The Eucla Basin has the largest onshore extent of Cenozoic marine sediments anywhere in the world. The sediments provide a record of the evolving marine environments of the Southern Ocean and the terrestrial hinterland of the Australian continent. However, owing to its size and remoteness, the Eucla Basin is comparatively understudied. This is exacerbated by the scattered and often deeply weathered nature of the outcrops along the margins of the basin, and the inaccessibility of exposures in the basin centre, except in cliffs and caves. The extent and isolation of the Eucla Basin over two states has resulted in conflicting and overlapping stratigraphic nomenclature, especially of the marginal sediments. Therefore, we propose rationalising the nomenclature of the Eocene rocks in the region based on three guiding principles: the use of consistent terminology across the region; the recognition of the importance of allostratigraphy in defining stratigraphic architecture, in particular two 3rd-order cycles correlated with the Tortachilla and Tuketja transgressions; and continuity with past usage wherever possible, with a minimum of new terminology. We propose eight major changes to the existing nomenclature: (i) abandoning the term Bremer Basin for the marine and marginal marine to non-marine Eocene sediments that infill palaeovalleys and form a veneer across crystalline basement in southwest Western Australia and including these sediments in the margin of the Eucla Basin; a similar situation exists in the east, where the Eocene sediments that have been included in the Polda Basin are likewise a marginal extension of the Eucla Basin; (ii) introducing the term Maralinga Formation for all Middle Eocene non-marine to marginal marine sediments, including those previously included in the lower part of the Pidinga Formation in South Australia, and North Royal Formation for similar sediments in Western Australia; these replace the previous informal usage of lower Pidinga and lower Werillup Formation, respectively; (iii) restricting Hampton Sandstone to its original usage for a calcareous marine sand underlying the Wilson Bluff Limestone; (iv) raising the Paling Member of the Wilson Bluff Limestone to formation status; (v) using Pidinga Formation for all Upper Eocene carbonaceous sediments on the margins of the Eucla Basin in South Australia, and Werillup Formation for all such sediments in Western Australia, including the marginal palaeovalleys; terms such as Wollubar Sandstone in the palaeovalleys of the Yilgarn Craton, and Poelpena and Wanilla Formations in the Eocene part of the former Polda Basin should be abandoned; (vi) using the term Pallinup Formation for all Upper Eocene spicule-rich sediments along the western margin of the Eucla Basin; (vii) recognising the formation status of the Upper Eocene spicular marine sediments in the eastern Eucla Basin that were formerly termed the Khasta Member of the Hampton Sandstone and the Bring Member of the Pidinga Formation, abandoning the term Bring Member, and including those rocks, and similar sediments of the Poelpena Formation in the Polda Basin, in the new Khasta Formation; and (viii) abandoning the term Toolinna Limestone previously applied to Upper Eocene grainstone along the western margin of the Eucla Basin as it is a facies of the Wilson Bluff Limestone, whereas the grainstone at the type locality at Toolinna Cove is in fact Abrakurrie Limestone and is indistinguishable from the rest of that formation. We believe this rationalisation emphasises the unity of stratigraphy across much of southern Australia and, thus, will facilitate research on the Eucla Basin as a whole.

KEY WORDS: Eocene, Eucla Basin, South Australia, stratigraphy, Western Australia.

INTRODUCTION

The Eucla Basin is the largest onshore example of Cenozoic marine sediments in the world. The basin extends 2000 km from east to west and, including offshore extensions, 500 km from north to south. These successions show a remarkably consistent stratigraphy across the entire basin (Clarke et al. 1996; James & Bone 2000). Despite this remarkable consistency, there is a plethora of often confusing stratigraphic names reflecting, in part, the occurrence of these sediments in two states and three basins, together with the isolated, fragmented and often deeply weathered nature of many outcrops. In the past the Polda Basin in the east and the Bremer Basin in the west have been considered separate entities to the Eucla Basin. However, during the Eocene, deposition was continuous across these three basins and the sediments are best considered as being stratigraphically continuous. The
objectives of this paper are to rationalise the Eocene stratigraphy of the Eucla Basin and its extensions, with due reference to the St Vincent Basin near Adelaide. This basin, although separate from the others, provides a biostratigraphic and allostratigraphic reference section for the Middle and Upper Eocene and there are also similarities in depositional facies. The following principles guided our rationalisation: (i) consistent stratigraphic terminology across the region; (ii) recognition of the importance of allostratigraphic processes in stratigraphic architecture; and (iii) continuity with past usage wherever possible, with a minimum of new terminology.

BASIN FRAMEWORK

The boundary between the Eucla and the Bremer Basins (Figure 1) was always regarded as arbitrary. Hocking (1990a, b) followed previous workers and placed the boundary at Mt Ragged. More recently Hocking (1994) showed the boundary as occurring further west. Because the same inshore lithologies extend from the eastern Bremer Basin into the western Eucla Basin we propose that the term Bremer Basin be abandoned for the Eocene succession, which makes up the bulk of the onshore sediments of the basin. The sediments of the onshore Bremer Basin are a veneer, locally thicker in palaeovalleys, of marine to marginal marine and non-marine sediments that onlap the Yilgarn Craton and Albany–Fraser Orogen and are inseparable from the Eocene succession of the Eucla Basin. The term Bremer Basin should continue to be used for the Mesozoic succession offshore.

The eastern margin of the Eucla Basin is very similar to the western margin. For a width of 100–150 km the western Gawler Craton is onlapped by a veneer of Eocene sediments, locally thicker in palaeovalleys (Alley & Lindsay 1995; Hou et al. 2003). The associated palaeodrainage systems (Rogers 1999; Hou et al. 2003) are quite distinct. These sediments are again part of the margin of the Eucla Basin. Some of these sediments have been previously included in the Polda Basin. Although in the Mesozoic and earlier times this narrow east–west rift was a distinctive feature (Krieg 1995), by the Eocene it was no longer a zone of active subsidence and its margins play no role in the distribution of Eocene sediments. Therefore, we do not regard it as a separate entity during the Eocene (or the entire Cenozoic), and all Cenozoic sediments in it should be considered to be an eastward extension of the Eucla Basin. However, it remains a valid basin for the Mesozoic and Palaeozoic.

The St Vincent Basin is isolated from the Eucla Basin by the extensive bedrock high of the Gawler Craton. The St

Table 1  Biostratigraphic framework for the margins of the Eucla Basin.

<table>
<thead>
<tr>
<th>Age</th>
<th>Transgression</th>
<th>Planktonic foraminiferal zones</th>
<th>Spore-pollen zones</th>
<th>Dinoflagellate zones</th>
<th>Age (Ma)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Latest Eocene (Rupelian)</td>
<td>Aldinga</td>
<td>P17</td>
<td>Upper N. asperus</td>
<td>Spiniferites ramosus</td>
<td>40.0–33.8</td>
</tr>
<tr>
<td>Late Eocene (Priabonian)</td>
<td>Tuitja</td>
<td>P16</td>
<td>Middle N. asperus</td>
<td>Corrubdinium incompositum</td>
<td>35.2–34.0</td>
</tr>
<tr>
<td>Late Eocene (Priabonian)</td>
<td>Tuketja</td>
<td>P15</td>
<td>Middle N. asperus</td>
<td></td>
<td>&lt;38.4–35.2</td>
</tr>
<tr>
<td>Middle Eocene (Bartonian)</td>
<td>Tortachilla</td>
<td>P14–15</td>
<td>Lower N. asperus</td>
<td></td>
<td>40.5–35.2</td>
</tr>
<tr>
<td>Middle Eocene (Bartonian)</td>
<td>Wilson Bluff</td>
<td>P12</td>
<td>Lower N. asperus</td>
<td>Achilleodinium biformoides</td>
<td>43.6–40.5</td>
</tr>
</tbody>
</table>
Vincent Basin is much more complex tectonically than the Eucla Basin, with numerous fault-bounded sub-basins (Alley & Lindsay 1985). However, its biostratigraphy and sea-level history are very similar to that of the Eucla Basin, and it provides a critical baseline.

