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GSWA YINNI 1 WELL COMPLETION REPORT (INTERPRETIVE) GASCOYNE PLATFORM SOUTHERN CARNARVON BASIN WESTERN AUSTRALIA

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Geological Survey of Western Australia

GEOLOGICAL SURVEY OF WESTERN AUSTRALIA

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GSWA Yinni 1 well completion report (interpretive), Gascoyne Platform, Southern Carnarvon Basin, Western Australia

by
M. Dixon[1], D. W. Haig[1], A. J. Mory, J. Backhouse[1], K. A. R. Ghori, and P. A. Morris

Abstract

Yinni 1 is a shallow stratigraphic well drilled in 2001 at latitude 26°03'22.8"S, longitude 114°48'58.5"E on the Gascoyne Platform (Southern Carnarvon Basin) to a total depth of 158.2 m. The interval from 36.7 to 87.9 m was continuously cored and intersected the fine-grained part of the Winning Group beneath Quaternary alluvium (38.7 m). The Winning Group (38.7 – 145 m; 'lower Gearle Siltstone', Windalia Radiolarite, Muderong Shale, and Birdrong Sandstone) was deposited in a progressively deeper and less-restricted shallow-marine environment. The oldest unit of the group, the Upper Cretaceous (Valanginian or Barremian) Birdrong Sandstone, overlies the Lower–Middle Jurassic (Toarcian–Bajocian) Woodleigh Formation. The lower part of the Birdrong Sandstone was probably deposited in a non-marine paralic setting, whereas the upper part was deposited under nearshore marginal-marine conditions. The Muderong Shale (Barremian to lower Aptian) accumulated in a low-energy, innermost-neritic environment. The upper Aptian Windalia Radiolarite was deposited in the mid-neritic zone (probably about 30–50 m deep), whereas water depths of 50–100 m are deduced for the lower Albian Gearle Siltstone. Based on comparisons with coeval stratigraphic sections in the region, uniform water depths were present throughout most of the Southern Carnarvon Basin, indicating a very low gradient sea floor. The Woodleigh Formation in Yinni 1 is argillaceous and was deposited in a lacustrine environment similar to that of other borehole sections within the Woodleigh impact structure.

Although all samples analysed are organic-rich, maturity is low, with vitrinite reflectance values of 0.33 – 0.38%, indicating that the section is immature for oil generation and has not been buried more than a few hundred metres than it is at present.

KEYWORDS: stratigraphy, biostratigraphy, foraminifera, palynology, geochemistry, Cretaceous, Jurassic, Southern Carnarvon Basin

Introduction

Geological Survey of Western Australia (GSWA) Yinni 1 is a stratigraphic well located about 78 km southeast of Carnarvon on Woodleigh Station (Fig. 1). The well lies 6 km due east of the homestead (Fig. 1), which is situated 43 km by road east of the North West Coastal Highway, and 1 km south of the station track to the Woodleigh 3 water bore. The nearest petroleum exploration and stratigraphic wells are Woodleigh 1, Woodleigh 2A, and Yaringa 1, located 15, 29, and 45 km to the west respectively (Fig. 2). Yinni 1 was drilled within a topographic low over a gravity anomaly interpreted to lie on the eastern flank of the central uplift of the Woodleigh impact structure (Iasky et al., 2001; Fig. 2). No hydrocarbons were detected, nor was there evidence of significant mineralization.

The primary objective of Yinni 1 was to investigate the nature of thinning within the Winning Group towards the eastern margin of the Gascoyne Platform by continuously coring the Winning Group. In previous drilling in this part of the Gascoyne Platform, the Cretaceous section was not cored, thereby hindering the identification of constituent formations, their precise thickness, and the magnitude of the breaks within this section. Drilling was undertaken in collaboration with the University of Western Australia as part of an Australian Research Council project on the Cretaceous succession. The joint project also involved drilling two other wells (Edaggee 1 and Boologooro 1, 94 and 215 km to the north-northwest respectively; Mory and Dixon, 2002b,c; Dixon et al., in prep. a,b; Fig. 3). Because seismic control in the region

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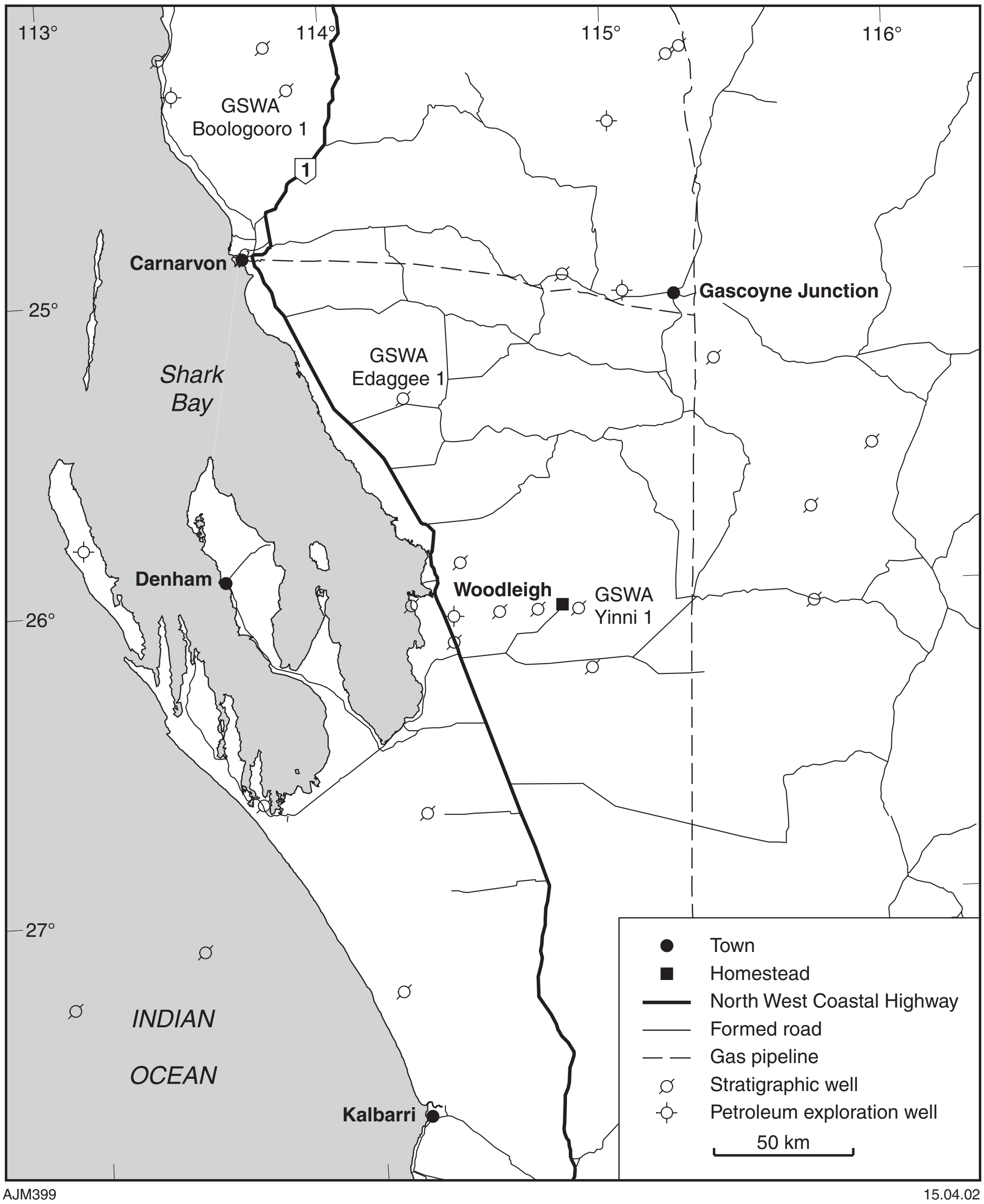

Figure 1. Access roads and location of petroleum exploration and stratigraphic wells in the southern Gascoyne Platform

is sparse and of poor quality, Yinni 1 was located with secondary objectives — to investigate underlying strata and the nature of a gravity anomaly within the Woodleigh impact structure. Another consideration for favouring this locality was that water for drilling is easily accessible from the network of pipelines on Woodleigh Station.

Yinni 1 was terminated within the Woodleigh Formation after it became difficult to maintain the stability of the hole due to caving of soft shale within this formation and the overlying Birdrong Sandstone. For this reason the hole was not logged and the secondary objective, to evaluate the source of the underlying gravity anomaly, was not achieved.

This Record provides the interpretation of palaeontological and geochemical data for Yinni 1. These data include biostratigraphy and depositional environments deduced from foraminifera and radiolaria (Appendix 1) and palynomorphs (Appendix 2). Also presented are data on petroleum geochemistry (Appendix 3), whole-rock chemistry (Appendix 4), a gazetteer of localities and wells mentioned (Appendix 5), a well index sheet (Appendix 6), and a composite well log (Plate 1). The operations report and core photographs can be obtained from Mory and Dixon (2002a, appendices 1 and 2, included on the compact disk accompanying this Record).

Well history

General data

Permit:	Vacant
Location:	Latitude 26°03'22.8"S, Longitude 114°48'58.5"E (GDA94) Northing 7116250, Easting 281530 (MGA Zone 50), determined from Global Positioning System (GPS)
Derivation of name:	Yinni Tank on the Wooramel River floodplain, 24 km north of Yinni 1
Total depth (TD):	158.2 m (driller)
Date spudded:	28 May 2001
Reached TD:	1 June 2001
Logging:	Not logged due to excessive caving of soft shale within the Woodleigh Formation and the overlying Birdrong Sandstone
Date abandoned:	2 June 2001
Elevation:	131 m Australian Height Datum (AHD), estimated from Woodleigh 1:100 000 topographic map (1990)
Drill floor:	Ground level
Status:	Abandoned for possible future use as a water bore

Drilling data

Drilling contractor:	Mt Magnet Drilling, 33 Paramount Drive, Wangara, W.A. 6065	
Rig:	Hydco SD 1000	
Rig datum:	Ground level	
Hole size:	0–18 m	140 mm with HW casing cemented into place
	18 – 36.7 m	115 mm with HWT casing (retrieved)
	36.7 – 92.8 m	90 mm with HQ casing (retrieved)
	92.8 – 158.2 m	76 mm open hole (NQ)
Mud:	Mixture of KCl and polymer-based muds	
Core recovery:	36.7 – 87.9 m	(HQ) 63.5 mm diameter; recovered 43.57 m (85%)
	Note that below 81.7 m the recovered sand with minor clay could be more appropriately regarded as cuttings, as the bit effectively reamed its way through this loose uncemented material and completely obliterated any sedimentary structures	
Hole deviation:	Not measured	

Regional structural setting

Yinni 1 was drilled within the southwestern part of the Gascoyne Platform (Fig. 2) in the Southern Carnarvon Basin — a structurally high area between the Merlinleigh, Byro, and Coolcalalaya Sub-basins to the east, and the Bernier Platform and Edel Terrace to the west (Fig. 2; Hocking et al., 1987; Hocking et al., 1994; Iasky and Mory, 1999). The Gascoyne Platform contains a thin cover of mostly subhorizontal Cretaceous strata and, locally, Lower Jurassic strata, unconformably overlying up to 5000 m of faulted and folded Ordovician–Devonian strata (Fig. 4; Iasky and Mory, 1999). The Wandagee and Ajana Ridges mark the raised eastern rim of the platform. The Merlinleigh, Byro, and Coolcalalaya Sub-basins were a major mid-Carboniferous to Permian depocentre along the eastern margin of the Southern Carnarvon Basin. Yinni 1 was drilled on the eastern flank of the central uplift of the Late Devonian Woodleigh impact structure (Mory et al., 2000; Iasky et al., 2001; Uysal et al., 2001). Drilling was terminated within the Jurassic strata, and therefore the well does not contain any direct evidence of the impact. Dips in the Cretaceous section within Yinni 1 are typically less than 2°, whereas correlation with nearby wells indicates that dips to the west are less than 0.2° (Fig. 5).

Stratigraphy

The southern Gascoyne Platform contains Ordovician–Devonian, Lower Jurassic, and Cretaceous units (Fig. 4). Yinni 1 was spudded in Quaternary sand and then intersected the Cretaceous Winning Group overlying the Lower Jurassic Woodleigh Formation (Figs 6 and 7).

Quaternary sediments

The uppermost section of Yinni 1 (0 – 38.7 m) comprises red to brown, very coarse to medium-grained loose sand with minor silt and clay and is interpreted as alluvium. The base of this section at 38.7 m is an erosion surface cut into weathered Gearle Siltstone.

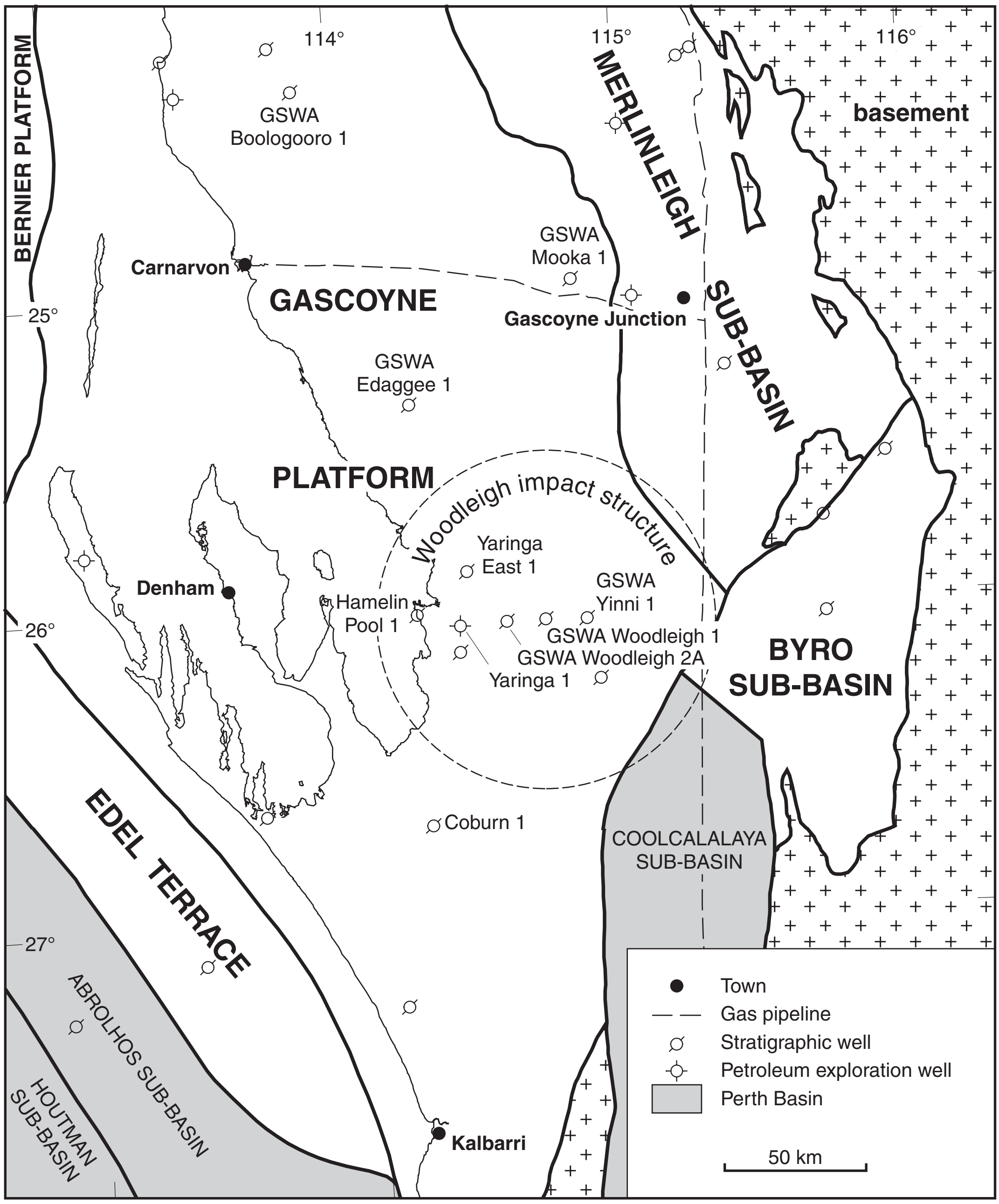

Figure 2. Tectonic elements of the southern Gascoyne Platform showing the location of petroleum exploration and stratigraphic wells

Winning Group

All formations of the Winning Group (in descending order: Gearle Siltstone, Windalia Radiolarite, Muderong Shale, and Birdrong Sandstone) are present in Yinni 1, although the upper part of the Gearle Siltstone is missing, presumably due to erosion. These units are separated by minor breaks that are well documented in other wells within the region, such as Barrabiddy 1/1A (Mory and Yasin, 1999), Coburn 1 (Yasin and Mory, 1999a), Edaggee 1 (Mory and Dixon, 2002c; Dixon et al., in prep. a), and Boologooro 1 (Mory and Dixon, 2002b; Dixon et al., in prep. b).

Gearle Siltstone

Lithostratigraphy

The interval from 38.7 to 52.3 m consists of variably weathered, mottled green-grey, brown, and yellow claystone, showing common small-scale bioturbation (mainly *Chondrites*) and rare medium-scale burrows, and is assigned to the Gearle Siltstone (Fig. 8a). In the lower part of the interval, rare phosphatic and ferruginous nodules and silicified patches are present. The interval from 47.7 to 52.3 m becomes progressively more calcareous, and includes rare belemnites.

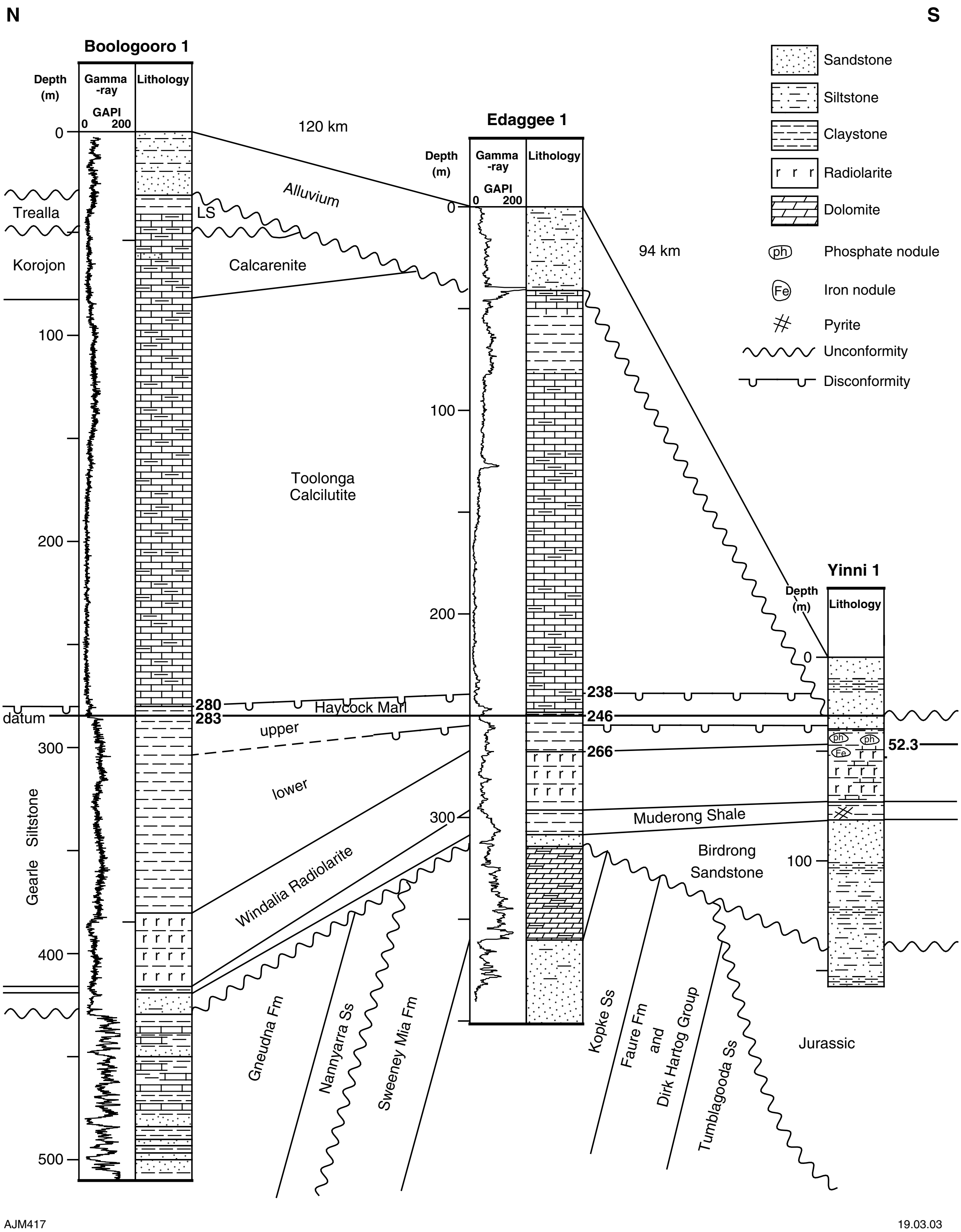

Figure 3. Correlation of Yinni 1 with Boologooro 1 and Edaggee 1. See Figure 2 for location of wells

The sand component of the claystone at 39.05 m contains abundant poorly preserved radiolaria together with fine-grained glauconite. Between 49.35 and 50.85 m, the claystone contains common, well-preserved calcareous foraminifera (including rare planktonic types), common to abundant radiolaria of variable preservation, and rare fragments of belemnite guards, echinoid spines, fish bone and teeth, and sponge spicules.

