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Cainozoic stratigraphy of the Yeelirrie area, northeastern Yilgarn Block, Western Australia

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Abstract

Seven new formations are recognized in the Cainozoic continental cover of the Yeelirrie area, northeastern Yilgarn Block Western Australia. The oldest is the Westonia Formation, a mainly massive, light grey sandy claystone with local silicification and basal conglomerate. It unconformably overlies Precambrian basement and is overlain by the Mulline Formation, a mainly pisolithic reddish brown to reddish yellow quartz or quartz and kaolin spherite sand with a supporting silt-clay matrix of iron and aluminum minerals. Next, the Menzies Formation, consists of variably altered red sandy clay and sandy claystone; within this formation there is the Bungarra Member, a red kaolin mudstone, the Volpress Member a saprolitic kaolin mudstone, and the Yeelirrie Member, a red sandy claystone with secondary calcrete, sparry calcite and dolomite. The Mulline and Menzies Formations are unconformably overlain by the Gibson Formation, a mainly massive, red to yellow, quartz and kaolin spherite clayey sand and clay which forms much of the present land surface throughout major interfluves and valley sides and interflingers with the next three formations. The Wirraway Formation consists mainly of massive red quartz sand and clayey sand and occurs along major valley bottoms and channel/border plays. The Nuendah Formation consists of gravel, sand and clayey sand, channel/overbank, ridge-foot/slope and breakaway-front deposits. The Darlot Formation consists mainly of massive to stratified pan/playa gypsum and kaolin muds, and contains the Miranda Member, a massive to stratified gypsum deposit. This lithostratigraphic framework provides a basis for future work into the nature and origin of the Cainozoic cover in the Yeelirrie area and also throughout other parts of the Yilgarn Block.

Introduction

A continental cover mainly of Cainozoic age extends throughout much of southwestern Australia, covering more than 70% of the Precambrian bedrock (Jutson 1914, 1934; Stace et al. 1968; Playford et al. 1975). The cover ranges up to 80 m in thickness but is usually less than 30 m (Australian Groundwater Consultants 1972, Geological Survey of Western Australia 1975).

Many aspects of this cover have been documented in terms of geology, stratigraphy, petrology, physiography, palaeogeography, geomorphic processes, geomorphic history, pedology, weathering and groundwater (Jutson 1914, 1934; Mabbutt et al. 1963; Beard 1973, 1982; Butt et al. 1977; Churchward 1977; Mann & Deutscher 1978; Lively et al. 1979; Mann & Horwitz 1979; van de Graaff et al. 1979; Butt 1983, 1985; Bettenay 1984). However, no formal lithostratigraphic framework has been developed for these materials, and their nature (geometry, structure, texture, composition) and origin are still imperfectly known.

This paper divides the Cainozoic cover in the Yeelirrie area (Fig. 1) into seven new formations and four new members. The units are introduced to provide a framework and basis for later studies into the stratigraphy, geomorphology, lithology, granulometry, mineralogy, geochemistry, petrogenesis and developmental history of the cover in the Yeelirrie area and throughout other parts of the Yilgarn Block (Fig. 1B).

A formal lithostratigraphic approach is taken because it provides the most objective basis from which origins may be inferred. This approach follows that adopted elsewhere wherein formal rock unit status has been given to similar clay and claystone (Lowry et al. 1972, Barnett 1980), laterite (Lindner & Drew in McWae et al. 1958, de la Hunt 1965, Barnett 1980), sandy clay (Cullen and Tedford 1976), calcere (Maitland 1904, Glauert 1911, Semeniuk 1983) and siliciclastic sand (Logan et al. 1970, Playford & Low 1972, Semeniuk 1980, 1983).

Methods

Stratigraphic sections were examined and sampled from limited natural outcrop, drill core, auger holes, costeans and pits at more than 100 sites.

Type, reference and supplementary stratigraphic sections were sampled vertically by collecting samples from a representative portion of all lithic and diagenetically distinct units. Sketches were made and photographs were taken to record structures and facies associations.

To extract the sand fraction from unindurated specimens selected samples were weighed, broken into chips and boiled in NaOH and/or HCl. Saponite and sandy claystone chips were repeatedly boiled in NaOH. Lateritic duricrust chips were boiled in HCl and bauxitic duricrust chips were boiled repeatedly in NaOH and then HCl.
Residues were washed through a 0.045 mm screen, dried, weighed and sieved. Loose sands were air dried, weighed and also sieved at half phi intervals. Terminology and procedures on sieving and grain size statistics are after Folk (1974). Selected samples were processed in the following manner: (1) impregnated with resin and thin sectioned; (2) examined with petrographic, electron and scanning electron microscopes; (3) examined with a microprobe; and (4) X-rayed using CoK-alpha radiation. X-ray diffractograms were interpreted according to JCPDS (1974) and Brindley & Brown (1980). The data are presented, along with inferred origins, in Glassford (1980).
Figure 2.—Legend for stratigraphic sections.
Stratigraphic procedures and nomenclature are after Hedberg (1976) and Staines (1985). The legend for stratigraphic sections is presented in Fig. 2.

**General setting**

The Cainozoic cover of the Yeelirrie area is influenced by climate, topography and basement geology. These factors are described below.

The Yeelirrie area has a sub-tropical arid climate with 150-200 mm median annual precipitation and 4000 mm annual mean evaporation (Gentilli 1971; Bureau of Meteorology 1973a,b).

Topographically the Yeelirrie area is between 650 to 450 m above mean sea level in the upper reaches of a south-east sloping major valley which begins at the continental divide (after Surveys and Mapping 1980). The major valley contains a chain of "salt lakes", which include Lake Miranda and Lake Darlot and is referred to here as the Yeelirrie valley.

Basement is interpreted to be predominantly Precambrian granite rock (Williams 1975, Bunting & Williams 1979, Tingey 1985). The granite rock weathers to saprolite which consists mainly of secondary aluminium minerals (kaolin, halloysite, gibbsite; c. 68%) and iron minerals (haematite, goethite; c. 2%) and residual quartz (e. 30%). (Grubb 1966, 1972; Gilkes et al. 1973; Sadlier & Gilkes 1976; Davy 1979; Anand & Gilkes 1984 a,b,c,d; Anand et al. 1985). Thus the saprolite of granite rock has a matrix support fabric with about 30% quartz sand supported in a mainly kaolin clay matrix.

**Stratigraphy**

The lithostratigraphic units recognized in the cover of the Yeelirrie area are (time ranges from 1:250 000 geological map legends of Bunting & Williams 1979 and Tingey 1985):

1. Westonia Formation
2. Mulline Formation
3. Menzies Formation
4. Gibson Formation
5. Wirraway Formation
6. Nuendah Formation
7. Darlot Formation

The major lithostratigraphic attributes of all units are summarized in Table 1 and general descriptions of type section lithology are presented in Tables 2 to 6, 8 and 9.

The Westonia and Mulline Formations are poorly represented in the Yeelirrie area, consequently their type sections are located outside the study area and units in the study area have been assigned to them by sequential lithostratigraphic correlation (Fig. 3).

<table>
<thead>
<tr>
<th>Unit</th>
<th>Lithology</th>
<th>Geometry and dimensions</th>
<th>Structure</th>
<th>Stratigraphic relationships</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Westonia</td>
<td>Light grey sandy claystone to claystone minor clayey sandstone and</td>
<td>Tabular to</td>
<td>Massive to locally</td>
<td>Unconformably overlies</td>
<td>Outcrop is very poor and typically confined to breakaways. The</td>
</tr>
<tr>
<td>Formation</td>
<td>conglomeratic sandstone.</td>
<td>lenticular to</td>
<td>crudely bedded.</td>
<td>saprolite and Precambrian</td>
<td>Westonia Formation differs from saprolite by being: generally</td>
</tr>
<tr>
<td></td>
<td></td>
<td>channel-fill shaped and up to 5 m thick.</td>
<td></td>
<td>basement; typically overlain by the Mulline</td>
<td>green; locally stratified; locally conglomeric in thin layers;</td>
</tr>
<tr>
<td>Mulline</td>
<td>Reddish brown to yellowish brown lateritic/bauxitic duricrust of</td>
<td>Sheet and blanket to</td>
<td>Pisolitic to nodular to</td>
<td>Mulline Formation; over lain by</td>
<td>Outcrop is poor and typically confined to breakaways. Pisolites and</td>
</tr>
<tr>
<td>Formation</td>
<td>quartz and/or kaolin spherite sand supported in a silt-clay matrix of</td>
<td>lese form &amp; less than 1 m to over 1 m thick.</td>
<td>lathyphild (root/burrow structured).</td>
<td>Gibson Formation.</td>
<td>nodules of quartz and kaolin sand with a matrix of iron (goethite,</td>
</tr>
<tr>
<td></td>
<td>iron and aluminium minerals (mainly goethite, haematite, kaolin, gibbsite).</td>
<td></td>
<td></td>
<td></td>
<td>haematite) and aluminium (kaolin gibbsite) minerals are diagnostic;</td>
</tr>
</tbody>
</table>