**BIOSTRATIGRAPHIC FRAMEWORK**

McGowran *et al.* (1997), based on earlier studies (McGowran 1989; McGowran *et al.* 1992), provided detailed marine biostratigraphic correlations in the southern Australian basins. He identified four Eocene transgressions from foraminiferal evidence, which he named Wilson Bluff, Tortachilla, Tuketja and Tuit (Table 1). Of these, the Tortachilla and Tuketja are widely recognised in southern Australia: the Tuit and Wilson Bluff are at present of local significance, recognised only from the St Vincent Basin and central Eucla Basin, respectively. A fifth transgression, the Aldinga, was initially considered to be of latest Eocene age (McGowran 1989), but was subsequently placed into the earliest Oligocene. The correlations of Berggren *et al.* (1995) suggested that the P17 zonal assemblage found in the Aldinga is indeed latest Eocene in age. The planktonic data in Table 1 integrate the global marine biostratigraphic scheme of Berggren *et al.* (1995) with the local foraminiferal correlations of McGowran *et al.* (1997), the palynological compilations of Gallagher and Holdgate (2000) and the dinoflagellate zonation of Harris (1985).

Non-marine and often lignitic successions in the basin margins and associated palaeovalley fills have been correlated palynologically (Holdgate & Clarke 2000). Interbedding of marine and non-marine strata in these marginal facies allows the palynology to be tied to the marine biostratigraphic succession (Table 1).

Planktonic foraminifers are sparse in the marine sediments of the Eucla Basin, typically coarse-grained limestone and calcareous sandstone, whereas those of southwestern Western Australia are often leached of carbonate. Even the fine-grained carbonates from the central part of the basin contain a sparse planktonic component. Thus, correlation of these sediments with those in the palaeovalley fills and central Eucla Basin are tentative. It was possible to date some of the strata with (semi)endemic benthic foraminifers (Li *et al.* 1996b).

The most important datum in the Eocene biostratigraphy of the Eucla Basin is the boundary between the Tortachilla and Tuketja successions. This probably equates to the Priabonian–Bartonian boundary, which is in the middle of zone P15. This makes a strong case for our use of allostratigraphy to define the architecture of the basin stratigraphy.

**ALLOSTRATIGRAPHIC FRAMEWORK**

Various authors (Clarke *et al.* 1996; McGowran *et al.* 1997; Holdgate & Clarke 2000) have linked the biostratigraphically confirmed transgressions to the global sea-level curve of Haq *et al.* (1988). While these correlations are possible, they must be assessed as tentative and used with caution. The sea-level cycles of Haq *et al.* (1988) are approximately of the same duration as the planktonic foraminiferal zones and half the duration of the palynological zones. A single mismatch in the biostratigraphy of these zones could significantly change the correlation of sea-level highstands. This is shown by comparing the correlations of Holdgate and Clarke (2000) and McGowran *et al.* (1997) who correlate the transgressions to different parts of the Haq curve. However, the terms Tortachilla and Tuketja apply to individual highstands that can be correlated across southern Australia from Adelaide to Walpole, regardless of their relationship to the global sea-level chart or the validity of that chart. Therefore, in this paper we use allostratigraphic principles in correlation, but do not attempt to tie specific transgressions to any global correlation.

**Correlations**

The existing stratigraphic nomenclature is shown in Table 2 and our proposed stratigraphic revisions are given in Table 3. The Eocene stratigraphic architecture of the eastern and northeastern Eucla Basin is shown in Figure 2, that of the western part near Balladonia in Figure 3, and that of the Lefroy Palaeodrainage in Figure 4. Stratigraphic architecture of the Eucla Basin margins in southwestern Western Australia are depicted in Figure 5 and that of the Cowan Palaeovalley in Figure 6. In the following sections we discuss the proposed revisions of each formation and member.

**TORTACHILLA TRANSgression**

Transgressive systems tract

**MARALINGA FORMATION (EUCLA BASIN, SOUTH AUSTRALIA)**

We propose this new formation for all Middle Eocene clastics and lignites, together with their lithified and weathered equivalents, that were deposited in non-marine environments along the margins of the Eucla Basin in South Australia, especially in the palaeovalleys. The term replaces the previous nomenclature of the earlier terms, lower Pidinga, Poelpena and Wanilla Formations. It is the direct equivalent of the North Royal Formation (see below) in Western Australia.

A multiplicity of names has been applied to Middle Eocene gravel, sand, clay and lignite and their lithified and weathered equivalents along the margins of the Eucla Basin. Along the northeastern margin of the Eucla Basin in South Australia the carbonaceous Tertiary clay at Lake Pidinga (now Lake Ifould) was named ‘Pidinga Clay and Sands’ by Ludbrook (1958). The Pidinga Formation was defined by Harris (1966) as consisting of Eocene carbonaceous and locally lignitic sand, clay and silt along the margins of the eastern Eucla Basin. The type section was a bore at Lake Ifould; unfortunately this material has been lost (Rankin *et al.* 1996). The lithology also forms the bulk of the Eocene sediments filling the marginal palaeovalleys (Hou *et al.* 2000). Clarke and Hou (2000) used the informal terms upper and lower Pidinga to differentiate between Pidinga rocks deposited during the Middle and Late Eocene Tortachilla and Tuketja transgressions. Each of
<table>
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<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Tuketja Transgression</td>
<td>Pallinup Formation (Fitzgerald Member)</td>
<td>Princess Royal Spongolite</td>
<td>Pallinup Formation or Toolinna Limestone</td>
<td>Princess Royal Spongolite and Hampton Sandstone</td>
<td>Perkolilli Shale</td>
<td>Wilson Bluff Limestone</td>
<td>upper Hampton Sandstone (Khasta Member) + Pidinga Formation (Bring Member) Ooldea Sand (locally)</td>
<td>Pidinga Formation (Bring Member)</td>
</tr>
<tr>
<td>Late Eocene</td>
<td>upper Werillup Formation</td>
<td>No unit recognised</td>
<td>upper Werillup Formation</td>
<td>No unit recognised</td>
<td>Pidinga Formation</td>
<td>Wollubar Sandstone</td>
<td>Wilson Bluff Limestone</td>
<td>Poelpena Formation sequence 3</td>
</tr>
<tr>
<td>Tortachilla Transgression</td>
<td>Nanarup Limestone Formation and Neridup limestone lenses</td>
<td>Norseman Formation</td>
<td>Wilson Bluff Limestone</td>
<td>Wilson Bluff Limestone</td>
<td>Wilson Bluff Limestone</td>
<td>Wilson Bluff Limestone (Paling Member) Ooldea Sand (locally)</td>
<td>No unit recognised</td>
<td>Tortachilla Formation</td>
</tr>
<tr>
<td>Middle Eocene</td>
<td>lowerWerillup Formation</td>
<td>Hampton Sandstone</td>
<td>Pidinga Formation</td>
<td>Wollubar Sandstone</td>
<td>Hampton Sandstone</td>
<td>Pidinga Formation</td>
<td>Poelpena Formation sequence 2</td>
<td>upper Maslin Sand</td>
</tr>
</tbody>
</table>
these was capped by a highstand marine lithology, the calcareous Paling Member (see below) for the lower part of the Pidinga Formation and the Khasta Member of the Hampton Sandstone for the upper part of the Pidinga Formation. Hou et al. (2003) carried out a detailed description and analysis of these palaeovalley facies.

