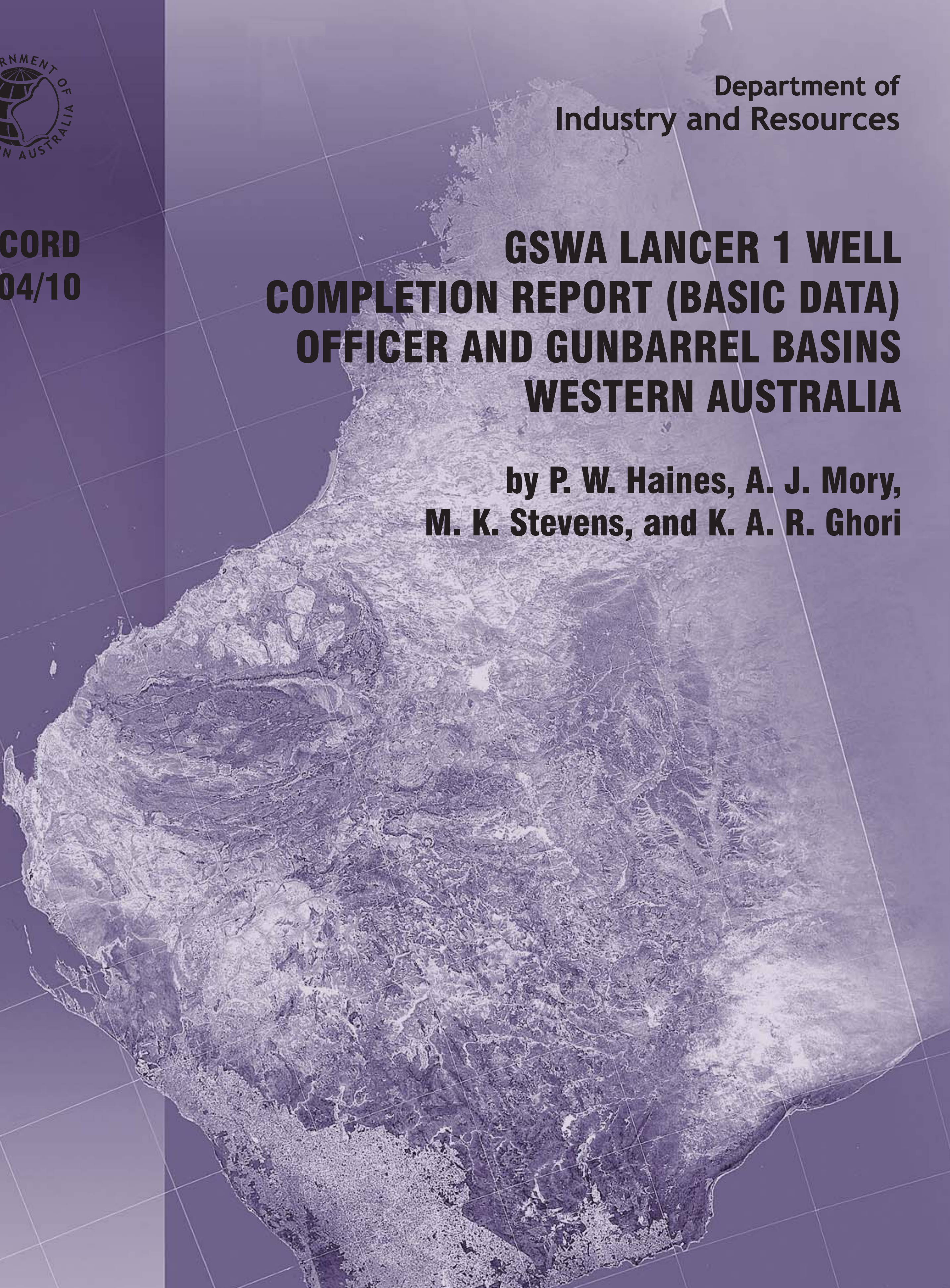
Department of Industry and Resources

RECORD 2004/10

GSWA LANCER 1 WELL COMPLETION REPORT (BASIC DATA) OFFICER AND GUNBARREL BASINS WESTERN AUSTRALIA

by P. W. Haines, A. J. Mory, M. K. Stevens, and K. A. R. Ghori



Geological Survey of Western Australia

GEOLOGICAL SURVEY OF WESTERN AUSTRALIA

Record 2004/10

GSWA LANCER 1 WELL COMPLETION REPORT (BASIC DATA) OFFICER AND GUNBARREL BASINS, WESTERN AUSTRALIA

by
P. W. Haines, A. J. Mory, M. K. Stevens, and K. A. R. Ghori

with a contribution by A. C. Cook
Keiraville Konsultants, 7 Dallas Street, Keiraville, N.S.W. 2500

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GSWA Lancer 1 well completion report (basic data), Officer and Gunbarrel Basins, Western Australia

by

P. W. Haines, A. J. Mory, M. K. Stevens, and K. A. R. Ghori
with a contribution from A. C. Cook*

Abstract

GSWA Lancer 1 is a stratigraphic well drilled in 2003 at latitude 25°02'44.5"S, longitude 123°45'20.7"E in the Officer and Gunbarrel Basins in Western Australia to a depth of 1501.3 m (driller's depth). The interval from 104 to 1501.3 m was continuously cored by diamond drilling with almost 100% recovery. Lancer 1 penetrated Carboniferous to ?Permian Paterson Formation of the Gunbarrel Basin below Quaternary alluvium and the Neoproterozoic Lungkarta, Wahlgu, Kanpa, Hussar, and Browne Formations of the Officer Basin before being terminated within ?Mesoproterozoic pebbly, well-cemented sandstone. A mafic extrusive unit (Keene Basalt, new name) was penetrated in the Kanpa Formation. Dips throughout the section are low. There are no hydrocarbon shows or indications of mineralization.

The entire Neoproterozoic section shows evidence of shallow, marginal, and nonmarine conditions ranging from high-energy shoreface and eolian–beach–barrier environments to lagoons and evaporitic supratidal mudflats and coastal sabkhas. The basal part of the Browne Formation in Lancer 1 is remarkably similar, particularly in thickness, to that in drillhole GSWA Empress 1/1A, 260 km to the southeast. This implies a low gradient across the 'western platform' of the basin during deposition of this formation, as well as a low-relief hinterland, and regional-scale controls on deposition and subsidence across this part of the Officer Basin. Eolian sandstone facies at the top of the formation (Lancer Member, new name) are laterally equivalent to halite-dominated facies in Empress 1/1A. A series of basalt flows within the Kanpa Formation is the second record of extrusive igneous rocks within the Neoproterozoic succession of Western Australia. Most of the section can be correlated with scattered outcrops in the basin west and northwest of Lancer 1.

Preliminary analyses reveal that sandstone facies in the well typically have excellent reservoir characteristics (with porosities up to 29% and permeabilities up to 10 darcies), and that there are potential regional seals at the base of the Hussar and Kanpa Formations. Organic richness, however, is low with just two samples yielding total organic carbon of more than 0.5%.

KEYWORDS: Carboniferous, Neoproterozoic, stratigraphy, diamond drilling, basalt, Mesoproterozoic, petroleum geology, reservoir data, well logs, stromatolites, Officer Basin, Gunbarrel Basin.

Introduction

The Geological Survey of Western Australia's (GSWA's) Lancer 1 is a stratigraphic hole drilled in the Officer Basin, on the HERBERT† 1:250 000 map sheet (SG 51-7), 390 km east-northeast of Wiluna and 115 km northeast of Carnegie Homestead (Fig. 1), at SP 690 on line N83-08 of the Gibson Seismic Survey (Fig. 2). The drillhole is 69 km west-northwest of Mungilli Outstation, which, in turn, lies 16 km north of the junction of the Gunbarrel and Eagle Highways. Access to Lancer 1 is via the Gunbarrel and Eagle Highways to the Mungilli Outstation, and then along seismic line N83-08. The nearest wells are Hussar 1 (67 km to the northeast), GSWA Trainor 1 (120 km to the northwest), BMR Browne 1 (160 km to the east-southeast), and Lungkarta 1 (184 km southeast). GSWA Empress 1/1A lies 264 km to the south (Fig. 2). The nearest outcrops of the Officer Basin succession are 80 km to the northwest (Skates Hills), 125 km to the north-northwest (Constance Headland), and 110 km to the north-northeast (around the Madley Diapir).

The primary objective of Lancer 1 was to continuously core the Neoproterozoic section of the Officer Basin in order to gain geological information on the basin and evaluate its hydrocarbon generation potential, as well as reservoir and sealing characteristics in a section no more than 1500 m thick. A secondary objective was to core underlying strata to provide data on the older Proterozoic rocks between those exposed in the Oldham Inlier of the northwest Paterson Orogen, and the Musgrave Complex. Lancer 1 was terminated within immature, well-cemented cross-bedded sandstone of probable Mesoproterozoic age.

* Keiraville Konsultants, 7 Dallas Street, Keiraville, N.S.W. 2500.
† Capitalized names refer to standard 1:250 000 map sheets.

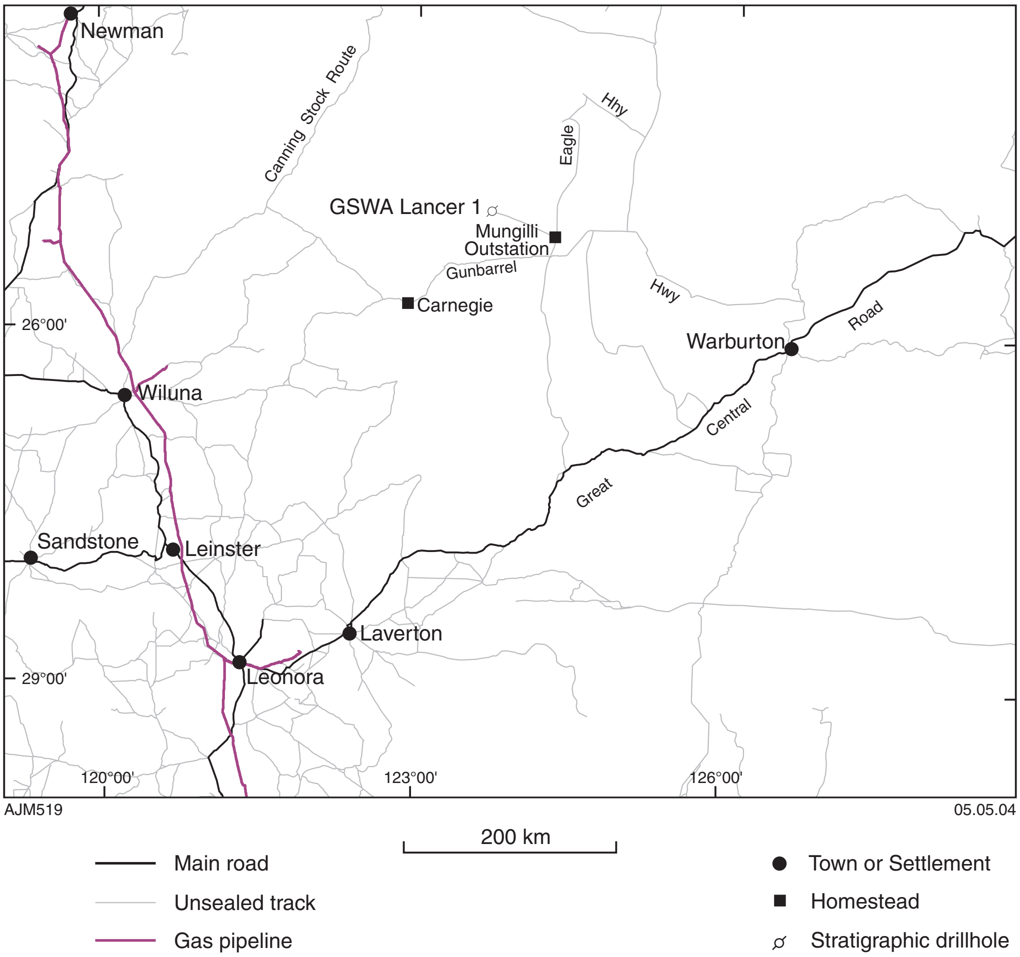


Figure 1. Well location and access map

Hydrocarbons were not expected in this drillhole because a trap is not evident in the seismic data. During drilling, traces of hydrocarbons were interpreted from fluorescence within thin zones in the Hussar and Wahlgu Formations, but subsequent studies showed that these are almost entirely due to carbonate cements. The hole was geophysically logged by Geoscience Associates. At abandonment, the well was plugged at the base of the HWT casing and at surface. An artesian flow from the Wahlgu Formation is contained behind the HWT casing.

This Record provides the basic data for Lancer 1 including the operations report (Appendix 1), core photographs (Appendix 2), definition of two newly recognized units (Appendix 3), a provisional well index sheet (Appendix 4), and a provisional composite well log (Plate 1). Additional analyses, including petroleum and mineral geochemistry, igneous petrography, radiometric dating, and palynology will be released at a future date as a series of complementary reports.

The core depths cited within this Record are, unless otherwise specified, those reported by the drillers as modified by the drillsite geologists. In the composite well log (Plate 1), core descriptions are consistent with these core depths, as are the lithology, grain size, and sedimentary structures columns.

Well history

General data

Permit:	Vacant
Location:	Latitude 25°02'44.5"S*, Longitude 123°45'20.7"E* (GDA94) Northing 7229780, Easting 576235* (MGA Zone 51J), estimated from Global Positioning System (GPS) and SP 690 on line N83-08 of the Gibson Seismic Survey
Derivation of name:	Following the cavalry theme of Eagle Corporation wells, (Dragoon 1 and Hussar 1)
Total depth (TD):	1501.3 m (driller), 1502.25 m (logger)
Date spudded:	14:00 Friday 10 October 2003
Reached TD:	19:15 Monday 17 November 2003
Logging:	03:15 Tuesday 18 November – 14:30 Wednesday 19 November 2003

* Drillhole location preliminary, to within 100 m.

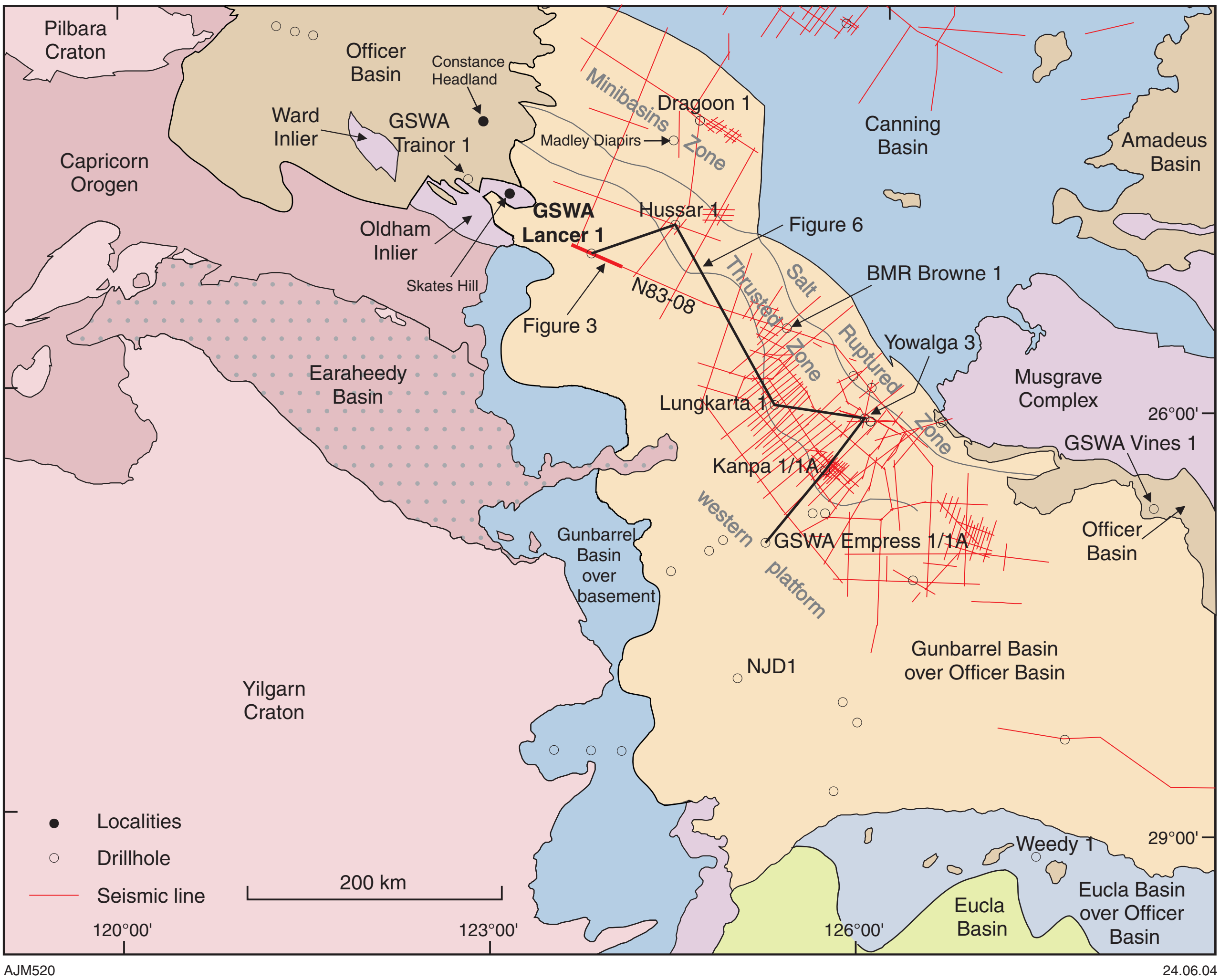


Figure 2. Tectonic elements of the Officer and Gunbarrel Basins (after Carlsen et al., 2003)

Date completed:	14:45 Thursday 20 November 2003
Elevation:	450 m Australian Height Datum (AHD), estimated from shot point heights in Gibson Seismic Survey
Drill floor:	70 cm above ground level
Status:	Plugged and abandoned

Drilling data

Drilling contractor:	Drillcorp Western Deephole, 42 Paramount Drive, Wangara, W.A. 6065	
Rig:	UDR 1500	
Rig datum:	Rig floor	70 cm above ground level
Hole size:	0–6 m	216 mm with 178 mm casing
	6–104 m	159 mm with PW casing cemented to surface
	104–429.5 m	115 mm PQ with HWT casing cemented from 428 m to about 90 m
	429.5 – 1501.3 m	96.1 mm HQ open hole

Mud:	Mixture of KCl, NaCl, and polymer-based muds
Core recovery:	104.0 – 429.5 m PQ (85.0 mm diameter) recovered 325.3 m (~100%) 429.5 – 1501.3 m HQ (63.5 mm diameter) recovered 1071.4 m (~100%)
Hole deviation:	Within 0.9° of vertical
Plug:	Two van Ruth plugs: at 448 m (HQ) and 35 m (PQ), capped by about 40 and 34 m of cement respectively

Logging data

Logging contractor:	Geoscience Associates, 20 Oborn Road, Enterprise Park, Mount Barker, S.A. 5251

Logs run:	Run 1:	16" normal resistivity	420–1501 m
	Run 2:	64" normal resistivity	420–1501 m
	Run 3: (Gam/G-N)	single point resistance	420–1501 m
		spontaneous potential	420–1501 m
		neutron	0–1501 m
	Run 4: (GAA/DDC)	gamma ray	0–1501 m
		long-spaced density	0–1501 m
		short-spaced density	0–1501 m
		caliper	0–1501 m
	Run 5:	sonic	420–1501 m
	Run 6:	BHTV (sonic scanner)	1450–1500 m 1200–1365 m 420–900 m

Note: the 16" normal resistivity, 64" normal resistivity, and single-point resistance logs are considered unreliable due to the highly saline mud in the hole (required to core halite in the Browne Formation). In addition, the long-spaced density log values may be unreliable because they are greater than the short-spaced density values where the caliper indicates no reason for such a difference.

Regional structural setting

Lancer 1 was drilled in the northern part of the Neoproterozoic–Cambrian Officer Basin (Fig. 2) in an area where thin Carboniferous–Cretaceous strata of the Gunbarrel Basin (Sherriff Shelf) obscure the Neoproterozoic succession of the Officer Basin. The drillhole is along structural strike from the Mesoproterozoic Ward and Oldham Inliers, the nearest outcrops of which lie 67 km to the west in the Oldham Inlier. The Palaeoproterozoic Earaheedy Basin outcrops 140 km to the south-southwest. Structural subdivisions of the Officer Basin are presently in flux. Lancer 1 is in an area previously assigned to the Westwood Shelf (Hocking, 1994), but now referred to less formally as the 'western platform' (Carlsen et al., 2003).

Lindsay (2002) recognized six periods of regional deformation in the Officer Basin, but the western portion of seismic line N83-08 (Fig. 3) shows that Lancer 1 was drilled in a region of the Officer Basin with low dips and there is little evidence of these events apart from some minor faults with associated low-amplitude rollovers. The region around the well is part of the 'western platform' of JNOC (1998) and Carlsen et al. (2003), which is the part of the basin farthest from the Musgrave Complex and least deformed. Salt development near Lancer 1 was minor so that structures such as saltwalls and diapirs, found in the region to the northeast, are absent. In comparison, the underlying ?Mesoproterozoic section shows much more deformation in the seismic data, indicating that there was little deformation in the region after the start of the Neoproterozoic. Structural dips in the Officer Basin portion of Lancer 1 are all less than 2°, and even the single siltstone bed in the ?Mesoproterozoic section dips at about 4°.

Stratigraphy

The regional Officer Basin stratigraphy in Lancer 1 follows that detailed in Grey et al. (in prep.; Fig. 4). Younger strata are mostly Carboniferous – Lower Permian glacial deposits assigned to the overlying Gunbarrel Basin. Lancer 1 was spudded in Cainozoic sand and ferricrete. The boundary between Cainozoic sediments and sedimentary rocks of the Upper Carboniferous to Lower Permian Paterson Formation is placed tentatively at 17 m. Flat-lying Cretaceous strata outcrop in the region, but only at higher elevations than the Lancer 1 location. The top of the Officer Basin succession is placed tentatively at 169.1 m, and includes the Lungkarta, Wahlgu, Kanpa, Hussar, and Browne Formations, in descending order.

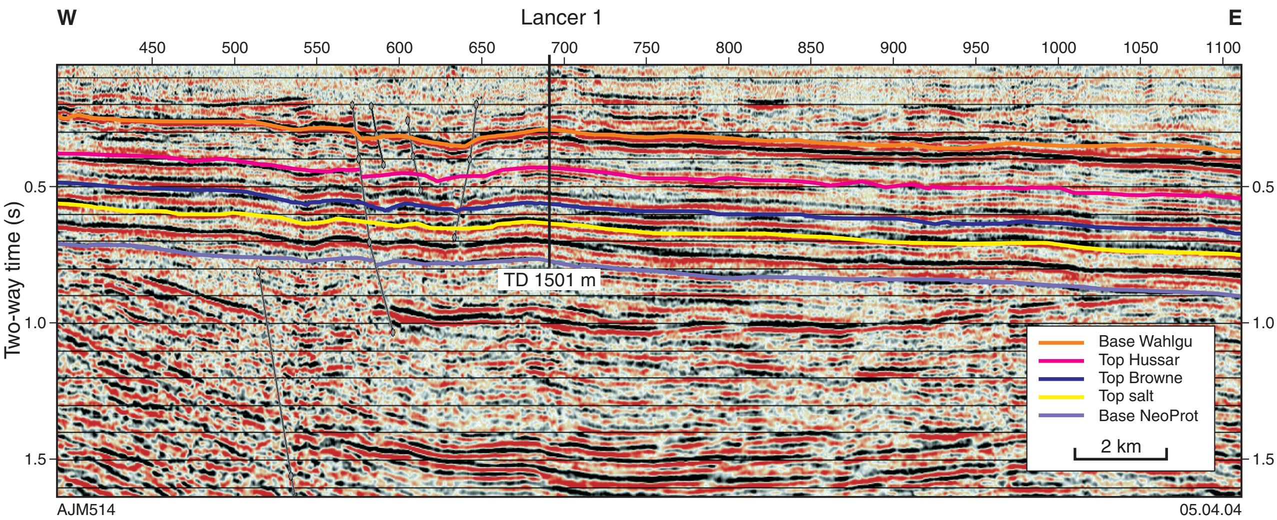


Figure 3. Western end of seismic line N83-08 across Lancer 1 (see Fig. 2 for location)

Well-cemented sandstone, tentatively correlated with the pre-Officer Basin Cornelia Sandstone, was intersected between 1478.9 m and total depth (TD) at 1501.2 m (Fig. 5). Formation assignments and boundary positions are tentative and subject to change following more-detailed studies, including palaeontological, palaeomagnetic, and radiometric dating. A 1:100 graphic sedimentological log was recorded at the drillsite, and has been placed in the Department of Industry and Resources' statutory petroleum exploration report S20880, which is part of the Department's WAPIMS (Western Australian petroleum information management system) database.

