereas numbers denote sections measured by others (1 = BMR'S Mt. Peachy and 2 = Conrad's Bloodwood Bore).
Figure 11. Isopachous map showing thickness of Unit 2 of the Arumbera Sandstone in the Gardiner Range. Contour Interval is 50 meters.
Figure 12. Isopachous map showing thickness of Unit 3 of the Arumbera Sandstone in the James Ranges. Contour Interval is 50 meters. Letters denote measured sections of this report (A = Billabong Bore East, B = Billabong Bore West, C = Walkabout, and D = Tidenvale), whereas numbers denote sections measured by others (1 = BMR'S Mt. Peachy and 2 = Conrad's Bloodwood Bore).
Figure 13. Downcurrent paleocurrent directions of Unit 1 of the Arumbera Sandstone in the James Ranges. Arrows mark azimuths (corrected for slope and dip) of mean vectors (see Table 6). Letters denote measured sections of this report (A = Billabong Bore East, B = Billabong Bore West, C = Walkabout, and D = Tidenvale), whereas numbers denote sections measured by others (1 = BMR'S Mt. Peachy and 2 = Conrad's Bloodwood Bore).
Figure 14. Downcurrent paleocurrent directions of lithofacies 2a of the Arumbera Sandstone in the James Ranges. Arrows mark azimuths (corrected for slope and dip) of mean vectors (see Table 6). Letters denote measured sections of this report (A = Billabong Bore East, B = Billabong Bore West, C = Walkabout, and D = Tidenvale), whereas numbers denote sections measured by others (1 = BMR'S Mt. Peachy and 2 = Conrad's Bloodwood Bore).
Figure 15. Downcurrent paleocurrent directions of lithofacies 2b of the Arumbera Sandstone in the James Ranges. Arrows mark azimuths (corrected for slope and dip) of mean vectors (see Table 6). Letters denote measured sections of this report (A = Billabong Bore East, B = Billabong Bore West, C = Walkabout, and D = Tidenvale), whereas numbers denote sections measured by others (1 = BMR'S Mt. Peachy and 2 = Conrad's Bloodwood Bore).
Figure 16. Downcurrent paleocurrent directions of lithofacies 2c of the Arumbera Sandstone in the James Ranges. Arrows mark azimuths (corrected for slope and dip) of mean vectors (see Table 6). Letters denote measured sections of this report (A = Billabong Bore East, B = Billabong Bore West, C = Walkabout, and D = Tidenvale), whereas numbers denote sections measured by others (1 = BMR'S Mt. Peachy and 2 = Conrad's Bloodwood Bore).
Figure 17. Downcurrent paleocurrent directions of lithofacies lc of the Arumbera Sandstone in the Gardiner Range. Arrows mark azimuths (corrected for slope and dip) of mean vectors (see Table 6).
Figure 18. Downcurrent paleocurrent directions of lithofacies 1d of the Arumbera Sandstone in the Gardiner Range. Arrows mark azimuths (corrected for slope and dip) of mean vectors (see Table 6).
Figure 19. Downcurrent paleocurrent directions of lithofacies 2a of the Arumbera Sandstone in the Gardiner Range. Arrows mark azimuths (corrected for slope and dip) of mean vectors (see Table 6).
Figure 20. Downcurrent paleocurrent directions of lithofacies 2b of the Arumbera Sandstone in the Gardiner Range. Arrows mark azimuths (corrected for slope and dip) of mean vectors (see Table 6).
Figure 21. Downcurrent paleocurrent directions of lithofacies A2 of the Quandong Conglomerate. Arrows mark azimuths (corrected for slope and dip) of mean vectors (see Table 6). Also shown are locations of measured sections of the Areyonga Formation.
Figure 22. Stratigraphic cross sections of the Arumbera Sandstone from the James Ranges 'B' anticline (Tidenvale) through the eastern James Ranges to the Deep Well Range (Bloodwood Bore, Conrad, 1981). Datum: base of the Chandler Formation.
Figure 23. Stratigraphic cross section of the Arumbera Sandstone within the Gardiner Range anticline. Datum: base of the Chandler Formation.
Appendix B

Tables
Table 1. Thickness of the Arumbera Sandstone in meters, east-central Amadeus Basin.

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*Intertongued; Cumulative thickness of each lithofacies used.

Cl = Chandler Formation
Puj = Julie Formation
Pua = Areyonga Formation
Pup = Pertatataka Formation
Pub = Bitter Springs Formation
Table 2. Quartz types, roundnesses and shapes of grains, statistical parameters, and mineralogical data for classification for the Arumbera Sandstone and Quandong Conglomerate, east-central Amadeus Basin.

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<th>Grain Roundness (% of Grains)</th>
<th>Grain Shape (% of Grains)</th>
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(Average per Thin Section) 227 18 39 28
Table 4. Comparison of size, roundness, and shape of quartz, feldspar, and chert grains in the Arumbeera Sandstone and Quandong Conglomerate, east-central Amadeus Basin.

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1 Longest diameters of grains measured in thin section.
2 WR = well rounded, R = rounded, SR = subrounded, SA = Subangular, A = angular, and VA = very angular; based on the visual scale of Powers (1953).
3 Shape: length/width ratio: Equant (E) is 1.5/1, subequant (SE) is 2/1, and bladed (B) is 6/1.
Table 5. Coarsest 1%, median, sorting, graphic mean, skewness type, kurtosis type, and textural maturity (from Folk, 1974) for the Arumbera Sandstone and Quandong Conglomerate, east-central Amadeus Basin.

<table>
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<th>COARSEST 1% Ø MM</th>
<th>MEDIAN Ø MM</th>
<th>SORTING (I)</th>
<th>GRAPHIC MEAN (II)</th>
<th>SKEWNESS TYPE (III)</th>
<th>KURTOSIS TYPE (IV)</th>
<th>TEXTURAL MATURITY (V)</th>
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Table 5. Continued.

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I II IV
WS = Well Sorted CSi = Coarse Silt L = Leptokurtic
MWS = Moderately Well Sorted VFS = Very Fine Sand M = Mesokurtic
MS = Moderately Sorted FS = Fine Sand P = Platykurtic
PS = Poorly Sorted MS = Medium Sand VP = Very Platykurtic
VPS = Very Poorly Sorted CS = Coarse Sand VL = Very Leptokurtic
VCS = Very Coarse Sand

III V
NS = Near Symmetrical CS = Coarse Skewed M = Mature
SFS = Strongly Fine Skewed FS = Fine Skewed S = Submature
SCS = Strongly Coarse Skewed I = Immature
Table 6. Orientations of paleocurrents measured in the Arumbera Sandstone and Quandong Conglomerate, east-central Amadeus Basin.

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**Notes:**
- **N** = Number of Measurements
- **R** = Magnitude of Resultant Vector
- **r** = Mean (Downcurrent Direction)
- **W** = Standard Deviation
- **S** = Confidence Interval
- **n1** = Normally Distributed
- **r1** = Bimodal
- **q1** = Polymodal

---

**Legend:**
- **Cal** = Calpeupelle
- **K** = Koolapatam
- **Pl** = Pulu
- **Strat.** = Stratigraphic
- **Lithofacies** = Lithofacies
- **Distribution Type** = Distribution Type
- **Class** = Class
- **CI** = Confidence Interval
- **U** = Unimodal
- **B** = Bimodal
- **P** = Polymodal

---

**Additional Notes:**
- Measurements are presented with mean values and confidence intervals for each stratigraphic section and lithofacies, indicating the orientations of paleocurrents for the Arumbera Sandstone and Quandong Conglomerate in the east-central Amadeus Basin.
Table 7. Mineralogic data for ternary diagrams of Dickinson and Suczek (1979), east-central Amadeus Basin.Accessory minerals are ignored.

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Q = Stable quartzose grains, including monocrystalline quartz grains (Qm) and polycrystalline quartzose lithic fragments (Ql), the latter are chiefly chert.
F = Monocrystalline feldspar grains including plagioclase (P) and K-feldspar (K), and secondary pore spaces derived from dissolution of feldspar grains.
L = Unstable polycrystalline lithic fragments including volcanic and metavolcanic types (Ll), sedimentary and metasedimentary types (Ls) other than chert, and secondary pore spaces derived from dissolution of either of these grain types.

Lt = sum of L and Qm.

Quandong Conglomerate

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<th>L</th>
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<th>Fm</th>
<th>Lm</th>
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<th>LF</th>
<th>LQ</th>
<th>PF</th>
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<td>57</td>
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<td>23 81 - -</td>
<td>19  89 9 2 9</td>
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<tr>
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<td>51</td>
<td>18</td>
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Q = Stable quartzose grains, including monocrystalline quartz grains (Qm) and polycrystalline quartzose lithic fragments (Ql), the latter are chiefly chert.
F = Monocrystalline feldspar grains including plagioclase (P) and K-feldspar (K), and secondary pore spaces derived from dissolution of feldspar grains.
L = Unstable polycrystalline lithic fragments including volcanic and metavolcanic types (Ll), sedimentary and metasedimentary types (Ls) other than chert, and secondary pore spaces derived from dissolution of either of these grain types.

Lt = sum of L and Qm.
Table 8. Qualitative mineralogy of selected samples of the Arumbera Sandstone and Quandong Conglomerate determined by X-ray diffraction.

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<td>quartz, kaolinite, chlorite, bayerite</td>
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<tr>
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<td>49 (DW-21)</td>
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<td>quartz, orthoclase, kaolinite, chlorite, illite, bayerite</td>
</tr>
<tr>
<td>2b</td>
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<td>quartz, orthoclase, kaolinite, chlorite</td>
</tr>
<tr>
<td>2c</td>
<td>44 (DW-48)</td>
<td>sandstone</td>
<td>quartz, chlorite, bayerite</td>
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<td>42 (DW-54)</td>
<td>sandstone</td>
<td>quartz, kaolinite, chlorite, bayerite</td>
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<td>GARDINER RANGE</td>
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<td>quartz, kaolinite, chlorite, illite, smectite/palygorskite</td>
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<td>quartz, kaolinite, chlorite, illite, palygorskite</td>
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<td>lc</td>
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<td>conglomerate sandstone</td>
<td>quartz</td>
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Table 8. Continued.

<table>
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<td>2b</td>
<td>10 (PT-22)</td>
<td>sandstone</td>
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<td>2b</td>
<td>14 (PT-28)</td>
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<td>2b</td>
<td>21 (RG-13)</td>
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**GARDINER RANGE CONTINUED**

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**JAMES RANGES 'B' ANTICLINE**

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<th>MINERALOGY</th>
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<tr>
<td>A₂</td>
<td>39 (TD-10)</td>
<td>sandstone</td>
<td>quartz, kaolinite, chlorite, illite</td>
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</table>

**QUANDONG CONGLOMERATE**

1 Section codes: DW = Billabong Bore West; PT = Pattalindama Gap; PP = Pine Point; RG = West Gardiner Range; KG = Katapata Gap; TV = Tidenvale; TD = Tempe Downs North

2 Minerals are listed in order of decreasing peak heights. Minerals not underlined are present in minor amounts as estimated from relative peak heights.
Table 9. Diagenetic sequence of the Arumbera Sandstone and Quandong Conglomerate, east-central Amadeus Basin.

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* 1 = Mechanical Compaction
* 2 = "Dust Rims" (Fe(?)-chlorite, Iron, and/or illite)
* 3 = Tourmaline Overgrowths
* 4 = Syntaxial Feldspar Overgrowths
* 5 = Syntaxial Quartz Overgrowths
* 6 = Fractures
* 7 = Clay-mineral Cement
* 8 = Calcite Cement
* 9 = Dolomite Rhombs
* 10 = Dissolution of Grains
* 11 = Pyrite Pore-filling
* 12 = Alteration of Feldspars
* 13 = Iron Oxide Replacement and/or Authigenic Clay Minerals
* 14 = Expansion Fractures
* 15 = Pore-filling Kaolinite Cement and Replacement
* 16 = Chert Cement and Replacement of grains
* 17 = Opal Cement
Appendix C

Plots of Compositional Data:

Classification and Provenance
Figure 24. Mineralogic classification of the Arumbera Sandstone in the Eastern James Ranges (after Folk, 1974). Q = all types of quartz including metaquartzite (but not chert); F = all single feldspars, granite, and gneiss fragments, plus all secondary porosity resulting from dissolution of feldspars; R = all other rock fragments (chert, slate, schist, volcanics, etc.), plus any secondary pore space that resulted from dissolution of one of these grain types. Clay matrix, cement, glauconite, heavy minerals, mica flakes, etc., are ignored. Numbers represent the various thin sections examined in this report.
Figure 25. Mineralogic classification of the Arumbera Sandstone in the Gardiner Range (after Folk, 1974). Q = all types of quartz including metaquartzite (but not chert); F = all single feldspars, granite, and gneiss fragments, plus all secondary porosity resulting from dissolution of feldspars; R = all other rock fragments (chert, slate, schist, volcanics, etc.), plus any secondary pore space that resulted from dissolution of one of these grain types. Clay matrix, cement, glauconite, heavy minerals, mica flakes, etc., are ignored. Numbers represent the various thin sections examined in this report.
Figure 26. Mineralogic classification of the Arumbera Sandstone in the James Ranges 'B' anticline and the Quandong Conglomerate in the Deception Creek anticline (after Folk, 1974). Q = all types of quartz including metaquartzite (but not chert); F = all single feldspars, granite, and gneiss fragments, plus all secondary porosity resulting from dissolution of feldspars; R = all other rock fragments (chert, slate, schist, volcanics, etc.), plus any secondary pore space that resulted from dissolution of one of these grain types. Clay matrix, cement, glauconite, heavy minerals, mica flakes, etc., are ignored. Numbers represent the various thin sections examined in this report.
Polycrystalline Quartz
(2-3 crystal units per grain; ≥75% of total polycrystalline quartz)

Non-undulatory quartz

Figure 27. Four-variable plot of quartz populations in thin sections of the Arumbera Sandstone in the eastern James Ranges (classification and fields from Basu et al., 1975). Thin sections 42, 43, 45, 47, and 49-51 meet the medium-grained size criterion, whereas the remaining thin sections are either too fine (41) or too coarse (44, 46, 48).
Non-undulatory quartz
(2-3 crystal units per grain; ≥75\% of total polycrystalline quartz)

Polycrystalline quartz
(>3 crystal units per grain; >25\% of total polycrystalline quartz)

Undulatory quartz

Figure 28. Four-variable plot of quartz populations in thin sections of Unit 1 of the Arumbera Sandstone in the Gardiner Range (classification and fields from Basu et al., 1975). Thin sections 25 and 29 meet the medium-grained size criterion, whereas the remaining thin sections are either too fine (2-4, 6, 7, 28, 30) or too coarse (1, 18, 20, 26, 27).
Polycrystalline Quartz
(2-3 crystal units per grain; ≥75% of total polycrystalline quartz)

Figure 29. Four-variable plot of quartz populations in thin sections of Unit 2 of the Arumbera Sandstone in the Gardiner Range (classification and fields from Basu et al., 1975). Thin sections 8, 10-12, 15, 17, and 24 meet the medium-grained size criterion, whereas the remaining thin sections (5, 9, 13, 14, 16, 19, 21, 22, 23) are too fine.
Polycrystalline Quartz
(2-3 crystal units per grain; ≈75% of total polycrystalline quartz)

Non-undulatory quartz

Undulatory quartz

Polycrystalline quartz
(>3 crystal units per grain; ≈25% of total polycrystalline quartz)

Figure 30. Four-variable plot of quartz populations in thin sections of the Arumbera Sandstone in the James Ranges 'B' anticline and Quandong Conglomerate in the Deception Creek anticline (classification and fields from Basu et al., 1975). Thin section 34 of the Arumbera and thin sections 39 and 40 of the Quandong meet the medium-grained size criterion, whereas the remaining thin sections are either too fine (31-33, 35, 36, 38) or too coarse (37).
Figure 31. Quartz (Q), feldspar (F), and lithics (L) plot of samples of the Arumbera Sandstone in the eastern James Ranges (cf. Dickinson and Suczek, 1979). Numbers represent thin sections.
Figure 32. Quartz (Q), feldspar (F), and lithics (L) plot of samples of the Arumbera Sandstone in the Gardiner Range (cf. Dickinson and Suczek, 1979). Numbers represent thin sections.
Figure 33. Quartz (Q), feldspar (F), and lithics (L) plot of samples of the Arumbera Sandstone in the James Ranges 'B' anticline and Quandong Conglomerate in the Deception Creek anticline (cf. Dickinson and Suczek, 1979). Numbers represent thin sections.
Figure 34. Monocrystalline quartz (Qm), feldspar (F), and lithics plus polycrystalline quartz (Lt) plot of samples of the Arumbera Sandstone in the eastern James Ranges (cf. Dickinson and Suczek, 1979). Numbers represent thin sections.
Figure 35. Monocrystalline quartz (Qm), feldspar (F), and lithics plus polycrystalline quartz (Lt) plot of samples of the Arumbera Sandstone in the Gardiner Range (cf. Dickinson and Suczek, 1979). Numbers represent thin sections.
Figure 36. Monocrystalline quartz (Qm), feldspar (F), and lithics plus polycrystalline quartz (Lt) plot of samples of the Arumbera Sandstone in the James Ranges 'B' anticline and Quandong Conglomerate in the Deception Creek anticline (cf. Dickinson and Suczek, 1979). Numbers represent thin sections.
Figure 37. Polycrystalline quartz (Qp), volcanic lithics (Lv), and sedimentary lithics (Ls) plot of samples of the Arumbera Sandstone in the eastern James Ranges (cf. Dickinson and Suczek, 1979). Numbers represent thin sections.
Figure 38. Polycrystalline quartz (Qp), volcanic lithics (Lv), and sedimentary lithics (Ls) plot of samples of the Arumbera Sandstone in the Gardiner Range (cf. Dickinson and Suczek, 1979). Numbers represent thin sections.
Figure 39. Polycrystalline quartz (Qp), volcanic lithics (Lv), and sedimentary lithics (Ls) plot of samples of the Arumbera Sandstone in the James Ranges 'B' anticline and Quandong Conglomerate in the Deception Creek anticline (cf. Dickinson and Suczek, 1979). Numbers represent thin sections.
Figure 40. Monocrystalline quartz (Qm), plagioclase (P), and K-feldspar (K) plot of samples of the Arumbera Sandstone in the eastern James Ranges (cf. Dickinson and Suczek, 1979). Numbers represent thin sections.
Figure 41. Monocrystalline quartz (Qm), plagioclase (P), and K-feldspar (K) plot of samples of the Arumbera Sandstone in the Gardiner Range (cf. Dickinson and Suczek, 1979). Numbers represent thin sections.
Figure 42. Monocrystalline quartz (Qm), plagioclase (P), and K-feldspar (K) plot of samples of the Arumbera Sandstone in the James Ranges 'B' anticline and Quandong Conglomerate in the Deception Creek anticline (cf. Dickinson and Suczek, 1979). Numbers represent thin sections.
Appendix D

Thin Section and Largest Pebble Data:

C-M Diagrams, Size Analyses, Histograms, and Largest Pebble Plots
Figure 43. Coarsest 1% (C) verses Median (M) diagram for marine-dominated lithofacies of the Arumbera Sandstone in the Gardiner Range and eastern James Ranges based on grain sizes in thin sections (corrected from graph of Friedman, 1958; approximate fields after Passega, 1964).
Figure 44. Coarsest 1% (C) verses Median (M) diagram for fluvial-dominated lithofacies of the Arumbera Sandstone in the Gardiner Range and eastern James Ranges based on grain sizes in thin sections (corrected from graph of Friedman, 1958; approximate fields after Passega, 1964).
Figure 45. Coarsest 1% (C) verses Median (M) diagram for lithofacies of the Arumbera Sandstone in the James Ranges 'B' anticline and Quandong Conglomerate in the Deception Creek anticline based on grain sizes in thin sections (corrected from graph of Friedman, 1958; approximate fields after Passega, 1964).
Figure 46. Cumulative-Frequency Probability Curves (after Friedman, 1958) for Units 1 and 3 of the Arumbera Sandstone in the eastern James Ranges.
Figure 47. Cumulative-Frequency Probability Curves (after Friedman, 1958) for lithofacies 2a and 2c of the Arumbera Sandstone in the eastern James Ranges.
Figure 48. Cumulative-Frequency Probability Curves (after Friedman, 1958) for lithofacies 2b of the Arumbera Sandstone in the eastern James Ranges.
Figure 49. Cumulative-Frequency Probability Curves (after Friedman, 1958) for lithofacies 1a of the Arumbera Sandstone in the Gardiner Range.
Figure 50. Cumulative-Frequency Probability Curves (after Friedman, 1958) for lithofacies 1b and 1c of the Arumbera Sandstone in the Gardiner Range.
Figure 51. Cumulative-Frequency Probability Curves (after Friedman, 1958) for lithofacies 1d of the Arumbera Sandstone in the Gardiner Range.
Figure 52. Cumulative-Frequency Probability Curves (after Friedman, 1958) for lithofacies 2a of the Arumbera Sandstone in the Gardiner Range.
Figure 53. Cumulative-Frequency Probability Curves (after Friedman, 1958) for lithofacies 2b of the Arumbera Sandstone in the Gardiner Range.
Figure 54. Cumulative-Frequency Probability Curves (after Friedman, 1958) for lithofacies 2b of the Arumbera Sandstone in the Gardiner Range.
Figure 55. Cumulative-Frequency Probability Curves (after Friedman, 1958) for lithofacies 1d and 2b of the Arumbera Sandstone in the James Ranges 'B' anticline.
Figure 56. Cumulative-Frequency Probability Curves (after Friedman, 1958) for lithofacies A2 of the Quandong Conglomerate.
Figure 57. Histograms of grain size versus weight percent for lithofacies of the Arumbera Sandstone in the eastern James Ranges. Sieve-equivalent grain-size data are divided into intervals of 0.5 phi for each thin section.
Figure 58. Histograms of grain size verses weight percent for lithofacies 1a, 1b, 1d, 2a, and 2b of the Arumbera Sandstone in the Gardiner Range. Sieve-equivalent grain-size data are divided into intervals of 0.5 phi for each thin section.
Figure 59. Histograms of grain size verses weight percent for lithofacies 1c, 2a, and 2b of the Arumbera Sandstone in the Gardiner Range. Sieve-equivalent grain-size data are divided into intervals of 0.5 phi for each thin section.
Figure 60. Histograms of grain size verses weight percent for lithofacies of the Arumbera Sandstone in the James Ranges 'B' anticline and Quandong Conglomerate in the Deception Creek anticline. Sieve-equivalent grain-size data are divided into intervals of 0.5 phi for each thin section.
Figure 61. Isopachous map showing thickness of lithofacies 1c and largest observed pebbles of the Arumbera Sandstone in the Gardiner Range. Contour interval is 5 m.
Figure 62. Largest observed pebbles in lithofacies 2a of the Arumbera Sandstone in the Gardiner Range.
Appendix E

Measured Stratigraphic Sections - Graphic
KEY TO GRAPHIC LOGS

Formations

Ct = Tempe Formation
Cl = Chandler Formation
Ca = Arumbera Sandstone
Cn = Eninta Sandstone
"Cq" = "Quandong Conglomerate"
Cq = Quandong Conglomerate
Cp = Undifferentiated Deposits
Puj = Julie Formation
Puy = Cyclops Member
Pup = Pertatataka Formation
Pua = Areyonga Formation
Pub = Bitter Springs Formation

Rock Characteristics

1. Pi and omikron cross-stratification
2. Alpha, beta, and gamma cross-stratification
3. Xi cross-stratification
4. Mu and nu cross-stratification
5. Kappa and lambda cross-stratification
6. Herringbone cross-stratification
7. Ripple laminated
8. Flaser bedding
9. Wedging channels
10. Planar parallel laminae
11. Clay partings
12. Load deformation
13. Mud pebbles
14. Mudcracks
15. Glaucovite
16. Micaceous
17. Calcareous
18. Ferruginous
19. Trace Fossils
20. Gypsum

Rock Types

Sandstone
Conglomeratic Sandstone
Conglomerate
Limestone
Covered
Siltstone
Shale
Paraconglomerate
Dolostone
Partially Covered
### Section A - Billabong Bore East Section

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![Graph with data points and lines indicating geological layers and facies](image-url)
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### Legend:
- L: Lithology
- S: Sedimentology
- F: Facies
- M: Microfacies
- C: Correlation
- Clg: Clay Size

### Depth Markers:
- 0 m to 70.0 m
### Section H - Pine Point Section

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- **Fm**: Formation
- **Porosity %**: Percentage of porosity
- **Thickness (meters)**: Thickness in meters
- **Paleol. Corr. Dir. (/f)**: Paleontological correlation direction
- **Sample Location (1-1)**: Sample location
- **Unit**: Geologic unit
- **Facies**: Geologic facies
- **Gr. Size**: Grain size
- **Sl**: Silt
- **F**: Fine sand
- **M**: Medium sand
- **Cb**: Coarse boulders
- **Gp**: Gravel

*Covered*
Section J - Missionary View Section
### Section L - Tempe Downs North Section

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**Legend:**
- FM: Fine Muddy
- PM: Poor Muddy
- SM: Shaly Muddy
- CM: Coarse Muddy
- FM: Fine Sandy
- PM: Poor Sandy
- SM: Shaly Sandy
- CM: Coarse Sandy

**Notes:**
- **PA:** P.A. Formation
- **X:** X Formation
- **PA:** P.A. Formation

**Scale:**
- 0 to 425 meters
- 168.0 meters

**Caveats:**
- Sections marked with "**" are covered.
- The diagram includes various formations and facies, indicating different geological layers and their characteristics.
Appendix F

Measured Stratigraphic Sections - Verbal
Section A - Billabong Bore East Section

Location: Approximately 18 km southwest of Deep Well Homestead and 7 km north of Bokhara Homestead, Northern Territory, Australia, on the Rodinga 1:250,000 scale geologic map, at 134° 02' E longitude and 24° 26' S latitude (Australian Grid Coordinates: 1 95 8500 y N, 18 1000 y E, Zone 5). Composite section: upper three-fourths was measured east of the road to Bokhara Homestead, whereas the lower one-fourth was measured west of the same road. The section is located in an unnamed east-west strike ridge in the southern part of the James Ranges, north of the Oliffe Ranges. Beds face and dip north.


Formation

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<td>1. Limestone and dolomitic limestone. Light gray (5YR N-7), weathers light bluish gray (5B 7/1); fine-crystalline; chert in thin lenses; laminated to thin bedded; mostly contorted bedding; locally brecciated; chert often dark gray or black in color; foetid odor from freshly broken surfaces; forms a mostly covered valley with scattered outcrops.</td>
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Sharp contact: picked at the base of the lowest limestone bed. Outcrops of the Arumbera Sandstone and limestones of the Chandler Formation are present within one-half meter.

Arumbera Sandstone

Unit 3

1. Sandstone and siltstone. Pale red purple (5RP 6/2) and very dusky red purple (5RP 2/2), weathers pale yellow brown (10YR 6/2), gray brown (5YR 3/2), and light brown (5YR 6/4); very fine- to fine-grained with siltstone interbedded near the top; lenses of granular orthoconglomerate near the base of the unit; granules and locally scattered pebble-size grains consist of subangular quartzite and chert up to 2 cm in diameter; planar to wavy parallel bedding; average bed thickness: 3 cm, range: 1-6 cm; wavy irregular bedding with basal scours; mu and nu small-scale cross-stratification; locally
ripple laminated; planar parallel laminae 0.5-2 mm thick; cross laminae 0.5-2 mm thick; scattered mud pebbles and mud-pebble casts up to 2 cm in diameter; feldspathic; calcareous; ferruginous; somewhat silica cemented; local manganese staining; poor to good porosity (1 to 15%), mostly fair porosity (4 to 9%); forms a mostly covered gentle slope.

Sharp topographic contact and somewhat gradational lithologic contact: picked at the top of a small strike ridge. Above the contact, fine-grained sandstone beds dominate and form a valley and gentle slopes. Below the contact, orthoconglomeratic beds dominate and form a low strike ridge.

Lithofacies 2c

1. Orthoconglomerate, conglomeratic sandstone, and sandstone. Grayish orange pink (10R 8/2), light gray (5YR 7/1), and pale red (5R 6/2), weathers light brown (5YR 5/6), light brownish gray (5YR 6/1), and pale reddish brown (10R 5/4); fine- to coarse-grained groundmass and sandstone; contains granular to pebble-size lithoclasts up to 2 cm in diameter; the lithoclasts consist mostly of subangular chert fragments, subrounded quartzite, and minor rounded vein quartz; granular conglomerate composed chiefly of rounded quartz grains; average bed thickness: 20 cm, range: 10-50 cm; wedging cut-and-fill channels 10-15 m in lateral extent; alpha, beta, and gamma medium-scale solitary cross-stratification 10-24 cm thick lamina sets; Liesegang banding; planar parallel laminae 3-5 mm thick; cross laminae 1-5 mm thick; flute casts; load deformation; mud pebbles and mud pebble casts up to 5 cm in diameter; feldspathic; much of the feldspar has been altered to kaolinite; ferruginous; well cemented with silica; poor to fair porosity (trace to 5%); forms a small strike ridge with local cliff-forming beds.

Sharp erosional contact: picked at the base of the lowest conglomerate bed. Above the contact, orthoconglomerates dominate. Below the contact, fine- to medium-grained sandstones predominate and conglomerates are absent.

Lithofacies 2b

1. Interbedded sandstone, siltstone, shale, and other mudrock. Grayish red purple (5RP 4/2) and light olive gray (5Y 6/1), weathers grayish red (5R 4/2) and moderate yellow brown (10YR 5/4); Sandstone: fine-to medium-grained, moderately well sorted subangular to subrounded grains, average bed thickness: 6 cm, range: 2-10 cm,
planar to wavy parallel bedding, wavy irregular erosional basal bedding contacts, mu and nu major cross-stratification, minor pi, omikron, alpha, beta, and gamma cross-stratification 6-10 cm thick lamina sets, planar parallel laminae 1-7 mm thick, cross laminae 1-6 mm thick, traces of glauconite, micaceous, feldspathic, silica cemented, locally ferruginous, fair to good porosity (4 to 12%); Siltstone, shale, and other mudrocks: laminated, planar parallel laminae 1-7 mm thick, mu and nu cross-stratification, micaceous, ferruginous, poor porosity (trace); forms a mostly concealed valley.

Slightly gradational contact: picked at the top of the uppermost granular conglomerate. Above the contact, recessive fine-grained sandstones and siltstones are present. Below the contact, orthoconglomeratic beds are present.

**Lithofacies 2a**

1. Interbedded orthoconglomerate, conglomeratic sandstone, and sandstone. Light gray (5YR N-7) and moderate red (5R 5/4), weatohers pale brown (5YR 5/2), dark yellow orange (10YR 6/6), and grayish red (10R 4/2); Orthoconglomerate and conglomeratic sandstone: fine- to coarse-grained groundmass, contains subangular to subrounded chert fragments up to 2 cm in diameter, subrounded quartzite up to 1 cm in diameter, minor rounded vein quartz up to 0.5 cm in diameter, and fragments with silicified ooids up to 2 cm in diameter, average bed thickness: 25 cm, range: 4-45 cm, wedging cut-and-fill channels 10-30 m in lateral extent, pi and omikron cross-stratification 6-20 cm thick lamina sets, local graded bedding (conglomerate grading upwards into sandstone), cross laminae (heterogeneous and homogeneous compositions) 4-15 mm thick, local Liesegang banding, mud pebbles and mud-pebble casts up to 7 cm in diameter, local load deformation, minor slumped bedding and cross-stratification, scoured bedding contacts, feldspathic, locally ferruginous near the top of the unit, silica cemented, local manganese staining, poor to fair porosity (trace to 6%); Sandstone: medium- to coarse-grained; moderately sorted subangular to subrounded grains, lenticular-shaped bedding, scoured bedding contacts; average bed thickness: 12 cm, range: 6-20 cm, ripple laminated, current ripples (up to 6 cm wavelength), pi, omikron, alpha, beta, and gamma cross-stratification 6-12 cm thick lamina sets, minor kappa and lambda cross-stratification, planar parallel laminae 1-10 mm thick, wavy laminae 1-5 mm thick, cross laminae 0.5-8 mm thick, load deformation, minor herringbone cross-stratification, feldspathic, silica cemented,
local traces of calcite cement, poor to good porosity (1 to 15%), mostly fair porosity (4 to 7%); forms a prominent strike ridge.

Sharp erosional contact: picked at the base of the lowest conglomerate bed. Above the contact, orthoconglomerates and medium- to coarse-grained sandstones are dominant. Below the contact, very fine- to medium-grained sandstones and siltstones predominate.