Chronostratigraphy

Planktonic foraminifera from the interval 49.35 – 50.85 m indicate that this section belongs to the *Blefuscuiana* Zone (*Hedbergella planispira* Zone of Haig et al., 1996) of early to middle Albian age. Benthic foraminifera include lagenid, buliminid, and rotaliid species (Appendix 1) previously described from the basal Gearle Siltstone (lower Albian) in the Giralia Anticline (Haig et al., 1996). The benthic foraminifera from 49.35 – 50.85 m are indicative of the *Berthelina intermedia* Zone (following Haig, 1979; Haig and Lynch, 1993) and support an early to middle Albian age.

The radiolaria at 39.05 m are too poorly preserved for identification and age determination. Their presence, however, suggests that this level probably belongs within the lower (Albian) part of the Gearle Siltstone because the Cenomanian portion of the formation elsewhere in the Southern Carnarvon Basin lacks common radiolaria. Absence of calcareous foraminifera from the interval 38.7 – 49.35 m is attributed to dissolution during weathering of the upper part of the bore section.

Because of the weathered nature of the claystone, no palynomorphs were recovered from the Gearle Siltstone in Yinni 1. However, the *Canninginopis denticulata* dinoflagellate zone (lower Albian) is tentatively identified at the base of this unit in Woodleigh 2A, 30 km to the west (Mory et al., 2001, appendix 5).

Regional correlations

Within the Southern Carnarvon Basin, the *Blefuscuiana* Zone has been identified in the Gearle Siltstone in: at least the basal 4.5 m at the type area (Giralia Anticline; Haig et al., 1996); the interval 253.85 – 261.0 m in Edaggee 1 (Mory and Dixon, 2002c); the interval 365.05 – 376.10 m in Boologooro 1 (Mory and Dixon, 2002b); the interval 79.7 – 97.4 m in Barrabiddy 1/1A (Mory and Yasin, 1999); and the interval 90.22 – 92.45 m in Cyanamid 3A (D. Haig, unpublished data).

To the southeast of Yinni 1, the *Blefuscuiana* Zone is known from the type section of the Alinga Formation (D. Haig, unpublished data). No planktonic foraminifera were recovered from the glauconitic sandstone in Coburn 1, assigned to the Alinga Formation (Yasin and Mory, 1999a). However, benthic foraminifera from this unit suggest that it belongs to the *Berthelina intermedia* Zone and is coeval with the Gearle Siltstone in Yinni 1.

The radiolarian assemblage from the interval 49.35 – 50.85 m includes two unnamed nasellarians that are not present in the underlying Windalia Radiolarite. These may provide an additional means for distinguishing the basal Gearle Siltstone from the Windalia Radiolarite.

Depositional environment

The foraminiferal assemblage suggests a mid-neritic (water depths of 50–100 m) depositional environment, based on criteria cited by Haig et al. (1996). The lowest occurrence of planktonic foraminifera in the bore section, together with diverse benthic lagenids and rotaliids and the fragmentary evidence of echinoids, belemnites, and sponges, suggest deeper water deposition than for the underlying Windalia Radiolarite. In comparison to other coeval sections of the Gearle Siltstone in the region, the similarity in the microfaunal assemblage suggests that similar water depths existed over a broad area of the basin. The lower-diversity foraminiferal assemblages in the coeval Alinga Formation to the southwest of Yinni 1 suggest that the Alinga Formation may have accumulated either in shallower water than the Gearle Siltstone or under more-restricted bottom-water conditions.

Windalia Radiolarite

Lithostratigraphy

The Windalia Radiolarite (52.3 – 74.2 m) is characterized by distinctly siliceous, radiolarian-rich, dark-grey to black siltstone and claystone. Decimetre-scale interbeds of these rock types are present and the radiolarite commonly shows small-scale fractures (Fig. 8b). The intensity of bioturbation (mainly small-scale but with some medium-scale burrows) varies. Pyrite veinlets and rare phosphatic nodules are present. Sand fractions from disaggregated samples (Appendix 1) contain common coarse-grained glauconite at 53.25 m and fine-grained glauconite at 54.65 and 67.2 m. Fine-grained quartz is rare in the interval 67.2 – 69.45 m and abundant in the interval 71.35 – 73.1 m. Sand-size aggregates of pyrite are abundant at 65.76 m.

The biogenic component of the samples varies throughout the section (Appendix 1). Radiolaria are abundant between 53.25 and 69.45 m, but rare in the interval 71.35 – 73.1 m. The preservation of radiolaria varies, and in some samples pyritized casts and ferruginous moulds exist alongside siliceous tests. The excellent preservation of siliceous radiolaria in many samples indicates very little burial diagenesis. In contrast to the distribution of radiolaria throughout the formation, foraminifera are recorded only between 54.65 and 58.75 m. Calcitic guards of belemnites (including microscopic specimens) are present between 52.3 and 58.75 m, and chitinophosphatic shell fragments attributed to an inarticulate lingulid brachiopod are present in the interval 54.65 – 67.2 m and at 72.2 m. Calcitic echinoid spines are present only at 58.75 m. Siliceous sponge spicules and carbonaceous scolecodonts are rare and sporadic, and phosphatic fish debris is abundant to common throughout the formation. Pyritized diatoms (originally opaline silica) are common at 73.1 m. The palynomorph assemblage is dominated by dinoflagellates (70–75% of the total assemblage) and shows excellent preservation (Appendix 2).

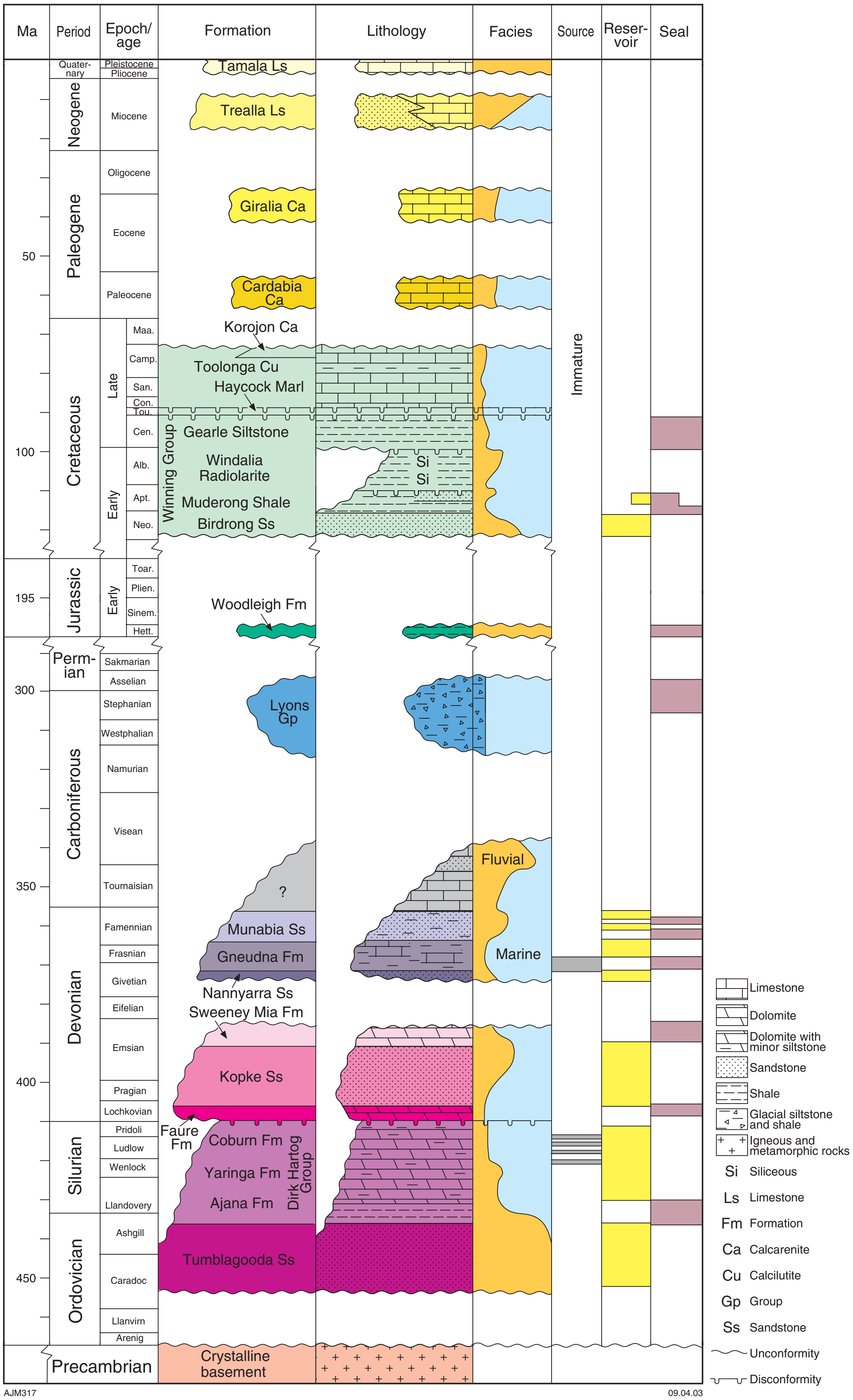

Figure 4. Regional stratigraphy of the Gascoyne Platform

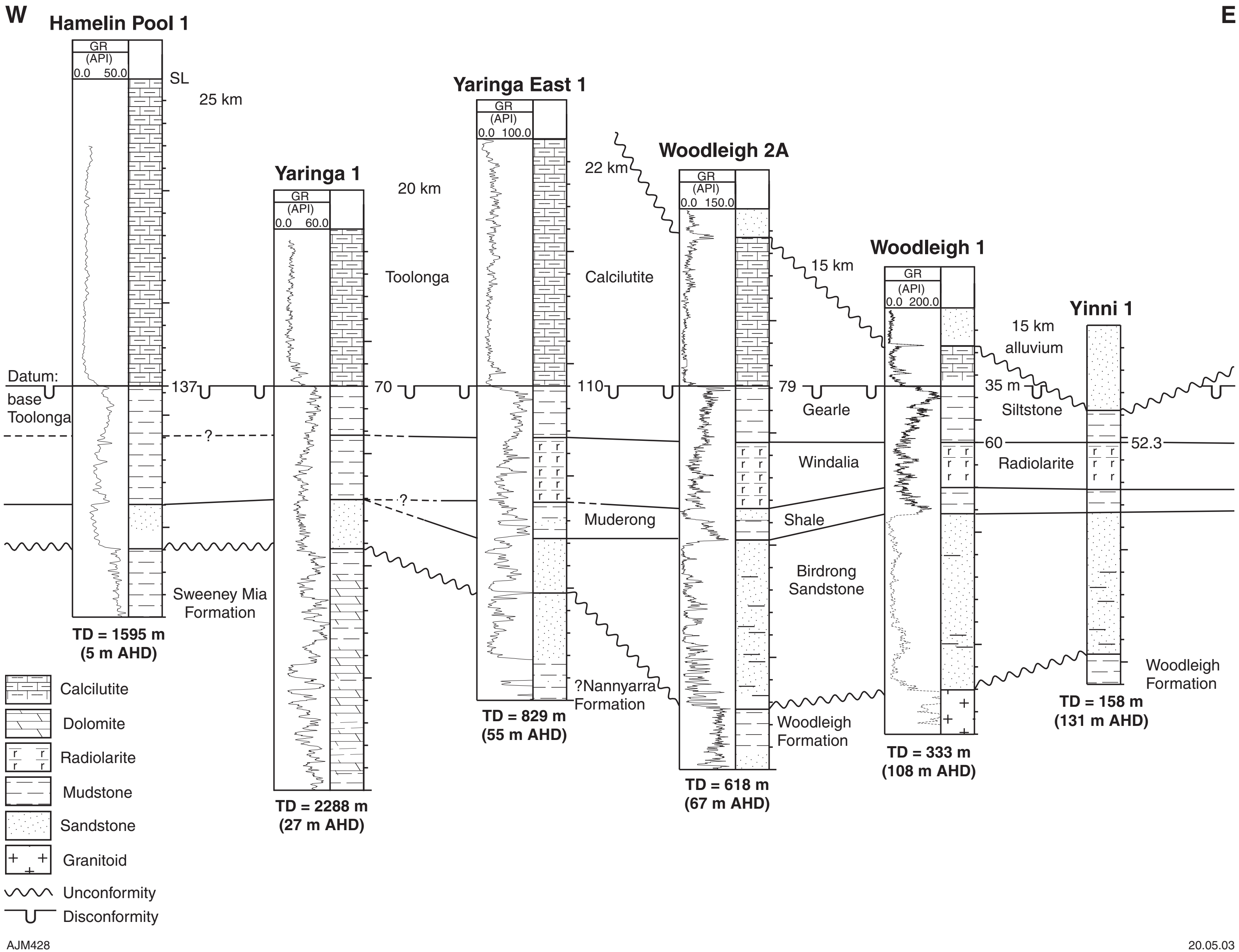

Figure 5. Correlation of Yinni 1 with nearby petroleum exploration and stratigraphic wells. See Figure 2 for location of wells

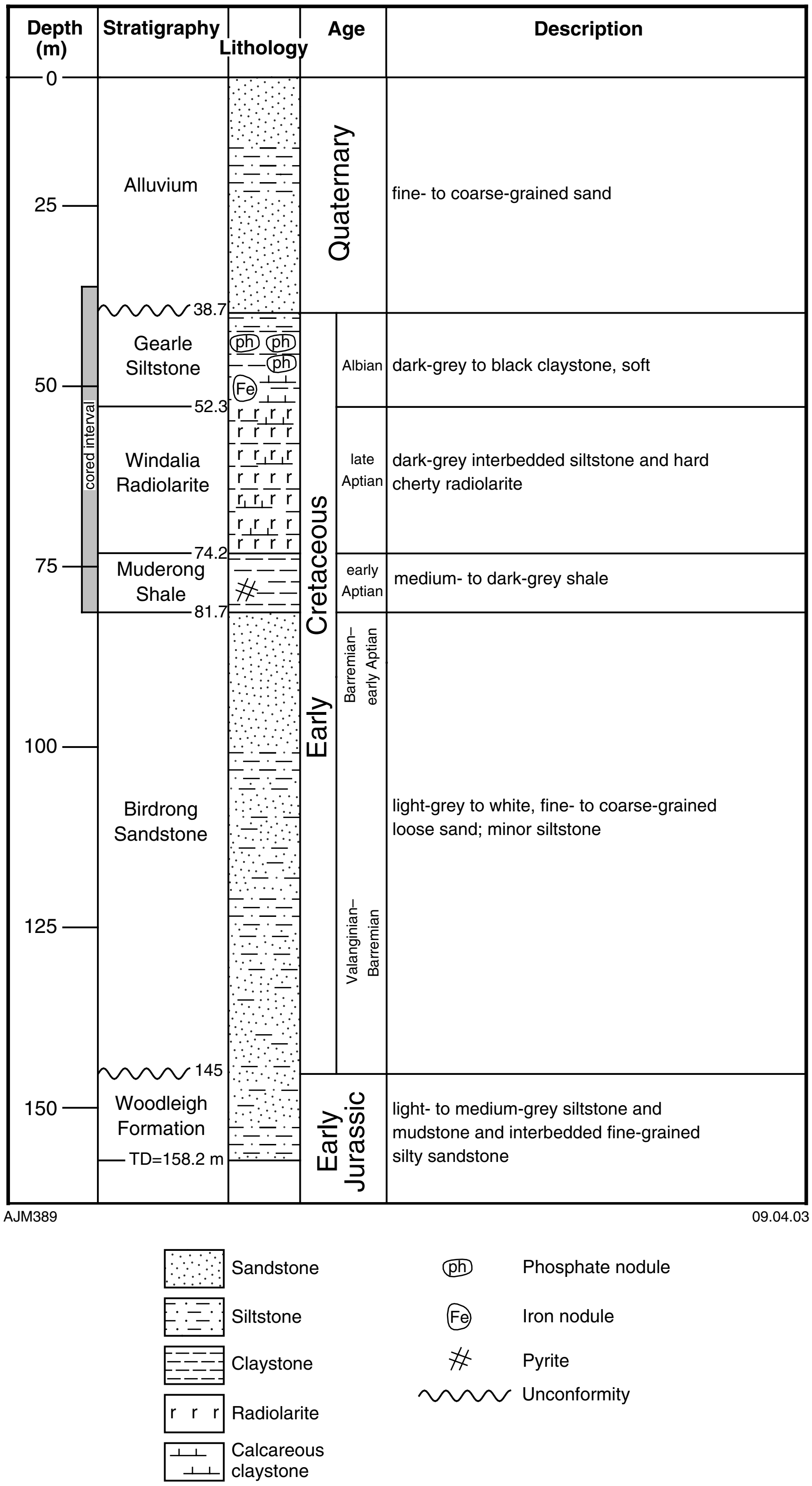

Figure 6. Yinni 1 stratigraphy

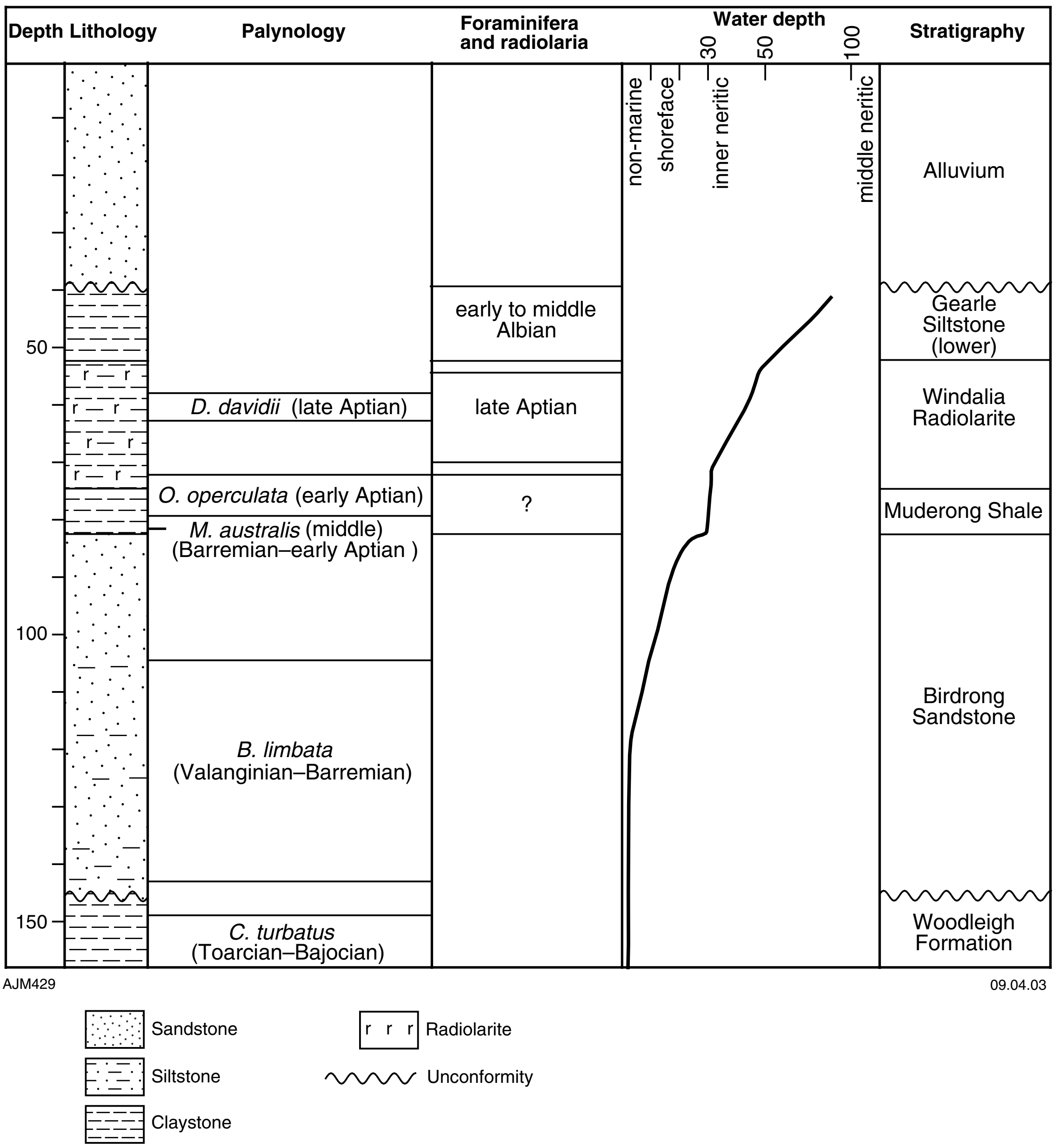

Figure 7. Cretaceous stratigraphy, biostratigraphy, and depositional environment for Yinni 1

Chronostratigraphy

Based on benthic foraminifera (Appendix 1), the interval between 54.65 and 57.05 m correlates with the upper part of the *Aaptotoichus pitmani* Zone, which is present in the upper Aptian sections of the Eromanga, Surat, Carpentaria, Laura, and Maryborough Basins of eastern Australia (following Haig and Lynch, 1993; Campbell and Haig, 1999). Dinoflagellates in samples from 57.05 and 62.2 m belong to the *Diconodinium davidii* Zone (Appendix 2) and indicate that this interval also belongs to the upper Aptian (following Helby et al., 1987). Dinoflagellates from a sample at 72.2 m belong to the *Odontochitina operculata* Zone (as does the interval 75.1 – 79.25 m in the underlying Muderong Shale; Appendix 2), which also represents an Aptian age, but the position of the boundary between the *D. davidii* and *O. operculata* Zones in the 62.2 – 72.2 m section has not been determined. The radiolarian assemblage is similar to that described by Ellis (1993) from the type section of the Windalia Radiolarite, where it is associated with ammonites considered to be of late Aptian age. However, a radiolarian zonation for the region that allows an independent stage correlation has not been established.

