REVISED LATE JURASSIC AND EARLY CRETACEOUS STRATIGRAPHY IN THE PERTH BASIN

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ABSTRACT

The name, Parmelia Formation, is proposed for a widespread unit of sandstone, siltstone, and shale that was formerly included in the Yarragadee Formation. The type section is in Peel 1 between 1625 m and 3551 m. Palynological evidence indicates a Tithonian to Berriasian age range for the formation. The Otorowiri Member at the base and the Carnac Member are extensive siltstone-shale units within the formation and represent extended periods of lacustrine or, in the case of the Otorowiri Member, possibly restricted marine deposition. The remainder of the formation is predominantly a fluviatile deposit with thin lacustrine beds. The formation was deposited in a rapidly subsiding rift-valley system immediately prior to the separation of southwest Australia from the Indian plate.

INTRODUCTION

Detailed palynological study of boreholes in the Vlaming Sub-basin and Dandaragan Trough of the Perth Basin (Fig. 1) has facilitated a re-assessment of the sediments assigned to the Cretaceous part of the Yarragadee Formation by Cockbain and Playford (1973) and Playford and others (1976).

Between 1968 and 1981 a number of oil-exploration wells were drilled in the offshore Vlaming Sub-basin, principally by West Australian Petroleum (Wapet). All these wells encountered a sequence of interbedded shale, siltstone, and sandstone conformably overlying the predominantly sandstone, Jurassic Yarragadee Formation and unconformably overlain by the Early Cretaceous Warnbro Group. The type section of the Yarragadee Formation cannot be firmly dated, but mapping and palynological evidence from nearby boreholes suggest that it is significantly older than the siltstone, shale, and sandstone section in the Vlaming Sub-basin. A shale unit at the base of this sequence was informally named the "Quinns Shale" (Bozanic, 1969). A thick sequence of (predominantly) siltstone and shale, some distance above the "Quinns Shale", was referred to in unpublished Wapet reports as the "Carnac Formation" (D. C. Lowry, pers. comm.). Cockbain and Playford (1973) and Playford and others (1976) included in the Yarragadee Formation all the sequence between the top of the Middle Jurassic Cadda Formation and the base of the Warnbro Group (Fig. 2). They recognized two members, the "Quinns Shale Member" in the Vlaming Sub-basin, and the "Otorowiri Siltstone Member" in the Dandaragan Trough. From their similar stratigraphic position, Backhouse (1975; 1978) concluded that the two members are the same unit, and used the earlier name "Otorowiri Siltstone Member".

Drilling by the Western Australian Mines Department in the central Dandaragan Trough between 1967 and 1977 revealed a thick succession of siltstone, shale, and minor sandstone overlying Jurassic sandstones. This section correlates with the section in the Vlaming Sub-basin above the "Otorowiri Siltstone Member" and is lithologically comparable with the "Carnac Formation" of Wapet.

It is proposed to refer all the sediments between the base of the Otorowiri Member and the base of the Warnbro Group to a new unit, the Parmelia Formation. The Yarragadee Formation is restricted to the section between the Cadda Formation and the base of the Otorowiri Member. A new member, the Carnac Member, is proposed for the Parmelia Formation. The Otorowiri Member is placed at the base of the Parmelia Formation, and the term siltstone is dropped from the name because shale is as common as siltstone in the unit.

YARRAGADEE FORMATION

The type section (Fairbridge, 1953), and the two surface reference sections (McWhae and others, 1958) for the Yarragadee Formation are stratigraphically below the Otorowiri Member. The subsurface reference section in Gingin 1, suggested by Playford and others (1976) is amended from 188 m-3 315 m to 356 m-3 315 m. The definition and description of the Yarragadee Formation as stated by Playford, Wilmott, and McKellar in McWhae and others (1958), and reiterated by Playford and others (1976) is retained, except that it now excludes the section above the base of the Otorowiri Member. No members are now recognized in the Yarragadee Formation.