**Unit 1**

2. Sandstone locally interbedded with dolomitic sandstone, silty dolostone, siltstone, shale, and other mudrock. Moderate red (5R 5/4), weathers pale brown (5YR 5/2); Sandstone: very fine- to medium-grained, poorly to moderately sorted subangular to subrounded grains, scattered granule- to gravel-size chert fragments, quartzite, and vein quartz grains up to 1 cm in diameter, average grain size increases up section silt and clay to very fine-grained sand at the base to very fine- to medium-grained sand near the top), laminated bedding, planar to wavy parallel bedding, local lenticular-shaped bedding, average bed thickness: 5 cm, range: 1-10 cm, mu and nu major cross-stratification, minor pi and omikron cross-stratification, planar parallel laminae 0.3-15 mm thick, cross laminae 0.5-2 mm thick, current ripples filling scours, mud pebbles and mud-pebble casts up to 2 cm in diameter, minor load deformation, locally calcareous, micaceous, feldspathic, ferruginous, somewhat silica cemented, poor to fair porosity (trace to 5%); Siltstone, shale, and other mudrocks: laminated bedding, planar parallel laminae 0.5-2 mm thick, wavy (discontinuous and continuous types) parallel laminae 0.3-2 mm thick, scoured bedding contacts, micaceous, locally dolomitic, rare mud pebbles up to 1 cm in diameter, ferruginous, poor porosity (trace); Dolomitic sandstone, dolomitic siltstone, and silty dolostone: silt-size to very fine-grained sand, planar to wavy parallel bedding, average bed thickness: 3 cm, range: 1-4 cm, nu major cross-stratification, current ripples filling scours, local desiccation mud cracks, minor load deformation, scour bedding contacts, feldspathic, ferruginous, minor silica cemented; micaceous, poor porosity (trace to 2%); local fractures filled by iron-oxide cement; forms a mostly concealed talus slope.

Gradational contact through several meters: picked at the base of the lowest siltstone bed. Above the contact, fine-grained sandstones are locally interbedded with siltstones and other mudrocks. Below the contact, fine- to medium-grained sandstones dominate.
1. Sandstone. Grayish pink (5R 8/2) to pale red (10R 6/2), weathers light gray (5YR N-7) and light brown (5YR 6/4); fine- to mostly medium-grained; generally rounded, well sorted grains; granules of rounded quartzite and vein quartz; wavy parallel to lenticular-shaped bedding; average bed thickness: 10 cm, range: 3-15 cm; pi, xi, omikron, and nu major cross-stratification; herringbone cross-stratification; planar parallel laminae 0.5-5 mm thick; wavy and cross laminae 1-7 mm thick; scoured bedding contacts; calcareous; locally ferruginous; feldspathic; somewhat silica cemented; good porosity (10 to 15%); forms a low strike ridge or bench.

Sharp erosional contact: picked at the top of the uppermost green shale bed. Above the contact, medium-grained sandstone beds predominate. Below the contact, greenish gray shales and siltstones are present. The contact possibly represents an angular unconformity. The underlying siltstone/shale unit appears to dip 10° to 14° less steeply to the north than the overlying sandstone unit.

Pertatataka Formation

1. Interbedded very fine-grained sandstone, siltstone, shale, and other mudrocks. Grayish orange pink (5YR 7/2), bluish white (5B 9/1), and brown gray (5YR 4/1), weathers light brown (5YR 5/6) and moderate orange pink (5YR 8/4); laminated bedding; lenticular-shaped to wavy parallel bedding; locally contorted bedding; average bed thickness: 3 cm, range: 1-4 cm; mu and nu cross-stratification; planar parallel laminae 0.2-2 mm thick; wavy discontinuous laminae 0.4-2 mm thick; cross laminae 0.5-3 mm thick; friable; highly fractured; micaceous; calcareous; ferruginous; sandstones are mostly silica cemented and feldspathic; poor porosity (trace), weathers to good porosity (15%); forms a covered valley with rare exposures in gullies.
Section B – Billabong Bore West Section

Location: Approximately 22 km southwest of Deep Well Homestead and 9 km northeast of Bloodwood Bore, Northern Territory, Australia, on the Rodinga 1:250,000 scale geologic map, at 133° 58' E longitude and 24° 24' S latitude (Australian Grid Coordinates: 196 1500 y N, 17 3500 y E, Zone 5). The section is located in an unnamed east-west strike ridge in the southern part of the James Ranges, and northwest of the Oliffe Ranges. Beds face and dip steeply north.

Measured by: J. O. Phillips and John Cullen with a 50-meter tape, two Jacob staffs, and an Abney hand level. Mark Farrell and James Deckelman assisted in locating the section. Measured up section from south to north, 4-8 July 1982.

Formation

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<th>Thickness</th>
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Lower Chandler Formation

2. Limestone, dolomitic limestone, and dolostone. Very pale orange (10YR 8/2), weathers the same color; fine-crystalline to micritic; laminated to thin bedded; beds are often contorted and locally brecciated; chert forms thin lenses and is generally gray to black in color; dark gray limestones give a foetid odor from freshly broken surfaces; step-like gentle ridges are present where chert is abundant; forms a covered valley and low-lying strike ridge.

Concealed contact: picked at the base of the lowest exposed limestone bed. Above the contact, carbonate beds are exposed. Below the contact, the unit is concealed.

1. Siltstone, shale, and limestone(?). Covered interval. 114.8

Concealed contact, probably gradational: picked 4 meters above the highest sandstone outcrop. This contact is traced 400 meters laterally along bedding strike to a contact which represents a change from dominantly sandstones below the contact to dominantly siltstones and shales above the contact. The interval above the contact is mostly covered. Below the contact, sandstone beds form a gentle to moderate dipslope. The contact was picked at the base of this dipslope.
Arumbera Sandstone

Unit 3

3. Sandstone with interbedded siltstone and shale. Moderate orange pink (10R 7/4), weathers light brown (5YR 5/6); Sandstone: very fine- to fine-grained, poorly sorted subangular to subrounded grains, wavy parallel bedding, laminated to thin bedded, average bed thickness: 3 cm, range: 1-5 cm, nu major cross-stratification, planar parallel laminae 1-2 mm thick, cross laminae 0.5-1.5 mm thick, micaceous, feldspathic, ferruginous, silica cemented, locally calcareous, poor porosity (trace); Siltstone and shale: laminated, micaceous, ferruginous, locally calcareous, poor porosity (trace); forms a mostly covered recessive, gentle to moderate slope. 8.0

Sharp contact: picked at the top of the uppermost bed of orthoconglomerate. Above the contact, fine-grained sandstones dominate. Below the contact, orthoconglomerates dominate. These conglomeratic beds form a small strike ridge or bench that is discontinuous laterally.

2. Orthoconglomerate, conglomeratic sandstone, and sandstone. Pale brown (5YR 5/2), weathers grayish red (5R 4/2); fine- to coarse-grained groundmass and sandstone; poorly sorted subangular to subrounded grains; contains lithoclasts of subangular chert fragments up to 1 cm in diameter, subrounded quartzite up to 0.5 cm in diameter and minor rounded vein quartz up to 0.3 cm in diameter; wedging channels with lenticular-shaped bedding; average bed thickness: 15 cm, range: 10-20 cm; xi and pi cross-stratification up to 8 cm thick lamina sets; planar parallel laminae 1-3 mm thick; cross laminae (heterogeneous and homogeneous compositions) 3-15 mm thick; local load deformation; mud pebbles and mud-pebble casts up to 7 cm in diameter; feldspathic; silica cemented; poor to fair porosity (trace to 5%); forms a gentle to moderate dipslope or bench. 3.0

Slightly gradational contact: picked at the lowest sandstone bed with greater than 5% gravel. Above the contact, orthoconglomerates dominate. Below the contact, fine-grained sandstones dominate.

1. Sandstone and siltstone. Grayish red (10R 4/2), pale reddish brown (10R 5/4), and grayish orange pink (5Y 7/2), weathers light brown (5YR 6/4 and 5YR 5/6) and pale reddish brown (10R 5/4); very fine- to fine-grained sandstone; poorly to moderately sorted subangular to subrounded grains; rare scattered chert fragments up to 2 cm in diameter near the top of the unit; laminated bedding; wavy parallel bedding; local
lenticular-shaped bedding; average bed thickness: 5 cm, range: 1-10 cm; pi and nu cross-stratification up to 8 cm thick lamina sets; planar parallel laminae 1-3 mm thick; cross laminae 1-2 mm thick; parting lineations; rare mud pebbles and mud-pebble casts up to 2 cm in diameter; scoured bedding contacts; micaceous; feldspathic; slightly ferruginous; silica cemented; poor to fair porosity (1 to 9%); forms a recessive dipslope. 17.6

Sharp contact: picked at the top of the uppermost conglomerate bed. Above the contact, very fine- to fine-grained sandstones are present. Below the contact, orthoconglomerates dominate.

Lithofacies 2c

1. Orthoconglomerate, conglomeratic sandstone, and sandstone. Grayish red (10R 4/2) and moderate red (5R 5/4), weathers light brown (5YR 5/6); fine- to mostly medium- to coarse-grained groundmass; poorly sorted subrounded grains; contains granule- to pebble-size lithoclasts of subangular to subrounded chert fragments up to 3 cm in diameter, subrounded to rounded quartzite up to 1.5 cm in diameter, and rounded vein quartz up to 0.5 cm in diameter; granules and gravel generally concentrated near the bases of beds; wedging cut-and-fill channels with up to 60 m lateral extent; average bed thickness: 40 cm, range: 14-90 cm; pi and xi with minor alpha, beta, and gamma cross-stratification 16-40 cm thick lamina sets; planar parallel laminae 3-10 mm thick; cross laminae (heterogeneous and homogeneous compositions) 4-20 mm thick; scoured bedding contacts; mud pebbles and mud-pebble casts up to 6 cm in diameter; load deformation; slumped bedding and cross-stratification; feldspathic; ferruginous; silica cemented; fair to good porosity (4 to 10%); forms a prominent strike ridge and dipslope. 37.7

Slightly gradational contact: picked at the base of the lowest conglomeratic bed. Above the contact, orthoconglomerates dominate. Below the contact, interbedded fine-grained sandstones, siltstones, shales, and limestones predominate.

Lithofacies 2b

1. Sandstone interbedded with siltstone, shale, other mudrocks, and limestone. Sandstone: pale red (10R 6/2), moderate red (5R 5/4), and grayish orange pink (10R 8/2), weathers pale reddish brown (10R 5/4) and moderate red (5R 5/4), very fine- to medium-grained, poorly to moderately sorted subangular to subrounded grains, locally with a muddy matrix, planar to wavy
parallel bedding with local lenticular-shaped bedding, average bed thickness: 7 cm, range: 1-13 cm, alpha, beta, and gamma major cross-stratification up to 12 cm thick lamina sets, local pi, omikron, mu, and nu cross-stratification, local flaser bedding, planar parallel laminae 1-4 mm thick, cross laminae 1-6 mm thick, load deformation, slumped bedding and cross-stratification, local ball-and-pillow structures, local Lisegang banding, clay parting, mud pebbles and mud-pebble casts up to 3 cm in diameter, micaceous, feldspathic, ferruginous, calcareous, minor silica cement, good porosity (9 to 15%); Siltstone and shale: pale red (10R 4/2) and grayish red (10R 4/2), weathers light brown (5YR 5/6) and grayish orange pink (10R 8/2), laminated to thin bedded, wavy parallel bedding, average bed thickness: 3 cm, range: 1-4 cm, mu and nu cross-stratification, locally highly fractured, local flaser bedding, micaceous, calcareous, ferruginous, fair to good porosity (4 to 12%), porosity largely due to surface weathering; Limestone: very pale orange (10YR 8/2), weathers light brown (5YR 6/4), fine-crystalline, wavy parallel to lenticular-shaped bedding, thin bedded, average bed thickness: 7 cm, range: 1-13 cm, contains clay- and silt-size terrigenous grains, local shale partings, poor porosity (trace to 3%); limestone beds are present near the top of the unit; unit forms a recessive, mostly concealed, dipslope.

Sharp contact: picked at the top of the uppermost conglomerate bed. Above the contact, fine-grained sandstones with siltstones, shales, and local limestone interbeds are present. Below the contact, orthoconglomerates dominate.

**Lithofacies 2c**

1. Orthoconglomerate and conglomeratic sandstone. Pale red (10R 6/2), weathers light brown (5YR 5/6); medium- to coarse-grained sandy groundmass; poorly sorted subrounded grains; contains granule- to pebble-size lithoclasts of subangular to subrounded chert fragments up to 4 cm in diameter, rounded quartzite up to 2 cm in diameter, and minor well rounded vein quartz up to 1 cm in diameter; local graded bedding (several beds grade from conglomerate near the base to fine- to medium-grained sandstones upwards; lithoclasts decrease in number and size upward in the unit; wedging cut-and-fill channels up to 8 m in lateral extent and 1 m thick; thick bedded; average bed thickness: 40 cm, range: 15-100 cm; pi major cross-stratification with up to 25 cm thick lamina sets; minor gamma cross-stratification; scoured bedding contacts; cross laminae: 1-5 mm thick; local load deformation; slumped bedding and cross-stratification;
mud pebbles and mud-pebble casts up to 3 cm in diameter; feldspathic; ferruginous; calcareous; minor silica cement; fair porosity (3 to 9%); forms a prominent strike ridge with distinctive dipslope. . . . . . . 7.9

Gradational contact: picked at the base of the lowest bed of granular conglomeratic sandstone. Above the contact, orthoconglomerates dominate. Below the contact, coarse-grained sandstones fine downsection into fine-grained sandstones with interbeds of siltstones, shales, and other mudrocks.

**Lithofacies 2b**

3. Sandstone interbedded with siltstone, shale, and other mudrocks. Pale red (10R 6/2), very pale orange (10YR 8/2), and pale reddish brown (10R 5/4), weathers light brown (5YR 5/6 and 5YR 6/4); Sandstone: very fine-to coarse-grained (coarsens upward: very fine-grained at the base increasing to coarse-grained at the top), poorly to moderately sorted subrounded grains, wavy parallel to lenticular-shaped bedding, average bed thickness: 10-10 cm, range: 1-24 cm, local wedging cut-and-fill channels 30 m in lateral extent, alpha, beta, gamma, pi, and omikron major cross-stratification with up to 20 cm thick lamina sets, local mu and nu cross-stratification, planar parallel laminae 1-4 mm thick, cross laminae 1-3 mm thick, clay partings, local flaser bedding, load deformation, load casts, local lenses of gypsum, feldspathic, calcareous, micaceous, locally ferruginous, silica cemented, traces of glauconite, poor to fair porosity (trace to 5%); Siltstone, shale, and other mudrock: laminated to thin bedded, highly fractured, slightly micaceous, locally calcareous, local gypsum lenses, locally ferruginous, poor porosity (trace); locally weathers into rounded nodules; forms a recessive dipslope. . . . . . . . . . . . . 13.6

Sharp contact: picked at the top of the uppermost conglomeratic sandstone bed. Above the contact, sandstones with interbeds of siltstones, shales, and mudrocks are present. Below the contact, conglomeratic sandstones dominate.

2. Sandstone and conglomeratic sandstone. Very pale orange (10YR 8/2), weathers light brown (5YR 5/6); fine- to coarse-grained groundmass and sandstone; poorly sorted subrounded grains; contains lithoclasts of subrounded chert and quartzite up to 2 cm in diameter; grain size increases toward the top of the unit; wavy irregular to lenticular-shaped bedding; local wedging channels up to 100 m in lateral extent; average bed thickness: 35 cm, range: 15-50 cm; alpha, beta, and gamma cross-stratifi-
cation with 11-27 cm thick lamina sets; minor pi and xi cross-stratification with 6-11 cm thick lamina sets; flute casts; planar parallel laminae 1-4 mm thick; cross laminae 1-10 mm thick; prod marks(?); vertical burrows(?) or water-escape structures; rare mud pebbles and mud-pebble casts up to 2 cm in diameter; traces of glauconite; locally calcareous; feldspathic; silica cemented; poor porosity (trace); forms a low but prominent strike ridge with nearly vertical beds.

Gradational contact: picked at the base of the lowest granular conglomeratic sandstone. Above the contact, conglomeratic sandstones dominate. Below the contact, fine-grained sandstones with interbeds of siltstones, shales, other mudrocks, and minor limestones are present.

1. Sandstone interbedded with siltstone, shale, other mudrock, and minor limestone. Pale red (10YR 6/2 and 5R 8/2), very pale orange (10YR 8/2), and grayish pink (5R 8/2), weathers light brown (5YR 6/4), pale yellow brown (10YR 6/2) and dusty brown (5YR 2/2); Sandstone: very fine- to fine-grained, poorly sorted subangular to subrounded grains, wavy parallel to lenticular-shaped bedding, average bed thickness: 10 cm, range: 2-30 cm, scoured bedding contacts, pi up to 8 cm thick lamina sets, mu, and nu cross-stratification, local alpha, beta, and gamma cross-stratification, local flaser bedding, planar parallel laminae 1-4 mm thick, cross laminae 1-5 mm thick, clay partings, local heavymineral bands, local lenses of gypsum, load deformation, load casts, ball-and-pillow structures, slumped bedding and cross-stratification, brush and prod marks, desiccation mudcracks, minor parting lineations, horizontal and shallow vertical burrows(?), friable with local cobbly weathering, micaceous, feldspathic, calcareous, silica cemented, poor to fair porosity (trace to 5%), mostly poor porosity; Siltstone, shale, and other mudrocks: wavy laminated, thin bedded, average bed thickness: 3 cm, range: 1-4 cm, micaceous, local gypsum lenses, calcareous, greatly fractured, poor porosity (trace); Limestone: fine-crystalline, lenticular-shaped bedding, contains clay- to silt-size terrigenous grains; forms a recessive dipslope.
Lithofacies 2a

1. Sandstone with minor interbeds of siltstone and shale. Grayish orange pink (10R 8/2), grayish pink (5R 8/2), and very pale orange (10YR 8/2), weathers pale red (10R 6/2), light brown (5YR 6/4), and moderate brown (5YR 4/4); fine- to coarse-grained (mostly medium-grained); poorly to moderately well sorted subrounded grains; wavy parallel to lenticular-shaped bedding; local wedging channels up to 7 m in lateral extent; average bed thickness: 25 cm, range: 5-50 cm; pi and omikron major cross-stratification with 6-30 cm thick lamina sets; local alpha, beta, gamma, and nu cross-stratification; local megaripples up to 2.5 m wavelength and 1 m thick; linguoid, sinuous, and straight-crested ripples; grouped in-phase stacked straight-crested ripples; planar parallel laminae 1-5 mm thick; cross laminae 1-8 mm thick; wavy continuous laminae 2-14 mm thick; scoured bedding contacts; rare mud pebbles and mud-pebble casts up to 5 cm in diameter; parting lineations; local clay partings; heavy-mineral bands near the top and base of the unit; locally micaceous; feldspathic; silica cemented; poor to good porosity (trace to 11%); mostly fair porosity (3 to 6%); forms a prominent strike ridge with cliffs. 37.6 194.7

Sharp erosional contact: picked at the base of the cliff-forming sandstones. Above the contact, the sandstones form a prominent strike ridge and are generally well exposed. The beds of this subunit are dominated by grouped sets of cross-stratification and are light in color. Below the contact, fine-grained sandstones interbedded with siltstones, shales, and other mudrocks are present. These beds are pale red in color and mostly concealed beneath talus from the cliffs above. They form a recessive slope.

Unit 1

1. Sandstone with interbeds of siltstone, shale, and other mudrocks. Pale brown (5YR 5/2), grayish red (5R 4/2), and grayish pink (5R 8/2), weathers pale red (5R 6/2), light brown (5YR 5/6), and moderate brown (5YR 4/4); Sandstone: very fine- to fine-grained, poorly sorted subangular to subrounded grains, laminated bedding, planar to wavy parallel bedding, average bed thickness: 6 cm, range: 1-12 cm, mu and nu cross-stratification, planar parallel laminae 1-2 mm thick, cross laminae 1-3 mm thick, local scoured bedding contacts, local heavy-mineral laminae, locally micaceous, local load deformation, minor slumped bedding, locally calcareous, locally ferruginous, silica cemented, local manganese staining, poor porosity (trace); Siltstone, shale, and other mudrocks: laminated bedding, micaceous, locally
Possible gradational lithologic contact but sharp color change at the contact: picked where calcareous cement diminishes (going up section), and where the color changes from gray and greenish gray, below the contact, to red and reddish gray above the contact. Above the contact, sandstones are the dominant lithology. Below the contact, siltstones and shales predominate. Generally the contact is concealed laterally along strike. At this section, weathering and erosion have disguised the contact.

Pertatataka Formation

2. Very fine-grained sandstone, siltstone, shale, and limestone. Light olive gray (5Y5/2), weathers light brown (5YR 6/4); laminated to thin bedded; poorly sorted; most of the unit is dominated by shales and siltstones; average bed thickness: 2 cm, range: 1-3 mm; lenticular-shaped to wavy bedding; local desiccation mudcracks; locally micaceous; calcareous; silica cemented; poor porosity (trace); outcrops are present only in the larger gullies cutting this unit; forms a recessive slope which is nearly always covered.

Concealed contact: picked at the base of the gentle slope.


Concealed contact: picked at the top of the uppermost exposed sandstone bed. This sandstone bed is part of a sequence of sandstones that form a low-lying strike ridge.

Areyonga Formation (?)

2. Sandstone with local siltstone interbeds. Pale yellow brown (10YR 6/2), weathers light brown (5YR 5/6); very fine- to fine-grained; moderately sorted; lenticular-shaped bedding; average bed thickness: 7 cm, range: 1-10 cm; scoured bedding contacts; μ and ν major cross-stratification; local κ and λ cross-stratification; planar parallel laminae 1-2 mm thick; cross laminae 1-3 mm thick; wavy discontinuous laminae 0.5-2 mm thick; flute casts; local load deformation; feldspathic; well cemented by silica; poor porosity (trace); forms a low strike ridge.
Concealed contact: picked at the base of the low strike ridge.


Concealed contact: picked at the top of the uppermost exposed dolostone bed.

**Bitter Springs Formation** (Loves Creek Member, Unit 2 of Oaks, 1983)

1. Dolostone, dolomitic limestone, and minor limestone. Fine-crystalline to micritic; contorted bedding; locally brecciated; contains thin chert lenses and small chert nodules; cryptalgal laminae; algal domes; locally silty; foetid odor from freshly brokened surfaces; forms a round-crested strike ridge.
Section C - Walkabout Section

Location: Approximately 33 km southwest of Deep Well Homestead, 6.5 km northwest of Picnic Bore, and 13 km north-northeast of Gum Tree Bore, Northern Territory, Australia, on the Rodinga 1:250,000 scale geologic map, at 133° 50'E longitude and 24° 24'S latitude (Australian Grid Coordinates: 1 96 1000 y N, 16 0500 y E, Zone 5). The section is located in the western part of an unnamed east-west strike ridge in the southern part of the James Ranges, and northwest of the Oliffe Ranges. Beds face and dip steeply north.

Measured by: J. O. Phillips and John Cullen with a 60-meter tape, two Jacob staffs, and an Abney hand level. Measured up section from south to north, 1-2 September 1982.

Formation

Lower Chandler Formation

2. Limestone and dolomitic limestone. Medium light gray (N-6) and medium dark gray (N-4), weathers light gray (N-7); fine-crystalline to micritic; laminated to thin bedded; average bed thickness: 10 cm, range: 1-20 cm; local contorted bedding; wavy parallel to lenticular-shaped bedding; horizontal and wavy laminae 0.5-1.5 mm thick; lenses of light gray chert 1-2 cm thick and local nodules of chert up to 4 cm in diameter; very poor porosity (trace); forms a small, mostly concealed, strike ridge.

Covered contact: picked at the lowest exposed limestone bed. Above the contact, exposed limestones are present. Below the contact, a covered interval is present.


 Covered contact: picked at the base of the gentle, concealed dipslope which represents more resistant bedrock than the overlying covered valley. Above the contact, a covered valley is present. Below the contact, a gentle to moderately steep dipslope, which is covered, is present. The contact appears to be gradational.
Arumbera Sandstone

Unit 3

3. Sandstone and minor siltstone. Grayish orange pink (IOR 8/2), weathers light brown (5YR 5/6 and 5YR 6/4); medium-grained; poorly sorted subrounded to rounded grains; thin bedded; wavy parallel bedding; calcareous; feldspathic; minor silica cement; good porosity (10 to 15%); pits were dug in order to determine the lithology and sedimentary features; forms a covered gentle slope. 

Covered contact: picked at the top of the uppermost exposed sandstone bed. Above the contact, a covered gentle slope is present. Below the contact, exposed sandstones are present.

2. Sandstone. Pale red (5R 6/2) and grayish orange pink (IOR 8/2), weathers pale red (IOR 6/2) and light brown (5YR 5/6 and 5YR 6/4); medium- to coarse-grained; poorly to moderately sorted subrounded to rounded grains; lenticular-shaped bedding; average bed thickness: 12 cm, range: 6-26 cm; wavy scoured bedding contacts; mu and nu major cross-stratification; minor alpha, beta, and gamma cross-stratification 8-15 cm thick lamina sets; planar parallel laminae 0.5-4 mm thick; cross laminae 1-5 mm thick; feldspathic; locally calcareous; silica cemented; good porosity (10 to 15%); forms a recessive gentle slope with local small benches running parallel to bedding strike.

Covered contact, probably gradational: picked at the lowest exposed sandstone bed. Above the contact exposed sandstones are present. Below the contact, a covered interval is present.

1. Sandstone with local siltstone interbeds. Pale red (5R 6/2), weathers grayish red (IOR 4/2); fine- to medium-grained; moderately well sorted subangular to subrounded grains; wavy parallel to lenticular-shaped bedding; average bed thickness: 6 cm, range: 5-8 cm; planar parallel laminae 0.5-4 mm thick; traces of glauconite; micaceous; feldspathic; ferruginous; silica cemented; poor porosity (trace to 1%); pits dug in order to determine lithology and sedimentary features; forms a covered bench.

Covered contact, probably sharp: picked at the top of the uppermost exposed bed. Above the contact, a concealed interval is found. Below the contact, well exposed orthoconglomerates are dominate.
Lithofacies 2c

1. Conglomerate. Grayish red purple (5RP 4/2) and pale reddish brown (10R 5/4), weathers very dusky red purple (5RP 2/2) and pale reddish brown (10R 5/4); fine- to coarse-grained groundmass (mostly fine-grained); poorly sorted subangular grains; contains lithoclasts of subangular to rounded chert fragments up to 8 cm in diameter, subrounded to rounded quartzite up to 4 cm in diameter, minor rounded fragments with silicified ooids up to 2 cm in diameter, local rounded granite fragments up to 5 cm in diameter, and rounded vein quartz up to 1 cm in diameter; most lithoclasts are gravel size; wedging cut-and-fill channels; average bed thickness: 40 cm, range: 25-60 cm; irregular scoured bedding contacts; pi, gamma, and xi major cross-stratification with 5-15 cm thick lamina sets; planar parallel laminae 2-9 mm thick; cross laminae (heterogeneous and homogeneous compositions) 2-10 mm thick; rare mud pebbles and mud-pebble casts up to 10 cm in diameter; feldspathic; ferruginous; silica cemented; poor porosity (trace to 1%); forms a prominent strike ridge with a distinctive dipslope.

Sharp erosional contact: picked at the base of the lowest conglomerate bed. Above the contact, orthoconglomerates dominate. Below the contact, fine- to medium-grained sandstones dominate.

Lithofacies 2b

1. Sandstone. Pale red (5R 6/2) and grayish orange pink (10R 8/2), weathers pale red (10R 6/2) and light brown (5YR 6/4); fine- to medium-grained; poorly to moderately well sorted subangular grains; lenticular-shaped bedding; average bed thickness: 10 cm, range: 7-12 cm; mud and nu cross-stratification; planar parallel laminae 1-4 mm thick; cross laminae 1-5 mm thick; load deformation; slumped bedding; slightly micaceous; traces of glauconite; feldspathic; calcareous; ferruginous; silica cemented; local manganese staining; good porosity (12 to 15%); forms a recessive valley.

Sharp contact: picked at the top of the uppermost conglomerate bed. Above the contact, a recessive interval consisting of fine- to medium-grained sandstones is present. Below the contact, orthoconglomerates dominate.

Lithofacies 2c

1. Orthoconglomerate with interbeds of conglomeratic sandstone and sandstone. Pale reddish brown (10R 5/4),
pale red (5R 6/2), moderate orange pink (10R 5/4), and grayish orange (10YR 7/4), weathers light brown (5YR 5/6), moderate brown (5YR 4/4), and grayish orange pink (5YR 7/2); fine- to coarse-grained groundmass and sandstones; poorly sorted subangular to rounded grains; contains lithoclasts of subangular to subrounded chert fragments up to 6 cm in diameter, subrounded quartzite up to 5 cm in diameter, minor subrounded to rounded vein quartz up to 2 cm in diameter, rare subrounded to rounded fragments with silicified ooids up to 2 cm in diameter, and rare subrounded to rounded sandstone up to 2 cm in diameter; most lithoclasts are gravel size; wedging cut- and-fill channels and local lenticular-shaped bedding; average bed thickness: 35 cm, range: 9-45 cm; scoured bedding contacts; local graded bedding (orthoconglomerate --> conglomeratic sandstone --> sandstone); pi major cross-stratification with 10-20 cm thick lamina sets; minor xi, alpha, beta, and gamma cross-stratification with 8-20 cm thick lamina sets; planar parallel laminae 1-7 mm thick; cross laminae (heterogeneous and homogeneous compositions) 1-10 mm thick; load deformation; slumped bedding and cross-stratification; ball-and-pillow structures; mud pebbles and mud-pebble casts up to 6 cm in diameter; feldspathic; ferruginous; silica cemented; traces of glauconite; local manganese staining; poor to good porosity (1 to 14%); mostly fair to good porosity (5 to 10%); forms a prominent ridge-top and a distinctive dipslope.

Sharp erosional contact: picked at the base of the lowest conglomerate bed. At the contact, an orthoconglomerate, lying above the contact, fills scours that cut into underlying siltstones. The lithofacies above the contact is dominated by orthoconglomerates, whereas the lithofacies below the contact is dominated by fine-grained sandstones and dirty carbonates.

Lithofacies 2b

1. Dolostone, dolomitic siltstone, dolomitic sandstone, calcareous sandstone, siltstone, and shale. Moderate orange pink (10R 7/4), greenish gray (5G 6/1), and pale red (10R 6/2), weathers light brown (5YR 5/6) and light grayish brown (5YR 6/1); Dolostone and dolomitic siltstone: micritic to fine-crystalline, laminated bedding, wavy parallel bedding, thin bedded, average bed thickness: 4 cm, range: 1-7 cm, dolostone dominates most of the lithofacies; Sandstone and dolomitic sandstone: very fine- to fine-grained, poorly sorted subangular to subrounded grains, thin bedded, wavy parallel to lenticular-shaped bedding, average bed thickness: 5 cm, range: 1-10 cm, wavy scoured bedding contacts, nu major
cross-stratification, minor kappa and lambda cross-stratification, planar parallel (discontinuous and continuous types) laminae 0.5-3 mm thick, cross laminae 1-2 mm thick, wavy discontinuous laminae 1-3 mm thick, load deformation, slumped bedding, feldspathic, micaceous, calcareous and dolomitic, slightly silica cemented, poor porosity (trace); Dolomitic siltstone and siltstone: laminated bedding, locally micaceous, poor porosity (trace); this subunit is composed of the following sequence: fine-grained sandstone --> siltstone --> dolostone --> very fine-grained sandstone --> fine-grained sandstone (with slumped bedding); forms a recessive ridge top.

Gradational contact: picked where the proportion of siltstone and very fine-grained sandstone is greater than fine-grained sandstone. Above the contact, a recessive dolostone-dominated interval is present. Below the contact, fine- to medium-grained sandstones dominate.

**Lithofacies 2a**

1. Sandstone with minor siltstone interbeds near the top of the lithofacies. Very light gray (N-8), grayish orange (10YR 7/4), and pinkish gray (5YR 8/1), weathers grayish orange (10YR 7/4), light brown (5YR 5/6), and light gray (N-7); very fine- to coarse-grained (mostly medium-grained); poorly to moderately sorted subrounded to rounded grains; local coarse-grained lenses; average grain size fines upward within this lithofacies (medium- to coarse-grained at the base to very fine-grained at the top); wavy parallel to lenticular-shaped bedding; average bed thickness: 20 cm, range: 4-47 cm; scoured bedding contacts; pi and xi major large scale cross-stratification with 3-8 cm thick lamina sets; nu, kappa, and lambda major small scale cross-stratification; minor alpha, beta, and gamma cross-stratification with 5-8 cm thick lamina sets; local herringbone cross-stratification near the base of the lithofacies; climbing ripples; ripple surfaces (straight crested and bifurcated types); local flaser bedding at the base of the lithofacies; planar parallel laminae 0.5-3 mm thick; wavy continuous (stacked in-phase and out-of-phase types) laminae 5-25 mm thick; cross laminae 1-3 mm thick; local clay partings; minor load deformation; load casts; local mud-pebble conglomerate as basal parts of beds near the base of the lithofacies up to 3 cm thick; mud pebbles and mud-pebble casts up to 7 cm in diameter; traces of glauconite near the base of the lithofacies; feldspathic; traces of calcite cement at the top of the lithofacies; silica cemented; local manganese staining; poor to fair porosity (trace to 5%), mostly poor
porosity (trace to 2%); forms a prominent strike ridge with cliff-forming members.

Concealed contact, probably sharp: picked at the base of the lowest exposed sandstone bed. Above the contact, light gray, medium-grained sandstones dominate. Below the contact, a mostly concealed interval is present. Here siltstones and very fine-grained sandstones are present where outcrops are exposed.

Unit 1

1. Interbedded sandstone, siltstone, and shale. Dusky yellow (5Y 6/4), moderate red (5R 5/4) and bluish white (5B 9/1), weathers light brown (5YR 5/6), moderate red (5R 5/4), and very light gray (N-8); very fine-grained sandstones; laminated to thin bedded; fissile; planar parallel laminae 0.5-2 mm thick; wavy discontinuous laminae 0.5-2 mm thick; micaceous; feldspathic sandstones; silica cemented; poor porosity (trace to 1%); most of the unit is covered; outcrops only exposed in a gully; forms a recessive talus slope.