There are numerous sections of carbonaceous sediment penetrated by drilling on the Eyre Peninsula (Alley & Lindsay 1995). These have been described as Poelpena Formation in the Polda Basin and Yaninee Palaeovalley and the Vanilla Formation in the Cummins and Vanilla Palaeovalleys. Rogers (1999) equated the Poelpena Formation in the Polda Trough and the Vanilla Formation in the Cummins Palaeovalley on the Eyre Peninsula with the Pidinga Formation. Palynological data (Harris & Foster 1974) indicates the presence of sediments of *Tricorites magnificus* age, equivalent to the Lower *Nothofagidites asperus* zone of Partridge (1976), in the Polda Basin. The sediments were entirely non-marine and Harris (1985) assigned them to his sequence 2.

Given the widespread occurrence of carbonaceous Eocene clastics deposited during the Tortachilla transgression we believe that the lower Pidinga Formation should be formalised as a separate formation and propose Maralinga Formation as the name for this unit, which occurs entirely in the subsurface. The Maralinga locality is underlain by Eocene sediments and is not far from the borehole CRAE 2, which we nominate as the type section. The coordinates of the borehole are 228637mE, 6658008mN (Barton 1:250 000 map sheet), and the cuttings are held in the PIRSA (Primary Industries and Resources South Australia) core library in Glenside.

In CRAE 2, the Maralinga Formation is 98 m thick, extending from 35 to 133 m (TD) below surface. The base of the unit is not exposed, but because drilling shows that the Eocene carbonaceous sediments rarely exceed a thickness of 100 m in this area, we believe the bore has penetrated to near the base of the unit. The lithology in the core consists mostly of quartz sand, locally carbonaceous and gravelly in composition. The upper part is composed of 6 m of carbonaceous silt and clay. The upper surface of the Maralinga Formation is gradational into the calcareous Paling Formation (see below), where present, or else truncated by a disconformity. We predict that the basal surface of the unit unconformably overlies older sediments or crystalline basement.

The Maralinga Formation in Ooldea Range 6 contains palynoflora of the lower *N. asperus* zone (Alley & Benbow 1989), whereas the overlying carbonaceous clay of the Pidinga Formation is best assigned to the middle *N. asperus* zone, which is now recognised as late Middle to early Late Eocene (Alley & Beecroft 1993) rather than Eocene or even earliest Oligocene (Benbow et al. 1982).

### NORTH ROYAL FORMATION (EUCLA BASIN, WESTERN AUSTRALIA)

We propose this new formation for Middle Eocene clastics and lignites, together with their lithified and weathered equivalents, that were deposited in non-marine to marginal marine environments along the margins of the Eucla Basin in Western Australia, especially in the
palaeovalleys. The term replaces the earlier terms lower Pidinga Formation, lower Werillup Formation and Wollubar Sandstone. It is the direct equivalent of the Maralinga Formation in South Australia. It is stratigraphically unrelated to the Princess Royal Formation except that both can be present in the same succession.

In southwestern Western Australia (formerly Bremer Basin), Cockbain (1968b) defined the Werillup Formation from the Werillup 3 borehole near Albany prison. This formation has been spelt in various ways by different authors, we recommend this spelling which is that of the locality from which it takes its name. The Werillup Formation in the type section is a succession of carbonaceous sands, silt and clay with local lignite found in rare outcrops along the southern coastal exposures of southwestern Western Australia and quite commonly in the subsurface (Cockbain & van de Graaff 1973; Elms et al. 1982). Clarke (1993) divided the Werillup Formation into informal upper and lower members separated by the Norseman Formation. The lower Werillup Formation contained a Lower *N. asperus* palynoflora. As the lower Werillup Formation is usually preserved only where overlain by the Norseman Formation and its equivalents (see below), its distribution is limited. Both the upper and lower members consist of upward-fining successions of basal sand and gravel grading into silt and then clay and with minor lignite in the upper part.

We propose the name of North Royal Formation for all sediments previously placed in the lower Werillup Formation. The formation is named after the North Royal openpit at Norseman, whose coordinates are 387750E and 6443255N on the Norseman 1:250 000 map sheet (SI51-02). The Eocene sediments fill a north-trending palaeovalley that was a tributary to the trunk Cowan palaeovalley. The type locality of the formation is in the North Royal pit. Approximately 35 m of Cenozoic sediment was exposed in the pit (Watchorn 1980), of which the lower 13 m consisted of the North Royal Formation (Figure 7). The formation consisted of an upward-fining succession with lithic cobbles at the base, fining upwards into sand and then clay.

![Figure 2](image-url)  
**Figure 2** Schematic stratigraphic architecture of the northeastern margin of the Eucla Basin.
The North Royal Formation is now deeply weathered throughout. The uppermost part of the formation in the North Royal open pit was originally lignitic, as evidenced by the presence of a widespread horizon of erect tree stumps in the upper part. In the subsurface of the Cowan trunk palaeovalley drilling has indicated that organic material in the North Royal Formation is still well preserved where groundwater saturation has precluded weathering.

Although slumping has made the sides of the pit difficult to access, approximately 30 m of Eocene sediments are still present in the northeastern corner. The top of the North Royal Formation is still visible and consists of deeply weathered clays. The tree stump horizon at this locality consists of iron-oxide mineralised stumps approximately 8 cm across and up to 30 cm high. The stumps project 10–20 cm into the base of the overlying Norseman Formation, which has been extensively dolomitised. The Norseman Formation here contains an abundant mollusc fauna, along with echinoids and minor bryozoans.

The basal surface of the North Royal Formation was deposited in the North Royal palaeovalley incised in weathered Archaean bedrock. The top of the overlying Norseman Formation is sharp. Clearly there has been a sudden change in depositional environment from non-marine or marginal marine to fully marine. This contact dates the North Royal Formation as being older than the Tortachilla transgression.

HAMPTON SANDSTONE

We recommend that the Hampton Sandstone be confined to its original usage, as a basal sandstone below the Wilson Bluff Limestone.

Fairbridge (1953) recognised the Hampton Conglomerate as a discontinuous sand unit found at the base of the Wilson Bluff Limestone in Transcontinental Railway Bore No. 1. Lowry (1968) formally defined the Hampton Sandstone in the western half of the Eucla Basin as consisting of sand and sandstone, often calcareous and gritty containing marine fossils, that underlies the Wilson Bluff Limestone. The same unit has also been recognised in the eastern Eucla Basin (Alley & Lindsay 1975). We believe that the term should be restricted to lithologies occurring in this stratigraphic position at the base of the Wilson Bluff Limestone.