Cainozoic section

Unnamed regolith

The uppermost regolith at the Lancer 1 site is about 20 cm of unconsolidated red sand and soil with scattered ferricrete pebbles. This overlies well-indurated nodular and pisolitic ferricrete, which is exposed in some areas near the drillsite, the remainder being interpreted from rotary cuttings. The upper 5 m consists of ferricrete and brown to yellow ferruginous mudstone with minor fine-grained sandstone. The interval from 5 to 8 m comprises consolidated brown to yellow mudstone and light-grey sandstone in approximately equal proportions, with sandstone grain size increasing downward from fine to medium. Sandstone, commonly medium grained, predominates over minor mudstone between 8 and 17 m, with coarse-grained sandstone in the basal 3 m. The upper 3 m of the interval is poorly consolidated. Porosity varies from fair to excellent, and this sandstone unit is presumably the shallow aquifer intersected in nearby water bores.

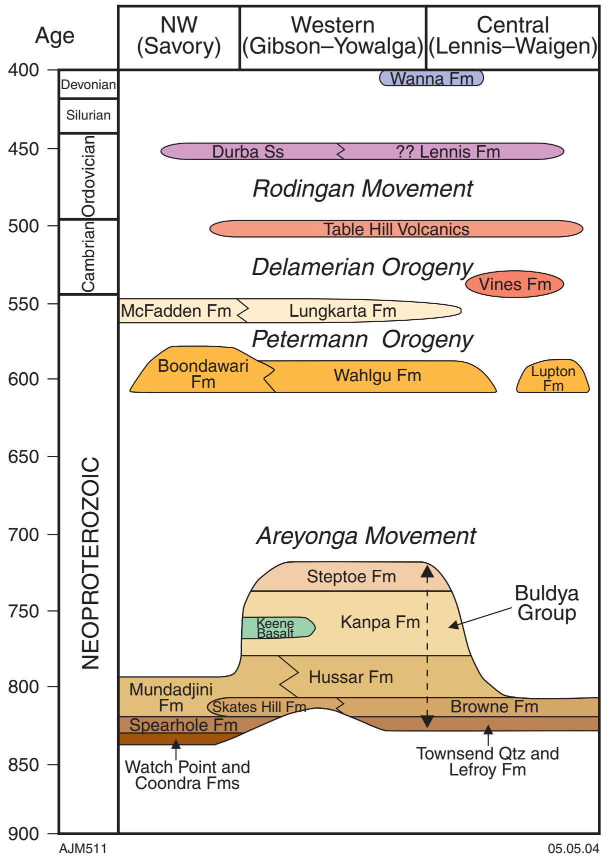


Figure 4. Regional stratigraphy of the Officer Basin (after Grey et al, in prep.) with tectonic events

In the absence of palaeontological age constraints in this preliminary report, any attempt at subdivision is speculative. However, the Cretaceous section does not outcrop below 450 m AHD (the level at which Lancer 1 was spudded) within 50 km of Lancer 1, and the pre-Cainozoic topographically lower outcrops are all assigned to the Palaeozoic Paterson Formation. This implies that the top of the Paterson Formation is best placed at the sudden change from possible Cainozoic sandstone of fluvial–lacustrine origin to predominantly claystone at 17 m.

Palaeozoic section

Paterson Formation

The upper part of the Paterson Formation (?17 – ?169.1 m) is interpreted from rotary cuttings above 104 m. The interval from 17 to 70 m is dominated by claystone, with minor sandy interbeds in the upper 4 m. Traces of sand and granules are probably contamination from higher in the hole. Below 40 m the claystone is light to moderate grey, but higher in the hole yellow to pale-green and pink colouration suggest various degrees of oxidation. Consolidation is variable, but particularly poor below 33 m. The claystone unit is underlain by a 4.5 m-thick conglomeratic unit between 70 and 74.5 m, which contains subangular to subrounded pebble clasts mostly of sedimentary origin.

The interval from 74.5 to 93 m is dominated by light- to moderate-grey mudstone, locally containing minor dark carbonaceous material in samples from intervals 81–82 m, 86–88 m, and 91–93 m. Minor conglomeratic material near the top of the interval is interpreted as contamination from the conglomeratic unit above. Cuttings from 93 to 104 m contain similar mudstone with increasing proportions of fine-grained sandstone up to about 40%. However, when PQ coring commenced at 104 m the lithology was found to be predominantly sandstone, with mudstone only as sparse intraclast horizons. Hence, a significant proportion of the mudstone in the interval from 93 to 104 m may represent contamination from higher in the hole.

The interval below 104 m is dominated by sandstone, but with significant mudstone intervals below 155 m, and conglomerates in the basal 2 m below 167 m. The sandstone is mostly grey above 133 m, but undergoes a gradational change to predominantly reddish-brown and brown below this depth. At about this depth the average grain size increases from uniform medium-grained sandstone above to alternating medium- to coarse-grained sandstone below. Most of the sandstone is cross-bedded,

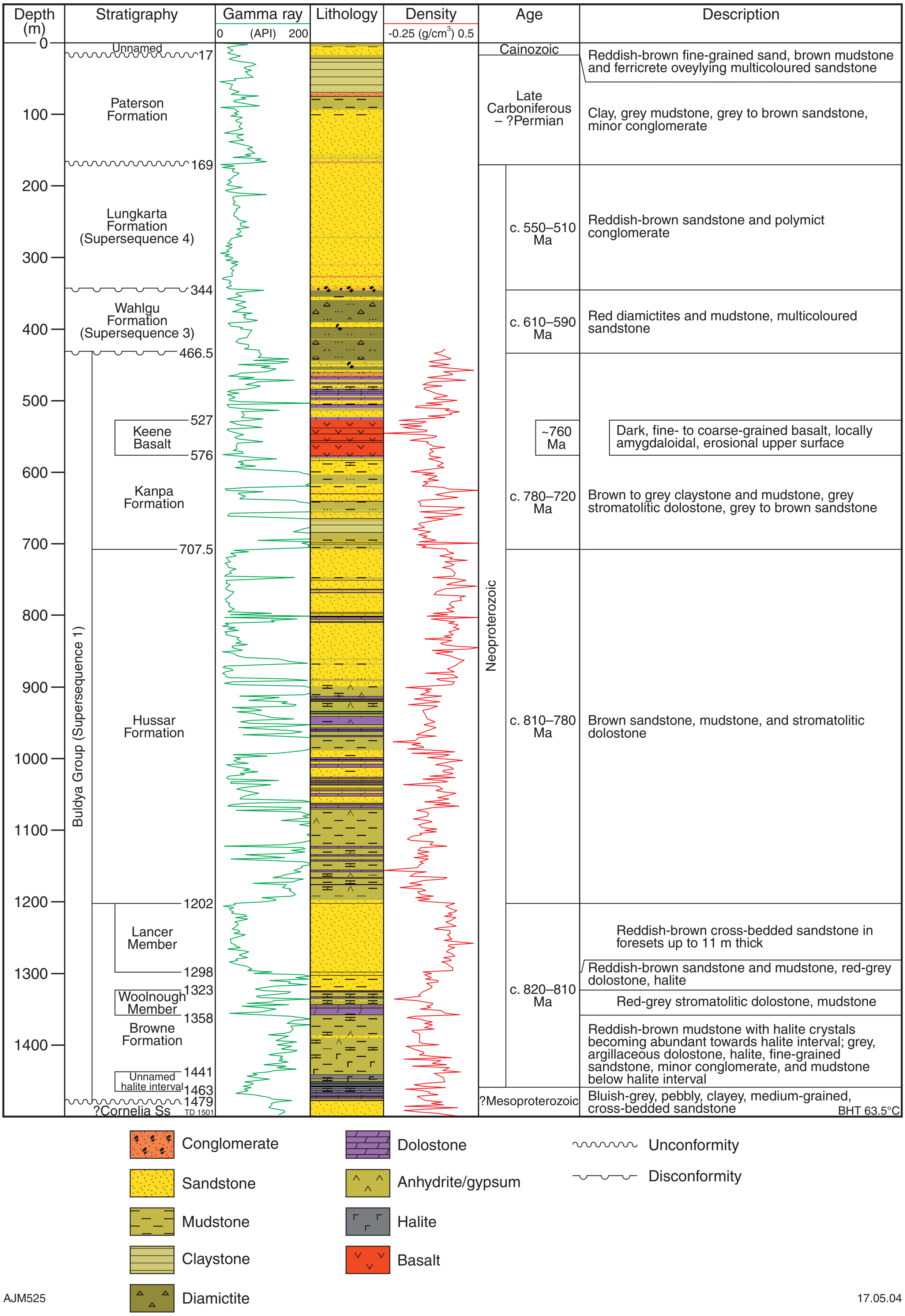


Figure 5. Lancer 1 stratigraphic summary (Officer Basin ages from Grey et al., in prep.)

some on a large scale. There is patchy calcareous cementation between 155 and 164 m. The base is tentatively assigned to a sharp erosional contact overlain by a thin polymict pebble conglomerate at 169.1 m, which is also marked by a distinct change in the gamma-ray signature.

In Lancer 1 the Paterson Formation is interpreted to be mainly of fluvial origin. Glacial diamictites, as seen elsewhere, are absent. The age of the formation is considered to be ?Permian, based on one possibly Permian spore from the 50–52 m interval, to Late Carboniferous, based on likely Stage 1 (late Westphalian to Stephanian) palynomorphs from the 86–88 m interval (Backhouse, J., written comm., 2004). Four siltstone beds near the base of the unit were completely devoid of organic material. Other wells in the region, such as Empress 1/1A (Stevens and Apak, 1999), have yielded Early Permian and Late Carboniferous palynomorphs from this unit.

Neoproterozoic–Cambrian section

Lungkarta Formation

The Lungkarta Formation (?169.1 – 344.3 m) of Supersequence 4 is defined in Grey et al. (in prep.) with its type section in Lancer 1, although it is widely recognized on seismic sections and in other drillholes. The unit was previously identified as the 'Babbagoola beds' (Townson, 1985) or 'McFadden Formation equivalent' (Apak and Moors, 2000). In Lancer 1 the top of the formation is tentatively picked at an erosional surface at 169.1 m, as previously described for the overlying Paterson Formation.

The upper part of the formation from 169.1 to 205 m consists of light-brown, medium-grained, moderately sorted and rounded, quartz-rich sandstone. It displays minor clay matrix, rare red mudstone interbeds and intraclasts, common siliceous concretions in the lower half, and is sparsely pyritic mainly near the base. Sedimentary structures are restricted to abundant cross-bedding.

The interval from 205 to 214 m is an overall fining-upward, mostly flat-bedded, succession of reddish-brown, fine- to coarse-grained, poorly sorted sandstone with lithic-granule conglomerate horizons in the lower half.

The remainder of the formation, from 214 to 344.3 m, is dominated by orange-brown to reddish-brown, medium-grained, well-sorted, well-rounded, porous, quartz sandstone. It is characterized by very large foresets, possibly exceeding 30 m in thickness, with dips up to 30°, but also contains flat-bedded intervals. The upper 22 m contains sparse pyrite. There are minor mudstone and polymict conglomeratic intervals, the latter increasing in abundance towards the base. The base of the formation is placed at the sharp erosive base of a polymict granule conglomerate at 344.3 m. This contact may represent an erosional hiatus of uncertain duration.

The upper part of the Lungkarta Formation (169.1 – 214 m) was deposited subaqueously, probably in a fluvial or possibly high-energy shallow-marine environment. The lower part (214 – 344.3 m) was deposited under mainly eolian conditions as indicated by textural evidence and the scale and angle of foresets. Particularly diagnostic is the reversely graded translatent strata (Hunter, 1977) produced by laterally migrating wind ripples. Conglomeratic and mudstone intervals probably result from fluvial and playa deposition between migrating dunes. The age of the Lungkarta Formation is constrained only by its stratigraphic position. Because it disconformably overlies the upper Neoproterozoic Wahlgu Formation and is overlain by the Cambrian or Lower Ordovician Table Hill Volcanics in other drillholes, it can be constrained to the upper Neoproterozoic or possibly Cambrian (Grey et al., in prep.).

Neoproterozoic section

Wahlgu Formation

The Wahlgu Formation (344.3 – 466.5 m) of Supersequence 3 is defined in Grey et al. (in prep.) with its type section in Empress 1/1A (317.1 – 483 m) and Lancer 1 as a reference section. In Lancer 1 the formation is characterized by massive diamictite. The diamictite is typically reddish-brown, less commonly grey, and has a mudstone or sandy mudstone matrix containing scattered granule, pebble, cobble, and boulder clasts. The largest observed clast is about 0.5 m across. Large clasts range from angular to well rounded and some have well-developed facets and striations typical of ice transport. Clast compositions include a variety of sedimentary, igneous, and metamorphic rock types. The largest clasts are most commonly mafic igneous rocks.

The diamictite intervals are interpreted to be of glacial origin because of their massive and extremely poorly sorted nature, and the faceted and striated clasts typical of ice transport. The relatively fresh nature of labile igneous clasts is also indicative of very cold conditions. Most of the diamictite shows little or no evidence of reworking by currents, suggesting a subaerial or subaqueous moraine resulting from sediment dumped by retreating ice sheets.

Also present are minor intervals of moderately to well-sorted sandstone, mudstone, and conglomerate. In contrast to the diamictite, these intervals are commonly well stratified. Some sandstone horizons contain green clay pellets, which may be glauconite. The interval from 391 to 397 m consists of porous coarse-grained to pebbly reddish-brown sandstone with large foresets and is an artesian aquifer. Soft-sediment deformation, including contorted bedding, small slumps, and syndepositional faulting, is common in stratified intervals, particularly in the lower 12 m of the formation. The sandstone, mudstone, and conglomerate intervals indicate periodic reworking by currents in an aquatic (marine, lacustrine or fluvial) environment. The presence of possible glauconite in some sandstone horizons, if confirmed, suggests at least periodic marine influence.

The base of the formation — an erosional disconformity overlying Kanpa Formation dolostones — is put at 466.5 m, but could be slightly higher. The 466.5 m position marks the top of the highest definitely in situ, although somewhat brecciated, dolostone bed. This bed is overlain by 4 m of sandstone, dolostone, and dolostone-clast conglomerate. It is inferred that apparent dolostone beds in this interval are actually large tabular dolostone clasts. An alternate explanation is that the disconformity surface is very complex due to karstification and that the 466.5 m contact represents the bottom of a small cavern fill.

The cap dolostone, present in Empress 1/1A (Stevens and Apak, 1999) and in the Boondawarri Formation to the north (Grey et al., in prep.), was not recognized in Lancer 1. The Wahlgu Formation has been correlated with the Marinoan glacial succession throughout the Centralian Superbasin and the Adelaide Rift Complex, and with outcropping Boondawari Formation in the adjacent northwestern Officer Basin (Grey et al., in prep.).

Keene Basalt (new name)

The upper Kanpa Formation sedimentary succession is disrupted by 48.8 m of basalt flows, (527.4 – 576.2 m) here named the Keene Basalt (Appendix 3). The base overlies a vuggy dolostone, which has been coarsely recrystallized and silicified to grey and black laminated chert within 15 cm of the contact. The basal 3 m of basalt is very fine grained with irregular and inclined amygdaloidal zones and some brecciation, possibly the result of subaerial extrusion over wet sediments. There are at least four and possibly five distinct flows with tops and bases marked by fine-grained amygdaloidal basalt, whereas flow centres comprise coarse-grained massive basalt. The basalt is typically dark grey to greenish, but is reddened at the base and at two of the flow tops. Veins filled with calcite, red chert or chlorite are common, and amygdales are filled with similar material. The top of the basalt member is not fine grained, amygdaloidal or reddened, indicating that the top of the last flow was eroded before resumption of clastic deposition. It is sharply overlain by 35 cm of grey muddy sandstone followed by stromatolitic dolostone. The depositional environment before and after basalt extrusion was very similar, suggesting that subsidence kept pace with extrusion. Based on broad regional correlations, the Keene Basalt could correlate with (but would not be comagmatic with) the Cadlareena Volcanics of the northeastern Officer Basin in South Australia, which has an age between 780 and 760 Ma (Morton, 1997), and also the Boucaut Volcanics dated at 777 ± 7 Ma in the Adelaide Rift Complex (Barovich et al., 2001).

Buldya Group

The Buldya Group erected by Grey et al. (in prep.), which encompasses previously ungrouped formations assigned to Supersequence 1, was intersected between 466.5 and 1478.9 m (466.6 –1480.3 m log depth). The basalt within the Kanpa Formation (Appendix 3), however, is not considered to be part of the group.

Kanpa Formation

The Kanpa Formation (466.5 – 707.5 m core depth, 466.6 –708.0 m log depth) is a mixed succession of dolostone, mudstone, claystone, and sandstone. In Lancer 1, an informal two-part division is made with an upper interval from 466.5 to 583 m containing seven stromatolitic dolostone cycles, and a lower interval from 583 to 707.5 m of mainly mudstone, claystone, and sandstone. Unique to Lancer 1 is the 49 m-thick basalt unit within the upper dolomitic section.

The upper interval comprises seven major dolostone units from 3 to 10 m thick, separated by units of dolomitic mudstone or sandstone, or both, from 2 to 11.5 m thick. The dolostone is grey, stylolitic, and ranges from relatively pure to argillaceous and sandy. Dolomitic mudstone and sandstone form thin interbeds locally. Grainstone and packstone, incorporating ooids, small intraclasts or other unidentified allochems, are common. All except the top dolostone unit are partly stromatolitic, but it is possible that its stromatolitic component has been truncated by erosion. Pending more-detailed analysis, the stromatolites are considered to include elements of the *Baicalia burra* Stromatolite Assemblage (Grey, 1996). The lowest two dolostone-bearing units are separated by basalt, as described below. Sandstones are light grey to brown, fine to coarse grained and mostly well sorted, rounded, and porous. Mudstones are mostly grey and locally black, flat laminated, and dolomitic, with common thin dolostone interbeds.

The lower Kanpa Formation contains a number of sandstone-dominated intervals, up to 22 m thick, grading upward into intervals of mudstone or claystone, with or without interbedded sandstone. Sandstone is typically white to light brown or grey, medium grained, well sorted, well rounded, and commonly porous. Sedimentary structures include flat bedding and high- to low-angle cross-bedding. Mudstone intervals are mostly grey and flat laminated. Where thin fine-grained sandstone interbeds are present, sedimentary structures include flat laminations, ripple cross-laminations, synaeresis cracks, soft-sediment deformation, and pot and gutter casts produced by the infilling of erosional scours.

The megascopic alga *Chuaria* sp. is tentatively identified in grey shale beds between 651.7 and 651.9 m, and possibly also at 659.35 m. It consists of dark carbonaceous discs, about 1 mm across, with concentric wrinkles and radial fractures on several bedding planes. The genus is generally known from Neoproterozoic deposits ranging in age from 1000 to 700 Ma.

The lowest 44 m of the Kanpa Formation is predominantly very fine grained, but has fine- to medium-grained sandstone interbeds below 689 m, including a sandstone-rich interval between 695.6 and 699.7 m. The interval between 663.8 m and about 686 m comprises laminated grey claystone, with sparse graded siltstone interbeds. Several claystone beds between 676 and 677 m and at approximately 683.5 m are notably hygroscopic and may be bentonites (ash beds). The base of the Kanpa Formation at 707.5 m is placed at a sharp conformable boundary between a 55 m-thick medium- to coarse-grained sandstone at the top of the Hussar Formation and brown mudstone with minor thin sandstone interbeds above.

The Kanpa Formation is considered to be of shallow-marine to coastal origin. The upper part shows an alternation of environments typical of shallowing-upward peritidal carbonate cycles (Pratt et al., 1992). In contrast, the lower part displays mainly deepening-upward cycles from high-energy beach–barrier–shoreface sands to quieter basinal mudstones. Where fine sandstone interbeds are present there is evidence of storm-wave reworking, but laminated claystone near the base of the formation was deposited below storm wave-base. The tentative identification of the *B. burra* Stromatolite Assemblage implies correlation with the Tarcunyah Group of the northwestern Officer Basin and the Burra Group of the Adelaide Rift Complex (Grey et al., in prep.).

Hussar Formation

The Hussar Formation (707.5 – 1201.9 m core depth, 708.0 –1202.8 m log depth) is a thick and lithologically diverse formation of sandstone, mudstone, dolostone, and evaporite. The unit is widespread in the western Officer Basin with its type section in drillhole Yowalga 3 (Grey et al., in prep.). In Lancer 1 it is subdivided into four informal units for ease of description:

- an upper sandstone-dominated unit (707.5 – 898.5 m);
- an upper middle evaporitic mudstone and dolostone unit (898.5 – 988.5 m);
- a lower middle sandstone and dolostone unit (988.5 – 1069.7 m);
- a lower evaporitic mudstone-dominated unit (1069.7 – 1201.9 m).

Upper and lower contacts of the formation are sharp. The upper contact is apparently conformable, but the lower may represent a minor erosional hiatus.

The uppermost Hussar Formation is marked by 55 m of predominantly medium- to coarse-grained sandstone with minor mudstone interbeds in two broadly coarsening-upward cycles (707.5 – 750.5 m and 750.5 – 762.7 m). The sandstone is white to light brown and light reddish-brown, well sorted, rounded, and porous. Consolidation varies with most being subfriable, but an interval of very coarse to coarse-grained sand from 713.3 to 713.6 m is completely unconsolidated. Bedding ranges from flat bedding to high- to low-angle cross-bedding. Some intervals are massive or structureless.

The top of the lower cycle is coarsely dolomitic and vuggy, and is capped by white nodular magnesite or anhydrite. Dolostone-rich intervals with interbedded mudstone and sandstone are present between 762.7 and 768.2 m, 794.5 and 797.5 m, and 800.3 and 809.5 m. The dolostone is mostly brown to grey, locally silicified, and commonly stromatolitic and stylolitic. Thin ooid grainstones are present locally, and intraclast horizons and anhydrite nodules are common. Sandstone between the dolostone-rich intervals is similar to that described above. The section from 809.5 to 899 m is dominated by medium- to coarse-grained sandstone, but with intervals of interbedded finer sandstone and mudstone between 833.1 and 838 m, 859.6 and 870.5 m, and 888.8 and 891.8 m. The main sandstone intervals comprise white to light-brown and light reddish-brown, well-sorted, rounded, subfriable, and porous sandstone. Sedimentary structures include flat bedding and high- to low-angle cross-bedding, with some massive intervals and soft-sediment deformation. Pyrite is sparse and anhydrite rare. Mudstone-bearing intervals vary from brown to yellow and green. Some green clay pellets may be glauconite. Current ripples are common in the fine-grained sandstone beds. Anhydrite nodules are common between 859.5 and 870.5 m.

The upper middle unit of the Hussar Formation (899 – 988.5 m) comprises evaporitic mudstone and dolostone. The upper part (899 – 929 m) is marked by red dolomitic mudstone with abundant desiccation cracks, rip-up clasts, current ripples and anhydrite nodules and veins. Red and brown dolostone interbeds between 912.5 and 921 m are commonly stromatolitic and stylolitic. Between 929 and 970 m the mudstone changes colour to predominantly grey, contains common grey dolostone interbeds and sparse pyrite, but lacks obvious evidence of desiccation. Thicker dolostone beds are commonly stromatolitic and stylolitic. Anhydrite is typically as ‘cauliflower’ nodules, and some beds display ‘chicken-wire’ texture. Thicker beds of massive white anhydrite are present from 929.3 to 929.5 m and in three beds between 933.6 and 936.1 m interbedded with dolostone. The interval from 969 to 988.5 m is dominated by brown and reddish-brown, flat-laminated mudstone with flat- to ripple cross-laminated siltstone and fine-grained sandstone interbeds. Green reductions spots are common, but evaporite minerals are absent.