Sharp contact: picked at the base of the lowest red shale. Although the contact is mostly covered, a gully cutting the base of the slope exposes a 10 meter interval where shale beds abruptly change from green to red. Above the contact, shales and siltstones of the Arumbera are reddish in color. Below the contact, the Pertatataka shales are greenish in color. Due to intense fracturing and weathering of these beds, the nature and dip of the bedding surfaces across the contact is obscured.

Pertatataka Formation

1. Interbedded siltstone and shale. Grayish green (5GY 6/1), light olive gray (5YR 5/2), light bluish gray (5B 7/1), and pale brown (5YR 5/2), weathers the same colors; laminated bedding; fissile; planar parallel laminae 0.5-2 mm thick; wavy discontinuous laminae 0.5-2 mm thick; calcareous; micaceous; poor porosity (trace to 1%); forms a covered valley and a very recessive covered slope.
Section D - Tidenvale Section

Location: Approximately 33 km northwest of Orange Creek Homestead, 6 km southwest of Mt. Keartland, and 15 km east-southeast of Exoil's James Ranges No. 1 Well, Northern Territory, Australia, on the Henbury 1:250,000 scale geologic map, 133° 9' E longitude and 24° 14' S latitude (Australian Grid Coordinates: 1 98 3000 y N, 63 8500 y E, Zone 5). The section is in the core of the James Range 'B' anticline where the "Quandong Conglomerate" forms an east-west strike ridge. Beds face and dip north on the north side.

Measured by: J. O. Phillips and John Cullen with a 50-meter tape, two Jacob staffs, and an Abney hand level. The "Quandong" was measured up section from south to north, 9-11 July 1982.

Formation | Thickness (meters)
--- | ---

Lower Chandler Formation (Jay Creek Limestone)

3. Limestone and dolomitic limestone. Dusty yellow brown (10YR 2/2), weathers pale yellow brown (10YR6/2); micritic to fine-crystalline; laminated to thin bedded; average bed thickness: 5 cm, range: 1-8 cm; contorted and locally brecciated beds; thin dark gray to black chert lenses; local chert nodules 1-4 cm in diameter; foetid odor on freshly broken surfaces; mostly non-fossiliferous; local algal domes up to 2 cm high and cryptalgal laminae 1-4 mm thick; poor porosity (trace); forms a low step-like strike ridge.

Covered contact: picked at the base of the lowest exposed limestone bed. Above the contact, exposed limestones are present. Below the contact, a covered interval is present.

2. Covered interval. 120.0

Covered contact: picked at the top of the highest exposed limestone bed. Above the contact, a covered interval is present. Below the contact, exposed limestones are present.

1. Limestone and dolomitic limestone. Dusky yellow brown (10YR 2/2), weathers pale yellow brown (10YR 6/2); micritic to fine-crystalline; laminated to thin bedded; scattered chert lenses 2 mm thick and 6 cm long; rare chert nodules up to 1 cm in diameter; mostly non-fossiliferous, occasional algal domes and cryptalgal
laminae; poor porosity (trace); forms a moderately steep dipslope.

10.0

Sharp contact: picked at the base of the lowest limestone bed and the top of a calcareous sandstone 1 meter thick. Directly above the contact, limestones are present. Below the contact, fine-grained sandstones are present.

"Quandong Conglomerate"

**Lithofacies 2a [Unit Y]**

3. Sandstone. Light brown (5YR 5/6 and 5YR 6/4), weathers moderate brown (5YR 4/4) and moderate yellow brown (10YR 5/4); very fine- to fine-grained; poorly to moderately sorted subrounded grains; scattered lenses of coarse sand, granules, and pebbles (pebbles are generally less than 5% of the lenses); granules are well rounded, whereas the pebbles are generally subrounded quartzite and vein quartz; wavy parallel to wavy irregular; average bed thickness: 5 cm, range: 2-10 cm; pi and nu major cross-stratification with up to 8 cm thick lamina sets; minor kappa and lambda cross-stratification; planar parallel laminae (heterogeneous and homogeneous compositions) 4-15 mm thick; cross laminae (homogeneous and heterogeneous compositions) 1-10 mm thick; scoured bedding contacts; calcareous; feldspathic; somewhat silica cemented; poor porosity (trace); forms a moderately steep dipslope.

Gradational contact: picked at the base of the lowest calcareous sandstone bed. Above the contact, fine-grained calcareous sandstones dominate. Below the contact, fine- to coarse-grained, non-calcareous sandstones are present.

2. Orthoconglomerate, conglomeratic sandstone, and sandstone. Moderate yellow brown (10YR 5/4) and pale yellow brown (10YR 6/2), weathers light brown (5YR 5/6 and 5YR 6/4); Orthoconglomerate and conglomeratic sandstone: fine- to coarse-grained groundmass; poorly sorted subangular to subrounded grains; contains granule- to cobble-size lithoclasts of subangular to subrounded chert up to 8 cm in diameter, subrounded to rounded quartzite up to 12 cm in diameter, and minor rounded vein quartz up to 4 cm in diameter, wedging cut-and-fill channels 3-6 m thick and 10-30 m lateral extent, average bed thickness: 40 cm, range: 10-60 cm, pi, xi, and minor omikron, alpha, beta, and gamma cross-stratification with 6-20 cm thick lamina sets, local kappa and lambda cross-stratification, planar parallel
laminae 1-10 mm thick, cross (heterogeneous and homogeneous compositions) laminae 2-10 mm thick, wavy (continuous and discontinuous types) laminae 1-5 mm thick, current ripples up to 2 cm wavelength, wavy irregular scoured bedding contacts, load deformation, ball-and-pillow structures, slumped bedding and cross-stratification, local mud-pebble conglomerate as basal parts of beds up to 3 cm thick, mud pebbles and mud-pebble casts up to 5 cm in diameter, Liesegang banding, feldspathic, silica cemented, poor to good porosity (trace to 12%), mostly fair porosity (4 to 8%);
Sandstone: very fine- to coarse-grained, mostly fine- to medium-grained, poorly to moderately sorted subrounded grains, lenticular-shaped bedding, average bed thickness: 10 cm, range: 6-20, pi and nu with minor omikron, mu, alpha, beta, and gamma cross-stratification with up to 13 cm thick lamina sets, local kappa and lambda cross-stratification, planar parallel laminae 0.5-5 mm thick, wavy continuous and discontinuous laminae 1-4 mm thick, scoured bedding contacts, straight-crested symmetric ripples up to 2 cm wavelength, local load deformation, minor slumped bedding, rare ball-and-pillow structures, vertical burrows(?), Liesegang banding, clay partings, local mud pebbles and mud-pebble casts up to 4 cm in diameter, feldspathic, silica cemented, fair to good porosity (4 to 15%); forms a small, prominent strike ridge with a steep dipslope and local cliff.

Sharp erosional contact: picked at the base of the lowest conglomerate bed. Above the contact, orthoconglomerates dominate. Below the contact, fine- to medium-grained sandstones are dominant.

1. Sandstone. Moderate yellow brown (10YR 5/4) and light brown (5YR 5/6), weathers moderate brown (5YR 4/4) and light brown (5YR 5/6); fine- to medium-grained; moderately sorted subangular grains; lenticular-shaped bedding with local wedging cut-and-fill channels; average bed thickness: 30 cm, range: 10-62 cm; pi major cross-stratification with up to 10 cm thick lamina sets, minor nu, kappa and lambda cross-stratification; planar parallel laminae 1-3 mm thick; cross laminae 4-15 mm thick; wavy discontinuous laminae 2-5 mm thick; local load deformation; minor slumped bedding; rare sand volcanoes (water-escape structures); convolute bedding; scattered mud pebbles and mud-pebble casts up to 2 cm in diameter; traces of glauconite; feldspathic; silica cemented; fair porosity (4 to 6%); forms a mostly covered talus slope with local cliff.
Sharp erosional contact: picked at the base of the lowest fine- to medium-grained sandstone bed which fills scours in the underlying siltstones and very fine-grained sandstones. Above the contact, fine- to medium-grained sandstones dominate. Below the contact, interbedded very fine-grained sandstones, siltstones, and shales dominate.

**Lithofacies 1d [Unit X]**

1. Interbedded sandstone, siltstone, shale, and other mudrocks. Grayish red (5R 4/2), and pale reddish brown (10R 5/4), weathers pale red (5R 6/2) and grayish red (10R 4/2); very fine- to fine-grained sandstone; wavy parallel bedding with local lenticular-shaped bedding; average bed thickness: 3 cm; range: 1-4 cm; local mu and nu cross-stratification; planar parallel laminae 0.5-2 mm thick; cross laminae 0.5-2 mm thick; siltstones, shales, and other mudrocks are highly fractured and brokened; scattered mud pebbles and mud-pebble casts up to 1 cm in diameter; local clay partings; local clay drapes within the sandstone beds; micaceous; calcareous; ferruginous; feldspathic; minor silica cement, poor porosity (trace to 1%); forms a mostly concealed, gentle slope. 

The base of Unit 1 is not exposed. Unit 1 may be the basal Unit of the "Quandong Conglomerate". However, its base and the lower boundary of the "Quandong Conglomerate" are not exposed in the core of the James Range 'B' anticline.
Section E - N-matjiras Section

Location: Approximately 10 km southeast of the Arengnonga Native Settlement and 3 km west of the Namatjiras Copper Prospect, Northern Territory, Australia, on the Henbury 1:250,000 scale geologic map, in the Gardiner Range anticline, at 132° 21' E longitude and 24° 8' S latitude (Australian Grid Coordinates 1 99 6000 y N, 55 0000 y E, Zone 5). The Eninta Sandstone forms an east-west strike ridge. Beds face and dip south.


<table>
<thead>
<tr>
<th>Formation</th>
<th>Thickness (meters)</th>
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<tbody>
<tr>
<td>Tempe Formation</td>
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<tr>
<td>1. Covered.</td>
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Concealed contact: picked at the top of the uppermost exposed limestone bed.

Lower Chandler Formation

2. Limestone and dolomitic limestone interbedded with calcareous sandstone and silty limestone. Limestone, dolomitic limestone, and silty limestone: grayish pink (5R 8/2) and moderate red (5R 5/4), weathers white (N-9) and bluish white (5B 9/1), very fine-crystalline to micritic, thin bedded with wavy parallel laminae, contains chert lenses up to 4 cm thick and/or nodules up to 5 cm in diameter, darker beds have foetid odor on freshly broken surfaces; Calcareous sandstone: pale reddish brown (10R 5/4), light brown (5YR 5/6), and dark yellow brown (10YR 5/6), weathers light brown (5YR 5/6), very fine- to fine-grained, poorly sorted, laminated to thin bedded, average bed thickness: 4 cm, range: 1-10 cm, wavy and planar parallel laminae 0.5-2 mm thick, micaceous, muddy to silty matrix, local calcite filled fractures, sandstone proportion increases up section, poor porosity (trace to 1%); forms a mostly concealed valley.  

Sharp contact: picked at the base of the lowest limestone.
1. Siltstone and other mudrocks. Pale reddish brown (IOR 5/4), weathers light brown (5YR 5/6); laminated bedding, planar parallel discontinuous laminae 0.5-3 mm thick; micaceous; calcareous; slightly ferruginous; poor porosity (trace to 1%); forms a concealed valley.

Gradational contact through several meters: picked at the top of the uppermost sandstone bed. Below the contact, the amount of sandstone is greater than siltstone. The unit just below the contact forms a small bench consisting of exposed sandstones and covered by Spinifex. Above the contact there is very little Spinifex.

Eninta Sandstone

Lithofacies 2a [Unit L]

2. Sandstone and siltstone. Moderate orange pink (5YR 8/4), weathers light brown (5YR 5/6 and 5YR 6/4); fine- to medium-grained; grain size fines upwards; poorly to moderately well sorted subangular to subrounded grains; sorting decreases upsection; scattered granules; laminated to thin bedded; average bed thickness: 8 cm, range: 1-15 cm; kappa, minor lambda, mu, and nu cross-stratification; planar parallel discontinuous and wavy discontinuous laminae 1-7 mm thick; mud pebbles and mud-pebble casts up to 3 cm in diameter; micaceous; traces of calcite cement at top of the unit; scattered chert fragments up to 0.7 cm in diameter; silica cemented; feldspathic; slightly ferruginous; poor porosity (trace to 1%); forms a mostly covered and somewhat recessive dipslope.

Gradational contact: picked where the amount of scattered chert fragments is less than 5%. Below the contact the dipslope is moderately recessive.

1. Conglomeratic, sandstone, granular orthoconglomerate, and sandstone. Grayish orange pink (5YR 7/2) and moderate orange pink (5YR 8/4), weathers light brown (5YR 6/4); medium- to coarse-grained with local fine- to medium-grained groundmass; poorly sorted subangular to subrounded grains; scattered subrounded to subangular chert fragments up to 4 cm in diameter with most being of granule size, and subrounded quartzite up to 2 cm in diameter; wavy parallel to lenticular-shaped bedding; average bed thickness: 12 cm, range: 6-30 cm; pi, alpha, beta, and gamma large-scale cross-stratification and mu and nu small-scale cross-stratification; planar parallel high velocity laminae 0.5-4 mm thick; cross laminae 1-
4 mm thick; minor load deformation; minor slumped beds; local mud-pebble conglomerate as basal parts of beds up to 2 cm thick; mud pebbles and mud-pebble casts up to 8 cm in diameter; feldspathic; silica cemented; rare traces of glauconite; poor porosity (1 to 3%); forms a prominent dipslope.

Sharp contact: picked at the base of the lowest conglomeratic sandstone bed.

Lithofacies 2b [Unit K]

2. Sandstone and very minor conglomeratic sandstone. Moderate orange pink (5YR 7/2), weathers light brown (5YR 5/6 and 5YR 6/4); contains white (N-9) clay pebbles; fine- to medium-grained; moderately well sorted subrounded grains; local scattered chert fragments up to 2 cm in diameter and form less than 2% of the total composition; Laminated to thin bedded; wavy and planar parallel bedding with local thin lenticular-shaped beds of conglomeratic sandstone; scoured bedding contacts; average bed thickness: 14 cm, range: 1-30 cm; alpha, beta, and gamma major cross-stratification, local kappa and lambda cross-stratification; grouped in-phase current ripples and dunes (megasipples); planar parallel high velocity laminae 0.5-8 mm thick; cross laminae 1-6 mm thick; local mud-pebble conglomerate as basal parts of beds up to 2 cm thick; mud pebbles and mud-pebble casts up to 10 cm in diameter; load deformation; slumped bedding and cross-stratification; ball-and-pillow structures; convolute bedding; water-escape structures; load casts; parting lineations; local traces of mica near the base of this unit; feldspathic; silica cemented; fair to poor porosity (trace to 6%); forms a prominent dipslope and steps.

Sharp contact based on color change: picked at the base of the lowest grayish orange pink bed. Above the contact the rocks are fine- to medium-grained sandstones, whereas below the contact they are very fine- to fine-grained sandstones.

1. Sandstone. Pale reddish brown (10R 5/4), weathers grayish red (10R 4/2); very fine- to fine-grained; poorly to moderately well sorted subangular grains; mostly laminated with minor thin bedded; wavy to planar parallel bedding; average bed thickness: 6 cm, range: 1-21 cm; kappa and lambda major cross-stratification, local alpha, beta, and gamma cross-stratification with 6-8 cm thick lamina sets; repeated vertical sequences: (base) horizontal laminated --> alpha cross stratification --> horizontal laminated --> contorted, slumped
or convolute bed --> horizontal laminated (top); planar parallel continuous laminae 0.5-6 mm thick; planar parallel discontinuous laminae 1-3 mm thick; cross laminae 1-6 mm thick; wavy discontinuous laminae 1-4 mm thick; sets of planar parallel laminae to 2 m thick; mud pebbles and mud-pebble casts up to 3 cm in diameter; scattered clay partings; minor load deformation; minor slumped beds; local convolute bedding; micaceous; feldspathic; silica cemented; poor to good porosity (1 to 15%); forms a mostly concealed gentle to moderate slope and recessive valley.

Gradational contact: picked at the top of the uppermost conglomeratic sandstone. Above the contact, the sandstones are very fine- to fine-grained. Below the contact, the beds are commonly conglomeratic.

Lithofacies 2a [Unit J]

1. Conglomeratic sandstone and sandstone. Grayish orange pink (5YR 7/2) and light brown (5YR 6/4), weathers light brown (5YR 6/4); Conglomeratic sandstone: fine- to medium-grained groundmass, poorly sorted subrounded grains, subangular to subrounded chert fragments up to 3 cm in diameter, lenticular-shaped bedding, thin bedded, average bed thickness: 15 cm, range: 4-20 cm, alpha, beta, and gamma cross-stratification with 12-20 cm thick lamina sets; Sandstones: fine- to medium-grained, moderately well sorted subrounded grains, laminated to thin bedded, lenticular-shaped to planar parallel bedding, average bed thickness: 8 cm, range: 1-20 cm, omikron and alpha cross-stratification with 12-20 cm thick lamina sets, planar parallel high velocity laminae 0.5-5 mm thick, cross laminae 2-8 mm thick; parting lineations; local mud-pebble conglomerate as the basal parts of beds up to 2 cm thick; mud pebbles and mud-pebble casts up to 12 cm in diameter; mud pebbles contain mica, load deformation; slumped bedding and cross-stratification; convolute bedding; load casts; feldspathic; silica cemented; Liesegang banding; poor to fair porosity (trace to 5%); weathers massive with rounded surfaces; forms a prominent dipslope.

Sharp erosional contact: picked at the base of the lowest conglomeratic sandstone.

Lithofacies 2b [Unit I]

1. Sandstone. Moderate orange pink (5YR 8/4), light brownish gray (5YR 6/1), and light brown (5YR 6/4 and 5YR 5/6), and white (N-9); fine- to medium-grained with local lenses of medium- to coarse-grained; moderately
well sorted subrounded grains; laminated to thin bedded; average bed thickness: 12 cm, range: 1-20 cm; alpha, beta, and gamma major cross-stratification; climbing ripples; local outcrops of bluish white (5B 9/1) calc- crete; planar parallel high velocity laminae 0.5-10 mm thick; planar parallel and wavy discontinuous laminae 1-9 mm thick; local clay partings; rare flaser bedding; local mud-pebble conglomerate as the basal parts of beds up to 3 cm thick; mud pebbles and mud-pebble casts up to 4 cm in diameter; load deformation; convolute bedding; slumped bedding and cross-stratification; water-escape structures; rare ball-and-pillow structures; load casts; calcareous; feldspathic; silica cemented; possible shallow (1 cm in depth) vertical worm burrows(?) near the top; good porosity (9 to 15%); forms a moderate to recessive slope with local cliff-forming units near the top.

Gradational contact: picked at the top of sandstones dominated by the pi and omikron cross-stratification.

Lithofacies 2a [Unit H]

2. Sandstone. Grayish pink (5R 8/2), weathers grayish red (10R 4/2) and light brown (5YR 5/6); medium-grained; moderately well to well sorted subrounded to rounded grains; local lenses coarse-grained; lenticular-shaped bedding; thin to medium bedded; average bed thickness: 15 cm, range: 4-20 cm; pi and omikron major cross-stratification with 6-12 cm thick lamina sets, local mu and nu cross-stratification with 2-4 cm thick lamina sets; planar parallel laminae 3-6 mm thick; cross laminae 2-9 mm thick; local convolute bedding; minor slumped cross-stratification; mud pebbles and mud-pebble casts up to 5 cm in diameter; calcareous; silica cemented; feldspathic; good porosity (15%); forms a prominent dipslope.

Gradational contact: picked at the top of the uppermost sandstone bed containing greater than 5% chert pebbles.

1. Orthoconglomerate, conglomeratic sandstone, granular orthoconglomerate, and sandstone. Grayish pink (5R 8/2), weathers grayish red (10R 4/2) and light brown (5YR 5/6); Orthoconglomerate, conglomeratic sandstone, and granular orthoconglomerate: medium- to coarse-grained sandy groundmass, granule-sized rounded vein quartz and quartzite and subangular chert fragments up to 3 cm in diameter, lenses of well-sorted rounded to well rounded granular orthoconglomerate, thin to medium bedded, lenticular-shaped bedding with local wedging chan-
nels, average bed thickness: 14 cm, range: 10-100 cm, pi and omikron cross-stratification with 6-8 cm thick lamina sets, mud pebbles and mud-pebble casts up to 3 cm in diameter, silica cemented, feldspathic, locally calcareous, cross laminae homogenous and heterogenous compositions) 2-10 mm thick; Sandstone: fine- to medium-grained with local medium- to coarse-grained, wavy parallel to lenticular-shaped bedding, average bed thickness: 8 cm, range: 6-20 cm, load deformation, slumped bedding and cross-stratification, water-escape structures, convolute bedding, minor ball-and-pillow structures, local parting lineations, locally micaceous, planar parallel high velocity laminae 0.5-10 mm thick, silica cemented, locally calcareous; forms a moderately steep slope with good exposures.

Sharp contact: picked at the base of the lowest conglomeratic sandstone.

**Lithofacies 1d [Unit G]**

1. Sandstone. Pale reddish brown (10R 5/4) and moderate red (5R 5/4), weathers grayish red (10R 4/2), pale reddish brown (10R 5/4), and light brown (5YR 5/6); very fine- to fine-grained; moderately well sorted subangular to subrounded grains; locally fine- to medium-grained near the top of the unit; planar and wavy parallel bedding; locally laminated; average bed thickness: 7 cm, range: 1-12 cm; mu, nu, kappa, and lambda major cross-stratification, local alpha, beta, and gamma cross-stratification near the top of the lithofacies; planar parallel high velocity laminae 0.5-6 mm thick; cross laminae 1-3 mm thick; wavy discontinuous laminae 2-7 mm thick; climbing ripples; load deformation; convolute bedding; load casts; slumped bedding and cross-stratification; water-escape structures; local current ripples; scattered mud pebbles and mud-pebble casts up to 3 cm in diameter; rare clay partings; micaceous; silica cemented; ferruginous; feldspathic; traces of glauconite; fair to good porosity (7 to 12%); forms a partly concealed, moderately steep slope.

Gradational contact: picked where color and average grain size changes. Very fine- to fine-grained, pale reddish brown to moderate red sandstones dominate above the contact. Below the contact, fine- to medium-grained, pale red sandstones dominate.
Lithofacies 2a [Unit F]

2. Sandstone. Pale red (5R 6/2), weathers light brown (5YR 6/4); fine- to medium-grained; poorly to moderately well sorted subangular to subrounded grains; lenticular-shaped bedding with local parallel bedding near the top of the lithofacies; average bed thickness: 6 cm, range: 1-10 cm; minor kappa and lambda cross-stratification; planar parallel high velocity laminae 0.5-5 mm thick; wavy discontinuous laminae 2-7 mm thick; planar parallel discontinuous laminae 2-9 mm thick; minor load deformation; rare load casts; parting lineations; scattered clay partings; local mud-pebble conglomerate as the basal parts of beds up to 2 cm thick; mud pebbles and mud-pebble casts up to 3 cm in diameter; micaceous; feldspathic; slightly ferruginous; silica cemented; rare traces of glauconite near the top of the unit; fair porosity (6%); forms a recessive slope.

Gradational contact: picked at the top of the uppermost conglomeratic sandstone bed which has greater than 5% lithoclasts.

1. Orthoconglomerate interbedded with conglomeratic sandstone and sandstone. Light brownish gray (5YR 6/1), weathers light brown (5YR 5/6 and 5YR 6/4); fine- to coarse-grained groundmass, most of the groundmass is medium- to coarse-grained and poorly sorted; contains interbeds of medium-grained sandstone; the conglomeratic units contain lithoclasts of subangular chert fragments up to 3 cm in diameter, subrounded quartzite up to 2 cm in diameter, and rounded vein quartz of granule size; medium to thick bedded; wedging cut-and-fill channels with local normally graded bedding; average bed thickness: 35 cm, range: 25-65 cm; pi and omikron with alpha, beta, and gamma cross-stratification with 20-25 cm thick lamina sets; cross laminae 2-12 mm thick; local load deformation; rare convolute bedding; minor slumped bedding and cross-stratification; local clay partings; rare mud-pebble conglomerate up to 3 cm thick; mud pebbles and mud-pebble casts up to 6 cm in diameter; feldspathic; silica cemented; poor porosity (trace to 1%); forms a moderately steep to steep slope with fairly well exposed outcrops.

Sharp erosional contact: picked at the base of the lowest orthoconglomerate bed.
Lithofacies 1d [Unit E]

1. Sandstone. Pale reddish brown (10R 5/4), pale red (5R 6/2), and minor grayish orange pink (5YR 7/2), weathers light brown (5YR 6/4 and 5YR 5/6), pale reddish brown (10R 5/4), grayish orange pink (10R 8/2), grayish red (10R 4/2), and very pale orange (10YR 8/2); very fine- to medium-grained; poorly to moderately well sorted subangular to subrounded grains; laminated to thin bedded; wavy to planar parallel bedding; average bed thickness: 8 cm, range: 1-23 cm; kappa and lambda major cross-stratification, minor mu and nu (1-3 cm thick lamina sets) and local alpha, beta and gamma (10-15 cm thick lamina sets) cross-stratification; current ripples; climbing ripples; dunes (megaripples), some with superimposed climbing ripples; local clay partings; rare flaser bedding; planar parallel laminae (continuous and discontinuous types) 0.5-5 mm thick; parting lineations; stacked in-phase straight-crested ripples and dunes (megaripples); mud pebbles and mud-pebble casts up to 5 cm in diameter; load deformation; slumped bedding and cross-stratification; water-escape structures; local convolute bedding; ferruginous; silica cemented; feldspathic; locally micaceous; fair porosity (2 to 9%); forms a moderately steep slope with fairly well exposed outcrops.

Gradational contact: picked at the top of the uppermost siltstone bed.

Lithofacies 1c [Unit D]

2. Interbedded sandstone and siltstone. Pale reddish brown (10R 5/4), weathers grayish red (10R 4/2) and pale reddish brown (10R 5/4); Siltstone: laminated bedding, micaceous; Sandstone: very fine- to fine-grained; poorly sorted subangular grains; laminated to thin bedded; parallel bedding; average bed thickness: 8 cm, range: 1-34 cm; kappa, lambda, and nu major cross-stratification, minor omikron cross-stratification with 2-6 cm thick lamina sets; planar parallel laminae 0.5-4 mm thick; wavy discontinuous laminae 1-4 mm thick; parting lineations; local flaser bedding; scattered lithoclasts of subangular chert fragments up to 5 cm in diameter; micaceous; silica cemented; ferruginous; fair porosity (5 to 7%); forms a somewhat recessive slope with local exposures only in gullies.
Sharp contact: picked at the base of a sandstone bed 34 cm thick. Below the contact, orthoconglomerates dominate. Above the contact, sandstones with local siltstone interbeds dominate.

1. Orthoconglomerate and conglomeratic sandstone. Grayish red purple (5RP 4/2) and pale reddish brown (10R 5/4), weathers very dusky red (10R 2/2) and pale reddish brown (10R 5/4); muddy to medium-grained sandy groundmass; very poorly sorted; contains angular to subangular lithoclasts of silicified ooids, chert, quartzite, sandstone, limestone, and dolostone; these fragments range from granule size to 5 cm in diameter; lenticular-shaped bedding with local wedging channels; beds pinch out along strike; ferruginous; feldspathic; somewhat silica cemented, traces of calcite cement; poor porosity (trace); forms a low bench which is generally concealed.

Sharp scour contact: picked at the base of the lowest orthoconglomerate. Due to the lenticular nature of the orthoconglomerates, they are often difficult to follow along strike, especially because most are concealed. Below the contact, siltstones are present. Above the contact, orthoconglomerates dominate.

Lithofacies la [Unit C]

1. Siltstone with interbedded sandstone and other mudrocks. Pale reddish brown (10R 5/4) and pale red (5R6/2), weathers pale reddish brown (10R 5/4), light brown (5YR 6/4), and minor very pale orange (10R 8/2); Sandstone: very fine-grained, laminated to thin bedded, average bed thickness: 4 cm, range: 1-6 cm, mu and nu cross-stratification, calcareous, micaceous, feldspathic, ferruginous, slightly silica cemented; fair to poor porosity (1 to 5%); Siltstone: laminated bedding, micaceous; ferruginous, locally calcareous, poor porosity (trace to 2%); forms a recessive, mostly concealed, gentle to moderate slope.

Very sharp erosional contact: picked at the base of the lowest reddish siltstone bed. Unconformably below this siltstone bed is a limestone bed. The contact represents an angular unconformity. Above the contact, reddish siltstones are interbedded with reddish sandstones. The actual contact is covered beneath alluvium and talus but it was followed along strike (approximately 10 meters) in order to observe the relationship between the lower Eninta Sandstone and the upper beds of the Areyonga Formation. Beds of the Eninta dip moderately steeply to the south, whereas the beds of the Areyonga are overturned and dip steeply to the north.
Areyonga Formation

2. Limestone and dolomitic limestone. Pale blue and light bluish green; fine-crystalline; thin bedded with local contorted bedding; brecciated; contains black to gray chert lenses and fragments; forms a recessive slope.

Concealed contact, possibly gradational: picked at the lowest Spinifex cover. This plant cover ends just above an outcrop of calcareous sandstone.

1. Sandstone, conglomeratic sandstone, and orthoconglomerate. Grayish orange pink (10R 8/2) and moderate orange pink (10R 7/4), weathers light brown (5YR 6/4); Sandstone: fine- to coarse-grained, poorly sorted, mostly medium-grained, medium bedded, generally weathers massive, scoured bedding contacts; Orthoconglomerate and conglomeratic sandstone: fine- to coarse-grained sandy groundmass, poorly sorted, contains lithoclasts up to 15 cm in diameter of chert, dolostone, sandstone, and quartzite, medium bedded, weathers massive, calcareous; fair to good porosity (7 to 15%); overturned beds; forms a recessive valley near the top of the unit and two prominent strike ridges in the middle and lower portions of the unit.
Section F - Pattalindama Gap Section

Location: Approximately 4 km southeast of the Areyonga Native Settlement and 7 km north of Bowson Waterhole in the Gardiner Range anticline, on the Hembury 1:250,000 scale geologic map, at 132° 17' E longitude and 24° 6' S latitude (Australian Grid Coordinates: 1 99 8500 y N, 54 2500 y E, Zone 5). The Eninta Sandstone forms an east-west strike ridge. Beds face and dip south.


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<th>Formation</th>
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<td>Tempe Formation</td>
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<td>1. Covered.</td>
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Concealed contact: picked at the top of the uppermost exposed limestone bed.

Lower Chandler Formation

2. Limestone and dolomitic limestone interbedded with siltstone, shale, silty limestone, calcareous siltstone, and very fine-grained sandstone. Sandstone, siltstone, calcareous siltstone, and shale: pale red (5R 6/2), weathers dark reddish brown (10R 3/4), laminated bedding, locally thin bedded, micaceous; Limestone, dolomitic limestone, and silty limestone: blue, weathers tan and white (N-9), contains thin chert lenses (3-10 mm thick) that are pink to medium dark gray (N-4) in color, laminated bedding, average bed thickness: 4 cm, range: 2-6 cm, foetid odor on freshly broken surfaces of the darker limestones, beds are wavy lenticular with local contorted and wavy discontinuous laminae 0.5-6 mm thick, very poor porosity (trace), forms a covered gentle slope and recessive valley with only local outcrops that are poorly exposed. . . . . . . . . .

Gradational contact: picked at the base of the lowest exposed limestone bed. Above the contact, limestones dominate. Below the contact, pale red siltstones dominate.

1. Siltstone with minor very fine-grained sandstone and other mudrocks. Pale red (5R 6/2), weathers dark reddish brown (10R 3/4); laminated bedding; locally thin bedded;
mu and nu cross-stratification; planar parallel laminae 1-5 mm thick; micaceous; calcareous; slightly ferruginous; poor porosity (trace to 1%); forms a recessive valley with outcrop exposures found only in a gully that runs parallel to strike.

Sharp contact: picked at the top of the uppermost non-calcareous sandstone. Above the contact, pale red siltstones dominate. Below the contact, non-calcareous medium-grained sandstones, which form a prominent dipslope, are dominant.

Eninta Sandstone

Lithofacies 2a [Unit L]

1. Sandstone. Pale red (10R 6/2), weathers light brown (5YR 5/6); medium- to coarse-grained; moderately well sorted subrounded grains; wavy irregular to lenticular-shaped bedding; scoured bedding contacts; average bed thickness: 6 cm, range: 4-10 cm; omikron cross-stratification with 6 cm thick lamina sets; planar parallel laminae 1-8 mm thick; vertical bioturbation(?); feldspathic; silica cemented; good porosity (10 to 15%); forms a prominent dipslope.

Sharp scour contact: picked at the base of the lowest medium- to coarse-grained sandstone bed. Below the contact, fine- to medium-grained sandstones are present which are generally concealed. Above the contact, medium- to coarse-grained sandstones are present which form a prominent dipslope.