Subsequent to its original definition other authors used the term Hampton Sandstone more loosely for other stratigraphic units. Jones (1990) and Clarke (1995), for example, correlated sand interbedded and underlying carbonaceous clay in the Lefroy Palaeovalley in Western Australia as Hampton Sandstone. However, we believe that these sediments are best included in the North Royal and Werillup Formations. Benbow (1993) included spicular sediments overlying the Pidinga Formation in the Hampton Sandstone and proposed the name Khasta Member of the Hampton Sandstone for them. As detailed below, we regard the Khasta Member as a separate formation.

Highstand systems tract

The highstand systems tract of the Tortachilla transgression consists of marine carbonate rocks in the main part of the basin and lenses of limestone and calcareous sandstone within fine-grained siliciclastic rocks found in former protected settings such as lagoons, archipelagos and estuaries. The continuous outboard lithologies are separated from the more discontinuous inboard units by a gap and, in the northern and eastern Eucla Basin, by barrier sands. The gap is probably due to development of a ravinement surface in shallow water during the highstand. The Wilson Bluff Limestone records the highstand systems tract in the central part of the Eucla Basin, whereas along the margins the highstand is represented by a number of units including the Norseman Formation, Nanarup Limestone Member and the Paling Formation. The lower Ooldea Sand preserves the shoreline facies of this highstand.

WILSON BLUFF LIMESTONE

Singleton (1954) proposed the name Wilson’s Bluff Limestone for soft chalky limestone exposed in the lower part of the coastal cliffs of the Nullarbor Plain. McWhae et al.
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(1958) amended the name to the geographically correct Wilson Bluff Limestone and nominated the section at Wilson Bluff on the South Australian/Western Australian border as the type locality. Lowry (1968) suggested that the type section of the Wilson Bluff Limestone, by then known to be of Eocene age, should be relocated several hundred metres further east to make it more accessible. Typically the Wilson Bluff Limestone consists of a fine-grained to chalky limestone, commonly rich in bryozoans and echinoids, and locally rich in molluscs and brachiopods. The poorly defined 'Wilson Bluff transgression' occurs near the base of the formation, but is not known from outcrop. The Tortachilla transgression (McGowran 1989) has not been recognised to date from the Wilson Bluff Limestone, although it occurs in the Paling Formation (see below).

PALING FORMATION (EUCLA BASIN, SOUTH AUSTRALIA)

We propose that the Paling Member of the Wilson Bluff Limestone be raised to formation status and be used for all Middle Eocene limestone in the lagoons along the north-eastern margin of the Eucla Basin. The Paling Formation forms the highstand systems tract of the Tortachilla transgression in these areas.

A thin glauconitic and carbonaceous limestone composed of fragmentary bryozoans, molluscs, echinoids, foraminifers, ostracods, sponge spicules and coralline algae occurs locally between the Barton and Ooldea Ranges (Benbow et al. 1982; Alley & Beecroft 1993; Rankin et al. 1996). The lithology was found in the subsurface in the CRAE 2 and Karrari 1 bores and in Tietkens Well. Closely associated with limestone is calcareous sand, sometimes shown as Hampton Sandstone on previous geological cross-sections (Rankin et al. 1996; Alley & Benbow 1989). The lithology is shown as the Paling Member of the Wilson Bluff Limestone in the correlation chart of Alley and Beecroft (1993), from a name proposed for it by M. C. Benbow (pers. comm. 2001), although the unit has never been formally defined. The name is taken from the Paling Range.

Here we define this unit as the Paling Formation. We justify this on the following grounds, that the unit has been recognised as a distinctive and probably continuous unit for at least 1000 km² (a greater area than the equivalent Norseman Formation in Western Australia) and it defines the highstand systems tract of the Tortachilla transgression: the unit is also not in stratigraphic continuity with the Wilson Bluff Limestone (of which it was formerly a member), although it is laterally equivalent to it.

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**Figure 4**  Schematic stratigraphic architecture of the Lefroy Palaeovalley fill at Kambalda. Legend as in Figure 2.

**Figure 5**  Schematic stratigraphic architecture of the margins of the Eucla Basin in southwestern Western Australia, as exposed along the south coast. Legend as in Figure 2.
The type locality of the formation is in the borehole CRAE 2, held in the PIRSA core library. In this bore the Paling Formation occurs in cuttings at depths between 28 and 35 m, for a total thickness of 7 m (Figure 8). It consists of 75% carbonate, 20% quartz and 5% glaucony, occurring as sand- to silt-sized grains (Benbow et al. 1982). It is overlain along an inferred disconformity by Upper Eocene carbonaceous black clay of the Pidinga Formation and grades up from the black carbonaceous silt, sand and clay of the Maralinga Formation. The limestone of the Paling Formation passes laterally into calcareous sand (see cross-sections in Rankin et al. 1996 and Alley & Benbow 1989).

Foraminifers from the formation at Tietkens Well (McGowran 1989) as well as in CRAE 2 and Karari 1 (Alley & Beecroft 1993) indicate that the Paling Formation is Middle Eocene in age. This is consistent with the presence of latest Eocene palynomorphs in overlying carbonaceous clay of the Pidinga Formation in the type locality (Benbow et al. 1982). The Paling Formation is laterally equivalent to the Wilson Bluff Limestone, although there is no known lateral continuity between the two formations. This could be due to erosion after deposition, non-deposition of the Wilson Bluff Limestone inshore, or a combination of these factors.

The Paling Formation contains a diverse marine biota, together with abundant glaucony, which indicates normal marine salinities. The unit is also highly carbonaceous with abundant plant fragments, like the Pidinga Formation above and the Maralinga Formation below. It is found landward of the Immarna and Pidinga passes through the Ooldea Range (Clarke & Hou 2000). Thus, either exchange between the ocean and the lagoon behind the barrier of the Ooldea Range was sufficient for normal salinity to be established and with it a normal marine biota, or carbonate sand from the shelf was swept through the passes and deposited as flood-tide delta lobes.

**NORSEMEN FORMATION AND EQUIVALENTS (EUCLA BASIN, WESTERN AUSTRALIA)**

The Norseman Limestone was defined by Cockbain (1968a) as a calcareous sand to grainstone dominated by bryozoans, coralline algae, echinoids and molluscs. The formation was redefined as the Norseman Formation by Clarke et al. (1996) to recognise the extent of poorly calcareous lithologies, chiefly sand and gravel, intimately associated with it in the subsurface. The type locality is just to the north of the Norseman township and the unit extends as scattered outcrops along the shores of Lake Cowan (Clarke et al. 1948) and also in the subsurface (Clarke 1993). The formation forms the highstand systems tract overlying the transgressive systems tract of the North Royal Formation.

The Norseman Formation onlaps onto an erosional...
surface at an elevation of ~260 m in the Cowan Palaeovalley. This represents a ravinement surface cut during the highstand.

Local lenses of limestone occur in bores at Neridup, near Esperance (Cockbain 1967), and in the Nanarup quarry near Albany (the ‘Nanarup Limestone’ of Quilty 1969, 1981). These have yet to mapped away from their original localities, so have not been formalised as formations. We believe these occupy the sample stratigraphic position as the Norseman Formation and the Paling Formation. We predict that with further drilling additional units of limestone in the same stratigraphic position will also be found in other localities in southwestern Western Australia. At such a time these units, such as the Nanarup Limestone Member, should be elevated to the Nanarup Formation.