Table 1

Summary of major characteristics of stratigraphic units which form the Cainozoic continental cover of the Yeelirrie area, northeastern Yilgarn Block, Western Australia.
<table>
<thead>
<tr>
<th>Unit</th>
<th>Lithology</th>
<th>Geometry and dimensions</th>
<th>Structure</th>
<th>Stratigraphic relationships</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Menzies Formation</td>
<td>Mainly red sandy clay and sandy claystone with some other facies (see members below). Framework sand consists of quartz and kaolin spherules rich in iron minerals. Matrix silt-clay consists mainly of goethite, haematite and kaolin.</td>
<td>Basin to broad major valley shaped fill. Typically up to 20 m thick.</td>
<td>Massive to weakly stratified</td>
<td>Unconformably overlies Precambran basement; typically overlain by Gibson Formation</td>
<td>Outcrop is poor and typically confined to the bottom of major valleys. Red colour plus framework sand supported by a silt-clay matrix are diagnostic features.</td>
</tr>
<tr>
<td>Bungarra Member of Menzies Formation</td>
<td>Red kaolin mudstone with minor quartz and carnallite.</td>
<td>Tabular to lens shaped up to 1 m thick. Locally may have a thin lens of sand at upper boundary.</td>
<td>Massive with scattered vesicles.</td>
<td>Overlies red sand claystone facies and is overlain by Volpress Member.</td>
<td>Differs from the mud facies of the Darlent Formation by: having vesicles; being hard and brittle; and breaking with a subcylindrical fracture; lacks gypsum; and is buried in contrast to Darlent Formation mud facies which may be buried or form modern playa mud flats.</td>
</tr>
<tr>
<td>Volpress Member of Menzies Formation</td>
<td>Black, grey and white siltitic kaolin mudstone with minor carnallite.</td>
<td>Tabular, lens to pod shaped and from less than 1 m to over 2 m thick.</td>
<td>Massive to weakly to moderately brecciated with anastomose sepiolite.</td>
<td>Overlies Bungarra Member and is overlain by the Yeelirrie Member.</td>
<td>May be confused with calcite but differs from the Yeelirrie Member by: not containing calcite; contains sepiolite; has a &quot;mudstone&quot; fabric and does not contain red sandy claystone.</td>
</tr>
<tr>
<td>Yeelirrie Member of Menzies Formation</td>
<td>White to pale brown to white with red. Red sandy clay and sandy claystone with yellow silt/clay. Framework sand consists of quartz and kaolin spherules which typically contain iron minerals (goethite, haematite).</td>
<td>Mound to pod to lens shaped and up to 5 m thick.</td>
<td>Massively to weakly bioturbated and locally cross-stratified.</td>
<td>Overlies Volpress Member locally and integrates vertically and laterally with red sandy clay and sandy claystone facies. Locally overlain by Gibson Formation.</td>
<td>Outcrop is poor and typically confined to the bottom of major valleys. Calcitization of sandy clay and claystone are distinctive features.</td>
</tr>
<tr>
<td>Gibson Formation</td>
<td>Red to reddish yellow to yellow and sometimes locally white framework support siliciclastic clays and sand. Framework grains mainly include quartz and kaolin spherules which typically contain iron minerals (goethite, haematite).</td>
<td>Sheet, interdune sheets up to 4 m thick and linear hills or ridges typically up to 10 m thick Overall up to 14 m thick.</td>
<td>Massive (ant. termite and root bioturbated) to rarely cross stratified.</td>
<td>Overlies the Mulline Formation and Menzies Formation; may interfinger or be overlain by the Nuendah, Warray and Darlent Formations.</td>
<td>The upper boundary forms much of the present day hardpan surface. distinctive features include: massive structure; silt-clayey coarse and fine sand; minor to co-dominant amounts of nearly perfectly rounded and opalinus developed kaolin spherules pigmented with iron minerals; reddish yellow to yellow colour resulting from goethite and haematite pigmentation kaolin coatings on grains; and numerous ana holes and terracottas.</td>
</tr>
<tr>
<td>Warrway Formation</td>
<td>Red to reddish yellow quartz sand and clayey sand.</td>
<td>Shelves, linear hills, mounds or ridges and horite hills or ridges up to more than 3 m thick.</td>
<td>Massive (ant. termite and root bioturbated) to locally cross-stratified.</td>
<td>Overlies the Menzies Formation and interfingers and overlies the Gibson, Nuendah and Darlent Formations.</td>
<td>Occurs along the axis of major valleys between around and on the margins of playas. In hand specimen the Warrway Formation may be confused with the Gibson Formation. However the Warrway Formation consists mainly of quartz with no kaolin spherules or minor amounts of very iron rich kaolin spherules and fragments of kaolin sphérules.</td>
</tr>
<tr>
<td>Nuendah Formation</td>
<td>Pale brown lithic gravel, quartz sands and clayey quartz sands.</td>
<td>Ridge-foot-slope channel and fan shaped and breakup-front ridges from less than 1 m to more than a few metres in thickness.</td>
<td>Massive to bedded to laminated. Bedding may be graded.</td>
<td>Overlies and interfingers with the Gibson and Warrway Formations; overlies Precambran basement and the Menzies Formation.</td>
<td>Has modern and pre-modern facies. Occurs along Precambran basinment ridge-foot-slopes, along breakup-fronts and along dendritic tributary drainage tracts of major valley sides.</td>
</tr>
</tbody>
</table>
### Table 2
General description of lithology, Westonia Formation type section.

<table>
<thead>
<tr>
<th>Depth (m)</th>
<th>Description</th>
<th>Rock unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-0.5</td>
<td>Sandy laterec, reddish brown</td>
<td>Mulline Formation</td>
</tr>
<tr>
<td>0.5-0.75</td>
<td>Sandy claystone: light grey, massive, matrix supported, with unimodal, medium to fine, quartz and kaolin spherite sand, reddish brown self float mottles</td>
<td>Mulline Formation</td>
</tr>
<tr>
<td>0.75-1.0</td>
<td>Sandy claystone: as above but unconsolidated and without colour mottles</td>
<td>Mulline Formation</td>
</tr>
<tr>
<td>1.0-2.0</td>
<td>Sandy claystone: light grey, massive and rough stratified, matrix supported, with unimodal, medium to fine quartz and kaolin spherite sand, hard, fint clay fracture</td>
<td>Westonia Formation</td>
</tr>
<tr>
<td>2.0-4.0</td>
<td>Sandy claystone: light grey massive and post-structured, matrix supported with unimodal, medium to fine, quartz and kaolin spherite sand; hard reddish brown nodular and irregular mottles</td>
<td>Westonia Formation</td>
</tr>
<tr>
<td>4.0-4.2</td>
<td>Pebby sandy claystone; light grey, massive, with quartz pebbles supported in a matrix of quartz and kaolin spherite sand and kaolin fint clay</td>
<td>Westonia Formation</td>
</tr>
<tr>
<td>4.2-5.0+</td>
<td>Gneissic sapphireite</td>
<td>Archean Basement</td>
</tr>
</tbody>
</table>

Westonia Formation

Westonia Formation is the name proposed for a unit of light grey sandy claystone plus minor conglomeratic and other facies. The formation overlies unweathered and weathered (saprolite) Precambrian basement and is overlain by the Mulline Formation. (Tables 1, 2).

**Derivation of name.** Named after Westonia, a gold mining town several hundred metres south of the type section, lat. 31° 18'S, long. 118° 41'E. Southern Cross 1:250 000 sheet.

**Type section.** The designated type section is an escarpment produced by the collapse of a portion of the roof of the old Edna May gold mine, lat. 31° 18'S, long. 118° 41'E. Southern Cross 1:250 000 sheet (Table 2; Figs 3, Tr. 6 and 4, TSI).

A new phase of underground gold mining in the vicinity of the type section may progress to open cut mining and thereby endanger the designated type section. Therefore two reference sections are also designated. The first is in the face of a breakaway, lat. 30° 7'S, long. 120° 14'E. Kalgoorlie 1:250 000 sheet (Tr. 4-1 of Fig. 3). This section is remote with access by a track which is very poorly defined and difficult to negotiate. Therefore a second readily accessible but incomplete and thinner section is also designated. This section is a low breakaway on the north side of the Perth to Kalgoorlie main road, lat. 31° 16'S, long. 120° 1'E. Boorabbin 1:250 000 sheet (Tr. 5-1 of Fig. 3).

**Distribution.** The Westonia Formation does not crop out extensively and is poorly represented in the Yeelehe area. Outcrop is typically confined to interfluve breakaways and outside the study area to valley bottom breakaways which in places border playas (Figs 3.5).

**Surface features.** Where the upper surface of the Westonia Formation crops out the exposure is typically limited to a few square metres and is characterized by an irregular surface of erosion.

**Geometry and dimensions.** Although there are only a few clear exposures, extrapolation of discontinuous exposures indicate that the formation is thin and generally tabular, lobate to lenticular to channel-like-fill shaped, with maximum thickness up to 5 m (Fig. 3).

**Lithic characteristics.** The Westonia Formation is massive to crudely trough bedded. It is usually pale grey with scattered red to orange mottles. The formation has vertical pipes filled with sandy claystone similar to the host sandy claystone within which the pipes occur. Pipe structures are usually outlined by red margins, are more mottled, and may contain scattered sesquioxide gravels.

The formation has the following facies (Figs 3.4):

1. Sandy claystone and claystone facies. Sandy claystone is massive and at hand specimen scale has a matrix support fabric. At a microscopic scale it has a grain support fabric with framework grains of quartz and kaolin spherite sand (Kilgrew & Glassford 1976) and a matrix of disordered kaolin clay. Claystone is also massive and at a hand specimen scale has a "mudstone" fabric (fabric term after Dunham 1962), and at the microscopic scale it typically has a grain support fabric with a framework of kaolin spherite sand. Both facies may locally be partly silicified (Figs 3.4, TSI).
Figure 3.—Regional to medium scale settings for Westonia Formation and Mulline Formation type sections. A, B, C. Location of stratigraphic transects (Tr.) in the Yilgarn Block, Western Australia, Tr.1 to Tr.6 transects showing large to medium scale geomorphic and stratigraphic settings for stratigraphic sections. D. Generalized stratigraphic sections showing that the Westonia (Tr.6-1) and Mulline (Tr.3-1) Formations can be correlated from their respective type sections (Tr.6-1 and Tr.3-1) to the Yeelirrie area (Tr.1-land Tr.2-1).
2. Sandstone to muddy sandstone facies. This facies is massive to locally bedded and has a
grain support fabric with a quartz sand framework and a disordered kaolin clay or
flint-clay matrix. In the Yeelirrie area this facies is
nearly wholly silicified (Butt 1983, 1985).

3. Conglomeratic facies. This facies varies from
clayey conglomerate through sand and clayey
conglomerate to conglomeratic sandstone (Figs
3; 4. TSI). It is commonly a basal unit and
massive to crudely layered. Gravels are typically
rounded, pebble sized (4 to 64 mm in diameter)
quartz. Matrix material is composed of kaolin
spherie sand and/or disordered kaolin clay.
The (basal) conglomerate facies is sporadic in
occurrence.

The kaolin clay component of all facies is typically
hard, does not develop plasticity and commonly breaks
with an uneven or sub-conchoidal fracture. These
properties of the Westonia Formation are also shared by

Fossils. The Westonia Formation generally lacks fossils
but in places it contains roughly ellipsoidal casts 2 to 5 cm
long and 1 to 2 cm in diameter which have been attributed
by Kriewaldt (1969, p. 50-54) to the pupae of Leptopius
sp. (Jackson 1941, p. 72-74). However they are more
likely to be the brood cell of solitary native bees,
superfamily Apoidea (T. S. Houston, W.A. Museum, pers.
comm. 1986b). Some brood cells are connected to a
krotovina. The sandy claystone of the formation is
generally light grey but in the vicinity of brood cells it is
red to orange for 1 to 20 mm. The brood cells are usually
part to completely filled with relatively more porous
quartz and kaolin spherite sand and this fill is typically
red or orange. Pipes within the formation may be tap-root
casts.