Lithofacies 2b [Unit K]

4. Sandstone. Grayish red purple (5RP 4/2), weathers light brown (5YR 6/4); fine- to medium-grained; moderately well sorted subrounded grains; wavy to planar parallel bedding; laminated bedding; average bed thickness: 7 cm, range: 4-15 cm; alpha, beta, and gamma cross-stratification with 8-15 cm thick lamina sets in upper half, kappa and lambda cross-stratification in the lower half of the lithofacies; planar parallel laminae 1-6 mm thick (dominate the lithofacies); cross laminae 2-8 mm thick; minor load deformation; slumped bedding and cross-stratification; scattered mud pebbles and mud-pebble casts up to 4 cm in diameter; feldspathic; ferruginous; silica cemented; poor porosity (trace to 1%); weathers massive; forms a prominent to gentle dipslope with locally good outcrop exposures.
Gradational contact: picked based on a change in the average grain size.
Below the contact, very fine- to fine-grained sandstones are dominant.
Above the contact, fine- to medium-grained sandstones dominate.

3. Sandstone. Grayish red purple (5RP 4/2), weathers light brown (5YR 6/4) and locally light gray (5YR 7/0); very fine- to fine-grained; poorly to moderately sorted sub-rounded grains; planar to wavy parallel bedding; average bed thickness: 6 cm, range: 1-12 cm; kappa and lambda major cross-stratification; minor mu and nu cross-stratification; planar parallel laminae 0.5-5 mm thick; wavy discontinuous laminae 2-7 mm thick; cross laminae 1-4 mm thick; current ripples 2-4 cm wavelength; climbing ripples; parting lineations; planar parallel high velocity laminae; load deformation; slumped bedding; convolute bedding; mud pebbles and mud-pebble casts up to 10 cm in diameter; syneresis shrinkage cracks; locally micaceous; feldspathic; silica cemented; ferruginous; poor to fair porosity (trace to 5%); weathers massive or as rounded boulders; forms a prominent dipslope.

Gradational contact: picked based on a change in the average grain size.
Below the contact, fine- to medium-grained sandstones dominate. Above the contact, very fine- to fine-grained sandstones dominate.

2. Sandstone. Grayish red purple (5RP 4/2), grayish red (10 4/2), and dark reddish brown (10R 3/4), weathers light brown (5YR 6/4); fine- to medium-grained (mostly fine-grained); moderately well sorted subrounded to rounded grains; parallel bedding with local wavy irregular bedding; laminated bedding; average bed thickness: 8 cm, range: 1-20 cm; xi mixed with alpha, beta, and gamma cross-stratification with 3-10 cm thick lamina sets; minor mu and nu cross-stratification; planar parallel laminae 0.5-6 mm thick; wavy discontinuous laminae 2-12 mm thick; cross laminae 0.5-3 mm thick; parting lineations; load deformation; slumped bedding and cross-stratification; water-escape structures; rare ball-and-pillow structures; convolute bedding; mud pebbles (micaceous) and mud-pebble casts up to 4 cm in diameter; scoured bedding contacts; planar parallel high velocity laminae; feldspathic; silica cemented; ferruginous; brachiopod mold(?); poor to good porosity (1 to 15%); mostly fair to good porosity (4 to 10%); locally weathers massive; forms a cliff-bearing dipslope.

Gradational contact: picked at the top of the uppermost siltstone bed.

1. Interbedded sandstone and siltstone. Dark reddish brown (10R 3/4), pale reddish brown (10R 5/4), and locally
grayish red (10R 4/2), weathers light brown (5YR 6/4) and pale reddish brown (10R 5/4); Sandstone: very fine- to fine-grained, poorly sorted and generally with a muddy matrix, wavy to planar parallel bedding, laminated bedding, average bed thickness: 5 cm, range: 1-18 cm, alpha and beta major cross-stratification with 3-12 cm thick lamina sets, local kappa and lambda cross-stratification, climbing ripples, planar parallel laminae 0.5-2 mm thick, cross laminae 2-6 mm thick, load deformation; slumped bedding and cross-stratification, water-escape structures, ball-and-pillow structures, convolute bedding, parting linations, mud pebbles and mud-pebble casts up to 5 cm in diameter, feldspathic, micaceous, ferruginous, somewhat silica cemented, fair to good porosity (5 to 15%), mostly good porosity (10 to 15%); Siltstone: laminated (wavy to planar parallel) bedding, micaceous, ferruginous, poor porosity (trace to 3%); forms a recessive saddle and/or valley between two prominent strike ridges.

Sharp contact: picked at the top of the uppermost conglomeratic sandstone bed. Above the contact, fine-grained sandstones and siltstones dominate. Below the contact, orthoconglomerates dominate.

Lithofacies 2a [Unit H]

1. Orthoconglomerate and conglomeratic sandstone. Pale reddish purple (5RP 6/2) and minor pale reddish brown (10R 5/4), weathers light brown (5YR 6/4); very fine- to coarse-grained sandy groundmass; poorly sorted subangular to subrounded grains; contains lithoclasts of subangular to subrounded chert fragments up to 2 cm in diameter, subrounded quartzite up to 1.5 cm in diameter, and minor subrounded vein quartz up to 0.5 cm in diameter; wedging cut-and-fill channels 10-15 m lateral extent; local normally graded bedding; scoured bedding contacts; average bed thickness: 25 cm, range: 6-60 cm; pi and omikron major cross-stratification with 7-10 cm thick lamina sets, local alpha, beta, and gamma cross-stratification with 7-28 cm thick lamina sets; planar parallel laminae 0.5-2 mm thick; cross laminae 2-7 mm thick; brush marks; local load deformation; slumped bedding and cross-stratification; rare water-escape structures; mud pebbles and mud-pebble casts up to 7 cm in diameter; feldspathic; somewhat silica cemented; fair to good porosity (5 to 15%); ridge top and cliff-forming unit.
Sharp erosional contact: picked at the base of the lowest conglomeratic bed. Below the contact, fine- to medium-grained sandstones dominate. Above the contact, orthoconglomerates dominate.

**Lithofacies 1d [Unit G]**

1. Sandstone. Very pale orange (10YR 8/2), grayish pink (5R 8/2), and pale reddish brown (10R 5/4), weathers light brown (5YR 6/4 and 5YR 5/6) and moderate brown (5YR 4/4), locally white (N-9); fine-grained; moderately well sorted subrounded grains; locally interbedded with very fine-grained muddy sandstone; laminated bedding; parallel bedding; average bed thickness: 7 cm, range: 1-16 cm; alpha, beta, and gamma major cross-stratification with 2-12 cm thick lamina sets; local kappa, lambda, mu, and nu with rare omikron and pi (7-14 cm thick lamina sets) cross-stratification; climbing ripples; parting lineations; local current ripples up to 4 cm wavelength; planar parallel laminae 0.5-7 mm thick; wavy discontinuous laminae 1-10 mm thick; cross laminae 0.5-4 mm thick; minor load deformation; slumped bedding and cross-stratification; local convolute bedding; mud pebbles and mud-pebble casts up to 6 cm in diameter; mud-pebble conglomerate as basal parts of beds up to 4 cm thick; local clay partings; rare flaser bedding; syneresis shrinkage cracks; traces of glauconite; micaceous; feldspathic; ferruginous; silica cemented; minor Liesgang banding; poor to fair porosity (trace to 5%); locally weathers massive; forms a steep slope with local small cliffs.

Gradational contact: picked where the average grain-size changes. Below the contact, the sandstones are primarily very fine-grained. Above the contact, the sandstones are primarily fine-grained. There is also a slight color change across the contact, with the rocks below the contact being a more darker and distinctive red than those above the contact.

**Lithofacies 2a [Unit F]**

1. Sandstone. Dusty red (5R 3/4), weathers dark reddish brown (10R 3/4) and locally white (N-9); very fine- to fine-grained; poorly to moderately sorted, at the top of the lithofacies contains a muddy matrix; wavy irregular bedding with local lenticular-shaped bedding; average bed thickness: 8 cm, range: 1-16 cm; mu and nu major small-scale cross-stratification, pi and omikron major large-scale cross-stratification with 6-10 cm thick lamina sets; planar parallel laminae 1-15 mm thick; wavy discontinuous laminae 2-8 mm thick; cross laminae 2-10 mm thick; local differential weathering creates the white bands observed; scattered mud pebbles and mud-pebble casts up to 2 cm in diameter; feldspathic;
ferruginous; silica cemented; fair porosity (5 to 9%); forms a moderately steep slope which is generally concealed by talus.

Lithofacies 1d [Unit E]

1. Sandstone. Pale reddish brown (10R 5/4) and grayish red (5R 4/2), weathers light brown (5YR 6/4), moderate reddish brown (10R 4/6), and locally white (N-9); very fine- to medium-grained; poorly to moderately sorted; locally contains muddy matrix; laminated bedding; average bed thickness: 7 cm, range: 1-12 cm; mu, nu, kappa, and lambda major cross-stratification; planar parallel laminae 1-7 mm thick; wavy discontinuous laminae 2-8 mm thick; cross laminae 1-6 mm thick; parting lineations; minor load deformation; local slumped bedding and cross-stratification; rare mud pebbles and mud-pebble casts up to 2 cm in diameter; micaceous; feldspathic; ferruginous; silica cemented; fair to poor porosity (trace to 6%); forms a moderately steep slope which is generally concealed by talus.

Lithofacies 1c [Unit D]

1. Orthoconglomerate and conglomeratic sandstone with locally interbedded sandstone and siltstone. Gray reddish purple (5RP 4/2) and grayish red (10R 4/2), weathers grayish brown (5YR 3/2); Sandstone: fine- to medium-grained, lenticular-shaped bedding, average bed thickness: 8 cm, range: 2-10 cm, pi, nu, and xi major cross-stratification, minor kappa and lambda cross-stratification, planar parallel laminae 0.5-2 mm thick, cross laminae 1-5 mm thick, wavy discontinuous laminae 1-5 mm thick, ferruginous, feldspathic, silica cemented, poor porosity (trace to 1%); Orthoconglomerate and conglomeratic sandstone: clay-size to coarse-grained sandy groundmass (mostly fine-grained), poorly sorted, contains lithoclasts of angular to subangular chert fragments up to 5 cm in diameter, rounded shale pebbles up to 3 cm in diameter, subrounded quartzite up to 3 cm in diameter, subangular to rounded limestone and dolostone fragments up to 2 cm in diameter, and rare
rounded vein quartz up to 0.5 cm in diameter, lenticular bedding with wedging cut-and-fill channels up to 10 m in lateral extent, average bed thickness: 12 cm, range: 6-30 cm, irregular scoured bedding contacts, very ferruginous, calcareous, feldspathic, slightly cemented by silica, poor porosity (trace); forms a gentle to moderately steep slope which is mostly concealed. . . . . . . 11.0 236.7

Sharp erosional contact: picked at the base of the lowest conglomerate bed. Above the contact, orthoconglomerates dominate. Below the contact, siltstones and other mudrocks dominate.

**Lithofacies la [Unit C]**

1. Siltstone, other mudrocks, and minor dolomitic mudrock. Pale reddish brown (10R 5/4) and dark reddish brown (10R 3/4), weathers grayish red (5R 4/2), moderate reddish brown (10R 4/6), and locally white (N-9); laminated bedding; wavy parallel to lenticular-shaped bedding; average bed thickness: 2 cm, range: 1-6 cm; nu and mu cross-stratification; planar parallel laminae 0.5-4 mm thick; wavy discontinuous laminae 0.5-4 mm thick; rare rounded granules of quartzite; scattered mud pebbles up to 2 cm in diameter; ferruginous; micaceous; locally calcareous; poor porosity on fresh surface (trace to 2%); good porosity on weathered surface (10%); forms a recessive, concealed, gentle slope with outcrops only occurring in gullies. . . . . . . . . . . . . . . . 13.4 250.1

Sharp angular unconformable contact: picked at the base of the lowest 'brick' red siltstone. Across the contact there is a 220° change in dip. The beds below the contact dip 85° south while the beds above the contact dip 63° south.

**Pertatataka Formation**

3. Very fine-grained sandstone, siltstone, silty limestone, calcareous siltstone, and shale. Light olive gray (5Y 6/1) and medium dark gray (N-4), weathers moderate yellow brown (10YR 5/4) and dark gray (N-3); laminated bedding; thin bedded (range: 1-3 cm); lenticular to wavy parallel bedding; nu cross-stratification; planar parallel laminae 0.5-4 mm thick; calcareous siltstone and silty limestone beds are present within the top 3 m of this lithofacies; micaceous; silica cemented; locally calcareous near the top of the lithofacies; poor porosity (trace); forms a recessive, mostly concealed, gentle slope. . . . . . . . . . . . . . . . . 19.4 19.4
Sharp contact: picked at the base of a small shalely interval and the top of the uppermost fine- to medium-grained sandstone bed.

2. Sandstone. Light gray (N-7), weathers moderate yellow brown (10YR 5/4); fine- to medium-grained (mostly fine-grained); moderately well sorted rounded grains; lenticular-shaped bedding; average bed thickness: 4 cm; range: 1-8 cm; mu and nu cross-stratification; planar parallel laminae 1-3 mm thick; well-cemented by silica; feldspathic; poor porosity (trace); forms a small bench on a gentle slope.

Sharp erosional contact: picked at the base of the lowest exposed fine- to medium-grained sandstone bed. Above the contact, fine to medium-grained sandstones dominate. Below the contact, interbedded siltstones and very fine-grained sandstones dominate.

1. Interbedded very fine-grained sandstone and siltstone. Pale olive (10Y 6/2) and grayish brown (5YR 3/2), weathers light olive gray (5Y 5/2) and pale brown (5YR 5/2); laminated bedding; thin bedded (range: 1-6 cm); wavy irregular to lenticular-shaped bedding; mu and nu cross-stratification; planar parallel and cross laminae 0.5-4 mm thick; local clay partings; rare mud pebbles 3-10 mm in diameter; local scoured bedding contacts; micaceous; silica cemented; poor porosity (trace); forms a recessive, mostly concealed, gentle slope and valley.
**Section G - Areyonga Section**

**Location:** Approximately 5.5 km west-northwest of the Areyonga Native Settlement in the Gardiner Range anticline, on the Henbury 1:250,000 scale geologic map, at 132° 14' E longitude and 24° 3' S latitude (Australian Grid Coordinates: 2 00 5500 y N, 53 6000 y E, Zone 5). The section was measured very near BMR section HvR-3. The Eninta Sandstone forms a southeast-northwest strike ridge. Beds face and dip south.

**Measured by:** J. O. Phillips and Peter Kotz with a 60-meter tape, two Jacob staffs, and an Abney hand level. Measured up section from north to south, 24-25 July 1982.

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<th>Formation</th>
<th>Thickness (meters)</th>
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<tbody>
<tr>
<td><strong>Tempe Formation</strong></td>
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<tr>
<td>1. Covered.</td>
<td></td>
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</tbody>
</table>

Concealed contact: picked at the top of the uppermost exposed limestone bed.

| **Lower Chandler Formation** |                    |
| 2. Limestone, dolomitic limestone, and silty limestone. Blue, gray, grayish blue, and greenish gray; weathers tan and white; fine-crystalline to micritic; thin chert lenses up to 2 cm thick; thin bedded; dark limestone beds have foetid odor on freshly broken surfaces; very poor porosity (trace); forms a recessive, concealed valley; the only outcrop found was in a dry stream bed that cuts the valley. |                    |

Concealed contact: picked at the base of the lowest exposed limestone bed. This bed was found in the dry stream bed.

1. **Siltstone, other mudrocks, and very fine-grained sandstone.** Grayish red (5R 4/2), weathers moderate reddish brown (10R 4/6); laminated bedding; locally thin bedded; wavy parallel bedding; micaceous; calcareous; poor porosity (trace to 1%); forms a gentle concealed slope. |

Gradational contact: picked at the top of the uppermost sandstone bed which forms a more prominent dipslope. Above the contact, siltstones form a gentle, recessive, mostly concealed slope.

20.0

20.0
Eninta Sandstone

**Lithofacies 2b [Unit I]**

1. Sandstone with minor siltstone. Pale reddish purple (5RP 6/2) and grayish red (5R 4/2), weathers pale reddish brown (10R 5/4) and moderate reddish brown (10R 4/6); very fine- to fine-grained with scattered interbeds of siltstone; poorly sorted with a muddy matrix; laminated bedding; lenticular-shaped to planar parallel bedding; average bed thickness: 3 cm, range: 1-20 cm; mu and nu cross-stratification; planar parallel laminae 0.3-5 mm thick; cross laminae 0.5-10 mm thick; parting lineations; load deformation; slumped bedding; current ripples; scattered mud pebbles up to 2 cm in diameter; micaceous; feldspathic; slightly silica cemented; locally calcareous; fair to good porosity (7 to 10%); forms a recessive dipslope and benches.

Gradational contact: picked at the base of a steep dipslope. The lithofacies below the contact contains moderately well sorted, fine- to medium-grained sandstones. Above the contact, the sandstones are poorly sorted and very fine- to fine-grained.

**Lithofacies 2a [Unit H]**

2. Sandstone. Pale reddish purple (5RP 6/2), weathers pale reddish brown (10R 5/4) and grayish orange red (10R 4/2); fine- to medium-grained (mostly fine-grained); moderately well sorted grains; scattered rounded quartzite and chert granules; wavy parallel to lenticular-shaped bedding; laminated bedding; average bed thickness: 7 cm, range: 3-20 cm; alpha, beta, and gamma major cross-stratification with 7-15 cm thick lamina sets; minor kappa and lambda cross-stratification; local xi cross-stratification 2 m from the top of the lithofacies; planar parallel laminae 0.3-5 mm thick; wavy discontinuous laminae 2-8 mm thick; cross laminae 3-10 mm thick; dunes (megaripples) up to 1 m wavelength and 16 cm thick; climbing ripples; linguoid ripples; parting lineations; load deformation; slumped bedding and cross-stratification; water-escape structures; mud pebbles and mud-pebble casts up to 3 cm in diameter; local scoured bedding contacts; micaceous; traces of glauconite; ferruginous; feldspathic; silica cemented; fair to good porosity (7 to 15%); forms a prominent dipslope.
Somewhat gradational contact: picked at the top of the uppermost conglomeratic sandstone bed. Above the contact, fine- to medium-grained sandstones dominate. Below the contact, orthoconglomerates dominate.

1. Orthoconglomerate, conglomeratic sandstone, and sandstone. Pale red (5R 6/2), weathers moderate reddish brown (10R 4/6); Sandstone: fine- to medium-grained, moderately well sorted, lenticular-shaped bedding, average bed thickness: 25 cm, range: 15-40 cm; Orthoconglomerate and conglomeratic sandstone: fine- to medium-grained sandy groundmass, local graded bedding, contains lithoclasts of angular to subangular chert fragments up to 2 cm in diameter and subrounded quartzite up to 5.5 cm in diameter, lenticular-shaped bedding with local wedging channels, average bed thickness: 20 cm, range: 15-38 cm, local well rounded granular orthoconglomerate lenses, alpha, beta, gamma, pi, and omikron cross-stratification with 15-30 cm thick lamina sets, cross laminae 2-10 mm thick, scoured bedding contacts, load deformation, slumped bedding and cross-stratification, water-escape structures, mud pebbles and mud-pebble casts up to 7 cm in diameter; feldspathic; silica cemented; slightly ferruginous; poor to good porosity (trace to 10%); weathers massive; cliff-forming lithofacies.

Sharp erosional contact: picked at the base of the lowest conglomerate bed. Below the contact, fine- to medium-grained sandstones dominate. Above the contact, orthoconglomerates dominate.

Lithofacies 1d [Unit E]

1. Sandstone. Grayish red (10R 4/2 and 5R 4/2) and dark reddish brown (10R 3/4), weathers dark reddish brown (10R 3/4) and moderate reddish brown (10R 4/6); fine-to medium-grained; local lenses of medium- to coarse-grained sandstone and local lenses of very fine- to fine-grained sandstone; moderately well sorted subrounded to rounded grains; laminated bedding; parallel bedding with minor lenticular-shaped bedding; average bed thickness: 6 cm, range: 1-15 cm; alpha, beta, and gamma cross-stratification with 7-10 cm thick lamina sets; local kappa and lambda cross-stratification; planar parallel laminae 0.3-8 mm thick; wavy discontinuous laminae 1-6 mm thick; cross laminae 0.3-7 mm thick; parting lineations; dunes (megaripples) up to 1 m wavelength and 20 cm thick; current ripples; climbing ripples; load deformation; slumped bedding and cross-stratification; water-escape structures; minor convolute bedding; syneresis shrinkage cracks; mud pebbles and mud-pebble casts up to 4 cm in diameter; micaceous; feldspathic; ferruginous; silica cemented; poor to good
porosity (1 to 15%); porosity decreases upwards; mostly fair to good porosity; locally weathers massive; forms a steep slope with local cliff-forming members.

Sharp erosional contact; picked at the top of the uppermost conglomerate bed. Above the contact, fine- to medium-grained sandstones dominate. Below the contact, orthoconglomerates are present.

**Lithofacies 1c [Unit D]**

2. Sandstone. Grayish red (5R 4/2), weathers dark reddish brown (10R 3/4) and moderate reddish brown (10R 4/6); very fine- to medium-grained; poorly sorted; wavy to planar parallel bedding with local lenticular-shaped bedding; laminated to medium bedded; average bed thickness: 8 cm, range: 2-20 cm; omikron and xi cross-stratification, minor alpha, beta, and gamma cross-stratification with 4-12 cm thick lamina sets; planar parallel laminae: 0.5-2 mm thick; cross laminae: 0.3-7 mm thick; parting lineations near the top of the lithofacies; micaceous; feldspathic; ferruginous; silica cemented; good porosity (15%); forms a steep slope with well exposed beds.

Gradational contact: picked at the top of the highest conglomeratic sandstone bed. Above the contact, fine- to medium-grained sandstones are dominant. Below the contact, a conglomeratic sandstone is present.

1. Ortho- and Paraconglomerate and conglomeratic sandstone. Dark reddish brown (10E 3/4), weathers moderate reddish brown (10R 4/6); clay-size to coarse-grained sandy groundmass; very poorly sorted; contains lithoclasts of subangular chert fragments up to 1 cm in diameter, minor subrounded quartzite up to 0.5 cm in diameter, and rounded shale pebbles up to 2 cm in diameter; lenticular-shaped bedding; local wedging cut-and-fill channels along strike; average bed thickness: 10 cm, range: 5-10 cm; wavy irregular scoured bedding contacts; feldspathic; very ferruginous; silica cemented; poor porosity (trace to 1%); forms a moderately steep slope.

Sharp erosional contact: picked at the base of the conglomerate bed which fills scours that cut into the top of a silver gray, very micaceous, siltstone. There is a sharp color change at the contact: silver gray siltstone beneath the contact and reddish brown ortho- to para-conglomerates above the contact. The contact was picked at the top of the uppermost light gray siltstone.
Pertatataka Formation

1. Siltstone with minor interbedded very fine-grained sandstone. Light gray (N-7) and light brownish gray (5YR 6/1), weathers light gray (N-7) and grayish red (10R 4/2); laminated bedding; average bed thickness: 2 cm, range: 0.5-20 cm; lenticular-shaped bedding; one bed of load deformation; one ball-and-pillow structure; current ripples; planar parallel discontinuous laminae: 0.2-2 mm thick; very micaceous; calcareous; somewhat silica cemented; poor porosity (trace to 1%); forms a gentle slope and recessive valley, mostly concealed.
Section H - Pine Point Section

**Location:** Approximately 2.5 km south of Pine Point, 15 km northwest of Arengona Native Settlement, and 25 km south-southeast of Undandita Native Camp, on the Hermannsburg 1:250,000 scale geologic map, at 132° 9' E longitude and 23° 59' S latitude (Australian Grid Coordinates: 2 01 3500 y N, 52 8500 y E, Zone 4) in the Gardiner Range anticline. The Eninta Sandstone forms a southeast-northwest ridge. Beds face and dip southwest.

**Measured by:** J. O. Phillips and Leon Amadio with a 30-meter tape, two Jacob staffs, and an Abney hand level. Measured up section from north to south, 6-9 August 1982.

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<tr>
<td><strong>Lower Chandler Formation</strong></td>
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<tr>
<td>2. Limestone and dolomitic limestone. Pale blue (5PB 7/2), weathers yellow gray (5Y 7/2), laminated bedding, fine-crystalline, contains chert nodules up to 6 cm in diameter and thin chert lenses up to 2 cm thick, chert is grayish black (N-2) to light gray (N-7), thin bedded, foetid odor on freshly broken surfaces of the darker limestones; poor porosity (trace); forms a gentle slope with low-lying benches scattered across it.</td>
<td>12.3</td>
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Concealed contact: picked at the base of the lowest exposed limestone bed. Above the contact, limestones are exposed. Below the contact, the unit is mostly covered.

1. Calcareous siltstone and sandstone, siltstone, and shale: Dusky blue (5PB 3/2), pale purple (5PB7/2), and medium gray (N-9), weathers dusky gray (N-3) and moderate reddish orange (10R 6/6); very fine- to fine-grained sandstone; micaceous; locally very micaceous; laminated bedding; average bed thickness: 12 cm, range: 5-22 cm; mu and nu cross-stratification; planar parallel laminae 0.5-4 mm thick; wavy discontinuous laminae 1-3 mm thick; parting lineations; feldspathic; fair to good porosity (5 to 15%); forms a mostly concealed, recessive valley. 12.3
Gradational contact: picked at the top of the uppermost sandstone bed which represents the change from siltstone to sandstone dominance. Below the contact, sandstones form the base of a prominent dipslope. Above the contact, only a recessive slope and gully are found. Here siltstones dominate.

Eninta Sandstone

Lithofacies 2b [Unit I]

6. Sandstone. Grayish red purple (5RP 4/2), very dusky red purple (5RP 2/2), and dusky red (5R 3/4), weathers dark reddish brown (10R 3/4) and moderate reddish brown (10R 4/6); fine-grained with local fine- to medium-grained intervals; moderately well sorted subrounded grains; planar to wavy parallel bedding; laminated bedding; average bed thickness: 7 cm, range: 1-34 cm; alpha, beta, and gamma major cross-stratification with 5-18 cm thick lamina sets; minor kappa and lambda cross-stratification; planar parallel laminae 0.5-7 mm thick; cross laminae 2-9 mm thick; wavy discontinuous laminae 2-4 mm thick; local climbing ripples; dunes (megaripples) locally with climbing ripples superimposed on them; local current ripples; parting lineations; local load deformation; slumped bedding and cross-stratification; water-escape structures; ball-and-pillow structures; parting lineations; feldspathic; micaceous; calcareous; locally silica cemented; fair to good porosity (4 to 15%); locally weathers massive; forms a prominent dipslope. 25.7

Gradational contact: picked at the top of the uppermost calcareous, very fine-grained sandstone. Above the contact, fine-grained sandstones are dominant. Below the contact, interbedded siltstones and very fine-grained sandstones dominate.

5. Interbedded sandstone and siltstone. Moderate red (5R 5/4), weathers moderate brown (5YR 4/4); very fine- to fine-grained; poorly sorted with a muddy matrix; wavy irregular bedding; average bed thickness: 6 cm, range: 4-10 cm; mu and nu cross-stratification; planar parallel laminae 1-5 mm thick; cross laminae 2-4 mm thick; parting lineations; feldspathic; micaceous; calcareous; locally silica cemented; poor to good porosity (2 to 15%); forms a recessive bench. 8.0
Gradational contact: picked at the base of the lowest very fine-grained calcareous sandstone bed. Above the contact, interbedded siltstones and very fine-grained sandstones dominate. Below the contact, fine- to medium-grained sandstones dominate.

4. Sandstone. Moderate red (5R 5/4) and dusky red (5R 3/4), weathers moderate brown (5YR 4/4) and dark reddish brown (10R 3/4); fine- to medium-grained moderately well sorted subrounded grains; laminated bedding; wavy to planar parallel bedding; average bed thickness: 6 cm, range: 1-35 cm; alpha, beta, and gamma major cross-stratification; minor kappa and lambda cross-stratification; dunes (megaripples) with 1-2 m wavelength and 15-25 cm thickness; climbing ripples (many are superimposed on the dunes); planar parallel high velocity laminae 0.5-6 mm thick; cross laminae 3-10 mm thick; wavy discontinuous laminae 1-4 mm thick; load deformation; slumped bedding and cross-stratification; ball-and-pillow structures; water-escape structures; load casts; mud pebbles and mud-pebble casts up to 4 cm in diameter; rare clay partings; very rare flaser bedding; feldspathic; locally micaceous; locally calcareous; silica cemented; ferruginous; locally weathers massive with rounded surfaces; fair to good porosity (4 to 15%); forms a prominent ridge crest and dipslope.

Gradational contact: picked at the top of the uppermost very fine-grained sandstone bed. Above the contact, the sand grain size is fine-to medium-grained whereas below the contact, it is very fine- to fine-grained. Also the contact marks the boundary between the prominent ridge crest, above the contact, and the mostly recessive unit which lies below the contact.

3. Interbedded siltstone, very fine-grained sandstone, and other mudrocks. Moderate red (5R 5/4), weathers dark reddish brown (10R 3/4); poorly sorted; muddy matrix; laminated bedding; lenticular-shaped bedding with local wedging channels found along strike which consist of up to 2 m thick sandstone units; fine- to medium-grained sandstone; average bed thickness: 4 cm, range: 2-6 cm; planar parallel laminae 1-7 mm thick; micaceous; calcareous; slightly ferruginous; feldspathic; somewhat silica cemented; fair porosity (9%); forms a recessive, mostly concealed, ridge top.

Gradational contact: picked at the base of the lowest very fine-grained calcareous sandstone. Above the contact, interbedded siltstones and fine-grained sandstones dominate. Below the contact, fine- to medium-grained sandstones dominate.
2. Sandstone. Dusky red (5R 3/4), weathers dark reddish brown (10R 3/4); fine- to medium-grained; moderately well sorted subrounded grains; laminated bedding; lenticular-shaped to wavy parallel bedding; average bed thickness: 7 cm, range: 1-30 cm; kappa and lambda major cross-stratification; local alpha, beta, and gamma cross-stratification with 6-12 cm thick lamina sets; rare pi cross-stratification with 12-25 cm thick lamina sets; dunes (megarripples) with 1-2 m wavelength and 15-20 cm thickness; climbing ripples (often superimposed on the dunes); find several vertical sequences like the following: (base) planar parallel high velocity laminae--> dune--> planar parallel high velocity laminae--> convolute bedding--> planar parallel high velocity laminae; planar parallel laminae 0.5-5 mm thick; cross laminae 2-12 mm thick; wavy discontinuous laminae 3-6 mm thick; parting lineations; load deformation; slumped bedding and cross-stratification; ball-and-pillow structures; water-escape structures; load casts; convolute bedding; local mud-pebble conglomerate as basal parts of beds 1-3 cm thick; mud pebbles and mud-pebble casts up to 7 cm in diameter; local clay partings; very rare flaser bedding; locally micaceous; feldspathic; ferruginous; silica cemented; poor to good porosity (trace to 10%); forms a slightly recessive ridge crest. 

Gradational contact: picked at the lowest megarippled sandstone bed. Above the contact, the sandstones contain abundant dune structures. Below the contact, these structures are not found.

1. Sandstone. Dusky red (5R 3/4), weathers dark reddish brown (10R 3/4); fine- to medium-grained; moderately well sorted subrounded grains; wavy to planar parallel bedding; average bed thickness: 20 cm, range: 7-40 cm; weathers massive; alpha, beta, and gamma cross-stratification with 10-13 cm thick lamina sets; planar parallel high velocity laminae 0.5-4 mm thick; cross laminae 2-6 mm thick; load deformation; slumped bedding and cross-stratification; ball-and-pillow structures; water-escape structures; load casts; parting lineations; mud pebbles and mud-pebble casts up to 4 cm in diameter; traces of glauconite; feldspathic; ferruginous; silica cemented; poor porosity (trace); forms prominent cliffs.

Somewhat gradational contact: picked at the top of the uppermost conglomeratic sandstone bed. Above the contact, fine- to medium-grained sandstones dominate. Below the contact, orthoconglomerates dominate.
Lithofacies 2a [Unit H]

1. Orthoconglomerate and conglomeratic sandstone. Light olive gray (5R 5/2) and moderate yellow (5Y 7/6), weathers moderate reddish brown (10R 4/6); fine- to coarse-grained sandy groundmass (mostly medium- to coarse-grained); poorly sorted; contains angular to subangular chert fragments up to 3 cm in diameter, subrounded to rounded quartzite up to 3 cm in diameter, rounded vein quartz of granule size, and mud pebbles and mud-pebble casts up to 10 cm in diameter; wedging cut-and-fill channels 10-20 m in lateral extent; average bed thickness: 25 cm, range: 20-60 cm; pi and omikron major cross-stratification with 8-35 cm thick lamina sets; local mu, nu, alpha, beta, and gamma cross-stratification; heterogenous cross laminae 3-12 mm thick; minor planar parallel laminae 2-10 mm thick; normally graded bedding (beds exhibit the following: [base] conglomerate--> conglomeratic sandstone--> sandstone [top]); scoured bedding contacts; traces of glauconite; feldspathic; slightly ferruginous; silica cemented; poor to fair porosity (2 to 6%); prominent cliff-forming lithofacies.

Sharp erosional contact: picked at the base of the lowest conglomerate bed. Above the contact, orthoconglomerates dominate. Below the contact, fine- to medium-grained sandstones dominate.