The lower middle unit (988.5 – 1069.7 m) is dominated by sandstone, but contains numerous stromatolitic dolostone intervals up to 5 m thick. The sandstone is medium to coarse grained, moderately to well sorted, rounded, locally subfriable, and variably porous. Sedimentary structures include flat bedding and high- to low-angle cross-bedding and current ripple laminations. Colour varies from light brown to reddish-brown, green, and light grey. Mudstone forms interbeds in places, some with desiccation cracks. Dolostone intervals are mainly reddish-brown, and locally argillaceous. Ooid and other grainstone and packstone beds and intraclast horizons are common, but recrystallization of some beds makes identification of primary allochems difficult. Vugs and stylolites are locally common. Most dolostone horizons also contain anhydrite nodules, some partly replaced by chert.

The lower evaporitic mudstone unit from 1069.7 to 1201.9 m is dominated by reddish-brown mudstone, with local thin, graded, very fine grained sandstone to siltstone interbeds. The basal 5 m of the unit contain numerous medium-grained sandstone interbeds. Sulfate evaporites (predominantly anhydrite) form small nodules and are in veins, the latter including subvertical veins intersecting the core for up to 3 m. Greenish zones, mottles, and reduction spots are present throughout. The mudstone is commonly weakly dolomitic or calcareous and contains seven dolostone intervals ranging from less than 0.5 to 3 m thick. The dolostone intervals are typically grey and contain chert nodules or horizons, with sulfate evaporites common as layers, nodules or crosscutting veins. A 0.5 m-thick dolostone bed at the top of the unit contains possible halite pseudomorphs. One dolostone bed (1140.8 – 1143.1 m) contains partly silicified stromatolites.

The Hussar Formation was deposited in shallow- and marginal-marine conditions ranging from high-energy shoreface and beach–barrier environments to lagoons and evaporitic supratidal mudflats and coastal sabkhas.

Browne Formation

The Browne Formation (1201.9 – 1478.9 m, core depth, 1202.8 – 1480.3 m log depth) is widespread in the western Officer Basin, and shows limited variation (Grey et al., in prep.). In Lancer 1 the top of the Browne Formation is placed at a sharp contact at 1201.9 m between evaporitic mudstone of the lower Hussar Formation above and an orange-brown sandstone unit below. Correlation of this boundary to other wells is difficult because the Lancer Member (Grey et al., in prep.) has not been intersected in other wells. Elsewhere the upper boundary is defined at the top of a halite-bearing unit. The lower contact between the Browne Formation and an underlying well-cemented sandstone unit, tentatively identified as the Cornelia Sandstone, is placed at 1478.9 m and is considered to represent an erosional unconformity or disconformity.

The Browne Formation can be subdivided into an upper sandstone-dominated succession including the Lancer Member, a central stromatolitic dolostone and mudstone unit named the Woolnough Member, and a lower mudstone and evaporite succession. An upper evaporite succession, as seen in Hussar 1, Empress 1A, and other wells (Stevens and Apak, 1999), is not in Lancer 1.

Lancer Member (new name)

The Lancer Member (1201.9 – 1297.7 m core depth, 1202.8 –1298.7 m log depth) comprises the uppermost part of the Browne Formation in Lancer 1. Grey et al. (in prep.) discussed regional correlations for the unit. The upper contact with mudstone of the basal Hussar Formation is sharp and erosional, but it is unclear if a significant hiatus is involved. The Lancer Member comprises fine- to coarse-grained orange-brown to reddish-brown quartz sandstone, most of which is medium grained, well sorted, well rounded, and porous. It displays large cross-beds with foresets up to 11 m in thickness and foreset dip angles up to 27° (assuming negligible structural dip). Foreset beds grade downward with decreasing foreset angle into irregularly horizontally laminated sandstone zones, which are more poorly sorted and commonly display an alternation of grain size from fine to medium and locally to coarse. In places the foreset strata contains reversely graded translatent strata (Hunter, 1977). Inclined sandstone dykes a few millimetres to about a centimetre in thickness along small-scale normal faults within the foreset facies are interpreted as mainly of syndepositional origin. The Lancer Member sharply overlies reddish-brown mudstone and very fine grained sandstone at 1297.7 m.

The combination of primary sedimentary features indicates an eolian depositional environment for the Lancer Member. The large foresets are interpreted as deposition from migrating eolian dunes, whereas the irregularly laminated zones are considered to represent deposition within an inter-dune facies. The latter are most abundant and thickest in the lower part of the unit, whereas the foreset dune facies increases in abundance and thickness in the upper part. The Lancer Member has not been recognized elsewhere, but may correlate with sandy facies of the Mundadjini Formation in the northwest Officer Basin, which shows similar large cross-bedding (Williams, 1992; Grey et al., in prep.). Comparison with the section intersected by Empress 1A (Stevens and Apak, 1999) indicates that the member could be laterally equivalent to the halite and mudstone interval in the upper Browne Formation elsewhere. Thus in Lancer 1 the subaqueous evaporitic succession of the main basin depocentre is replaced by a mostly subaerial clastic facies, which apparently formed near the basin margin. Although the top of the Browne Formation in Lancer 1 is picked for convenience at the sharp top of the Lancer Member, it remains unclear how this stratigraphic position correlates to other drillholes.

Undifferentiated upper Browne Formation

The 25.7 m interval (1297.7 to 1323.4 m core depth, 1298.7 – 1324.4 log depth) between the Lancer and Woolnough Members is characterized by reddish-brown, poorly sorted, very fine grained sandstone and mudstone with irregular laminations. The upper contact is very sharp. Medium-grained and, rarely, coarse-grained sandstone are present near the base and top. Minor greenish sandstone beds are cleaner and better sorted. The contact with the carbonate-rich Woolnough Member at 1323.4 m is sharp, but conformable. The interval was deposited under frequently or predominantly emergent conditions such as on a supratidal flat or playa lake.

Woolnough Member

The Woolnough Member (first named the 'Woolnough beds' by Jackson and van de Graaff, 1981; Grey et al., in prep.) consists of dolostone, argillaceous dolostone, dolomitic mudstone, and minor dolomitic sandstone over the interval 1323.4 – 1357.7 m (1324.4 – 1358.7 m log depth). Dolostone beds vary from pink-grey to brownish-grey, whereas muddy horizons alternate between reddish-brown, green, and grey. There are at least nine distinct stromatolite horizons, although some appear to be an amalgamation of several stacked bioherms. The most distinctive type shows an upward transition from domal to narrow columnar form similar to *Acaciella australica*. Some of the nonstromatolitic dolostone beds appear to be grainstones, although recrystallization makes the identification of primary allochems difficult. Laminated muddy horizons show evidence of desiccation, and rip-up mud clast and dolostone clast horizons are common. Anhydrite–gypsum is mainly a vein-filling material. The largest veins are subvertical and intersect the core for up to 3 m.

The Woolnough Member conformably overlies red dolomitic mudstones at 1357.7 m and is overlain abruptly by sandstone at 1323.4 m. It was deposited in shallow-water to periodically emergent conditions, probably in an intertidal to lagoonal environment. Individual stromatolitic bands are interpreted as small-scale shallowing-upward cycles. The presence of the *A. australica* Stromatolite Assemblage allows correlation with the Skates Hill Formation in the northwestern Officer Basin, the Loves Creek Member of the Bitter Springs Formation in the Amadeus Basin, the Yackah beds in the Georgina Basin, and the Coominaree Dolomite in the Adelaide Rift Complex (Grey, 1995; Hill et al., 2000; Grey et al., in prep.).

Lower Browne Formation

The lower Browne Formation (1357.7 to 1478.9 m core depth, 1358.7 – 1480.3 log depth) is dominated by mudstone and evaporites. The interval from 1357.7 to 1382.2 m comprises reddish-brown weakly dolomitic mudstone with common mottled-green reduction spots. The mudstone is massive to irregularly laminated, and contains horizons of scattered sand grains near the base of the interval. Unlike deeper parts of the formation it is devoid of evaporite minerals or their pseudomorphs. White anhydrite–gypsum forms nodules, veins, and pseudomorphs after halite below 1382.2 m, embedded in an otherwise similar mudstone succession. Thin interbedded dolostone beds are also present below this depth, together with current ripples and probable desiccation cracks. Thin medium- to coarse-grained immature sandy and granule interbeds are typically sparse, but are abundant between 1386.5 and 1390 m.

The first preserved halite appears at 1408.5 m, and between this position and 1415 m the halite forms cores within partial anhydrite–gypsum pseudomorphs. Because most of the halite along the core surface was dissolved out during drilling, the appearance is of voids lined with white anhydrite–gypsum. From 1415 to 1442 m, reddish-brown massive to weakly laminated dolomitic mudstone with green reduction spots contains common clear halite as isolated crystals, crystal clusters, and veins. The halite forms distinct layers of greater abundance below 1428 m, but there are no massive halite beds in this interval. ‘Pagoda’-shaped skeletal halite is common. The mudstone contains sparse thin coarse-grained immature sandy beds.

The interval from 1440.8 to 1472.4 m consists of coarse-grained massive halite interbedded with reddish-brown dolomitic mudstone and grey dolostone. Individual halite beds are more than 0.5 m thick, whereas fine-grained clastic interbeds range from centimetre scale to 3 m in thickness. Interbedded lithologies contain scattered halite as isolated crystals and veins, variably dissolved out during drilling. The halite crystals are mostly euhedral or subhedral, although commonly distorted by compaction. ‘Pagoda’-shaped skeletal halite is locally common, for example around 1465 m. The halite varies from nearly colourless to (more commonly) orange.

The basal 6.5 m of the formation (1472.4 – 1478.9 m) consists of interbedded grey laminated argillaceous and silty dolostone and dolomitic sandstone, with thin dark-grey to black mudstone interbeds and minor conglomeratic horizons. Minor halite and anhydrite are present. The halite is more abundant at the top of the interval, but has commonly been dissolved out by drilling fluids leaving voids. A 10 cm-thick sandy conglomeratic bed overlies the erosional basal contact of the Browne Formation.

The lower Browne Formation is interpreted as a shallowing-upward, shallow- to marginal-marine evaporite succession. After a thin transgressive interval, massive halite beds were deposited under brine pool conditions. The thickness of massive halite is indicative of a marine brine source, but with tenuous connection to the ocean allowing hypersaline conditions to develop under the influence of an arid climate. The depositional environment shallowed over time, leading to a supratidal evaporitic mudflat environment. Strong similarities in both facies and thickness to the lower Browne Formation in Empress 1A, 260 km to the south (Stevens and Apak, 1999; Figs 6 and 7), suggest subdued topography and uniform subsidence during this part of the basin’s history, at least across the western part of the basin.

?Mesoproterozoic section

?Cornelia Sandstone

The oldest stratigraphic unit penetrated in Lancer 1 contains bluish-grey, well-cemented feldspathic and micaceous sandstone from 1478.9 to 1501.2 m (1480.3 – 1502.25 m log depth). The sandstone is moderately sorted and mostly medium grained, but contains coarse and granular horizons and sparse small pebbles. The unit contains minor clay matrix, probably derived from the breakdown of labile minerals. There is no visible porosity, although the sonic log indicates some porosity, but the density log implies that this interval is denser than quartz. Medium-scale (10–30 cm) cross-bedding is ubiquitous. There is a single thin (~1 cm) mudstone interbed at 1498.2 m. Deposition occurred in a fluvial or, less likely, a high-energy shallow-marine environment.

The total thickness of the unit is unknown, as only the top 22.3 m was penetrated in Lancer 1. The contact with the overlying Browne Formation at 1478.9 m is erosional. A hiatus of uncertain duration is thus indicated, although there is no evidence of significant metamorphism or tectonism in the older unit. Fractures become more common toward the upper contact and some are filled with halite or calcite. The top surface of the thin mudstone interbed at 1498.2 m dips at 4° to the horizontal (assuming vertical core axis), in contrast to average dips derived from the lower Browne Formation of about 2°.

Although a slight angular relationship is possible, it is uncertain if the mudstone surface represents a reliable primary horizontal surface. The age of the unit is poorly constrained, being early Neoproterozoic or older. It is tentatively assigned to the Cornelia Sandstone, a unit of probable Mesoproterozoic age that forms much of the Oldham Inlier and underlies the Officer Basin succession in northwestern areas (Hocking et al., 2000; Jones et al., 2000).

An alternative possibility is that the unit correlates with the Townsend Quartzite of the north-central Officer Basin, although the absence of this formation in Empress 1A makes this unlikely, as does the apparent structural discontinuity with the overlying Officer Basin succession visible on seismic data.

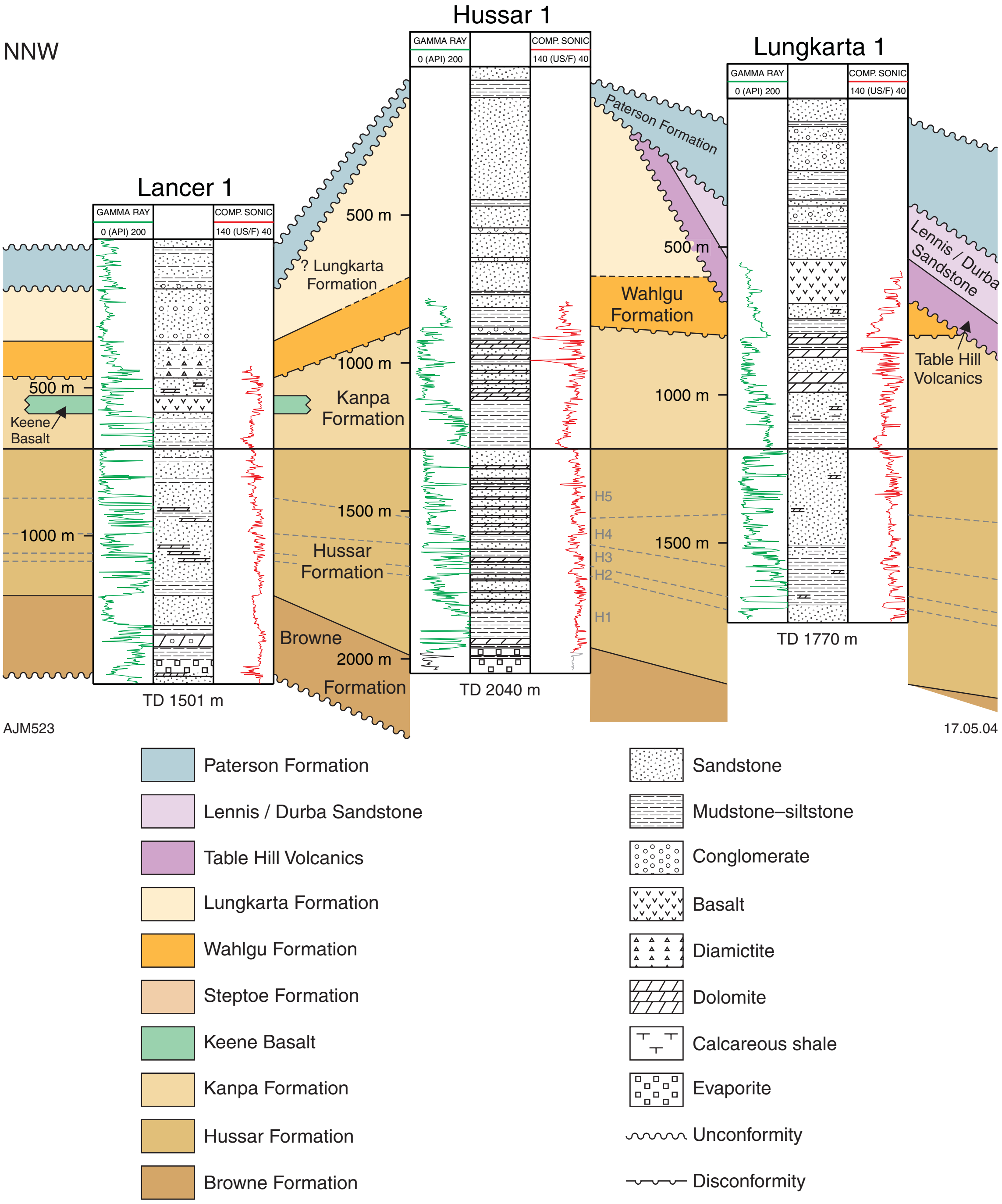
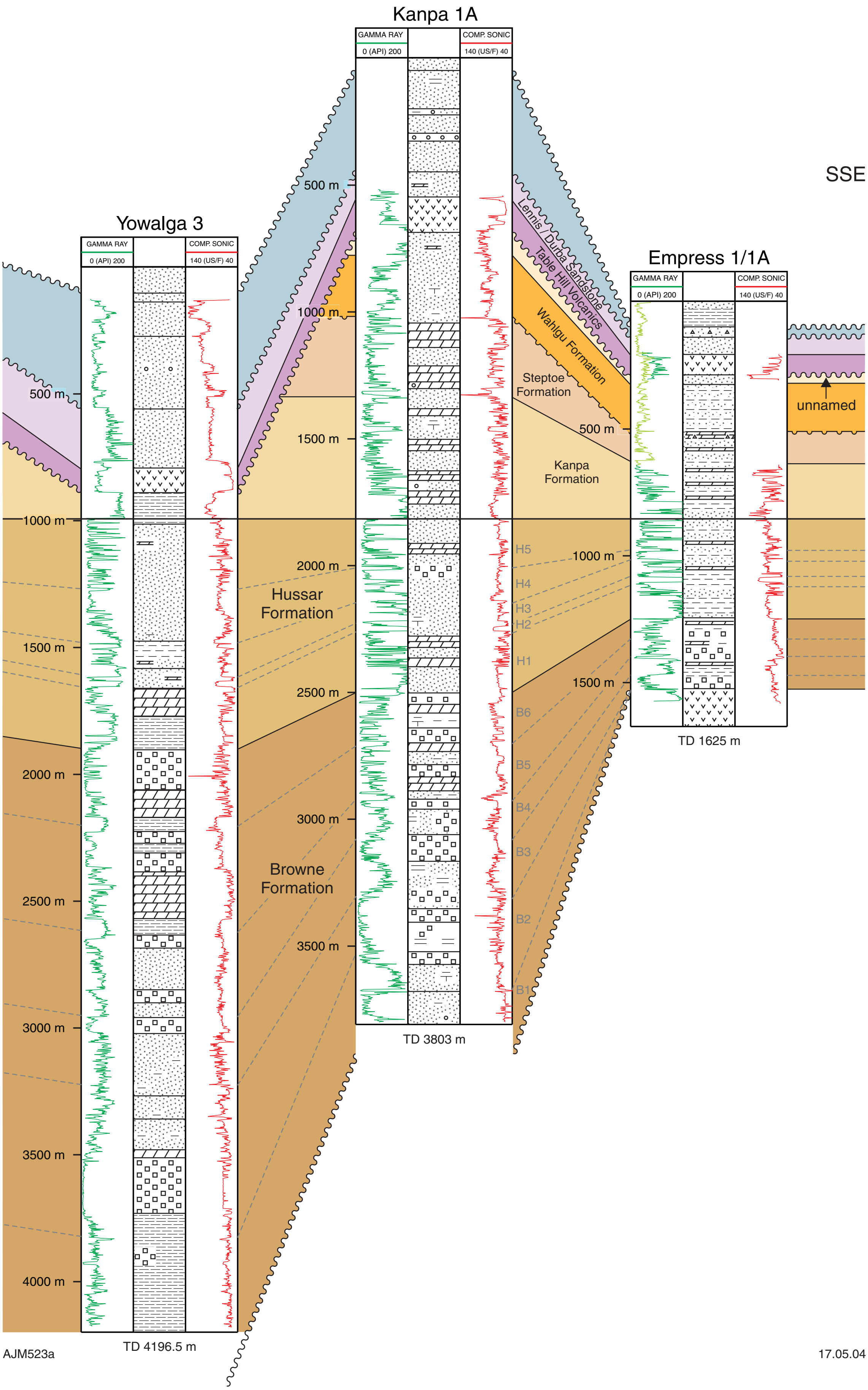


Figure 6. (This and facing page) Correlation of Lancer 1 with petroleum and stratigraphic wells (after Moors and Apak, 2002, and Apak and Moors, 2000). Line of section shown on Figure 2


Kanpa 1A
Yowalga 3
Empress 1/1A
SSE
GAMMA RAY
0 (API) 200
COMP. SONIC
140 (US/F) 40
Lennis / Durba Sandstone
Table Hill Volcanics
Wahlgu Formation
Steptoe Formation
Kanpa Formation
unnamed
Hussar Formation
Browne Formation
H5
H4
H3
H2
H1
B6
B5
B4
B3
B2
B1
500 m
1000 m
1500 m
2000 m
2500 m
3000 m
3500 m
4000 m
TD 4196.5 m
TD 3803 m
TD 1625 m
AJM523a
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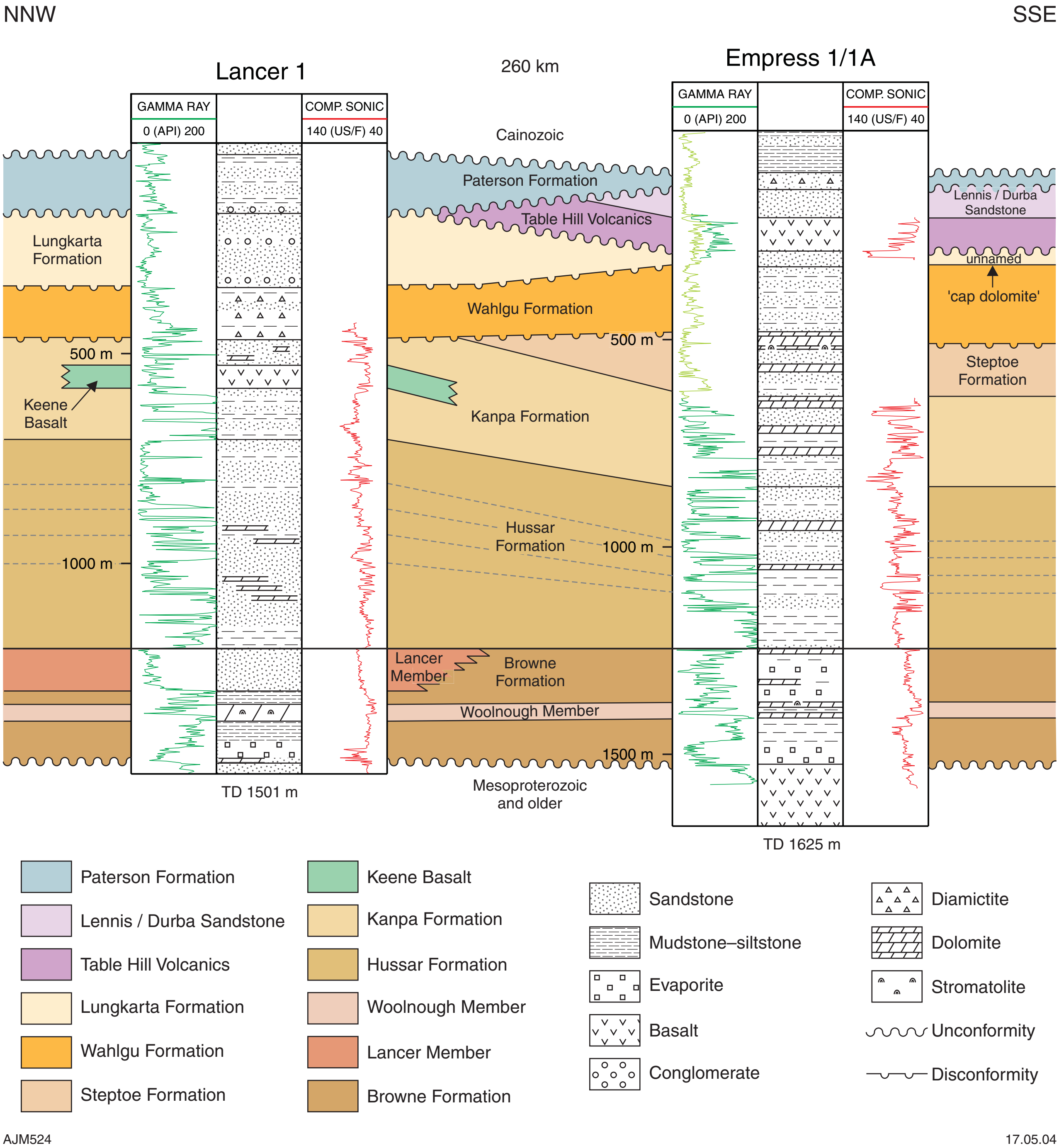


Figure 7. Correlation of Lancer 1 with Empress 1/1A

Petroleum geology (preliminary)

Source potential

Of the 22 samples of fine-grained siliciclastic rock analysed by Geotechnical Services (Table 1), only two from the Kanpa Formation yielded total organic carbon (TOC) greater than 0.5% (Fig. 8). Rock-Eval pyrolysis indicates that it is a poor source rock (S_2 = 1.14 mg/g) likely to generate predominately gas (hydrogen index of 163).