Stratigraphic relationships. At the type section the
Westonia Formation unconformably overlies gneissic
saprolite and is itself overlain by the Mulline Formation.
The lower boundary of the Westonia Formation is sharp,
flat to gently dipping, and near planar, and locally varies
to irregular and steeply dipping in the form of V
and U-shaped valleys (Fig. 3, T. 3). These valleys have
amphitheatre faceting and are fringed with a few
breakaways. The lower boundary is typically concealed and in places
characterised by a thin basal conglomerate. The upper
boundary is commonly sharp to abruptly gradational with
overlying Mulline Formation, and it is generally flat to
gently dipping, and near-planar to broadly undulate.

The Westonia Formation may be laterally equivalent
geographically, but not temporally equivalent, to in situ
palidal zone (saprolite) for where contacts are discernible
the Westonia Formation unconformably overlies
saprolite.

Discussion. The Westonia Formation is easily confused with
in situ weathered Precambrian basement rock. This
applies especially to the sandy claystone facies of the
formation because it is similar in hand specimen with
granitic saprolite. However sandy claystone and claystone
facies typically have kaolin spherites whereas deeply
weathered granite rock does not contain kaolin spherites
(Killigrew & Glassford 1976). Furthermore, Westonia
Formation can be distinguished from saprolite by
neatly being grey, the presence of stratification,
conglomerate layers and sporadic well-rounded quartz
pebbles. Sub-conchoidal fractures can be distinguished from
the Westonia Formation by generally being white, the
presence of quartz veins and their truncation at the
unconformity between saprolite and Westonia
Formation, and by palimpsest gneissic structures and
granitic fabrics.

In the Yeelirrie area the Westonia Formation has been
previously mapped as Falconer and Nuendah
landform—regolith systems (modified from land systems
of Mabbutt et al. 1963) by Churchward (1977) and as
deeply weathered rock, silcrete-sillicon rock with
angular quartz grains, and sandstone, silstone, claystone
and conglomerate by Bunting and Williams (1979). In the
Kalgoorlie 1:250 000 sheet area it has been mapped and
described as Old Alluvium (Kriewaldt 1969, p. 22-31).
Throughout the Yilgarn Block it has been referred to as
saprolite derived alluvial sediment (Killigrew &
Glassford 1976).

Stratified and kaolin spherite-rich sandy claystone,
designated here as Westonia Formation, has been
incorrectly identified in the Meekatharra area (Brewer &
Bettinen 1973) and in the Westonia area (Webster &
Mann 1984) as the mottled and palled zones of in situ
weathered Precambrian basement granitic rock.

Mulline Formation

The Mulline Formation is the name proposed for a unit of
reddish brown to yellowish brown sandy lateritic to
baxtitic duricrust which overlies saprolite and Westonia
Formation and typically is overlain by the Gibson
Formation (Tables 1, 3).

Derivation of name. Named after the abandoned gold
inging town of Mulline, lat. 29° 47'S, long. 120° 31'E,
Menzies 1:250 000 map sheet.

Type section. The designated type section is the face of
a breakaway, west of a small playa, lat. 29° 47'S, long. 120°
57'E, Menzies 1:250 000 map sheet (Table 3, Figs 3, Tr. 3;
TS3).

Distribution. The Mulline Formation is poorly exposed and
typically covered by sand of the Gibson Formation
throughout much of the Yeelirrie area, including the
continental divide (Figs 3, 4, 5). Outside the Yeelirrie area
outcrop occurs as lateritic gravel plains (Stace et al. 1968)
or at the top and the face of breakaways. The formation
occurs throughout the northern interfluve plateau and the
southern valley side of the Yeelirrie valley.

Surface features. Where the Mulline Formation crops out
it has a relief surface. The outcrop is often characterized
at a small to fine scale by an irregular morphology and
patchy veneers of hard, pisolithic to nodular sandy gravel.

Geometry and dimensions. The formation is typically
sheet-like and usually less than 1 m thick over areas of
a few tens of square kilometres to many tens of square
kilometres outside the study area. Its geometry is inferred by
correlating and extrapolating the discontinuous
outcrops.

Lithic characteristics. The Mulline Formation consists of
reddish to yellowish brown sandy lateritic to baxtitic
duricrust materials. It locally exhibits crude bedding, but
generally it lacks bedding and is typically characterized by
a pisolithic, nodular, platy or laminarid structure (Fig. 4).

Pisolithes, nodules and plates consist of a nucleus
(ranging from a few mm to many cm in diameter) and a
thin (c. 0.125 to 5 mm) laminated envelope. The pisolithic
nucleus typically consists of a framework of quartz or
quartz and kaolin spherite sand supported in a silt-clay
Figure 4.—Type section (TS) stratigraphic sections for the: Westonia Formation (TS1); Mulline Formation (TS2); Menzies Formation (TS3); Gibson Formation (TS4); Wirraway Formation (TS5); Nuendah Formation (TS6); and Darlot Formation (TS7). See Fig. 1 for location.
Table 3
General description of lithology, Mulline Formation type section.

<table>
<thead>
<tr>
<th>Depth (m)</th>
<th>Description</th>
<th>Rock unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0-0.5</td>
<td>Clayey sand; reddish yellow</td>
<td>Gibson Formation</td>
</tr>
<tr>
<td>0.5-1.75</td>
<td>Sandy laterite: yellowish brown, pisolithic; pisolites form a framework supported fabric; pisolites have a nucleus of fine skewed, moderately well to poorly sorted, fine to very fine quartz and kaolin silt-clay sand supported in a silt and clay matrix of goethite, haematite, kaolin and quartz; pisolites have a thin laminated envelope or pellicle of silt and clay sized goethite, haematite, kaolin and quartz.</td>
<td>Mulline Formation</td>
</tr>
<tr>
<td>1.75-3.1</td>
<td>Claystone: light grey, colour mottled.</td>
<td>Westonia Formation</td>
</tr>
<tr>
<td>3.1-3.5+</td>
<td>Geniculate sapprolite</td>
<td>Archaean Basement</td>
</tr>
</tbody>
</table>

Labyrinthoid structure consists of a tortuous arrangement of vermiciform to vesicular voids and labyrinthoid walls. The walls are similar to the nuclei of pisolites in that they consist of quartz and kaolin spherite sand. Labyrinthoid matrix is mainly composed of iron and aluminium minerals and quartz. The inter-pisolite/nodule/pluton dome may consist of void space and/or sandy silt-clay or silt-clayey sands.

Framework quartz and kaolin spherite sand of pisolites and nodules from the type section constitute 15 to 20% by weight of the rock in which they are fine skewed, moderately well to poorly sorted, fine to very fine sand. The mean size of the silt fraction greater than 0.045 mm is 0.078 mm or very fine sand.

Mulline Formation kaolin spherite sand and matrix silt-clay are pigmented red and yellow by haematite and goethite. This contrasts with the kaolin spherites and most of the silt-clay of the Westonia Formation, which are essentially free of haematite and goethite.

Fossils. The formation in places contains trace fossils which are similar to those previously described in the Westonia Formation. The fossils have also been noted by Kriewaldt (1967, 1969, 1970) in the same unit. designated here as the Mulline Formation (Fig. 3) throughout much of the Menzies and Kalgoorlie 1:250,000 map areas.

Stratigraphic relationships. The Mulline Formation has an abrupt to gradational contact with underlying Westonia Formation and an abruptly gradational contact with overlying Gibson Formation. Both upper and lower contacts are low-angled and near-planar (Figs. 3, 4).

Discussion. The Mulline Formation can be distinguished from other units mainly by its lateritic or bauxitic duricrust nature; this includes pisolithic, nodular, platy, and labyrinthoid structures, iron and aluminium minerals (e.g. goethite, haematite, kaolin, gibbsite); and silt-clay sized matrix which supports a framework of quartz or quartz and kaolin spherite sand.

The unit designated Mulline Formation has been mapped previously in the Yeelirrie and Arlanger and Nuendah landform-regolith systems by Churchward (1977), Tertiary lateritic (massive and pisolithic limonite deposits and cemented ironstone gravel) by Bunting and Williams (1979), and described or mapped in the Yeelirrie and surrounding areas as, sandy laterite or duricrust, and as variously altered, wholly or partly desert aeolian sediment (Killigrew and Glassford 1976, Glassford & Killigrew 1979, and Glassford 1980).

Menzies Formation

The Menzies Formation is the name proposed for a unit of red sandy clay and sandy claystone which encloses lesser amounts of calcic-cemented sandy clay, sepiolite-cemented mudstone, mudstone, laminated calcite and clayey sand. The formation typically overlies granitic rock and is overlain by the Gibson Formation (Tables 1, 4).

There are three distinct and spatially inter-related lithologies in the formation which are given member

Table 4
General description of lithology, Menzies Formation type section.