Lithofacies 1d [Unit E]

3. Sandstone. Moderate red (5R 5/4), weathers grayish pink (5R 8/2) and grayish red (5R 4/2); fine- to medium-grained; moderately well sorted subrounded grains; lenticular-shaped to wavy parallel bedding; local wedging channels near the base of the lithofacies; laminated bedding; average bed thickness: 8 cm, range: 1-20 cm; kappa and lambda cross-stratification at the top of the lithofacies and mu and nu with minor alpha, beta, and gamma cross-stratification near the base of the lithofacies; climbing ripples near the top of the lithofacies; planar parallel laminae 0.5-10 mm thick; wavy discontinuous laminae 3-9 mm thick; cross laminae 1-4 mm thick; load deformation; slumped bedding and cross-stratification; ball-and-pillow structures; water-escape structures; load casts; scoured bedding contacts; local clay partings; very rare flaser bedding; local mud-pebble conglomerate as basal parts of beds up to 2 cm thick; mud pebbles and mud-pebble casts up to 7 cm in diameter; traces of glauconite; locally micaceous; feldspathic; ferruginous; silica cemented; fair porosity
Gradational contact: picked at the base of the lowest bed exhibiting load deformation.

2. Sandstone with local granular conglomeratic sandstone. Moderate red (5R 5/4), weathers grayish pink (5R 8/2) and grayish red (5R 4/2); fine- to medium-grained; local coarse-grained to granular conglomeratic sandstone; poorly to moderately well sorted subrounded grains; wavy to planar parallel bedding; laminated bedding; average bed thickness: 13 cm, range: 5-23 cm; omikron with minor mu, nu, kappa, and lambda cross-stratification, local xi, alpha and beta cross-stratification with 8-20 cm thick lamina sets; planar parallel laminae 0.5-10 mm thick; cross laminae 2-10 mm thick; local climbing ripples; clay partings; scattered mud pebbles and mud-pebble casts up to 6 cm in diameter; parting lineations; locally micaceous; feldspathic; silica cemented; good porosity (10 to 15%); forms a moderately steep, prominent slope which is locally covered by talus.

Gradational contact: picked at the top of the uppermost bed exhibiting load deformation. Above the contact, load deformation is not present. Below the contact, load deformation is present.

1. Sandstone. Dusky red (5R 3/4) and moderate red (5R 5/4), weathers moderate reddish brown (10R 4/6), dark reddish brown (10R 3/4), and grayish red (5R 4/2); fine- to coarse-grained; poorly to moderately well sorted subrounded grains; wavy parallel to lenticular-shaped bedding; average bed thickness: 14 cm; range: 7-40 cm; alpha, beta, and gamma major cross-stratification with 4-30 cm thick lamina sets; local kappa and lambda and minor omikron cross-stratification; dunes (megaripples) up to 0.5 m wavelength and 20 cm thickness; climbing ripples (often superimposed on the megaripples); planar parallel laminae 0.5-4 mm thick; cross laminae 2-4 mm thick; wavy discontinuous laminae 1-6 mm thick; local load deformation; minor slumped bedding and cross-stratification; water-escape structures; ball-and-pillow structures; load casts; rare mud pebbles and mud-pebble casts up to 3 cm in diameter; traces of glauconite; locally micaceous; feldspathic; slightly ferruginous; silica cemented; poor porosity (trace to 2%); forms a moderately steep slope with local cliffs and scattered talus.
Slightly gradational contact: picked at the top of the uppermost poorly sorted, very fine-grained sandstone bed. Above the contact, fine- to medium-grained sandstones dominate. Below the contact, very fine- to fine-grained sandstones dominate.

Lithofacies lc [Unit D]

2. Sandstone with locally interbedded siltstone. Dusky red (5R 3/4), weathers dark reddish brown (10R 3/4) and moderate reddish brown (10E 4/6); very fine- to fine-grained sandstone; poorly sorted subangular grains; muddy matrix; laminated bedding; planar parallel bedding; average bed thickness: 10 cm, range: 1-20 cm; pi, mu, and nu major cross-stratification with 2-17 cm thick lamina sets, local omikron, alpha, kappa, and lambda cross-stratification; planar parallel laminae 0.5-3 mm thick; cross laminae 1-4 mm thick; wavy discontinuous laminae 2-5 mm thick; very minor load deformation; rare slumped bedding and cross-stratification; parting lineations; scattered mud pebbles and mud-pebble casts up to 4 cm in diameter; minor clay partings; feldspathic; silica cemented; locally calcareous; ferruginous; poor to fair porosity (trace to 5%); forms a moderately steep slope near the base of the strike ridge.

9.5 178.4

Sharp contact: picked at the top of the uppermost conglomeratic sandstone bed. Above the contact, interbedded siltstones and fine-grained sandstones dominate. Below the contact, an ortho- to paraconglomerate is present.

1. Ortho- to paraconglomerate. Dusky red (5R 3/4), weathers the same color; very fine- to medium-grained sandy groundmass; poorly sorted subangular grains; contains lithoclasts of subangular chert fragments up to 5 cm in diameter, subangular to subrounded quartzite up to 2 cm in diameter, subangular limestone and dolostone up to 2 cm in diameter, subrounded fragments with silicified ooids up to 3 cm in diameter, subrounded sandstone fragments up to 2 cm in diameter, and rounded shale pebbles up to 4 cm in diameter; also present are granule size subrounded to rounded quartz grains; lenticular-shaped bedding; average bed thickness: 15 cm, range: 8-20 cm; calcareous; richly ferruginous; graywacke; poor to good porosity (1 to 15%); forms a small bench on a gentle to moderately steep slope.

0.2 178.6

Sharp erosional contact: picked at the base of the lowest conglomerate bed. Above the contact, an ortho- to paraconglomerate fills scours that cut into underlying siltstones. Below the contact, siltstones dominate.
Lithofacies 1a [Unit C]

1. Siltstone with interbedded very fine-grained sandstone, calcareous siltstone, dolomitic limestone, and shale. Siltstone, sandstone, calcareous siltstone, and shale: dark reddish brown (10R 3/4) and grayish red (10R 4/2), weathers dark reddish brown (10R 3/4), laminated bedding, locally thin bedded, wavy parallel to lenticular-shaped bedding, minor mu and nu cross-stratification, planar parallel laminae 0.5-4 mm thick, cross laminae 4-8 mm thick, micaceous, feldspathic, silica cemented, locally calcareous, ferruginous, poor porosity (trace to 2%); Limestone and dolomitic limestone: very minor constituent, pale reddish brown (10R 4/6), fine-crystalline, laminated bedding, thin bedded; forms a recessive, mostly concealed, gentle slope.

Sharp contact: picked at the base of the lowest siltstone bed and the top of a granular orthoconglomerate bed. Above the contact, calcareous siltstones and silty sandstones dominate. Below the contact, a 15 cm thick granular orthoconglomeratic bed is present.

Lithofacies 1b [Unit B]

1. Sandstone with local interbedded granular orthoconglomerate/ conglomeratic sandstone. Yellow gray (5Y 7/2), weathers pale reddish purple (5RP 6/2) and moderate reddish orange (10R 6/6); medium grained; moderately well sorted to well sorted subrounded to rounded grains; a 15 cm thick coarse-grained to granular conglomeratic sandstone bed is found at the top of the lithofacies; lenticular-shaped bedding; average bed thickness: 16 cm, range: 7-30 cm; alpha, beta, and possibly xi cross-stratification; planar parallel laminae 1-10 mm thick; cross laminae 4-8 mm thick; feldspathic; traces of glauconite; calcareous; silica cemented; good porosity (10 to 15%); forms a low strike ridge.

Gradational contact: picked at the base of the lowest exposed sandstone bed. Above the contact, medium-grained sandstones dominate. Below the contact, the unit is mostly concealed.

Lithofacies 1a [Unit A]

1. Very fine-grained sandstone interbedded with siltstone and shale. Dark reddish brown (10R 3/4), weathers light brown (5 YR 5/6); laminated bedding; micaceous; ferruginous; calcareous; poor porosity (trace to 2%); forms a mostly concealed gentle slope.
Sharp irregular scour contact: picked where siltstones fill scours cut into underlying limestones. This contact represents an angular unconformity. There is a change of 20° in dip of the beds across the contact. Above the contact, the siltstones dip 35° south. Below the contact, the limestones dip 55° south. This change in dip takes place within less than 1 meter.

Julie Formation

1. Limestone and dolomitie limestone. Yellow gray (5Y 7/2), weathers light gray (N-7); fine-crystalline to micritic; laminated (wavy and planar parallel laminae) bedding; average bed thickness: 6 cm, range: 1-15 cm; thin lenses of pink to gray chert; slight foetid odor on freshly broken surfaces; forms a rounded low-lying strike ridge which is covered by Spinifex . . . . . . . .

Concealed contact: covered by a sandy soil.

Pertatataka Formation

1. Covered gentle slope. . . . . . . . . . . .
Section 1- Katapata Gap Section

**Location:** Approximately 5.5 km west of Katapata Gap, 22 km northwest of Areyonga Native Settlement, 22 km southwest of Undandita, and 6.5 km northwest of Pine Point, in the Gardiner Range anticline on the Hermannsburg 1:250,000 scale geologic map, at 132° 06' E longitude and 23° 56' S latitude (Australian Grid Coordinates: 2 01 8500 y N, 52 3000 y E, Zone 4). The section is very near BMR section MLX-X7. The Eninta forms a northwest-southeast strike ridge. Beds face and dip southwest.

**Measured by:** J. O. Phillips and Leon Amadio using a 30-meter tape, two Jacob staffs, and an Abney hand level. Measured up section from northeast to the southwest. 2-5 August, 1982.

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<tr>
<td>1. Covered.</td>
<td>. . . . . . . .</td>
</tr>
</tbody>
</table>

Concealed contact: picked at the top of the uppermost exposed limestone bed.

**Lower Chandler Formation**

2. Limestone and dolomitic limestone. Bluish gray, pink, and blue, weathers tan, whitish pink, and whitish gray; fine-crystalline to micritic; laminated (wavy and planar parallel) bedding; average bed thickness: 8 cm, range: 2-15 cm; horizontal laminae: 0.5-1.5 mm thick; wavy laminae: 0.5-1.5 mm thick; contains dark gray to gray chert nodules 1-8 cm in diameter and chert lenses 1-2 cm thick; darker limestone beds have foetid odor on freshly broken surfaces; local silty and clayey limestone; forms a rounded strike ridge. . . . . . . . . .

Gradational contact through several meters: picked at the base of the lowest exposed cherty limestone bed. Above the contact, limestones are exposed. Below the contact, the unit consists mostly of concealed siltstones and very fine-grained sandstones.

1. Siltstone and shale with minor interbedded very fine-grained sandstone. Pale reddish brown (10R 5/4), weathers moderate reddish brown (10R 4/6); planar parallel and wavy laminae: 0.5-3 mm thick; calcareous; micaceous; poorly sorted with muddy matrix; felds-
pathic; somewhat silica cemented; poor porosity (trace to 2%); forms a recessive valley (mostly concealed).

Sharp contact: picked at the top of the uppermost conglomeratic sandstone which directly underlies a siltstone sequence. Above the contact, siltstones dominate. Below the contact, conglomeratic sandstones are present.

Eninta Sandstone

Lithofacies 2a [Unit L]

3. Conglomeratic sandstone. Pale reddish purple (5RP 6/2), and grayish pink (5R 8/2), weathers moderate reddish orange (10R 6/6); fine- to coarse-grained sandy groundmass; poorly sorted; average bed thickness: 10 cm, granule- to pebble-sized lithoclasts; lithoclasts consist of subrounded chert fragments up to 2 cm in diameter, subrounded to rounded quartzite up to 2 cm in diameter, and mud pebbles up to 9 cm in diameter; wavy pinch and swell type bedding with erosional basal contacts; feldspathic; silica cemented; fair porosity (5%); forms a steeply dipping dipslope.

Sharp erosional contact: picked at the base of the lowest conglomeratic sandstone bed. Above the contact, conglomeratic sandstones are present. Below the contact, fine- to medium-grained sandstones dominate.

2. Sandstone. Grayish pink (5R 8/2) and grayish orange pink (5YR 7/2), weathers light brownish gray (5YR 6/1) and moderate reddish orange (10R 6/6); fine- to medium-grained; moderately well sorted to well sorted subrounded to rounded grains; laminated bedding; average bed thickness: 25 cm, range: 3-90 cm; planar parallel bedding; xi, alpha, beta, and gamma major crossstratification with 4-15 cm thick lamina sets; minor kappa and lambda cross-stratification; abundant load deformation; slumped bedding and cross-stratification; load casts; ball-and-pillow structures; mud pebble conglomerate as local basal members of beds; mud pebbles and mud pebble casts up to 6 cm in diameter; climbing ripples; local dunes (megaripples) with 1-2 m wavelength and often superimposed with climbing ripples; local vuggy and knobby surfaces (represents weathering of clay pebbles or maybe very shallow worm burrows); feldspathic; silica cemented; rare clay partings; traces of mica; traces of glauconite; rare scattered chert pebbles (up to 1.5 cm in diameter); weathers massive; forms a steeply dipping dipslope.
Gradational contact: picked where the major cross-stratification type changes. Above the contact, xi, alpha, beta, and gamma cross-stratification dominate. Below the contact, pi and omikron cross-stratification dominate.

1. Sandstone. Light gray (N-7), grayish orange pink (5YR 7/2), grayish pink (5R 8/2), and pale yellow orange (10YR 8/6), weathers moderate reddish orange (10R 6/6), light brownish gray (5YR 6/1), and moderate reddish brown (10R 4/6); fine- to medium-grained; moderately well sorted subrounded grains; laminated bedding; average bed thickness: 10 cm, range: 1-20 cm; wavy to planar parallel bedding; pi and omikron with local alpha, beta, and gamma large-scale cross-stratification with 3-10 cm thick lamina sets, mu and nu with local kappa and lambda small-scale cross-stratification; load deformation; slumped bedding and cross-stratification; load casts; ball-and-pillow structures; local mud drapes and/or mud pebbles and mud pebble casts up to 6 cm in diameter; local climbing ripples (near the base of the lithofacies); feldspathic; silica cemented; traces of glauconite; weathers massive; poor to fair porosity (1 to 7%); forms a steeply dipping dipslope.

Gradational lithological contact but a distinct color change: picked at a sharp color change, with gray dominating above the contact and red below the contact.

Lithofacies 2b [Unit I]

3. Sandstone. Grayish red (5R 4/2) and pale red (5R 6/2), weathers pale brown (5YR 5/2) and moderate reddish brown (10R 4/6); fine- to medium-grained; moderately well sorted subrounded grains; average bed thickness: 8 cm, range: 1-38 cm; mostly planar parallel laminated bedding; alpha, beta, and gamma cross-stratification with 4-25 cm thick lamina sets; local xi and mu cross-stratification; load deformation; load casts; ball-and-pillow structures; water escape structures; minor clay partings; rare mud pebble conglomerate as basal members of beds 1-4 cm thick; mud pebbles and mud pebble casts up to 8 cm in diameter; horizontal and cross laminae: 1-10 mm thick; rare flaser bedding; ripple surfaces; parting lineations; mud pebbles up to 6 cm in diameter; locally micaceous; feldspathic; silica cemented; slightly ferruginous; fair porosity (3 to 9%); cliff-forming interval at the base grading to a talus covered interval near the top.

Lithofacies 2b [Unit I]

3. Sandstone. Grayish red (5R 4/2) and pale red (5R 6/2), weathers pale brown (5YR 5/2) and moderate reddish brown (10R 4/6); fine- to medium-grained; moderately well sorted subrounded grains; average bed thickness: 8 cm, range: 1-38 cm; mostly planar parallel laminated bedding; alpha, beta, and gamma cross-stratification with 4-25 cm thick lamina sets; local xi and mu cross-stratification; load deformation; load casts; ball-and-pillow structures; water escape structures; minor clay partings; rare mud pebble conglomerate as basal members of beds 1-4 cm thick; mud pebbles and mud pebble casts up to 8 cm in diameter; horizontal and cross laminae: 1-10 mm thick; rare flaser bedding; ripple surfaces; parting lineations; mud pebbles up to 6 cm in diameter; locally micaceous; feldspathic; silica cemented; slightly ferruginous; fair porosity (3 to 9%); cliff-forming interval at the base grading to a talus covered interval near the top.
Gradational lithological contact but a sharp change in cross-stratification: picked at the base of the lowest $\xi$ cross-stratified bed. Above the contact, $\xi$ cross-stratification is present. Below the contact, the beds are mostly planar parallel laminated.

2. Sandstone. Grayish red (5R 4/2) and pale red (5R 6/2), weathers pale brown (5YR 5/2) and moderate reddish brown (10R 4/6); very fine- to medium-grained; poor to moderately well sorted subrounded grains; average bed thickness: 11 cm, range: 1-23 cm; mostly planar parallel laminated bedding; kappa and lambda major cross-stratification; minor $\mu$ and $\nu$ cross-stratification; dunes (megaripples) with 1-1.5 m wavelengths and 8-25 cm thickness; climbing ripples (often superimposed on the megaripples); scattered clay partings; locally parting lineations sandwiched between groups of megaripples; local load deformation; slumped bedding and cross-stratification; water escape structures; load casts; mud pebbles and mud pebble casts up to 3 cm in diameter; wavy discontinuous laminae 1-7 mm thick; planar parallel laminae 0.5-10 mm thick; cross laminae 1-7 mm thick; wavy parallel sets of stacked megaripples; feldspathic; locally micaceous; ferruginous; silica cemented; poor porosity (1 to 5%); forms a slightly recessive talus slope.

Slightly gradational contact: picked where the average grain size changes. Above the contact, very fine- to fine-grained sandstones dominate. Below the contact, fine- to medium-grained sandstones dominate.

1. Sandstone. Grayish red (5R 4/2) and pale red (5R 6/2), weathers pale brown (5YR 5/2); fine- to medium-grained; moderately well sorted subrounded grains; planar parallel bedding; average bed thickness: 7 cm, range: 1-12 cm; $\mu$ major cross-stratification; minor $\alpha$ and $\beta$ cross-stratification; most beds are slumped from load deformation; ball-and-pillow structures; water escape structures; load casts; slumped bedding and cross-stratification; parting lineations; planar parallel laminae 0.5-8 mm thick; cross laminae 1-10 mm thick; local climbing ripples; local current ripples; mud pebbles and mud-pebble casts up to 4 cm in diameter; local lenses of mud-pebble conglomerate as basal parts of beds up to 4 cm thick; feldspathic; ferruginous; silica cemented; very rare flaser bedding; fair porosity (4 to 9%); forms a prominent dipslope.
Gradational contact through several meters: picked at the top of the uppermost conglomeratic sandstone bed. Above the contact, fine- to medium-grained sandstones dominate. Below the contact, orthoconglomerates dominate.

**Lithofacies 2a [Unit H]**

1. **Orthoconglomerate and conglomeratic sandstone.** Pale reddish brown (10R 5/4), weathers moderate reddish brown (10R 4/6) and moderate reddish orange (10R 6/6); fine- to coarse-grained sandy groundmass; poorly sorted; subangular to subrounded chert fragments up to 2 cm in diameter and subrounded quartzite up to 2 cm in diameter; wedging channels 7-20 m in lateral extent; average bed thickness: 26 cm, range: 15-35 cm; pi and omikron major cross-stratification with 10-20 cm thick lamina sets; local alpha, beta, gamma, and possibly xi cross-stratification with 7-25 cm thick lamina sets; heterogenous cross laminae 3-15 mm thick; rare planar parallel laminae 2-8 mm thick; load deformation; slumped bedding and cross-stratification; mud pebbles and mud-pebble casts up to 7 cm in diameter; locally calcareous; feldspathic; silica cemented; traces of glauconite; fair porosity (1 to 7%); forms local cliffs and a prominent dipslope.

Sharp erosional contact: picked at the base of the lowest conglomerate bed. Above the contact, orthoconglomerates dominate. Below the contact, fine- to medium-grained sandstones dominate.

**Lithofacies 1d [Unit E]**

1. **Sandstone.** Pale red (5R 6/2) and grayish red purple (5RP 4/1), weathers moderate brown (5YR 4/4), moderate reddish brown (10R 4/6), and minor pinkish gray (5YR 8/1); fine- to medium-grained with local lenses of coarse-grained; moderately well sorted subrounded grains; planar parallel bedding; average bed thickness: 7 cm, range: 1-23 cm; planar parallel high velocity laminae 0.5-4 mm thick; wavy discontinuous laminae 0.5-6 mm thick; xi, alpha, beta, and gamma major large-scale cross-stratification with 7-25 cm thick lamina sets, kappa, lambda, mu, and nu major small-scale cross-stratification; minor omikron cross-stratification; cross laminae 2-10 mm thick; load deformation; load casts; ball-and-pillow structures; slumped bedding and cross-stratification; water-escape-structures; scattered clay partings; rare flaser bedding; local mud-pebble conglomerate as basal parts of beds up to 3 cm thick; mud pebbles and mud-pebble casts up to 4 cm in diameter; current ripples; climbing ripples; locally micaceous; traces of glauconite; ferruginous; feldspathic; silica
cemented; poor to good porosity (2 to 15%); forms a prominent slope with talus and local cliff-forming beds.

Gradational contact through several meters: picked where the grain size changes from fine- to medium-grained sandstone above the contact, to very fine- to fine-grained sandstone below the contact.

Lithofacies 1c [Unit D]

2. Sandstone with local interbedded siltstone and rare conglomeratic sandstone. Pale red (5R 6/2) and moderate reddish brown (10R 4/6), weathers grayish red (5R 4/2) and pale red (5R 4/2); very fine- to fine-grained; poorly sorted subrounded grains; laminated bedding; planar parallel bedding with local lenticular-shaped bedding; average bed thickness: 3 cm, range: 1-5 cm; omikron and pi with local kappa, lambda, mu, and nu cross-stratification; planar parallel and cross laminae 0.5-6 mm thick; micaceous; calcareous; silica cemented; ferruginous; feldspathic; poor porosity (trace to 1%); forms a talus covered slope.

Sharp contact: picked at the top of the paraconglomerate bed. Above the contact, fine-grained sandstones dominate. Below the paraconglomerate bed at the contact, siltstones dominate.

2. Paraconglomerate and conglomeratic sandstone. Moderate red (5R 5/4), weathers grayish red (5R 4/2); muddy to medium-grained sandy groundmass; angular to subangular chert, limestone, dolostone, and minor quartzite lithoclasts up to 4 cm in diameter; wedging- to lenticular-shaped bedding; average bed thickness: 15 cm, range: 1-20 cm; lithofacies pinches out laterally with scoured-filled contacts; non-laminated; calcareous; ferruginous; feldspathic; silica cemented; poor porosity (traces to 1%); forms a small bench on the normally gentle to moderate slope surrounding it; the lithofacies is mostly covered.

Sharp erosional contact: picked at the base of the paraconglomerate. Above the contact, a paraconglomerate is present. Below the contact, interbedded siltstones and very fine-grained sandstones dominate.

Lithofacies 1a [Unit C]

1. Interbedded very fine-grained sandstone, siltstone, calcareous siltstone, shale, and rare limestone. Pale reddish brown (10R 5/4) and moderate reddish brown
Gradational contact through several meters: picked at the top of the uppermost medium-grained sandstone bed. Above the contact, interbedded siltstones and very fine-grained sandstones dominate. Below the contact, medium-to coarse-grained sandstones dominate.

**Lithofacies lb [Unit B]**

1. Sandstone. Grayish orange pink (5YR 7/2 and 10R 8/2) and very light gray (N-8), weathers light brown (5YR 6/4); medium-to coarse-grained; poorly to moderately well sorted subrounded grains; parallel bedding; average bed thickness: 16 cm; range: 10-23 cm; current ripples; mu and nu major cross-stratification; local alpha, beta, and gamma cross-stratification with 7-10 cm thick lamina sets; planar parallel laminae 3-12 mm thick; wavy discontinuous laminae 3-12 mm thick; feldspathic; calcareous; somewhat silica cemented; poor to fair porosity (1 to 4%); forms a small strike ridge.

Gradational lithological contact but sharp color change contact: picked based on the average grain size. Below the contact, fine- to medium-grained sandstones dominate. Above the contact, medium- to coarse-grained sandstones dominate. Besides the decrease in the average grain size below the contact, there is a color change across the contact: pale red below the contact, and grayish orange pink above the contact.

**Lithofacies la [Unit A]**

1. Sandstone with minor siltstone interbeds. Pale red (5R 6/2), weathers grayish red (10R 4/2) and light brown (5YR 6/4); very fine- to medium-grained; poorly sorted; laminated bedding; thin bedded; planar parallel bedding; mu, nu, lambda, and kappa cross-stratification; planar parallel discontinuous laminae 1-3 mm thick; current ripples; ferruginous; traces of mica; feldspathic; silica cemented; slightly calcareous; poor to good
porosity (trace to 15%); forms a recessive slope (mostly concealed).

Gradational contact through several meters: picked at the lowest fine-to medium-grained sandstone bed. Below the contact, the sandstones are very fine-grained. Also the proportion of siltstone dominates over sandstone below the contact.

2. Siltstone with interbedded shale and very fine-grained sandstone. Light brown (5YR 6/4), dusky red (5R 3/4), and pale red (5R 6/2 and 10R 6/2), weathers the same; laminated bedding; minor mu, nu, kappa, and lambda cross-stratification; planar parallel discontinuous laminae 0.5-2 mm thick; wavy discontinuous laminae 0.5-2 mm thick; local parting lineations; slightly ferruginous; feldspathic; traces of calcite cement; micaceous; poor porosity (trace to 2%); local manganese stains; forms a concealed gentle slope.

Sharp erosional contact: angular unconformity. Above the contact, red siltstones dominate. Below the contact, dolomitic limestones dominate. There appears to be an erosional surface on top of the carbonate beds. Due to intense weathering, dips of bedding surfaces along the contact could not be measured. However, there appeared to be a slight change in bedding dip across the contact.

Julie Formation

1. Limestone and dolomitic limestone. Light olive gray (5Y 6/1), weathers yellow gray (5Y 8/1); micritic; laminated bedding; thin bedded; wavy irregular bedding; locally brecciated; contains yellow gray (5R 1/1), light gray (N-7), and medium dark gray (N-4) chert lenses; forms a low strike ridge.

Concealed contact:

Upper Pertatatataka Formation (Cyclops Member)

1. Sandstone with minor siltstone. Greenish gray (5GY 6/1), weathers the same; fine-grained; micaceous; "booky beds"; forms a gentle strike ridge.
Section J - Missionary View Section


Measured by: J. O. Phillips and John Cullen with a 50-meter tape, two Jacob staffs, and an Abney hand level. Measured up section from northeast to southwest, 16-18 August 1982.

<table>
<thead>
<tr>
<th>Formation</th>
<th>Thickness (meters)</th>
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</thead>
<tbody>
<tr>
<td><strong>Tempe Formation</strong></td>
<td></td>
</tr>
<tr>
<td>1. Covered</td>
<td></td>
</tr>
<tr>
<td>Concealed contact: picked at the top of the uppermost exposed limestone bed.</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Lower Chandler Formation</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>2. Limestone and dolomitic limestone. Very pale orange (10YR 8/2), medium light gray (N-6), weathers bluish white (5B 9/1); fine-crystalline to micritic; contains terrigenous silt-size particles; thin bedded; wavy parallel bedding; contains gray to black chert lenses, locally chert appears brecciated; darker limestone beds give foetid odor on freshly broken surfaces; forms a recessive valley and gentle slope with low-lying, poorly exposed outcrops.</td>
<td></td>
</tr>
<tr>
<td>Concealed contact: picked at the lowest exposed carbonate bed.</td>
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</tr>
</tbody>
</table>

1. Siltstone with interbedded mudrock, shale, and minor sandstone. Moderate reddish brown (10R 6/6), weathers light brown (5YR 5/6); Sandstone: very fine- to fine-grained, laminated bedding, thin bedded, micaceous, slightly calcareous, slightly silica cemented; Siltstone, shale, and mudrock: laminated bedding; micaceous, locally calcareous; planar parallel laminae 0.5-3 mm thick; wavy discontinuous laminae 1-3 mm thick; poor porosity (trace to 1%); forms a covered valley with
the only outcrops occurring in a stream bed which cuts the valley parallel to strike.  

Gradational lithological contact but sharp topographic relief contact: picked at the top of the uppermost sandstone bed which marks the top of a small strike ridge. Above the contact, siltstones dominate and only minor sandstones are present. Below the contact, sandstones are interbedded with siltstones. Here sandstone dominates over the proportion of siltstone. These units below the contact are usually marked by strike ridges which pinch out towards the east.

**Eninta Sandstone**

**Lithofacies 2b [Unit M]**

1. Interbedded sandstone and siltstone. Moderate reddish brown (10R 6/6), light brown (5YR 6/4), pale reddish brown (10R 5/4), weathers light brown (10R 5/4); Sandstone: laminated bedding, micaceous, ferruginous, kappa and lambda cross-stratification; Siltstone: very fine- to fine-grained, poorly sorted subangular grains with muddy matrix, laminated bedding, thin bedded, average bed thickness: 6 cm, range: 4-12 cm, lenticular-shaped to parallel bedding, mu and nu major cross-stratification, planar parallel laminae 0.5-5 mm thick, cross laminae 1-3 mm thick, parting lineations, local load deformation, minor convolute bedding, rare slumped bedding, micaceous, ferruginous, locally calcareous, somewhat silica cemented, feldspathic, poor to fair porosity (1 to 8%); forms three low-lying strike ridges with recessive valleys between them.  

Gradational contact through several meters: picked at the top of the uppermost grayish sandstone bed. Below the contact, moderately well sorted non-ferruginous fine- to medium-grained sandstones dominate. Above the contact, poorly sorted ferruginous, very fine- to fine-grained sandstones interbedded with siltstones are present.

**Lithofacies 2a [Unit L]**

3. Sandstone. Grayish pink (5R 8/2), light gray (N-8), and pinkish gray (5YR 8/1), weathers light brown (5YR 5/6 and 5YR 6/4); fine- to medium-grained; moderately well sorted subrounded grains; contains local lenses of medium- to coarse-grained; local beds with scattered subangular chert fragments up to 1 cm in diameter; lenticular-shaped to parallel bedding; laminated bedding; average bed thickness: 10 cm, range: 8-30 cm; alpha, beta, and gamma major cross-stratification with 10-25 cm thick lamina sets; local kappa, lambda, mu and
pi (8-12 cm thick lamina sets) cross-stratification; planar parallel laminae 2-7 mm thick; wavy discontinuous laminae 2-6 mm thick; local load deformation; minor slumped bedding and cross-stratification; rare ball-and-pillow structures; minor convolute bedding; load casts; clay partings; mud-pebble conglomerate as basal parts of beds up to 3 cm thick; mud pebbles and mud-pebble casts up to 4 m in diameter; parting lineations; traces of glauconite; feldspathic; silica cemented; poor porosity (trace to 1%); forms a well exposed dipslope.

Gradational contact through several meters: picked at the top of the uppermost conglomeratic sandstone bed which has greater than 5% lithoclasts. Below the contact, orthoconglomerates and conglomeratic sandstones dominate. Above the contact, fine- to medium-grained sandstones dominate.

2. Orthoconglomerate, granular orthoconglomerate, conglomeratic sandstone, and granular conglomeratic sandstone interbedded with sandstone. Grayish pink (5R 8/2) and grayish orange pink (5YR 7/2), weathers light brown (5YR 6/4 and 5YR 5/6); Sandstone: fine- to medium-grained, local medium- to coarse-grained, poorly sorted subangular to subrounded grains, lenticular-shaped bedding, average bed thickness: 10 cm, range: 7-17 cm, pi cross-stratification with 10-15 cm thick lamina sets, planar parallel laminae 1-10 mm thick, cross laminae 1-9 mm thick, parting lineations, minor load deformation, slumped bedding and cross-stratification, convolute bedding, ball-and-pillow structures, load casts, mud pebbles and mud-pebble casts up to 4 cm in diameter, feldspathic, silica cemented, well cemented, poor porosity (trace to 2%); Orthoconglomerate, conglomeratic sandstone, granular orthoconglomerate, and granular conglomeratic sandstone: fine- to coarse-grained sandy groundmass, poorly sorted subangular grains, contains lithoclast of subangular to subrounded chert fragments up to 2 cm in diameter, subrounded quartzite up to 1 cm in diameter, and rounded granule-sized vein quartz and quartzite, wedging cut-and-fill channels and lenticular-shaped bedding, average bed thickness: 30 cm, range: 20-35 cm, pi with local alpha, beta, and gamma cross-stratification with 12-30 cm thick lamina sets, heterogeneous planar parallel laminae 2-10 mm thick, heterogeneous cross laminae 1-9 mm thick, load deformation, slumped bedding and cross-stratification, mud pebbles and mud-pebble casts up to 6 cm in diameter, feldspathic, silica cemented, poor to fair porosity (2 to 9%); forms a prominent ridge top and dipslope.
Gradational contact through several meters: picked at the base of the lowest conglomeratic sandstone bed. Below the contact, medium-grained sandstones dominate. Above the contact, orthoconglomerates dominate.