Palynomorphs with a thermal alteration index of 2 (immature to mid-mature) were recovered from the Paterson Formation (Backhouse, J., written comm., 2004). Two samples (from 504.8 and 937.4 m) yielded reflectance values from nonfluorescing lamalginite (Table 2). In the higher sample the colours and intensity of fluorescing lamalginite are consistent with a vitrinite reflectance equivalent of about 0.85%, which is close to the maximum reflectance value measured from nonfluorescing lamalginite (0.86%), and indicates that the Neoproterozoic section is within the oil-generative window, as does the presence of rare oil droplets (Table 2). Lower reflectance values were obtained from the lower sample, but the lamalginite fluorescence is much weaker and overall indicates a more mature part of the section compared to the higher sample (Table 2). In comparison, the low temperature of maximum pyrolytic yield (T_{max}; Table 1) and the high permeabilities throughout the Neoproterozoic and overlying section (Table 3) imply that it is immature for oil generation, but are not considered reliable guides to maturity.

Reservoir characteristics

On the basis of 40 core measurements (Table 3), overall sandstone reservoir quality is excellent, with several intervals having porosities of more than 20% and permeabilities above 1 darcy. Intervals with reservoir quality of this calibre include the Lancer Member of the Browne Formation, sandstone in the upper Hussar Formation, the upper Wahlgu Formation, and sandstone of the Lungkarta and Paterson Formations. Intermediate-quality reservoirs (porosity 12–23%, permeability 50–700 mD) include thin sandstone beds in the lower parts of the Hussar and Kanpa Formations. The dolostones have very poor reservoir characteristics.

Twenty-eight samples were from sandstone, and the best porosity (26.5%) is recorded at 753.5 m in the Hussar Formation, with 3447 mD permeability. The two best permeabilities are from 393.1 m (Wahlgu Formation, 10 080 mD, 25.7% porosity), and 1202.6 m (Browne Formation, 9980 mD, 26.2% porosity).

Ten samples were from dolostone, of which the best porosity (5.3%) is recorded at 477.0 m in the Kanpa Formation, with less than 0.01 mD permeability. The best permeability is from 498.1 m (Kanpa Formation, 0.16 mD, 2.3% porosity).

Table 1. TOC and Rock-Eval data from Lancer 1 core samples

Depth (m)	*Formation*	*Lithology*	*T_{max} (°C)*	*S_1*	*S_2*	*S_3 mg/g*	*S_1+S_2*	*S_2/S_3*	*PI*	*TOC (%)*	*HI*	*OI*
472.70	Wahlgu Fm	medium-grey mudstone	nd	nd	nd	nd	nd	nd	nd	0.20	nd	nd
504.50	Kanpa Fm	medium-grey mudstone	419	0.02	0.34	0.17	0.36	2.00	0.06	0.52	65	33
504.80	Kanpa Fm	medium-grey mudstone	420	0.00	1.14	0.12	1.14	9.50	0.00	0.70	163	17
505.08	Kanpa Fm	medium-grey mudstone	nd	nd	nd	nd	nd	nd	nd	0.26	nd	nd
508.90	Kanpa Fm	pale-grey siltstone	nd	nd	nd	nd	nd	nd	nd	0.02	nd	nd
605.14	Kanpa Fm	dark-grey siltstone	nd	nd	nd	nd	nd	nd	nd	0.12	nd	nd
614.10	Kanpa Fm	medium-grey mudstone	nd	nd	nd	nd	nd	nd	nd	0.17	nd	nd
621.85	Kanpa Fm	medium-grey mudstone	nd	nd	nd	nd	nd	nd	nd	0.02	nd	nd
648.35	Kanpa Fm	medium-grey mudstone	nd	nd	nd	nd	nd	nd	nd	0.05	nd	nd
666.00	Kanpa Fm	dark-grey mudstone	nd	nd	nd	nd	nd	nd	nd	0.16	nd	nd
672.70	Kanpa Fm	medium-grey mudstone	nd	nd	nd	nd	nd	nd	nd	0.14	nd	nd
681.00	Kanpa Fm	dark-grey mudstone	nd	nd	nd	nd	nd	nd	nd	0.17	nd	nd
690.35	Kanpa Fm	medium-grey siltstone	nd	nd	nd	nd	nd	nd	nd	0.09	nd	nd
937.44	Hussar Fm	dark-grey mudstone	nd	nd	nd	nd	nd	nd	nd	0.25	nd	nd
942.50	Hussar Fm	dark-grey mudstone	nd	nd	nd	nd	nd	nd	nd	0.05	nd	nd
965.00	Hussar Fm	dark-grey mudstone	nd	nd	nd	nd	nd	nd	nd	0.06	nd	nd
1088.00	Hussar Fm	very pale grey mudstone	nd	nd	nd	nd	nd	nd	nd	0.03	nd	nd
1142.83	Hussar Fm	pale-grey mudstone	nd	nd	nd	nd	nd	nd	nd	0.06	nd	nd
1348.35	Browne Fm	very pale grey mudstone	nd	nd	nd	nd	nd	nd	nd	0.02	nd	nd
1470.58	Browne Fm	dark-grey mudstone	nd	nd	nd	nd	nd	nd	nd	0.08	nd	nd
1475.00	Browne Fm	dark-grey mudstone	nd	nd	nd	nd	nd	nd	nd	0.25	nd	nd
1498.22	?Cornelia Ss	pale green-grey siltstone	nd	nd	nd	nd	nd	nd	nd	0.05	nd	nd

NOTES:
Fm: Formation; OI: oxygen index; S_1: existing hydrocarbons; S_1+S_2: potential yield
HI: hydrogen index; PI: production index; S_2: pyrolytic yield of hydrocarbons; T_{max}: temperature of maximum pyrolytic yield (S_2)
nd: not determined; Ss: Sandstone; S_3: organic carbon dioxide; TOC: total organic carbon

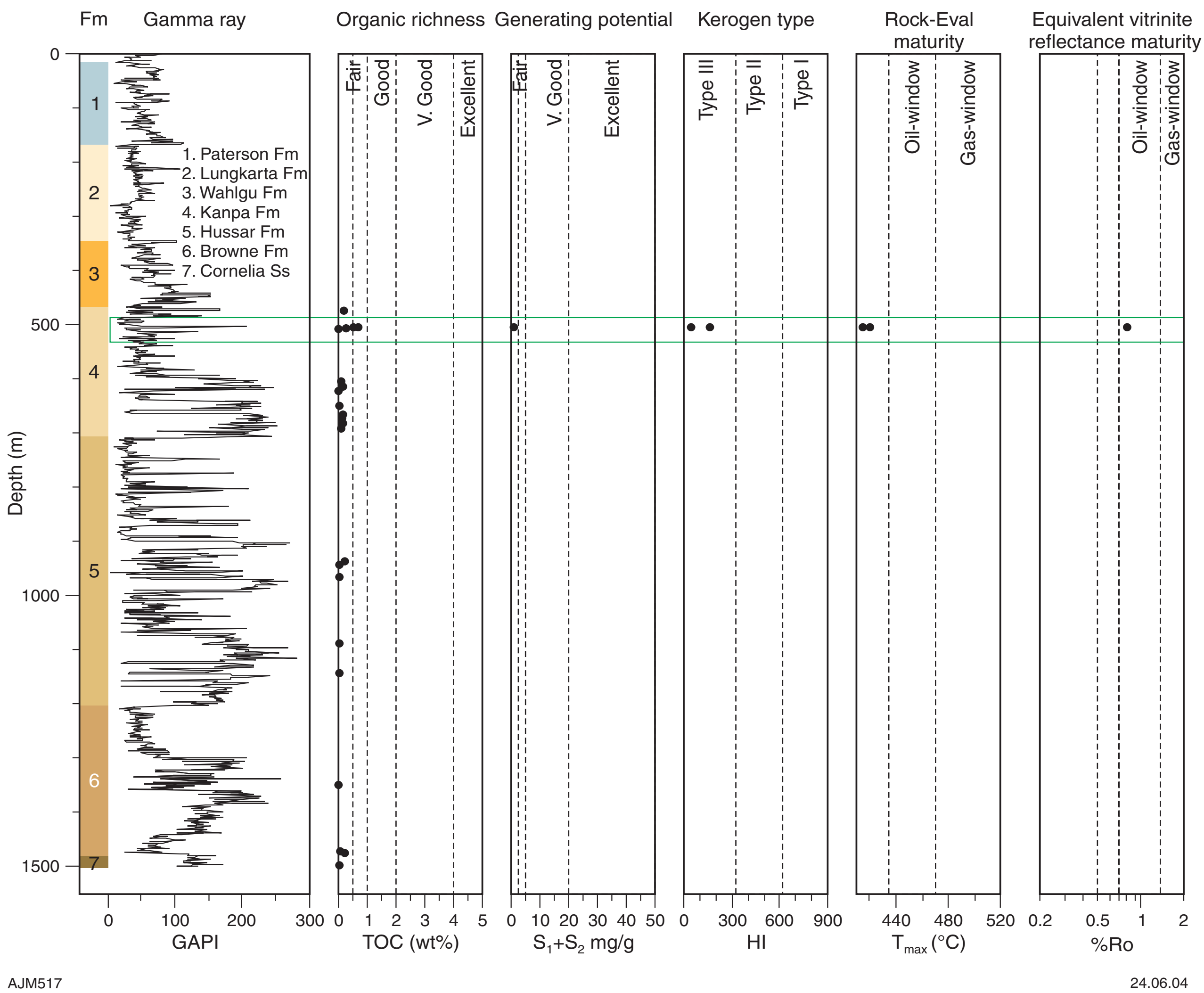


Figure 8. Petroleum-source generating potential, kerogen type, and thermal maturity, Lancer 1

A dolostone–sandstone sample from the Kanpa Formation has a porosity of 5.6% and permeability of less than 0.01 mD.

A conglomerate sample from the Browne Formation has a porosity of 0.8% and permeability of less than 0.01 mD.

Seals

Potential regional seals include mudstone at the base of the Hussar and Kanpa Formations. The artesian flow from the Wahlgu Formation, which could not be controlled with 1.2 SG mud weight, demonstrated that the formation contains a regionally significant reservoir–seal couplet.

A leak-off test in the Wahlgu Formation confirmed excellent sealing qualities, with the diamictite able to take 2.67 SG mud weight.

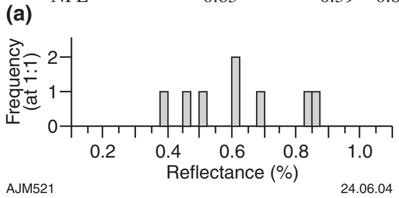
Shows

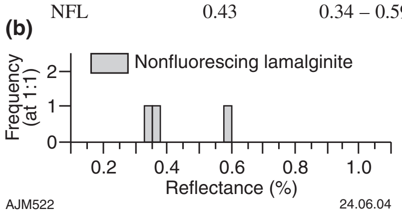
No anomalous mud-gas was recorded during drilling, and all fluorescence observed appears to be of mineral origin. Intra-Hussar and Wahlgu Formation hydrocarbon occurrences implied by slow solvent cut and a faint smell of oil in the field do not appear to be significant because organic petrography of these levels indicates that most fluorescence is from carbonate cement, with traces of bitumen and oil (Table 2).

The night-shift drilling crew noticed ‘frothing’ from the surface of the core at 534.4 m in the Keene Basalt, but the presumed release of gas stopped before the geologist inspected the core a short time later. The ‘frothing’ may have been a chemical reaction rather than release of gas, but in either case it could not be evaluated as it did not reoccur when the next tube was recovered, nor was anomalous gas recorded by the mud-gas detector at the time.

Table 2. Organic petrography of seven core samples, Lancer 1 (by A. C. Cook, Keiraville Konsultants)

KK ref no.	*Depth (m)*	$\overline{R}_{max}$	R_{max} *range*	*N*	*Sample description including liptinite fluorescence, maceral abundances, and mineral fluorescence*
T9570	504.8 NFL	0.63	0.39 – 0.86[(a)]	8	Abundant lamalginite dull orange. (Siltstone. DOM abundant, L only, I and V absent. Lamalginite abundant. The lamalginite occurs as thin wisps and as thicker felted lamellar masses. Locally, the lamalginite is reflecting and the reflectance of this component has been reported. The reflectances obtained and the fluorescence colours and intensity for the lamalginite are consistent with a vitrinite reflectance equivalent of about 0.85%. Rare very small bright-yellow oil drops, mostly associated with the lamalginite, but some within or coating quartz grains. Mineral fluorescence weak dull orange within clay-sized particles, and absent from quartz grains. Pyrite abundant)
T8444	861.44 – 861.57	–	–	–	Fluorescing liptinite absent. (Sandstone with calcite cement. DOM absent. Sandstone contains irregular pale patches up to 1 cm across that are associated with strong yellow to yellowish-orange fluorescence from the matrix, probably from calcite. Surrounding the paler sandstone, fluorescence is weak to absent. No evidence of free oil was found in association with the bright fluorescing matrix. Pyrite absent)
T8438	869.38 – 869.50	–	–	–	Fluorescing liptinite absent. (Sandstone with calcite cement. DOM absent. One grain of quartz contains rare small yellow oil inclusions. Mineral fluorescence mostly weak to absent, but patches up to 0.2 mm across with strong yellow fluorescence that appears to come from carbonate. Pyrite absent)
T8439	890.17 – 890.32	–	–	–	Fluorescing liptinite absent. (Sandstone with calcite cement. DOM absent. Mineral fluorescence mostly weak to absent, but patches up to 0.2 mm across with strong yellow fluorescence that appears to come from carbonate. Pyrite absent)
T8445	891.83 – 891.98	–	–	–	Fluorescing liptinite absent. (Sandstone with calcite cement and thin layer of micaceous claystone. DOM absent. Mineral fluorescence mostly weak to absent, but patches up to 0.2 mm across with strong yellow fluorescence that appears to come from carbonate. Pyrite absent)
T9571	937.44 NFL	0.43	0.34 – 0.59[(b)]	3	Sparse lamalginite dull orange. (Calcareous claystone. DOM L only, I and V absent. The lamalginite occurs as thin weakly fluorescing wisps. Similar shaped wisps of diffuse humic matter probably represent lamalginite coalified to the point where it has lost its fluorescence, but most has not taken a polish. The reflectances obtained are lower than those from 504 m, but the lamalginite fluorescence is much weaker and overall the indications are of a more mature part of the section compared with 504 m. Mineral fluorescence very weak dull orange. Iron oxides sparse. Pyrite abundant)
T9572	1475	–	–	–	Sparse lamalginite yellowish-orange to dull orange. (Calcareous claystone. Dom L>>? I and V absent. The lamalginite occurs as thin wisps that show marginally brighter fluorescence compared with T9571. Similar shaped wisps of diffuse humic matter probably represent lamalginite coalified to the point where it has lost its fluorescence, but none took a polish. A single small grain with reflectance of 1.54% is referred to as inertinite, but is of unknown origin. The lamalginite fluorescence is marginally stronger compared with T9571, possibly representing different algal entities, but also probably indicating a low maturation gradient. Mineral fluorescence very weak dull orange. Iron oxides sparse. Pyrite abundant)





NOTES:

DOM:	dispersed organic matter	NFL:	nonfluorescing lamalginite	I:	inertinite
L:	liptonite	V:	vitrinite	–:	not determined
$\overline{R}_{max}$:	mean maximum reflectance value	R_{max}:	maximum reflectance value	N:	number of samples

The samples were examined as polished sections that had been impregnated with polyester resin and the rough sawn surfaces were also examined using both reflected white-light mode and fluorescence mode. The four sandstone samples from 861 to 892 m are to evaluate possible oil occurrences, whereas the other three are to evaluate thermal maturity.

No free oil was found in the samples from 861 to 892 m (eight blocks in all), and only one grain of quartz contains oil inclusions (sample T8438 from 869.38 – 869.50 m). In these samples the patches with strong yellow fluorescence probably represent calcite with some bitumen dispersed in the calcite. Normal quartz grains and calcite cement surround the brightly fluorescing areas, with both these components showing weak to no fluorescence. The reason for the very localized nature of the brightly fluorescing patches is not clear. In T8444, large pale areas show strong interstitial fluorescence, but a similar colour pattern in T8445 does not show the same pattern of distribution of fluorescence. If attempts were made to recover hydrocarbons from these samples, extraction of untreated samples is likely to yield only contaminants. It is probable that dissolving the calcite cement with hydrochloric acid would liberate some hydrocarbons. Complete dissolution with hydrofluoric acid is not likely to yield additional hydrocarbons.

The fine-grained clastic samples contain lamalginite showing variable fluorescence. The lowest maturity is clearly at 504.8 m. Some reflectance measurements were made on nonfluorescing lamalginite that had taken a polish. As well as the fields that had taken a polish, coalified lamalginite remains are present in all the cores of fine clastics as diffused humic organic matter.

The fluorescing lamalginite provides better indications of the level of maturation compared with the sandstone cores. The characteristics of the shales indicate that the brightly fluorescing patches within the sands could be related to the presence of oil, but the fluorescence within the rocks that contains the lamalginite is relatively weak. This could be taken to indicate that oil generation has not occurred or that it has occurred and that migration has been relatively efficient. The second option seems more likely.

Table 3. Core porosity, grain density and permeability, Lancer 1

Depth (m)	*Formation*	*Lithology*	*Porosity helium (%)*	*Grain density (g/cm³)*	*Permeability to air (mD)*
131.9	Paterson Formation	Mottled medium-grained muddy sandstone	28.6	2.66	1 655
149.5	Paterson Formation	Light-brown coarse-grained sandstone	26.3	2.65	3 940
174.5	Lungkarta Formation	Light-brown medium-grained sandstone	21.8	2.65	1 109
225.2	Lungkarta Formation	Brown medium-grained muddy sandstone	24.8	2.64	1 713
305.5	Lungkarta Formation	Red-brown medium-grained muddy sandstone	18.8	2.67	197
337.0	Lungkarta Formation	Red-brown medium-grained muddy sandstone	22.4	2.66	37.2
358.0	Wahlgu Formation	Red-brown medium- to coarse-grained sandstone	24	2.67	1 624
393.1	Wahlgu Formation	Brown pebbly coarse-grained muddy sandstone	25.7	2.65	10 080
450.8	Wahlgu Formation	Light-brown fine- to medium-grained sandstone	13.4	2.68	2.94
458.0	Wahlgu Formation	Brown medium-grained muddy sandstone	13.3	2.71	0.08
477.0	Kanpa Formation	Grey fine-grained stromatolitic dolostone	5.3	2.82	<0.01
498.1	Kanpa Formation	Light-grey stromatolitic dolostone	2.3	2.85	0.16
506.0	Kanpa Formation	Light-grey dolostone and fine-grained sandstone	5.6	2.83	<0.01
597.1	Kanpa Formation	Brown fine- to medium-grained sandstone	23.7	2.64	68.5
624.0	Kanpa Formation	Light-brown medium-grained sandstone	16	2.64	400
662.0	Kanpa Formation	Dark-brown medium-grained sandstone	20.9	2.66	667
696.2	Kanpa Formation	Light-grey medium-grained sandstone	19.3	2.65	691
708.5	Hussar Formation	Grey medium- to coarse-grained sandstone	13.8	2.64	1 380
737.9	Hussar Formation	Light-grey medium- to coarse grained sandstone	22.1	2.64	3 273
753.5	Hussar Formation	Brown medium-grained sandstone	26.5	2.65	3 447
767.1	Hussar Formation	Light fine-grained laminated dolostone	2.1	2.8	<0.01
780.1	Hussar Formation	Light-brown medium-grained sandstone	29	2.64	5 660
804.1	Hussar Formation	Light-grey fine-grained stylolitic dolostone	0.5	2.84	<0.01
839.7	Hussar Formation	Brown medium- to coarse-grained sandstone	18.1	2.64	818
863.4	Hussar Formation	Light-grey medium-grained sandstone	21.2	2.64	252
872.9	Hussar Formation	Light-grey medium-grained sandstone	11.8	2.64	287
896.2	Hussar Formation	Light-green medium- to coarse-grained sandstone	20.9	2.64	1 880
914.4	Hussar Formation	Light-grey fine-grained dolostone	0	2.82	<0.01
967.0	Hussar Formation	Grey argillaceous dolostone	0.1	2.7	<0.01
990.1	Hussar Formation	Light-brown medium-grained sandstone	12	2.64	239
1 030.1	Hussar Formation	Light-grey dolostone	0.3	2.84	<0.01
1 055.0	Hussar Formation	Light-grey medium-grained sandstone	18.5	2.65	272
1 122.9	Hussar Formation	Light-grey cherty dolostone	0.1	2.77	0.01
1 142.6	Hussar Formation	Light-grey dolostone	1.1	2.98	<0.01
1 156.1	Hussar Formation	Light-grey-brown dolostone	0.2	2.77	<0.01
1 202.6	Browne Formation	Light-brown medium-grained sandstone	26.2	2.63	9 980
1 292.1	Browne Formation	Brown medium-grained sandstone	20.2	2.65	1 943
1 475.3	Browne Formation	Light-brown conglomerate, sedimentary clasts	0.8	2.75	<0.01
1 477.6	Browne Formation	Light-brown fine-grained sandstone	2.1	2.52	2.68
1 488.1	?Cornelia Sandstone	Light-grey fine- to medium-grained sandstone	0.5	2.61	<0.01

Contributions to geological knowledge

Lancer 1 provides a second fully cored section of the Officer Basin succession, in a position close to the northwest Paterson Orogen and the exposed succession in the northwestern Officer Basin. The ability to compare this section with others to the east, southeast, and south, particularly Empress 1/1A, is a major contribution to the knowledge of the basin. Lancer 1 allows the stratigraphic framework used in outcrop, and as penetrated by Boondawari 1 and Mundadjini 1, of the northwestern Officer Basin (the Sunbeam Group, Boondawari Formation, and Disappointment Group), to be correlated with the succession known from drillholes, seismic mapping, and a few diapirs and scattered outcrops in the main part of the Officer Basin in Western Australia. These correlations are discussed in detail by Grey et al. (in prep.).

Sections of the Browne Formation in Lancer 1 and Empress 1A, 260 km to the southeast, are remarkably similar, especially in thickness. The principal difference is a sandstone unit of eolian origin at the top of the formation in Lancer 1 (Fig. 7), here named the Lancer Member. This member correlates with evaporites (halite dominated) in Yowalga 3, Kanpa 1A, and Empress 1A (Fig. 6). The remarkable similarity with Empress 1A, and pronounced similarities to other well intersections, implies a low topographic gradient across the 'western platform' of the basin during deposition of the Browne Formation, a low-relief hinterland, and regional-scale controls on deposition and subsidence across this part of the Officer Basin. Regional correlations with wells farther southeast (Fig. 6) show a dramatic increase in the thickness of the Browne Formation (by 800% from Empress 1A to Yowalga 3) to the northeast, in part due to westward onlap onto basement rocks. The overlying Hussar Formation shows little variation in facies other than minor thinning from 494 m in Lancer 1 to 390 m in Empress 1A (Fig. 7). This is attributed to a continued decrease in thermal subsidence within the western Officer Basin, perhaps as a product of far-field tectonics associated with a waning mantle plume beneath central Australia.