‘LOWER’ OOLEDA SAND (OOLEDA RANGE)

Benbow (1990) recognised the Ooldea, Barton and Paling Ranges as an Eocene barrier island complex, and named the unit comprising them the Ooldea Sand. Clarke and Hou (2000) suggested that the Ooldea Sand in the Ooldea Range was deposited during the Tortachilla transgression. In this paper, we informally refer to this as the ‘lower’ Ooldea Sand. The units can be differentiated from the ‘upper’ Ooldea Sand where they occur in different dune systems, but no physical or boundary criteria are presently known that would allow them to be differentiated should they occur in the same stratigraphic section. The only exposure of the ‘lower’ Ooldea Sand is in the Immarna cutting on the Trans-Australian railway line, to the east of Immarna Siding.

TUKEJTJA TRANSGRESSION

Transgressive systems tract

PIDINGA FORMATION (EUCLA BASIN, SOUTH AUSTRALIA)

We propose that the name Pidinga Formation be restricted to Upper Eocene clastics and lignites, together with their lithified and weathered equivalents, that were deposited in non-marine to marginal-marine environments along the South Australian margins of the Eucla Basin, especially in the palaeovalleys. The term replaces the earlier terms of upper Pidinga Formation, Poelpena Formation and Wanilla Formation. The Pidinga Formation is directly equivalent to the Werillup Formation in Western Australia.

The Pidinga Formation (previously informally referred to as the upper Pidinga Formation) consists of Upper Eocene carbonaceous and locally lignitic sands, clays and silt along the edges of the Eucla Basin and extending up into the marginal palaeovalleys (Clarke 1993; Hou et al.)
The Pidinga Formation is lithologically similar to the Maralinga Formation, but can be distinguished from it on a number of criteria: (i) continuous succession with the overlying Khasta Formation; (ii) a Late Eocene palynoflora (Alley & Benbow 1989); and (iii) disconformable position above earlier highstand units such as the Paling or Norseman Formations, where these are present. Biostratigraphic data on the Pidinga Formation indicates that the formation is of Middle N. asperus age (Stover & Partridge 1982; Milne 1988; Alley & BeeCroft 1993; Clarke 1993; Alley & Lindsay 1995).

As noted above, Rogers (1999) equated the Poelpena Formation in the Polda Trough and the Wilamina Formation in the Cummins and Wilamina Palaeovalleys on Eyre Peninsula with the Pidinga Formation. These units include sediments that contain a palynoflora of Upper N. asperus age and were placed by Harris (1985) in his sequence 3. The similarities with lithologies elsewhere assigned to the Pidinga Formation are clear and these units appear to be both laterally equivalent and continuous. Therefore, we propose that all Upper Eocene marginal to non-marine transgressive systems tract sediments of the Eucla Basin in South Australia be placed in the Pidinga Formation. Lignite is much more common in the Upper Eocene than the Middle Eocene clastics (Holdgate & Clarke 2000).

WERILLUP FORMATION (EUCLA BASIN, WESTERN AUSTRALIA)

We propose that the name Werillup Formation be restricted to Upper Eocene clastics and lignites, together with their lithified and weathered equivalents, that were deposited in non-marine to marine environments along the Western Australian margins of the Eucla Basin, especially in the palaeovalleys. The term replaces the earlier terms upper Werillup Formation, Roilos Bore Formation and Wollubar Sandstone, and usage of Pidinga Formation in Western Australia. It is directly equivalent to the Pidinga Formation in South Australia.

Clarke (1993) recognised an informal upper member to the Werillup Formation in the Lake Cowan area, separated by the Norseman Formation. It consisted of an upward-fining succession of basal gravel and sand grading up into silt and then clay and with lignite at the top and contained an Upper N. asperus palynoflora. The upper Werillup Formation was much more extensive in distribution than the lower member and comprised most or all of the Werillup Formation in most sections. Because most exposures of the Werillup are in fact of Late Eocene age we recommend that the term be restricted to sediments of this age and that the new name of North Royal Formation be applied to older Eocene clastic sediments. All the lignite resources identified along the margins of the Eucla Basin in Western Australia occur in the Werillup Formation as we have redefined it (see Elms et al. 1982; Holdgate & Clarke 2000).

Kern and Commander (1993) defined two palaeovalley-filling units in the Kalgoorie area, the Wollubar Sandstone and the Perkolilli Shale. The Wollubar Sandstone forms the fills in the deepest part of the palaeovalleys, is interbedded with clays, and is often carbonaceous where unweathered. The Perkolilli Shale overlies the Wollubar Sandstone and is always oxidised. We recommend that both these terms be abandoned. The term Wollubar Sandstone should be abandoned because it is often not a sandstone, and is equivalent to the Werillup Formation: both units are laterally equivalent and probably laterally continuous. As defined the Perkolilli Shale includes weathered clay units in the Wollubar Sandstone and red clay lacustrine deposits of probable Neogene age and, hence, should be abandoned.

HIGHSTAND SYSTEMS TRACT

The highstand systems tract of the Tuketja transgression consists of the Wilson Bluff Limestone in the central part of the Eucla Basin and, sheltered behind archipelagos in lagoons and estuaries, the spicular sediments of the Pallinup and Khasta Formations.

WILSON BLUFF LIMESTONE

McGowran (1989) noted that evidence for the Tuketja transgression had not been found west of the St Vincent Basin. However, indirect evidence (Clarke et al. 1996) shows that the Princess Royal Formation (and thus the laterally equivalent upper part of the Wilson Bluff Formation) is the same age as the Tuketja transgression. Outcrop samples from near the type locality of the Wilson Bluff Limestone indicate that it contains Wadella cf. hamiltonensis, suggesting a Middle to Late Eocene (P14–P16) age (Li et al. 1996a). While this is most probably equivalent to the sediments of the Tuketja transgression it is nevertheless imprecise. Exact correlation of the Wilson Bluff Limestone is difficult, despite its chalky nature, because of the rarity of planktonic foraminifers as a result of extensive winnowing or an oligotrophic environment. Samples from the Wilson Bluff Limestone at Point Culver supports this, containing the foraminifers Truncorotaloides collactea, Globigerina linaperta and Globorotaloides turridus. This information, together with the data in Lowry (1970) from Point Culver, Booanya Rock and Ballardona, suggest a P14–P17 zonal age range, with P15–P17 as the most likely. Consequently the Wilson Bluff Limestone at Point Culver is most probably of Tuketja age, as is the spicular Pallinup Formation along its western margin (Table 3). Similar siliceous sponge-rich limestone occurs near Ballardona, separated from equivalent Pallinup Formation by outcrop chains of crystalline basement. Where these outcrops are absent, Wilson Bluff Limestone, with or without siliceous sponge fossils, abuts the Fraser Range. Interfingering of the Wilson Bluff Limestone and Pallinup Formation was found in a drillhole at North Rocks, northeast of Ballardona (J. D. A. Clarke unpubl. data).

KHASTA FORMATION (EUCLA BASIN, SOUTH AUSTRALIA)

We propose raising the Khasta Member in the Eucla Basin in South Australia to formation status. This replaces usage of Hampton Sandstone for Upper Eocene spicular sand and sandstone.

As noted above, Lowry (1970) defined the Hampton Sandstone as sand and calcareous sandstone underlying
that

Ceduna scattered outcrop and numerous boreholes show Western Australia.

the Fitzgerald Member of the Pallinup Formation of Ceduna, although not in the abundance characteristic of some localities. Body fossils of lithistid sponges are also Thallasinoides weathered cross-bedded spicular sands with abundant of the Pidinga Formation on Eyre Peninsula. Outcrops

map sheet.