The Yarragadee Formation of this report is a predominantly fluviatile deposit of discontinuous

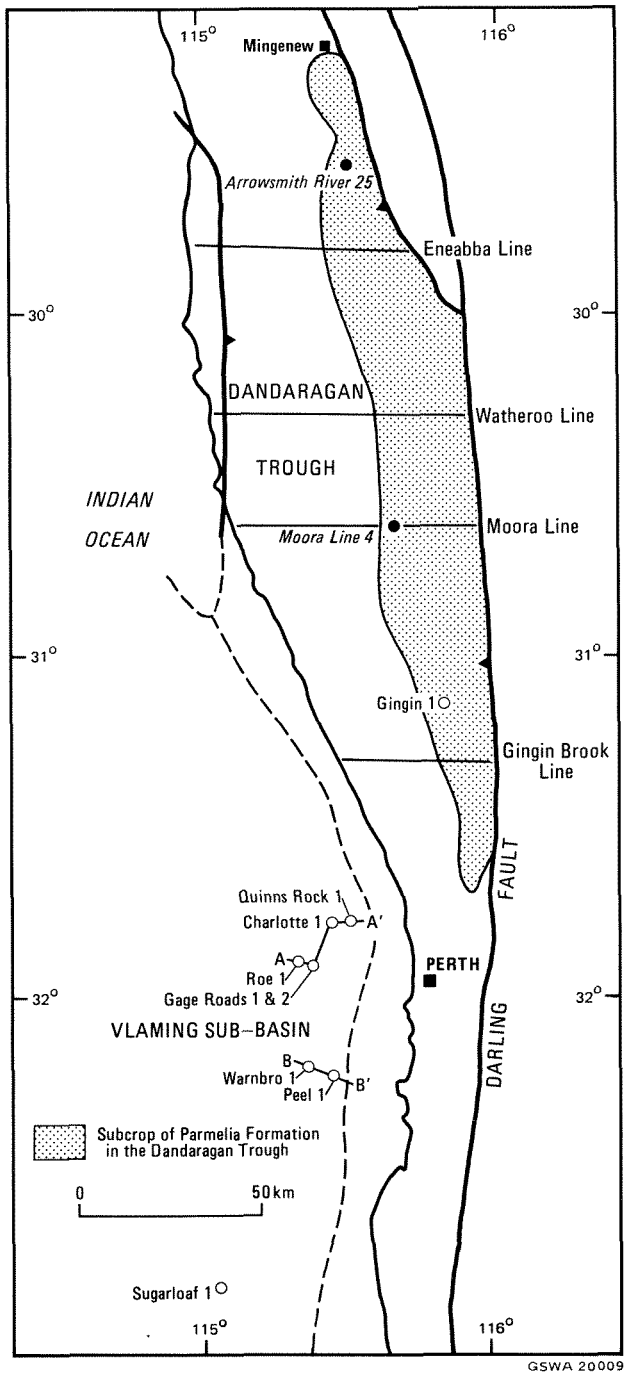

Figure 1 Location map showing boreholes and sections mentioned in text.

sandstone units and thin shale beds. The sandstone is predominantly medium grey to white, fine to coarse grained and poorly sorted. Carbonaceous stringers are common.

Biostratigraphy

Palynomorphs are the only frequently recorded fossils in the formation. Filatoff (1975) provided a palynological zonation for the Jurassic of the Perth Basin. In terms of this zonation, the Yarragadee formation ranges from the *Dictyotosporites complex* Oppel-zone up to, and including, the *Murospora florida* Microflora. Backhouse (1978) zoned the upper part of the Jurassic in the Dandaragan Trough. The *Retitriletes watherooensis*, and *Aequitriradites acusus* Zones of this zonation are in the Yarragadee Formation.

Age

The Yarragadee Formation ranges in age from Middle Jurassic (Bathonian) to Late Jurassic (Tithonian).

PARMELIA FORMATION

The name, Parmelia Formation, is proposed for the sediments between the top of the Yarragadee Formation, as redefined above, and the unconformity at the base of the Warnbro Group. It represents the last period of sedimentation in the Perth Basin before extensive block faulting of Jurassic and older sediments. This period of faulting was associated with the separation of southwestern Australia from the Indian plate. It was followed by rapid erosion of the freshly deposited sediments and by a marine transgression in the Valanginian which led to deposition of the Warnbro Group.

The type section of the Parmelia Formation is between 1 625 m and 3 551 m in Peel 1 (Lat. 32°15′47.8″S, Long. 115°26′43.0″E). Two members are recognized, the Otorowiri Member (formerly the "Otorowiri Siltstone Member" of the Yarragadee Formation), and the Carnac Member.