1. Sandstone with local granular orthoconglomerate lenses. Grayish orange pink (5YR 7/2), Light gray (N-8), pinkish gray (5YR 8/1), and grayish pink (5R 8/2), weathers light brown (5YR 5/6 and 5YR 6/4); fine- to coarse-grained; poorly to moderately well sorted subrounded grains; lenticular-shaped to wavy parallel bedding; average bed thickness: 12 cm, range: 6-30 cm; pi with minor alpha, beta, and gamma cross-stratification with 12-26 cm thick lamina sets; local kappa and lambda cross-stratification; planar parallel laminae 0.5-5 mm thick; wavy discontinuous laminae 2-8 mm thick; local lenses of moderately well sorted granular orthoconglomerate (6-12 cm thick beds with rounded grains of vein quartz and quartzite); parting lineations; load deformation; slumped bedding and cross-stratification; ball-and-pillow structures; convolute bedding; local load casts; scattered clay pebbles and clay-pebble casts up to 5 cm in diameter and white [N-9] in color; traces of glauconite; silica cemented; feldspathic; locally calcareous; poor to fair porosity (1 to 9%); weathers massive; found mostly as rounded and slumped beds; forms a rounded ridge top with scattered outcrops. 349 26.3 96.3

Gradational contact based on a change in grain size but a sharp contact based on a change in color: picked at the top of the uppermost brownish red sandstone bed. Above the contact, gray is the dominant color. Below the contact, brownish red is the dominant color. (This is primarily due to a recognizable presence of ferruginous cement in the lithofacies below the contact).

Lithofacies 2b [Unit I]

3. Sandstone. Moderate brown (5YR 4/4), pale red (5R 6/2), and minor grayish red (10R 4/2), weathers light brown (5YR 5/6 and 5YR 6/4), pale reddish brown (10R 5/4), and gray red (10R 4/2); fine- to medium-grained; poorly to moderately well sorted subangular to subrounded grains; laminated bedding; planar to wavy parallel bedding; average bed thickness: 9 cm, range: 1-30 cm; alpha, beta, and gamma major cross-stratification with 7-26 cm thick lamina sets; local kappa and lambda and minor xi (5-12 cm thick lamina sets), pi (15-25 cm thick lamina sets), mu, and nu cross-stratification; planar parallel laminae 0.5-8 mm thick; wavy continuous and discontinuous laminae 2-9 mm thick; cross laminae 2-8 mm thick; parting lineations; current ripples; in-phase stacked straight-crested ripples; local clay partings;
climbing ripples; scour-filled bedding contacts; rare
mud-pebble conglomerate as basal parts of beds up to
4 cm thick; mud pebbles and mud-pebble casts up to 6 cm
in diameter; load deformation; slumped bedding and
cross-stratification; ball-and-pillow structures; water-
escape structures; convolute bedding; load casts; traces
of glauconite; micaceous; feldspathic; silica cemented;
ferruginous; mostly good porosity (8 to 15%); often
covered with Spinifex; generally weathers massive; forms
a prominent strike ridge with local cliffs.

Gradational contact through several meters: picked where the average
grain size decreases. Above the contact, sandstones are well exposed and
mostly fine- to medium-grained. Below the contact, they are fine-grained
and recessive in nature.

2. Sandstone. Pale red (5R 6/2) and moderate red (5R 5/4),
weathers pale reddish brown (10R 5/4) and light brown
(5YR 5/6); fine-grained; local fine- to medium-grained;
poorly to moderately well sorted subrounded grains;
planar parallel bedding; laminated bedding; average bed
thickness: 8 cm, range: 5-15 cm; mu, nu, and pi major
cross-stratification; rare alpha and beta cross-
stratification with 8-15 cm thick lamina sets near the
top of the lithofacies; planar parallel laminae 0.5-7 mm
thick; cross laminae 2-8 mm thick; parting lineations;
local load deformation; minor convolute bedding; rare
water-escape structures; mud-pebble conglomerate as
thin basal parts of beds up to 2 cm thick and which
often overlie convolute bedding; mud pebbles and mud-
pebble casts up to 3 cm in diameter; micaceous;
feldspathic; somewhat silica cemented; locally
ferruginous; generally poorly cemented; good porosity
(9 to 10%); forms a small valley and recessive, mostly
concealed, talus slope.

Gradational lithological contact through several meters but sharp
topographic relief contact: picked where the average grain size
increases (at the base of a prominent dipslope). Above the contact,
the lithofacies is mostly recessive. Below the contact, the lithofacies is more prominent with well exposed outcrops.

1. Sandstone. Moderate red (5R 5/4) and gray (N-7),
weathers grayish red (10R 4/2) and light brown
(5YR 5/6); fine- to medium-grained; moderately well
sorted subangular to subrounded grains; planar to wavy
parallel bedding; laminated bedding; average bed thick-
ness: 20 cm, range: 8-27 cm; alpha, beta, and gamma
major cross-stratification with 8-26 cm thick lamina
sets; minor pi and omikron cross-stratification with
8-12 cm thick lamina sets near the base of the litho-
facies; planar parallel laminae 1-12 mm thick; wavy continuous laminae 4-9 mm thick; cross laminae 3-12 mm thick; planar parallel high velocity laminae; wavy in-phase stacked straight-crested ripples; parting lineations; local load deformation; slumped bedding and cross-stratification; water-escape structures; rare ball-and-pillow structures; load casts; scattered mud pebbles and mud-pebble casts up to 5 cm in diameter; feldspathic; locally ferruginous; silica cemented; traces of glauconite near the base of the lithofacies; poor porosity (trace to 3%); weathers massive; forms a prominent ridge top and dipslope.

Sharp lithologic contact: picked at the top of the uppermost conglomeratic sandstone bed. Fine- to medium-grained sandstones are present above the contact. Below the contact, conglomeratic sandstones dominate.

Lithofacies 2a [Unit H]

1. Orthoconglomerate and conglomeratic sandstone with local interbeds of sandstone. Grayish orange pink (5YR 7/2), weathers light brown (5YR 5/6 and 5YR 6/4); Sandstone: medium- to coarse-grained, poorly to moderately well sorted subangular to subrounded grains, lenticular-shaped bedding, average bed thickness: 40 cm, range: 20-60 cm, pi cross-stratification with 10-25 cm thick lamina sets; Orthoconglomerate and conglomeratic sandstone: fine- to coarse-grained sandy groundmass, poorly sorted subangular to subrounded grains, contains subangular to subrounded chert fragments up to 4 cm in diameter and rounded to subrounded vein quartz and quartzite granules, wedging cut-and-fill channels with local lenticular-shaped bedding, average bed thickness: 35 cm, range: 20-60 cm, alpha, beta, and gamma cross-stratification with 20-30 cm thick lamina sets, planar parallel (homogenous and heterogeneous compositions) laminae 2-10 mm thick, wavy continuous in-phase laminae 4-8 mm thick, local load deformation; slumped bedding and cross-stratification, convolute bedding, scoured bedding contacts, local current ripples; rare dunes (megaripples), rare clay partings, minor mud-pebble conglomerate as basal parts of beds up to 4 cm thick, mud pebbles and mud-pebble casts up to 10 cm in diameter, traces of glauconite, feldspathic, silica cemented, poor to fair porosity (1 to 7%); forms cliffs.

Sharp erosional contact: picked at the base of the lowest conglomerate bed. Below the contact fine- to medium-grained sandstones dominate. Above the contact orthoconglomerates dominate.
Lithofacies 1d [Unit G]

2. Sandstone. Light brownish gray (5YR 6/1) and grayish red (10R 4/2), weathers light brown (5YR 6/4); fine-to medium-grained; moderately well sorted subrounded grains; planar to wavy parallel bedding; average bed thickness: 15 cm, range: 1-25 cm; alpha, beta, and gamma major cross-stratification with 8-13 cm thick lamina sets; minor mu, kappa, and lambda cross-stratification; planar parallel laminae 5-8 mm thick; cross laminae 1-7 mm thick; wavy discontinuous laminae 2-6 mm thick; parting lineations; load deformation; slumped bedding and cross-stratification; ball-and-pillow structures; water-escape structures; convolute bedding; load casts; local mud-pebble conglomerate as basal parts of beds up to 7 cm thick; mud pebbles and mud-pebble casts up to 7 cm in diameter; locally slightly ferruginous; silica cemented; feldspathic; poor porosity (trace to 3%); weathers massive with rounded surfaces; forms a somewhat concealed gentle to moderate slope.

Gradational contact based on grain size but a sharp contact based on color: picked at the top of the uppermost moderate red ferruginous sandstone. Above the contact, only minor iron staining exists. Below the contact the iron staining is consistently present.

1. Sandstone. Moderate red (5R 5/4), pale red (5R 6/2), pale reddish brown (10R 5/4), and locally grayish orange pink (10R 8/2) or grayish pink (5R 8/2), weathers light brown (5YR 5/6 and 5YR 6/4) and pale reddish brown (10R 5/4); fine-to medium-grained; poorly to moderately well sorted subrounded grains; scattered medium- to coarse-grained sandstones; average bed thickness: 7 m, range: 1-26 cm; alpha, beta, and gamma major cross-stratification with 4-15 cm thick lamina sets; local kappa and lambda with minor mu and nu cross-stratification; planar parallel laminae 1-5 mm thick; cross laminae 2-4 mm thick; wavy discontinuous laminae 2-8 mm thick; local wavy continuous (stacked in-phase) laminae 3-5 mm thick; parting lineations; dunes (megaripples); climbing ripples (often superimposed on the megaripples); rare current ripples; local planar parallel high velocity laminae; load deformation; slumped bedding and cross-stratification; convolute bedding; load casts; scattered mud pebbles and mud-pebble casts up to 3 cm in diameter; local clay partings; rare flaser bedding; locally micaceous; ferruginous; feldspathic; silica cemented; possible syneresis shrinkage cracks; local traces of glauconite; fair to good porosity (4 to 15%), mostly fair porosity; forms a moderately steep slope with scattered outcrops.
Gradational contact through several meters: picked at the top of the uppermost conglomeratic sandstone bed. Above the contact, fine- to medium-grained sandstones dominate. Below the contact, orthoconglomerates dominate.

Lithofacies 2a [Unit F]

1. Orthoconglomerate and conglomeratic sandstone with interbeds of sandstone and granular orthoconglomerate. Light brown (5YR 5/6), weathers grayish orange pink (5YR 7/2) and pale red (5R 6/2); medium- to coarse-grained groundmass and sandstones; poorly sorted subangular to subrounded grains; lithoclasts consists of angular to subangular chert fragments up to 7 cm in diameter and subrounded quartzite up to 1 cm in diameter; local lenses of granule-sized rounded quartzite and vein quartz; wedging cut-and-fill channels to lenticular-shaped bedding; average bed thickness: 25 cm, range: 16-37 cm; scour-filled bedding contacts; alpha, beta, and gamma cross-stratification with 15-26 cm thick lamina sets; planar parallel laminae (homogeneous and heterogeneous compositions) 0.5-10 mm thick; cross laminae 2-8 mm thick; minor load deformation; load casts; mud pebbles and mud-pebble casts up to 5 cm in diameter; most of the lithofacies is cross-stratified; feldspathic; ferruginous; silica cemented; poor porosity (trace); forms a moderately steep slope with local well exposed outcrops.

Sharp erosional contact: picked at the base of the lowest conglomerate bed. Below the contact, siltstones and very fine-grained sandstones dominate. Above the contact, conglomeratic sandstones dominate.

Lithofacies 1d [Unit E]

1. Interbedded sandstone and siltstone. Pale reddish brown (10R 5/4), weathers the same color; Sandstone: very fine- to fine-grained, poorly sorted, laminated bedding, planar parallel bedding, average bed thickness: 8 cm, range: 1-10 cm, alpha, beta, and gamma cross-stratification with 3-6 cm thick lamina sets, planar parallel laminae 2-6 mm thick, local load deformation, rare slumped bedding, minor convolute bedding, micaceous, feldspathic, slightly silica cemented, ferruginous, fair to good porosity (5 to 15%), good porosity largely due to extensive surface weathering; Siltstone: laminated bedding, wavy parallel bedding, micaceous, ferruginous, poor porosity (trace); forms a recessive slope with rare outcrops.
Sharp contact: picked at the top of the uppermost conglomeratic mudstone bed. This bed possesses a very silty matrix. Below the contact, lenses of paraconglomerates are present. Above the contact, interbedded siltstones and very fine-grained sandstones are present.

**Lithofacies 1c [Unit D]**

1. Paraconglomerate with interbedded conglomeratic sandstone, conglomeratic mudstone, sandstone, and siltstone. Pale red (5R 6/2), weathers pale red (10R 6/2); Siltstone laminated bedding, micaceous; Sandstone: very fine- to medium-grained, (mostly medium-grained), laminated bedding, lenticular-shaped bedding, average bed thickness: 7 cm, range: 4-12 cm, locally micaceous, feldspathic, ferruginous, calcareous, somewhat silica cemented, poor porosity (trace to 1%); Paraconglomerate, conglomeratic sandstone, and conglomeratic mudstone: clay-sized to coarse-grained sandy groundmass, very poorly sorted, contains angular lithoclasts of chert, sandstone, dolostone, limestone, quartzite, and fragments with silicified ooids up to 4 cm in diameter, wavy lenticular-shaped bedding, average bed thickness: 10 cm, range: 1-20 cm, calcareous, very ferruginous, slightly silica cemented; poor porosity (trace to 1%); forms a gentle to moderate slope which is mostly covered. . . . . . . . . . . 7.2

Sharp erosional contact: picked at the base of the lowest conglomerate bed which fills scours that cut into the siltstones below it. Below the contact, siltstones and very fine-grained sandstones dominate. Above the contact, paraconglomerates dominate.

**Lithofacies 1a [Unit C]**

1. Siltstone with minor sandstone and rare conglomeratic sandstone interbeds. Pale reddish brown (10R 5/4), weathers the same color; very fine-grained sandstone; laminated bedding; scattered subangular chert, limestone, sandstone, and quartzite lithoclasts up to 5 cm in diameter; planar parallel discontinuous laminae 0.5-3 mm thick; wavy discontinuous laminae 0.5-3 mm thick; calcareous; micaceous; ferruginous; most of this lithofacies is siltstone to very fine-grained sandstone; poor porosity (trace); forms a recessive slope which is mostly covered. . . . . . . . . . . 27.4

Sharp contact: picked at the top of the uppermost dolomitic limestone bed. The contact represents an angular unconformity with siltstones resting unconformably on top of dolomitic limestones. There is a change in dip across this contact (50° south for the dolomitic limestone beds and 44° south for the siltstone beds overlying them).
Julie Formation

1. Dolomitic limestone, limestone, calcareous sandstone, and conglomeratic limestone. Light brown (5YR 5/6), weathers pale red (5R 6/2); fine-crystalline to micritic; lenticular-shaped bedding; average bed thickness: 10 cm, range: 8-16 cm; wavy laminated bedding; locally contains silt-sized terrigenous grains; scattered chert nodules up to 2 cm in diameter; the basal bed of this unit is a conglomeratic limestone which contains subrounded chert pebbles; poor porosity (trace); forms a recessive gentle slope which is mostly covered. Concealed contact: picked at the base of a conglomeratic limestone bed which is the lowest exposed carbonate bed.

Pertatataka Formation (Cyclops Member)

3. Siltstone and shale interbeds. Greenish gray (5GY 6/1), light brownish gray (5YR 6/1), dark yellow brown (10YR 4/2), and grayish pink (5R 8/2), weathers light brown (5YR 5/6) and greenish gray (5GY 6/1); laminated bedding; thin bedded; mud cross-stratification; planar parallel discontinuous laminae 1-7 mm thick; micaceous; locally calcareous; fissile; poor porosity (trace); forms a recessive valley with rare exposures found in gullies cutting perpendicular to strike. Concealed contact: picked at the lowest exposed siltstone outcrop.

2. Covered area. Probably siltstone and shale beds similar to those described in the overlying unit; forms a recessive valley. Concealed contact: picked at the top of the uppermost exposed bed. Above the contact, the unit is concealed. Below the contact, the beds are dominantly fine-grained sandstones.

1. Sandstone with local siltstone interbeds. Yellow gray (5Y 8/1), grayish orange (10YR 7/4), grayish red (10R 4/2), and light olive gray (5Y 6/1), weathers grayish orange (10YR 7/4) and light brown (5YR 5/6 and 5YR 6/4); "Booky beds"; very fine- to fine-grained sandstone; poorly to moderately well sorted grains; wavy parallel bedding; average bed thickness: 9 cm, range:
4-17 cm; kappa, lambda, mu, and nu cross-stratification; local current ripples up to 5 cm wavelength; planar parallel laminae 0.5-4 mm thick; wavy discontinuous laminae 1-3 mm thick; cross laminae 1-3 mm thick; rare mud-pebble casts; traces of glauconite; micaceous to locally very micaceous; feldspathic; silica cemented; poor porosity (trace to 1%); forms a low strike ridge with numerous outcrops.
Section K - West Gardiner Range Section

Location: Approximately 42 km northeast of the West Mereenie No. 2 well and 32 km southeast of Camel's Hump, in the Gardiner Range anticline, on the Mount Liebig 1:250,000 scale geologic map, at 131° 56' E longitude and 23° 53' S latitude (Australian Grid Coordinates: 202 6000 y N, 50 3500 y E, Zone 4). The Eninta Sandstone forms an east-west strike ridge. Beds face and dip south.

Measured by: J. O. Phillips and Leon Amadio with a 30-meter tape, two Jacob staffs, and an Abney hand level. Measured up section from the north to the south, 30-31 July and 1 August 1982.

<table>
<thead>
<tr>
<th>Formation</th>
<th>Thickness (meters)</th>
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<tr>
<td>Tempe Formation</td>
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<tr>
<td>1. Covered</td>
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<tr>
<td>Concealed contact:</td>
<td>picked at the top</td>
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<tr>
<td>of the uppermost</td>
<td>exposed limestone</td>
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<tr>
<td>bed</td>
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Lower Chandler Formation

3. Limestone and dolomitic limestone. Gray; fine-crystaline to micritic; contains lenses of dark gray chert; very poorly exposed; highly weathered. . . .

Concealed contact: picked at the base of the only observed limestone outcrop. Below the contact, there is a large covered interval. Above the contact, there is a small limestone bed which becomes covered laterally. Above this cherty limestone bed is another large covered interval.

2. Concealed interval. Probably siltstone and other mudrocks with minor very fine-grained sandstone. . . 200.0

Concealed contact: picked at the top of the uppermost exposed very fine-grained sandstone bed.

1. Siltstone and shale with minor very fine-grained sandstone. Moderate reddish brown (10R 4/6), weathers moderate brown (5YR 4/4); laminated bedding; wavy parallel bedding; average bed thickness: 2 cm, range: 0.5-4 cm; minor kappa and lambda cross-stratification; planar parallel laminae 0.5-4 mm thick; wavy discontinuous laminae 0.5-3 mm thick; parting
lineations; micaceous; slightly ferruginous; locally silica cemented; poor porosity (trace to 1%); mostly concealed unit; forms a gentle, recessive slope.  .  .  .  .  . 8.5

Gradational contact: picked at the top of the uppermost sandstone bed. Above this sandstone the amount of siltstone and shale dominates over the amount of sandstone. Below the contact, the proportion of sandstone is greater than siltstone.

Eninta Sandstone

Lithofacies 2b [Unit M]

1. Sandstone and minor siltstone. Dark reddish brown (10R 3/4) and moderate red (5R 5/4), weathers moderate reddish brown (10R 4/6); very fine- to fine-grained sandstone; poorly to moderately well sorted; wavy irregular to planar parallel bedding; laminated bedding; average bed thickness: 3 cm, range: 1-7 cm; kappa and lambda cross-stratification; planar parallel laminae 0.5-5 mm thick; wavy discontinuous laminae 0.5-4 mm thick; climbing ripples; current ripples; clay partings; rare flaser bedding; rare load deformation; rare slumped bedding; mud pebbles and mud-pebble casts up to 2 cm in diameter; micaceous; feldspathic; ferruginous; somewhat silica cemented; good porosity (10 to 15%), porosity largely due to weathering; forms a recessive gentle slope which is mostly concealed.  .  .  .  .  . 9.7

Sharp contact based on a change in topography: picked at the top of the uppermost sandstone bed which forms a steeply dipping, prominent dipslope. Above the contact, the sandstones form a recessive gentle slope. Below the contact, the sandstones form a prominent dipslope.

Lithofacies 2a [Unit L]

1. Sandstone interbedded with conglomeratic sandstone and granular orthoconglomerate. Pale pink (5RP 8/2), weathers grayish orange pink (5YR 7/2) and moderate reddish brown (10R 4/6); Sandstone: fine- to medium-grained, moderately well sorted subrounded grains, laminated bedding, lenticular-shaped to parallel bedding, average bed thickness: 6 cm, range: 1-15 cm, planar parallel high velocity laminae 0.5-6 mm thick, parting lineations, load deformation, slumped bedding, load casts, ball-and-pillow structures, scattered mud pebbles and mud-pebble casts up to 4 cm in diameter, traces of glauconite near the top of the lithofacies, feldspathic, silica cemented, poor porosity (1 to 5%); Conglomeratic sandstone and granular orthoconglomerate:
fine- to coarse-grained sandy groundmass, contains granule- to pebble-sized lithoclasts of well rounded to rounded vein quartz and quartzite up to 1 cm in diameter and subangular to subrounded chert fragments up to 2 cm in diameter, lenticular-shaped bedding, average bed thickness: 9 cm, range: 5-15 cm, some of the lenses are well sorted granular orthoconglomerate whereas others are poorly sorted conglomeratic sandstone, scour-filled bedding contacts, local normally graded bedding (fining-upward sequence or decrease in the amount of lithoclasts upwards in the bed), average bed thickness: 12 cm, range: 5-25 cm, pi, alpha, beta, and gamma major cross-stratification with 4-8 cm thick lamina sets, rare kappa and lambda cross-stratification near the top of the lithofacies, one xi cross-stratification present at the base of the lithofacies, planar parallel laminae 1-10 mm thick, wavy discontinuous laminae 1-4 mm thick, cross laminae 1-3 mm thick, load deformation, slumped bedding and cross-stratification, load casts, mud pebbles and mud-pebble casts up to 6 cm in diameter, feldspathic, traces of glauconite near the top of the lithofacies, well cemented by silica, poor to fair porosity (trace to 4%), mostly poor porosity, locally weathers massive or as rounded boulders; forms a prominent dipslope.

Sharp contact: picked at the base of the lowest conglomeratic sandstone bed. Above the contact, interbeds of sandstones and conglomeratic sandstones occur. Below the contact, fine- to medium-grained sandstones dominate. There is also a sharp color change across the contact. Above the contact, the beds are pale pink, whereas below the contact the beds are grayish red.

Lithofacies 2b [Unit I]

5. Sandstone. Grayish red (5R 4/2), weathers moderate reddish orange (10R 6/6); fine- to medium-grained; moderately well sorted subrounded grains; parallel bedding; laminated bedding; average bed thickness: 7 cm, range: 1-15 cm; kappa and lambda major cross-stratification; local alpha, beta, and gamma cross-stratification with up to 7 cm thick lamina sets; planar parallel laminae 0.3-4 mm thick, cross laminae 0.5-6 mm thick, wavy discontinuous laminae 0.3-4 mm thick; parting lineations; load deformation, ball-and-pillow structures, slumped bedding, water-escape structures, local convolute bedding; current ripples; climbing ripples; clay partings; local mud-pebble conglomerate as basal parts of beds up to 2 cm thick; mud pebbles and mud-pebble casts up to 7 cm in diameter; rare flaser bedding; locally micaceous; feldspathic; ferruginous; silica cemented; poor to good porosity (trace to 15%).
locally weathers massive; forms a rounded, Spinifex covered, ridge crest. 27.7

Gradational contact through several meters: picked at the base of the lowest fine- to medium-grained sandstone bed. Below the contact, very fine- to fine-grained sandstones dominate.

4. Sandstone. Grayish red (5R 4/2), weathers moderate reddish orange (10R 6/6); very fine- to fine-grained; poorly to moderately well sorted subangular to subrounded grains; locally contains a clayey matrix; wavy parallel bedding; laminated bedding; average bed thickness: 4 cm, range: 1-7 cm; kappa and lambda cross-stratification; planar parallel high velocity laminae; cross laminae 0.3-5 mm thick; parting lineations; load deformation, water-escape structures, slumped bedding; local mud-pebble conglomerate as basal parts of beds up to 1 cm thick; mud pebbles and mud-pebble casts up to 3 cm in diameter; clay partings; rare flaser bedding; micaceous; feldspathic; ferruginous; somewhat silica cemented; good porosity (10 to 15%); most porosity is largely due to surface weathering; forms a recessive valley and mostly concealed, gentle talus slope. 8.0

Gradational contact through several meters: picked at the base of the lowest very fine- to fine-grained sandstone bed. Above the contact, very fine- to fine-grained sandstones dominate. Below the contact, fine- to medium-grained sandstones dominate.

3. Sandstone. Grayish red (5R 4/2), weathers moderate reddish brown (10R 4/6) and moderate reddish orange (10R 6/6); fine- to medium-grained; moderately well sorted subrounded to rounded grains; laminated bedding; parallel bedding; average bed thickness: 6 cm, range: 2-12 cm; alpha, beta, and gamma major cross-stratification with up to 8 cm thick lamina sets; local kappa and lambda cross-stratification; planar parallel high velocity laminae; planar parallel laminae 0.5-8 mm thick; cross laminae 1-4 mm thick; wavy discontinuous laminae 0.5-4 mm thick; parting lineations; load deformation, slumped bedding and cross-stratification, ball-and-pillow structures, water-escape structures; local mud-pebble conglomerate as basal parts of beds up to 3 cm thick; mud pebbles and mud-pebble casts up to 4 cm in diameter; clay partings; very rare flaser bedding; feldspathic; silica cemented; locally ferruginous; poor to fair porosity (trace to 9%); weathers massive with rounded surfaces; forms a rounded ridge crest and gentle dipslope. 14.8
Gradational contact through several meters: picked at the base of the lowest fine- to medium-grained sandstone bed. Above the contact, fine- to medium-grained sandstones dominate. Below the contact, very fine- to fine-grained sandstones dominate.

2. Sandstone. Grayish red (5R 4/2), weathers moderate reddish brown (10R 4/6); very fine- to fine-grained; poorly to moderately well sorted; laminated bedding; parallel bedding; planar parallel high velocity laminae; average bed thickness: 2 cm, range: 1-6 cm; kappa and lambda cross-stratification; planar parallel laminae 0.5-4 mm thick, wavy discontinuous laminae 0.5-4 mm thick; parting lineations; rare load deformation, rare ball-and-pillow structures, minor slumped bedding; scattered mud pebbles and mud-pebble casts up to 4 cm in diameter; rare flaser bedding; micaceous; calcareous; feldspathic; silica cemented; ferruginous; traces of glauconite; fair to good porosity (7 to 15%); forms a recessive, mostly concealed, talus slope and valley.

Gradational contact through several meters: picked at the base of the lowest very fine- to fine-grained sandstone bed. Above the contact, very fine- to fine-grained sandstones dominate. Below the contact, fine- to medium-grained sandstones dominate.

1. Sandstone. Grayish red (5R 4/2) and dusky red (5R 3/4), weathers moderate reddish brown (10R 4/6) and dark reddish brown (10R 3/4); fine- to medium-grained; moderately well sorted subrounded grains; laminated bedding; parallel bedding; average bed thickness: 6 cm, range: 1-10 cm; kappa and lambda major cross-stratification, local alpha, beta, and gamma cross-stratification with up to 7 cm thick lamina sets; planar parallel laminae 0.5-10 mm thick, wavy discontinuous laminae 1-4 mm thick, cross laminae 2-12 mm thick; planar parallel high velocity laminae; clay partings; rare flaser bedding; flute casts; local scoured bedding contacts; climbing ripples; load deformation, slumped bedding, water-escape structures, ball-and-pillow structures, minor convolute bedding; load casts; parting lineations; local mud-pebble conglomerate as basal parts of beds up to 4 cm thick; mud pebbles and mud-pebble casts up to 8 cm in diameter; locally micaceous; feldspathic; ferruginous; silica cemented; poor to good porosity (trace to 10%); forms a moderately steep dipslope with locally good outcrop exposures.

Gradational contact through 1 meter: picked at the top of the uppermost conglomeratic sandstone bed. Above the contact, fine- to medium-grained sandstones dominate. Below the contact, conglomeratic sandstones dominate.
Lithofacies 2a [Unit H]

1. Orthoconglomerate, conglomeratic sandstone, and sandstone. Grayish purple (5P 4/2), weathers dark reddish brown (10R 3/4); Sandstone: medium- to coarse-grained, moderately well sorted, lenticular-shaped bedding, average bed thickness: 8 cm, range: 3-15 cm, feldspathic, ferruginous, silica cemented, traces of glauconite, good porosity (10 to 15%); Orthoconglomerate and conglomeratic sandstone: very fine- to coarse-grained sandy groundmass, poorly sorted subangular grains, contains lithoclasts of subangular to subrounded chert fragments up to 3 cm in diameter, subrounded to rounded quartzite up to 2 cm in diameter, and minor subrounded to rounded vein quartz up to 0.5 cm in diameter, wedging cut-and-fill channels with lenticular-shaped bedding, average bed thickness: 15 cm, range: 6-25 cm, local lenses of well sorted to moderately well sorted rounded granular conglomerate, local normally graded bedding (conglomerate --> sandstone), pi and omikron cross-stratification, scattered mud pebbles and mud-pebble casts up to 4 cm in diameter, minor load deformation, rare slumped bedding, traces of glauconite, feldspathic, silica cemented, locally weathers massive, poor to good porosity (1 to 10%); cliff-forming unit.

Sharp erosional contact: picked at the base of the lowest orthoconglomerate. Above the contact, orthoconglomerates dominate. Below the contact, fine- to medium-grained sandstones dominate.

Lithofacies 1d [Unit E]

3. Sandstone. Dusky red (5R 3/4) and grayish red (5R 4/2), weathers dark reddish brown (10R 3/4) and moderate reddish brown (10R 4/6); fine- to medium-grained; moderately well sorted subrounded grains; parallel bedding; laminated bedding; average bed thickness: 5 cm, range: 1-9 cm; planar parallel high velocity laminae; local kappa and lambda cross-stratification; minor alpha and beta cross-stratification with up to 8 cm thick lamina sets; planar parallel laminae 0.5-12 mm thick, wavy discontinuous laminae 1-8 mm thick, cross laminae 1-8 mm thick; climbing ripples; parting lineations; local load deformation, minor slumped bedding, local water-escape structures, minor ball-and-pillow structures; load casts; scattered mud pebbles and mud-pebble casts up to 6 cm in diameter; locally micaceous; feldspathic; ferruginous; silica cemented; traces of glauconite; fair to good porosity (4 to 15%); locally weathers massive with rounded surfaces; forms a mostly concealed, Spinifex covered, ridge crest.
Gradational contact through several meters: picked at the top of the uppermost coarse-grained sandstone bed. Above the contact, fine- to medium-grained sandstones dominate. Below the contact, coarse-grained sandstones with scattered granule-sized clasts and/or interbedded conglomerates are present.

2. Sandstone and minor lenses of granular orthoconglomerate. Grayish red (5R 4/2), weathers moderate reddish brown (10R 4/6); fine- to medium-grained with local lenses of coarse-grained sandstone and/or granule-size orthoconglomerate; generally moderately well sorted subrounded grains; laminated bedding; lenticular-shaped to parallel bedding; average bed thickness: 10 cm, range: 6-20 cm; planar parallel high velocity laminae; alpha, beta, and gamma major cross-stratification with 6-15 cm thick lamina sets; local kappa and lambda with minor xi (5-10 cm thick lamina sets) cross-stratification; planar parallel laminae 0.3-7 mm thick, wavy discontinuous laminae 2-6 mm thick, cross laminae 1-10 mm thick; parting lineations; load deformation, minor slumped bedding and cross-stratification, ball-and-pillow structures; load casts; clay partings; mud pebbles and mud-pebble casts up to 6 cm in diameter; locally micaceous; feldspathic; ferruginous; silica cemented; poor to fair porosity (1 to 9%); forms a moderately steep slope which is locally concealed by talus.

Gradational contact through several meters: picked at the base of the lowest coarse-grained sandstone bed. Above the contact, lenses of coarse-grained sandstones and/or granule-sized orthoconglomerates dominate. Below the contact, fine- to medium-grained sandstones dominate.

1. Sandstone. Grayish red (5R 4/2), weathers moderate reddish brown (10R 4/6); fine- to medium-grained; moderately well sorted subrounded to rounded grains; laminated bedding; parallel bedding; average bed thickness: 5 cm, range: 1-30 cm; planar parallel high velocity laminae; kappa and lambda major cross-stratification; local alpha, beta, and gamma cross-stratification with up to 8 cm thick lamina sets; planar parallel laminae 0.5-8 mm thick, wavy discontinuous laminae 2-12 mm thick, cross laminae 1-8 mm thick; current ripples; climbing ripples; parting lineations; local load deformation, minor slumped bedding and cross-stratification, local ball-and-pillow structures; minor convolute bedding; scattered mud pebbles and mud-pebble casts up to 3 cm in diameter; feldspathic; ferruginous; silica cemented; poor to fair porosity (trace to 7%).
locally weathers massive with rounded surfaces; forms a moderately steep slope covered by Spenifex and locally covered by talus. 39.7

Sharp contact: picked at the top of the uppermost conglomerate bed. Above the contact, fine- to medium-grained sandstones dominate. Below the contact, ortho- to paraconglomerates are present.