6687542mN. The name is taken from the Khasta 1: 50 000 based on M. C. Benbow , unpubl. data) at 302142mE, Khasta Formation.

tinction is not useful. Unlike the Pallinup Formation, pure Member and the Khasta Formation, which we have observed, is that the former is carbonaceous. As all out-

distribution in the eastern Eucla Basin and its equivalents in the eastern Eucla Basin. Clarke (1990) also applied the term to spicular sand associated with the Princess Royal Spongolite. We recommend that all such usage be replaced by Pallinup and Khasta Formation in the western and eastern extremities of the Eucla Basin, respectively.

Benbow (1993) referred to the Khasta Member of the Hampton Sandstone as fine to medium-grained sandstone and siltstone, with parallel and ripple lamination, marine trace fossils, and up to 25% siliceous sponge spicules. We have observed that the Khasta Member also commonly contains laminae and beds of clays (carbonaceous in unweathered sections) that define flaser and lenticular bedding, especially in the lower part. Heavy minerals are common. The trace-fossil assemblage inland is dominated by Skoliolithos, although Thallasioides is also present in some localities. Body fossils of lithistid sponges are also locally present, for example, near Arthurs lake, northeast of Ceduna, although not in the abundance characteristic of the Fitzgerald Member of the Pallinup Formation of Western Australia.

A number of occurrences of spicular sandstone with lesser clay and silt have been mapped as the Bring Member of the Pidinga Formation on Eyre Peninsula. Outcrops along the Ceduna foreshore (Rankin & Flint 1991) consist of weathered cross-beded spicular sands with abundant Thallasinoides, Skoliolithos and Ophiomorpha. Northeast of Ceduna scattered outcrop and numerous boreholes show that carbonaceous spicular clay and spicular sand fill the Narlaby Palaeovalley (Rankin & Flint 1991). In the Cummins and Wanilla Palaeovalleys on Eyre Peninsula there are sediments containing dinoflagellates assignable to the Corrulidinium incompostum zone (Harris & Foster 1974; Harris 1985) and a sparse fauna of siliceous spicules, foraminifers and very fragmentary bryozoans in glauconitic and carbonaceous sediments (Lindsay 1974). These were placed by Harris (1985) in his sequence 3.

In this paper, we suggest that the Khasta Member be raised to formation status, while retaining the original type locality (Figure 9)—on the western side of a small unnamed salt lake on the Tallaringa 1:250 000 map sheet, east of Wilkinson Lakes (P Rogers pers. comm. 2001, based on M. C. Benbow, unpubl. data) at 302142mE, 6687542mN. The name is taken from the Khasta 1: 50 000 map sheet.

Raising the member to formation status recognises its widespread distribution in the eastern Eucla Basin and eliminates the problems of an upper and lower Hampton Sandstone noted above. We propose that rocks originally assigned to the Bring Member of the Pidinga Formation, described by Benbow (1993) as consisting of spicular carbonaceous clay with sand laminae, be included in the Khasta Formation. The only difference between the Bring Member and the Khasta Formation, which we have observed, is that the former is carbonaceous. As all outcrops of the Khasta Formation are weathered, this distinction is not useful. Unlike the Pallinup Formation, pure spiculites and spongolites have not been reported from the Khasta Formation.

Benbow (1993) also proposed the name Moorillana Member for the upper part of the Hampton Sandstone. The significance of this unit is obscure, and we recommend its use be avoided pending clarification.

Benbow (1990) showed a scarp locally defining the landward extent of his Eocene transgression (the Tuketja shoreline of our reconstruction) in the northern and eastern Eucla Basin. This he interpreted to be formed by coastal erosion, a conclusion with which we agree. Other coastal erosion features have been noted in Western Australia associated with the Tuketja transgression (see below).

PALLINUP FORMATION (EUCLA BASIN, WESTERN AUSTRALIA)

We propose extending the Pallinup Formation to include all spicular marble sediments along the margin of the Eucla Basin in Western Australia. This includes lithologies formerly referred to as upper Hampton Sandstone. We also recommend changing the status of the Princess Royal Spongolite from a separate formation to the Princess Royal Member of the Pallinup Formation. The Pallinup Formation is the direct equivalent of the Khasta Formation in South Australia.

Cockbain (1968b) defined spicular siltstone, sandstone and mudstone grading to spiculite of the Bremer Basin as the Pallinup Siltstone, with the type locality at Beaufort Inlet. Gammon et al. (2000) redefined this unit as the Pallinup Formation. The same lithologies are laterally continuous in the subsurface between the coastal outcrops of southwest Western Australia and the former Princess Royal Spongolite in the Cowan Palaeovalley. Scattered outcrops of these lithologies occur almost continuously across the watershed between the Cowan palaeovalley (which drained south) and the Lefroy Palaeovalley (which drained east) (Clarke 1994). They also occur semicontinuously around the palaeoshoreline from Esperance to north of Ballardina (Doepel & Lowry 1970a, b; Morgan & Peers 1973) where they were also assigned to the Pallinup Siltstone. Therefore, we propose that the term Pallinup Formation be extended to include all such lithologies along the western margin of the western Eucla Basin throughout this area. These include the spicular sandy sediments that were interpreted as upper Hampton Sandstone by Clarke (1993).

The Pallinup Formation at the type locality (Gammon et al. 2000) consists of four informal members, typically conglomeratic sand in the lowermost, sand in the second and spicular muds in the third and fourth. These informal members can be recognised along the length of southwest Western Australia. A fifth, uppermost, member was formally defined by Gammon et al. (2000) as the Fitzgerald Member, with its type locality in the Fitzgerald River National Park. Carbonate biota is normally rare, but can be moderately common in some beds. Molluscs, with less abundant bryozoans, brachiopods and echinoids dominate the calcareous biota. Cyclic bedding is common through much of the unit, as is glaucony. The trace-fossil assemblage is dominated by Thalassinoides and Chondrites. The unusual opal-dominated biota occurs on the landward side of palaeotopographic barriers formed by bedrock highs that would have been rocky reefs and islands in the Eocene.
The easternmost known occurrence of the Pallinup Formation is at Ponton Creek. There are no known outcrops of the Khasta Formation west of the Serpentine Lakes Palaeovalley. The 500 km gap between these similar and equivalent lithologies is the reason why we have retained different names for them. It is possible that minor occurrences of these units may be present in the subsurface of the lower reaches of the Carey, Baker, Throssel, Wanna and Serpentine lakes Palaeovalleys. The Neales embayment might provide an analogous Eocene lagoonal environment to the Immarna lagoon further east, and Pallinup lithologies may be common there. The 9-second Australian Digital Elevation Model shows a low but prominent ridge in this area, paralleling the margin of the embayment and another less prominent ridge along its outer edge and separating it from the Nullarbor Plain. These might represent Eocene barriers analogous to the Ooldea and Barton Ranges further east, but this area has never been investigated.