The Parmelia Formation is a sequence of sandstone, shale, and siltstone. The sandstone is light grey to white, fine to very coarse grained, moderately

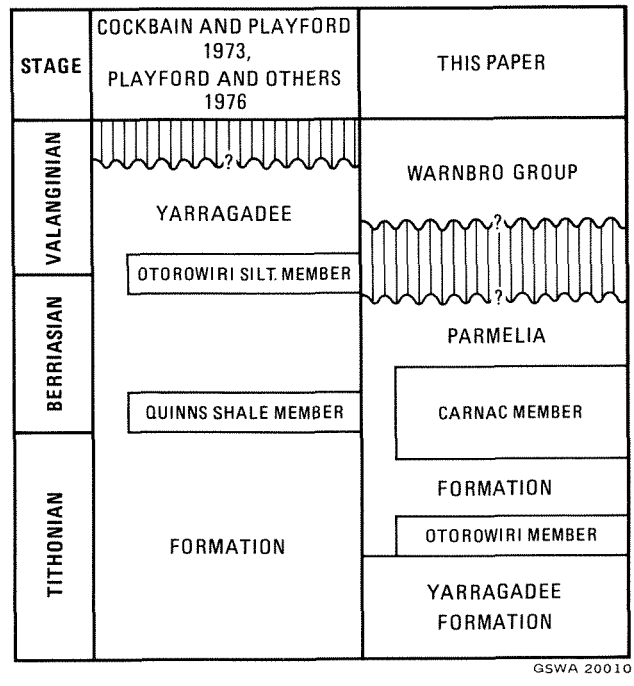

Figure 2 Revised nomenclature and age of the units.

to poorly sorted and contains subrounded to subangular grains in a kaolinitic or siliceous cement. Fragments of coal are incorporated in the sediments at some horizons. The shale is light grey, dark grey, or brownish grey, micaceous, carbonaceous, silty, and subfissile. The light-grey siltstone is usually present as thin laminae in the shale, but occasionally forms thicker beds.

The frequency of shale and siltstone beds varies vertically and horizontally. The Otorowiri Member at the base, and the Carnac Member in the middle of the formation are composed predominantly of siltstone and shale. The Parmelia Formation above the Otorowiri Member and below the Carnac Member contains silty shale beds from a few centimetres to several metres thickness, and is often similar in gross lithology to the Yarragadee Formation. Only two sections of the Parmelia Formation above the Carnac Member have been drilled: one is in Peel 1 (see below), and the other, in Charlotte 1 between 1 593 m and 2 164 m. Shale intervals in this section are infrequent, and usually thin.

A description of the type section of the Parmelia Formation in Peel 1 based partly on the unpublished well-completion report by Phillips Australian Oil Company is given below.

* * * * *

	Thickness
Warnbro Group 859-1 625 m	
Parmelia Formation 1 625-3 551 m	**1 926**
1 625-2 409 m Predominantly sandstone with a few thin shale beds. The sandstone is quartzose, white, light grey, or tan, poorly sorted, fine to very coarse grained and contains occasional pebbles. The grains are subangular to subrounded, and the cement is kaolinitic or siliceous. The shale is firm, dark grey, black, or brownish grey, micaceous, carbonaceous, and silty. Rare, thin coal seams are recorded	895
2 409-3 064 m (Carnac Member). Sandstone, siltstone, and shale continuously interbedded. The sandstone is white, light grey, or tan, fine to medium grained, and often well sorted. Individual grains are subangular to subrounded, and the cement is kaolinitic or siliceous. The siltstone and shale are medium grey, or brownish grey, firm, micaceous, carbonaceous, and sub-fissile. The siltstone forms lighter coloured laminae, or intergrades with the shale.	655.
3 064-3 505 m Predominantly sandstone with frequent thin to moderately thick (up to 5 m) siltstone and shale beds. The sandstone is white, light grey, or tan, fine to coarse grained, and poorly sorted. The grains are subangular to subrounded; the cement is kaolinitic, siliceous or, rarely, carbonaceous. The siltstone and shale are medium grey, black, or brownish grey, micaceous, carbonaceous, and occasionally pyritic	441
3 505-3 551 m (Otorowiri Member) Shale with minor siltstone and fine-grained sandstone. The shale is medium grey or brownish grey, micaceous, carbonaceous, and often silty. Siltstone and fine-grained sandstone laminae are evident at some horizons	46
Yarragadee Formation 3 551-3 714 m	

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The section in Moora Line 4 hydrogeological borehole between 0 and 484 m is suggested as a reference section for the Parmelia Formation in the Dandaragan Trough. A description of this section based partly on the unpublished borehole completion report is given below.