Based on the presence of *A. australica* Stromatolite Assemblage in both, the Browne Formation correlates with the Skates Hills Formation, and probably the lower Mundadjini Formation. The upper Mundadjini Formation may, based on lithological similarity and comparison of the sequences in Lancer 1 and Mundadjini 1, correlate in part with the upper Browne Formation and in part with the Hussar Formation. The Kanpa Formation appears to be stratigraphically higher than the exposed Sunbeam Group, but may correlate with part of the Tarcunyah Group, which is of established Supersequence 1 age (Bagas et al., 1999) but more deformed than most other Supersequence 1 rocks. The stratigraphic relationships both within the Tarcunyah Group and with the remainder of the Officer Basin succession remain imprecise.

The top of the Kanpa Formation is possibly karstified in Lancer 1, and almost certainly has been eroded beneath the Wahlgu Formation, implying a pronounced hiatus. The Wahlgu Formation in Lancer 1 is very similar lithologically to outcrops of parts of the Boondawari Formation, although the outcrops appear to extend stratigraphically higher than in Lancer 1, with a significant thickness of related rock above the 'cap dolomite'. The eolian sandstone of the Lungkarta Formation is remarkably similar to, and in the same relative stratigraphic position as, the McFadden Formation as exposed in the Durba and Diemels hills. It is also possible that the Durba Sandstone in the northwestern Officer Basin, which is probably younger than the Cambrian, correlates with the interval between 101 and 169 m in Lancer 1, which may in turn correlate with the Lennis Sandstone of the southern Officer Basin.

A series of basalt flows (Keene Basalt) within the Kanpa Formation is the second record of extrusive igneous rocks within the Neoproterozoic succession of Western Australia, and may provide a regionally significant tie to the radiometric timescale. Weedy 1 (600 km to the south-southeast on JUBILEE) intersected basaltic rocks with K–Ar ages of 657 ± 8 and 640 ± 10 Ma (Nelson, 2002), at shallow depths in channels evident on magnetic data. The stratigraphic affinities of the enclosing section are uncertain (Grey et al., in prep.), and it is unlikely that these basalts are similar in age to the Keene Basalt.

Acknowledgements

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Appendix 1

Operations report

Introduction

Lancer 1 is a stratigraphic drillhole that was drilled in the Officer Basin by Drillcorp Western Deephole using a UDR 1500 rig. The drillhole was spudded at 14:00 h on Friday 10 October 2003 and reached a total depth (TD) of 1501.3 m (drillers depth) at 19:15 h on Monday 17 November 2003, after being continuously cored from 104 to 1501.3 m. Time taken to reach TD was 38 days and 5 hours, and the total time the rig was deployed at the site was 41 days and 1 hour. Lancer 1 was plugged and abandoned at 14:45 h on Thursday 20 November 2003 (Fig. 1.1). The relative duration of the operational activities for Lancer 1 is summarized in Figure 1.2.

During geophysical logging from 18 to 19 November 2003, Geoscience Associates recorded a TD of 1502.25 m, and a bottomhole temperature of 63.5°C. The logging tools went into HWT casing at 428 m.

Note that the rig datum of Lancer 1 was raised 10 cm between the drilling of the PQ corehole at 429.5 m and the HQ corehole below this depth, in order to install the blow-out prevention (BOP) on the HWT casing string on 22 October.

Drilling operations

Drilling shifts:	Two 12-hour shifts operated each day (Table 1.1). Shift change was at 06:00 h and 18:00 h.
Drilling crews:	Each crew consisted of one driller and two or three driller's offsiders. The drillers were R. Armstrong, C. Behan, R. Russel, M. Hillier, and B. Roberts.
GSWA personnel:	Geologists: P. W. Haines, A. J. Mory, A. P. Simeonova, and M. K. Stevens; Field assistants: D. J. Clark, R. A. Green, M. Holmes, and J. C. Stedman.
Orientation surveys:	Hole orientation was monitored during drilling operations at various intervals between 111.5 m and 1223.3 m with an Eastman single shot camera (Table 1.2). Because deviations were minimal (<1° from vertical), surveys were not carried out below this depth.
Mud system:	Additives used during drilling are summarized in Table 1.3
Casing:	The casing strings used in Lancer 1 are shown in Table 1.4 and in Figure 1.3.
Time–depth curve:	The time–depth curve (Fig. 1.1) shows the progress of the drillhole during drilling based on times recorded in Table 1.1.
Core recovery:	PQ core recovery was approximately 325.3 m or 99.94% of 325.5 m drilled. HQ core recovery was approximately 1071.3 m or 99.96% of 1071.8 m drilled. The only zone of core loss greater than 15 cm was 27 cm at 795.30 – 795.57 m (Table 1.5).
Sampling	Cuttings samples were collected at 1 m intervals to 104 m from the returning mud at the wellhead using a bucket, and were later amalgamated to make a 3 m composite sample. Washed cuttings (up to 0.6 kg) were collected in plastic bags and dried. PQ and HQ core were placed in metal core trays in which core length was measured using a steel tape and the percentage recovery was calculated for each run (Table 1.5).
Mud-gas detection:	Two mud-gas detectors (CL 2100 and CL 900) were installed on 16 October at 294.5 m, but proved unreliable as shown by a large drift, especially during the day, possibly due to the slow rate of penetration and the fine grain size of the cuttings during wireline coring. The lack of air conditioning in the driller's office where the detectors were located may have contributed to their unreliability.
Blow-out preventor:	A 2000 psi annular BOP with a kill line incorporating a 2000 psi check valve was fitted on the HWT casing on 21 October at 428 m to safely release unexpected well fluids away from the rig via a flare line, but no such fluids were encountered.
Water supply:	Water for drilling and camp use was pumped from HRBB 2, a water bore drilled 1 km to the west of Lancer 1, which was completed from 18 to 24 m and produced water from a sandstone probably in the Paterson Formation. The water bore HRBB 1 was drilled 30 m north of Lancer 1, but only produced fresh water intermittently before watering out.

Drilling problems

Significant difficulties experienced in the drillhole included, in approximate chronological order:

- 100% lost circulation in sandstone at 9 m was solved by adding large amounts of lost circulation material, including diesel, Aus Gel, and sealant.
- Pulling out of the hole and reaming back to the bottom was required to deal with clays binding around collars and stabilizers at 75 m.
- One hour was spent reaming down through tight sections of PW casing while running in with PQ3 barrel for first time.

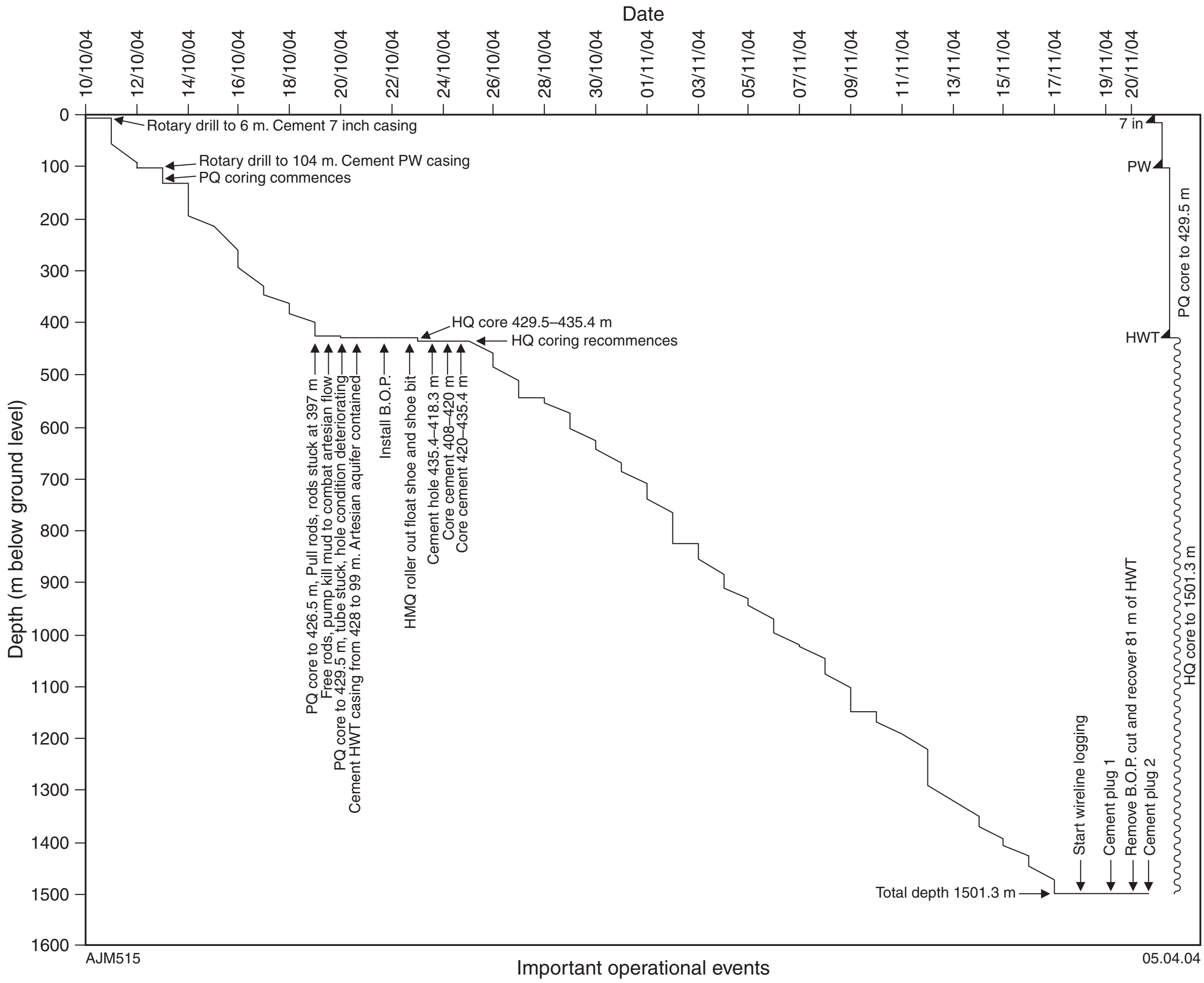

Figure 1.1. Time versus depth curve for Lancer 1

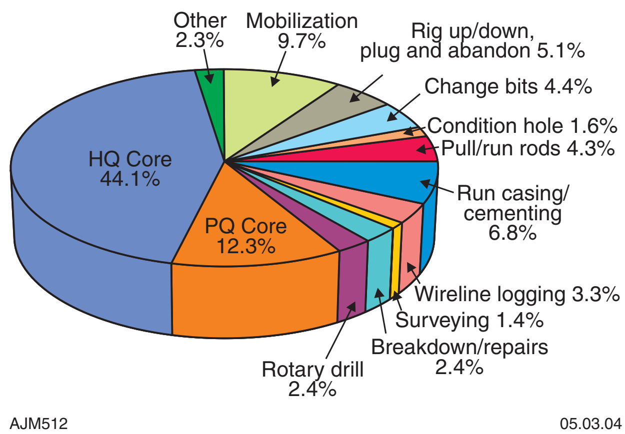

Figure 1.2. Breakdown of operation time for Lancer 1

- Rods had to be pulled to retrieve core that dropped from the barrel at about 400 m. No core was lost or damaged.
- On 19 October, after reaching a depth of 426.5 m, the rods were pulled to put on a softer bit. The rods became stuck at 397 m and an artesian water flow, presumed to be from 390.5 to 397 m, was swabbed in while freeing the drill string. Kill mud with specific gravity of 1.2 (the maximum available on site) failed to completely stop this flow, but reduced it to about 1 litre per second. After coring ahead for 3 m (depth 429.5 m) the tube was unable to be recovered, and mud properties could not be controlled because of dilution by the artesian aquifer. Considerable sand was noted in the possum belly, and also in the sand trap in the flow line. HWT casing was run in earlier than planned, but the HWT shoe could only be washed down to 428 m (1.5 m off bottom). The HWT casing was cemented from 428 to 99 m within the PW casing, which successfully contained the artesian flow. HQ coring below the HWT casing shoe confirmed that the anulus from 428 to 429.5 m was not cemented.

Table 1.1. Chronological summary of drilling operations

Date	*Shift*	*Time (indicative)*	*Activity*
10 October	Day	06:00–14:00 rig up 14:00–16:30 rotary drill 16:30–18:00 case and cement	Rig up, spud at 14:00 h, rotary drill with 215.9 mm, 8.5" rock roller bit 0–6 m, run 6 m of 177.8 mm (7") casing (6 m)
11 October	Day	06:00–07:00 rotary drilling 07:00–07:30 condition hole 07:30–09:00 pulling rods 09:00–18:00 rotary drilling	Rotary drill with 155.8 mm (6.25") rock roller bit 6–56 m, 100% loss of mud returns at 9 m (50 m)
	Night	18:00–24:00 rotary drilling 24:00–01:30 pulling rods 01:30–03:00 reaming 03:00–06:00 rotary drilling	Rotary drill with 155.8 mm (6.25") rock roller bit 56–92 m, pull rods at 75 m, ream back to bottom (36 m)
12 October	Day	06:00–09:00 rotary drilling 09:00–09:30 condition hole 09:30–17:30 pulling and running rods/casing 17:30–18:00 prepare to cement	Rotary drill with 155.8 mm (6.25") rock roller bit 92–104 m, run PW shoe bit and float shoe (12 m)
	Night	18:00–20:00 cement 20:00–06:00 wait on cement	Cement through PW float shoe at 104 m to surface
13 October	Day	06:00–08:00 wait on cement 08:00–09:30 running rods 09:30–10:30 drill out shoe 10:30–11:30 pulling rods 11:30–15:30 repair foot clamps 15:30–16:30 ream 16:30–18:00 PQ3 core	Ream out with 121 mm (4.75") rock roller, PQ3 core 104–108 m (4 m)
	Night	18:00–19:30 PQ3 core 19:30–19:45 survey at 111.5 m 19:45–21:00 repair bean pump 21:00–06:00 PQ3 core	PQ3 core 108 – 132.5 m (24.5 m)
14 October	Day	06:00–12:00 PQ3 core 12:00–12:15 survey at 141.5 m 12:15–12:30 reconfigure mud system 12:30–18:00 PQ3 core	PQ3 core 132.5 – 165.5 m (33 m)
	Night	18:00–20:00 PQ3 core 20:00–20:15 survey at 171.5 m 20:15 21:45 repair rig motor 21:45–06:00 PQ3 core	PQ3 core 165.5 – 195.5 m (30 m)
15 October	Day	06:00–15:00 PQ3 core 15:00–15:15 survey at 201.5 m 15:15–15:45 repair hydraulic hose 15:45–17:30 bit change 17:30–1800 PQ3 core	PQ3 core 195.5 – 216.5 m (21 m) Bit change at 205.2 m (Bit 4 101.2 m)
	Night	18:00–05:30 PQ3 core 05:30–06:00 surveys at 231.5 and 261.5 m	PQ3 core 216.5 – 261.5 m (45 m)
16 October	Day	06:00–17:15 PQ3 core 17:15–17:30 standby 17:30–18:00 survey at 291 m	PQ3 core 261.5 – 294.5 m (33 m) Install CL 2100 and CL 900 mud-gas detectors
	Night	18:00–05:30 PQ3 core 05:30–06:00 survey at 321.5 m	PQ3 core 294.5 – 329.6 m (35.1 m)
17 October	Day	06:00–14:00 PQ3 core 14:00–17:30 bit change 17:30–18:00 condition hole	PQ3 core 329.6 – 348.5 m (18.9 m) Bit change at 329.6 m (Bit 5 124.4 m) and 348.5 m (Bit 6, 100%) to suit ground conditions
	Night	18:00–03:00 PQ3 core 03:00–05:30 bit change 05:30–06:00 condition hole	PQ3 core 348.5 – 363.1 m (14.6 m) Bit change at 348.5 m (Bit 7) to suit ground conditions. Survey at 348.5 m
18 October	Day	06:00–08:00 PQ3 core	PQ3 core 361.3 – 384.5 m (21.4 m)
	Night	18:00–05:300 PQ3 core 05:30–06:00 survey at 384.5 m	PQ3 core 384.5 – 399.5 m (15 m)
19 October	Day	06:00–15:00 PQ3 core 15:00–15:30 condition hole 15:30–18:00 pull and run rods	PQ3 core 399.5 – 417.5 m (18 m) Dropped core but 100 % recovery
	Night	18:00–22:300 PQ3 core 22:30–23:00 survey at 417.5 m 23:00–02:00 free rods and ream 02:00–02:30 pull rods 02:30–03:30 consult client 03:30–06:00 pump kill mud	PQ3 core 417.5 – 426.5 m (9 m) Commence pulling rods to put softer bit on. Rods stuck at 397 m. Free stuck rods. Pump kill mud to combat artesian water flow

Table 1.1. (continued)

Date	*Shift*	*Time (indicative)*	*Activity*
20 October	Day	06:00–08:00 pump kill mud 08:00–09:30 PQ3 core 09:30–10:30 ream to bottom 10:30–12:30 attempt to retrieve tube 12:30–13:30 consult client 13:30–14:30 construct packer 14:30–18:00 pull and run rods	PQ3 core 426.5 – 429.5 m (3 m) (Bit 7, 95%, 81 m). Pump kill mud (nearly contain aquifer), ream, core, tube stuck and hole making sand Pull barrel, construct packer element and run float shoe and packer element to 428 m
	Night	18:00–20:00 cement casing 20:00–06:00 wait on cement	Cement HWT casing from 428 to 99 m. Artesian aquifer contained
21 October	Day	06:00–12:00 wait on cement 12:00–18:00 dig cellar	Wait for cement to set before cracking head. Dig cellar for BOP
	Night	18:00–02:00 dig cellar 02:00–06:00 install BOP	Install BOP on HWT casing
22 October	Day	06:00–14:00 install BOP 14:00–17:00 rig up 17:00–18:00 run rods	Nipple up BOP, assemble kill line, flow line. Raise drill floor 10 cm, install Jeronimo line. Run HMQ roller bit
	Night	18:00–00:30 ream 00:30–02:00 roll out shoe bit 02:00–05:00 pull and run rods 05:00–06:00 repair triplex pump	Run HMQ roller bit, hanging up at intervals below 318 m. Roll out float shoe at 428 m with HMQ roller bit. Run HQ 3 m STD barrel to 429.5 m
23 October	Day	06:00–11:00 HQ core 11:00–12:00 condition hole 12:00–18:00 standby	HQ core 429.5 – 435.4 m (5.9 m) Condition hole, wait for cement to arrive on site
	Night	08:00–21:00 pull rods 21:00–22:30 run rods 22:30–01:30 cementing 01:30–06:00 wait on cement	Pull 3 m barrel, run HMQ blank. Wait for cement to arrive on site Cement hole 435.4 – 418.3 m
24 October	Day	06:00–18:00 wait on cement	
	Night	18:00–02:30 wait on cement 02:30–04:00 run rods 04:00–06:00 HQ3 core	HQ3 core cement 408 – 420 m (Bit 9)
25 October	Day	06:00–12:00 wait on cement 12:00–17:30 HQ3 core 17:30–18:00 condition hole	Wait on cement to ensure good integrity HQ3 core cement from 420 to 435.4 m
	Night	18:00–18:45 leak off test 18:45–05:30 HQ3 core 05:30–06:00 survey at 441.4 m	LOT 2.67 SG, 22.48 ppg max kill mud weight HQ3 core 435.4 – 459.4 m (24 m)
26 October	Day	06:00–17:30 HQ3 core 17:30–18:00 survey at 477.4 m	HQ3 core 459.4 – 486.4 m (27 m), Unconsolidated sand at 462 m
	Night	18:00–05:30 HQ3 core 05:30–06:00 survey at 510.4 m	HQ3 core 486.4 – 513.4 m (27 m)
27 October	Day	06:00–13:45 HQ3 core 13:45–16:45 breakdown 16:45–18:00 change bit	HQ3 core 513.4 – 531.4 m (18 m), Repair Bean pump Bit change at 531.4 m (Bit 9 0%, 101.9 m formation and 27.4 m cement)
	Night	18:00–20:00 change bit 20:00–03:00 HQ3 core 03:00–03:30 condition hole 03:30–06:00 breakdown	HQ3 core 531.4 – 544.4 m (13 m). Bean pump stalling under pressure Frothing mud noted at 534.4 m while retrieving tube
28 October	Day	06:00–11:00 HQ3 core 11:00–13:30 bit change 13:30–15:00 HQ3 core 15:00–15:30 condition hole 15:30–18:00 breakdown	HQ3 core 544.4 – 555.4 m (11 m) Bit change at 553.4 m (Bit 10 100%, 22 m) to suit ground conditions Repair Bean pump and kill pumps
	Night	18:00–05:30 HQ3 core 05:30–06:00 survey at 558.4 m	HQ3 core 555.4 – 576.4 m (21 m)
29 October	Day	06:00–17:15 HQ3 core 17:15–18:00 survey at 594.4 m	HQ3 core 576.4 – 603.4 m (27 m)
	Night	18:00–05:00 HQ3 core 05:00–06:00 breakdown	HQ3 core 603.4 – 627.4 m (24 m) Repair hydraulic hose
30 October	Day	06:00–13:00 HQ3 core 13:00–16:00 bit change 16:00–17:30:00 HQ3 core 17:30–18:00 condition hole	HQ3 core 627.4 – 645.7 m (18.3 m) Bit change at 642.4 m (Bit 11 60%, 74 m) Change from 3 m to 6 m barrel
	Night	18:00–05:15 HQ3 core 05:15–06:00 survey at 648.7 m	HQ3 core 645.7 – 669.7 m (24 m)

Table 1.1. (continued)