<table>
<thead>
<tr>
<th>Depth (m)</th>
<th>Description</th>
<th>Rock unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.55</td>
<td>Sandy clay; light to medium reddish brown, massive, matrix supported; unimodal, fine skewed, moderately sorted, fine, quartz and kaolin spherite sand with a silt and clay matrix of calcite, quartz and kaolin; scattered calcite pisolithos and rhizocorropions.</td>
<td>Yeelirrie Member of the Menzies Formation</td>
</tr>
<tr>
<td>0.55-0.65</td>
<td>Sandy gypse; white.</td>
<td>Darlot Formation</td>
</tr>
<tr>
<td>0.65-0.75</td>
<td>Laminae calcite breccia; off white to light brown, angular gravels of laminae calcite.</td>
<td>Yeelirrie Member of the Menzies Formation</td>
</tr>
<tr>
<td>0.75-2.50</td>
<td>Sandy clay; light to medium reddish brown, massive, matrix supported unimodal, fine skewed, moderately sorted, fine quartz and kaolin spherite sand with a silt and clay matrix of calcite, quartz and kaolin; scattered calcite pisolithos and rhizocorropions.</td>
<td>Yeelirrie Member of the Menzies Formation</td>
</tr>
<tr>
<td>2.5-4.5</td>
<td>Calcrete; reddish brown and white; red sandy claystone breccia supported in cryptoocrystalline calcite; red sandy claystone breccia domains have a matrix supported fabric; framework gravels are unimodal, fine skewed, moderately sorted, quartz and kaolin spherite sand; matrix silt and clay is mainly kaolin, minor carnotite; calcite domains are cryptoocrystalline calcite with scattered quartz and kaolin sand; quartz grains in calcite have ragged edges.</td>
<td>Yeelirrie Member of the Menzies Formation</td>
</tr>
<tr>
<td>4.5-5.6</td>
<td>Sepiolite claystone; dark grey and white, kaolin mudstone with veins of sepiolite; minor carnotite.</td>
<td>Volpress Member of the Menzies Formation</td>
</tr>
<tr>
<td>5.6-5.7</td>
<td>Clayey sand; light reddish brown, unimodal, framework supported; moderately sorted, coarse, quartz sand; soft, unconsolidated.</td>
<td>Bungarra Member of the Menzies Formation</td>
</tr>
<tr>
<td>5.7-6.1</td>
<td>Mudstone; red, vesicular and massive kaolin mudstone; minor carnotite; brittle, subconchoidal fracture.</td>
<td>Menzies Formation</td>
</tr>
<tr>
<td>6.1-7.0+</td>
<td>Sandy claystone; reddish brown, massive, matrix supported fabric; framework gravels unimodal, fine skewed, moderately sorted, fine, quartz and kaolin spherite sand.</td>
<td>Menzies Formation</td>
</tr>
</tbody>
</table>
Figure 5.—Map showing distribution of formations in the upper central Yeelirrie valley. See Fig. 1 for locations.
status. The members are: Bungarra Member; Volpress Member; and Yeelirrie Member and they are described later.

**Derivation of name.** Named after Menzies townsite, lat. 29°41'S, long. 121°2'E. Menzies 1:250 000 sheet.

**Type section.** The designated type section is a uranium exploration trench, termed by Western Mining Corporation, number 2 slot or bottle-slot lat. 27°11'S, long. 119°55'E. Sandstone 1:250 000 sheet (Table 4: Figs 4.7S3:6A).

**Distribution.** The Menzies Formation has been encountered in outcrops (Western Mining Corporation's slots 1 and 2), drill holes, trenches and creek incisions throughout valley, side and valley floor landsurface positions of the Yeelirrie area. Outcrop is poor and generally occurs as small patches along the axis of the Yeelirrie valley and along the floors and sides of tributary incisions (Fig. 5).

**Surface features.** Red sandy clay and sandy claystone generally forms the upper part of the formation in valley-side gully locations of the Yeelirrie valley and it usually has a flat to gullied erosional surface. The calcite-cemented portion of the formation usually occurs along the axis of the Yeelirrie valley and has a broad hummocky erosional surface, locally with a veneer of gravely calcite and calcareous sandy silt-clay.

**Geometry and dimensions.** In the Yeelirrie area the Menzies Formation forms a very broad basin-shaped valley fill. The lower boundary is concealed and has only been noted at a depth of about 18 m (Fig. 7, Site 175). Seismic contour and drilling data suggest the lower boundary is a broad valley form with the thickness of the formation increasing down valley (Australian Groundwater Consultants 1972).

**Lithic characteristics.** The Menzies Formation consists mainly of red sandy clay to red sandy claystone and locally red clayey sand and sandstone which are laterally and vertically interrelated in that they are interbedded and intergradational over a few metres. These main lithologies are also interlayered with other diagenetic and allochthonous sediment types such as (Fig. 7): (1) calcitic sandy clay to calcite with minor dolomite-cemented red sandy claystone; (2) sepiolite-cemented kaolin mudstone; (3) red kaolin mudstone; (4) laminar calcite and (5) very coarse to coarse clayey sand (Fig. 4.7S3); these latter lithologic intercalations however are minor components within the red sandy clay and sandy claystone which form the bulk of the formation.

The red sandy clay and sandy claystone is massive to weakly stratified. Stratification is most apparent where occasional thin calcite laminae occur. The sediment is composed of quartz, kaolin spherules (pigmented with goethite and haematite) and rare feldspar and sesquioxide (lateritic) framework grains with a goethite and haematite pigmented kaolin silt-clay matrix. Monocrystalline quartz grains predominate, although locally, policrystalline quartz grains occur in minor amounts. The quartz grains generally have a haematite and goethite pigmented coating of kaolin. The matrix often has a curvilinear laminated structure consistent with flow lines and meniscus lines. These features indicate that much of the matrix is a cement formed after the framework grains were deposited.

The fraction of the red sandy claystone and clayey sandstone greater than 0.045 mm is 20 to 80% sand by weight. The sand is bimodal to very poorly unimodal, strongly fine skewed to near-symmetrical, moderate to poorly sorted, medium to fine sand, in places ranging from coarse to very fine sand.

**Fossils.** Apart from possible algal filaments in the Bungarra Member the formation appears to be devoid of fossils.

**Stratigraphic relationships.** The Menzies Formation has a sharp contact with underlying granitic rock and is unconformably overlain, usually with a sharp contact, by the Gibson, Wirraway and Nuendah formations (Fig. 7). It tends to be laterally equivalent geographically to, but generally does not overlie the Mulline Formation. This is because the Mulline Formation is typically confined to upland plateaux and the Menzies Formation is best developed under major valley sides and bottoms. Where the Mulline Formation has undergone reworking it may overlie the Menzies Formation (Fig. 8, Section 138).

**Bungarra Member of Menzies Formation.** Named after Bungarra rockhole, lat. 27°21'S, long. 119°36'E. Sandstone 1:250 000 sheet.

The Bungarra Member is a massive red kaolin mudstone up to 1 m thick which in places has a thin lens of clayey coarse sand at upper levels (Fig. 7, section 156). It was encountered in two trenches excavated by Western Mining Corporation and in drill cores over a distance of more than 10 km, and at a depth of about 1 to 8 m. This distribution is probably not continuous. Distinguishing features include: tabular shape with approximately straight and parallel upper and lower boundaries; massive structure with scattered millimetre-sized vugs; brittle with a sub-conoidal fracture; “mudstone” fabric; red colour and dominantly kaolin clay composition with minor to trace amounts of silt to fine sand sized quartz; moderate amounts of carnitite; and a sparse network of dark fibres which may be fossilised algal filaments.

The Bungarra Member has a sharp near-horizontal contact with underlying and overlying red sandy clay and sandy claystone portions of the Menzies Formation, and in places underlies septolitic mudstone of the Volpress Member.

**Volpress Member of Menzies Formation.** Named after Volpress Well, lat. 27°34'S, long. 120°21'E. Sir Samuel 1:250 000 sheet.

The Volpress member is a black to grey and white mottled and veined septolitic mudstone (Fig. 4.7S3). It is characterised by: tabular to lens to pod shape; “mudstone” fabric with trace amounts of silt to fine sand sized quartz; white to black mottled appearance; septolitic kaolin composition with white anastomosing veins and blebs of septolite; minor amounts of carnitite; traces of smectite; and 0.12 to 0.36% organic carbon.

There is a lower sharp straight contact with red mudstone of the Bungarra Member and a discordant contact with the overlying calcite-cemented red sandy clay and sandy claystone facies of the Yeelirrie Member. The upper contact is gradational and undulating.

**Yeelirrie Member of the Menzies Formation.** Named after Yeelirrie homestead, lat. 27°20'S, long. 120°14'E. Sir Samuel 1:250 000.
The Yeelirrie Member is up to 5 m thick and crops out intermittently as broad mounds and depressions along the bottom of the Yeelirrie valley for over 100 km (Fig. 5). It forms thick lenses to pods tens of metres in diameter. In place pods exhibit a crude domal or arcuate structure which is roughly parallel with their dome surface form and similar to the calcite pseudo-anticlines of Jennings & Sweeting (1961). This member consists of five lithofacies: (a) white and red calcite sandy claystone breccia; (b) massive white calcite; (c) massive to cavernous, white and grey pods of calcite and dolomite; (d) laminar calcite sheets and brecciod clasts of laminar calcite; and (e) pisolitic to nodular to rhizocretenary calcite supported in sandy clay (Fig. 4, TS3).

The white and red calcite sandy claystone breccia facies forms a transitional zone between red sandy claystone and massive calcite or calcite. The massive to cavernous, white and grey pods of calcite and dolomite form a zone within the red calcite sandy claystone breccia. The lamellar calcite sheets and brecciod clasts of lamellar calcite plus pisolite to rhizocretenary calcite in sandy clay tend to overlie the other facies. Minor to trace amounts of goethite occurs in association with the calcite and dolomite domains of all facies.

Following the digestion of carbonates in HCl, up to 15% by weight of greater than 0.045 mm quartz and kaolin spherite grains remain. This residue is typically poorly unimodal, fine skewed, moderately sorted, fine sand.

The Yeelirrie Member has a broad gradational lateral contact with red sandy claystone and an irregular discordant contact with the underlying Volpress Member. The Yeelirrie Member is unconformably overlain by the Gibson, Wirraway, Nuendah and Darlot Formations or, in places along the axis of the Yeelirrie valley, it forms the contemporary landsurface.

Discussion: The red sandy clay and sandy claystone facies of the Menzies Formation has a varied provenance. Monocrystalline quartz, polycrystalline quartz and feldspar indicate contributions from granitic rock, sandstone and the Westonia Formation. Kaolin spherites and laterite clasts indicate contributions from laterite of the Mulline Formation. Much of the matrix material of the red sandy clay and sandy claystone facies is a cement of kaolin, goethite and haematite which formed after the framework grains were deposited. This host red sandy clay and sandy claystone has been locally overprinted by calcite thereby forming the Yeelirrie Member.