The Yinni 1 section has provided some of the best-preserved foraminiferal, radiolarian, and palynomorph assemblages known from the Windalia Radiolarite. The excellent preservation is probably the result of little burial diagenesis, and will facilitate a more integrated

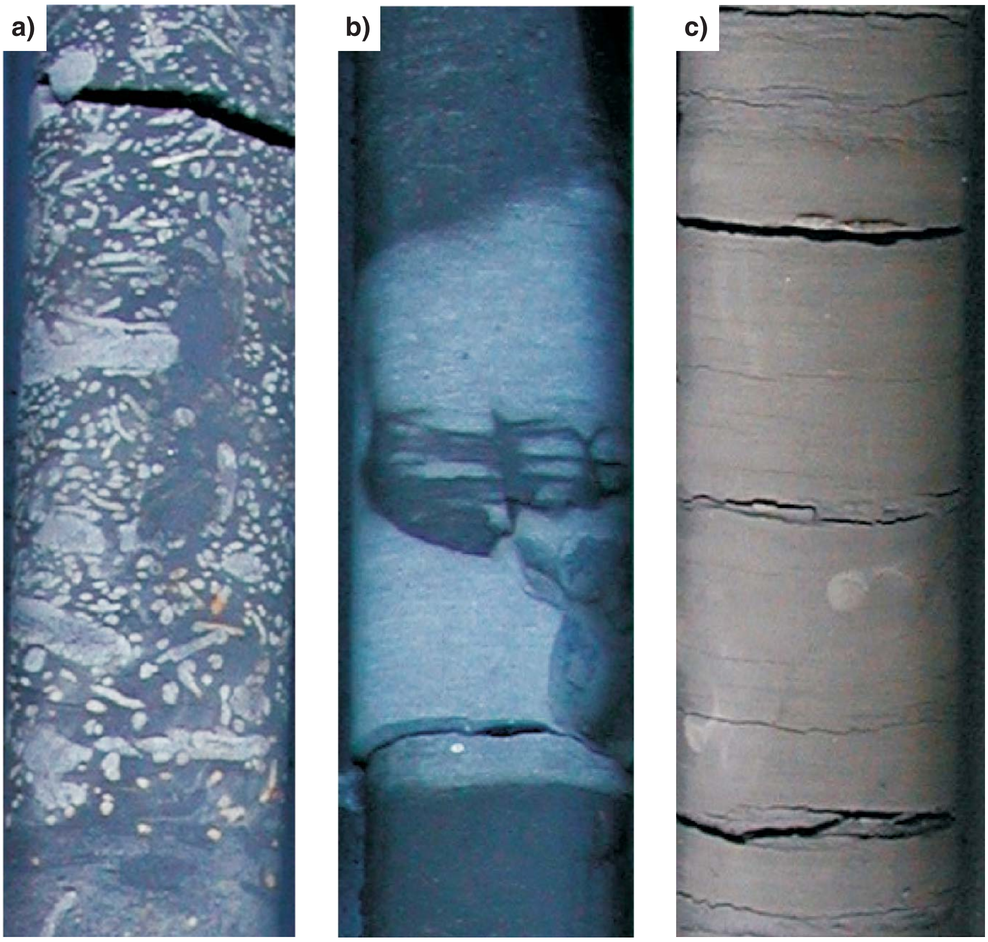

Figure 8. Representative core photographs of the Winning Group in Yinni 1: a) 52.2 – 52.3 m: bioturbation in the Gearle Siltstone; b) 60.7 – 60.8 m: interbedded fractured radiolarite and mudstone in the Windalia Radiolarite; and c) 72.3 – 72.4 m: laminated mudstone of the Muderong Shale

biostratigraphic appraisal of the Aptian section in the basin.

Regional correlations

Other wells in the region that intersected the *D. davidii* Zone include Woodleigh 2A at 120–132 m (Mory et al., 2001), Yaringa East 1 at 147–150 m (Yasin and Mory, 1999b), Edaggee 1 at 280.80 – 290.60 m (Mory and Dixon, 2002c), Mooka 1 at 55–57 and 73–75 m (Mory and Yasin, 1998), Barrabiddy 1/1A at 98.7 – 144.1 m (Mory and Yasin, 1999), and Giralia 1 at 15.2 m (McLoughlin et al., 1995). The boundary between the *D. davidii* and *O. operculata* Zones is present in the interval 144.1 – 145.8 m in Barrabiddy 1/1A close to the base of the Windalia Radiolarite. Samples from the interval 295.4 – 296.0 m in Edaggee 1, at the base of the Windalia Radiolarite, belong either to the *D. davidii* Zone or to the upper part of the *O. operculata* Zone. The regional correlations are consistent with the position of the boundary between the *D. davidii* and *O. operculata* Zones in the lower part of the Windalia Radiolarite in Yinni 1 (62.2 – 72.2 m), and suggest that the base of the Windalia Radiolarite may be synchronous across the region.

In terms of formation thickness, the Windalia Radiolarite in Yinni 1 (21.9 m thick) is thinner than sections to the north (30.7 m in Edaggee 1; 47 m in Barrabiddy 1/1A; 36 m in outcrop at the type section at Windalia Hill, although the top of the formation is not preserved), except for at Mooka 1, where thicknesses are similar. In the lower Murchison River region to the southeast, outcrop sections of the formation are less than 10 m thick.

Depositional environments

Foraminifera indicate inner- to mid-neritic conditions (water depths of about 30–50 m; Appendix 1) for the interval 54.65 – 58.75 m. The water was deeper and had less-restricted circulation than the depositional setting of the underlying Muderong Shale, but shallower than that of the overlying Gearle Siltstone. The absence of calcareous skeletons below 58.75 m suggests that these fossils were dissolved from the lower section of the formation, probably during early diagenesis. Based on the distribution of coeval radiolaria elsewhere in Australian Cretaceous sections (Haig and Barnbaum, 1978; Haig and

Lynch, 1993), the presence of abundant radiolaria is consistent with the inner- to mid-neritic bathymetric interpretation. The presence of small lingulid brachiopods also suggests restricted shallow-marine conditions (Archbold, 1981). Fine-grained quartz is abundant in the basal Windalia Radiolarite in Yinni 1, but absent higher in the section (above 67.2 m), indicating increasing water depths during deposition of the lower part of the unit.

Muderong Shale

Lithostratigraphy

The interval 74.2 – 79.0 m consists of uniform, dark-green to grey carbonaceous siltstone (Fig. 8c). Medium-scale burrows are present towards the top of the interval and are replaced by smaller-scale bioturbation lower in the section. Pyrite aggregates are present in sand residues washed from samples taken throughout the unit (Appendix 1). Biogenic grains recovered from sand fractions of disaggregated siltstone in this interval include: rare organic-cemented, siliceous, agglutinated foraminifera from the interval 76.1 – 76.9 m; siliceous and pyritized radiolaria from the interval 75.1 – 76.9 m; rare pyritized diatoms from the interval 75.1 – 76.9 m; rare sponge spicules at 76.9 m; and rare to common phosphatic fish debris. Faecal pellets are abundant in the interval 75.1 – 76.1 m. The palynomorph assemblage at 75.1 m is dominated by dinoflagellates and shows excellent preservation (Appendix 2).

The interval 79.0 – 81.7 m includes thin interbeds of black claystone in dark-green to grey siltstone. Small-scale bioturbation is present throughout the interval. Pyrite aggregates are present in the sand fractions of disaggregated samples, and quartz and glauconite is abundant in the basal sample at 81.1 m. Rare organic-cemented, siliceous, agglutinated foraminifera are present at 79.25 m, pyritized diatoms at 79.25 – 80.15 m, pyritized sponge spicules at 81.1 m, and phosphatic fish debris at 79.25 m (Appendix 1). The palynomorph assemblage at 79.25 m is dominated by dinoflagellates and shows excellent preservation (Appendix 2).

Chronostratigraphy

Based on dinoflagellates (Appendix 2), the interval 75.1 – 79.25 m correlates with the Aptian *Odontochitina operculata* Zone (following the correlation of Helby et al., 1987). The underlying *Muderongia australis* Zone is identified at 81.55 m in the Birdrong Sandstone. The precise position of the boundary between the *O. operculata* and *M. australis* Zones has not been determined.

Regional correlations

Other wells in the region where the *O. operculata* Zone has been recognized include Coburn 1 at 130.5 – 160.0 m (Yasin and Mory, 1999a), Edaggee 1 at 301.15 m (Mory and Dixon, 2002c; Dixon et al., in prep. a), and Barrabiddy 1/1A at 145.8 m (Mory and Yasin, 1999). The boundary between the *O. operculata* and *M. australis* Zones lies: in the interval 160.0 – 167.0 m in Coburn 1, within the lower Windalia Sandstone Member or in the basal mudstone unit of the Muderong Shale; in the interval 145.8 – 147.4 m in Barrabiddy 1/1A, within the uppermost Windalia Sandstone Member of the Muderong Shale; and in the interval 301.15 – 308.80 m in Edaggee 1, within mudstone facies units of the Muderong Shale. The Windalia Sandstone Member is not present in Yinni 1. Palynological correlations suggest that the Windalia Sandstone Member has a patchy distribution in the Southern Carnarvon Basin and that the shale facies units of the Muderong Shale may be diachronous across the region.

The foraminifera from the Muderong Shale in Yinni 1 include some species found in the type section, but lack several characteristic species described by Taylor and Haig (2001) from this section. This suggests that the Muderong Shale in Yinni may be younger than the type section of the formation.

Depositional environment

The foraminiferal assemblage is composed only of organic-cemented agglutinated species. Sponges, diatoms, and fish debris in argillaceous deposits indicate deposition in a low-energy, innermost-neritic environment, just below the intertidal zone (Appendix 1).

Birdrong Sandstone

Lithostratigraphy

The Birdrong Sandstone (81.7 – 145 m) can be divided into an upper, sand-rich unit (81.7 – 101 m) and a lower, finer-grained and muddier unit (101 – 145 m). The sand-rich unit comprises extremely friable, well-sorted, well-rounded, medium- to coarse-grained quartz sand that was not possible to core. The washed sand fraction at 81.85 m contains abundant quartz, mica, and fine-grained glauconite, and rare pyrite aggregates (Appendix 1). No mineralized biogenic grains are present. The palynomorph assemblage is dominated by dinoflagellates and displays excellent preservation (Appendix 2).

Chronostratigraphy

Based on dinoflagellates (Appendix 2), a core sample at 81.55 m correlates with the upper part of the lower Aptian or upper Barremian *M. australis* Zone (Helby et al., 1987). Cuttings from 104–107 m belong to the middle part of this zone (Barremian), but may be the result of caving from slightly higher in the section. Based on spore pollen (Appendix 2), cuttings from the lower part of the formation (125–143 m) correlate with the *Balmeiopsis limbata* Zone of the Barremian or Valanginian (following Helby et al., 1987).

Regional correlations

Other wells in the region where the *M. australis* Zone has been recognized include: Woodleigh 1 at 144–160 m (Mory et al., 2001); Woodleigh 2 at 144–180 m (Mory et al., 2001); Woodleigh 2A at 135–180 m (Mory et al., 2001); Yaringa East 1 at 174–219 m and possibly as high as 156–159 m (Yasin and Mory, 1999b); Coburn 1 at 167.0 – 182.4 m (Yasin and Mory, 1999a); Edaggee 1 at 308.8 – 309.65 m (Mory and Dixon, 2002c); Mooka 1 at 80.45 – 91.8 m (Mory and Yasin, 1998); Barrabiddy 1/1A at 147.4 – 190.25 m (Mory and Yasin, 1999); and Giralia 1 at 88.4 – 112.8 m (D. Haig, unpublished data). In these wells the *M. australis* Zone is known from the Muderong Shale and the underlying Birdrong Sandstone. Except for the interval 193.2 – 197.6 m in Woodleigh 2 (Mory et al., 2001), the non-marine *B. limbata* Zone, beneath the marine *M. australis* Zone, has not been recognized in the Birdrong Sandstone in this region.

Depositional environments

Dinoflagellates in the upper part of the Birdrong Sandstone (*M. australis* Zone) indicate marine conditions. In the upper, sandier unit the absence of foraminifera and other skeletal microfossils and the well-sorted quartz sand suggest a nearshore, marginal-marine environment. Most of the lower, muddier unit (*B. limbata* Zone), which lacks marine indicators, was probably deposited in a non-marine paralic environment and may be coeval with the sandy, cross-bedded, non-marine unit in the lower part of the Birdrong Sandstone type section (Mory and Yasin, 1999, fig. 7).

Woodleigh Formation

Lithostratigraphy

The Woodleigh Formation (145 – 158.2 m) comprises black carbonaceous claystone. The unit was not cored and is differentiated from the overlying muddy facies unit of the Birdrong Sandstone entirely on the basis of the contained palynoflora, which is dominated by pollen with a few spores (Appendix 2). Palynomorph preservation is excellent.

Chronostratigraphy

Spores and pollen (Appendix 2) indicate that the Woodleigh Formation correlates with the Middle–Lower Jurassic (Bajocian to Toarcian) *Callialasporites turbatus* Zone (Helby et al., 1987).

Regional correlations

Other wells in the region where the *C. turbatus* Zone has been identified, such as Woodleigh 2A (at 284 – 441.7 m in the Woodleigh Formation), are restricted to the Woodleigh impact structure. By comparison, this zone has an extensive distribution in the Perth and Northern Carnarvon Basins.

Depositional environment

The absence of marine indicators in the carbonaceous claystone suggests that the formation was deposited in a non-marine lacustrine environment. Palynomorphs of probable Early Permian age make up about 3% of the spore–pollen assemblage (Appendix 2), and indicate that at least part of the provenance of the Woodleigh Formation is from Permian shale units.

Petroleum potential

Source potential

All seven samples analysed are organic-rich, with a total organic carbon (TOC) range of 0.94 – 2.41% and potential yield (S_1+S_2) values of 1.75 – 3.96 mg/g rock. Samples from the Woodleigh Formation have fair organic richness and hydrocarbon-generating potential, whereas samples from the Muderong Shale and Windalia Radiolarite have good organic richness with fair hydrocarbon-generating potential (Appendix 3).

Maturation

Mean vitrinite reflectance (%Ro) values in the Jurassic Woodleigh Formation and Cretaceous Muderong Shale and Windalia Radiolarite range from 0.33 to 0.38%, indicating that these units are immature for oil generation and have not been buried more than a few hundred metres than they are at present. Analyses of the Rock-Eval parameter T_{max} range from 408 to 411°C, similarly indicating that the section is immature for oil generation.

Reservoir character and seals

No porosity or permeability analyses were made, but the virtually uncemented lithology of the Birdrong Sandstone in Yinni 1, and its hydrological properties as indicated from nearby water bores, imply an average porosity of over 20% and a high average permeability, especially within the upper part of this unit at this location. The only other unit intersected that may be considered as a potential reservoir, the Windalia Radiolarite, was strongly cemented overall with little indication of fracture porosity in Yinni 1 (Fig. 8b).

Potential seals penetrated in Yinni 1 include mudstone and tight radiolarite of the Gearle Siltstone and Muderong Shale (which form an effective aquiclude to the underlying Birdrong Sandstone) and mudstone of the Woodleigh Formation.

Mineral potential

Five core samples were analysed from the Gearle Siltstone and Windalia Radiolarite for base metals, rare earth elements, and phosphate (Appendix 4). Results were not encouraging. Statistical comparisons to units above and below show that the Gearle Siltstone has higher median values for MgO, Rb, and Th, and lower median values for P_2O_5 and the chalcophile index.

In drillcore the Gearle Siltstone shows little in common with stream sediments derived from the same unit on the Winning Pool – Minilya* 1:250 000 map sheet, whereas there is little variation in this unit between Edaggee 1 and Boologooro 1. The stream sediments possibly represent the combined effects of barite veining and low-temperature alteration, in addition to surface silicification and subsequent mechanical sorting and chemical weathering during the regolith-forming process.

Contributions to geological knowledge

In comparison to other cored sections of the Winning Group in the Southern Carnarvon Basin, Yinni 1 is significant because of the low degree of burial diagenesis that has affected the section and the more proximal location of the well with respect to the inferred Cretaceous shoreline. Because of excellent preservation of microfossils, Yinni 1 will be important for the development of an integrated palynological and foraminiferal zonation, and will also be a source of well-preserved skeletal material from which a parallel stable-isotope stratigraphy may be developed.

The section from the Birdrong Sandstone to the lowermost Gearle Siltstone provides a record of progressive marine flooding of the basin during the Valanginian to early Albian. The low-gradient nature of the Cretaceous sea floor is confirmed by the interpretations made for Yinni 1 and the comparisons with coeval stratigraphic sections in the region. Foraminifera indicate a general increase in palaeobathymetry throughout the Cretaceous, from low-energy shore-face conditions in the innermost-neritic zone during the initial Barremian transgressive phase (Birdrong Sandstone), to mid-neritic (50–100 m) water depths in the Albian (‘lower Gearle Siltstone’). The most significant increases in palaeobathymetry coincide with the boundary between the Windalia Radiolarite and ‘lower Gearle Siltstone’.

The eastern limit of the Woodleigh Formation, a lacustrine deposit over the central part of the Woodleigh impact structure, lies east of Yinni 1, contrary to geological cross sections shown by Iasky et al. (2001) and Mory et al. (2001).

At Yinni 1, the low maturity of the Cretaceous and Jurassic succession (0.33 to 0.38%Ro) limits petroleum potential and implies that the succession has been buried by no more than a few hundred metres. Nevertheless, the succession has fair to good organic richness with fair hydrocarbon-generating potential.

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* Capitalized names refer to standard 1:250 000 map sheets.

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Appendix 1

Foraminifera and radiolaria

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Summary

Table 1.1 shows the correlations derived from foraminifera and radiolaria recovered from washed sand fractions of 24 core samples from 39.05 to 81.85 m in Yinni 1.

Introduction

The foraminiferal and radiolarian analyses are based on comprehensive picks of the washed sand fractions (63 µm – 2 mm) of 24 core samples taken from between 39.05 and 81.85 m (Table 1.2). Foraminiferal distributions are recorded in Table 1.3 and radiolarian distributions in Table 1.4. Because of variable preservation (particularly among the radiolaria and organic-cemented agglutinated foraminifera), systematic counts were not attempted. Species abundances were estimated as follows: more than 20 specimens observed is considered 'abundant'; 10–20 specimens is considered 'common'; and less than 10 specimens is considered 'rare'.

The recovered assemblages are compared to those recorded previously from the Muderong Shale (McLoughlin et al., 1995; Taylor and Haig, 2001), Windalia Radiolarite (Ellis, 1993; Haig, 1999), and Gearle Siltstone (Haig et al., 1996; Haig, 1999; Howe et al., 2000).

General observations

39.05 m

This sample contains abundant poorly preserved radiolaria. Weathered, fine-grained glauconitic sand is also present. The absence of foraminifera and other calcareous microfossils is probably the result of dissolution associated with the modern weathering profile.

49.35 – 50.85 m

This mudstone interval contains common well-preserved calcareous foraminifera, common to abundant radiolaria of variable preservation, and rare fragments of belemnite guards, echinoid spines, fish bone and teeth, and sponge spicules.

53.25 m

This sample contains abundant well-preserved radiolaria, rare sponge spicules, rare belemnite fragments, and fish debris, but lacks foraminifera. Coarse-grained glauconite is a common component of the sand. The presence of sponges suggests that the bottom waters were well oxygenated.

54.65 – 57.05 m

These two samples contain abundant calcareous foraminifera, radiolaria, and fish debris. Organic-cemented agglutinated foraminifera, shell fragments (possibly from a brachiopod comparable to *Lingula*), and belemnite guard fragments are rare to common.