Date	*Shift*	*Time (indicative)*	*Activity*
31 October	Day	06:00–12:00 HQ3 core	HQ3 core 669.7 – 687.7 m (18 m)
		12:00–15:00 bit change	Bit change at 681.7 m to suit ground conditions (Bit 12 100%,
39.3 m)			
		15:00–17:30 HQ3 core	Mudstone blocking bit and balling up around bit and reamer
		17:30–18:00 condition hole	
	Night	18:00–05:00 HQ3 core	HQ3 core 687.7 – 711.7 m (24 m)
		05:00–06:00 survey at 711.7 m	
1 November	Day	06:00–14:30 HQ3 core	HQ3 core 711.7 – 741.7 m (30 m), unconsolidated sand at 713.4 m
		14:30–18:00 bit change	
	Night	18:00–03:30 HQ3 core	HQ3 core 741.7 – 766.2 m (24.5 m)
		03:30–06:00 bit change	Bit change at 766.2 m (Bit 13 0%, 84.5 m)
2 November	Day	06:00–06:45 bit change	HQ3 core 766.2 – 795.7 m (29.5 m)
		06:45–07:15 condition hole	
		07:15–08:15 HQ3 core	
		08:15–09:15 survey at 771.7 m	
		09:15–18:00 HQ3 core	
	Night	18:00–03:00 HQ3 core	HQ3 core 795.7 – 825.7 m (30 m)
		03:00–04:00 survey at 819.7 m	
		04:00–06:00 HQ3 core	
3 November	Day	06:00–15:15 HQ3 core	HQ3 core 825.7 – 855.7 m (30 m). Bit change at 855.7 m
		15:15–06:00 bit change	(Bit 14, 60%, 89.5 m), pull out as unable to retrieve inner tube
	Night	18:00–19:45 bit change	HQ3 core 855.7 – 885.7 m (30 m)
		19:45–01:30 HQ3 core	
		01:30–02:30 survey at 873.7 m	
		02:30–06:00 HQ3 core	
4 November	Day	06:00–18:00 HQ3 core	HQ3 core 885.7 – 912.7 m (27 m)
	Night	18:00–04:00 HQ3 core	HQ3 core 912.7 – 930.7 m (18 m), mudstone gumming up bit and reamer
		04:00–05:00 repairs to pump	Repair bean pump
		05:00–06:00 orientation survey at 930.7 m	
5 November	Day	06:00–11:30 bit change	HQWh core 930.7 – 946.3 m (15.6 m). Bit change at 930.7 m (Bit 14A, 75.0 m)
		11:30–12:00 condition hole	Change barrel configuration from 6 m STD to 9 m STD
		12:00–18:00 HQ core	Lost 10–15 % mud returns
	Night	18:00–06:00 HQ core	HQWh core 946.3 – 973.5 m (27.2 m). Lost 10–15 % mud returns
6 November	Day	06:00–17:00 HQ core	HQWh core 973.5 – 997.3 m (23.8 m)
		17:00–18:00 survey at 997.3 m	Start adding flossy salt as expect to intersect halite beds of Browne Formation
	Night	18:00–05:00 HQ core	HQWh core 997.3 – 1020.8 m (23.5 m)
		05:00–06:00 bit change	Bit change at 1020.8 m (Bit 15 0%, 90.8 m)
7 November	Day	06:00–10:00 bit change	HQWh core 1020.8 – 1024.3 (3.5 m)
		10:00–12:00 HQ core	
		12:00–17:30 repairs to pump	Repair Bean pump and fluid system
		17:30–18:00 condition hole	
	Night	18:00–06:00 HQ core	HQWh core 1024.3 – 1048.3 m (24 m)
8 November	Day	06:00–18:00 HQ core	HQWh core 1048.3 – 1078.3 m (30 m)
	Night	18:00–24:00 HQ core	HQWh core 1078.3 – 1105.3 m (27 m)
		00:00–01:00 survey at1093.3 m	
		01:00–06:00 HQ core	
9 November	Day	06:00–18:00 HQ core	HQWh core 1105.3 – 1135.3 m (30 m), sludge building up on bit, barrel and tube
	Night	18:00–21:30 HQ core	HQWh core 1135.3 – 1150.3 m (15 m)
		21:30–02:30 change bit	Bit change at 1143.3 m (Bit 16 10%, 122.5 m)
		02:30–03:00 condition hole	
		03:00–06:00 HQ core	
10 November	Day	06:00–18:00 HQ core	1150.3 – 1171.3 m (21 m). Slow penetration in mudstone
	Night	18:00–06:00 HQ core	HQWh core 1171.3 – 1193.3 m (22 m)
11 November	Day	06:00–18:00 HQ core	HQWh core 1193.3 – 1222.3 m (29 m)
	Night	18:00–06:00 HQ core	HQWh core 1222.3 – 1253.3 m (31 m)
		18:30–17:45 orientation survey at 1223.3 m	
12 November	Day	06:00–15:00 HQ core	HQWh core 1253.3 – 1273.3 m (20 m)
		15:00–18:00 pull rods	Unable to seat tube due to pressure at bit face. Wireline loggers mobilize
	Night	18:00–23:00 flush hole, run rods	HQWh core 1273.3 – 1292.3 m (19 m), flush hole at intervals while
		23:00–06:00 HQ core	running rods to relieve pressure at bit face

Table 1.1. (continued)

Date	*Shift*	*Time (indicative)*	*Activity*
13 November	Day	06:00–17:30 HQ core	HQWh core 1292.3 – 1321.3 m (29 m)
		17:30–18:00 standby	Standby for lightning storm
	Night	18:00–06:00 HQ core	HQWh core 1321.3 – 1351.3 m (30 m)
14 November	Day	06:00–18:00 HQ core	HQWh core 1351.3 – 1372.3 m (21 m)
	Night	18:00–06:00 HQ core	HQWh core 1372.3 – 1396.3 m (24 m)
15 November	Day	06:00–11:15 HQ core	HQWh core 1396.3 – 1407.3 m (11 m)
		11:15–16:15 change bit	Bit change at 1407.3 m (Bit 17, 264 m)
		16:15–17:00 standby	Standby for lightning storm
		17:00–18:00 change bit	
	Night	18:00–19:00 condition hole	HQWh core 1407.3 – 1427.3 m (20 m)
		19:00–06:00 HQ core	Intersect salt beds at 1410 m
16 November	Day	06:00–15:30 HQ core	HQWh core 1427.3 – 1447.3 m (20 m)
		15:30–18:00 change wireline	Replace wireline with 2,500 m spool
	Night	18:00–06:00 HQ core	HQWh core 1447.3 – 1474.3 m (27 m). Wireline loggers on site at 19:00 h
17 November	Day	06:00–18:00 HQ core	HQWh core 1474.3 – 1498.3 m (24 m)
	Night	18:00–19:15 HQ core	HQWh core 1498.3 – 1501.3 m (24 m)
		19:15–22:45 condition hole for logging	Reached total depth of 1501.3 m at 19:15 h.
		22:45–03:15 pull rods	Increase mud viscosity to 36 for wireline logging. Pull HMQ rods
		03:15–06:00 standby for logging	03:15–06:00 logging run 1 16N
18 November	Day	06:00–18:00 standby for logging	06:00–08:00 logging run 1 16N 08:00–15:00 logging run 2 64N 15:00–18:00 logging run 3 SPR-SP-N
	Night	18:00–06:00 standby for logging	18:00–19:00 logging run 3 SPR-SP-N 19:00–24:00 logging run 4 GR-LD-Caliper 24:00–06:00 logging run 5 sonic
19 November	Day	06:00–14:30 standby for logging	06:00–07:00 logging run 5 sonic 07:00–14:30 logging run 6 acoustic scanner
		14:30–18:00 plugging	Run HMQ blank, pump van Ruth plug to 448 m, cement plug from 448–408 m (base PW casing at 428 m), pull HMQ blank
20 November	Day	06:00–14:45 plug and abandon 14:45–18:00 pack up	Remove BOP, cut HWT at 93 m unsuccessful, cut HWT at 81 m and recover 81 m of HWT casing, surface plug in PW casing from 35 to 1.5 m, fit standpipe to well head. Lancer 1 plugged and abandoned at 14:45 h.

Therefore the annulus below the HWT casing shoe was also cemented before recommencing HQ coring. This part of the Wahlgu Formation also caused drilling problems in Empress 1/1A.

- After HQ coring ahead to 435.4 m an additional cement plug was set from 435.4 to 408 m, and although this was successful in sealing off the annulus below the HWT casing, this caused further delays waiting for cement to set before drilling could recommence. Additional unconsolidated sands were noted at 462, 500.5, 500.6 and 713.4 m in the core, but did not cause any difficulties.
- Mud viscosity was reduced to counter mud blocking the bit face and barrel at about 560 m.
- A bit change was required at 681.7 m in a mudstone interval to alleviate mud blocking the bit, and balling up around the bit and reamer. The core recovered from this interval was extremely broken up in places.
- The rods had to be pulled at 855.7 m to retrieve the inner tube as the knuckle head had failed, and the overshot was unable to attach.
- Drilling slowed at about 920 m in mudstone, which gummed up the bit and reamer.
- About 10% loss of mud returns between 930 and 970 m.
- At about 1110 m the third mud pit was used to minimize build up of solids and sludging of bit, barrel, and tubes.
- Drilling slowed at about 1150 m due to mudstone balling up at the bit.
- Unable to seat tube at 1273.3 m due to pressure at bit face.
- On abandonment only the uppermost 81 m of the HWT casing was recovered after the casing could not be lifted from a deeper cut at 93 m. This indicates that the cement used to hold this casing in place had risen above 93 m.

Depth matching of core to logs

Ninety-four tie points were established between the core and wireline logs (Fig. 1.4, Table 1.6) and a line of best fit was calculated using the equation: Wireline logger's depth (m) = 1.0012 × driller's depth (m) – 0.5361. However, no depth corrections were applied to the lithological column in Plate 1.

Table 1.2. Eastman camera deviation survey results for Lancer 1

Depth (m)	*Deviation (°)*	*Azimuth (°)*
111.5	89.5	109
141.5	89.5	145
171.5	89.0	130
201.5	89.3	109
231.5	89.1	128
261.5	89.6	100
291.0	89.6	130
321.5	89.3	120
351.5	89.2	115
384.5	89.6	160
417.5	89.4	064
441.4	89.1	122
477.4	89.1	118
510.4	89.1	163
558.4	89.5	174
594.4	89.5	150
648.7	89.7	154
711.7	89.7	161
771.7	89.9	280
819.7	89.7	090
873.7	89.6	117
930.7	89.7	310
997.3	89.9	155
1 093.3	89.9	280
1 223.3	89.9	285

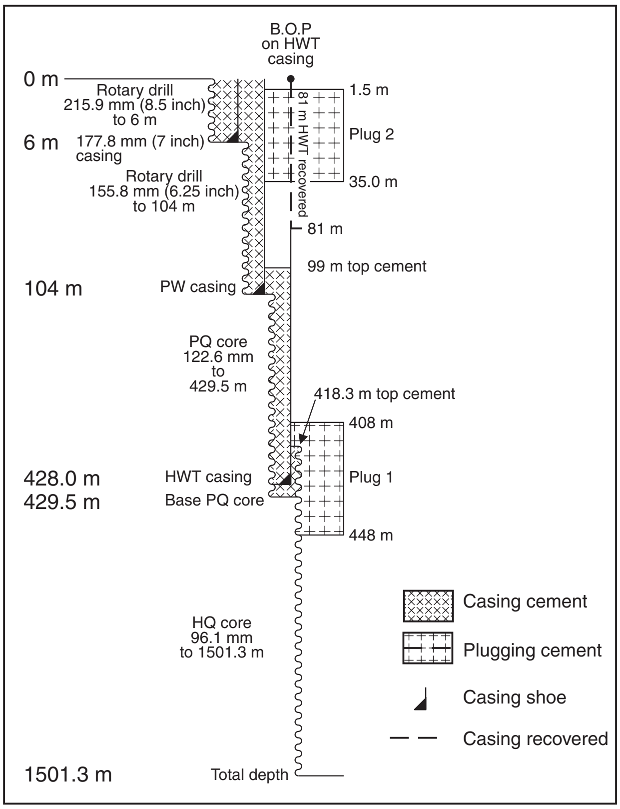

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Figure 1.3. Engineering diagram for Lancer 1

Table 1.3. Chemicals and other additives used in Lancer 1

Chemical/additive	*Amount*
Rotary 215.9 mm (8.5'') hole from surface to 6 m:	
Cement	20 kg × 10
CR 650	15 kg × 4
Pac-R	15 kg × 2
Rotary 158.8 mm (6.25'') hole from 6 to 104 m:	
Aus Gel Extra	25 kg × 8
Aus-Plug	8 kg
Aus-Trol	1 kg × 110
Cement	20 kg × 32
CR 650	15 kg × 7
Diesel	100 L
Pac-R	15 kg × 6
PQ corehole from 104 to 429.5 m:	
Aus-Plug	8 kg
Aus-Trol	15 kg × 7
Cement	20 kg × 53
CR 650	15 kg × 14
KCl	25 kg × 356
Pac-R	15 kg × 5
Soda ash	25 kg × 3
Sure Seal	10 kg
HQ corehole from 429.5 to 1501.3 m:	
Aus Det	25 kg × 47
Aus-Trol	15 kg × 2
Cement	20 kg × 58
CR 650	15 kg × 8
Flossy salt	25 kg × 758
KCl	25 kg × 264
Pac-R	15 kg × 22
Soda ash	25 kg × 5
Total chemicals consumed for drillhole:	
Aus Det	25 L × 47
Aus Gel Extra	25 kg × 8
Aus-Plug	8 kg × 2
Aus-Trol	119 kg
Cement	20 kg × 153
CR 650	15 kg × 33
Diesel	100 L
Flossy salt	25 kg × 758
KCl	25 kg × 620
Pac-R	15 kg × 35
Soda ash	25 kg × 8
Sure Seal	10 kg

Table 1.4. Casing strings used in Lancer 1

Casing	*Outer diameter (mm)*	*Inner diameter (mm)*	*Depth interval (m)*
7"	177.8	172.0	0–6 m
PW	139.7	127.0	0–104 m (cemented into place)
HWT	114.3	101.6	0–428 m (cemented into place below 99 m; 0–81 m retrieved)

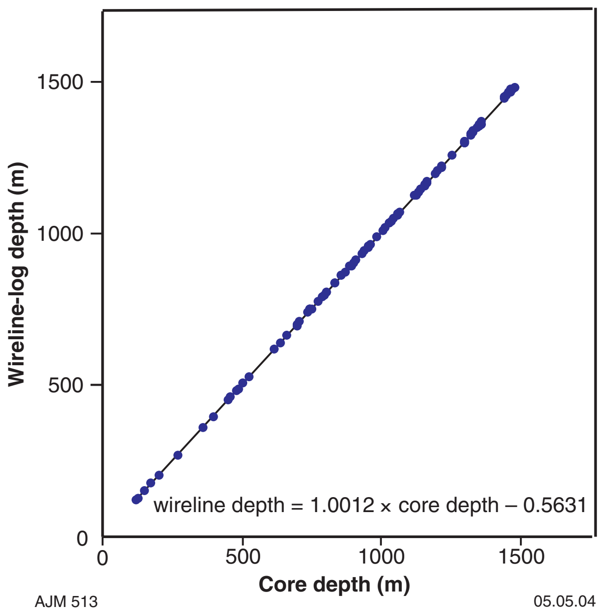

Figure 1.4. Relationship between wireline and core depths for Lancer 1

Completion

Lancer 1 was completed on 20 November 2003 with all free casing and drill strings pulled out. The well was plugged using a HQ van Ruth plug in the Wahlgu Formation 20 m below the HWT casing shoe at 448 m and was capped with 40 m of cement. An attempt to retrieve the HWT casing down to 96 m failed, indicating that it was cemented to the PW casing. The second attempt at 81 m was successful and a PW van Ruth plug was inserted at 35 m and capped by cement to 1.5 m. A capped steel pipe, on which the well name and the total depth are recorded, was left on the PW surface casing.

Table 1.5. Core recovery from Lancer 1

From (m)	*To (m)*	*Metres drilled*	*Metres recovered*	*Recovery rate %*	*Discrepancy with driller (m)*	*Comments*
104.0	105.5	1.5	1.53	102	0.03	
105.5	108.0	2.5	2.52	101	0.05	
108.0	109.7	1.7	1.66	98	0.01	
109.7	111.5	1.8	1.82	101	0.03	
111.5	114.5	3.0	2.82	94	–0.15	
114.5	116.0	1.5	1.65	110	0.00	
116.0	117.5	1.5	1.50	100	0.00	
117.5	120.5	3.0	3.02	101	0.02	
120.5	123.5	3.0	2.98	99	0.00	
123.5	126.5	3.0	2.95	98	–0.05	5 cm core loss
126.5	129.5	3.0	3.05	102	0.00	
129.5	132.5	3.0	3.01	100	0.01	
132.5	135.5	3.0	3.01	100	0.02	
135.5	137.2	1.7	1.70	100	0.02	
137.2	140.3	3.1	3.08	99	0.00	
140.3	143.4	3.1	3.08	99	–0.02	
143.4	146.5	3.1	3.12	101	0.00	
146.5	149.6	3.1	3.10	100	0.00	
149.6	152.7	3.1	3.12	101	0.02	
152.7	155.8	3.1	3.08	99	0.00	
155.8	158.9	3.1	3.12	101	0.02	
158.9	162.0	3.1	3.11	100	0.03	
162.0	165.0	3.0	3.00	100	0.03	6 cm extra (cf. 126.5 m)
165.0	168.1	3.1	3.07	99	0.00	
168.1	171.2	3.1	3.10	100	0.00	mismarked: 4 cm extra
171.2	174.3	3.1	3.12	101	0.02	
174.3	177.4	3.1	3.08	99	0.00	
177.4	180.1	2.7	2.71	100	0.01	
180.1	182.7	2.6	2.59	100	0.00	
182.7	185.8	3.1	3.10	100	0.00	
185.8	188.9	3.1	3.10	100	0.00	
188.9	192.0	3.1	3.10	100	0.00	
192.0	195.1	3.1	3.10	100	0.00	
195.1	198.2	3.1	3.12	101	0.02	
198.2	201.2	3.0	2.98	99	0.00	
201.2	204.3	3.1	3.10	100	0.00	
204.3	205.2	0.9	0.90	100	0.00	
205.2	207.5	2.3	2.26	98	–0.04	
207.5	210.5	3.0	2.98	99	–0.06	
210.5	213.5	3.0	3.10	103	–0.05	
213.5	216.5	3.0	3.05	102	0.00	
216.5	219.5	3.0	2.95	98	–0.05	Note dropped core
219.5	222.5	3.0	3.05	102	0.00	
222.5	225.5	3.0	2.99	100	–0.01	
225.5	228.5	3.0	3.03	101	0.02	
228.5	231.5	3.0	3.0	99	0.0	
231.5	234.5	3.0	2.98	99	0.00	
234.5	237.5	3.0	3.00	100	0.00	
237.5	240.5	3.0	3.00	100	0.00	
240.5	243.5	3.0	3.00	100	0.00	
243.5	246.5	3.0	3.00	100	0.00	
246.5	249.5	3.0	2.97	99	–0.03	
249.5	252.5	3.0	3.03	101	0.00	
252.5	255.5	3.0	3.02	101	0.02	
255.5	258.5	3.0	2.98	99	0.00	
258.5	261.5	3.0	2.99	100	–0.01	
261.5	264.5	3.0	2.97	99	–0.04	
264.5	267.5	3.0	3.04	101	0.00	
267.5	270.5	3.0	3.00	100	0.00	
270.5	273.5	3.0	3.00	100	0.00	
273.5	276.5	3.0	3.00	100	0.00	
276.5	279.5	3.0	3.03	101	0.03	
279.5	282.5	3.0	2.97	99	0.00	
282.5	285.5	3.0	2.97	99	–0.03	
285.5	288.5	3.0	3.04	101	0.01	
288.5	291.5	3.0	2.97	99	–0.05	

Table 1.5. (continued)

From (m)	*To (m)*	*Metres drilled*	*Metres recovered*	*Recovery rate %*	*Discrepancy with driller (m)*	*Comments*
291.5	295.5	4.0	3.99	100	–0.06	
295.5	297.5	2.0	2.01	101	–0.05	
297.5	300.5	3.0	2.98	99	–0.07	
300.5	303.5	3.0	3.07	102	0.00	
303.5	306.5	3.0	2.99	100	–0.01	
306.5	309.5	3.0	2.99	100	–0.02	
309.5	312.5	3.0	3.01	100	–0.01	
312.5	315.5	3.0	3.06	102	0.05	
315.5	318.5	3.0	2.90	97	–0.05	
318.5	321.5	3.0	3.05	102	0.00	
321.5	324.5	3.0	2.94	98	–0.06	
324.5	327.5	3.0	3.01	100	–0.05	
327.5	329.6	2.1	2.14	102	–0.01	
329.6	332.7	3.1	3.11	100	0.00	in friable sandstone
332.7	335.8	3.1	3.01	97	–0.09	9 cm core loss
335.8	338.9	3.1	3.19	103	0.00	
338.9	342.0	3.1	3.05	98	–0.05	5 cm core loss
342.0	345.1	3.1	3.04	98	–0.11	
345.1	347.2	2.1	2.11	100	–0.10	rubbly
347.2	347.5	0.3	0.40	133	0.00	rubbly
347.5	348.5	1.0	1.02	102	0.02	
348.5	351.5	3.0	2.93	98	–0.05	
351.5	354.5	3.0	3.02	101	–0.03	
354.5	357.5	3.0	3.09	103	0.06	
357.5	360.0	2.5	2.40	96	–0.04	
360.0	363.1	3.1	3.13	101	–0.01	
363.1	366.2	3.1	3.11	100	0.00	
366.2	369.3	3.1	3.05	98	–0.05	
369.3	372.4	3.1	3.10	100	–0.05	very rubbly core around 372.4 m
372.4	375.5	3.1	3.09	100	–0.06	
375.5	378.5	3.0	3.10	103	0.04	mismarked: extra 4 cm below 378.0 m
378.5	381.5	3.0	2.96	99	0.00	
381.5	384.5	3.0	2.98	99	–0.02	
384.5	387.5	3.0	3.02	101	0.00	
387.5	390.5	3.0	2.99	100	–0.01	
390.5	393.5	3.0	3.01	100	0.00	
393.5	396.5	3.0	3.01	100	0.01	
396.5	399.5	3.0	2.98	99	–0.01	
399.5	402.5	3.0	3.06	102	0.05	401.5 m block missing
402.5	405.1	2.6	2.65	102	0.10	
405.1	408.2	3.1	3.00	97	0.00	
408.2	411.3	3.1	3.10	100	0.00	
411.3	414.4	3.1	3.10	100	0.00	
414.4	417.5	3.1	3.04	98	–0.06	
417.5	420.5	3.0	3.06	102	0.00	
420.5	423.3	2.8	2.78	99	–0.02	
423.3	426.5	3.2	3.32	104	0.00	
426.5	429.5	3.0	3.00	100	0.00	
429.5	429.9	0.4	0.40	100	?0.00	start of HQ core, broken up at base
429.9	432.4	2.5	2.50	100	?0.00	rubbly near base
432.4	433.0	0.6	0.60	100	?0.00	
433.0	435.4	2.4	2.40	100	?0.00	
435.4	438.4	3.0	2.90	97	–0.10	
438.4	441.4	3.0	3.10	103	0.00	
441.4	444.4	3.0	3.00	100	?0.00	core broken up
444.4	447.4	3.0	3.00	100	?0.00	core very rubbly
447.4	450.4	3.0	3.06	102	0.06	mismarked: extra 6 cm to 450.5 m
450.4	453.4	3.0	2.95	98	0.01	
453.4	456.4	3.0	2.99	100	0.00	
456.4	459.4	3.0	3.00	100	0.00	
459.4	462.4	3.0	3.05	102	0.05	mismarked: extra 5 cm to 450.5 m
462.4	465.4	3.0	3.01	100	0.06	
465.4	468.4	3.0	2.95	98	0.01	
468.4	471.4	3.0	2.98	99	–0.01	
471.4	474.4	3.0	3.00	100	–0.01	
474.4	477.4	3.0	3.00	100	–0.01	

Table 1.5. (continued)