The red sandy clay and sandy claystone facies of the Menzies Formation can be distinguished from the Westonia Formation by its redness, goethite and haematite pigmented kaolin spherites and matrix silt-clay. The matrix material breaks with an uneven fracture rather than a film-clay sub-conchoidal fracture typical of the Westonia Formation. The red sandy clay and sandy claystone facies may also be superficially confused with the Wiluna Hardpan of Bettenay & Churchward (1974). However at its type section (lat. 24°3′S, long. 119°34′E, near Bullo Downs in the Bangemall Basin, c. 370 km NW of Yeelirrie) the Wiluna Hardpan is a conglomerate with pebbles of lateritic duricrust, quartzite, silcrete and shale supported in a red sandy clay matrix. Thus the Menzies Formation is not conglomeratic and can be distinguished from the Wiluna Hardpan which is conglomeratic. Furthermore, the different lithic nature of the Wiluna Hardpan, as defined by Bettenay & Churchward (1974) at its type section reflects its location in the Bangemall Basin: in contrast the Menzies Formation type section is located in the Yilgarn Block and reflects that province.

The red sandy clay and sandy claystone facies in the Yeelirrie area has been referred to previously as hardpan (Tacket 1936, 1950; Mabbutt et al. 1963). Wiluna Hardpan (Bettenay & Churchward 1974), alluvium (Haycraft 1976), mainly altered desert aeolian valley fill (Glassford 1980) and as alluvial/fluvial/colluvial/aeolian channel fill (Arakel & McConchie 1982). The Yeelirrie Member has been referred to as: calcite (Sofoulis 1963, Sanders 1974, Haycraft 1976, Arakel & McConchie 1982); valley or groundwater calcite (Carlisle et al. 1978, Mann & Horwitz 1979); calcited drainage lines (Churchward 1977); and calcite and dolomite brecciated, cemented and replaced, desert aeolian valley fill (Glassford 1980). The Volpress Member has been referred to as transition calcite (Haycraft 1976), altered playa-lake sediment (Glassford 1980) and moltted calcite (Arakel & McConchie 1982). The Bungarra Member has been referred to previously as altered playa and playa input fan sediment (Glassford 1980).

Gibson Formation

Gibson Formation is the name proposed for a unit which forms sand sheets and linear dunes. It is massive to locally weakly stratified red through reddish yellow to yellow and in places white clayey sand and sand. The formation typically overlies the Mulline and Menzies Formations (Tables 1-5).

Derivation of name: Named after the Gibson Desert the western margin of which includes the Yeelirrie area.

Type section: The designated type section is the face of a quarry in a linear dune on the south side of the Agnew to Sandstone road and 11 km west of the Agnew to Wiluna road, lat. 27°58′S, long. 120°24′E, Sir Samuel 1:250 000 sheet (Table 5, Figs 4, TS5:6B).

Distribution: The Gibson Formation is areally the most dominant land surface unit throughout the area. It occurs as a patchwork of large scale sand sheets on interfluve plateaux, valley side plains and on the continental divide between westerly and easterly sloping major valley systems (Figs 5: 6A, B3).

Surface features: The surface of the Gibson Formation has four major expressions in the Yeelirrie area: recti spinifex covered sand flats; recti spinifex covered linear dunes; erosional aeolia-covered sand flats; and erosional and depositional denticrite to braided shallow channels.

Table 5: General description of lithology, Gibson Formation type section.

<table>
<thead>
<tr>
<th>Depth (m)</th>
<th>Description</th>
<th>Rock unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-5.0</td>
<td>Sand: yellowish red to red, massive framework supported: from top to bottom grades uniformly from unimodal to poorly unimodal and from fine to more fine skewed, and from well to moderately well sorted, and from fine to medium quartz and kaolin spherite sand.</td>
<td>Gibson Formation</td>
</tr>
<tr>
<td>5.0-6.5</td>
<td>Sand, slightly clayey: red, massive to faintly stratified, framework supported: fine skewed, moderately sorted, medium sand; coarse sand consists of quartz, finer sand consists of quartz and kaolin spherite,</td>
<td>Gibson Formation</td>
</tr>
<tr>
<td>6.5-7.0</td>
<td>Sandy laterite: brownish red.</td>
<td>Mulline Formation</td>
</tr>
</tbody>
</table>
The surface of linear dunes is generally loose sand, however the surface of interdunes and spinifex covered sand sheets generally consists of a thin (c. 1 cm) coherent crust overlain by a thin (c. 1 cm) veneer of loose coarse sand. The coherent crust is formed by the packing of fines between larger grains, probably by rain-drop impact, and the binding action of Chara sp. filaments.

**Geometry and dimensions.** The Gibson Formation is a sand sheet which has been reworked into few to numerous linear dunes. The sand sheet in the Yeelirrie area is typically about 1 to 4 m thick and the linear sand dunes are generally about 5 to 10 m high (Figs 4:6b). Linear dunes are 0.5 to 3.5 km long, and 0.25 to 2 km apart. Dune orientation on average is 129° or NW to SE and ranges from 100° to 156°. Some dunes are symmetrical or asymmetrical in cross-section, others exhibit complex cross-sectional asymmetry. That is crest to mid-flanks may be symmetrical and lower flanks on the same dune may be asymmetrical and vice versa. Thus the dunes are termed linear rather than the genetic terms longitudinal or transverse.

**Lithic characteristics.** Sands of the Gibson Formation range from red to yellowish red to reddish yellow to yellow and in places white. Sand sheets and linear sand dunes of the formation are usually massive, but relatively rare very faint cross-stratification occurs in some wind-exposed quarry faces. The formation has two primary facies, a sand sheet facies (which includes interdune sand sheet) and a linear sand dune facies.

Sand sheet facies typically consist of sand which is bimodal to poorly unimodal, fine skewed, moderately well to poorly sorted, coarse to fine sand with dust (silt-clay). The “coarse” mode ranges from very coarse to medium sand (2.0 to 0.25 mm) and the “fine” mode ranges from medium to very fine sand (0.25 to 0.125 mm). Sand sheet facies have approximately 2 to 20% fines (less than 0.09 mm fraction). The sand-dune facies contain sand which is bimodal to unimodal, fine skewed, moderate to well sorted and medium to fine. Sand dune facies have approximately 0.5 to 8% fines (less than 0.09 mm fraction).
All facies have two major framework grain types, quartz grains and kaolin spherules. Quartz grains have a characteristic coating of haematite and goethite—pigmented (bordered) kaolin in addition to 25 to 60% quartz sand. Kaolin spherules are best developed and most abundant in fine sand-sized material (0.025 to 0.125 mm) of sand sheet, interdune sand sheet and linear dune facies. The spherules are unimodal, fine skewed, well to moderately sorted fine sand. They are extremely well rounded and pigmented red, reddish brown, reddish yellow or yellow by haematite and goethite. Kaolin spherules usually have a nucleus of pelritic to crudely oriented kaolin which is typically free of haematite and goethite and less commonly, quartz, opaque minerals or smaller spherules. The nucleus is encapsulated by a haematite and goethite pigmented oolitic kaolin envelope. Locally (e.g. some leeward dune flanks) sand to silt sized microcline may occur in minor amounts.

The silt-clay fraction of sand sheet and sand dune facies usually consists of quartz, disordered kaolin, haematite, goethite and minor feldspar and anastase.

Fossils. No fossils have been found in the formation.

**Stratigraphic relationships.** The Gibson Formation overlies the Mulline Formation and the Menzies Formation and in places is overlain by the Wirraway and Nuendah Formations. The lower boundary of the formation is sharp, flat to gently dipping and planar. The upper boundary is typically the present day land surface (Figs 3, 4, 6, 8).

**Discussion.** The occurrence, size, shape, roundness, internal structure, colour and composition of kaolin spherules in the Gibson Formation are consistent with it being mainly derived from the Menzies, Mulline and Westonia Formations.

The surface of the unit designated Gibson Formation has been mapped previously in the Yeklinie area as: (1) Bullimora land system, sand plain or aeolian sand and described as red sand consisting of reworked and residual lateritic soils by Mabbutt et al. (1963); (2) Quaternary aeolian deposits described as unconsolidated sheets and dunes of sand by Australian Groundwater Consultants (1972); (3) Bullimora landform-regolith system (modified from Bullimora land system of Mabbutt et al., 1963); (4) depositional sand plains of aeolian and fluviatile deep sands, grits and clays by Churchward (1977); (5) Quaternary aeolian deposits (Qps), red and yellow quartz sand in dunes and sheets; and (6) Quaternary colluvium and alluvium (Qp), dark red to brown clay to sandy loam by Bunton and Williams (1979); (7) spinifex sand plain with longitudinal dunes and aeolian sand plain and described as relic desert aeolian sand sheet and dunes by Glassford (1980); and (8) aeolian sand plains with few or weak dunes by Beard (1984).

**Wirraway Formation**

The Wirraway Formation is the name proposed for a sheet to dune unit of massive to stratified, mainly red to reddish yellow quartz sand to quartz clayey sand. The formation typically overlies the Menzies and Gibson Formations, and interdigitates with the Nuendah and Darlot Formations (Tables 1,6).

**Type section.** The designated type section is a low, broad, linear dune south of Lake Darlot, lat. 27°56'S, long. 121°13' E, Sir Samuel 1:250 000 sheet Table 6; Figs 4, 55; 6A, C, D).

**Distribution.** The Wirraway Formation occurs discontinuously along the axis of the Yeklinie valley. It occurs near and between playas (extra-playa) as low broad linear channel-border dunes, around and on the edges of playas and pans (playa-border) as pan or playa-contiguous sheets and sinuous to lunate dunes, and within playas (intra-playa) as sheets and dunes (Figs 9, 10).

**Surface features.** The surface is usually relict to erosional and vegetated. It may also be bare of vegetation as a reworked or primary depositional surface with sand ripples produced by the wind.

**Geometry and dimensions.** The Wirraway Formation occurs as thin sheets, low broad linear dunes and as sinuous to lunate dunes. It ranges from 1 to over 5 m thick (Figs 4, 6 A, C, D).

**Lithic characteristics.** The Wirraway Formation is a sheet to dune unit which consists typically of massive to locally stratified, red to reddish yellow to yellow quartz sand to quartz clayey sand. Outside the study area it has scattered rhizoconcretions at depth. On the basis of geometry and relation to playas it may be divided into facies (Table 7). Channel-border dune facies tend to be red to reddish brown whereas other facies tend to be yellowish red to reddish yellow because of goethite and haematite pigmented kaolin clay coatings on quartz sand grains. The formation is typically massive but some lunate and modern dune facies are stratified. Overall, Wirraway Formation sand is positively skewed, moderately well to poorly sorted, locally very coarse but usually medium to fine quartz with 0.5 to 26% fines (Table 7). The crests of channel-border dunes are relatively coarser than the flanks. This is similar to some lunate dunes and contrasts with linear dunes of the Gibson Formation which have dune crests which are relatively finer than flanks.