Fitzgerald Member
Gammon et al. (2000) defined the Fitzgerald Member as the uppermost member of the Pallinup Formation. It consists mainly of spiculite to muddy spiculite. Body fossils of lithistid sponges are locally abundant, forming sponge conglomerate or rudstone in a spiculite matrix. This facies is best developed in the Fitzgerald River National Park where the type section is located, although it occurs sporadically in several localities. The member occurs in former sheltered localities behind barriers formed by bedrock highs that formed rocky reefs and islands during the Eocene. Elsewhere in the Fitzgerald Member calcareous biota can be common, with large fenestrate bryozoans, epifaunal bivalves and echinoids in a spiculite matrix. It is particularly well exposed at Bremer Bay, Thomas River east of Esperance, and near Balladonia. This lithology of large carbonate bioclasts floating in a spicular matrix may represent a transitional facies between the sponge-rich Pallinup Formation and the Wilson Bluff Limestone. We note that the Wilson Bluff Limestone exposed at Point Culver and found in drillholes near Balladonia contains common body fossils of siliceous sponges and may represent a further aspect of this transition. While interfingering, the transition from biosiliceous to calcareous lithologies is rapid (Jones 1990), and probably occurs over a distance of a few hundreds of metres, explaining the scarcity of transitional facies.

Foraminifers found in samples from Blue Dam north of Balladonia contain the semiendemic benthic rotaliid taxon *Maslinella chapmani*. This suggests a Middle to Late Eocene (P14–P15) age, with the possibility that it may be as young as P16–P17. This assemblage indicates a Tuketja age for the Pallinup Formation.

Princess Royal Member
Units mapped as Princess Royal Spongolite (Glauert 1926) occur in the Cowan (Cockbain 1968a), Lefroy (Jones 1990; Clarke 1993) and Ponton Creek (Doepel & Lowry 1970b) Palaeovalleys. These units are not, however, spongolites *sensu stricto* (sediments comprised largely of sponge body
fossils), but consist of spicular sands, silt and clay and lenses of pure spiculite. Because spiculite comprises only a fraction of the lithology as a whole, we propose that the unit be known as the Pallinup Formation, with which it is continuous, and that the name Princess Royal Member be used for the spiculite (~50% siliceous spicules) unit within it.

The original type locality for the Princess Royal Spongolite was at the Princess Royal townsite near Norseman. This area has now been extensively mined and the original section is no longer accessible. We propose a replacement type section for the redefined unit as the drillhole CD1916 (37°58′00″E 53°34′00″N, Widgiemooltha 1:250 000 map sheet SH51-14). The core is stored in the WMC core farm at Kambalda. In this core the Pallinup Formation is 34 m thick and the Princess Royal Member comprises the lower 12.5 m. We recommend that the Cenozoic portion of this core be retrieved and stored with the Geological Survey of Western Australia. The remainder of the Pallinup Formation consists of spicular sandstone (formerly upper Hampton sandstone of Clarke 1993). The Princess Royal Member typically comprises most or all of the Pallinup Formation in the upper reaches of marine influence in the palaeovalleys.

Fossils other than siliceous sponges are rare in the Princess Royal. The most common consists of carbonaceous fragments followed by calcareous spicules, which in one area studied comprised approximately 9% of the total (Igoe 1998). Phytoliths are also present. Very occasionally, bryozoan and echinoid fragments have been seen in thin-section, typically in ironstone facies, and one example of a sponge body fossil has been found (M. Dusci pers. comm. 1998). Localised mollusc-bearing beds are occasionally found.

Because spicular marine sediments occur continuously (usually in the subsurface) between Norseman and the coast near Esperance and from Norseman northeast into the Lefroy Palaeovalley we believe that the term Pallinup Formation should be extended to all occurrences and the Princess Royal Member should refer only to the most spicular (~50% siliceous spicules) units within the narrow confines of palaeovalleys and embayments. The Princess Royal Member is lithologically equivalent to the Fitzgerald Member, but can be differentiated from it by its restriction to palaeovalleys, rather than along margins of the more open part of the basin. Unlike the Princess Royal Member, where the biota is composed almost entirely of siliceous sponge spicules, the Fitzgerald Member has beds rich in sponge body fossils and calcareous biota.

In the Lefroy Palaeovalley the Princess Royal Member rests in part on a bench eroded into weathered bedrock and terminated by an increase in slope. This bench occurs at 270–280 m and represents a coastal platform cut during the transgression. In the Cowan Palaeovalley the upper part of the Princess Royal Member also rests on a bench eroded into weathered bedrock and terminated by an increase in slope. This bench occurs at 270–280 m and represents a ravinement surface cut during the transgression. These surfaces closely resemble the surface approximately 20 m lower in elevation that may have been cut during the Tortachilla transgression. Similar surfaces occur throughout southwest Western Australia, but are generally less well defined though lack of exposure. However on the slopes at Mt Ragged there is a very prominent erosion surface recognised by many authors, including Lowry (1970), as an Eocene marine erosion surface. Previous workers have said that this terrace occurs at 300 m altitude, but GPS altimetry (position error of 5 m at the time of measurement) in 2001 indicated that it occurs between 260 and 280 m. We believe these features are genetically related to the scarp, at ~140 m, identified by Benbow (1990) in the northeastern Eucla Basin.

‘UPPER’ OOLDEA SAND (BARTON AND PALING RANGES)

Clarke and Hou (2000) interpreted the Ooldea Sand of Benbow (1990) in the Barton and Paling Ranges as being the barrier complexes developed during the Tuketja transgression. Only further drilling to determine the geometric relationships can test this suggestion. The Ooldea Sand itself is unfossiliferous. We informally refer to the Ooldea Sand in the Barton and Paling Ranges as the ‘Upper’ Ooldea Sand.

TOOLINNA LIMESTONE

We propose that this term be abandoned as the type locality is of Abrakurrie Formation and other occurrences mapped as this unit are of Wilson Bluff Limestone.

This unit was proposed by Lowry (1968) to describe Eocene bryozoan grainstone of Eocene age along the western margin of the Eucla Basin, in contrast to the chalkier lithology of the Wilson Bluff Limestone. Lindsay and Harris (1975) extended the term to similar lithologies in the South Australian part of the basin. However, James and Bone (1994) and Li et al. (1996a) demonstrated that the Toolinna Limestone at the type locality of Toolinna Cove is in fact Oligocene in age, part of the Abrakurrie Limestone, and indistinguishable from it.

However, elsewhere, rocks mapped as Toolinna Limestone appear to be valid Eocene stratigraphic units. Those mapped as Toolinna Limestone that crop out at Point Culver are indistinguishable from the Wilson Bluff Limestone. Examples of cross-bedded grainstone crop out sporadically on the Ballardia map sheet (Doepel & Lowry 1970a), where they are mapped as Toolinna Limestone. They are too coarse to contain diagnostic foraminifers of sufficient biostratigraphic resolution, but they occur only a few kilometres away from, and at the same elevation as, muddy spicular facies of Tuketja age, thus it is almost certain that they are correlatives. Jones (1990) demonstrated that the Pallinup Formation (Princess Royal Spongolite in his terminology) passed abruptly into the Wilson Bluff Limestone in the lower reaches of the Lefroy Palaeovalley. Therefore, we recommend that the term Toolinna Limestone be abandoned. While there are bryozoan grainstone facies in the Wilson Bluff Limestone, at this stage they should be included in that formation. Should they prove to be mappable units, these bryozoan grainstone lithologies should be given a new name as a member of the Wilson Bluff Limestone.
DISCUSSION

Unit continuity

With the revised and simplified stratigraphy it is clear that many units occur continuously across the entire basin. The palaeodrainage successions in southwestern Western Australia have the same stratigraphic architecture as those of the northeastern margin of the Eucla Basin. This continuity illustrates the very strong allostratigraphic control on sedimentation. The reason for this is the stability of the cratonic basement that floors much of the Eucla Basin and that sedimentation is due largely to flooding of that basement rather than to subsidence.