58.75 m

This sample contains abundant radiolaria but rare foraminifera. Rare shell fragments (cf. *Lingula*), belemnite guard fragments, echinoid spines, scolecodonts, and common fish debris are also present.

62.2 – 69.45 m

No foraminifera are present in the samples between 62.2 and 69.45 m. Radiolaria are abundant and well preserved

Table 1.1. Formation ages and water depths indicated by foraminifera and radiolaria in Yinni 1

Depth (m)	*Stratigraphy*	*Water depth*	*Age*
39.05 – 50.85	'lower Gearle Siltstone'	middle neritic (probably 50–100 m)	early to middle Albian
53.25 – 69.45	Windalia Radiolarite	inner to middle neritic (probably 30–50 m)	late Aptian
71.35 – 81.85	Muderong Shale	innermost neritic (probably < 30 m)	uncertain

Table 1.2. General composition of washed sand residues in core samples from 39.05 to 81.85 m

	Sampled depths (metres below surface)																							
	81.85	*81.1*	*80.15*	*79.25*	*78.4*	*76.9*	*76.1*	*75.1*	*73.1*	*72.2*	*71.35*	*69.45*	*68.55*	*67.2*	*65.75*	*62.2*	*58.75*	*57.05*	*54.65*	*53.25*	*50.85*	*49.9*	*49.35*	*39.05*
General composition of sand fraction																								
Quartz >150 µm	A	A	–	–	–	–	–	–	–	R	–	–	–	R	–	–	–	–	–	–	–	–	–	–
Quartz 63–150 µm	A	A	–	–	–	–	–	–	A	A	A	R	R	R	–	–	–	–	–	–	–	–	–	–
Mica >150 µm	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Mica 63–150 µm	A	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Glauconite >150 µm	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	R	C	–	–	–	–
Glauconite 63–150 µm	A	A	–	–	–	–	–	–	–	R	–	–	–	R	–	–	–	–	R	A	–	R	–	A*
Pyrite (aggregate grains) >150 µm	–	–	–	–	R	R	–	–	R	R	–	–	–	–	A	–	–	–	R	–	–	–	–	–
Pyrite (aggregate grains) 63–150 µm	R	R	C	R	R	A	R	–	A	R	R	–	–	–	C	–	–	–	–	–	–	–	–	–
Pyrite (smooth sphere) 63–150 µm	–	R	R	R	–	R	–	–	R	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Pyrite (aggregates in cylinder) >150 µm	–	–	–	–	–	–	–	R	–	–	C	R	–	–	–	–	–	–	–	–	–	–	–	–
Pyrite (aggregates in cylinder) 63–150 µm	–	–	–	–	–	–	–	–	C	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Agglutinated (organic-cemented) foraminifera >150 µm	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	R	R	–	–	–	–	–	–
Agglutinated (organic-cemented) foraminifera 63–150 µm	–	–	–	R	–	R	R	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Hyaline calcitic foraminifera >150 µm	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	R	A	R	–	C	C	C	–
Hyaline calcitic foraminifera 63–150 µm	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	A	A	–	C	–	C	–
	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Radiolaria >150 µm	–	–	–	–	–	–	–	–	–	–	–	A	A	A	A	A	A	A	C	A	C	C	R	–
Radiolaria 63–150 µm	–	–	–	–	–	–	R	R	R	R	R	A	A	A	A	A	A	A	A	A	A	–	C	A*
Radiolaria (pyritized) >150 µm	–	–	–	–	–	R	–	–	R	–	–	–	–	–	–	–	R	–	C	–	–	–	–	–
Radiolaria (pyritized) 63–150 µm	–	–	–	–	–	C	–	R	–	–	–	C	–	C	–	R	A	R	C	–	–	–	–	–
Radiolaria (‘iron-oxide’ moulds) >150 µm	–	–	–	–	–	–	–	–	–	–	–	–	–	A	–	–	–	–	–	–	–	–	–	–
Radiolaria (‘iron-oxide’ moulds) 63–150 µm	–	–	–	–	–	–	–	–	–	–	–	–	–	A	–	–	–	–	–	–	–	–	–	–
Sponge spicules 63–150 µm	–	–	–	–	–	–	–	–	R	R	–	R	R	R	–	R	–	–	–	R	R	–	–	–
Sponge spicules (pyritized) 63–150 µm	–	R	–	–	–	R	–	–	R	–	R	R	–	–	–	–	–	–	–	–	–	–	–	–
Diatoms (pyritized) 63–150 µm	–	–	R	R	–	R	R	R	C	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Shell fragments (?‘lingulid-type’ brachiopod) >150 µm	–	–	–	–	–	–	–	–	–	C	–	–	–	R	R	R	R	R	C	–	–	–	–	–
Shell fragments (?‘lingulid-type’ brachiopod) 63–150 µm	–	–	–	–	–	–	–	–	–	C	–	–	–	–	R	–	–	–	C	–	–	–	–	–
Belemnite guard fragments >150 µm	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	R	R	–	R	–	R	–	–
Echinoid spines >150 µm	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	R	–	–	–	–	–	–	–
Echinoid spines 63–150 µm	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	R	R	R	–
Fish debris >150 µm	–	–	–	R	C	C	R	R	C	C	C	A	R	A	C	R	C	A	C	R	C	R	R	–
Fish debris 63–150 µm	–	–	–	R	–	–	R	C	C	R	–	–	R	C	C	–	–	–	A	–	C	–	R	–
Scolecodonts 63–150 µm	–	–	–	–	–	–	–	–	–	–	–	R	R	–	–	–	R	–	–	–	–	–	–	–
Pellets >150 µm	–	–	–	–	–	–	A	A	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Pellets 63–150 µm	–	–	–	–	–	–	R	R	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Dinoflagellate cysts 63–150 µm	C	C	C	R	R	R	R	–	R	R	–	A	–	–	R	R	R	R	R	–	–	–	–	–
Wood and cuticle fragments >150 µm	–	–	–	–	–	–	–	–	R	–	–	–	–	–	R	–	–	–	–	–	–	–	–	–
Wood and cuticle fragments 63–150 µm	R	R	–	–	–	–	–	–	–	R	–	–	–	–	–	–	–	–	–	–	–	–	–	–

NOTES: A: Abundant
C: Common
R: Rare (by visual estimation)
–: Not present
* Very poorly preserved

Table 1.3. Distribution of foraminifera in the Winning Group, Yinni 1

	Sampled depths (metres below surface)																						
	81.85	*81.1*	*80.15*	*79.25*	*78.4*	*76.9*	*76.1*	*75.1*	*73.1*	*72.2*	*71.35*	*69.45*	*68.55*	*67.2*	*65.75*	*62.2*	*58.75*	*57.05*	*54.65*	*53.25*	*50.85*	*49.9*	*49.35*	*39.05*
Agglutinated foraminifera	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Ammobaculites humei Nauss 1947	–	–	–	R	–	R	R	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Ammodiscus glabratus Cushman and Jarvis 1928	–	–	–	R	–	R	R	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Bimonilina sp. (A3)	–	–	–	R	–	–	R	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Haplophragmoides sp. indet.	–	–	–	–	–	–	R	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Hyaline foraminifera (Lagenida)																								
Astacolus calliopsis (Reuss 1863)	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	R	R	–	R	R	R	–
Astacolus sp. cf. *A. howchini* Ludbrook 1966	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	R	R	–	–	–	R	–
Astacolus sp. (N9)	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	R	–	–	–	–	–	–
Citharina sp. cf. *C. angustissima* (Reuss 1863)	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	R	–
Citharina sp. cf. *C. petila* Eicher and Worstell 1970	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	R	–	–
Citharina sp. (N5)	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	C	A	–	R	–	R	–
Globulina lacrima Reuss 1845	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	R	–	–	–	–	R	–
Globulina prisca Reuss 1863	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	R	–	R	R	–	–
Hemirobulina hamulus (Chapman 1894)	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	R	R	–	R	–	C	–
Laevidentalina hamiltonensis (Ludbrook 1966)	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	A	R	–	A	C	A	–
Laevidentalina luma (Belford 1960)	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	R	R	–	R	R	R	–
Laevidentalina sp. 1 (N13)	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	R	–	–	–	–	R	–
Laevidentalina sp. (N22)	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	R	–	–	–	–	–
Lenticulina sp. (N1)	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	A	–	–	–	–	–	–
Lenticulina sp. (N2)	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	A	R	–	–	–	–	–
Lenticulina sp. (N3)	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	A	–	–	–	–	–	–
Lingulina sp. (N18)	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	R	R	–	–	–	–	–
Marginulinopsis arimensis Ludbrook 1966	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	C	R	–	C	R	A	–
Marginulinopsis pristipellis Ludbrook 1966	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	R	–	–
Marginulinopsis sp. cf. *M. jonesi* (Reuss 1863)	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	R	–	–	–
Marginulinopsis sp. (N4)	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	C	–	–	R	–	R	–
Pseudonodosaria sp. of Haig, Watkins, and Ellis 1996	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	R	–	–	R	R	–
Psilocitharella recta (Reuss 1863)	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	R	–	–
Psilocitharella thoerenensis (Bartenstein and Brand 1951)	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	R	–
Pyramidulina flexocarinata (Khan 1950)	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	R	R	–	R	R	R	–
Pyramidulina sp. cf. *P. obscura* (Reuss 1845)	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	R	R	–	–	–	R	–
Pyramidulina prismatica (Reuss 1860)	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	R	R	R	–
Pyramidulina sceptrum (Reuss 1863)	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	R	–	–	–	R	–
Pyramidulina sp. 1 (N19)	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	R	C	–	R	–	–	–
Ramulina sp. A of Belford 1960	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	R	–	R	C	C	–
Ramulina sp. A of Haig 1982	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	R	–	–	–	–	–
Saracenaria bononiensis (Berthelin 1880)	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	R	R	–	–	–	–	–
Saracenaria sp. 1 of Haig, Watkins, and Ellis 1996	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	R	R	–	–	–	?	–
Saracenaria sp. 2 (N24)	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	R	–	–	R	R	–
Saracenaria sp. 4 (N32)	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	R	R	–
Hyaline foraminifera (Buliminida)																								
Coryphostoma sp. of Haig, Watkins, and Ellis 1996	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	R	R	R	–
Pleurostomella reussi Berthelin 1880	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	R	–
Turrilina? hergottensis (Ludbrook 1966)	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	A	R	–	–	–	–	–
Turrilina? moorei (Haig 1982)	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	A	R	–	–	–	–	–

Table 1.3. (continued)

	Sampled depths (metres below surface)																						
	81.85	*81.1*	*80.15*	*79.25*	*78.4*	*76.9*	*76.1*	*75.1*	*73.1*	*72.2*	*71.35*	*69.45*	*68.55*	*67.2*	*65.75*	*62.2*	*58.75*	*57.05*	*54.65*	*53.25*	*50.85*	*49.9*	*49.35*	*39.05*
Hyaline foraminifera (Rotaliida)																								
Gyroidinoides infracretaceus (Morozova 1948)	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	A	R	–	–	–		–
Lingulogavelinella sp. cf. *L. albiensis* of Haig and Lynch 1993	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	C	–	–	C	?	R	–
Lingulogavelinella innaminckae (Ludbrook 1966)	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	R	–
Lingulogavelinella santoodnae (Ludbrook 1966)	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	R	–	R	–
Lingulogavelinella sp. cf. *L. santoodnae* (Ludbrook 1966)	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	R	A	–	–	–	–	–
Berthelina intermedia (Berthelin 1880)	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	R	C	R	–
Berthelina sp. cf. *B. tenuissima* (Gawor-Biedowa 1992)	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	R	–
Berthelina sp. (R5)	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	R	–	–	–
Planktonic foraminifera (Globigerinida)																								
Blefuscuiana sp. (G1)	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	R	R	R	–

NOTES:
A: Abundant
C: Common
R: Rare (by visual estimation)
?: Possible
–: Not present

Coded numbers in brackets after species refer to UWA species collection

Table 1.4. Distribution of radiolaria in the Winning Group, Yinni 1

	Sampled depths (metres below surface)																						
	81.85	*81.1*	*80.15*	*79.25*	*78.4*	*76.9*	*76.1*	*75.1*	*73.1*	*72.2*	*71.35*	*69.45*	*68.55*	*67.2*	*65.75*	*62.2*	*58.75*	*57.05*	*54.65*	*53.25*	*50.85*	*49.9*	*49.35*	*39.05*
Radiolaria																								
Acaeniotyle longispina (Squinabol 1903)	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	R	–	–	–	–	–	–	–	–
Arachnosphaera exilis (Hinde 1893)	–	–	–	–	–	R	–	–	R	R	R	A	A	A	A	A	A	A	A	A	A	R	R	–
Archaeodictyomitra vulgaris (Pessagno 1977)	–	–	–	–	–	–	–	–	–	–	–	–	–	–	R	C	–	R	R	R	–	–	R	–
Archaeospongoprunum sp. (Rad 21)	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	R	R	R	R	R	–
Crucella messinae Pessagno 1971	–	–	–	–	–	–	–	–	–	–	–	R	R	R	R	C	R	R	R	R	R	–	–	–
Histastrum aster Lipman 1952	–	–	–	–	–	–	–	–	–	–	–	R	R	R	R	R	R	–	–	R	–	–	–	–
Orbiculiforma depressa Wu 1986	–	–	–	–	–	–	R	–	–	–	–	R	R	R	A	R	R	A	C	R	–	–	–	–
Orbiculiforma? sp. (Rad 20)	–	–	–	–	–	–	–	–	–	–	–	–	–	–	R	–	–	–	–	–	–	–	–	–
Patellula? sp. (Rad 10)	–	–	–	–	–	R	R	R	–	–	–	R	R	R	R	R	C	–	–	R	–	–	–	–
Paronaella sp. (Rad 4)	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	R	R	–	R	R	R	R	R	–
Praeconocaryomma excelsa Ellis 1993	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	R	–	–	–	–	–	–	–	–
Praeconocaryomma lipmanae Pessagno 1976	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	R	R	–	–	–	–	–	–	–
Praeconocaryomma prisca Pessagno 1977	–	–	–	–	–	–	–	–	–	–	–	R	R	A	–	A	R	R	R	–	–	–	–	–
Pseudodictyomitra? sp. (Rad 22)	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	R	R	A	R	R	–
Spongodiscus renillaeformis Campbell and Clark 1944	–	–	–	–	–	R	–	–	–	–	–	C	R	C	A	A	R	A	R	R	–	–	–	–
Spongopyle sp. (Rad 13)	–	–	–	–	–	R	–	–	–	–	–	R	R	–	–	R	–	–	–	R	–	–	–	–
Triactoma? sp. (Rad 8)	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	R	–	–	–	–	–	–	–	–
Tricolocapsa antiqua (Squinabol 1903)	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	R	–	–	–	R	–	–	–	–
Windalia pyrgodes (Renz 1974)	–	–	–	–	–	R	R	–	–	–	–	R	C	A	R	C	R	C	C	C	R	R	R	–
Nassellarian (Rad16)	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	R	–	–	–	–	–	–	–	–
Nassellarian (Rad 17)	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	R	–	–	–	–	–	–	–	–
Nassellarian (Rad 23)	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	C	R	R	–
Nassellarian (Rad 24)	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	C	–	–	–
Spumellarian (Rad 19)	–	–	–	–	–	–	–	–	–	–	–	–	–	R	R	R	R	R	–	–	–	–	–	–
Spumellarian (Rad 25)	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	R	–

NOTES:
A: Abundant
C: Common
R: Rare (by visual estimation)
–: Not present

Coded numbers in brackets after species refer to UWA species collection

Table 1.5. Major biotic events recognized in the Winning Group in Yinni 1, based on the distribution of biogenic grain types recovered from washed sand fractions of disaggregated samples

Depth (m)	*Biotic event*	*Depositional inference*
50.85	FO planktonic foraminifera	open-water circulation, mid-neritic water depths (~50–100 m)
57.05	FO abundant calcareous foraminifera and belemnites	open bottom-water circulation
69.45	FO abundant radiolaria	mid-neritic water depths (~30–50 m), open surface-water circulation
76.9	FO rare radiolaria	normal salinity levels in surface waters
79.25	FO organic-cemented agglutinated foraminifera and fish debris	?increasing salinity levels
80.15	FO diatoms	
81.1	FO sponge spicules	well-oxygenated bottom water
81.85	presence of common dinoflagellates	marginal marine (?brackish)

NOTE: FO: first occurrence up-section

in this interval. Other microfossils include rare shell fragments (cf. *Lingula*) and scolecodonts, and rare to abundant fish debris. Rare quartz is present in the sand residues in the interval 67.2 – 69.45 m, but not in shallower samples. Dissolution may explain the absence of calcareous skeletons over this interval.

71.35 – 73.1 m

Samples from this interval contain abundant fine-grained quartz sand. Pyrite (as aggregate grains) is rare to abundant. Apart from common fish debris, biogenic skeletal material is rare. Radiolaria are rare and foraminifera are absent. Diatoms are common in the fine-grained sand residue in the sample from 73.1 m.

75.1 m

Radiolaria and diatoms are rare in this sample and foraminifera are absent. Fish debris is common, and abundant faecal pellets (of coarse-sand size) are present.

76.1 – 76.9 m

Samples in this interval are marked by the co-occurrence of rare, poorly preserved, organic-cemented agglutinated foraminifera and radiolaria as well as rare to common fish debris. No radiolaria tests were recorded below 76.9 m.

78.4 – 81.1 m

Sparse mineralized skeletons are found in this interval: fish debris and organic-cemented agglutinated foraminifera are not recorded below 79.25 m; diatoms are not recorded below 80.15 m; and siliceous sponge spicules are not recorded below 81.1 m. Pyrite in the form of grain aggregates and smooth spheres is rare to common in all fine-grained sand fractions. Quartz is apparent in the washed sand fraction only at 81.1 m.

81.85 m

No mineralized skeletons are present at this level. Dinoflagellate cysts are common in the fine-grained sand fraction. Quartz is abundant and mica is rare in the washed sand fraction.

Comments

The distribution of grain types documented in Table 1.2 suggests a marine-transgressive succession encompassing the biotic events listed in Table 1.5. This succession is similar to that previously recorded by Haig and Lynch (1993) and Campbell and Haig (1999) for the coeval marine transgression in the Cretaceous interior basins of eastern Australia. Overall it represents progressive deepening from marginal-marine to middle-neritic water depths.

Foraminiferal observations

49.35 – 50.85 m

Diverse hyaline foraminifera, including rare planktonic types, are present in this interval. In species content, the microfauna is similar to that described by Haig et al. (1996) from the basal Gearle Siltstone in the Giralia Anticline, and to that recorded by Haig (1999) between 70.80 and 94.90 m in Barrabiddy 1. The interval corresponds to the *Blefuscuiana* Zone (*Hedbergella planispira* Zone of Haig et al., 1996) of early to middle Albian age.

The presence of rare, very small planktonic foraminifera, and of benthic *Pleurostomella*, *Coryphostoma*, and diverse lagenids and rotaliids, suggests a mid-neritic (50–100 m) water depth with well-oxygenated bottom water.

54.65 – 57.05 m

The diverse hyaline benthic foraminifera in this interval are similar in species content to those recorded by Haig (1999) between 126.50 and 144.00 m in Barrabiddy 1. The presence of *Turrilina*? *hergottensis* and its descendant *T.*? *moorei*, *Lingulogavelinella* sp. cf. *L. albiensis* and transitional forms to *L. santoodnae*, indicate a correlation to the upper part of the late Aptian *Aaptotoichus pitmani* Zone recognized in the Eromanga Basin of eastern Australia (Haig and Lynch, 1993; Campbell and Haig, 1999).

The absence of planktonic foraminifera, together with the diverse calcareous benthic assemblage, suggest that the water depth was in the inner-neritic to mid-neritic zone (less than 50 m deep). The presence of the diverse calcareous benthic foraminifera (along with rare echinoid spines and belemnite guards) suggests that bottom waters were well oxygenated.

76.1 – 79.25 m

Very poorly preserved, organic-cemented agglutinated foraminifera are rare in this interval. In terms of age correlation, this microfauna is not diagnostic, containing none of the species typical of the Muderong Shale (Taylor and Haig, 2001). *Ammobaculites humei* and *Ammodiscus glabratus* are present in type Muderong Shale assemblages, but extend into Upper Cretaceous strata elsewhere in the Southern Carnarvon Basin.

The low-diversity, organic-cemented agglutinated assemblage indicates an innermost-neritic, marginal-marine setting.

Radiolarian observations

39.05 m

Abundant spherical spumellarians are present at this level. The preservation is very poor and species determination is impossible.

49.35 – 50.85 m

The well-preserved radiolarian assemblage in this interval seems similar to that in the underlying interval, but is marked by the appearance of two unnamed nassellarians (coded Rad 23 and 24 in Table 1.4). Further work is required before the identity and stratigraphic significance of these species can be determined.