**Fossils.** Apart from rhizoconcretions at depth in channel-border dunes located outside the Yeklinie area, no fossils have been observed in the Wirraway Formation.

**Stratigraphic relationships.** The Wirraway Formation overlies the Menzies and Gibson Formations with a sharp, near-planar contact and locally interfingers with the Darlot Formation (Figs 4, 6A, C, D).

**Discussion.** Apart from its different land surface position, geometry, grain size properties and stratigraphic relationships the Wirraway Formation can be distinguished from the Gibson Formation because the Gibson Formation typically has moderate amounts of kaolin, quartz and goethite.

### Table 6

<table>
<thead>
<tr>
<th>Depth (m)</th>
<th>Description</th>
<th>Rock unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-1.5</td>
<td>Sand; red, massive, framework supported, unimodal, fine skewed, moderately to poorly sorted, medium quartz sand; fines (less than 0.09 mm) are 3.5% (top) to 6.8% (bottom).</td>
<td>Wirraway Formation</td>
</tr>
<tr>
<td>1.5-2.0+</td>
<td>Sandy claystone; reddish brown.</td>
<td>Menzies Formation</td>
</tr>
</tbody>
</table>
Figure 7.—Regional stratigraphy of the Menzies Formation in the Yeelirrie area. A,B. Location and geomorphic and stratigraphic settings of stratigraphic sections. C. Stratigraphic sections. Note: The Menzies Formation also occurs at the base of TS5 (see Fig. 4).

Legend for A

- **Wiluna**
- **Yeelirrie**
- **TS3**
- **TS4**
- **TS5**

- **Continental divide**
- **Yeelirrie Valley**
- **Lake Miranda**
- **Breakaways**

- **Cainozoic cover**

- **Legend**

- **175**
- **156**
- **72**
- **176**
- **86**
- **126**

- **(25 km east)**

- **Legend for A**

- **0**
- **40 km**

- **0**
- **50 km approx**
- **V = 250H approx**

- **0**
- **20 km approx**
- **V = 100H approx**
Figure 8.—Regional stratigraphy of the Gibson Formation in the Yeelirrie area. A. Location of sections. B, C, D, E, F, G, H. Geomorphic and stratigraphic settings of stratigraphic sections. I. Stratigraphic sections.
Figure 9.—Regional stratigraphy of the Wirraway, Nuendah and Darlot Formations in the Yeelirrie area. A. Location of stratigraphic sections. B,C,D,E,F. Geomorphic and stratigraphic settings of stratigraphic sections. G. Stratigraphic sections.

Optimally developed kaolin spherites whereas the Wirraway Formation typically has no kaolin spherites or very few iron-rich kaolin spherites and fragments of kaolin spherites.

The surface of the unit designated Wirraway Formation has been mapped previously in the Yeelirrie area as: (1) Bullimore and Albany landform-regolith systems and described as aeolian and fluviatile deep sands, grits and clays and deep fluviatile and aeolian deposits respectively by Churchward (1977); (2) Quaternary aeolian deposits (Qrs), white to yellow quartz sand, red brown silty sand, in sheets and dunes marginal to salt lakes and calcrete by

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Table 7

<table>
<thead>
<tr>
<th>Facies</th>
<th>General outline of grain size properties</th>
</tr>
</thead>
<tbody>
<tr>
<td>Extra-playa Channel-border dunes</td>
<td>Poorly unimodal to unimodal, strongly fine to fine-sifted, moderately to poorly sorted, fine sand with 4 to 26% fines (&lt;0.09 mm)</td>
</tr>
<tr>
<td>Playa-border Sheets</td>
<td>Poorly unimodal to unimodal, moderately well to poorly sorted, medium to fine sand with 8 to 14% fines (&lt;0.09 mm)</td>
</tr>
<tr>
<td>Sinuous dunes</td>
<td>Poorly unimodal to unimodal, strongly fine to fine-sifted, moderately well to moderately sorted, medium to fine sand with 3 to 7% fines (&lt;0.09 mm)</td>
</tr>
<tr>
<td>Lunate dunes</td>
<td>Poorly unimodal to unimodal, strongly fine to coarse-sifted, moderately well to poorly sorted, very coarse to fine sand with 4 to 20% fines (&lt;0.09 mm)</td>
</tr>
<tr>
<td>Intra-playa Sheets</td>
<td>Poorly unimodal to unimodal, near-symmetrical, moderately well to poorly sorted, medium to fine sand with up to 20% fines (&lt;0.09 mm)</td>
</tr>
<tr>
<td>Dunes (modern)</td>
<td>Poorly unimodal to unimodal, strongly fine-sifted to symmetrical, moderately well to moderately sorted, medium to fine sand with 0.5 to 3% fines (&lt;0.09 mm)</td>
</tr>
</tbody>
</table>

Bunting and Williams (1979); and (3) channel-border and playa-border aeolian clayey sand and sand (Glassford 1980).

**Nuendah Formation**

The Nuendah Formation is the name proposed for pale brown gravels, sands and clayey sands which occur along Precambrian basement ridge-footslope, breakaway-fronts and dendritic tributary drainage tracts of major valley sides. The formation typically overlies Precambrian basement and the Menzies and Gibson Formations (Tables 1-8).

**Derivation of name.** Named after Nuendah, lat. 27°2’S, long. 120°21’E, Sir Samuel 1:250 000 sheet.

**Type section.** The designated type section is the south bank of the Jones Creek, 47.5 km SE of Yeelirrie homestead where a telegraph line crosses Jones Creek, lat. 27°2’S, long. 120°21’E, Sir Samuel 1:250 000 sheet (Table 8; Figs 4,7,8,6A,E,F). One supplementary reference section west of the Yeelirrie to Community Bore road, lat. 27°4’S, long. 120°8’E, Sir Samuel 1:250 000 sheet (Fig. 9, site 169) is designated to include a facies not evident in the type section. This supplementary section exposes light brown clayey sand 50 m from the base of the breakaways.

**Distribution.** The Nuendah Formation occurs on valley sides of the Yeelirrie valley. At this scale it occurs as narrow belts along the base of NW to SE and west to east trending breakaways, along the footslopes of NNW trending Precambrian basement ridges and in dendritic tracts along tributary drainage lines which extend from breakaway-fronts and ridge-footslope to major valley bottoms (Fig. 10).

**Surface features.** Breakaway-front facies have relict depositional surfaces to locally modern depositional and erosional surfaces. Ridge-footslope facies have relict and erosional surfaces. Dentritic tributary facies have modern depositional surfaces.

**Geometry and dimensions.** The Nuendah Formation has a variable geometry. It occurs at the base of breakaways as a thin ribbon-like fringe or incipient bajada up to a few metres thick, a few hundred metres wide and up to many kilometres long. It occurs along the footslopes of Precambrian basement ridges as gullied fans and also extends as thin, braided to discontinuous veeveers, a few millimetres to a few decimetres thick, along intermittent tributary drainage lines (Figs 6A,E,F,9).

**Lithic characteristics.** The Nuendah Formation contains the following facies: (1) coarse to fine sand; (2) gravel to fine clayey sand; (3) medium to fine clayey sand; and (4) gravel to coarse sand.

The coarse to fine sand facies occurs in ridge-footslope overbank locations. Along the footslope drained by the Jones Creek it consists of two major beds. A basal upward fining graded bed of light brown, moderate to poorly sorted coarse quartz with minor amounts of basement lithoclast granule gravel to coarse quartz sand, and an upper, upward fining graded bed of light brown, coarse skewed, poorly sorted, medium to fine quartz sand.

The gravel to fine sand facies occurs in channels draining ridges and dendritic tributary channels which drain breakaway-fronts and major valley sides. It consists of basement lithoclast and quartz gravels and sands. The haematite and goethite pigmented kaolin grain-coatings are generally less on overbank and channel sands when compared with similar coatings on Gibson Formation sands.

The medium to fine clayey sand facies occurs along breakaway-fronts as bajada and pediment deposits. This facies is massive, light brown to light reddish brown, poorly sorted, medium to fine, clayey sand. It is composed of quartz and kaolin with minor kaolin spherules.

The gravel to coarse sand facies occurs at the base of breakaways as a scattered pebble to granule float or talus over the medium to fine clayey sand facies and is derived from the breakaways. Further from the breakaways the clayey sand is covered by a patchy, millimetre-thin veneer of white, moderate to poorly sorted, very coarse to coarse quartz sand.

**Fossils.** No fossils have been found in the formation.
Stratigraphic relationships. Along the front of breakaways the Nuendah Formation overlies plutonic rocks and interfingers with the Gibson Formation. Along the footslopes of basement ridges it overlies the Menzies Formation. In upper tracts of tributary drainage lines it overlies the Gibson Formation. In lower tracts of tributaries it overlies the Menzies Formation and interfingers with the Wirraway Formation (Figs 4,TS6: 6A,E,F,9).

The upper boundary of the Nuendah Formation is typically a modern land surface. The surface alternates with interminable ridges from one dominated by deposition to one dominated by erosion. Thus the upper bounding surface is commonly devoid of vegetation.

The facies of the Nuendah Formation are laterally equivalent because firstly they are still being formed at the present day land surface; secondly they are laterally intergradational in pit and outcrop profiles; and thirdly they all tend predominantly to overlie the Menzies and Gibson Formations.

Discussion. Along breakaway-fronts the Nuendah Formation is derived mainly from Gibson and Westonia Formations at the top of breakaways, and from deeply weathered granite rocks which comprise much of the lower part of breakaways. Near basement ridge-footslopes it is derived from basement rocks and the Wiluna Formation. Along the lower tracts of tributary drainage lines it is derived mainly from the Gibson and Wiluna Formations.

The unit designated Nuendah Formation has been mapped in the Yeelirrie area as: Nuendah, Marloo, Keith and Yakabinde landform—regolith systems by Churchward (1977): Quaternary alluvium (Qaz), and colluvium (Qqc, Qpm) by Bunting & Williams (1979); and as footslope channel, overbank and fan alluvial deposits (Glassford 1980).

Darlot Formation

The Darlot Formation is the name proposed for a unit of pan silt-clay, playa ("salt lake") gypsumous muds and playa border gypsum deposits which overlie Precambrian basement the Menzies and Gibson Formations and interfingers with the Wirraway and Nuendah Formations (Table 9). The Darlot Formation contains a lithologically distinct and mappable unit and it is proposed to name this unit the Miranda Member (see later).