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Top of formation removed

	Thickness
Parmelia Formation 0-484 m	**484**
0-9 Lateritic clay, brown, yellow, and white	9
9-364 m (Carnac Member) Claystone and shale, medium-grey to brownish-grey, micaceous, carbonaceous, and silty, with thin beds of siltstone and fine grained sandstone	355
364-428 m. As above, but with more sandstone. Sandstone fine- to coarse-grained, with clear and frosted quartz grains, and rare pyrite.	64
428-484 m (Otorowiri Member) Shale with minor siltstone. The shale is light grey or brownish grey, micaceous, carbonaceous, and sub-fissile. The siltstone is light grey or tan, and is present as fine laminae in the shale	56
Yarragadee Formation 484-732 m	

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Otorowiri Member

The Otorowiri Member was originally defined as the Otorowiri Siltstone Member of the Yarragadee Formation by Ingram (1967b). The type section is in Arrowsmith River 25 (Lat. 29°33′25″S, Long. 115°32′00″E) between 253 and 277 m. As mentioned above, Backhouse (1975; 1978) considered it to be the same unit as the "Quinns Shale" of the Vlaming Sub-basin. Subsequent work has reinforced this view. The type section erected for the Quinns Shale in Quinns Rock 1 between 1 590 m and 1 647 m (Bozanic, 1969) is suggested as a reference section for the Otorowiri Member in the Vlaming Sub-basin.

The Otorowiri Member is a silty shale unit, locally with a substantial siltstone component. The shale is light grey, dark grey, or brownish grey, carbonaceous, sub-fissile, and usually very micaceous. Thin fine-grained sandstone laminae are sometimes present.

The outcrop of the Otorowiri Member can be traced between the Arrowsmith River boreholes and the Moore River (Commander, 1978; A.D. Allen, pers. comm.). Some of this outcrop may include part of the Carnac Member, which in this part of the basin almost immediately overlies the Otorowiri Member. In the Vlaming Sub-basin, the top of the Otorowiri Member is an important seismic horizon (Playford and others, 1976).

Carnac Member

The name "Carnac Formation" has been used extensively in unpublished Wapet reports to refer to a thick siltstone and shale unit encountered in offshore wells in the Vlaming Sub-basin. The Carnac Member of this report is defined as the section in Peel 1 between 2408 m and 3064 m. The lithology of this section in Peel 1 is described above. Elsewhere the Carnac Member is similar to the type section, where light-grey, medium-grey, or brownish-grey silty shale is the dominant lithology. Sandstone units within the Carnac Member are thinner than in the rest of the formation, and the sandstone is moderately well sorted. Shale beds are often pyritic. Siltstone and fine grained sandstone form numerous thin laminae in some sections. The thickest (1 262 m) drilled section is an incomplete section in Roe 1 between 872 m and 2 134 m.

Biostratigraphy

Spores, pollen, acritarchs, and dinoflagellate cysts are recorded in great abundance from sections now referred to the Parmelia Formation (Ingram, 1967a,b; Backhouse, 1974, 1975; 1978; and unpublished Wapet and GSWA reports). A change in the microflora occurs in all sections at the base of the Parmelia Formation with the first appearance in the Perth Basin of species of the schizaeaceous spore genus *Cicatricosisporites*, and a number of other spore species. This is the base of the *Biretisporites eneabbensis* Zone of Backhouse (1978). In terms of Balme's (1957, 1964) broad subdivision, the Parmelia Formation lies within the lower part of the *Microcachryidites* Assemblage. Over ninety species of spores and pollen are known from the Parmelia Formation as well as a small number of acritarch and dinoflagellate cyst species. The acritarchs are principally forms of *Schizosporis* Cookson and Dettman and *Schizophacus* Pierce. The dinoflagellate cysts include a species of *Fusiformacysta* Morgan. The only described species of *Fuziformacysta, F. salasii* Morgan from the Great Australian Basin, was regarded by Morgan (1975) as a non-marine cyst. The other dinoflagellate cysts are undescribed forms, some of which are abundant in parts of the formation. Marine dinoflagellate cysts of similar age, such as those present in the Barrow Formation in the Carnarvon Basin, are almost entirely absent. The only examples are a number of specimens in the Otorowiri Member, which may be recycled from late Jurassic deposits in the Carnarvon Basin. Abundant recycled palynomorphs of Devonian, Permian, Triassic, and Jurassic age have been reported from the Otorowiri Member (Ingram, 1967b). Early Permian, and Early Triassic forms are common in the remainder of the Parmelia Formation, but Late Permian, Late Triassic and Jurassic forms are rare. Devonian forms are only recorded from the Otorowiri Member in the Dandaragan Trough north of Eneabba.