53.25 – 69.45 m

The abundant, diverse, and well-preserved radiolarian assemblage present in this interval is similar to that described by Ellis (1993) from the type section of the Windalia Radiolarite, and to the microfauna recorded by Haig (1999) from between 142.7 and 144 m in Barrabiddy 1.

71.35 – 76.9 m

The rare radiolaria present in this interval belong to species recorded in the overlying beds (53.25 – 69.45 m).

Conclusions

Three depositional cycles are evident in the Yinni 1 succession between 49.35 and 81.85 m:

1. The interval 71.35 – 81.85 m correlates in part with the Muderong Shale. It contains abundant quartz and some glauconite in its lower and upper parts, where deposition was in shallow water. Maximum flooding in the innermost-neritic zone is probably at 76.9 m.
2. The interval 53.25 – 69.45 m correlates with the Windalia Radiolarite of late Aptian age. Maximum flooding, in the middle-neritic zone (around 50 m water depth), is probably around 54.65 – 57.05 m, with a significant change, perhaps shallowing, evident at 53.25 m.
3. The interval 49.35 – 50.85 m (and perhaps to 39.05 m and above) correlates with the ‘lower Gearle Siltstone’ of early to middle Albian age.

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Appendix 2

Palynology

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Introduction

Palynological results from Yinni 1 are based on the samples listed in Table 2.1. Estimates of organic yield are based on the amount of residue produced after acid digestion. Species distributions, arranged by lowest occurrence, are presented in Table 2.2 for all Cretaceous samples. Approximately 200 specimens were counted in core samples, and 100 specimens in cuttings samples, with further taxa recorded as present. The counts are presented as percentages. A breakdown of the spore–pollen grouping is not presented because it adds little to the biostratigraphy, which is based largely on dinocysts. The two cuttings samples from the base of the section are Lower Jurassic and are not included in Table 2.2.

The major zonal subdivision used for the Cretaceous and Jurassic is based on Helby et al. (1987). Informal subzones used for the Cretaceous are based on unpublished work by B. S. Ingram, N. Hooker, and R. Morgan, and on proposed subzones presented by Foster (2001).

Palynological observations and comments

57.05 to 62.2 m, *Diconodinium davidii* Dinoflagellate zone

The sample above this interval (50.65 m) is barren of palynomorphs, presumably because of surface oxidation. *Diconodinium davidii* Morgan 1975 is present at 57.05 m, and *Muderongia tetracantha* (Gocht 1957), *Cribroperidinium edwardsii* (Cookson and Eisenack 1958), and *Endoceratium turneri* (Cookson and Eisenack 1958) are present at both 57.05 and 62.2 m. There is no evidence for higher zones in these samples.

Dinocysts make up approximately 70–75% of the total palynomorph assemblages at this level, which is rather lower than in the underlying *Odontochitina operculata* and *Muderongia australis* Zones. The environment of deposition is marine, and the dinocyst component suggests a shallow shelf. The interval is dated at late Aptian.

72.2 to 79.25 m, *Odontochitina operculata* Dinoflagellate zone

Samples from this interval do not contain *M. tetracantha, Endoceratium ludbrookiae* (Cookson and Eisenack 1958), or *Muderongia australis* Helby 1987, and are therefore assigned to the *O. operculata* Zone. The absence of *Muderongia mcwhaei* Cookson and Eisenack 1958 from the two samples at the top of this interval places them in the informal, upper subzone.

Many species are not found above 75.1 m, and further sampling is needed to determine whether their distribution limit is biostratigraphically significant. Overall, the samples yielded rich and diverse assemblages, with common *Sentusidinium aptiense* (Burger 1980), *Chlamydophorella ambigua* (Deflandre1 937),

Table 2.1. Summary of dinoflagellate and spore–pollen zones

Depth(m)	*Sample type*	*Organic yield (cc/g)*	*Microfossil yield*	*Preservation*	*Dinoflagellate or spore–pollen zone*	*Subzone*	*Age*
50.65	core	0.050	barren	–	–	–	–
57.05	core	0.371	high	excellent	D. davidii	Middle	late Aptian
62.2	core	0.329	high	excellent	D. davidii	?Lower	late Aptian
72.2	core	0.335	high	excellent	O. operculata	?Upper	early Aptian
75.1	core	0.406	high	excellent	O. operculata	?Upper	early Aptian
79.25	core	0.310	high	excellent	O. operculata	Lower	early Aptian
81.55	core	0.279	high	excellent	M. australis	?Upper	early Aptian – Barremian
104–107	cuttings	0.067	high	excellent	M. australis	Middle	early Aptian – Barremian
125–128	cuttings	0.028	high	excellent	B. limbata	–	Barremian–Valanginian
140–143	cuttings	nd	high	excellent	B. limbata	–	Barremian–Valanginian
149–152	cuttings	nd	high	excellent	C. turbatus	–	Early Jurassic
158	cuttings	0.050	high	excellent	C. turbatus	–	Early Jurassic

NOTE: nd: not determined
–: not applicable

Table 2.2. Distribution (by percentage) of Cretaceous species in Yinni 1

Palynomorphs	*Sampled depths (metres below surface)* 140–143	125–128	104–107	81.55	79.25	75.1	72.2	62.2	57.05
Dinocysts									
Dinocysts (indeterminate)	3	1	10	10.0	15.1	20.0	9.3	21.7	20.7
Ovoidinium cinctum	5	–	6	0.0	0.0	0.0	0.0	0.0	0.0
Circulodinium hirtellum	1	–	1	0.4	0.5	0.5	0.0	0.0	0.0
Cribroperidinium muderongense	2	1	7	3.9	3.0	2.0	0.5	0.0	0.0
Dingodinium cerviculum	1	–	–	1.3	7.5	5.5	2.9	0.6	1.8
Oligosphaeridium spp.	–	1	1	0.4	1.5	1.5	0.5	0.6	0.6
Sentusidinium aptiense	–	1	2	10.0	13.6	7.0	19.1	5.0	7.1
Aprobolocysta alata	–	–	P	0.0	0.0	0.0	0.0	0.0	0.0
Circulodinium attadalicum	–	–	1	0.0	0.0	0.0	0.0	0.0	0.0
Muderongia imparilis	–	–	P	0.0	0.0	0.0	0.0	0.0	0.0
Muderongia sp. aff. M. testudinaria	–	–	2	0.0	0.0	0.0	0.0	0.0	0.0
Scriniodinium attadalense	–	–	1	0.0	0.0	0.0	0.0	0.0	0.0
Muderongia australis	–	–	1	0.4	0.5	0.0	0.0	0.0	0.0
Muderongia mcwhaei	–	–	1	0.0	0.5	0.0	0.0	0.0	0.0
Epitricysta vinckensis	–	–	P	0.0	0.5	0.5	0.0	0.0	0.0
Exochosphaeridium spp.	–	–	1	0.4	0.5	0.5	1.0	0.6	0.6
Hystrichodinium spp.	–	–	1	0.9	0.5	0.0	0.5	1.9	3.6
Leiosphaeridia? perthensis	–	–	1	2.2	0.5	0.5	0.0	0.0	2.4
Sentusidinium spp.	–	–	4	1.3	2.0	0.5	4.4	8.7	8.3
Diconodinium micropunctatum	–	–	–	3.1	0.0	0.0	0.0	0.0	0.0
Druggidium rhabdoreticulatum	–	–	–	2.2	0.0	0.0	0.0	0.0	0.0
Endoscrinium campanulum	–	–	–	0.4	0.0	0.0	0.0	0.0	0.0
Apteodinium granulatum	–	–	–	1.3	1.0	0.0	0.0	0.0	0.0
Cernicysta helbyi	–	–	–	3.1	0.5	0.0	0.0	0.0	0.0
Aldorfia deflandrei	–	–	–	0.4	0.5	1.0	0.0	0.0	0.0
Batioladinium jaegeri	–	–	–	0.4	0.5	0.5	0.0	0.0	0.0
Cassiculosphaeridia magna	–	–	–	1.3	0.5	1.0	0.0	0.0	0.0
Coronifera oceanica	–	–	–	0.9	4.5	1.0	0.0	0.0	0.0
Kallosphaeridium coninckii	–	–	–	7.9	1.0	1.5	0.0	0.0	0.0
Palaeoperidinium cretaceum	–	–	–	2.2	1.5	1.0	0.0	0.0	0.0
Avellodinium lepidum	–	–	–	0.9	0.5	0.0	0.5	0.0	0.0
Canninginopsis colliveri	–	–	–	0.4	0.5	1.0	1.0	0.0	0.0
Kleithriaspharidium eoinoides	–	–	–	1.3	1.0	0.5	0.5	0.0	0.0
Batioladinium micropodum	–	–	–	0.4	0.5	0.0	0.0	0.6	0.0
Cleistosphaeridium spp.	–	–	–	1.3	0.5	2.5	0.0	0.6	0.0
Discorsia nanna	–	–	–	0.4	0.0	0.5	0.0	1.2	0.0
Tanyosphaeridium spp.	–	–	–	0.9	0.5	0.0	1.0	0.6	0.0
Gonyaulacysta helicoidea	–	–	–	0.4	0.5	0.5	0.5	0.6	0.0
Occisucysta tenuiceras	–	–	–	1.7	2.0	0.5	0.0	0.6	1.8
Spiniferites spp.	–	–	–	9.6	3.5	4.5	2.9	5.6	2.4
Cassiculosphaeridia reticulata	–	–	–	3.1	5.0	5.5	0.5	3.1	10.1
Chlamydophorella ambigua	–	–	–	3.5	5.5	3.0	12.7	4.3	1.8
Microdinium spp.	–	–	–	0.0	3.0	9.5	5.9	0.0	0.0
Angustidinium acribes	–	–	–	0.0	0.5	0.5	9.8	1.2	0.0
Fibradinium variculum	–	–	–	0.0	0.5	0.5	0.5	0.6	0.0
Prolixosphaeridium parvispinum	–	–	–	0.0	0.5	0.0	0.0	0.6	0.6
Impagidinium spp.	–	–	–	0.0	3.0	4.5	0.5	0.0	0.6
Carpodinium granulatum	–	–	–	0.0	0.5	0.0	1.0	0.0	0.6
Odontochitina operculata	–	–	–	0.0	0.0	0.5	0.0	0.6	0.6
Muderongia crucis	–	–	–	0.0	0.0	0.0	0.5	1.2	0.0
Protoellipsodinium densispinum	–	–	–	0.0	0.0	0.0	0.0	0.6	0.0
Yalkalpodinium scutum	–	–	–	0.0	0.0	0.0	0.0	0.6	0.0
Canninginopsis sp. A	–	–	–	0.0	0.0	0.0	0.0	1.2	1.2
Cribroperidinium edwardsii	–	–	–	0.0	0.0	0.0	0.0	0.6	1.8
Endoceratium turneri	–	–	–	0.0	0.0	0.0	0.0	0.6	0.6
Muderongia tetracantha	–	–	–	0.0	0.0	0.0	0.0	0.6	3.0
Trichodinium spp.	–	–	–	0.0	0.0	0.0	0.0	0.6	0.6
Diconodinium davidii	–	–	–	0.0	0.0	0.0	0.0	0.0	3.6
Florentinia spp.	–	–	–	0.0	0.0	0.0	0.0	0.0	1.2
Algae and acritarchs									
Pterospermella aureolata	1	1	1	1.7	0.5	0.5	0.5	0.0	0.0
Platycystidia eisenacki	–	–	P	0.0	0.0	0.0	0.0	0.0	0.0
Cymatiosphaera spp.	–	–	1	0.0	0.0	0.0	0.5	0.0	0.0
Rhombodella paucispina	–	–	P	0.0	0.0	0.0	4.9	0.6	0.0
Micrhystridium spp.	–	–	3	0.4	0.5	3.5	0.0	2.5	0.0

Table 2.2. (continued)

	Sampled depths (metres below surface)								
Palynomorphs	*140–143*	*125–128*	*104–107*	*81.55*	*79.25*	*75.1*	*72.2*	*62.2*	*57.05*
Botryococcus spp.	–	–	–	0.9	0.0	0.0	0.0	0.0	0.0
Nummus pentagonus	–	–	–	0.4	0.0	0.0	0.0	0.0	0.0
Veryhachium spp.	–	–	–	0.9	2.0	4.5	2.0	0.0	0.0
Fromea monilifera	–	–	–	0.4	0.0	0.0	1.0	1.2	0.6
Leiosphaeridia spp.	–	–	–	0.0	2.5	5.5	0.0	0.0	0.0
Fromea amphora	–	–	–	0.0	0.0	0.0	0.5	0.6	0.6
Wallodinium krutschii	–	–	–	0.0	0.0	0.0	0.5	0.6	0.0
Other palynomorphs									
Foraminiferal linings	–	1	–	0.4	0.0	0.0	1.0	0.0	0.6
Spores and pollen (undifferentiated)	87	94	55	16.2	10.1	7.5	13.2	28.6	23.1
Zone	*B. limbata*			*M. australis (upper)*	*O. operculata (lower)*	*O. operculata (upper?)*		*D. davidii*	

NOTE: P: Present
–: not present

Dingodinium cerviculum Cookson and Eisenack 1958, *Microdinium* spp., and *Spiniferites* spp.. Spores and pollen constitute about 10% of the assemblages. The interval is dated at early Aptian and was deposited in marine-shelfal conditions.

81.55 m, *Muderongia australis* Dinoflagellate zone

Only one core sample is unequivocally assigned to the *M. australis* Zone. The next cuttings sample below this (104–107 m) contains over 50% spores and pollen, and is assigned to the underlying non-marine Cretaceous interval, although it contains evidence for lower parts of the *M. australis* Zone. The 81.55 m sample lacks *M. mcwhaei*, *Ovoidinium cinctum* (Cookson and Eisenack 1958), and *Scriniodinium attadalense* (Cookson and Eisenack 1958), and is placed in the upper part of the *M. australis* zone.

The assemblage at 81.55 m is diverse, with 33 species of dinocysts, and is dominated by *S. aptiense*, *Kallosphaeridium coninckii* (Burger 1980), and *Spiniferites* spp.. The dinocysts *Cribroperidinium muderongense* (Cookson and Eisenack 1958), *Diconodinium micropunctatum* Backhouse 1988, *Druggidium rhabdoreticulatum* Habib 1973, *Cernicysta helbyi* (Morgan 1980), *Cassiculosphaeridia reticulata* Davey 1969, and *C. ambigua* are all prominent in the assemblage. Spores and pollen constitute 16% of the assemblage, similar to percentages in the *O. operculata* Zone. The environment of deposition is interpreted as a marine shelf. The age is Barremian.

Key dinocysts from the *Ovoidinium cinctum* acme interval and the informal middle *M. australis* subzone in the 104–107 m cuttings sample most likely come from caved intervals immediately above. *O. cinctum* is prominent, suggesting that the *O. cinctum* acme event is not far above 104 m, and the presence of *S. attadalense* suggests that the informal middle *M. australis* subzone is at around the same level or above. It is therefore probable that the marine *M. australis* Zone extends down to about 100 m.

104–107 to 140–143 m, *Balmeiopsis limbata* Spore–pollen zone

All three cuttings assemblages contain high percentages of spore and pollen, and therefore this interval is interpreted as non-marine. The presence of microplankton in this section is attributed to caving from the interval above. The presence of *Balmeiopsis limbata* (Balme 1956) and *B. robusta* Backhouse 1988, and the absence of index species for the underlying *Biretisporites eneabbaensis* Spore–pollen zone, place this interval in the *B. limbata* Zone.

The spore–pollen assemblages are dominated by small *Cyathidites* spp. *Microcachryidites antarcticus* Cookson 1947 and bisaccate pollen.

149–152 to 158 m, *Callialasporites turbatus* Spore–pollen zone

The two cuttings samples near the base of the section are dominated by Early Jurassic pollen with a few spores.

Both assemblages are dominated by *Corollina torosa* (Reissinger 1950), with common *Araucariacites australis* Cookson 1947 and *Callialasporites turbatus* (Balme 1957). The 149–152 m sample contains 3% reworked palynomorphs, probably all from the Early Permian. Caved Cretaceous dinocysts from higher in the well are rare. The age of this interval is estimated to be Bajocian to Toarcian, and the environment of deposition is probably non-marine, or possibly marginal marine.

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Appendix 3

Petroleum geochemistry

by K. A. R. Ghori

Introduction

The hydrocarbon-generating potential and thermal maturity of the succession in Yinni 1 (TD 158.2 m) was evaluated from six core samples and one cuttings sample. Of these samples, two are from the Lower Jurassic Woodleigh Formation, two from the lower Aptian Muderong Shale, and three from the upper Aptian Windalia Radiolarite. Core samples were selected from likely source-rock lithologies (fine-grained intervals of light to dark grey). One cuttings sample was analysed to determine if there is any mud-additive contaminants in samples that may affect geochemical results. Figure 3.1 summarizes hydrocarbon-generating potential, kerogen type, and maturity of the section in Yinni 1.

Total organic carbon (TOC), Rock-Eval pyrolysis, pyrolysis-gas chromatography (PGC), and gas chromatography and mass spectrometry (GC-MS) were undertaken to characterize source rocks, whereas organic petrology and the Rock-Eval parameter T_{max} provided the level of thermal maturity. Geotechnical Services Pty Ltd carried out the TOC and Rock-Eval pyrolysis analyses, and Keiraville Konsultants Pty did the organic petrology. The number and type of geochemical analyses carried out is summarized in Table 3.1.

Source-rock potential

Hydrocarbon-generating potential is quantified from TOC content (a measure of organic richness) and potential yield (S_1+S_2) from Rock-Eval pyrolysis. All samples are organic-rich with a TOC range of 0.94 – 2.41% and potential yield values of 1.75 – 3.96 mg/g rock. However, the core sample from 53.8 m in the Windalia Radiolarite has a low potential yield (0.08 mg/g rock) compared to its organic richness (2.29% TOC; Table 3.2). The analytical results show that the sample from the Woodleigh Formation has fair organic richness and hydrocarbon-generating potential, whereas samples from the Muderong Shale and Windalia Radiolarite have good organic richness with fair hydrocarbon-generating potential (Table 3.2 and Fig. 3.2).

Source-rock type

Pyrolysis-gas chromatography was used to supplement Rock-Eval pyrolysis to determine the type of kerogen present.

Rock-Eval pyrolysis: A plot of the Rock-Eval parameters, hydrogen index (HI) versus T_{max}, indicates that the kerogen present is predominantly gas-generating type III, except in the sample from 76.6 m (Muderong Shale), which can be classified as type II (Fig. 3.3).

Pyrolysis-gas chromatography: Two core samples, from the Muderong Shale (81.4 m) and Windalia Radiolarite (73.4 m), were analysed using PGC to confirm the quality of the kerogen because it provides a more accurate guide to oil- versus gas-generating potential of kerogen than Rock-Eval pyrolysis (Fig. 3.4). Tables 3.3, 3.4, and 3.5 list the basic analytical data, alkene and alkane components, and selected abundance parameters, respectively. These results indicate that both samples are gas generating. A plot of oil proneness (C_5 to C_{31} alkanes + alkenes) versus the gas–oil generation index (GOGI; (C_1–C_5)/C_{6+}) indicates that the kerogen in the Windalia Radiolarite sample is predominantly of the gas-generating type (Fig. 3.5). The sample from the Muderong Shale, however, can not be plotted meaningfully on this figure because its abundance of C_5–C_{31} alkane and alkene components is very low (2.38% of resolved compounds in S_2), whereas its GOGI is high (5.26; Table 3.5).

Extract analysis: The low quantity of extract from the 76.6 and 155.0 m samples (237.5 and 248.8 ppm respectively) precludes further analysis by GC-MS. A cuttings sample from 155.0 m was analysed for mud-additive contaminants, but none were found that could affect the interpretation of geochemical results (Fig. 3.6).

Source-rock maturity

Organic petrology was used to supplement the Rock-Eval pyrolysis to determine the levels of thermal maturity.

Organic petrology: The organic petrology of the three samples analysed is provided in Table 3.6 (basic data), Table 3.7 (data summary), and Figure 3.7 (histograms). Mean vitrinite reflectance (%Ro) values in the Jurassic Woodleigh Formation and the Cretaceous Muderong Shale and Windalia Radiolarite range from 0.33 to 0.38% (Table 3.7), indicating that these units are immature for oil generation and were not buried more than few hundred metres.

Rock-Eval pyrolysis: T_{max} is a maturation parameter measured in degrees Celsius at which the pyrolytic yield of hydrocarbons from a rock sample reaches its maximum. Values in the range 435–470°C commonly characterize the oil-generative window. Analysed samples returned T_{max} values of between 408 and 411°C, implying that these units are immature for oil generation (Table 3.2) and supporting the analyses of organic petrology.