Derivation of name. Named after Lake Darlot, lat. 27°45'S, long. 121°E to lat. 27°45'S, long. 121°30'E, Sir Samuel 1:250 000 sheet.

Type Section. The designated type section is a NE facing escarpment in an island in Miranda lake, lat. 27°40'S, long. 120°33'E, Sir Samuel 1:250 000 sheet (Table 9: Figs 4,TS7:6A,E,G).

Distribution. The Darlot Formation occurs intermittently along the axis of the Yeelirrie valley as a discontinuous series of ooli or sumps for surface and subsurface drainage. It extends down valley as a chain of pan, playa and playa-border deposits (Figs 4,6,9,10).

Surface features. All lithofacies have ancient buried and relict surfaces in addition to modern depositional surfaces. Modern mud flats and sand-dune surfaces have no vegetation. Relict gypsum surfaces have a very sparse to negligible vegetation typically Selenocharis sp., Arthrocnemum sp. and related genera whilst relict sand-dune surfaces have a variety of grasses, scattered shrubs and trees (Beard 1976).  

Geometry and dimensions. The formation varies markedly in geometry and thickness. It occurs as discrete tabular to lenticular sheets and ribbons, discrete circular to elongate to irregular basins, or as irregular to sinuous to lunate hills. It ranges from less than 1 m thick (e.g. small clay pans) to 7 m thick at the type section and to perhaps tens of metres thick (e.g. large playas).

Lithic characteristics. The Darlot Formation has the following facies: (a) gypsumous mud; (b) white quartz sand; and (c) a variety of gypsum deposits, which will be described under the Miranda Member (Figs 4,TS7:9).

Gypsumous mud facies occurs as modern playa mud flats at the surface. It ranges from red to reddish brown to locally grey, is massive to flat bedded and laminated and ranges from gypsumous kaolin mud to kaolinitic gypsum mud, usually with up to 5% very fine sand to silt sized quartz. Near the water table this facies generally consists of large crystals of authigenic spherical gypsum, often in rosettes, with moderate to minor kaolin mud matrix. Relict equivalents of this facies may be either buried with little alteration, or truncated with the upper gypsumous kaolin mud removed to leave underlying kaolinitic crystalline gypsum. Playa deposits are commonly buried under sheets and dunes of gypsumous silt-clay and dunes of gypsumous quartz and quartzite-sand and quartzose-gypsum sand.

White quartz sand facies occur as sheetlike sand deposits around the margins of playa mud flats. It varies from a few millimetres to several decimetres thick and from a few centimetres to a few metres wide. The sand commonly contains loose plant debris, algal filaments in patchy mats and sometimes bivalve and Coxiella shells. Fossils. A few Coxiella shells are locally buried in playa-border dunes.

### Table 9

<table>
<thead>
<tr>
<th>Depth (m)</th>
<th>Description</th>
<th>Rock unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.001</td>
<td>Muscovite; white, massive, hard, silt and clay sized gypsum.</td>
<td>Miranda Member of the Darlot Formation</td>
</tr>
<tr>
<td>0.01-1.25</td>
<td>Sandy silt-clay; white, soft, powdery, massive, silt and clay gypsum with minor unimodal, fine skewed, very fine, quartz sand.</td>
<td>Miranda Member of the Darlot Formation</td>
</tr>
<tr>
<td>1.25-1.45</td>
<td>Crystalline gypsum; white to light brown, hard, massive.</td>
<td>Miranda Member of the Darlot Formation</td>
</tr>
<tr>
<td>1.45-2.0</td>
<td>Sandy gypsum; white to light brown, poorly consolidated.</td>
<td>Miranda Member of the Darlot Formation</td>
</tr>
<tr>
<td>2.0-2.01</td>
<td>Crystalline gypsum; white to light brown, hard massive.</td>
<td>Miranda Member of the Darlot Formation</td>
</tr>
<tr>
<td>2.01-3.1</td>
<td>Sandy gypsum; white to light brown, cross-stratified quartz and gypsum sand.</td>
<td>Miranda Member of the Darlot Formation</td>
</tr>
<tr>
<td>3.13-4.5</td>
<td>Sandy gypsum; white to light brown, cross-stratified quartz and gypsum sand.</td>
<td>Miranda Member of the Darlot Formation</td>
</tr>
<tr>
<td>4.5-4.65</td>
<td>Crystalline gypsum; light brown, hard.</td>
<td>Miranda Member of the Darlot Formation</td>
</tr>
<tr>
<td>4.65-4.95</td>
<td>Crystalline gypsum; white to greenish grey, hydromorphic gypsum.</td>
<td>Miranda Member of the Darlot Formation</td>
</tr>
<tr>
<td>4.5-5.0</td>
<td>Crystalline gypsum; pink to red, hydromorphic gypsum.</td>
<td>Miranda Member of the Darlot Formation</td>
</tr>
<tr>
<td>5.0-5.6</td>
<td>Mud; red massively gypsumous kaolin mud with gypsum rosettes.</td>
<td>Miranda Member of the Darlot Formation</td>
</tr>
<tr>
<td>5.6-7.0</td>
<td>Concretion, silt.</td>
<td>Miranda Member of the Darlot Formation</td>
</tr>
<tr>
<td>7.0-8.0</td>
<td>Gypsumous mud; reddish brown gypsumous kaolin mud.</td>
<td>Miranda Member of the Darlot Formation</td>
</tr>
</tbody>
</table>
Figure 10.—Map showing distribution of formations in the lower central Yeelirrie valley. See Fig. 1 for location.
Stratigraphic relationships. The Darlot Formation occurs in the lowest part of the landsurface and therefore its lower boundary is nearly always concealed. However, coarse sand and pit excavations indicate that occasionally, clay pans of the Darlot Formation develop within, and therefore overlie the Gibson and Wirraway Formations, in addition to the Menzies Formation and Precambrian basement, with a sharp straight contact (Fig. 9).

Miranda Member of Darlot Formation. This unit is named after Lake Miranda, lat. 27°40'S, long. 120°33'E, Sir Samuel 1:250,000 sheet.

The Miranda Member consists of sheets and hills of gypseous sand, over 5 m thick at the type section (Fig. 4,TS7). The unit interdigitates with relict playa muds and also channel-border dunes of the Wirraway Formation. At the type section it consists of three main facies: (a) gypseous sand and sandstone; (b) crystalline gyspum; and (c) gypseous silt-clay.

Gypseous sand and sandstone facies occurs as sheets and dunes overlying and marginal to playa flats. It is loose to weakly lithified, crudely stratified and consists of brownish to off-white gypseous sand and minor to moderate amounts of quartz. The quartz is essentially clean, that is, it is associated with no goethite or haematite pigmented kaolinitic clay coatings.

Crystalline gyspum facies consists of tightly-packed crystals of idiomorphic gyspum. The primary gyspum has probably been modified by ground-water precipitation of secondary gypseous sand.

Gypseous silt-clay facies occurs as dunes and sheets marginal to modern playas or completely covering former playa mud flats. It is nearly everywhere massive, commonly white, and in places brownish white to grey. When dry the gyspum is a dusty powder. With increasing moisture content it grades to a soft plasticine-like consistency. This facies is commonly vegetated by Arthrocnemum and related sapphire genera plus the peculiar candelabrum-shaped Selenothamnus helmsii (Beard 1976).

Discussion. The Darlot Formation has a varied provenance. Sedimentary materials have been derived from both elastic and soluble components of Precambrian basement rocks in addition to all the previously described formations. Furthermore, the playa facies and playa-border facies have both acted intermittently as source materials for each other. However, playa facies appear to be the dominant source for playa margin deposits, whereas the latter facies appear to be a minor source for playa facies.

Kaolin spherules become pitted and fragmented and coatings of clay on quartz grains are removed when these grains are immersed in water. Consequently the presence of these grains in minor trace amounts in concretion with their relative degree of preservation can be used to distinguish between sands of the Nuendah or Darlot Formations which have themselves been derived from the Gibson and Menzies Formations.

The surface of the unit designated Darlot Formation has been mapped by previous authors as: Miranda landform—regolith system and described as deep fluviatile lacustrine and aeolian deposits of saline clays and gypseous and calcareous earths by Churchward (1977); Quaternary lacustrine (Qra), lacustrine and alluvial (Qrm), aeolian (Qpk) deposits by Bunting & Williams (1979); and playa and associated sub-aqueous and aeolian deposits (Glassford 1980).

### Table 10

<table>
<thead>
<tr>
<th>Name</th>
<th>Main lithology</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Westonia Formation</td>
<td>Gypseous sands and muds</td>
</tr>
<tr>
<td>2. Wirraway Formation</td>
<td>Lithoclast and gravel and sand</td>
</tr>
<tr>
<td>3. Nuendah Formation</td>
<td>Red quartz sand</td>
</tr>
<tr>
<td>4. Gibson Formation</td>
<td>Red to yellow sand and kaolin</td>
</tr>
<tr>
<td>5. Menzies Formation</td>
<td>Red sandy clay</td>
</tr>
<tr>
<td>6. Nuendah Formation</td>
<td>Red to yellow quartz and kaolin</td>
</tr>
<tr>
<td>7. Darlot Formation</td>
<td>Grey sandy claystone (in places silted)</td>
</tr>
</tbody>
</table>

1 Units are listed from youngest at top to oldest at bottom. It should be noted that the Darlot, Nuendah and Wirraway Formations interdigitate with each other and to a small extent with the Gibson Formation. The Gibson Formation occurs in the main area, unconformably overlies the Mulline and Menzies Formations and the Mulline and Menzies Formations typically, unconformably overlay the Westonia Formation which in turn typically, unconformably overlies sapphire which has developed in Precambrian Basement. The Mulline Formation includes primary and secondary (reworked) duricrust materials and in the Yekelir area the Westonia Formation has been silted.