From (m)	*To (m)*	*Metres drilled*	*Metres recovered*	*Recovery rate %*	*Discrepancy with driller (m)*	*Comments*
477.4	480.4	3.0	2.95	98	–0.06	
480.4	483.4	3.0	2.95	98	–0.11	
483.4	486.4	3.0	3.14	105	0.03	
486.4	489.4	3.0	3.01	100	0.04	
489.4	492.4	3.0	2.99	100	0.03	
492.4	495.4	3.0	2.96	99	0.01	
495.4	498.4	3.0	3.00	100	–0.01	
498.4	501.4	3.0	2.99	100	0.00	
501.4	504.4	3.0	2.95	98	–0.05	
504.4	507.4	3.0	3.08	103	0.03	
507.4	510.4	3.0	3.05	102	0.08	mismarked: 7 cm extra to 511.0 m
510.4	513.4	3.0	2.92	97	0.00	
513.4	516.4	3.0	3.00	100	0.00	
516.4	519.4	3.0	3.00	100	0.00	
519.4	522.4	3.0	3.00	100	0.00	
522.4	525.4	3.0	3.02	101	0.02	
525.4	528.4	3.0	2.98	99	0.00	
528.4	531.2	2.8	2.77	99	–0.03	
531.2	534.3	3.1	3.13	101	0.00	
534.3	537.4	3.1	3.06	99	–0.04	mismarked: 4 cm short to 538.0 m
537.4	540.4	3.0	3.05	102	0.01	
540.4	543.4	3.0	2.99	100	0.00	
543.4	544.4	1.0	0.90	90	–0.10	mismarked: 5 cm short to 545.0 m
544.4	546.4	2.0	2.05	103	–0.05	
546.4	549.4	3.0	3.08	103	0.03	
549.4	552.4	3.0	2.97	99	0.00	
552.4	553.5	1.1	1.08	98	–0.02	
553.5	555.4	1.9	1.97	104	0.05	
555.4	558.4	3.0	2.92	97	–0.03	
558.4	560.0	1.6	1.64	102	0.01	
560.0	561.4	1.4	1.39	99	0.00	
561.4	564.4	3.0	3.00	100	0.00	
564.4	567.4	3.0	3.00	100	0.00	
567.4	570.4	3.0	3.00	100	0.00	
570.4	573.2	2.8	2.80	100	0.00	core worn at 574.9 m implies a small core loss
573.2	576.3	3.1	3.14	101	0.04	
576.3	579.4	3.1	3.06	99	0.00	rubble makes measurement difficult
579.4	582.4	3.0	2.99	100	–0.01	
582.4	585.4	3.0	2.99	100	–0.08	
585.4	588.4	3.0	2.99	100	–0.03	
588.4	591.4	3.0	3.03	101	0.00	
591.4	594.4	3.0	3.00	100	0.00	
594.4	597.4	3.0	3.03	101	0.03	
597.4	600.4	3.0	2.97	99	0.00	
600.4	603.4	3.0	3.02	101	0.02	
603.4	606.4	3.0	3.00	100	0.02	
606.4	609.4	3.0	2.98	99	0.00	
609.4	612.4	3.0	3.03	101	0.03	
612.4	615.4	3.0	2.97	99	0.00	
615.4	618.4	3.0	3.00	100	0.00	
618.4	621.4	3.0	3.00	100	0.00	
621.4	624.4	3.0	3.00	100	0.00	
624.4	627.4	3.0	3.02	101	0.02	
627.4	630.4	3.0	3.00	100	0.02	
630.4	633.4	3.0	2.98	99	0.00	
633.4	636.4	3.0	3.00	100	0.00	
636.4	639.4	3.0	3.00	100	0.00	
639.4	642.4	3.0	2.98	99	–0.02	
642.4	648.7	6.3	6.35	101	0.03	
648.7	654.7	6.0	5.96	99	–0.01	
654.7	660.7	6.0	6.01	100	0.00	
660.7	666.7	6.0	6.00	100	0.00	
666.7	672.7	6.0	6.00	100	0.00	in rubbly shale
672.7	676.9	4.2	4.20	100	0.00	
676.9	681.1	4.2	4.20	100	0.00	shale disintegrating
681.1	687.7	6.6	6.60	100	0.00	

Table 1.5. (continued)

From (m)	*To (m)*	*Metres drilled*	*Metres recovered*	*Recovery rate %*	*Discrepancy with driller (m)*	*Comments*
687.7	693.7	6.0	6.00	100	0.00	
693.7	699.7	6.0	6.00	100	0.00	
699.7	705.7	6.0	5.98	100	–0.02	
705.7	711.7	6.0	5.98	100	–0.04	
711.7	714.8	3.1	3.21	104	0.07	
714.8	720.7	5.9	5.80	98	–0.03	mismarked: 3 cm short from 720.0 m
720.7	726.7	6.0	6.03	101	0.00	mismarked: 2 cm short from 726.0 m
726.7	732.7	6.0	6.00	100	0.00	
732.7	738.7	6.0	6.01	100	0.01	mismarked: 3 cm short from 738.0 m
738.7	744.7	6.0	5.99	100	0.00	mismarked: 4 cm short from 744.0 m
744.7	750.7	6.0	6.00	100	0.00	
750.7	756.7	6.0	5.99	100	–0.01	
756.7	762.7	6.0	5.99	100	–0.02	
762.7	766.2	3.5	3.51	100	–0.01	
766.2	771.7	5.5	5.51	100	0.00	
771.7	777.7	6.0	6.00	100	0.00	
777.7	783.7	6.0	6.03	101	0.03	
783.7	789.7	6.0	5.92	99	–0.05	mismarked: 6 cm short to 790.0 m
789.7	795.7	6.0	5.92	99	–0.13	27 cm core loss marked at 795.30 - 795.57 m
795.7	801.7	6.0	6.13	102	0.00	
801.7	807.7	6.0	6.00	100	0.00	
807.7	813.7	6.0	6.00	100	0.00	
813.7	819.7	6.0	6.02	100	0.02	
819.7	825.7	6.0	6.00	100	0.02	
825.7	831.7	6.0	5.93	99	–0.05	
831.7	837.7	6.0	6.04	101	–0.01	
837.7	843.7	6.0	6.01	100	0.00	
843.7	855.7	12.0	11.94	100	–0.06	
855.7	861.7	6.0	6.06	101	0.00	
861.7	867.7	6.0	6.00	100	0.00	
867.7	873.7	6.0	6.10	102	0.10	
873.7	879.7	6.0	5.83	97	0.10	
879.7	885.7	6.0	6.06	101	–0.07	
885.7	891.7	6.0	6.05	101	0.04	
891.7	897.7	6.0	5.96	99	0.00	
897.7	903.7	6.0	6.01	100	0.01	
903.7	909.7	6.0	5.99	100	0.00	
909.7	915.7	6.0	6.03	101	0.03	
915.7	921.7	6.0	5.95	99	–0.02	
921.7	925.2	3.5	3.56	102	0.04	
925.2	931.05	5.85	5.81	99	0.00	
931.05	940.3	9.25	9.19	99	–0.06	
940.3	949.3	9.0	9.03	100	–0.03	
949.3	958.3	9.0	9.02	100	–0.01	
958.3	967.3	9.0	9.02	100	0.01	
967.3	973.5	6.2	6.19	100	0.00	
973.5	980.1	6.6	6.66	101	0.06	
980.1	988.3	8.2	8.33	102	0.19	
988.3	997.3	9.0	9.05	101	0.14	
997.3	1006.3	9.0	8.76	97	0.00	
1006.3	1015.3	9.0	8.98	100	–0.02	
1015.3	1020.8	5.5	5.56	101	0.04	
1020.8	1022.5	1.7	1.66	98	0.00	core worn at 1022.5 m implies a small loss
1022.5	1030.3	7.8	7.82	100	0.02	
1030.3	1039.3	9.0	8.95	99	–0.03	
1039.3	1048.3	9.0	9.19	102	0.16	
1048.3	1057.3	9.0	8.93	99	0.08	
1057.3	1066.3	9.0	9.13	101	0.23	
1066.3	1075.3	9.0	9.13	101	0.33	
1075.3	1084.3	9.0	8.82	98	0.18	
1084.3	1093.3	9.0	8.99	100	0.18	
1093.3	1102.3	9.0	9.00	100	0.17	
1102.3	1111.3	9.0	8.94	99	0.11	
1111.3	1112.3	1.0	1.00	100	0.10	
1112.3	1122.1	9.8	9.76	100	0.06	
1122.1	1129.3	7.2	7.21	100	0.07	

Table 1.5. (continued)

From (m)	*To (m)*	*Metres drilled*	*Metres recovered*	*Recovery rate %*	*Discrepancy with driller (m)*	*Comments*
1129.3	1138.3	9.0	8.88	99	–0.06	
1138.3	1143.3	5.0	4.95	99	–0.11	
1143.3	1153.2	9.9	10.03	101	0.02	
1153.2	1163.3	10.1	10.09	100	0.07	
1163.3	1173.3	10.0	9.99	100	0.06	
1173.3	1183.3	10.0	10.01	100	0.07	
1183.3	1193.3	10.0	10.02	100	0.09	
1193.3	1203.3	10.0	10.06	101	0.15	
1203.3	1213.3	10.0	10.00	100	0.15	
1213.3	1223.3	10.0	9.97	100	0.12	
1223.3	1233.3	10.0	10.09	101	0.21	
1233.3	1243.3	10.0	10.01	100	0.22	
1243.3	1253.3	10.0	10.03	100	0.22	
1253.3	1263.3	10.0	9.96	100	0.25	
1263.3	1273.1	9.8	9.81	100	0.22	
1273.1	1282.3	9.2	9.09	99	0.11	
1282.3	1292.3	10.0	9.99	100	0.1	
1292.3	1302.3	10.0	10.03	100	0.13	
1302.3	1312.3	10.0	10.02	100	0.13	
1312.3	1322.3	10.0	10.03	100	0.16	
1322.3	1332.3	10.0	10.13	101	0.29	
1332.3	1342.3	10.0	9.87	99	0.16	
1342.3	1352.3	10.0	10.02	100	0.18	
1352.3	1362.3	10.0	10.01	100	0.18	
1362.3	1372.3	10.0	9.99	100	0.18	
1372.3	1382.3	10.0	10.01	100	0.19	
1382.3	1392.3	10.0	9.99	100	0.18	
1392.3	1402.1	9.8	9.77	100	0.15	
1402.1	1407.1	5.0	5.13	103	0.28	
1407.1	1407.3	0.2	0.14	70	0.22	
1407.3	1417.3	10.0	10.01	100	0.23	
1417.3	1427.3	10.0	9.98	100	0.21	
1427.3	1437.3	10.0	9.92	99	0.13	
1437.3	1447.2	9.9	9.76	99	–0.01	
1447.2	1457.2	10.0	10.05	101	0.04	
1457.2	1467.2	10.0	9.80	98	0.04	
1467.2	1477.2	10.0	9.93	99	–0.08	15 cm core loss in salt from 1467.10 to 1467.25 m
1477.2	1487.2	10.0	10.01	100	–0.07	
1487.2	1497.2	10.0	10.03	100	–0.05	
1497.2	1501.3	4.1	4.08	100	–0.07	
Totals:		**1397.3**	**1397.2**	**100%**		56 cm core loss in total; the higher apparent recovery is due to measurement errors

Table 1.6. Comparison of core and wireline log depths in Lancer 1

Core depth (m)	*Wireline depth (m)*	*Wireline – core depths (m)*	*Wireline – core depths / Wireline depth*
121.8	121.3	-0.5	-0.004122
128.7	129	0.3	0.002326
150.5	150	-0.5	-0.003333
175.5	175	-0.5	-0.002857
205	205	0	0
270.8	270.5	-0.3	-0.001109
359	358.5	-0.5	-0.001395
397	397	0	0
449.5	449.5	0	0
459	459	0	0
480	480	0	0
487	487	0	0
505	505	0	0
526	526	0	0
618.4	618.5	0.1	0.000162
639.6	639.6	0	0
663.8	664	0.2	0.000301
695.6	696	0.4	0.000575
696.9	697.1	0.2	0.000287
707.5	708	0.5	0.000706
746.5	746.9	0.4	0.000536
737.1	737.2	0.1	0.000136
746.5	746.9	0.4	0.000536
746.8	747	0.2	0.000268
750.5	751	0.5	0.000666
774.6	775	0.4	0.000516
790.6	791	0.4	0.000506
794.5	795.1	0.6	0.000755
802	802.6	0.6	0.000748
805.5	806	0.5	0.000620
833.2	833.8	0.6	0.000720
834.7	835.1	0.4	0.000479
859.6	860.1	0.5	0.000581
868.5	869	0.5	0.000575
888.8	889.2	0.4	0.000450
891.8	892.5	0.7	0.000784
859.7	860.2	0.5	0.000581
898.8	899.1	0.3	0.000334
913	913.5	0.5	0.000547
929.4	930	0.6	0.000645
940.2	940.6	0.4	0.000425
952.2	953	0.8	0.000839
956.5	956.9	0.4	0.000418
960.5	961.1	0.6	0.000624
988.5	989	0.5	0.000506
1 007	1 007.6	0.6	0.000595
1 017.3	1 017.9	0.6	0.000589
1 031	1 031.5	0.5	0.000485
1 031.9	1 032.6	0.7	0.000678
1 037.2	1 038	0.8	0.000771
1 047	1 047.5	0.5	0.000477
1 059.5	1 060	0.5	0.000472
1 062.2	1 062.9	0.7	0.000659
1 068	1 068.5	0.5	0.000468
1 121.6	1 122.5	0.9	0.000802
1 124.5	1 125.1	0.6	0.000533
1 134.1	1 135	0.9	0.000793
1 135.5	1 136.1	0.6	0.000528
1 140.8	1 141.9	1.1	0.000963
1 143.2	1 144	0.8	0.000699
1 154.5	1 155.3	0.8	0.000692
1 157	1 157.9	0.9	0.000777
1 165.6	1 166.8	1.2	0.001028
1 167.1	1 167.9	0.8	0.000685
1 195.1	1 196	0.9	0.000753
1 215	1 215.8	0.8	0.00066
1 201.9	1 202.8	0.9	0.00075

Table 1.6. (continued)

Core depth (m)	*Wireline depth (m)*	*Wireline – core depths (m)*	*Wireline – core depths / Wireline depth*
1 255.3	1256.2	0.9	0.00072
1 297.6	1298.6	1.0	0.00077
1 215	1215.8	0.8	0.00066
1 217.4	1217.8	0.4	0.00033
1 297.7	1298.7	1.0	0.00077
1 300.9	1301.9	1.0	0.00077
1 301.9	1302.9	1.0	0.00077
1 325.6	1326.5	0.9	0.00068
1 333.8	1334.8	1.0	0.00075
1 357.7	1358.8	1.1	0.00081
1 322.5	1323.6	1.1	0.00083
1 331.9	1332.5	0.6	0.00045
1 353.15	1354.5	1.35	0.00100
1 353.65	1354.6	0.95	0.00070
1 351.4	1352.4	1.0	0.00074
1 352.85	1353.85	1.0	0.00074
1 347.3	1348.3	1.0	0.00074
1 364.17	1365.6	1.43	0.00105
1 357.7	1358.9	1.2	0.00089
1 440.9	1442.8	1.9	0.00132
1 447	1447.1	0.1	0.00007
1 478.9	1480.3	1.4	0.00095
1 473.95	1474.6	0.65	0.00044
1 451.5	1453	1.5	0.00103
1 460.2	1461.4	1.2	0.00082
1 463.5	1465	1.5	0.00102
1 469.5	1471	1.5	0.00102
1 478.9	1481	2.1	0.00142

Appendix 2

Core photographs

(see core photo library on this disk)

Appendix 3

Definition of new stratigraphic units

Keene Basalt

Definition: Mafic extrusive igneous rocks within the Kanpa Formation in Lancer 1 are here named the Keene Basalt, after Lake Keene, 10 km west of the drillhole. It is regarded as a separate unit rather than a part of the Kanpa Formation or Buldya Group. There is no known synonomy.

Distribution and type section: The type section is the interval between 527.4 and 576.2 m in Lancer 1. The intersection is the first record of volcanic rocks within the Kanpa Formation, and the only known occurrence of the Keene Basalt.

Lithology: The basal 3 m of basalt is very fine grained with irregular and inclined amygdaloidal zones and some brecciation. There are at least four and possibly five distinct flows with tops and bases marked by fine-grained amygdaloidal basalt, whereas flow centres comprise coarse-grained massive basalt. The basalt is typically dark grey to greenish, but is reddened at the base and at two of the flow tops. Veins filled with calcite, red chert or chlorite are common, and amygdales are filled with similar material. There are no sediments interbedded within the basalt.

Relationships and boundary criteria: The strata beneath the flows have been baked and show some indications of dewatering; those above the flows are not contact metamorphosed, but show dewatering structures, perhaps indicative of earthquakes associated with volcanism (Pirajno, F., written comm., 2003). The top of the basalt is not fine grained, amygdaloidal or reddened, indicating that the top of the uppermost flow has been eroded down to its doleritic core before deposition of overlying fine-grained sediments.

Age and evidence: Based on broad regional correlations, the Keene Basalt could correlate with (but would not be comagmatic with) the Cadlareena Volcanics of the northeastern Officer Basin in South Australia, which have an age between 780 and 760 Ma (Morton, 1997), as well as the Boucaut Volcanics dated at 777 ± 7 Ma in the Adelaide Rift Complex (Barovich et al., 2001). Further details of petrography and age are not yet available, although work is in progress.

Depositional setting: From preliminary examination of the core, there appear to be up to five flows, with textures ranging from basaltic to doleritic in the central, slower cooling parts of each flow.

Lancer Member

Definition: The Lancer Member comprises very well-sorted medium-grained sandstone, showing large-scale cross-bedding, in the upper Browne Formation. The member has only been recognized in GSWA Lancer 1, after which it is named, but is sufficiently important to warrant recognition as a named member. There is no known synonomy.

Distribution and type section: The type section is the interval between 1201.9 and 1297.7 m (drilled depth, 95.8 m thickness) in Lancer 1. The member may correlate with sandy facies of the Mundadjini Formation in the northwest Officer Basin, or with the silty and sandy upper part of the Skates Hills Formation as described by Williams (1992). The section identified as Hussar Formation in WMC NJD 1 (330 – 376.85 m) by Hocking (2003) could instead be the Lancer Member, beneath silty lower Hussar Formation, based on the presence of the Lancer Member rather than evaporites in Lancer 1, and the similar position of Lancer 1 and NJD 1 relative to the inferred western basin margin.

Lithology: The Lancer Member consists of fine- to medium-grained, very porous, well-sorted orange-brown quartz sandstone, and minor silty beds up to 0.6 m thick. It shows very large scale cross-bedding with foresets up to 11 m thick dipping at up to 30°, and reverse-graded centimetre-scale beds (translatent strata of Hunter, 1977).

Relationships and boundary criteria: The Lancer Member rests on orange-brown siltstone and fine-grained sandstone, here considered to be undifferentiated Browne Formation. The contact is sharp, but this may simply reflect dunes migrating over playas or supratidal mudflats. The upper contact is steep (implying that the sandstone was at least partly lithified) and clearly erosional beneath basal Hussar Formation. Above it, there is 10 cm of reworked sandstone with mud clasts, then evaporitic mudstone of probable supratidal mudflat origin, with some reworked sand in the lower 5 m. Steep dune foresets are truncated at the boundary. This juxtaposition of facies requires some sort of hiatus, so the boundary is probably disconformable. Sandstone laminae are present in the mudstone but decrease upward over about 5 m.

Age and evidence: Palaeontological work has yet to be done on material from Lancer 1. The *Acaciella australica* Stromatolite Assemblage is present below the Lancer Member, in the Woolnough Member, and the *Baicalia burra* Stromatolite Assemblage is present above the Lancer Member. Correlation with other wells indicates that the member equates with the halite interval in the upper Browne Formation in Empress 1A, Kanpa 1A, and Yowalga 3. A likely correlative, based on lithology, facies, and comparison with Boondawari 1 and Mudadjini 1, is sandstone in the upper part of the Mundadjini Formation in the northwestern part of the Officer Basin.

Depositional setting: The sorting, lithology, very large cross-bedding and translatent strata indicate that the member is an eolian dune deposit. The siltstone beds intercalated within the sandstone are presumably interdune deposits, possibly reflecting shallow ephemeral lakes.

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Appendix 4

Preliminary well index sheet

ORGANIZATION: Geological Survey of Western Australia **Statutory Petroleum Exploration Report No.: S20880**
WELL: GSWA Lancer 1 **BASINS:** Gunbarrel Basin over Officer Basin **TYPE:** Stratigraphic
SPUDDED: 10 Oct 2003 **SUB-BASINS:** Sherriff Shelf over Westwood Shelf
COMPLETED: 20 Nov 2003 **ELEVATION GL**: 450 m AHD; RT: 449.3 m AHD
TD: 1501.3 m [(a)] **BHT:** 63.5°C **LATITUDE:** 25°02'44.5"S[(b)]; **LONGITUDE:** 123°45'21"E (GDA 94)[(b)]
STATUS: Plugged and abandoned **NORTHING:** 7229800; **EASTING:** 576200 (MGA Zone 51J) [(b)]

FORMATION	TOPS (m) DRILL	TOPS (m) SUBSEA	LITHOLOGICAL SUMMARY
GUNBARREL BASIN:			
Cainozoic	0	+450.0	Reddish-brown fine-grained sand, brown mudstone and ferricrete overlying multicoloured sandstone
Paterson Formation	?17	+433	Clay, grey mudstone, grey to brown sandstone, minor conglomerate
OFFICER BASIN:			
Lungkarta Formation	?169.1	+280.9	Reddish-brown sandstone and polymict conglomerate
Wahlgu Formation	344.3	+105.7	Red diamictites and mudstone, multicoloured sandstone
Kanpa Formation	466.5	16.5	Brown to grey claystone and mudstone, grey stromatolitic dolostone, grey to brown sandstone
Keene Basalt	527.4 – 576.2	77.4 – 126.2	Dark, fine- to coarse-grained basalt, locally amygdaloidal, erosional upper surface
Hussar Formation	707.5	257.5	Brown sandstone, mudstone and stromatolitic dolostone
Browne Formation	1201.9	751.9	Reddish-brown sandstone and mudstone, red–grey dolostone, halite
Lancer Member	1201.9 – 1297.7	751.9 – 847.7	Reddish-brown cross-bedded sandstone in foresets up to 11 m thick
Woolnough Member	1323.4 – 1357.7	873.4 – 907.7	Red–grey stromatolitic dolostone, mudstone
lower Browne Formation	1357.7 – 1478.9	907.7 – 1028.9	Reddish-brown mudstone with halite crystals becoming abundant towards halite interval; grey, argillaceous dolostone, halite, fine-grained sandstone,minor conglomerate and mudstone below halite interval
unnamed halite interval	1440.8 – 1472.4	990.8 – 1022.4	Halite, reddish-brown mudstone, grey argillaceous dolostone
?MESOPROTEROZOIC BASIN			
?Cornelia Sandstone	1478.9 – 1501.3	1028.9 – 1051.3	Bluish-grey, pebbly, clayey, medium-grained, cross-bedded sandstone, well cemented

CORES	Continuously cored:	PQ: 104–429.5 m;	HQ: 429.5–1501.3 m (driller; 100% recovery)
LOGS	Run 1:	16" normal resistivity	420–1501 m
	Run 2:	64" normal resistivity	420–1501 m
	Run 3 (Gam/G-N):	SPR	420–1501 m
		SP	420–1501 m
		N	0–1501 m
	Run 4 (GAA/DDC):	GR	0–1501 m
		LD	0–1501 m
		SD	0–1501 m
		Caliper	0–1501 m
	Run 5:	Sonic	420–1501 m
	Run 6:	BHTV (acoustic scanner)	1450–1500 m; 1200–1365 m; and 420–900 m
CASING	7" (OD 178 mm, ID 172 mm)		0–6 m
	PW (OD 140 mm, ID 127 mm):		0–104 m
	HWT (OD 114 mm, ID 102 mm):		0–428 m

NOTES: (a) Depth from driller
(b) Drillhole location preliminary, to within 100 m
The resistivity and SPR logs are adversely affected by the highly saline mud in the hole

HAINES et al.

GSWA Lancer 1 well completion report (basic data), Officer and Gunbarrel Basins, Western Australia

RECORD 2004/10

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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 Lancer 1
Composite well log

Company	Geological Survey of WA
Well Name	Lancer 1
Well type	Stratigraphic, vertical corehole
Status	Plugged and abandoned
Basins	Gunbarrel over Officer Basin
Sub-Basins	Sherrif Shelf over Westwood Shelf
Latitude	25°02'44.5" S*
Longitude	123°45'21" E*
Northing	7229780 (MGA Zone 51J)*
Easting	576235*
Elevation GL	450 m AHD
Elevation RT	449.3 m AHD
Height datum	Mean sea level
Total depth	1501.3 m (driller)
Bottom hole temperature	63.5°C
Date spudded	10 October 2003
Date completed	20 November 2003
Rig	UDR 1500
Drilling company	Drillcorp Western Deephole
Logging company	Geoscience Associates
Logging geologists	Peter Haines (core), Mark Stevens (cuttings)

CORES

PQ	104–429.5 m
HQ	429.5–1501 m

LOGS

	16" normal resistivity†	420–1501 m
Run 1	64" normal resistivity†	420–1501 m
Run 2	SPR†	420–1501 m
Run 3	SP	420–1501 m
	N	0–1501 m
	GR	0–1501 m
Run 4	LD	0–1501 m
	SD	0–1501 m
	Caliper	0–1501 m
	Sonic	420–1501 m
Run 5	HTV (acoustic scanner)	1450–1500 m;
Run 6		1200–1365 m;
		420–900 m

CASING

7"	0–6 m
PW	0–104 m
HWT	104–428 m

* Preliminary location, pending final site survey (GDA94).

† 16" normal resistivity, 64" normal resistivity, and single point resistance logs are considered unreliable due to the highly saline mud in the hole.