Age

On palynological evidence, the age of the Parmelia Formation ranges from Late Jurassic (mid or late Tithonian) to Early Cretaceous (Berriasian). A considerable thickness of sediment was removed from horst blocks in the Vlaming Sub-basin before deposition of the Warnbro group commenced, probably no later than mid Valanginian. Deposition of the Parmelia Formation probably ceased no later than late Berriasian, and probably by the mid Berriasian. Using the time scales of van Hinte (1976a,b), the time interval available for deposition is no more than 8 m.y. and may be as brief as 5 m.y. These time intervals give an average rate of deposition for the type section of approximately 0.2 and 0.4 mm/year respectively. An average rate of deposition four times these rates is indicated for the area west of Roe 1, where on seismic evidence the formation is over 8 000 m thick.

Distribution

The Parmelia Formation is encountered in all the offshore oil-exploration wells drilled to date between Sugarloaf 1 in the south and Quinns Rock 1 in the north. It is thickest towards the continental slope west of Roe 1. Geological cross-sections of this area by Jones and Pearson (1972) and Playford and others (1976), based on unpublished seismic evidence, indicate over 8 000 m of section for the Parmelia Formation (indicated on these cross-sections as Lower Cretaceous and Early Neocomian respectively).

Cross-sections between Roe 1 and Quinns Rock 1 (Fig. 3B) and between Warnbro 1 and Peel 1 (Fig. 3C) illustrate the distribution of the Parmelia Formation in oil-exploration wells in the Vlaming Sub-basin.

The Parmelia Formation has been removed from the north-trending positive area which separates the Vlaming Sub-basin and the Dandaragan Trough. It subcrops on the eastern side of the Dandaragan Trough between Mingenew and the Upper Swan area northeast of Perth (Fig. 1), and is encountered in the Eneabba Line boreholes (Commander, 1978),