Not all features are continuous over the entire region. A major source of discontinuity was formed by subaerial erosion between the deposition of the Tortachilla and Tuketja successions. In many places this erosion removed all the sediments deposited during the Tortachilla transgression, so that the sediments of the Tuketja transgression were deposited directly on bedrock.

Another source of discontinuity is facies changes. These are well developed in profiles from onshore to marine. The most striking occur in the very abrupt lateral transition from inshore biosiliceous sedimentation of the Khasta and Pallinup Formations to the central basin carbonate of the Wilson Bluff Limestone and the development of the barriers and lagoons of the northeastern Eucla basin (Clarke & Hou 2000). Within individual units, there are also abrupt facies changes caused by local features, such as channel meanders in the Pidina, the role of bedrock highs in the Fitzgerald Member, or the increasing prevalence of the Princess Royal Member in the upper reaches of palaeovalleys. Despite these changes, the overall impression is of remarkable lateral continuity of stratigraphy.

Interbasin correlation

The Eocene stratigraphy of the St Vincent Basin has long provided a basis for correlation of southern Australian Eocene sediments (McGowran 1989; McGowran et al. 1992, 1997). Recent research (Gammon et al. 2000; James & Bone 2000; this paper) has revealed how strikingly similar the lithostratigraphy is along the southern margin of Australia between the classic Blanche Point locality south of Adelaide to Walpole, the westernmost exposure in southwest Western Australia. The similarity extends not only to the same transgressions being recognised but to similar sedimentary and biogenic facies, especially that of biogenic silica, which marks the highest Eocene strandline across much of southern Australia.

How far east this similarity can be found is not clear. Eocene marine sediments are known in the subsurface of the Murray Basin and crop out in the east of the Otway Basin, where in the Browns Creek and Castle Cove area they are much affected by local tectonics. Upper Middle Eocene (P13–P14) siliciclastics are preserved as the discontinuous marginal marine Sturgess Point Member in the subsurface of the Otway Basin, unconformably overlying the Dillwyn Formation (Gallagher & Holdgate 2000). In the Otway subsurface, Upper Eocene (P15–P17) strata are preserved as non-spicular sandy carbonate in the Mepunga Formation. This formation was deposited in a high-energy shoreline to shelf palaeoenvironment (Gallagher & Holdgate 2000). Upper Middle to Upper Eocene shelfal marine siliciclastics and carbonates are preserved in Browns Creek and Castle Cove. In these sections siliceous sponge spicules are rare, in contrast with the Eucla and St Vincent Basins. Spicule-rich chalky limestone is intersected in the Mt Salt No. 1 well in the eastern end of the Murray Basin (Alley & Lindsay 1995). These resemble the spicule-rich chalks at Point Culver.

Controls

Such lateral continuity in inshore and marginal marine facies over a distance of more than 2000 km points to continuity in environmental controls over this distance. Controls include eustacy, tectonics, climate, hydrology and oceanography. Similar sea-level, tectonic regime, climate, terrestrial runoff and oceanographic conditions must have prevailed for the entire southern coastline, otherwise this continuity would not be present. Such uniformity existed despite the great range in shelf widths in the Eocene from 20 km in the narrowest part to 500 km in the widest part of the Eucla Basin. Eocene conditions, especially climate and oceanography, must have been more uniform than those of the present day, which sees a considerable latitudinal variation in oceanographic factors, climate and runoff from west to east and the resultant sedimentary facies (James et al. 2001).

The reasons for such uniformity are many. One is the low latitudinal temperature gradients of the Eocene greenhouse world, a world terminated by the abrupt shift to icehouse conditions at the end of the Eocene (Zachos et al. 1993; Berggren et al. 1997). A uniform high-rainfall terrestrial flora extended across the entire region (Alley et al. 1999). Another is the stability of the Australian continent at the time. The Middle to Late Eocene was characterised by mainly thermal subsidence in the marginal basins of southern Australia, except in the parts of the eastern Otway Basin where local uplift near the end of the Eocene may have caused the deposition of siliciclastic-rich facies (Gallagher & Holdgate 2000). It also pre-dates the uplift of many parts of eastern Australia in the Miocene. The Adelaide Hills (Alley & Lindsay 1995) and Eastern Highlands (Ollier & Pain 1994) were uplifted at this time. Gentle uplift of the Yilgarn Craton occurred after the Miocene, to judge from the ~150 m differential in elevation of the Tuketja shoreline between the eastern and western Eucla Basin. During the Middle to Late Eocene the oceanographic situation was also rather stable. The Southern Ocean south of Australia was comparatively narrow and circulation was dominated by west to east flow, fed by the circum-equatorial Tethys Ocean (Shackleton & Kennett 1975). Evidence for this is provided by the extra-tropical incursion of large benthic foraminifers into the Eocene sediments of southern Australia (McGowran & Beecroft 1980). The circulation would have exited eastwards over the shallow spillway of the South Tasman Rise. This simple circulatory situation would have become much more complex with the final separation of Antarctica from the South Tasman Rise, which led to the establishment of the
SUMMARY AND CONCLUSIONS

Our reworking of the Eocene stratigraphy of the Eucla, Bremer and Eocene Polda Basins into a single entity, the Eucla Basin, allows the following conclusions.

(1) Rationalised stratigraphic nomenclature of the margins of the onshore southern margin of Australia, which will greatly facilitate research in these areas by highlighting stratigraphic continuities between the basins and the major bounding discontinuities between the stratigraphic units common in each. Long-established names for laterally equivalent formations on the western and eastern margins are retained.

(2) Recognition and emphasis of the strong allochthonous control on Eocene stratigraphy down to third-order cycle level along much of the southern margin of Australia. The Eocene sediments were deposited in only two transgressions. the Tortachilla (Middle Eocene) and Tuketja (Late Eocene).

(3) Returning the Hampton Sandstone to its original usage as the calcareous marine sand underlying the Wilson Bluff Limestone avoids the conflicting use between South and Western Australia. This has entailed raising to formation status the Upper Eocene spicular marine Khasta Member of the Hampton Sandstone, abandoning the Bring Member and including all spicular marine and marginal-marine lithologies, including those of the Poelpena Formation in the Polda Basin, in the Khasta Formation.

(4) Simplifying the nomenclature of the marginal clastic successions by abandoning the terms Wollubur Sandstone, Vanilina Formation and Poelpena Formation and including the strata in the Pidina (Upper Eocene) and Maralinga (Middle Eocene) Formations in South Australia and Werrilup (Upper Eocene) and North Royal (Middle Eocene) Formations in Western Australia.

(5) Raising the Paling Member of the Wilson Bluff Limestone to formation status (by analogy with the Norseman Formation), given its stratigraphy discontinuity from the Wilson Bluff Limestone and its significance as a mappable lithological unit.

(6) Abandoning the Toolinna Limestone to describe Upper Eocene grainstone along the western margin of the Eucla Basin because the type section consists of Oligocene grainstone of the Abakarriue Formation and all rocks mapped elsewhere as Toolinna Limestone have proved to be Wilson Bluff Limestone. Eocene grainstones that have been locally recognised along the western margin of the Eucla Basin do exist, and in future may be definable as a member of the Wilson Bluff Limestone.

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