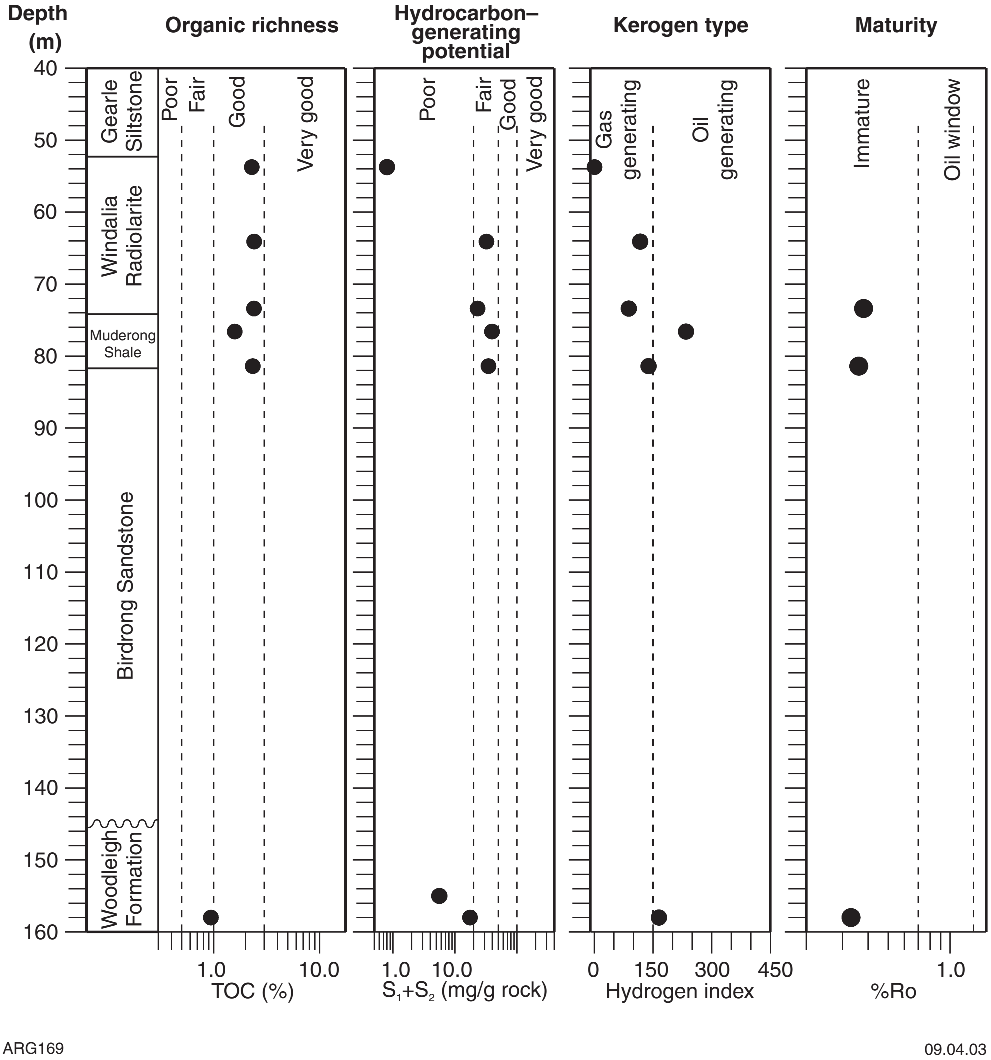

Figure 3.1. Petroleum-source potential of rocks from Yinni 1

Table 3.1. Geochemical analyses carried out on core and cuttings samples from Yinni 1

Analysis type	*No of samples*	*Purpose*	*Analyst*
Total organic carbon (TOC)	6	source potential	Geotech
Rock-Eval pyrolysis	7	source potential	Geotech
Pyrolysis-gas chromatography	2	source potential	Geotech
Gas chromatography – mass spectrometry	1	source potential	Geotech
Whole extract GC-MS (mud additives)	1	contaminants	Geotech
Organic petrology	3	source maturity	KK

NOTES: Geotech: Geotechnical Services Pty Ltd
KK: Keiraville Konsultants Pty Ltd

Table 3.2. TOC and Rock-Eval pyrolysis data of core and cuttings samples from Yinni 1

Depth (m)	*Sample type*	*TOC (%)*	T_{max} (°C)	S_1	S_2	S_3	S_1+S_2	S_2/S_3	*PI*	*HI*	*OI*
				(mg/g rock)							
53.8	core	2.29	nd	0.07	0.01	1.81	0.08	0.01	0.88	0	79
64.1	core	2.41	406	0.40	2.82	1.17	3.22	2.41	0.12	117	49
73.4	core	2.40	411	0.21	2.11	1.14	2.32	1.85	0.09	88	48
76.6	core	1.58	417	0.26	3.70	0.81	3.96	4.57	0.07	234	51
81.4	core	2.34	410	0.23	3.24	1.08	3.47	3.00	0.07	138	46
155–158	cuttings	nd	416	0.05	0.51	0.59	0.56	0.86	0.09	nd	nd
158*	cuttings	0.94	408	0.20	1.55	0.89	1.75	1.74	0.11	165	95

NOTES: TOC: total organic carbon; T_{max}: temperature of maximum pyrolytic yield (S_2); S_1: existing hydrocarbons (HC); S_2: pyrolytic yield (HC); S_3: organic carbon dioxide; $S_1 + S_2$: potential yield; PI: production index; HI: hydrogen index; OI: oxygen index; nd: not determined; * sample scraped from bit at end of hole

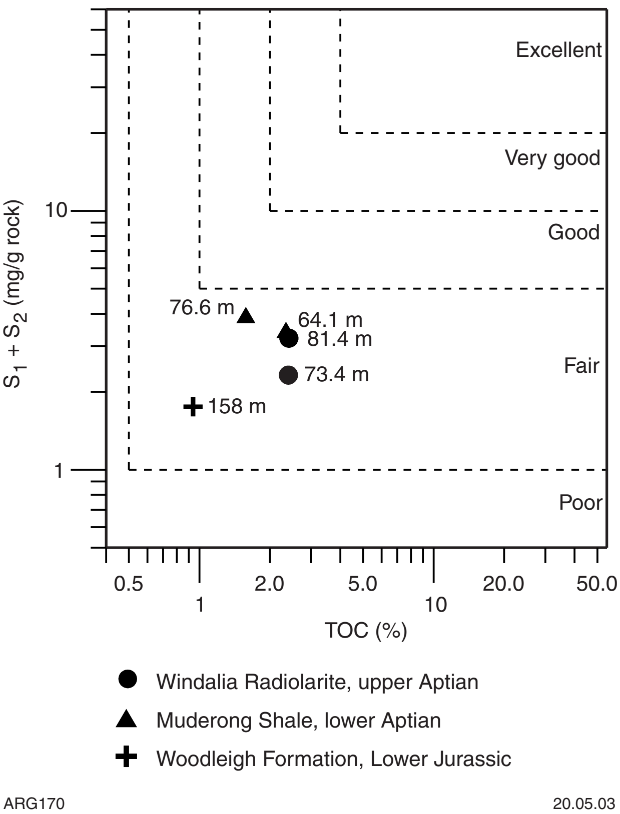

Figure 3.2. Hydrocarbon-generating potential of samples from Yinni 1

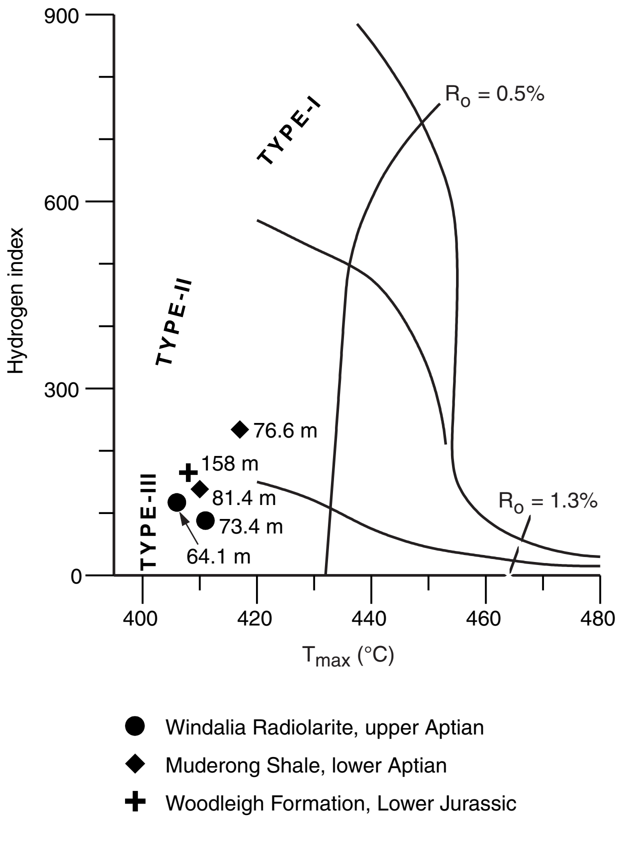

Figure 3.3. Source-rock kerogen typing by Rock-Eval pyrolysis of samples from Yinni 1

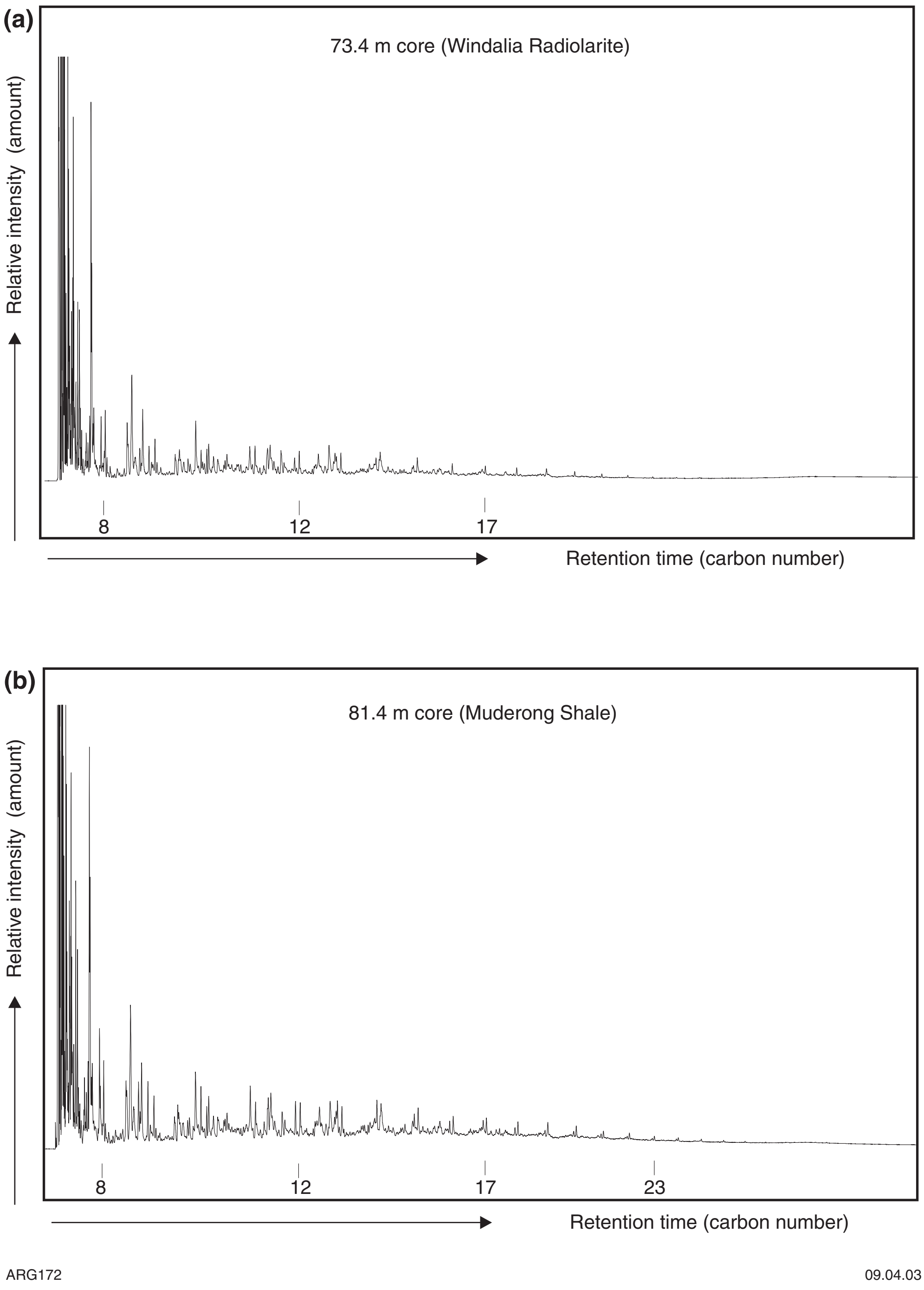

Figure 3.4. Gas chromatograms from pyrolysis-gas chromatography of two samples from Yinni 1: a) 73.4 m core from the Windalia Radiolarite; b) 81.4 m core from the Muderong Shale

Table 3.3. Basic analytical data from pyrolysis-gas chromatography of core samples from Yinni 1

	Sample			Sample	
	73.4 m	*81.4 m*		*73.4 m*	*81.4 m*
Compound	*Value*	*Value*	*Compound*	*Value*	*Value*
C_5 n-alkene	1.73	0.10	C_{22} n-alkane	0.02	0.01
C_5 n-alkane	1.39	0.24	C_{23} n-alkene	0.00	0.00
C_6 n-alkene	1.11	0.25	C_{23} n-alkane	0.01	0.01
C_6 n-alkane	0.72	0.15	C_{24} n-alkene	0.00	0.00
C_7 n-alkene	0.54	0.17	C_{24} n-alkane	0.01	0.01
C_7 n-alkane	0.97	0.14	C_{25} n-alkene	0.00	0.00
C_8 n-alkene	0.36	0.12	C_{25} n-alkane	0.01	0.00
C_8 n-alkane	0.49	0.10	C_{26} n-alkene	0.00	0.00
C_9 n-alkene	0.26	0.08	C_{26} n-alkane	0.00	0.00
C_9 n-alkane	0.33	0.07	C_{27} n-alkene	0.00	0.00
C_{10} n-alkene	0.20	0.08	C_{27} n-alkane	0.00	0.00
C_{10} n-alkane	0.31	0.08	C_{28} n-alkene	0.00	0.00
C_{11} n-alkene	0.41	0.09	C_{28} n-alkane	0.00	0.00
C_{11} n-alkane	0.25	0.06	C_{29} n-alkene	0.00	0.00
C_{12} n-alkene	0.15	0.05	C_{29} n-alkane	0.00	0.00
C_{12} n-alkane	0.19	0.05	C_{30} n-alkene	0.00	0.00
C_{13} n-alkene	0.26	0.06	C_{30} n-alkane	0.00	0.00
C_{13} n-alkane	0.21	0.05	C_{31} n-alkene	0.00	0.00
C_{14} n-alkene	0.15	0.05	C_{31} n-alkane	0.00	0.00
C_{14} n-alkane	0.21	0.05	C_1–C_4	38.84	83.21
C_{15} n-alkene	0.00	0.03	C_5	6.64	0.83
C_{15} n-alkane	0.19	0.05	C_6–C_8	17.53	6.13
C_{16} n-alkene	0.00	0.02	C_9–C_{14}	27.39	5.77
C_{16} n-alkane	0.12	0.03	C_{15}–C_{31}	9.59	4.07
C_{17} n-alkene	0.00	0.03	Benzene	0.92	0.19
C_{17} n-alkane	0.09	0.03	Toluene	1.75	0.34
C_{18} n-alkene	0.00	0.01	Ethylbenzene	0.45	0.10
C_{18} n-alkane	0.08	0.02	m- + p-xylene	1.35	0.32
C_{19} n-alkene	0.00	0.01	Styrene	0.274	0.089
C_{19} n-alkane	0.10	0.03	o-xylene	0.717	0.135
C_{20} n-alkene	0.00	0.01	Phenol	0.654	0.132
C_{20} n-alkane	0.05	0.02	o-cresol	0.000	0.000
C_{21} n-alkene	0.00	0.01	m- + p-cresol	0.000	0.000
C_{21} n-alkane	0.03	0.01	C_2 phenol	0.000	0.000
C_{22} n-alkene	0.00	0.00	C_2 phenol	0.000	0.000

Table 3.4. Alkene and alkane component from pyrolysis-gas chromatography of core samples from Yinni 1

Depth	*Carbon*	*Alkane + Alkene*			*Alkane*			*Alkene*			*Alkane/*
(m)	*number*	*A*	*B*	*C*	*A*	*B*	*C*	*A*	*B*	*C*	*Alkene*
73.4	1	–	–	–	–	–	–	–	–	–	–
	2	–	–	–	–	–	–	–	–	–	–
	3	–	–	–	–	–	–	–	–	–	–
	4	–	–	–	–	–	–	–	–	–	–
	5	3.114	0.066	0.027	1.387	0.029	0.012	1.727	0.036	0.015	0.80
	6	1.829	0.039	0.016	0.722	0.015	0.006	1.107	0.023	0.010	0.65
	7	1.514	0.032	0.013	0.972	0.021	0.009	0.543	0.011	0.005	1.79
	8	0.858	0.018	0.008	0.494	0.010	0.004	0.364	0.008	0.003	1.35
	9	0.587	0.012	0.005	0.326	0.007	0.003	0.260	0.005	0.002	1.25
	10	0.503	0.011	0.004	0.306	0.006	0.003	0.198	0.004	0.002	1.55
	11	0.652	0.014	0.006	0.247	0.005	0.002	0.405	0.009	0.004	0.61
	12	0.338	0.007	0.003	0.185	0.004	0.002	0.152	0.003	0.001	1.22
	13	0.473	0.010	0.004	0.209	0.004	0.002	0.264	0.006	0.002	0.79
	14	0.364	0.008	0.003	0.211	0.004	0.002	0.153	0.003	0.001	1.38
	15	0.188	0.004	0.002	0.188	0.004	0.002	0.000	0.000	0.000	–
	16	0.121	0.003	0.001	0.121	0.003	0.001	0.000	0.000	0.000	–
	17	0.091	0.002	0.001	0.091	0.002	0.001	0.000	0.000	0.000	–
	18	0.081	0.002	0.001	0.081	0.002	0.001	0.000	0.000	0.000	–
	19	0.099	0.002	0.001	0.099	0.002	0.001	0.000	0.000	0.000	–
	20	0.048	0.001	0.000	0.048	0.001	0.000	0.000	0.000	0.000	–
	21	0.035	0.001	0.000	0.035	0.001	0.000	0.000	0.000	0.000	–
	22	0.019	0.000	0.000	0.019	0.000	0.000	0.000	0.000	0.000	–
	23	0.013	0.000	0.000	0.013	0.000	0.000	0.000	0.000	0.000	–
	24	0.009	0.000	0.000	0.009	0.000	0.000	0.000	0.000	0.000	–
	25	0.006	0.000	0.000	0.006	0.000	0.000	0.000	0.000	0.000	–
	26	0.003	0.000	0.000	0.003	0.000	0.000	0.000	0.000	0.000	–
	27	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	–
	28	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	–
	29	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	–
	30	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	–
	31	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	–
81.4	1	–	–	–	–	–	–	–	–	–	–
	2	–	–	–	–	–	–	–	–	–	–
	3	–	–	–	–	–	–	–	–	–	–
	4	–	–	–	–	–	–	–	–	–	–
	5	0.342	0.007	0.003	0.239	0.005	0.002	0.103	0.002	0.001	2.32
	6	0.397	0.008	0.003	0.150	0.003	0.001	0.247	0.005	0.002	0.61
	7	0.312	0.007	0.003	0.141	0.003	0.001	0.170	0.004	0.001	0.83
	8	0.225	0.005	0.002	0.102	0.002	0.001	0.124	0.003	0.001	0.82
	9	0.149	0.003	0.001	0.068	0.001	0.001	0.081	0.002	0.001	0.85
	10	0.152	0.003	0.001	0.076	0.002	0.001	0.076	0.002	0.001	1.00
	11	0.151	0.003	0.001	0.057	0.001	0.001	0.094	0.002	0.001	0.61
	12	0.097	0.002	0.001	0.047	0.001	0.000	0.051	0.001	0.000	0.92
	13	0.108	0.002	0.001	0.051	0.001	0.000	0.058	0.001	0.001	0.87
	14	0.102	0.002	0.001	0.055	0.001	0.000	0.047	0.001	0.000	1.17
	15	0.076	0.002	0.001	0.050	0.001	0.000	0.025	0.001	0.000	2.00
	16	0.053	0.001	0.000	0.032	0.001	0.000	0.021	0.000	0.000	1.49
	17	0.052	0.001	0.000	0.026	0.001	0.000	0.026	0.001	0.000	0.98
	18	0.037	0.001	0.000	0.023	0.000	0.000	0.014	0.000	0.000	1.64
	19	0.037	0.001	0.000	0.027	0.001	0.000	0.010	0.000	0.000	2.81
	20	0.027	0.001	0.000	0.018	0.000	0.000	0.009	0.000	0.000	1.99
	21	0.018	0.000	0.000	0.011	0.000	0.000	0.007	0.000	0.000	1.49
	22	0.013	0.000	0.000	0.009	0.000	0.000	0.004	0.000	0.000	2.18
	23	0.010	0.000	0.000	0.007	0.000	0.000	0.003	0.000	0.000	2.66
	24	0.008	0.000	0.000	0.006	0.000	0.000	0.003	0.000	0.000	1.94
	25	0.004	0.000	0.000	0.004	0.000	0.000	0.000	0.000	0.000	–
	26	0.003	0.000	0.000	0.003	0.000	0.000	0.000	0.000	0.000	–
	27	0.002	0.000	0.000	0.002	0.000	0.000	0.000	0.000	0.000	–
	28	0.001	0.000	0.000	0.001	0.000	0.000	0.000	0.000	0.000	–
	29	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	–
	30	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	–
	31	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	–