**Lithofacies 1c [Unit D]**

1. Ortho- to paraconglomerate. Grayish red purple (5RP 4/2), weathers very dusky red (10R 2/2); clay-size to medium-grained sandy groundmass; very poorly sorted; contains lithoclasts of subangular to subrounded chert fragments up to 5 cm in diameter, subrounded quartzite up to 3 cm in diameter, rounded clay pebbles up to 2 cm in diameter, and subrounded dolomite, limestone, and sandstone fragments up to 2 cm in diameter; lenticular-shaped bedding; local wedging cut-and-fill channels; scour-filled bedding contacts; average bed thickness: 15 cm, range: 8-25 cm; pi major cross-stratification; graywacke; ferruginous; silica cemented; poor porosity (trace); forms a gentle slope which is mostly concealed. 10.8

Sharp erosional contact: picked at the base of the lowest conglomerate bed. Below the contact, siltstones are present. Above the contact, ortho- to paraconglomerates are present.

**Lithofacies 1a [Unit C]**

1. Siltstone and shale (?). Covered lithofacies which forms a moderate to gentle slope. 12.0

Concealed contact: picked where a moderate to gentle slope ends. Below the contact, the unit forms a concealed valley. Above the contact, a covered, mostly gentle slope is present.

**Pertatataka Formation**

1. Concealed interval. Valley forming unit. 300.0

Concealed contact: picked at the top of the uppermost exposed dolostone bed.
Bitter Springs Formation

1. Dolostone and dolomitic limestone. Pale bluish green, weathers tan, pink, white, and golden brown; very fine-crystalline to micritic; average bed thickness: 8 cm; range: 1-15 cm; mostly contorted and brecciated bedding; contains gray chert lenses and nodules; darker rocks have foetid odor on freshly broken surfaces; forms a rounded strike ridge.
**Section L – Tempe Downs North Section**

**Location:** Approximately 10 km northeast of Tempe Downs Homestead and 17 km north-northwest of White Horse Gap, on the Henbury 1:250,000 scale geologic map, at 132° 31' E longitude and 24° 20' S latitude (Australian Grid Coordinates: 1 97 0500 y N, 56 7500 y E, Zone 4). The section is north of the Househill Range and west of Deception Creek in the Deception Creek anticline. Beds of the Quandong Conglomerate face and dip steeply northwest and form a horse-shoe shaped ridge.

**Measured by:** J. O. Phillips and Leon Amadio with a 60-meter tape, two Jacob staffs, and an Abney hand level. Measured upsection from southeast to northwest, 24-27 August 1982.

<table>
<thead>
<tr>
<th>Formation</th>
<th>Thickness (meters)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Undifferentiated Cambrian Deposits</td>
<td></td>
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<tr>
<td>4. Covered siltstone and shale.</td>
<td>. . . . . . . .</td>
</tr>
</tbody>
</table>

Gradational contact: picked at the lowest exposed sandstone bed. Above the contact, fine- to medium-grained sandstones are present. Below the contact, a covered interval is present.

3. Sandstone with local interbedded siltstone. Pale yellow brown (10YR 6/2) and pale red (5R 6/2), weathers moderate brown (5YR 3/4) and grayish brown (5YR 3/2); fine- to medium-grained; moderately well sorted subangular to subrounded grains; parallel bedding; average bed thickness: 12 cm, range: 6-20 cm; thin to medium bedded; alpha, beta, and gamma major cross-stratification with 8-15 cm thick lamina sets; local omikron cross-stratification with up to 7 cm thick lamina sets; planar parallel laminae 0.5-4 mm thick; cross laminae 1-3 mm thick; parting lineations; local mud-pebble conglomerate as basal parts of beds up to 4 cm thick; mud pebbles and mud-pebble casts up to 4 cm in diameter; micaceous; slightly ferruginous; feldspathic; mostly silica cemented; locally calcareous; fair porosity (5 to 7%); forms a small strike ridge with local well exposed, near vertical beds. 35.0

Concealed contact: picked at the lowest exposed sandstone bed. Above the contact, fine- to medium-grained sandstones are exposed. Below the contact, a covered interval is present.
2. Covered interval. Probably siltstone and shale (?).
Forms a recessive valley.

Concealed contact: picked at the top of the uppermost exposed bed. Above the contact, a covered interval is present. Below the contact, exposed sandstones, siltstones, shales, and mudrocks are present.

1. Interbedded sandstone, siltstone, shale, and mudrock.
Moderate reddish brown (10R 4/6), grayish red (5R 4/2), and grayish red purple (5RP 4/2), weathers moderate reddish brown (10R 4/6) and dark reddish brown (10R 3/4); very fine- to fine-grained sandstone; laminated to thin bedded; planar to wavy parallel bedding; average bed thickness: 4 cm, range: 1-4 cm; mu, nu, kappa, and lambda cross-stratification; planar parallel laminae 0.5-2 mm thick; wavy discontinuous laminae 1-4 mm thick; cross laminae 1-4 mm thick; local convolute bedding; locally micaceous; locally ferruginous; feldspathic; sandstones are mostly silica cemented; locally calcareous; manganese staining; sandstones weather "brick red" with a pumice-like texture; forms a low strike ridge with recessive beds.

Sharp unconformable contact: picked at the top of the uppermost white siltstone bed containing chert lenses. The contact consists of a 1 meter zone of wavy white shale/siltstone with lenses of chert. Above the contact, reddish brown silstones and fine-grained sandstones are present. Below the contact, a 1 meter siltstone and shale interval that has been replaced by white chert is present.

Quandong Conglomerate

Lithofacies A₃ [Unit R]

1. Interbeds of silicified and chert replaced siltstone, shale, and very fine-grained sandstone. Very pale orange (10YR 5/6) and pale pink (5RP 8/2), weathers light brown (5YR 6/4) and white (N-9); laminated to thin bedded; average bed thickness: 4 cm, range: 1-6 cm; planar parallel laminae 0.5-2 mm thick; wavy discontinuous laminae 1-2 mm thick; local traces of calcite; chert cemented; poor porosity (trace to 4%); forms a recessive slope.

Sharp contact: picked at the top of the uppermost conglomerate bed. Above the contact, cherty siltstones dominate. Below the contact, orthoconglomerates dominate.
Lithofacies A₂ [Unit Q]

4. Orthoconglomerate, conglomeratic sandstone, granular orthoconglomerate, and sandstone. Very pale orange (10R 8/2), weathers light brown (5YR 5/6 and 5YR 6/4); fine- to medium-grained groundmass and sandstone; poorly to moderately well sorted subangular to subrounded groundmass and sandstone grains; lithoclasts consist of subrounded to rounded chert and quartzite up to 5 cm in diameter; lenticular-shaped bedding; medium bedded; average bed thickness: 25 cm range: 10-36 cm; rare cross-stratification; local alpha, beta, and gamma cross-stratification with 10-27 cm thick lamina sets; scour-filled bedding contacts; highly fractured due to nearby faulting; this faulting has destroyed most of the sedimentary structures; lenses of rounded to well rounded, moderately well sorted, granule-sized quartzite and vein quartz; feldspathic; silica cemented; poor to good porosity (trace to 12%), mostly fair porosity (5 to 9%); silica-filled fractures; local honeycomb-type weathering; forms a moderately steep slope with generally well exposed, near vertical beds. 17.0

Gradational contact: picked at the base of the lowest sandstone bed. Above the contact, there exists interbeds of orthoconglomerates, conglomeratic sandstones, and sandstones. Below the contact, orthoconglomerates with gravel-sized clasts dominate. Here sandstones are very rare.

3. Orthoconglomerate and conglomeratic sandstone. Very pale orange (10YR 8/2) and bluish white (5B 9/1), weathers light brown (5YR 5/6 and 5YR 6/4); fine- to coarse-grained sandy groundmass; poorly sorted subrounded grains; contains granule- to pebble-sized (up to 8 cm in diameter) lithoclasts of angular to subrounded chert and quartzite; most lithoclasts are gravel-size; wedging cut-and-fill channels with local lenticular-shaped bedding; average bed thickness: 45 cm, range: 20-65 cm; minor omikron cross-stratification with 15-30 cm thick lamina sets, rare alpha, beta, and gamma cross-stratification with 20-25 cm thick lamina sets; planar parallel laminae 2-8 mm thick; cross laminae (heterogenous composition) 4-10 mm thick; scour-filled bedding contacts; scattered mud pebbles and mud-pebble casts up to 7 cm in diameter; feldspathic; silica cemented; local traces of calcite cement; fair to good porosity (5 to 15%); weathers massive; silica-filled fractures; honeycomb-type weathering; forms a slightly recessive dipslope with local covered intervals. 64.3
Gradational contact through 5 m: picked at the top of the uppermost conglomeratic sandstone bed which contains abundant cross-stratification. Above the contact, cross-stratification is rare. Below the contact, abundant cross-stratification is present.

2. Interbedded orthoconglomerate, conglomeratic sandstone, and sandstone. Very pale orange (10YR 8/2), weathers light brown (5YR 5/6 and 5YR 6/4); fine- to coarse-grained groundmass and sandstone; generally poorly sorted subrounded groundmass and sandstone grains; contains lithoclasts of subangular chert up to 5 cm in diameter and subrounded to rounded quartzite up to 5 cm in diameter; wedging cut-and-fill channels with local lenticular-shaped bedding; average bed thickness: 45 cm, range: 30-60; abundant omikron cross-stratification with 10-40 cm thick lamina sets, local alpha, beta, and gamma cross-stratification with 15-25 cm thick lamina sets; planar parallel laminae (heterogeneous and homogeneous compositions) 2-7 mm thick; cross laminae (heterogeneous composition) 2-10 mm thick; scour-filled bedding contacts; minor mud-pebble conglomerate as basal parts of beds up to 2 cm thick; mud pebbles and mud-pebble casts up to 5 cm in diameter; local load deformation; feldspathic; silica cemented; fair porosity (5 to 8%); silica-filled fractures; honeycomb-type weathering; forms a prominent ridge top and a prominent dipslope.

Gradational contact: picked at the top of the sandstone bed which marks the change in the type of orthoconglomerates present. Above the contact, the orthoconglomerates are chiefly subangular gravel beds. Below the contact, the orthoconglomerates contain mostly rounded granule-sized lithoclasts.

1. Interbedded orthoconglomerate, granular orthoconglomerate, conglomeratic sandstone, and sandstone. Pale red (10R 6/2), dusky red (5R 3/4), and grayish pink (5R 8/2), weathers light brown (5YR 5/6 and 5YR 6/4); Sandstone: fine- to medium-grained, local medium- to coarse-grained, poorly sorted subangular grains, lenticular-shaped bedding, medium bedded, average bed thickness: 15 cm, range: 12-35 cm, rare cross-stratification, omikron major cross-stratification with 6-18 cm thick lamina sets, local xi cross-stratification with 6-10 cm thick lamina sets, minor alpha, beta, and gamma cross-stratification 5-25 cm thick lamina sets, planar parallel laminae 2-4 mm thick, cross laminae 2-5 mm thick, feldspathic, silica cemented, locally ferruginous, fair to good porosity (6 to 15%); Granular orthoconglomerate and granular conglomeratic sandstone: locally contains fine- to medium-grained sandy groundmass, poorly- to well-sorted
groundmass, granule-sized grains are rounded and generally well-sorted, granules consist mostly of vein quartz and quartzite with minor chert, lenticular-shaped bedding, medium bedded, average bed thickness: 20 cm, range: 9-40 cm, feldspathic, silica cemented, good porosity (10 to 15%); Orthoconglomerate and conglomeratic sandstone: minor constituent of this unit with only local occurrences, fine-to coarse-grained sandy groundmass, poorly sorted subrounded grains, contains lithoclasts of subrounded quartzite up to 6 cm in diameter and subangular to subrounded chert up to 5 cm in diameter, wedging cut-and-fill channels with lenticular-shaped bedding, average bed thickness: 30 cm, range: 12-40 cm, rare cross-stratification, omikron, alpha, beta, and gamma cross-stratification with 5-25 cm thick lamina sets, planar parallel laminae (heterogeneous composition) 2-5 mm thick, cross laminae (heterogeneous composition) 2-10 mm thick, scour-filled bedding contacts, rare load deformation, rare slumped bedding and cross-stratification, scattered mud pebbles and mud-pebble casts up to 6 cm in diameter, locally ferruginous, feldspathic, silica cemented, fair to good porosity (6 to 15%); silica cemented fractures; honeycomb-type weathering; forms a moderately steep slope with generally well exposed outcrops and local cliffs.

Sharp erosional contact: picked at the base of the lowest conglomerate bed. Above the contact, granular orthoconglomerates dominate. Below the contact, fine- to coarse-grained sandstones dominate.

**Lithofacies A$_1$ [Unit P]**

2. Sandstone. Very pale orange (10YR 8/2) and pale reddish purple (5RP 6/2), weathers the same; fine- to coarse-grained; poorly to moderately well sorted subangular to subrounded grains; lenticular-shaped bedding; medium bedded, average bed thickness: 15 cm, range: 7-18 cm; planar parallel laminae 4-10 mm thick; slightly ferruginous; feldspathic; poorly cemented by silica; good porosity (10-15%); highly weathered; forms a recessive, mostly concealed, gentle slope.

Gradational contact: picked at the top of the uppermost granular orthoconglomerate bed. Above the contact, fine- to medium-grained sandstones dominate. Below the contact, medium- to coarse-grained sandstones are interbedded with granular orthoconglomerates.
1. Sandstone interbedded with minor granular orthoconglomerate. Grayish red purple (5RP 4/2) and pale pink (5RP 8/2), weathers moderate orange pink (5YR 8/4); medium- to coarse-grained groundmass and sandstone; poorly sorted subrounded grains; lithoclasts consist of granule- to pebble-sized (up to 0.3 cm in diameter) subangular to subrounded chert and subrounded quartzite; lenticular-shaped bedding; average bed thickness: 12 cm, range: 7-18 cm; planar parallel laminae 4-10 mm thick; traces of glauconite; feldspathic; slightly ferruginous; silica cemented; slightly ferruginous; silica cemented; poorly cemented; good porosity (10 to 15%); forms a recessive, mostly concealed, gentle slope.

Concealed contact: picked at the base of the lowest exposed sandstone bed. Above the contact, medium- to coarse-grained sandstones are present. Below the contact, Tertiary (?) silica cemented (silcrete), rounded, conglomerate boulders are present along with alluvium.

(?) Formation (Concealed by Alluvium)

1. Conglomerate and alluvium. Moderate reddish brown (10R 6/6), weathers pale red (5R 6/8); fine-grained sandy groundmass; poorly sorted subangular grains; contains angular to subangular quartzite and chert lithoclasts up to 4 cm in diameter; massive; weathers into rounded irregular cobble- to boulder-sized masses; feldspathic; ferruginous; traces of calcite; silica cemented; poor to fair porosity (trace to 5%); forms a recessive, concealed, gentle slope and valley with local conglomerate boulders lying on the surface.

Concealed contact: picked at the base of the lowest conglomerate exposure. Above the contact, a covered interval with rounded conglomerate boulders is present. Below the contact, a covered interval with local chert beds is present.

Bitter Springs Formation

1. Covered interval with local chert-replaced siltstone and a local low-lying ridge of dolostone. Probably poorly cemented, chert-replaced sandstones, siltstones, and shales represent contact of the Bitter Springs flowage; Dolostone: bluish-gray unweathered and weathered colors; fine-crystalline to micritic; brecciated and contorted bedding; columnar stromatolites; poor porosity; forms a mostly covered recessive covered valley.
Concealed contact: picked at the top of the uppermost exposed sandstone bed. Above the contact, a mostly covered interval is present. Below the contact, fine- to medium-grained sandstones face and dip to the south. This represents a change in the direction the beds dip. Above the covered interval, which lies above this contact, the direction of bedding dip is towards the north. Probably a thrust fault here.

Areyonga Formation

1. Sandstone with lenses of conglomeratic sandstone.
   Grayish pink (5R 8/2) and moderate reddish orange (10R 6/6), weathers light brown (5YR 5/6); Sandstone: fine- to medium-grained, moderately well sorted subrounded grains, normally graded bedding (cross laminated coarse-grained sandstones --> planar parallel laminated fine- to medium-grained sandstones), lenticular-shaped bedding, medium bedded, average bed thickness: 25 cm, range: 20-35 cm, omikron major cross-stratification with 6-20 cm thick laminae sets; scour-filled bedding contacts, planar parallel laminae 3-9 mm thick, cross laminae (heterogeneous and homogeneous composition) 3-7 mm thick, feldspathic, silica cemented, local traces of calcite cement, poorly cemented, good porosity (10 to 15%); Conglomeratic sandstone: medium- to coarse-grained sandy groundmass, poorly sorted, contains lithoclasts of subangular to subrounded quartzite and minor subangular chert, lithoclasts range from granule- to pebble-sized (up to 4 cm in diameter), normally graded bedding (conglomeratic sandstone --> cross-stratified coarse-grained sandstone --> parallel laminated fine- to medium-grained sandstone), lenticular-shaped bedding, medium bedded, average bed thickness: 30 cm, range: 25-50 cm, omikron cross-stratification with up to 20 cm thick laminae sets, planar parallel laminae 3-9 mm thick, cross laminae (heterogeneous composition) 3-7 mm, feldspathic, locally calcareous; silica cemented, poorly cemented, good porosity (10 to 15%); contains silicafilled fractures; forms a small, somewhat prominent strike ridge.

Concealed contact: picked at the base of the lowest exposed sandstone bed. Above the contact, fine- to medium-grained sandstones are exposed. Below the contact, a covered interval is present.

Concealed interval. Covered by unconsolidated sand.
Section M - Tempe Downs South Section

Location: Approximately 1 km southeast of the Tempe Downs North section, 10 km northeast of Tempe Downs Homestead, and 16 km north-northwest of White Horse Gap, on the Henbury 1:250,000 scale geologic map, at 132° 31' E longitude and 24° 21' S latitude (Australian Grid Coordinates: 1 96 9500 y N, 56 8000 y E, Zone 4). The section is north of the Househill Range and west of Deception Creek on the southern limb of an unnamed horseshoe-shaped strike ridge. Beds of the Quandong Conglomerate face and dip to the south.


Formation

<table>
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<tr>
<th>Formation (Concealed by Quaternary alluvium)</th>
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</table>

Covered contact: picked at the base of a gentle to moderate slope. Above the contact, a covered interval is present that forms a flat valley. Below the contact, scattered outcrops of conglomeratic sandstones are exposed along strike.

Quandong Conglomerate

Lithofacies $A_2$ [Unit Q]

<table>
<thead>
<tr>
<th>Lithofacies</th>
<th>Thickness</th>
</tr>
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<tbody>
<tr>
<td>Orthoconglomerate and conglomeratic sandstone. Grayish pink (5R 8/2), weathers light brown (5YR 6/4); medium- to coarse-grained sandy groundmass; poorly sorted subrounded grains; contains granule- to pebble-sized (up to 5 cm in diameter) lithoclasts of subangular to subrounded chert and quartzite; most lithoclast are 0.5-1 cm in diameter; lenticular-shaped bedding; medium bedded; feldspathic; silica cemented; good porosity (10 to 15%); forms a mostly concealed dipslope.</td>
<td>26.5</td>
</tr>
</tbody>
</table>

Gradational contact: picked at the top of the uppermost sandstone bed which contains less than 5% lithoclasts. Above the contact, orthoconglomerates and conglomeratic sandstones are present. Below the contact, fine- to medium-grained sandstones are present.
4. Sandstone. Grayish pink (5R 8/2), weathers light brown (5YR 6/4); fine- to medium-grained; poorly to moderately well sorted subangular grains; lenticular-shaped bedding; thin to medium bedded; planar parallel laminae 1-4 mm thick; feldspathic; silica cemented; fair porosity (5%); forms a moderately steep dipslope.

Gradational contact: picked at the base of the lowest sandstone bed which contains less than 5% lithoclasts. Above the contact, fine- to medium-grained sandstones dominate. Below the contact, orthoconglomerates are present.

3. Orthoconglomerate with minor conglomeratic sandstone. Moderate orange pink (1OR 7/4), pale reddish purple (5RP 6/2), and light grayish brown (5YR 6/1), weathers light brown (5YR 6/4); medium- to coarse-grained sandy groundmass; poorly sorted subangular grains; contains granule- to pebble-sized (up to 6 cm in diameter) lithoclasts of subangular to subrounded chert and quartzite; most lithoclasts are gravel-size; wedging cut-and-fill channels with local lenticular-shaped bedding; medium bedded; average bed thickness: 40 cm range: 28-60 cm; rare cross-stratification; omikron with local alpha, beta, and gamma cross-stratification with up to 18 cm thick lamina sets; scattered mud pebbles and mud-pebble casts up to 5 cm in diameter; feldspathic; silica cemented; poorly cemented; good porosity (10 to 15%); silica-filled fractures; forms a moderately steep dipslope.

Gradational contact: picked at the top of the uppermost bed which contains abundant cross-stratification. Above the contact cross-stratification is rare. Below the contact, cross-stratification is very common.

2. Orthoconglomerate with local interbeds of conglomeratic sandstone and sandstone. Moderate orange pink (1OR 7/4), pale reddish purple (5RP 6/2), and light grayish brown (5YR 6/4), weathers light brown (5YR 6/4); medium- to coarse-grained sandy groundmass and sandstone; poorly sorted subangular grains; lithoclasts consist of mostly subangular to subrounded gravel-size chert and quartzite up to 6 cm in diameter; local normally graded bedding (conglomerate --> poorly sorted coarse-grained sandstone and conglomeratic sandstone --> cross-stratified medium-grained sandstone); wedging cut-and-fill channels with local lenticular-shaped bedding; mostly medium bedded; average bed thickness: 40 cm, range: 28-60 cm; abundant pi and omikron cross-stratification with up to 18 cm thick lamina sets; minor alpha, beta, and gamma cross-stratification with up to 18 cm thick lamina sets; planar parallel laminae (heterogeneous composition)
4-12 mm thick; cross laminae (heterogeneous composition)
4-10 mm thick; rare parting lineations; mud pebbles and
mud-pebble casts up to 7 cm in diameter; feldspathic;
silica cemented; good porosity (10 to 12%); silica-
filled fractures; rare honeycomb-type weathering; forms
a prominent ridge top and a prominent dipslope with well
exposed beds.

Gradational contact: picked at the base of the lowest conglomeratic
bed which contains abundant cross-stratification. Above the contact,
abundant cross-stratification is present. Below the contact, the beds
are rarely cross-stratified.

1. Orthoconglomerate and conglomeratic sandstone. Pale red
(10R 6/2), moderate reddish brown (10R 4/6), and dark
reddish brown (10R 3/4), weathers pale reddish purple
(5RP 6/2), moderate brown (5YR 3/4), and light brown
(5YR 6/4); medium- to coarse-grained sandy groundmass;
poorly sorted subangular grains; contains angular to
subrounded lithoclasts of chert and quartzite up to 5 cm
in diameter (mostly angular gravel-sized lithoclasts);
wedging cut-and-fill channels with local lenticular-
shaped bedding; medium to thick bedded; average bed
thickness: 45 cm, range: 25-65 cm; rare cross-stratifi-
cation; pi and omikron major cross-stratification with
15-23 cm thick lamina sets, minor alpha, beta, and gamma
cross-stratification with 6-18 cm thick lamina sets;
planar parallel laminae (heterogeneous composition)
3-12 mm thick; cross laminae (heterogeneous composition)
3-9 mm thick; rare clay partings; scour-filled bedding
contacts; scattered mud pebbles and mud-pebble casts up
to 13 cm in diameter; feldspathic; slightly ferruginous;
silica cemented; local purplish black manganese
staining; good porosity (9 to 15%); weathers massive;
local silica-filled fractures; forms a moderately steep
talus slope with local well exposed outcrops.

Concealed contact: picked at the base of the lowest exposed conglomerate
bed. Above the contact, orthoconglomerates dominate. Below the contact,
a covered interval is present.

(?) Formation (Concealed by Quaternary alluvium)

1. Covered interval. Concealed by vegetation and a deep
sandy soil. Probably a poorly cemented sandstones and/or
siltstones and shales. Forms a recessive valley with no
exposed outcrops.
**Section N - Tempe Downs Central Section**

**Location:** Approximately 10 km northeast of Tempe Downs Homestead and 17 km north-northwest of White Horse Gap, on the Henbury 1:250,000 scale geologic map, between the Tempe Downs North and Tempe Downs South sections, at 132° 31' E longitude and 24° 20' S latitude (Australian Grid Coordinates: 1 97 0500 y N, 56 8000 y E, Zone 4). The section is north of the Househill Range and west of Deception Creek in an east-west strike ridge that is part of the Deception Creek structure. Beds of the Areyonga Formation face and dip south.

**Measured by:** J. O. Phillips and Leon Amadio with a 60-meter tape, two Jacob staffs, and an Abney hand level. Measured upsection from north to south, 26 August 1982.

<table>
<thead>
<tr>
<th>Formation</th>
<th>Thickness (meters)</th>
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<tbody>
<tr>
<td>(? Formation (Concealed by Quaternary alluvium))</td>
<td></td>
</tr>
<tr>
<td>1. Covered interval. Forms a concealed valley.</td>
<td>99.6</td>
</tr>
</tbody>
</table>

Concealed contact: picked at the base of a gentle slope which contains locally exposed conglomeratic sandstones. Above the contact, a covered interval is present. Below the contact, interbedded conglomeratic sandstones and sandstones are present.

**Areyonga Formation**

**Lithofacies E**

4. Interbedded conglomeratic sandstone and sandstone.
Grayish red (10R 4/2) and grayish red purple (5RP 4/2), weathers grayish red (5R 4/2) and light brown (5YR 6/4); fine- to coarse-grained groundmass and sandstone (mostly medium-grained); poorly to moderately well sorted subangular to subrounded grains; lithoclasts consist of angular to subangular chert up to 6 cm in diameter and subangular quartzite up to 6 cm in diameter; most lithoclasts are 1-2 cm gravel-size; lenticular-shaped bedding with local wedging cut-and-fill channels; medium to thick bedded; average bed thickness: 50 cm, range: 20-200 cm; pi, omikron, and xi cross-stratification; planar parallel laminae (homogeneous and heterogeneous compositions) 1-7 mm thick; cross laminae (heterogeneous composition) 2-5 mm thick; local load deformation; minor slumped bedding and cross-stratification; scattered mud pebbles and mud-pebble casts up to 4 cm in diameter;
feldspathic; ferruginous; silica cemented; poor to fair porosity (trace to 9%); forms a moderately steep dipslope with mostly well exposed outcrops. 30.6

Sharp erosional contact: picked at the base of the lowest conglomeratic sandstone bed. Above the contact, interbedded sandstones and conglomeratic sandstones dominate. Below the contact, sandstones with interbedded siltstones dominate.

3. Sandstone interbedded with siltstone and shale. Grayish red purple (5RP 4/2), weathers grayish red (5R 4/2); Sandstone: very fine- to medium-grained, poorly sorted subangular grains, wavy parallel to lenticular-shaped bedding, laminated to medium bedded, average bed thickness: 9 cm, range: 1-25 cm, alpha, kappa, and lambda cross-stratification, local flaser bedding, planar parallel laminae 1-5 mm thick, cross laminae 1-4 mm thick, wavy discontinuous laminae 0.5-2 mm thick, scattered mud pebbles near the base of the unit up to 3 cm in diameter, locally scattered angular to subangular chert and quartzite pebbles near the base of the unit up to 3 cm in diameter, feldspathic, ferruginous, silica cemented, traces of glauconite, poor porosity (trace); Siltstone and shale: laminated bedding, poor porosity (trace); Forms a recessive, mostly concealed gentle slope. 6.1

Gradational contact: picked at the top of the uppermost conglomeratic sandstone bed. Above the contact, recessive fine-grained sandstones interbedded with siltstones and shales are present. Below the contact, well exposed conglomeratic sandstones dominate.

2. Orthoconglomerate, conglomeratic sandstone, and sandstone. Grayish red (10R 4/2) and grayish red purple (5RP 4/2), weathers grayish red (5R 4/2) and light brown (5YR 6/4 and 5YR 5/6); Orthoconglomerate and conglomeratic sandstone: fine- to medium-grained sandy groundmass, poorly sorted subangular to subrounded grains, lithoclasts consist of angular to subangular chert up to 7 cm in diameter and subangular to subrounded quartzite up to 7 cm in diameter, most lithoclasts are 1-2 cm gravel-sized pebbles, lenticular-shaped bedding with local wedging cut-and-fill channels, thin to thick bedded, average bed thickness: 40 cm, range: 5-76 cm, alpha, beta, and gamma cross-stratification with up to 18 cm thick lamina sets, planar parallel laminae 1-10 mm thick, cross laminae (heterogeneous composition) 2-7 mm thick, scour-filled bedding contacts, local clay partings, local load deformation, minor slumped bedding and cross-stratification, scattered mud pebbles and mud-pebble casts up to 6 cm in
diameter, feldspathic, ferruginous, silica cemented, fair porosity (6 to 9%); Sandstone: fine- to medium-grained, poorly sorted subangular to subrounded grains, lenticular-shaped bedding, medium bedded, average bed thickness: 25 cm, range: 5-50 cm, wavy irregular scour-filled bedding contacts, kappa and lambda major cross-stratification, local xi, alpha, beta, and gamma cross-stratification with 4-18 cm thick lamina sets, planar parallel laminae 1-9 mm thick, cross laminae 2-5 mm thick, wavy discontinuous laminae 2-12 mm thick, local flaser bedding, climbing ripples, minor clay partings, local load deformation, slumped bedding and cross-stratification, rare ball-and-pillow structures, mud pebbles and mud-pebble casts up to 6 cm in diameter, feldspathic, ferruginous, silica cemented, fair porosity (6 to 9%); forms a prominent dipslope with well exposed outcrops.  

Sharp contact: picked at the base of the lowest conglomeratic sandstone bed. Above the contact, orthoconglomerates and conglomeratic sandstones dominate. Below the contact, siltstones and shales with local sandstones are present.

1. Siltstone and shale with local sandstone interbeds. Grayish orange (10YR 7/4) and grayish red (5R 4/2), weathers moderate brown (5R 3/4) and light brown (5YR 5/6); Siltstone and shale: laminated bedding, planar parallel laminae 1-4 mm thick, wavy discontinuous laminae 1-5 mm thick, micaceous, poor porosity (trace); Sandstone: found mostly at the top and base of the unit, very fine- to coarse-grained (mostly medium-grained), local coarse-sand to granule-sized lenses, poorly sorted subangular grains, lenticular-shaped bedding, thin to medium-bedded, average bed thickness: 9 cm, range: 4-15 cm, mu and nu cross-stratification, planar parallel laminae 1-4 mm thick, cross laminae 1-4 mm thick, feldspathic, silica cemented, ferruginous, poorly cemented, good porosity (10 to 15%); forms a recessive ridge top and recessive dipslope with only local exposed outcrops.  

Gradational contact: picked at the top to the uppermost conglomeratic sandstone bed. Above the contact, poorly cemented sandstones grade upward into siltstones and shales. Below the contact, orthoconglomerates and conglomeratic sandstones are present.

**Lithofacies D**

4. Orthoconglomerate, conglomeratic sandstone, and sandstone. Grayish red (5R 4/2), weathers moderate brown (5R 3/4) and light brown (5YR 5/6); fine- to coarse-
grained groundmass and sandstone (mostly medium-grained); poorly sorted subangular grains; lithoclasts consist of subangular to subrounded quartzite up to 15 cm in diameter and minor subangular chert up to 4 cm in diameter; most lithoclasts are gravel-sized (1-2 cm in diameter) pebbles; some of the quartzite pebbles and cobbles are foliated; lenticular-shaped bedding; medium to thick bedded; average bed thickness: 40 cm, range: 20-100 cm; alpha, beta, and gamma cross-stratification with up to 20 cm thick lamina sets; planar parallel laminae 1-4 mm thick; cross laminae (base tangent and angular heterogeneous composition) 2-6 mm thick; local mud-pebble conglomerate as basal parts of beds up to 7 cm thick; scattered mud pebbles and mud-pebble casts up to 5 cm in diameter; feldspathic; locally ferruginous; silica cemented; fair to good porosity (8 to 12%); silica-filled fractures; local honeycomb-type weathering; forms a prominent strike ridge with local cliffs.

Sharp erosional contact: picked at the base of the lowest conglomeratic sandstone bed. Above the contact, orthoconglomerates and conglomeratic sandstones are present. Below the contact, interbedded siltstones and very fine-grained sandstones are present.

3. Siltstone and shale with local very fine-grained sandstone. Grayish orange (10YR 7/4), pale reddish purple (5RP 6/2), grayish red purple (5RP 4/2), and grayish red (5R 4/2), weather moderate brown (5YR 3/4), grayish orange (10YR 7/4), moderate orange pink (10R 7/4), and pale reddish purple (5RP 6/2); rare scattered chert pebbles up to 1 cm in diameter; laminated to thin bedded; average bed thickness: 4 cm, range: 1-20 cm; rare cross-stratification, alpha, beta, and gamma cross-stratification with up to 10 cm thick lamina sets; planar parallel laminae 1-6 mm thick; cross laminae 1-4 mm thick; local load deformation; micaceous; traces of glauconite; feldspathic; slightly ferruginous; silica cemented; poor to fair porosity (trace to 7%); local manganese staining; forms a recessive dipslope which is generally covered by talus.