Discussion

The stratigraphic details presented herein show that the Cainozoic cover of the Yekelir area consists of seven main lithological units (Table 10): (1) Westonia Formation (mainly gypseous and claystone with siltification); (2) Mulline Formation (mainly red sand and claystone); (3) Menzies Formation (mainly red sand and claystone); (4) Gibson Formation (mainly red sand); (5) Nuendah Formation (mainly gravel to gravelly sand to light brown clay sand); and (7) Darlot Formation (mainly gypseous sand and muds). In terms of landform occurrence, geomorphic expression, surface features, geometry, structure, fabric, texture (e.g. modalities, size, sorting, size distributions and fines), composition (e.g. mineralogy of grains, clay coatings), stratigraphic relationships and diagenetic/pedogenetic overprints (Table 1) these formations are distinctive and readily recognizable rock units.

These units are sufficiently distinctive and consistently distinguishable in the attributes outlined above to be mapped as separate discrete entities (Figs. 5,10), thereby satisfying the requirements for formation status (Hedberg 1976, North American Commission on Stratigraphic Nomenclature 1983, Staines 1985).

The proposed lithostratigraphic framework provides a relatively objective basis for more detailed future work into the nature and origin of the cover in the Yekelir area and also throughout other parts of the Yilgarn Block (Fig. 3). This is because the recognition and description of lithostratigraphic units is based on observable, non-genetic physical features (Hedberg 1976, p.31). In contrast to most previous work, a priori assumptions of genesis or developmental history, essentially play no part in the framework presented here. Consequently interpretations of origin for the units of this study have not been made. Such interpretations are considered premature at present because of the paucity of any integrated and thorough documentation of the major genetically critical attributes (e.g. stratigraphy, geometry, structure, texture and composition) of these or any other Cainozoic deposits of the Yilgarn Block. Interpretations
of origin will be presented at a later date after all the genetically critical attributes have been described for the respective units.

Acknowledgements: This paper is based on research initially carried out for a PhD dissertation in the Department of Soil Science and Plant Nutrition, University of Western Australia, with the financial support of a Commonwealth Postgraduate Research Award and subsequently additional private research. I thank Western Mining Corporations for logistic support and drill core; Australian Groundwater Consultants for drill core samples; the Bigonder family for their support at Yeeliddah. P. K. Killigrew and M. J. R. Kranawet for discussions and collaboration on the (M K) and many (L K) field trips; Dr. A. C. Cockbain, Dr. J. E. Glover and M. J. R. Kranawet for critically reviewing one drill and Dr. V. Swenman for discussions and critically reviewing many drafts of the manuscript; G. Edwards for typing; and B. V. Glasford for constant support and encouragement during field work through manuscript preparation.

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The Bridport Calcilutite

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Abstract

The term Bridport Calcilutite is proposed for the sequence of Holocene sediments consisting predominantly of homogeneous bioturbated carbonate mud and shelly carbonate mud. These sediments occur in the contemporary marine environment and in the subsurface of the coastal zone of the Swan Coastal Plain. The sediments have formed as submarine basin deposits in deep water quiescent environments in proximity to seagrass banks.

Introduction

The Holocene coastal zone of the Perth Basin presents a variable suite of facies and sedimentary deposition systems that include aeolian sands, beach deposits, seagrass bank accumulations, deltas, estuarine accumulations and sediments of the nearshore shelf and coastal rocky reefs. Generally each of these depositional systems are distinct in their mode of sedimentation, and they generate sediment accumulations which are of sufficient size and extent to be recognised as formations. Indeed, the various major types of Holocene coastal sediment accumulations already have been formally recognised as formations: e.g. the Safety Bay Sand, the Becher Sand, the Leschenault Formation (Passmore 1970; Playford et al. 1976; Semeniuk 1983; Semeniuk and Searle 1985).

Additional stratigraphic studies along the coastal and marine environments of southwestern Australia have further delineated a suite of coastal sediments, that have distinct lithologic characteristics, which should be formally assigned formation status. It is the purpose of this paper therefore to establish a new formation, the Bridport Calcilutite, for a sequence of Holocene deep water marine carbonate muds and shelly muds in the coastal region of southwestern Australia.

Data for this paper were obtained from coastal plain and submarine environments by reverse air core drilling, air-lift drilling and intact cores. Locations of drill sites that intersected the Bridport Calcilutite are shown in Fig. 1.

Regional Setting

The study area is set along the coastal zone and nearshore marine environment of the Rottnest Shelf of southwestern Australia (Carrigy and Fairbridge 1954). This coastal system is comprised of Holocene sediments as well as erosional surfaces cut into Pleistocene materials, and encompasses the seaward extremity of the Swan Coastal Plain, a Quaternary sedimentary system of the Phanerozoic Perth Basin (Playford et al. 1976).

The most important sites of sediment accumulation along the southwestern coast occur in the Cape Bouvard-Trigg Island sector of Searle and Semeniuk (1985). This sector is characterised by shore-parallel limestone ridges, in various stages of erosional degradation, with intervening deeper water marine depressions (Searle 1984). Holocene sedimentation, mainly restricted to loci termed accretionary cells (Searle 1984), has formed platforms, east-west oriented banks and subaerial promontories that span and segment the most eastern marine depression (the Cockburn-Warnbro Depression) to form a series of basins (Searle and Semeniuk 1985).

The shallow water submarine banks and platforms are seagrass-covered and are sites where seagrass-derived sediments (bioturbated to shelly quartz-skeletal sand and muddy sand) accumulate to form deposits referred to as Becher Sand (Semeniuk and Searle 1985). In the deeper water marine basins, where depths are >18 m and sediment floors are extensive, flat and featureless, there is accumulation of carbonate mud and shelly mud. These carbonate mud deposits have been described sedimentologically by Carrigy (1956) and Searle (1984), and are the lithotope of the Bridport Calcilutite, the subject matter of this paper.

Definition of the Bridport Calcilutite

The Bridport Calcilutite is the formation name proposed for the sequence of grey, structureless to bioturbated, calcareous (carbonate) mud with lesser shelly carbonate mud. The formation forms the floors and underlies modern (contemporary) deep water marine basins, and also occurs in the subsurface, typically underlying the Becher Sand. The formation name is derived from Bridport Point, in the southern part of Warnbro
Figure 1.—A and B. Locality diagram and setting within the Perth Basin.
C. Location of study area.
D. Location of drill sites where Bridport Calcilutite has been intersected.
E. Stratigraphic cross-section showing extent, thickness and east-west geometry of the Bridport Calcilutite along a transect situated near Rockingham. Radiocarbon ages within the Bridport Calcilutite at the type section are samples GX12904 and GX129033; both have been corrected for C13.
Sound, which is a basin where the Bridport Calcilitute is accumulating. The lithologic term calcilitute is aptly applied in that the proposed formation consists of calcareous lutaceous sediment (Bates and Jackson 1980).

Type Section: The core site on the west shore of Lake Richmond, in the Rockingham area, is designated as the type section (Fig. 1). Material from the core has been lodged with the Geological Survey of Western Australia. The sequence within the type section is described as follows:

Top (Becher Sand): fine to very coarse grey carbonate/quartz sand, locally shelly ..... 10.5 m

Bridport Calcilitute: homogeneous, grey/fawn, carbonate mud with seagrass fibre .............. 6.0 m

homogeneous, grey, carbonate mud with shell ........................................ 0.5 m

homogeneous, light grey, carbonate mud .... 3.0 m

Base (Tamala Limestone): calcified aeolianite limestone ........................................ 2.0 m

Distribution: The Bridport Calcilitute has been intersected in numerous cores and its distribution, both contemporary and subsurface, is widespread (Fig. 1).

Geometry and Thickness: The formation is up to 10 m thick under the coastal plain in the Rockingham area. Elsewhere the formation is generally 2-6 m thick. In localities where it is contemporary, the unit forms a sheet-like to lens-like body on basin floors. In the subsurface where it has been buried by the Becher Sand, as in the Becher Point-Rockingham Plain area, it forms a seaward thickening wedge body, or a thick prism.

Lithology: The dominant sediment in the formation is grey, structureless to bioturbated, calcium carbonate mud composed of clay-sized and silt-sized carbonate material. Locally there are layers with marine shells, layers of laminated calcareous mud, and horizons of seagrass fibre and seagrass peat.

Stratigraphic relationships: The formation overlies the following units:

1. Tamala Limestone (sharp unconformable contact).
2. Cooloongup Sand (bioturbated to gradational unconformable contact).
3. Mud of the Leschenault Formation (bioturbated, gradational, conformable contact).

The formation may be overlain by the bioturbated, grey sediments of the Becher Sand, and the contact is conformable and mostly sharp.

Age and fossils: The Bridport Calcilitute is wholly Holocene. Radiocarbon ages from shells in the unit are less than 7000 C14 yrs BP (Fig. 1). The Bridport Calcilitute is locally shelly and mollusc shells predominate. Molluscs include Bittium granarium and Chlamys sp. with less common Clanculius ptelebus, Cantharis lepidus, Cantharis fusiformis. Ethmolinia? vittiginea, Dila sp, Nassarius panperus, and Brachidontes usitatus.

Discussion

The sediments referred to here in the Bridport Calcilitute originally were considered part of the basal portion of the Becher Sand (see “unit of fawn coloured mud with seagrass fibre”, Table 2 of Semeniuk and Scarle 1983; “marine mud unit” in figure 2 of Semeniuk and Scarle 1985; and “mud” in Figure 3 of Semeniuk and Scarle 1986). However, the extensive drilling in the Rockingham-Becher Plain area has shown that the distinctive carbonate mud unit underlying the Becher Sand is up to 6 m thick, and that it is substantial enough in thickness and extent to be recognised as a separate formation. Drilling elsewhere, such as at Preston and Whitfords-Quinns Rock area, also has shown that the formation is not restricted just to the Cape Bovard-Trigg I coastal sector.

The occurrence of the unit has palaeo-environmental implications. In the modern environment the formation is accumulating in quiescent, protected, deep water marine basins such as Warnbro Sound and Cockburn Sound. The mud is derived from adjoining seagrass bank environments where wave agitation and reworking entrains fine carbonate sediment into the water column. The suspended mud finds its way into the basins and settles out as a suspension deposit. Periodically, the substrates of the basin are inhabited by a mollusc fauna which contribute their remains to the sediment to form shell layers. The Bridport Calcilitute thus represents deposits of quiescent deep water marine basins that adjourn, or are protected by, seagrass bank environments.

References


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The Journal publishes (after refereeing)
• papers dealing with original research done in Western Australia into any branch of the natural sciences;
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• authoritative overviews of any subject in the natural sciences, integrating research already largely published in the more specialized national or international journals, and interpreting such studies with the general membership of the Society in mind;
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