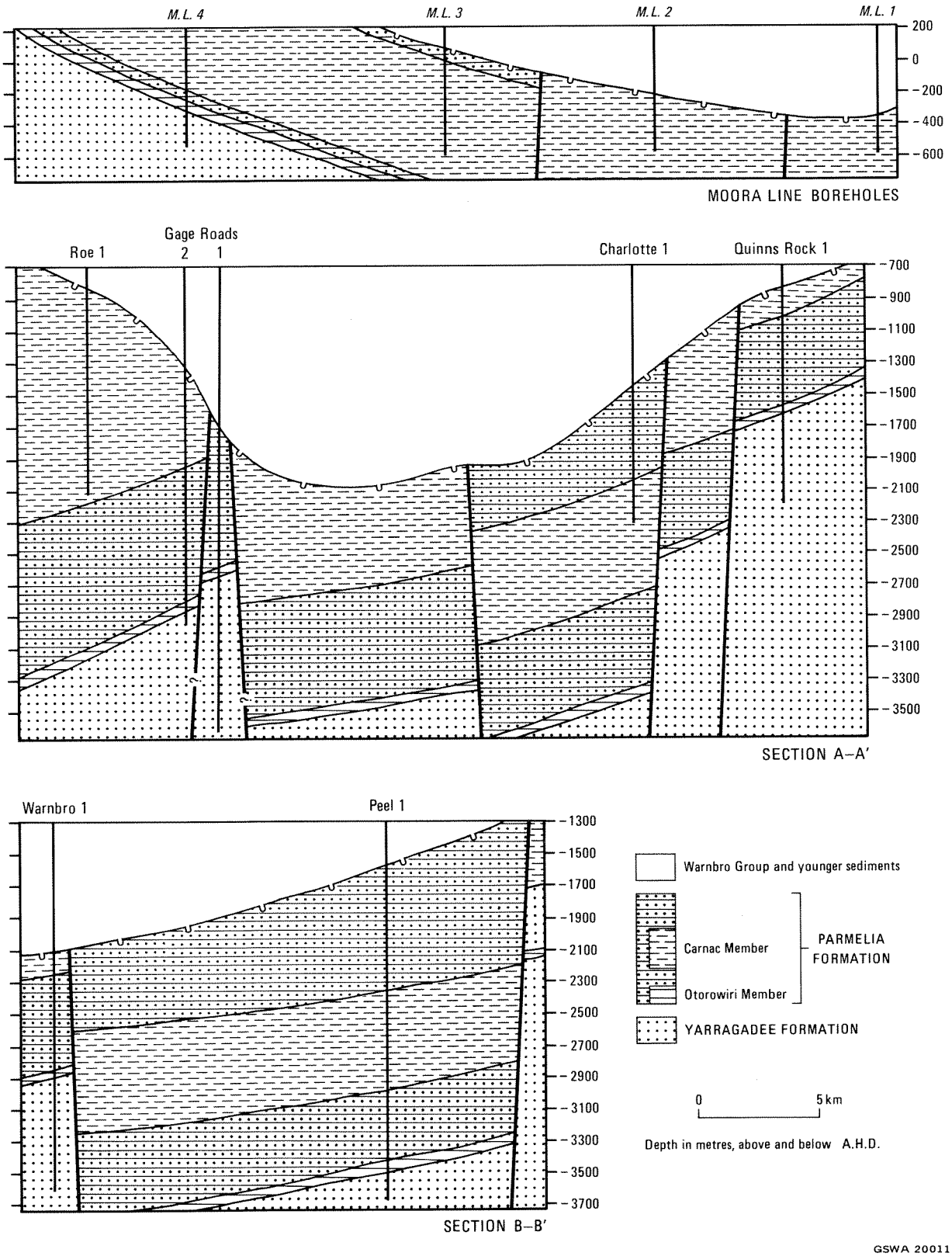

Figure 3 Geological cross-sections

A—Moora line boreholes B—Section A-B (*see* Figure 1 for location) C—Section C-D (*see* Figure 1 for location)

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the Watheroo Line boreholes (Harley, 1975), the Moora Line boreholes (Briese, 1979), and the Gingin Brook boreholes (Sanders, 1967). The maximum thickness in the Dandaragan Trough of approximately 900 m is attained in the vicinity of the Moora and Watheroo Line boreholes. A cross-section through the boreholes at the eastern end of the Moora Line illustrates the revised nomenclature in the Dandaragan Trough (Fig. 3A).

Environment of deposition

Jurassic sedimentation in the Perth Basin took place in a rapidly subsiding rift-valley system. Movement along the Darling Fault and associated smaller faults controlled the rate of subsidence on the eastern side of the rift valley; the western side, on the Indian plate, is no longer available for study.

The Yarragadee Formation was deposited as a mainly sandstone fluviatile deposit in the rift valley, with sediment input from a number of directions. The Otorowiri Member, at the base of the Parmelia Formation, represents a change to shale and siltstone deposition over most of the Vlaming Sub-basin and Dandaragan Trough. This took place in a large lake or marine embayment, possibly with a narrow northward connection to the sea.

In the Vlaming Sub-basin deposition of the Otorowiri Member was followed by a return to fluviatile sedimentation interspersed with intervals of local lacustrine deposition, and then by extensive lacustrine sedimentation with deposition of the Carnac Member. Evidence for the non-marine nature of these deposits is provided by the abundant non-marine dinoflagellate cysts. The upper part of the Parmelia Formation, above the Carnac Member, is a rapidly deposited fluviatile sandstone. Thin shale beds rich in non-marine dinoflagellate cysts represent brief periods of lacustrine deposition. This lithofacies is encountered in only two sections where the upper part of the Parmelia Formation has been preserved by faulting; its original extent is unknown.

In the Dandaragan Trough south of the Eneabba Line, lacustrine conditions continued after deposition of the Otorowiri Member. The lacustrine lithofacies represented by the Carnac Member immediately, or almost immediately, overlies the Otorowiri Member. In the Eneabba Line and in the Arrowsmith River boreholes alternating beds of sandstone and silty shale of fluvio-deltaic origin succeed the Otorowiri Member, suggesting a major sediment source to the north in the Dandaragan Trough.

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