NOTES: A: % of resolved compounds in S_2; B: mg/g rock (Rock-Eval); C: (mg/g rock)/TOC; –: not determined

Table 3.5. Selected parameters from pyrolysis-gas chromatography of core samples from Yinni 1

Depth (m)	*Parameter*	*Value*			
		A	*B*	*C*	*D*
73.4	C1–C4 abundance (all compounds)	38.84	0.82	0.34	–
	C5–C8 abundance (all resolved compounds)	24.18	0.51	0.21	–
	C5–C8 abundance (alkanes + alkenes)	7.32	0.15	0.06	–
	C9–C14 abundance (all resolved compounds)	27.39	0.58	0.24	–
	C9–C14 abundance (alkanes + alkenes)	2.92	0.06	0.03	–
	C15–C31 abundance (all resolved compounds)	9.59	0.20	0.08	–
	C15–C31 abundance (alkanes + alkenes)	0.71	0.02	0.01	–
	C9–C31 abundance (all resolved compounds)	36.99	0.78	0.33	–
	C9–C31 abundance (alkanes + alkenes)	3.63	0.08	0.03	–
	C5–C31 abundance (all resolved compounds)	61.16	1.29	0.54	–
	C5–C31 abundance (alkanes + alkenes)	10.95	0.23	0.10	–
	C5–C31 alkane abundance	5.77	0.12	0.05	–
	C5–C31 alkene abundance	5.17	0.11	0.05	–
	C5–C8 alkane/alkene	–	–	–	0.96
	C9–C14 alkane/alkene	–	–	–	1.04
	C15–C31 alkane/alkene	–	–	–	nd
	C5–C31 alkane/alkene	–	–	–	1.12
	(C1–C5)/$C6_+$	–	–	–	0.83
	m- + p-xylene/n-octene	–	–	–	3.70
81.4	C1–C4 abundance (all compounds)	83.21	1.76	0.73	–
	C5–C8 abundance (all resolved compounds)	6.95	0.15	0.06	–
	C5–C8 abundance (alkanes + alkenes)	1.28	0.03	0.01	–
	C9–C14 abundance (all resolved compounds)	5.77	0.12	0.05	–
	C9–C14 abundance (alkanes + alkenes)	0.76	0.02	0.01	–
	C15–C31 abundance (all resolved compounds)	4.07	0.09	0.04	–
	C15–C31 abundance (alkanes + alkenes)	0.34	0.01	0.00	–
	C9–C31 abundance (all resolved compounds)	9.84	0.21	0.09	–
	C9–C31 abundance (alkanes + alkenes)	1.10	0.02	0.01	–
	C5–C31 abundance (all resolved compounds)	16.79	0.35	0.15	–
	C5–C31 abundance (alkanes + alkenes)	2.38	0.05	0.02	–
	C5–C31 alkane abundance	1.20	0.03	0.01	–
	C5–C31 alkene abundance	1.17	0.02	0.01	–
	C5–C8 alkane/alkene	–	–	–	0.98
	C9–C14 alkane/alkene	–	–	–	0.87
	C15–C31 alkane/alkene	–	–	–	1.78
	C5–C31 alkane/alkene	–	–	–	1.03
	(C1–C5)/$C6_+$	–	–	–	5.26
	m- + p-xylene/n-octene	–	–	–	2.59

NOTES:
A: % of resolved compounds in S_2
B: mg/g rock (Rock-Eval)
C: (mg/g rock)/TOC
D: ratio
–: not applicable

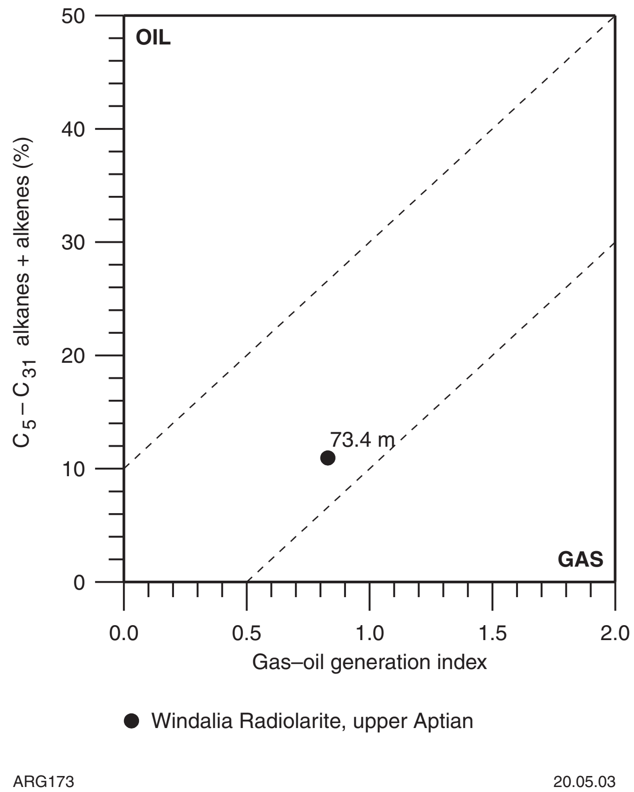

Figure 3.5. Kerogen typing by pyrolysis-gas chromatography of a core sample from 73.4 m in the Windalia Radiolarite, Yinni 1

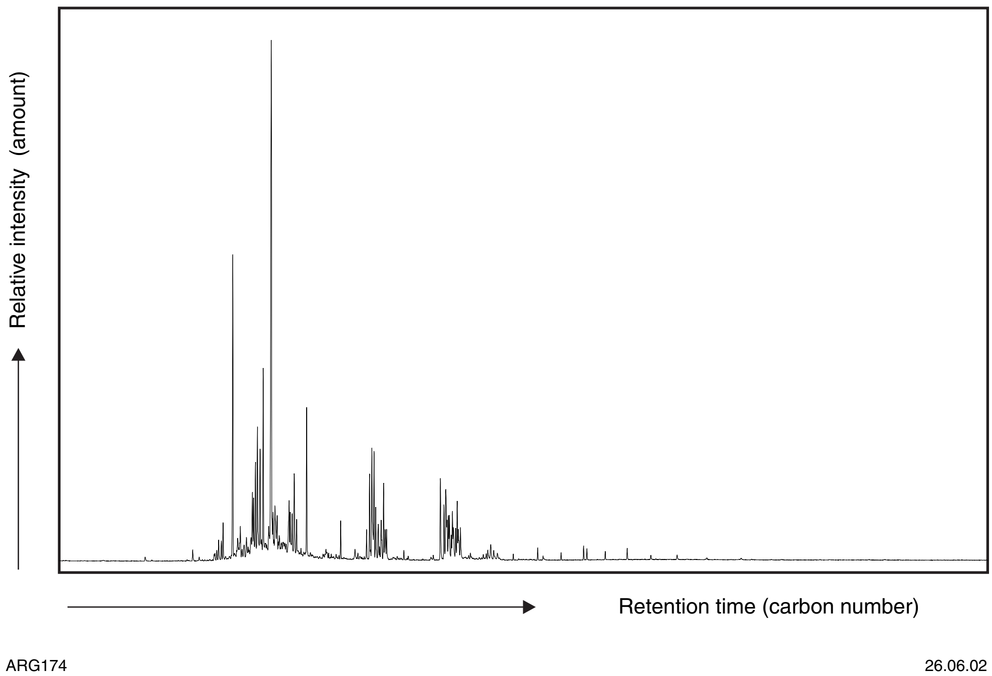

Figure 3.6. Gas chromatogram from whole-extract analysis by GC-MS for a cuttings sample from 155 m to test for mud-additive contaminants in Yinni 1

Table 3.6. Organic petrological basic data for samples from Yinni 1

Depth (m)	*Sample type*	*Maceral*	*%Ro*	*No. readings*
73.4	core	First generation vitrinite	0.30	1
		First-generation vitrinite	0.32	1
		First-generation vitrinite	0.39	1
		First-generation vitrinite	0.40	1
		First-generation vitrinite	0.48	1
		Inert	1.78	1
81.4	core	First-generation vitrinite	0.24	2
		First-generation vitrinite	0.25	1
		First-generation vitrinite	0.26	2
		First-generation vitrinite	0.29	1
		First-generation vitrinite	0.30	1
		First-generation vitrinite	0.31	1
		First-generation vitrinite	0.32	1
		First-generation vitrinite	0.33	1
		First-generation vitrinite	0.36	2
		First-generation vitrinite	0.37	1
		First-generation vitrinite	0.38	1
		First-generation vitrinite	0.39	1
		First-generation vitrinite	0.40	2
		First-generation vitrinite	0.41	4
		First-generation vitrinite	0.44	1
		First-generation vitrinite	0.46	1
		First-generation vitrinite	0.47	1
		First-generation vitrinite	0.48	1
		Inert	0.78	1
158.0	cuttings	First-generation vitrinite	0.22	1
		First-generation vitrinite	0.26	1
		First-generation vitrinite	0.27	1
		First-generation vitrinite	0.30	4
		First-generation vitrinite	0.31	3
		First-generation vitrinite	0.32	1
		First-generation vitrinite	0.33	4
		First-generation vitrinite	0.34	4
		First-generation vitrinite	0.35	1
		First-generation vitrinite	0.37	1
		First-generation vitrinite	0.38	2
		First-generation vitrinite	0.39	1
		First-generation vitrinite	0.43	1

Table 3.7. Summary of organic petrological data for samples from Yinni 1

Depth (m)	*Type*	*$\bar{R}$max (%Ro)*	*$R_V$max range (%Ro)*	*No of analyses*	*Sample description, including liptinite fluorescence, maceral abundance, and mineral fluorescence*
					Windalia Radiolarite
73.4	$R_V$max	0.38	0.30 – 0.48	5	Abundant lamalginite, yellow to yellowish orange. Claystone.
	$R_I$max	1.78	–	1	DOM abundant, L>V>I. Liptinite abundant, vitrinite and inertinite rare. Mineral fluorescence pervasive to weakly patchy moderate orange. Pyrite common to abundant
					Muderong Shale
81.4	$R_V$max	0.36	0.24 – 0.78	25	Common lamalginite, yellow to yellowish orange. Siltstone.
	$R_I$max	0.78	–	1	DOM common, L>V>I. Liptinite common, vitrinite sparse, and inertinite rare. Mineral fluorescence pervasive to weakly patchy moderate orange. Common iron oxides, possibly from oxidation of pyrite. Pyrite abundant
					Woodleigh Formation
158.0	$R_V$max	0.33	0.22 – 0.43	25	Sparse lamalginite, yellow to yellowish orange; sparse liptodetrinite, yellow to yellowish orange. Silty claystone>sandstone. DOM common, L>V>I. Liptinite common, vitrinite and inertinite sparse. Mineral fluorescence pervasive to weakly patchy moderate orange. Common iron oxides. Pyrite abundant

The section is immature and the Muderong Shale and Windalia Radiolarite have good source potential

NOTES: DOM: dispersed organic matter; I: inertinite; L: liptinite; $R_I$max: maximum inertinite reflectance; $R_V$max: maximum vitrinite reflectance; $\bar{R}$max: mean Rmax value; V: vitrinite

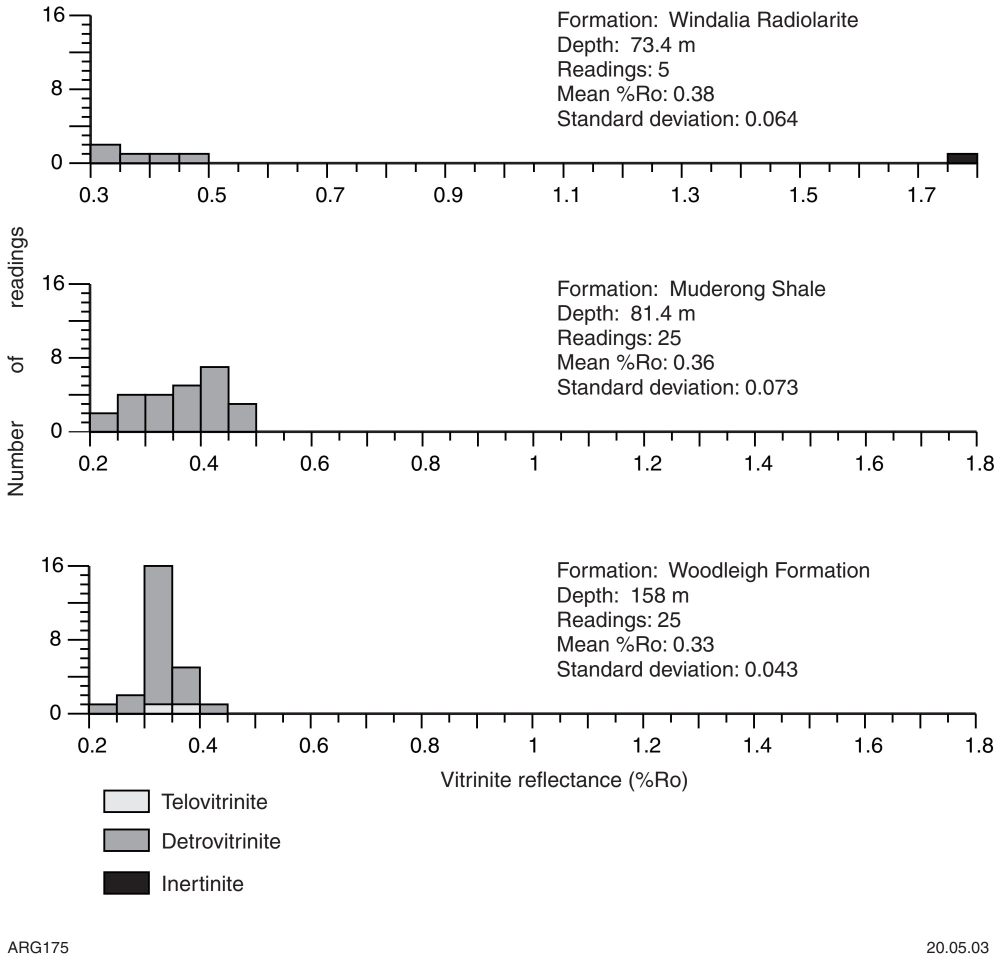

Figure 3.7. Percent reflectance histograms for three samples from Yinni 1

Conclusions

Rock-Eval, TOC, PGC, and organic petrology indicate that the Jurassic Woodleigh Formation has fair organic richness, as well as fair hydrocarbon-generating potential, and is immature for oil generation. Similarly, samples from the Cretaceous Muderong Shale and Windalia Radiolarite have good organic richness with fair hydrocarbon-generating potential and are immature for oil generation.

Appendix 4

Whole-rock chemistry

by P. A. Morris

Introduction

The five samples analysed from the Windalia Radiolarite (2) and Gearle Siltstone (3) in Yinni 1 span the Aptian to Albian (Cretaceous; Table 4.1). The analyses are compared with results from Edaggee 1 and Boologooro 1 to determine if whole-rock chemistry is a useful tool in lithostratigraphic correlation, and to see if the Gearle Siltstone in drillcore is compositionally similar to regolith derived from the same unit in parts of the WINNING POOL – MINILYA* 1:250 000 map sheet, where the unit hosts Ag–Pb–Zn nodules.

A total of 27 core samples have been analysed from Edaggee 1, Boologooro 1, and Yinni 1 in the Southern Carnarvon Basin, comprising six samples from the Windalia Radiolarite, 17 samples from the Gearle Siltstone (12 from the 'lower Gearle Siltstone' and five from the 'upper Gearle Siltstone'), and four from the overlying Haycock Marl. Analyses of pyrite nodules and a barite vein, from the Gearle Siltstone and Windalia Radiolarite respectively, have not been considered in any lithological comparisons. Analyses of samples from other units are also not discussed in statistical comparisons due to the small population size. Genalysis Laboratory Services Ltd carried out all analyses under conditions discussed in Morris (2000).

The analyses of 15 stream-sediment samples from the Gearle Siltstone over the Giralia Anticline on WINNING POOL – MINILYA (Sanders and McGuinness, 2001) are compared to these drillcore data. The analytical methodology for these samples is summarized by Sanders and McGuinness (2001) and Morris (2000). Stream sediments provide the closest approximation to bedrock chemistry compared to other regolith types sampled in the Geological Survey of Western Australia (GSWA) regolith geochemistry program (sandplain, soil, colluvium, lake sediment, sheetwash; Morris and Sanders, 2001).

Two indices have been calculated for all samples. The Chalcophile Index (CI) is the summed standard scores for As, Ag, Bi, Cd, Sb, Mo, W, and Se. A similar type of index was used by Smith et al. (1989) to identify chalcophile element corridors in Archaean greenstones of the Yilgarn Craton. Their approach has been adopted and modified in the GSWA regolith program (and in this Record) by first calculating the standard scores for each element so that the concentration of elements can be compared directly, rather than using the additive index. The CI is calculated for all samples discussed here, and is therefore an index particular to this dataset. The second index is the ratio CaO/SiO_2, which gives some indication of the siliciclastic or carbonate content of the sample.

Statistical comparison of sample populations has been made using the Mann–Whitney U test (also known as the Wilcoxon Rank Sum test), which compares population medians based on ranked data. Compared to other tests (e.g. Student's t-test, which compares population means), it is less sensitive to the effects of outliers, and is therefore more robust (Swan and Sandilands, 1995). Medians have been compared at the 95% level of significance, provided the median value is at least ten times the level of detection for both populations. Values below this level have been excluded, as they may be influenced by low precision near the minimum level of detection.

Visual inspection of the data, summary logs of each hole, and lithological descriptions provided in Sanders and McGuinness (2001) show that the Cretaceous stratigraphy contains locally heterogeneous assemblages, both in terms of host lithologies (e.g. carbonate, carbonaceous, and siliciclastic units), and in the development of pyrite and phosphate nodules and barite veining. In the Gearle Siltstone, the standard deviation over the 15 samples is high (occasionally exceeding the mean value) for some analytes, such as Ba (mean 614 ppm, standard deviation 675 ppm), S (8080, 6925 ppm), Sr (293, 161 ppm), CaO (7.4, 7.6%), and SiO_2 (52.7, 13.6%). In the same unit, pyrite nodules have high values for some analytes. These include 62.1% Fe_2O_3, 371 ppm As, and 475 800 ppm S in sample 176847 from the 'lower Gearle Siltstone' in Edaggee 1, and 59.59% Fe_2O_3 and 382 336 ppm S, but only 6 ppm As in nodule 176854B. Thus, there is the possibility that there is a greater compositional variation within, rather than between, units. The small population size for some groupings means that some statistical comparisons (e.g. involving the Toolonga Calcilutite and Sweeney Mia Formation, and sample populations from Yinni 1) are not possible.

Correlation of lithostratigraphic units using drillhole data

A statistical comparison to examine the degree of lithological homogeneity within the Gearle Siltstone has not been undertaken for Yinni 1 due to the small number of samples.

The Mann–Whitney U test applied to samples from Edaggee 1 and Boologooro 1 shows that there is a greater than 95% possibility that medians are different between the two populations for seven analytes. The median value for Ba of 1697 ppm in Edaggee 1 is an order of magnitude

* Capitalized names refer to standard 1:250 000 map sheets.