Gradational contact: picked at the top of the uppermost medium-grained sandstone bed. The contact is chosen where the sandstones form a prominent dipslope. Above the contact, recessive siltstones and shales dominate. Below the contact, well exposed medium-grained sandstones are present.
2. Sandstone. Moderate reddish brown (10R 5/4), weathers light brown (5YR 6/4 and 5YR 5/6); fine- to medium-grained; poorly to moderately well sorted subrounded grains; contains lenses of coarse-grained sandstone; rare chert and quartzite lithoclast up to 2 cm in diameter; lenticular-shaped bedding; medium bedded; average bed thickness: 15 cm, range: 10-22 cm; minor alpha, beta, and gamma cross-stratification with 15-20 cm thick lamina sets; planar parallel laminae 1-6 mm thick; cross laminae 2-5 mm thick; load deformation; slumped bedding; local ball-and-pillow structures; mud pebbles and mud-pebble casts up to 4 cm in diameter; traces of glauconite; feldspathic; locally ferruginous near the top of the unit; silica cemented; good porosity (10%); locally weathers massive; forms a prominent dipslope with generally well exposed outcrops.

3.4 98.6

Gradational contact: picked at the top of the uppermost conglomeratic sandstone bed which contains more than 5% lithoclasts. Above the contact, fine- to medium-grained sandstones dominate. Below the contact, conglomeratic sandstones are present.

1. Orthoconglomerate and conglomeratic sandstone. Moderate reddish brown (10R 4/6) and pale reddish brown (10R 5/4), weathers light brown (5YR 5/6 and 5YR 6/4); fine- to coarse-grained sandy groundmass; poorly sorted subangular grains; contains granular to cobble-sized lithoclasts up to 30 cm in diameter; lithoclasts consist of angular to subangular quartzite, chert, vein quartz, and fragments with silicified ooids; most lithoclasts are gravel-sized and present in very irregular shaped lenses; lenticular-shaped bedding; medium to thick bedded; average bed thickness: 30 cm, range: 13-50 cm; wavy irregular scour-filled bedding contacts; cross-stratification typically absent; rare flaser bedding; planar parallel laminae (heterogeneous and homogeneous compositions) 2-7 mm thick; wavy (stacked in-phase) continuous laminae 1-6 mm thick; parting lineations; local clay partings; minor load deformation; slumped bedding; rare, ball-and-pillow structures; feldspathic; traces of glauconite; silica cemented; good porosity (10 to 15%); weathers massive; silica-filled fractures; local honeycomb-type weathering; forms a prominent ridge top and cliffs.

15.8 114.4

Sharp erosional contact: picked at the base of the lowest conglomeratic sandstone bed. Above the contact, conglomeratic sandstones are present. Below the contact, recessive, manganese stained, siltstones, shales, and very fine-grained sandstones are present.
Lithofacies C

1. Interbedded siltstone, shale, sandstone and conglomeratic mudstone. Moderate red (5R 4/6), dark reddish brown (10R 3/4), pale yellow orange (10YR 8/6), dusky red (5R 3/4) and grayish red (5R 4/2), weathers very dark red (5R 6/2), dusky brown (5YR 2/2), and dark yellow orange (10YR 6/6); very fine- to fine-grained sandstone; poorly sorted subangular grains; scattered subangular chert and quartzite granule to 1 cm pebble-size; lenticular-shaped bedding; laminated to thin bedded; average bed thickness: 4 cm, range: 1-12 cm; planar parallel laminae 0.5-4 mm thick; traces of glauconite; feldspathic; ferruginous; manganese stained siltstones and shales; trace of silica cement; poor porosity (trace); forms a recessive bench with poorly exposed outcrops.

Sharp contact: picked at the base of the lowest siltstone/shale bed. Above the contact, recessive siltstones and shales dominate. These beds are commonly stained with manganese. Below the contact, fine- to medium-grained, bioturbated sandstones dominate.

Lithofacies B

2. Sandstone. Grayish red purple (5RP 4/2) and moderate yellow (5Y 7/6), weathers light brown (5YR 5/6 and 5YR 6/4) and dark reddish brown (10R 3/4); fine- to medium-grained, local lenses of medium- to coarse-grained; poorly to moderately well sorted subrounded to rounded grains; lenticular-shaped bedding; medium to thick bedded; scour-filled bedding contacts; alpha and beta cross-stratification; planar parallel laminae 1-5 mm thick; cross laminae 1-4 mm thick; local clay partings; minor load deformation; slumped bedding; top of the unit is bioturbated: vertical and horizontal burrows; local mud-pebble conglomerate as basal parts of beds up to 4 cm thick; mud pebbles and mud-pebble casts up to 5 cm in diameter; traces of glauconite; feldspathic; ferruginous; silica cemented; fair porosity (5%); silica-filled fractures; honeycomb-type weathering; forms a moderate to steep slope with local cliffs.

Gradational contact: picked at the top of the uppermost conglomeratic sandstone bed. Above the contact, bioturbated sandstones are present. Below the contact, conglomeratic sandstones interbedded with fine- to medium-grained sandstones dominate.
1. Conglomeratic sandstone and sandstone. Pale yellow orange (10YR 8/6), very pale orange (10YR 8/2), and grayish red purple (5RP 4/2), weathers dark yellow orange (10YR 6/6), moderate reddish brown (10R 4/6), dark reddish brown (10R 3/4), and light brown (5YR 6/4); fine- to medium-grained sandy groundmass and sandstone; local medium- to coarse-grained sandy lenses; poorly to moderately well sorted subrounded to rounded grains; angular chert and quartzite lithoclasts up to 3 cm in diameter; lenticular-shaped bedding; medium to thick bedded; average bed thickness: 35 cm, range: 20-80 cm; wavy irregular scour-filled bedding contacts; bedding surfaces hard to distinguish; cross-stratification not observed (this may be the result of weathering rather than a depositional feature); wavy irregular laminae 3-15 mm thick; planar parallel laminae 3-15 mm thick; traces of glauconite; feldspathic; locally ferruginous; silica cemented; fair to good porosity (6 to 10%); weathers massive; silica-filled fractures; honeycomb-type weathering surfaces; forms a moderately steep slope with good outcrop exposures.

Concealed contact: picked at the base of the lowest exposed sandstone bed. Above the contact, fine- to medium-grained sandstones are present. Below the contact, a covered interval is present which forms a recessive valley.

Lithofacies A

2. Covered interval. Concealed by vegetation and a thick sandy soil. Probably poorly cemented sandstone and/or siltstone and shale; forms a recessive valley.

Concealed contact: picked at the top of the uppermost exposed sandstone bed. This bed outcrops in a dry stream bed or gully that cuts the valley. Above the contact, a covered interval is present. Below the contact, a zone of poorly cemented sandstones are exposed in the creek bed.

1. Sandstone with local granular conglomeratic sandstone and conglomeratic sandstone interbeds. Grayish pink (5R 8/2) and moderate reddish orange (10R 6/6), weathers light brown (5YR 5/6); Sandstone: fine- to coarse-grained, poorly sorted subrounded to rounded grains, lenticular-shaped bedding, medium bedded, average bed thickness: 27 cm, range: 20-50 cm, scour-filled bedding contacts, omikron cross-stratification with up to 16 cm thick lamina sets, planar parallel laminae 3-9 mm thick, cross laminae 3-7 mm thick, feldspathic, calcareous, locally silica cemented, fair to good porosity (5 to 12%); Granular conglomeratic sandstone and conglomeratic
sandstone: fine- to coarse-grained sandy groundmass, lenses of moderately well to well sorted, rounded granule-sized grains, lithoclasts range from granule-size up to 4 cm size pebbles and consist of subangular to subrounded chert and quartzite, lenticular-shaped bedding, average bed thickness: 20 cm, range: 15-30 cm, planar parallel laminae (heterogeneous composition) 2-17 mm thick, feldspathic, calcareous, locally silica cemented, fair to good porosity (6 to 12%); silica-filled fractures; forms a low-lying strike ridge and recessive valley. . . . . . . . . . . . . . . . . . . 26.7

Concealed contact: picked at the base of the lowest exposed sandstone bed. Above the contact, locally exposed calcareous sandstones are present. Below the contact, a covered valley is present.

(?) Formation (Concealed by Quaternary alluvium)

1. Covered interval. Concealed by vegetation and a thick sandy soil. Probably poorly cemented sandstone and/or siltstone and shale; forms a recessive valley. . . .
Section O - Deception Creek Section

Location: Approximately 15 km northeast of Tempe Downs Homestead and 16 km north of White Horse Gap, Northern Territory, Australia, on the Henbury 1:250,000 scale geologic map, at 132° 34' E longitude and 24° 20' S latitude (Australian Grid Coordinates: 197 1500 y N, 57 3000 y E, Zone 4). The section is north of the Househill Range and 1.5 km west of Deception Creek in an east-west strike ridge that is part of the Deception Creek anticline. Beds of the Areyonga Formation face and dip south.

Measured by: J. O. Phillips and John Cullen with a 60-meter tape, two Jacob staffs, and an Abney hand level. Measured upsection from north to south, 6 September 1982.

Formation

<table>
<thead>
<tr>
<th>Formation (Concealed by Quaternary alluvium)</th>
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<tbody>
<tr>
<td>1. Covered valley. Concealed by vegetation and a thick sandy soil.</td>
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</tbody>
</table>

Concealed contact: picked at the top of the uppermost exposed sandstone bed. Above the contact, a broad covered valley is present. Below the contact, medium- to coarse-grained sandstones form a prominent dipslope.

Areyonga Formation

Lithofacies D

| 2. Sandstone with rare interbeds of conglomeratic sandstone. Grayish orange (10YR 7/4), pale yellow orange (10YR 8/6), and very pale orange (10YR 8/2), weathers light brown (5YR 5/6 and 5YR 6/4); medium- to coarse-grained; poorly sorted subangular to rounded grains; lenses of conglomeratic sandstone containing angular chert up to 4 cm in diameter and quartzite up to 3 cm in diameter lithoclasts; lenticular-shaped bedding; wavy irregular scour-filled bedding contacts; average bed thickness: 35 cm, range: 20-60 cm; minor alpha and beta cross-stratification; planar parallel laminae 1-5 mm thick; cross laminae 1-4 mm thick; feldspathic; traces of glauconite; silica cemented; locally calcareous; good porosity (8 to 15%); silica-filled fractures; local honeycomb-type weathering; forms a prominent strike ridge. | 18.1 |
Gradational contact: picked at the base of the lowest well exposed sandstone. Above the contact, medium- to coarse-grained sandstones form a prominent ridge with a distinctive dipslope. Below the contact, very fine- to coarse-grained sandstones form a recessive valley and talus slope.

1. Sandstone with local lenses of conglomeratic sandstone. Grayish orange pink (5YR 7/2) and pale yellow orange (10YR 8/6), weathers light brown (5YR 6/4) and grayish orange (10YR 7/4); very fine- to coarse-grained (mostly medium-grained); poorly sorted subangular to rounded grains; local lenses of coarse-grained sandstone and granular orthoconglomerate; lithoclasts consist of subangular chert and quartzite; lenticular-shaped bedding; scour-filled bedding contacts; average bed thickness: 15 cm, range: 8-20 cm; alpha, beta, and gamma major cross-stratification, planar parallel laminae 1-4 mm thick; cross laminae 1-3 mm thick; traces of glauconite; feldspathic; silica cemented; locally calcareous; traces of manganese staining; fair to good porosity (5 to 10%); abundant silica-filled fractures; abundant honeycomb-type weathering surfaces; forms a recessive valley and talus slope. 20.3

Gradational contact: picked at the top of the uppermost sandstone bed which marks the top of a prominent dipslope. Above the contact, a recessive valley and talus covered slope is present. Below the contact, fine- to coarse-grained sandstones form a prominent dipslope.

Lithofacies C

3. Sandstone and conglomeratic sandstone. Pale red (5R 6/2) and dark yellow orange (10YR 6/6), weathers pale red (10R 6/2) and light brown (5YR 6/4); fine- to coarse-grained (mostly medium-grained); poorly sorted subangular to rounded grains; local lenses of coarse-grained sandstone to granular and pebble-sized conglomeratic sandstone; lithoclasts consist of angular to subangular chert and quartzite up to 6 cm in diameter; scattered lenses of gravel-sized chert; lenticular-shaped bedding; scour-filled bedding contacts; average bed thickness: 20 cm, range: 10-30 cm; omikron, alpha, beta, and gamma cross-stratification; planar parallel laminae 1-5 mm thick; wavy parallel laminae (stacked out-of-phase) 4-12 mm thick; scattered mud pebbles and mud-pebble casts up to 3 cm in diameter; traces of glauconite; feldspathic; silica cemented; locally calcareous; poor to fair porosity (2 to 6%); abundant silica-filled fractures; local honeycomb-type weathering surfaces; forms a series of prominent benches with distinctive dipslopes and a prominent ridge top. 19.9
Sharp contact: picked at the base of the lowest exposed sandstone bed. Above the contact, fine- to coarse-grained sandstones form a prominent ridge top. Below the contact, a recessive ridge crest is present which is mostly covered.

2. Sandstone and conglomeratic sandstone. Grayish orange (10YR 7/4), weathers light brown (5YR 5/6) and pale yellow brown (10YR 6/2); fine- to medium-grained (mostly fine-grained); local lenses of coarse-grained sand and/or up to gravel-sized grains and lithoclasts; lithoclasts consist of angular to subangular chert; planar parallel laminae 1-6 mm thick; scattered mud pebbles up to 2 cm in diameter; feldspathic; silica cemented; locally calcareous; fair to good porosity (7 to 15%); forms a recessive ridge crest which is mostly covered.

Gradational contact: picked at the top of the uppermost exposed conglomeratic sandstone bed. Above the contact, a recessive interval is present. Below the contact, orthoconglomerates and conglomeratic sandstones dominate.

1. Orthoconglomerate and conglomeratic sandstone. Moderate orange pink (5YR 8/4) and pale yellow orange (10YR 8/6), weathers grayish orange (10 YR 7/4) and moderate orange pink (10YR 8/4); fine- to coarse-grained sandy groundmass; very poorly sorted subangular to rounded grains; lithoclasts consist of gravel-sized angular to subangular chert and quartzite; lenticular-shaped bedding; scour-filled bedding contacts; average bed thickness: 22 cm, range: 10-30 cm; minor alpha, beta, and gamma cross-stratification; planar parallel laminae (heterogeneous composition) 2-10 mm thick; scattered mud pebbles and mud-pebble casts up to 2 cm in diameter; feldspathic; silica cemented; locally calcareous; good porosity (10 to 12%); silica-filled fractures; forms a moderately steep to gentle dipslope and ridge top.

Gradational contact: picked at the base of the lowest conglomeratic sandstone which marks a change from dominantly conglomeratic sandstones to dominantly sandstones. Above the contact, orthoconglomerates and conglomeratic sandstones are present. Below the contact, fine- to coarse-grained sandstones are present.
Lithofacies B

2. Sandstone with local interbeds of granular conglomeratic sandstone. Grayish orange pink (5YR 7/2), very pale orange (10YR 8/2), and moderate orange pink (10R 7/4), weathers light brown (5YR 5/6 and 5YR 6/4), pale reddish brown (10R 5/4), and pale red (10R 6/2); fine- to coarse-grained; poorly sorted subangular to rounded grains; local lenses of coarse-grained sand with local inclusions of lithoclasts, lithoclasts consist of subangular to rounded chert, quartzite, and sandstone up to 2 cm in diameter; lenticular-shaped bedding; wavy irregular scour-filled bedding contacts; average bed thickness: 15 cm, range: 5-20 cm; minor alpha, beta, and gamma cross-stratification; planar parallel laminae 1-6 mm thick; cross laminae 1-3 mm thick; traces of glauconite; feldspathic; silica cemented; locally calcareous; local manganese staining; fair porosity (7 to 9%); silica-filled fractures; forms a prominent strike ridge.

Sharp erosional contact: picked at the base of the lowest sandstone bed which fills scours that cut into the underlying siltstones. Above the contact, fine- to coarse-grained sandstones dominate. Below the contact, siltstones dominate.

1. Siltstone interbedded with calcareous siltstone, silty limestone, and shale. Moderate orange pink (5R 8/4 and 10R 7/4) and pale yellow orange (10YR 8/6), weathers the same; clay to silt grain sizes; poorly sorted; wavy parallel bedding; laminated to thin bedded; planar parallel and wavy discontinuous laminae 1-2 mm thick; traces of glauconite; calcareous; poor porosity (trace); forms a recessive ridge top.

Gradational contact: picked where the proportion of siltstone is greater than sandstone. Above the contact, siltstones dominate. Below the contact, fine- to coarse-grained sandstones dominate.

Lithofacies A

1. Sandstone with interbedded conglomeratic sandstone. Moderate reddish orange (10R 6/6), pale reddish brown (10R 5/4), white (N-9), and moderate orange pink (5YR 8/4), weathers light brown (5YR 5/6) and pale red (5R 6/2); fine- to coarse-grained (mostly medium- to coarse-grained) sandy groundmass and sandstone; poorly sorted subangular to rounded grains; lithoclasts consist of subangular to rounded chert, quartzite, and fragments with silicified ooids up to 2 cm in diameter; most lithoclasts are gravel-sized; lenticular-shaped bedding;
scour-filled bedding contacts; thin to medium bedded; average bed thickness: 25 cm, range: 6-50 cm; minor alpha, beta, and gamma cross-stratification with 10-15 cm thick lamina sets; planar parallel laminae 1-7 mm thick; feldspathic; silica cemented; locally calcareous; local manganese staining; poor to good porosity (2 to 15%), mostly good porosity (10 to 15%); abundant silica-filled fractures; abundant honeycomb-type weathering surfaces; forms a prominent talus slope with local cliffs.

Covered contact: Concealed by vegetation and a thick sandy soil. The contact was picked at the base of the lowest exposed sandstone bed. Above the contact, fine- to coarse-grained sandstones form a prominent slope with locally well exposed outcrops. Below the contact, a covered interval is present.

(?) Formation (Concealed by Quaternary alluvium)

1. Covered interval. Concealed by vegetation and a thick sandy soil. Probably a poorly cemented sandstone and/or siltstone and shale; forms a broad covered valley.
**Section P - Petermann Creek Section**

**Location:** Approximately 8 km southwest of Tempe Downs Homestead and 22 km west-northwest of White Horse Gap, on the Henbury 1:250,000 scale geologic map on the southern flank of the Petermann Creek anticline, at 132° 22' E longitude and 24° 26' S latitude (Australian Grid Coordinates: 194 9000 y N, 551500 y E, Zone 4). The Areyonga forms an east-west strike ridge. Beds face and dip southwest.

**Measured by:** J. O. Phillips and John Cullen with a 60-meter tape, two Jacob staffs, and an Abney hand level. Measured up section from northeast to southwest, 5 September 1982.

<table>
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<td></td>
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<tr>
<td>1. Covered interval. Concealed by vegetation and a thick sandy soil. Probably poorly cemented sandstone and/or siltstone and shale; forms a broad covered valley.</td>
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Covered contact: picked at the top of the uppermost exposed sandstone. Above the contact, a covered interval is present. Below the contact, fine- to coarse-grained sandstones form a prominent dipslope.

**Areyonga Formation**

**Lithofacies E**

| Sandstone. Yellow gray (5YR 7/2) and very pale orange (10YR 8/2), weathers light brown (5YR 5/6 and 5YR 6/4); fine- to coarse-grained (mostly medium- to coarse-grained); poorly sorted subangular to rounded grains; lenses of coarse- to very coarse-grained sandstone; lenticular-shaped bedding; scour-filled bedding contacts; medium bedded; average bed thickness: 20 cm; range: 12-30 cm; cross-stratification observed; planar parallel laminae 1-7 mm thick; rare mud pebbles up to 3 cm in diameter; traces of glauconite; feldspathic; silica cemented; good porosity (12%); local manganese staining; silica filled fractures; forms a ridge crest and a prominent dipslope. | 8.8 |

8.8
Gradational contact: picked at the top of the uppermost conglomeratic sandstone bed. Above the contact, fine- to coarse-grained sandstones are present. Below the contact, conglomeratic sandstones are interbedded with sandstones.

4. Sandstone interbedded with granular conglomeratic sandstone and conglomeratic sandstone. Very pale orange (10YR 8/2), grayish orange pink (10YR 7/2), white (N-9), and yellow gray (5Y 8/1), weathers light brown (5YR 5/6 and 5YR 6/4); fine- to coarse-grained groundmass and sandstone (mostly medium-grained); poorly sorted angular to rounded grains; lithoclasts consist of granule- to pebble-sized subangular chert and quartzite up to 3 cm in diameter; normally graded bedding with conglomeratic sandstone (base) --> sandstone (top); conglomeratic sandstones mostly as basal parts of beds; lenticular-shaped bedding; scour-filled bedding contacts; thin to medium bedded; average bed thickness: 12 cm, range: 6-15 cm; mu and nu major cross-stratification; minor alpha, beta, and gamma cross-stratification; planar parallel laminae 1-3 mm thick; cross laminae 1-3 mm thick; local load deformation; minor slumped bedding; traces of glauconite; feldspathic; silica cemented; locally calcareous; local manganese staining; fair to good porosity (9 to 15%); silica-filled fractures; honeycomb-type weathering; forms a prominent strike ridge and a moderately steep dipslope.

Gradational contact: picked at the base of the moderately steep dip-slope. Above the contact, sandstones interbedded with conglomeratic sandstones dominate. Below the contact, sandstones interbedded with calcareous mudstones form a recessive valley.

3. Sandstone interbedded with calcareous mudstone, limestone, and minor conglomeratic sandstone. Pale yellow orange (10YR 8/6) and white (N-9), weathers grayish red (5R 4/2), light brown (5YR 5/6) and light gray (N-8); Sandstone: medium- to coarse-grained, poorly sorted angular to rounded grains, 2-4 cm thick lenses of coarse- to very coarse-grained sandstone; lenticular-shaped bedding, thin to medium bedded, mu and nu cross-stratification, planar parallel laminae 1-4 mm thick, cross-laminae 2-6 mm thick, scattered mud pebbles and mud-pebble casts up to 2 cm in diameter, traces of glauconite, feldspathic, silica cemented, locally calcareous, good porosity (10%); Conglomeratic sandstone: medium- to coarse-grained sandy groundmass, poorly sorted subangular to rounded grains, contains granule- to pebble-sized lithoclasts of subangular chert and quartzite up to 2 cm in diameter, lenticular-shaped bedding, medium bedded, mu and nu cross-stratification,
planar parallel laminae (heterogenous composition) 1-4 mm thick, cross laminae 2-6 mm thick, scattered mud pebbles and mud-pebble casts up to 2 cm in diameter, traces of glauconite, feldspathic, silica cemented, locally calcareous, good porosity (10%); Limestone and calcareous mudstone: clay- to silt-size terrigenous grains, fine-crystalline to micritic carbonates, lenticular-shaped bedding, thin bedded, poor porosity (trace); local manganese staining; forms a recessive valley covered by talus and sand. ... ... ... ... 11.3

Gradational contact, picked at the top of the uppermost sandstone bed. Above the contact, a recessive interval is present. Below the contact, medium- to coarse-grained sandstones form a prominent dipslope.

2. Orthoconglomerate, conglomeratic sandstone, and sandstone. Grayish pink (5R 8/2) and moderate orange pink (5YR 8/4), weathers grayish orange pink (5YR 7/2); medium- to coarse-grained groundmass and sandstone; poorly sorted subrounded to rounded grains; lithoclasts consist of granule- to pebble-sized angular to subangular chert and quartzite up to 4 cm in diameter; most lithoclasts are 1-2 cm; local normally graded bedding with conglomerate (base) --> conglomeratic sandstone --> sandstone (top); lenticular-shaped bedding; wavy irregular scour-filled bedding contacts; medium bedded; average bed thickness: 20 cm, range: 15-40 cm; omikron and xi major cross-stratification with 10-24 cm thick lamina sets, minor alpha, beta, and gamma cross-stratification with 10-24 cm thick lamina sets; planar parallel laminae (heterogeneous and homogeneous compositions) 1-4 mm thick; cross laminae (heterogeneous composition): 2-6 mm thick; scattered mud pebbles and mud-pebble casts up to 3 cm in diameter; traces of glauconite; feldspathic; silica cemented; locally calcareous; traces of manganese staining; good porosity (10 to 15%); silica-filled fractures; honeycomb-type weathering; locally weathers massive; forms a prominent strike ridge with well exposed outcrops. ... ... ... 6.5

Gradational contact: picked at the base of the strike ridge. Above the contact, orthoconglomerates form a prominent strike ridge. Below the contact, fine- to coarse-grained sandstones interbedded with siltstones and shales form a recessive valley.

1. Sandstone, siltstone, and shale with minor conglomeratic sandstone. Grayish pink (5R 8/2) and moderate orange pink (5YR 8/4), weathers grayish orange pink (5YR 7/2); Sandstone and conglomeratic sandstone: fine- to coarse-grained groundmass and sandstone, poorly sorted subrounded grains, lithoclasts consist of angular
to subangular chert, quartzite, and vein quartz up to 3 cm in diameter, lenticular-shaped bedding, thin to medium bedded, average bed thickness: 15 cm, range: 6-20 cm, planar parallel laminae 2-7 mm thick, local white clay pebbles up to 1 cm in diameter, feldspathic, somewhat silica cemented, calcareous, good porosity (15%); Siltstone and shale: laminated bedding, calcareous, poor porosity (trace); forms a recessive, mostly covered interval.

Gradational contact: picked at the top of the uppermost sandstone bed which marks the top of a prominent dipslope. Above the contact, a recessive interval is present. Below the contact, fine- to coarse-grained sandstones form a prominent ridge and dipslope.

Lithofacies D

1. Sandstone with minor granular conglomeratic sandstone. Moderate orange pink (10R 7/4 and 5YR 8/4), very pale orange (10R 8/2), light red (5R 6/6), light gray (N-8), and pale yellow brown (10YR 6/4), weathers pale red (10R 6/2), grayish orange pink (5YR 7/2), and light brown (5YR 6/4 and 5YR 5/6); fine- to coarse-grained groundmass and sandstone; poorly sorted subangular to rounded grains; lithoclasts consist of angular to subangular chert, quartzite, and vein quartz (granules); local lenses of granular orthoconglomerate and scattered lenses of coarse-grained sandstone 2-6 cm thick; lenticular-shaped bedding; wavy irregular scour-filled bedding contacts; thin to medium bedded; average bed thickness: 20 cm; range: 8-35 cm; omikron major cross-stratification with up to 15 cm thick lamina sets; minor mu and nu cross-stratification; local alpha, beta, and gamma cross-stratification with 10-20 cm thick lamina sets; planar parallel laminae 1-4 mm thick; cross laminae 1-3 mm thick; rare scattered white clay pebbles up to 1 cm in diameter; traces of glauconite; feldspathic; silica cemented; locally calcareous near the base of the lithofacies; local manganese staining; fair to good porosity (7 to 10%); silica-filled fractures; forms a prominent ridge with a prominent dipslope.

Covered contact: picked at the base of the lowest exposed sandstone bed. Above the contact, sandstones are well exposed. Below the contact, a covered interval is present.
Lithofacies C

1. Covered interval. Concealed by vegetation and a thick soil. Probably poorly cemented sandstone and/or siltstone and shale; forms a recessive valley between two strike ridges.

Covered contact: picked at the top of the uppermost exposed sandstone bed. Above the contact, a covered valley is present. Below the contact, fine- to coarse-grained sandstones form small steps with well exposed outcrops locally.

Lithofacies B

3. Sandstone. Light red (5R 6/6), grayish red (5R 4/2), and pinkish gray (5YR 8/2), weathers pale red (5R 6/2), light gray (N-8), and light brown (5YR 5/6 and 5YR 6/4); fine- to coarse-grained (mostly fine-grained); poorly sorted subangular to subrounded grains; wavy parallel to lenticular-shaped bedding; laminated to thin bedded; alpha, beta, and gamma cross-stratification with 4-10 cm thick lamina sets; minor mu cross-stratification; planar parallel laminae 0.5-3 mm thick; cross laminae 1-3 mm thick; planar parallel high velocity laminae; traces of glauconite; feldspathic; silica cemented; locally calcareous; local manganese staining; good porosity (15%); local poor porosity (trace); forms a step-like dipslope.

Gradational contact: picked at the base of the lowest well exposed sandstone bed. Above the contact, fine- to coarse-grained sandstones form a step-like dipslope. Below the contact, poorly exposed siltstones, mudrocks, and fine-grained sandstones dominate.

2. Siltstone, other mudrocks, calcareous mudrock, and minor sandstone. Very pale orange (10YR 8/2), white (N-9), and moderate orange pink (10R 7/4), weathers same; locally where the beds are manganese stained the color is pale purple (5P 6/2) or very dusky red purple (5RP 2/2); very fine- to fine-grained sandstone; poorly sorted; sandstones contain a muddy matrix; poorly exposed bedding; highly fractured; rare laminations; planar parallel laminae 0.5-2 mm thick; feldspathic; calcareous; traces of silica cement; local manganese staining; poor porosity (trace); forms a recessive step which is mostly covered.
Gradational contact: picked at the top of the uppermost sandstone bed, which forms a well exposed dipslope. Above the contact, a recessive interval is present. Below the contact, fine- to medium-grained sandstones form a well exposed dipslope.

1. Sandstone. Grayish pink (5R 8/2), moderate pink (5R 7/4), and white (N-9), weathers dark gray (N-3) and light brown (5YR 5/6 and 5YR 6/4); fine- to medium-grained; moderately well sorted subangular to rounded grains; lenticular-shaped bedding; thin to medium bedded; average bed thickness: 35 cm; range: 7-60 cm; rare cross-stratification, alpha and beta cross-stratification with 4-15 cm thick lamina sets; planar parallel laminae 1-3 mm thick; cross laminae 1-2 mm thick; traces of glauconite; feldspathic; silica cemented; locally calcareous; local manganese staining; fair to good porosity (9 to 15%); silica-filled fractures; honeycomb-type weathering; forms a prominent strike ridge with a well exposed dipslope at the top of the lithofacies and a talus-covered slope for the remaining parts of the lithofacies.

Sharp contact: picked at the top of the uppermost chert bed. Above the contact, fine- to medium-grained sandstones form a prominent strike ridge. Below the contact, cherts interbedded with calcareous siltstones, calcareous sandstones, and mudrocks form a recessive valley.

Lithofacies A

1. Chert interbedded with chert breccia, calcareous siltstone, calcareous sandstone, and mudrock. Great variety of light to dark colors (light blue to black); the chert beds are progressively darker up section; very fine- to fine-grained sandstone; poorly sorted subangular grains; wavy parallel to lenticular-shaped bedding; thin to medium bedded; local contorted bedding; yellow mudstone beds scattered within the lithofacies; mostly chert beds with minor interbeds of sandstone and/or mudrock; chert-replaced or chert-cemented sandstone and siltstone; calcareous; locally silica cemented; poor porosity (trace); outcrops found only in a gully; forms a recessive, mostly covered valley and gentle slope.

Covered contact: picked at the base of the lowest exposed chert bed. Above the contact, cherts locally interbedded with sandstones, siltstones, and mudrocks form a recessive valley and gentle slope. Below the contact, a covered interval is present.
Formation (Concealed by Quaternary alluvium)

Appendix G

Plates
Plate 1. Oblique aerial photograph of the Arumbera Sandstone in the Gardiner Range. The Arumbera Sandstone forms the ridge in the left foreground. Unit 1 forms the slope and Unit 2 forms the first ridge. The Chandler Formation and Tempe Formation form the strike valley just right of this ridge. View East. Photograph taken by Robert Q. Oaks, Jr., 1976.

Plate 2. Pertatataka Formation, Julie Formation, Units 1 and 2 of the Arumbera Sandstone, Chandler Formation, and Tempe Formation northwest of the Pine Point section. The Pertatataka and Julie formations form the strike valley in the right foreground. Unit 1 forms the slope and Unit 2 forms the ridge and dipslope. The Chandler and Tempe Formations form the strike valley in the left background.

Plate 4. Flaser bedding exposed in lithofacies 1d of the Arumbera Sandstone at the Areyonga section in the Gardiner Range. View south. Lens cap shown for scale.
Plate 5. Thin to medium thick parallel beds typical of Unit 1 of the Arumbera Sandstone. Photograph taken in lithofacies 1d at the Areyonga section in the Gardiner Range. View southwest. Staff is marked in decimeters.

Plate 6. Scours filled by small-scale cross-stratified, fine-grained sands with local climbing ripples. Photograph taken of lithofacies 1d of the Arumbera Sandstone at the Areyonga section in the Gardiner Range. View southwest. Lens cap shown for scale.
Plate 7. Scours and load deformation at the base of lithofacies 2a of the Arumbera Sandstone at the Katapata Gap section in the Gardiner Range. View southeast. Photograph taken by Robert Q. Oaks, Jr., September, 1982. Staff is marked in decimeters.

Plate 8. Pi cross-stratification present in lithofacies 2a of the Arumbera Sandstone at the Namatjiras section in the Gardiner Range. View southeast. Staff marked in decimeters.
Plate 9. Photomicrograph of thin section 10 (PT-22), lithofacies 2b. Note biotite or chlorite grain partially replaced by iron oxide, well developed dust rims on grains, and pore space partially filled by kaolinite and iron oxide cement and/or pseudomatrix. Plane light, 10x.

Plate 10. Photomicrograph of thin section 18 (MV-2), lithofacies 1c. Note graphic granite, undulatory quartz with well developed quartz overgrowth and dust rim, twinned plagioclase, sericitized plagioclase, nonundulatory quartz, and granite grains. Also note the thin section is well cemented by silica. Crossed nicols, 10x.
Plate 11. Photomicrograph of thin section 29 (PP-B), lithofacies 1b. Note tourmaline grain with tourmaline overgrowth. Also shown are stained orthoclase grains and unstained quartz grains. Both grain types possess clay coats and absence of overgrowths. Iron oxides are the matrix and pseudomatrix material. Plane light, 10x.