Table 4.1. Whole-rock analyses of sedimentary rocks from Yinni 1

		Sample/depth (m)					
Component	*DL*	*176842*	*176841*	*176840*	*176840^r*	*176879*	*176883*
		41.45	*47.10*	*52.05*	*52.05*	*54.85*	*66.10*
		Percent (%) unless otherwise shown					
SiO_2	0.1	60.1	81.4	65.2	65.5	70.5	88
TiO_2	0.05	0.67	0.2	0.41	0.42	0.28	0.1
Al_2O_3	0.02	12.7	3.65	7.54	7.71	6.17	1.62
Fe_2O_3	0.01	7.4	3.41	3.74	3.85	4.08	1.44
MnO (ppm)	1	85	33	55	51	28	17
MgO	0.01	3.04	0.98	1.87	1.91	1.65	0.38
CaO	0.1	0.4	1.9	6.1	6.3	2.4	0.3
Na_2O	0.02	9.55	5.65	6.86	6.72	7.24	3.61
K_2O	0.02	2.55	1.05	1.94	1.98	1.18	0.5
P_2O_5	0.01	0.08	0.02	0.1	0.1	0.02	–
LOI	0.01	6.77	4.39	9.39	9.49	10.99	4.03
		Parts per million (ppm) unless otherwise shown					
Ag	0.1	0.7	–	–	–	0.3	–
As	1	9	4	3	4	13	3
Au (ppb)	0.1	I/S	I/S	I/S	I/S	0.8	0.3
Ba	0.1	333.9	48.4	130	108.4	754.5	1624
Be	0.1	5.6	0.6	1.3	1.5	0.8	0.4
Bi	0.01	0.43	0.17	0.39	0.43	0.25	0.06
Cd	0.1	–	–	0.1	0.4	0.1	
Ce	0.01	59.46	17.41	51.24	53.82	27.2	8.1
Co	0.1	10.2	3.6	4.1	4.3	6.6	1.1
Cr	2	175	51	91	90	96	32
Cu	1	56	12	33	30	40	11
Ga	0.1	18.5	5.2	11.4	12.2	8	2.1
In	0.01	0.09	0.03	0.07	0.08	0.04	0.01
La	0.01	34.97	9.01	21.84	22.39	16.75	5.56
Li	0.1	31.5	8.9	19.7	21	22.7	4.2
Mo	0.1	0.5	0.2	0.3	0.3	13	2.8
Nb	10	12	–	–	–	–	–
Ni	1	61	32	28	27	95	15
Pb	2	22	6	10	10	7	3
Pd (ppb)	1	1	1	–	I/S	4	2
Pt (ppb)	1	2	2	1	I/S	3	1
Rb	0.05	144.17	50.53	87.03	92.91	46.45	22.28
S	10	50	40	30	30	15464	6972
Sb	0.05	0.45	0.17	0.22	0.19	0.57	0.16
Sc	1	18	5	11	10	8	2
Se	0.5	1.1	0.7	24.9	26.8	6.3	1.3
Sn	0.1	2.4	0.7	1.9	2	1.2	0.4
Sr	0.05	40.73	32.48	87.72	89.86	65.52	59.15
Ta	0.1	0.9	0.2	0.6	0.6	0.3	0.1
Te	0.1	–	–	–	–	–	–
Th	0.01	12.55	3.71	9.4	10.07	5.99	1.76
U	0.01	5.51	0.82	2.27	2.43	11.39	1.13
V	2	157	42	71	69	69	18
W	0.1	1.5	0.7	0.8	0.9	1.1	0.7
Y	0.05	35.15	7.43	14.11	14.74	19.22	4.76
Zn	1	167	51	78	74	61	33
Zr	5	109	40	74	76	52	22

NOTES: DL: detection level
I/S: insufficient sample for analysis
LOI: loss on ignition
–: less than detection level
r: repeat analysis

Analyses by Genalysis Laboratory Services. Methodology summarized in Morris (2000) higher than that in Boologooro 1 (183 ppm), and median values for P_2O_5 and Y are also higher in Edaggee 1. Median values for Fe_2O_3, V, and Be are lower in Edaggee 1 than in Boologooro 1. One interpretation of these comparisons is that differences in Ba, P_2O_5, and Y concentrations reflect localized development of barite and phosphate nodules, whereas differences in Fe_2O_3 and V concentrations could reflect different degrees of ferruginization. Following from this, nodule and vein development, and ferruginization could all be secondary processes superimposed on a relatively homogeneous parent lithology.

Comparison of Gearle Siltstone and Windalia Radiolarite

A statistical comparison shows that the Windalia Radiolarite (five samples) has higher median values for SiO_2, P_2O_5, Mo, and CI (Table 4.2), and lower median values for TiO_2, Al_2O_3, Fe_2O_3, MgO, Pb, Rb, Sc, Th, V, Y, Zn, and Zr than the Gearle Siltstone (15 samples). There is no difference in CaO/SiO_2 values. This statistical exercise shows the more siliceous nature of the Windalia Radiolarite (median value of 70.5% compared to the Gearle Siltstone median of 54.3%), with the higher CI values and higher values for 12 other analytes indicating a more diverse composition.

Comparison of Gearle Siltstone in drillcore with stream sediments derived from the Gearle Siltstone on WINNING POOL – MINILYA

Regolith from the Gearle Siltstone over the Giralia Anticline has exceptionally high concentrations of Ba (average 3543 ppm), along with high values for Fe_2O_3, CaO, As, Mo, Ni, Se, U, Zn, and LOI (loss on ignition), with some samples also having high values for P_2O_5, Co, Cu, In, Pd, S, Sn, and V (Sanders and McGuinness, 2001). High concentrations of Ba in regolith is probably associated with barite mineralization in the Cardabia Creek area of the Giralia Anticline, where there are beds of barite crystals in shales and siltstones up to 30 cm thick. On the western flank of this anticline, nodules of barite up to 30 cm in diameter are found over an area extending about 25 km from Cardabia Creek.

Statistics for the 15 stream sediments from the Giralia Anticline region on WINNING POOL – MINILYA (Sanders and McGuinness, 2001) show wide variations in the concentrations of some analytes, such as CaO (mean 8.41%, standard deviation 11.34 %), Na_2O (0.25, 0.52%), Ba (3840, 5878 ppm), Cr (44, 27 ppm), S (3200, 5967 ppm), Sr (376, 334 ppm), Zn (48, 23 ppm), and Zr (115, 62 ppm), and thus affect any comparison of median values.

A statistical comparison shows that stream sediments have higher median values for SiO_2, As, Ba, and Mo, and lower median values for TiO_2, Al_2O_3, MgO, Na_2O, K_2O, Ce, Co, Cr, Cu, Ga, La, Li, Nb, Ni, Pb, Rb, S, Sc, Th, Y, Zn, and CI compared to core samples (Table 4.2). There is no statistical difference between median values for CaO, LOI, Sn, Sr, U, V, Zr, and CaO/SiO_2. Overall the core samples show considerable differences in composition to the stream sediments. Sanders and McGuinness (2001) noted the presence of carbonate-rich duricrust and surface silicification in the Giralia Anticline region; the latter may explain the higher median SiO_2 value for stream sediments. Local development of barite in the Giralia Anticline region, also discussed by Sanders and McGuinness (2001), is reflected in the regolith samples by the wide variation in Ba content. It is therefore likely that the fundamental differences in chemistry between the Gearle Siltstone in the subsurface and derived stream sediment reflects a combination of lithological variability, coupled with localized development of barite, and subsequent mechanical and chemical weathering.

Discussion

Statistical comparisons of the Gearle Siltstone between wells, and between lower and upper parts of the same unit, show limited chemical heterogeneity despite the development of pyrite and phosphate nodules and barite veins and some heterogeneity in terms of lithology (e.g. carbonaceous and carbonate-rich, as well as siliciclastic, rock types). This is surprising, considering the extreme values for analytes such as S, As, Fe, and Ba in veins or nodules. Compared to units above and below, the Gearle Siltstone has higher median values for MgO, Rb, and Th, and lower median values for P_2O_5 and CI.

The large number of median values, which are statistically different between the Windalia Radiolarite and Gearle Siltstone, indicate the two formations have fundamentally different compositions, as could be expected.

In drillcore the Gearle Siltstone shows little in common with stream sediments derived from the unit on WINNING POOL – MINILYA, whereas there is little variation in the unit between Yinni 1, Edaggee 1, and Boologooro 1. An explanation for this is that the stream sediments represent the combined effects of barite veining and low-temperature alteration, in addition to surface silicification, and subsequent mechanical sorting and chemical weathering during the regolith-forming process.

Further work on the usefulness of sedimentary-rock chemistry from drillholes could include examination of provenance and some estimation of the parent rock and degree of weathering, as was done by Nesbitt and Young (1984) and Nesbitt et al. (1996). However, these studies have focused on siliciclastic assemblages, and before their application, it is necessary to account for both carbonate and phosphate components in analysed samples.

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Table 4.2. Median values for the Gearle Siltstone, Windalia Radiolarite, and Haycock Marl in Edaggee 1, Boologooro 1, and Yinni 1, as well as stream samples derived from the Gearle Siltstone in the Giralia Anticline area

	DL	*Gearle n=15*	*'lower Gearle' n=11*	*'upper Gearle' n=4*	*Windalia n=5*	*Haycock n=4*	*Stream n=15*
				Percent (%)			
SiO_2	0.1	54.3	55.8	35.2	70.5	9.9	73.1
TiO_2	0.01	0.6	0.6	0.6	0.3	0.2	0.3
AL_2O_3	0.02	12.7	12.7	11.7	6.2	3.0	4.2
Fe_2O_3	0.01	6.2	5.8	6.5	4.1	6.0	5.3
MnO	1	0.0	0.0	0.0	0.0	0.0	0.0
MgO	0.01	2.1	2.2	1.4	1.7	0.5	0.8
CaO	0.1	4.9	2.6	17.6	2.4	23.6	3.8
Na_2O	20	1.1	1.3	0.8	0.7	0.4	0.1
K_2O	0.02	2.5	2.5	2.4	1.2	0.7	0.9
P_2O_5	50	0.1	0.1	0.2	0.2	1.0	0.1
LOI	0.01	11.5	9.4	18.4	9.6	27.9	9.0
				Parts per million (ppm) unless otherwise shown			
Ag	0.1	0.1	0.1	0.1	0.3	0.4	0.0
As	1	8	8	6	13	10	16
Au (ppb)	1	I/S	I/S	I/S	1	1	1
Ba	0.1	221	221	905	1624	59	1040
Be	0.1	1.6	1.5	1.7	0.8	0.7	0.0
Bi	0.01	0.4	0.4	0.4	0.3	0.2	0.0
Cd	0.1	0.2	0.2	0.1	0.4	0.6	0.0
Ce	0.01	59	58	64	27	25	29
Co	0.1	14	12	16	7	27	6
Cr	2	116	123	107	96	120	31
Cu	1	41	41	32	20	45	19
Ga	0.1	17	17	16	8	5	6
In	0.01	0.1	0.1	0.1	0.0	0.1	0.0
La	0.01	27	28	26	15	23	17
Li	0.1	39	37	61	28	11	12
Mo	0.1	2.7	3.2	0.4	5.4	1.75	6
Nb	0.5	12	12	18	15	15	10
Ni	1	61	61	68	58	87	24
Pb	2	17	17	18	7	5	14
Pd (ppb)	1	1.5	1	2	2.5	6	1
Pt (ppb)	1	2	2	1	2.5	3	1
Rb	0.05	97	97	92	46	25	37
S	100	6100	5700	11050	15464	7944.5	2000
Sb	0.05	0.5	0.5	0.5	0.6	1.3	–
Sc	2	15	15	15	8	15	4
Se	0.5	1.5	1.7	1.3	1.6	7.5	1.1
Sn	0.1	2.1	2.1	2.2	1.2	0.75	2
Sr	0.05	288	278	454	77	386	279
Ta	0.1	0.7	0.7	0.7	0.3	0.5	–
Te	0.1	0.2	0.1	–	–	–	–
Th	0.01	13	13	12	5.99	2	7.1
U	0.01	4	4	3	3	8	4
V	2	115	115	118	69	110	98
W	0.1	1.2	1.2	1.5	1.1	1	–
Y	0.05	19	18	19	9	23	9
Zn	1	111	111	104	61	129	42
Zr	1	94	92	96.5	52	41.5	98
CI		0.60	1.30	0.17	4.33	6.25	-3.55
CaO/SiO_2(ratio)		0.09	0.05	0.52	0.03	4.05	0.05

NOTES: CI: chalcophile index (dimensionless)
DL: detection level
I/S: insufficient sample for analysis
LOI: loss on ignition
–: medians not calculated due to too many values less than detection level

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Appendix 5

Gazetteer of localities and wells

Name	*Latitude (S)*	*Longitude (E)*
Localities		
Cardabia Creek	23°06'50"	114°10'30"
Giralia Anticline	23°01'50"	114°05'10"
type section Alinga Formation	27°38'10"	114°10'10"
type section Birdrong Sandstone	24°14'50"	114°49'50"
type section Muderong Shale	24°08'10"	114°45'50"
Windalia Hill	23°16'10"	114°47'10"
Woodleigh Homestead	26°03'08"	114°45'20"
Wells		
Barrabiddy 1/1A	23°49'52"	114°20'05"
Boologooro 1	24°19'27"	113°53'53"
Coburn 1	26°41'59"	114°13'36"
Cyanamid 3A	24°16'15"	114°33'55"
Edaggee 1	25°21'27"	114°14'05"
Giralia 1	22°59'34"	114°10'10"
Mooka 1	24°58'31"	114°48'25"
Woodleigh 1	26°03'19"	114°39'56"
Woodleigh 2 and 2A	26°30'23"	114°31'39"
Woodleigh 3 water bore	26°03'09"	114°50'31"
Yaringa 1	26°03'54"	114°21'40"
Yaringa East 1	25°53'36"	114°23'32"
Yinni 1	26°03'23"	114°48'59"

Appendix 6

Well index sheet

ORGANIZATION: Geological Survey of Western Australia and University of Western Australia
WELL: GSWA Yinni 1
SPUDDED: 28 May 2001
COMPLETED: 2 June 2001
TD: 158.2 m
STATUS: Abandoned

BASIN: Carnarvon Basin
SUB-BASIN: Gascoyne Platform
ELEVATION (GL): 131 m AHD
LATITUDE: 26°3'22.8"S; **LONGITUDE:** 114°48'58.5"E (GDA94)
NORTHING: 7116250; **EASTING:** 281530 (MGA Zone 50)

Statutory Petroleum Exploration Report No.: S20734 V3
TYPE: Stratigraphic

FORMATION	TOPS (m)		LITHOLOGICAL SUMMARY
	DRILL	SUBSEA	
Alluvium	Surface	+131	Red-brown, fine- to coarse-grained sand
Gearle Siltstone	38.7	+92.3	Dark-grey to black claystone, soft
Windalia Radiolarite	52.3	+78.7	Dark-grey interbedded siltstone, hard cherty radiolarite
Muderong Shale	74.2	+56.8	Medium- to dark-grey shale
Birdrong Sandstone	81.7	+49.3	Light-grey to white, fine- to coarse-grained loose sand; minor siltstone
Woodleigh Formation	145	14	Light- to medium-grey siltstone and mudstone, interbedded fine-grained silty sandstone

CORE	Continuously cored; NQ: 36.7 – 87.9 m (85% recovery)		
LOGS	None		
CASING	PW	(OD 139.7 mm, ID 127.0 mm):	0 – 18 m
	HWT[(a)]	(OD 114.3 mm, ID 101.6 mm):	0 – 36.7 m
	HQ[(a)]	(OD 88.9 mm, ID 77.8 mm):	0 – 92.8 m

NOTE: (a) removed before abandonment

Government of Western Australia
Department of Industry and Resources
HON. CLIVE BROWN, M.L.A.
MINISTER FOR STATE DEVELOPMENT
JIM LIMERICK
DIRECTOR GENERAL

Geological Survey of Western Australia
TIM GRIFFIN
DIRECTOR

GSWA Yinni 1 composite well log

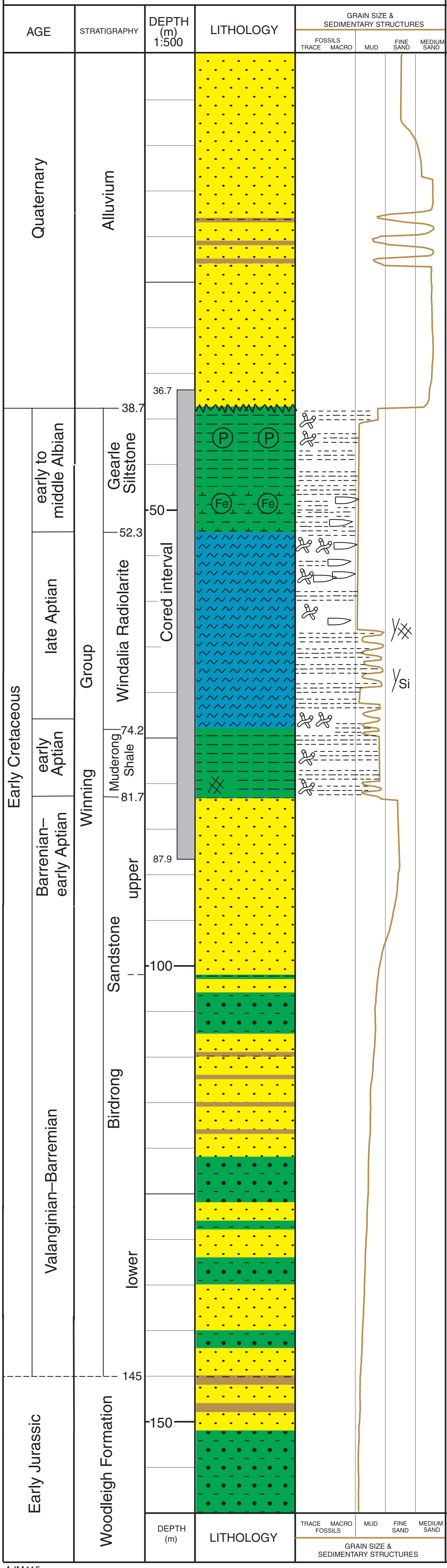
Company	Geological Survey of WA
Well Name	GSWA Yinni 1
Country	Australia
State	Western Australia
Rig	Hydco SD 1000
Latitude	26° 03' 22.8" S DMS
Longitude	114° 48' 58.5" E DMS
Permanent Datum	MSL
Elevation of PD	0 m
Elevation of DF	131 m
Elevation Log Zero	131 m
Log measured from	DF
Drill measured from	DF
Number of runs	0
Well class	Stratigraphic
Basin	Southern Carnarvon
Sub-Basin	Gascoyne Platform
Tenement/Concession	vacant
Geographic datum	GDA 94
On-Shore Flag	yes
Date spudded	28 May 2001
Date completed	2 June 2001

LITHOLOGIES

- Mudstone
- Calcareous mudstone
- Sandy mudstone
- Siltstone
- Sandstone
- Radiolarite

SYMBOL LEGEND

- Erosional boundary
- Planar laminations
- Pyrite
- Silica veinlets
- Pyrite veinlets
- Ferruginous nodules
- Phosphate nodules
- Burrow networks
- Belemnites



STRATIGRAPHY AND DESCRIPTION

0 – 38.7 m ALLUVIUM
0 – 12 Quartz sand: red, medium grained, aeolian
12 – 36.7 Quartz sand: yellow, very coarse grained, interbeds of white sandy silt

36.7 – 38.7 Quartzose sandy mud: brown, sand component fine grained

38.7 – 52.3 m GEARLE SILTSTONE
38.7 – 47.7 Claystone: leached green-grey becoming mottled grey-brown and yellow, common small-scale and rare medium-scale burrows, rare phosphatic and ferruginous (replaced pyrite) nodules, patchy silicification towards bottom of interval
47.7 – 52.3 Claystone: yellow, increasingly calcareous, carbonaceous, rare phosphatic and ferruginous (replaced pyrite) nodules, patchy silicification, rare belemnites

52.3 – 74.2 m WINDALIA RADIOLARITE
52.3 – 53.7 Claystone: dark grey, carbonaceous, thin interbeds of radiolarite (grey, porous), thickest claystone bed heavily bioturbated, common belemnites
53.7 – 58.5 Decimetre-scale interbeds of claystone (dark grey, calcareous, carbonaceous) and radiolarite (grey, porous), radiolarite beds thicker down interval, rare bioturbation, common large belemnites
58.5 – 62.0 Decimetre-scale interbeds of radiolarite (grey, porous) and claystone (dark grey, carbonaceous), rare bioturbation, rare small belemnites
62.0 – 68.5 Decimetre-scale interbeds of siltstone (dark grey, carbonaceous) and radiolarite (grey, porous), with rare thin interbeds of dark-grey carbonaceous claystone, rare pyrite veinlets
68.5 – 70.3 Decimetre-scale interbeds of claystone (dark grey, carbonaceous) and radiolarite (grey, porous), rare silica veinlets, rare phosphatic nodules towards bottom of interval
70.3 – 74.2 Siltstone: dark green-grey, carbonaceous, with rare thin interbeds of radiolarite (grey, porous), medium-scale burrows

74.2 – 81.7 m MUDERONG SHALE
74.2 – 79.0 Siltstone: dark green-grey, carbonaceous, medium-scale burrows towards top of interval, small-scale burrows towards bottom of interval, rare pyrite
79.0 – 81.7 Siltstone: dark green-grey, carbonaceous, thin interbeds of claystone (black, carbonaceous), small-scale burrows

81.7 – 101 m UPPER BIRDRONG SANDSTONE
81.7 – 101 Quartz sand: pale grey, mainly medium to coarse grained, but ranges from fine to very coarse grained, well sorted, well rounded

101 – 145 m LOWER BIRDRONG SANDSTONE
101 – 109 Interbeds of quartz sand (light grey, fine grained, well sorted, well rounded) and sandy mudstone (dark grey, sand component of quartz)
109 – 145 Mudstone: dark grey with interbeds of quartz sand (light grey, fine grained)

145 – 158.2 m WOODLEIGH FORMATION
145 – 158.2 Claystone: black, carbonaceous

DEPTH (m) | LITHOLOGY | TRACE MACRO FOSSILS | MUD | FINE SAND | MEDIUM SAND | GRAIN SIZE & SEDIMENTARY STRUCTURES | STRATIGRAPHY AND DESCRIPTION