LITHOLOGIES

Conglomerate
Sandstone
Mudstone
Claystone
Diamictite
Dolostone
Anhydrite/gypsum
Halite
Basalt

LITHOLOGY MODIFIERS

Pebbly
Pebbly (angular clasts)
Sandy
Argillaceous/silty
Dolomitic or dolostone interbeds
Oolitic
Cherty or chert beds/nodules
Anhydritic/gypsiferous
Halite-bearing

SYMBOLS

Flat bedding or lamination
Current ripple lamination
Cross-bedding
Large foresets
Irregular or wavy bedding
Unconformity
Flutes
Soft-sediment deformation, slump
Soft-sediment fault
Sandstone dyke along soft-sediment faults
Dessication cracks
Synaeresis cracks
Vein/fracture
Stylolites
Vugs
Stromatolites
Microbial lamination
Vesicles/amygdales
Pyrite
G Glauconite
Intraclasts (colour indicates lithology)

Scale 1:500

Lithological descriptions
Cutting: 0–104 m
Core: 104–1501 m

0.0 – ?17.0 m CAINOZOIC (?17.0 m thick)

0.0 – 0.2 m. Sand: reddish-brown, fine grained, unconsolidated
0.2 – 2.0 m. Mudstone and ferricrete: moderate brown to moderate yellowish-brown, ferruginous, minor quartz granules, well consolidated (rotary cuttings only)
2.0 – 5.0 m. Mudstone: moderate yellowish-brown, minor fine-grained sandstone (rotary cuttings only)
5.0 – 8.0 m. Mudstone: as for 2–5 m; Sandstone: grey, fine to medium grained, coarsening downhole (rotary cuttings only)
8.0 – 14.0 m. Sandstone: light yellow to light pink, medium grained (rotary cuttings only)
14.0 – 17.0 m. Sandstone: light grey to light yellow, fine to coarse grained, porous, 10–30% grey mudstone (rotary cuttings only)

?17.0 – ?169.1 m PATERSON FORMATION (?152.1 m thick)

17.0 – 21.0 m. Mudstone: light green, grey and yellow, minor fine to medium grained sandstone (rotary cuttings only)
21.0 – 33.0 m. Clay: brown to yellow, minor quartz granules above 25 m, unconsolidated (rotary cuttings only)
33.0 – 70.0 m. Clay: yellow, green, and grey (mostly grey below 58 m), unconsolidated, rare granule fragments at 39.0 – 41.0 m and 49.0 – 70.0 m, rare consolidated mudstone to very fine sandstone chips below 64 m (rotary cuttings only)
70.0 – 74.5 m. Mudstone and conglomerate: multicoloured, sedimentary clasts 1–10 mm, clasts sub-angular to sub-rounded (rotary cuttings only)
74.5 – 77.0 m. Mudstone: light grey, moderate consolidation, 80–90%; Conglomerate: as for 70.0 – 74.5 m, 10–20%, increases upward, probably contamination (rotary cuttings only)
77.0 – 93.0 m. Mudstone: moderate grey to moderate grey-green, poorly consolidated, fissile in parts, trace of carbonaceous material at 81.0 – 82.0 m, 86.0 – 88.0 m, 91.0 – 93.0 m (rotary cuttings only)
93.0 – 95.0 m. Mudstone: as for 77.0 – 93.0 m, 90%; Sandstone: light brown, very fine to fine grained, quartzose, poor to fair porosity, moderate consolidation (rotary cuttings only)
95.0 – 104.0 m. Mudstone and sandstone: as for 93.0 – 95.0 m, but sandstone increases downward to 40% (rotary cuttings only)
104.0 m. Start of PQ coring
104.0 – 125.0 m. Sandstone: light to moderate grey-green (locally reddish), medium grained, moderately well sorted, rounded, subfriable, porous, quartz dominant but significant lithic, feldspar, and mica content, cross-bedded, claystone intraclasts
125.0 – 133.0 m. Sandstone: as for 104.0 – 125.0 m, but alternating light grey to mottled reddish-brown.
133.0 – 155.5 m. Sandstone: light reddish-brown, medium to coarse grained, moderately to poorly sorted, cross-bedded, increased clay matrix and lithic-feldspathic content compared to 104.0 – 133.0 m, red mud-clast horizons, slightly pyritic in parts
155.5 – 156.0 m. Mudstone: red with greenish bands and mottles, minor sandy bands weakly fissile
156.0 – 159.1 m. Sandstone: as for 133.0 – 155.5 m, patchy calcareous cementation
159.1 – 159.8 m. Mudstone: as for 155.5 – 156.0 m
159.8 – 161.1 m. Sandstone: as for 156.0 – 159.1 m
161.1 – 162.7 m. Mudstone: as for 155.5 – 156.0 m
162.7 – 165.6 m. Sandstone: as for 156.0 – 159.1 m, green mudstone intraclasts at top
165.6 – 167.0 m. Mudstone: as for 155.5 – 156.0 m, poorly sorted coarse sandy to granule interbeds, possible desiccation cracks
167.0 – 168.2 m. Conglomerate: reddish-brown, polymict pebbles to 1 cm, rounded, very poorly sorted, alternates with red mudstone; in part a diamictite
168.2 – 169.0 m. Sandstone: reddish-brown, fine to medium grained, moderate to well sorted, current ripple cross-laminations
169.0 – 169.1 m. Erosional surface at 169.1 m overlain by 5 cm conglomerate with metamorphic clasts to 8 cm

?169.1 – 344.3 m. LUNGKARTA FORMATION (?175.2 m thick)

169.1 – 205.0 m. Sandstone: pale brown, medium grained, moderate sorted, generally rounded, quartz rich, minor clay matrix, rare red mudstone interbeds and intraclasts, cross-bedded, concretions common in lower half, sparse pyrite mainly near base
205.0 – 214.0 m. Sandstone: reddish-brown, fine to coarse grained, fining upward, lithic granule conglomerate horizons in lower half, poorly sorted, mostly flat-bedded
214.0 – 270.9 m. Sandstone: reddish-brown, medium grained, well sorted, well rounded, porous, very large foresets with dips up to 30°, sparse pyrite in upper 22 m
270.9 – 271.6 m. Diamictite: reddish-brown and minor grey, sandy mudstone with angular lithic clasts to 2 cm
271.6 – 310.2 m. Sandstone: as for 214.0 – 270.9 m, soft-sediment deformation at top of interval
310.2 – 311.0 m. Sandstone: reddish-brown, massive, pebbly, polymict angular granules and pebbles up to 8 mm
311.0 – 325.7 m. Sandstone: as for 214.0 – 270.9 m
325.7 – 326.5 m. Conglomerate: reddish-brown sandy matrix, polymict rounded to angular clasts up to 6 cm
326.5 – 339.9 m. Sandstone: as for 214.0 – 270.9 m
339.9 – 341.3 m. Conglomerate and sandstone: reddish-brown, sharp-based fining-upward succession from polymict granule conglomerate with coarse sandy matrix to cross-bedded, medium to coarse grained pebbly sandstone, poorly sorted, angular to rounded clasts
341.3 – 344.3 m. Conglomerate and sandstone: reddish-brown, sharp-based fining-upward succession from polymict granule conglomerate with coarse sandy matrix to flat-laminated medium-grained sandstone

344.3 – 466.5 m WAHLGU FORMATION (122.2 m thick)

344.3 – 345.7 m. Sandstone: white to green (reddened at top), medium grained, well sorted, rounded, porous, green claystone intraclasts, flat bedded
345.7 – 349.1 m. Diamictite: red, fine sandy matrix; Mudstone: red, sparse pebbles
349.1 – 350.0 m. Sandstone: green with red mottles, medium grained, poorly sorted with muddy matrix, sparse pebbles, weak lamination and soft-sediment deformation
350.0 – 354.5 m. Diamictite: red with green bands and mottles, matrix of very poorly sorted muddy sandstone, large striated igneous clast at 352.4 m
354.5 – 358.3 m. Sandstone: red, fine to coarse grained, moderately to well sorted, flat-bedding, foreset bedding, climbing current ripple lamination
358.3 – 359.0 m. Sandstone: white to pale green, medium to coarse grained, well sorted, rounded, foreset bedding, possible glauconite
359.0 – 388.0 m. Diamictite: red, local green reduction spots, matrix very poorly sorted muddy sandstone, pebble-, cobble- and boulder-size clasts, angular to rounded, some clasts striated, mostly massive, local soft-sediment deformation. Mudstone: red
388.0 – 390.2 m. Mudstone: red, scattered sand grains, rare pebbles
390.2 – 391.0 m. Sandstone: green grading to red at top, coarse grained, rounded, pebbly, abundant mud clasts, possible glauconite
391.0 – 397.0 m. Sandstone: red, coarse-grained, pebbly, moderately sorted, grains rounded, weak foreset bedding; 30 cm basal sandstone bed pale green to white, medium to coarse grained, well sorted, cross-bedded, possible glauconite
397.0 – 405.0 m. Diamictite: as for 359.0 – 388.0 m
405.0 – 413.5 m. Diamictite: as for 359.0 – 388.0 m, but mostly with mudstone matrix, clasts reach 0.5 m near base, largest clasts are mafic igneous
413.5 – 414.4 m. Sandstone: green with red centre, medium grained, green mudstone bands, irregular bedding
414.4 – 424.5 m. Diamictite: as for 359.0 – 388.0 m
424.5 – 427.9 m. Diamictite: moderate grey, mudstone matrix, massive
427.9 – 428.6 m. Sandstone: red, medium to coarse grained, graded, interbedded with red mudstone, possible glauconite
428.6 – 428.7 m. Conglomerate: red, polymict, clast supported, coarse-grained sandy matrix
428.7 – 443.7 m. Diamictite: brown (grey and red near top), mudstone matrix with significant fine sandy content below 439.0 m, massive; Sandstone dyke at 442. 2 – 443.7 m filled with white medium-grained well-silicified sandstone
443.7 – 449.5 m. Mudstone: brown, fractured, slickensides, massive to locally flat laminated, soft-sediment deformation, minor fine-grained green sandstone
449.5 – 452.0 m. Sandstone: brown, medium grained, poorly sorted, abundant sandstone and mudstone intraclasts in lower part, flat bedding and current ripple laminations, graded and reverse-graded beds
452.0 – 456.5 m. Diamictite: grey, varying to green and brown near base, soft-sediment deformation near base
456.5 – 457.0 m. Mudstone: reddish-brown, fractured
457.0 – 459.0 m. Sandstone: reddish-brown, poorly sorted, pebble clasts and mudstone intraclasts in lower part, flat-bedded, soft-sediment deformation and faulting
459.0 – 459.5 m. Mudstone: reddish-brown
459.5 – 462.5 m. Diamictite: reddish-brown, muddy sandstone matrix, grading down into poorly sorted sandstone, soft-sediment deformation and faulting
462.5 – 466.5 m. Dolostone and sandstone: interpreted as dolostone-clast conglomerate with sandy matrix and sandstone interbeds, grey to green. Sandstone: medium to coarse grained, poorly sorted

466.5 – 707.5 m KANPA FORMATION (122.2 m thick)

466.5 – 470.9 m. Dolostone: grey, argillaceous and locally sandy, fractured at top, 10 cm ooid packstone
470.9 – 474.8 m. Mudstone: dark grey to greenish-grey, sandy interbeds, strongly sheared (minor fault?), argillaceous dolostone at base
474.8 – 477.0 m. Dolostone: grey, argillaceous, stylolitic, stromatolitic and microbially laminated (at 476.2 – 477.0 m), vuggy dolostone intraclast conglomerate with medium to coarse sandy matrix at 475.0 – 475.4 m, dolomitic sandstone
477.0 – 481.0 m. Sandstone: grey to locally green and brown, fine to coarse grained, moderately sorted, locally porous and friable, dolomitic at top and base, mudstone interbeds
481.0 – 483.6 m. Mudstone: grey, flat laminated, dolomitic, dolostone interbeds
483.6 – 493.8 m. Dolostone: grey, argillaceous, stylolitic, stromatolitic at 486.1 – 486.4 m, 487.0 – 488.3 m, 490.2 – 490.6 m, 492.8 – 493.1 m, flat laminated, minor intraclasts and grainstone, dolomitic sandstone and mudstone interbeds, minor pyrite at top
493.8 – 495.4 m. Sandstone: light grey to green, medium to coarse grained, well sorted, in part porous and friable, dolomitic at top, thin mudstone at base
495.4 – 499.4 m. Dolostone: grey, stromatolitic, stylolitic, intraclast conglomerate at top, chert nodules at 498.8 m
499.4 – 501.5 m. Sandstone: grey, medium to coarse grained, mostly well rounded, well sorted, in part porous and friable, flat laminations, mudstone interbeds, dolomitic at top
501.5 – 505.5 m. Mudstone: dark grey to black in lower part, grey to green and brown above, coarsening upward, thin sandstone interbeds in upper part, flat laminated, dolomitic, intraclastic sandstone at base
505.5 – 510.5 m. Dolostone: grey, stromatolitic at 505.5 – 505.8 m, 506.6 – 506.9 m, 508.0 – 508.5 m, oiod grainstone at 506.9 – 507.7 m, intraclastic horizons, sandy horizons, stylolitic
510.5 – 514.0 m. Mudstone: grey in upper half, brown to green and black in lower, dolomitic, fine sandstone interbeds, flat laminations and current ripple laminations. Dolostone: stylolitic, possibly stromatolitic
514.0 – 522.0 m. Sandstone: grey, brown near top, coarsening upward from fine grained near base to medium and coarse at top, well sorted, rounded, porous, subfriable, weakly flat laminated, ripple cross-laminations, mudstone interbeds at base
522.0 – 527.0 m. Dolostone: grey, stromatolitic at 522.8 – 523.6 m, 524.7 – 525.5 m, 526.2 – 527.0 m, dolomitic sandstone and mudstone interbeds, locally oolitic, stylolitic, flat laminated where not stromatolitic
527.0 – 527.4 m. Sandstone: grey, muddy, coarse to fine grained, poorly sorted, pyritic, flat bedded, overlies erosional surface on top of basalt

527.4 – 576.2 m KEENE BASALT (48.8 m thick)

527.4 – 576.2 m. Basalt: dark greenish-grey to black, locally reddened, fine to coarse grained, locally amygdaloidal, common fractures filled with chlorite, calcite, and red chert, pyritic near top and base. Lava flows: 4 or 5 separate flows; flow tops at 537.4 m, ?545.5 m, 555.5 m and 558 m; flow tops typically fine grained, amygdaloidal and in some cases reddened; top of unit eroded

KANPA FORMATION (continued)

576.2 – 579.4 m. Dolostone: grey to locally red, variably recrystallized by contact metamorphism, top 15 cm mostly silicified, local vuggy porosity, stromatolitic at 576.5 – 577.1 m and possibly near base, grades down to dolomitic mudstone
579.4 – 582.0 m. Interbedded dolomitic and calcareous mudstone, sandstone and dolostone: grey to green, black mudstone near base, sandstone fine to medium grained, fining-upward sequence, flat to wavy laminations, synaeresis cracks
582.5 – 583.0 m. Dolostone: red and green, intraclastic, sandy
583.0 – 595.1 m. Sandstone: multicoloured, fine to medium grained, minor coarse grained near base, moderately sorted, dolomitic and calcareous in part, interbedded mudstone, flat laminations, synaeresis cracks
595.1 – 598.3 m. Sandstone: white to light brown, fine to medium grained, well sorted, rounded, weak flat bedding to low-angle cross-bedding
598.3 – 618.4 m. Mudstone: light to dark grey, locally green, brown near base, interbeds of fine- to medium-grained sandstone, flat laminations, pot and gutter casts, synaeresis cracks, soft-sediment deformation
618.4 – 629.2 m. Sandstone: white to light brown, locally greenish, mostly medium grained, well sorted, rounded, porous, weak flat bedding and low-angle cross-bedding, local mudstone interbeds, erosive base with mudstone intraclasts, locally ferruginous
629.2 – 639.6 m. Sandstone: light brown, reddened near top and base, medium grained, well sorted, rounded, porous, weak flat bedding and cross-bedding, erosional base with abundant green mudstone intraclasts
639.6 – 656.0 m. Mudstone: grey, flat laminated, thin graded fine- to medium-grained sandstone interbeds with flat to current ripple laminations, micaceous, locally pyritic, soft-sediment deformation and microfaulting
656.0 – 663.8 m. Sandstone: grey in upper half grading to reddish-brown in lower, medium grained, well sorted, rounded, flat bedded to cross-bedded, grey to black mudstone interbeds in upper half, ferruginous concretions near base
663.8 – 669.0 m. Mudstone: grey, thin very fine-grained sandstone interbeds, massive to flat laminated
669.0 – 680.0 m. Claystone: grey, minor siltstone interbeds, massive to flat laminated
680.0 – 689.5 m. Claystone coarsening to mudstone downhole: brown and grey in upper half, brown below, flat laminated, thin sandstone interbed near base
689.5 – 695.6 m. Mudstone: grey, fine- to medium-grained sandstone interbeds, flat to current ripple laminations, synaeresis cracks near base, local soft-sediment deformation
695.6 – 696.9 m. Sandstone: light grey, medium grained, well sorted, subfriable, porous, erosional fluted base, cross-bedding near top, vertical fractures
696.9 – 699.7 m. Sandstone: white to reddish-brown and green, fine to medium grained, common mudstone laminae, fining-upward sequence to greenish-brown mudstone at top
699.7 – 707.5 m. Mudstone: brown, fine- to medium-grained sandstone interbeds between 702.5 and 703.7 m, minor very fine-grained sandstone interbeds elsewhere, flat laminated, synaeresis cracks

707.5 – 1201.9 m HUSSAR FORMATION (494.4 m thick)

707.5 – 731.0 m. Sandstone: light brown to white, medium to coarse grained, well sorted, rounded, subfriable (unconsolidated at 413.3 – 413.6 m), porous, flat bedded and cross-bedded with massive intervals, local vertical fractures
731.0 – 746.5 m. Sandstone: as for 707.5 – 731.0 m, but colour changes to reddish-brown with some green horizons, becomes white near base, rare thin mudstone interbeds, minor pyrite at base
746.5 – 750.6 m. Mudstone: mostly greenish-grey, fine-grained sandstone interbeds, flat and current ripple laminations
750.6 – 762.7 m. Sandstone: reddish-brown in upper half to mainly white in lower, medium to coarse grained, well sorted, rounded, subfriable, porous, flat bedded to cross-bedded, 10 cm nodular magnesite or anhydrite at top, top 1 m dolomitic and vuggy
762.7 – 765.9 m. Dolostone: brown, possible stromatolites at 762.7 – 763.2 m, stylolitic. Sandstone: brown, medium grained, flat bedded, dolomitic, magnesite or anhydrite beds and intraclasts, vuggy, porous
765.9 – 768.2 m. Dolostone: grey-brown, stromatolitic at 766.7 – 768.0 m, 10 cm sandy ooid grainstone at base, stylolitic
768.2 – 774.3 m. Sandstone: light brown (top reddish-brown), upper half medium to coarse grained, well sorted, porous, subfriable, lower half fine to medium grained and less friable, flat laminations and cross-bedding
774.3 – 774.9 m. Mudstone: brown, flat laminated, fine sandy interbeds near base
774.9 – 794.5 m. Sandstone: white to very light brown, mostly medium grained (fine at top), mostly well sorted, rounded, subfriable and porous, quartzose, flat bedded to cross-bedded
794.5 – 797.5 m. Dolostone and sandstone: brown, interbedded lithologies, stromatolitic dolostone at 796.6 – 796.9 m, sandstone is medium to coarse grained, well sorted, rounded, porous, flat bedded and cross-bedded, anhydrite nodules
797.5 – 800.3 m. Sandstone: light brown, fine to medium, and locally, coarse grained, poorly to well sorted, porous near base, flat bedding and ripple cross laminations
800.3 – 800.7 m. Dolostone: brownish-grey, stromatolitic, stylolitic, anhydrite nodules
800.7 – 802.2 m. Mudstone: brown to minor green, flat laminated
802.2 – 805.1 m. Dolostone: brown, stromatolitic at 802.8 – 803.3 m, 803.9 – 804.1 m, stylolitic, intraclastic horizon, oolitic horizons, anhydrite nodules partly silicified
805.1 – 807.9 m. Sandstone and mudstone: brown, red, and green, interbedded lithologies
807.5 – 809.5 m. Dolostone: brown, stromatolitic at 808.8 – 809.1 m, stylolitic, chert and anhydrite nodules, sandy
809.5 – 833.1 m. Sandstone: light reddish-brown, medium to coarse grained, minor fine grained, mostly well sorted and rounded, subfriable, porous, flat bedded to cross-bedded, current ripple laminations, minor muddy intervals, local pyrite
833.1 – 838.0 m. Sandstone and dolomitic sandy mudstone: light brown to minor green, lithologies interbedded, sandstone medium to coarse grained, well sorted, porous, flat bedded to cross-bedded
838.0 – 859.6 m. Sandstone: pale brown, medium to coarse grained, mostly well sorted, rounded, subfriable to friable in parts, porous, flat bedded and cross-bedded, local soft-sediment deformation, local pyrite
859.6 – 861.4 m. Mudstone: brown, minor yellow and green, flat laminations, fine-grained sandstone interbeds, minor anhydrite
861.4 – 866.0 m. Sandstone: pale green, fine to medium grained, well sorted, rounded, slightly porous, flat laminations and current ripple cross-laminations, thin brown mudstone interbeds, minor anhydrite, possible glauconite
866.0 – 868.5 m. Mudstone: brown, flat laminations, fine-grained sandstone interbeds near top
868.5 – 888.8 m. Sandstone: upper half pale brown grading to white below, medium grained, well sorted, rounded, subfriable in parts, porous, massive to flat bedded and cross-bedded, anhydrite and mudstone interbeds in upper part
888.8 – 891.8 m. Mudstone: brown and green, common medium-grained sandstone interbeds; Sandstone: moderately to well sorted, rounded, slightly porous, flat laminations and current ripple laminations, possible glauconite
891.8 – 898.5 m. Sandstone: pale green, medium to coarse grained, mostly well sorted, rounded, subfriable, porous, flat bedded, cross-bedded near base
898.5 – 912.3 m. Mudstone: red, green reduction spots in lower part, locally dolomitic, massive to flat laminated, current ripple laminations, desiccation cracks, graded siltstone and very fine sandstone interbeds, anhydrite in nodules and veins
912.3 – 921.0 m. Dolostone: pale brown, stromatolitic at 913.5 – 913.9 m, 917.0 – 917.6 m, 919.0 – 919.3 m, stylolitic, interbeds of brown and reddish-brown mudstone and dolomitic mudstone, anhydrite and chert nodules, intraclasts common, local desiccation cracks
921.0 – 929.0 m. Mudstone: reddish-brown and green, dolomitic, dolostone interbeds, flat and current ripple laminations, common anhydrite nodules and veins, rip-up intraclasts, desiccation cracks
929.0 – 933.1 m. Mudstone: grey and reddish-brown, dolomitic, dolostone interbeds, flat and current ripple laminations, common anhydrite nodules and veins, 20 cm massive anhydrite bed below 929.3 m
933.1 – 936.1 m. Anhydrite: white, fine- to coarse-grained, massive, interbedded with and capped by argillaceous dolostone
936.1 – 952.3 m. Dolostone: grey, stromatolitic at 939.4 – 939.5 m, 940.1 – 941.9 m, 943.0 – 943.2 m, 944.9 – 945.15 m, 945.7 – 945.8 m, 948.1 – 948.3 m, 948.8 – 952.3 m, stylolitic, interbedded grey dolomitic mudstone, anhydrite nodules, sparse pyrite, soft-sediment deformation
952.3 – 956.5 m. Mudstone: dark grey to black, in part dolomitic, interbedded pale-grey dolostone, flat laminated, minor soft-sediment deformation, sparse fine pyrite
956.5 – 961.2 m. Dolostone: grey, stromatolitic at 956.5 – 957.2 m, 960.3 – 960.7 m, 961.0 – 961.2 m, stylolitic, dark-grey to black dolomitic mudstone interbeds, cauliflower anhydrite nodules, sparse fine pyrite
961.2 – 965.8 m. Mudstone: grey, minor brown and black horizons, dolomitic, massive to flat-laminated, dolostone intraclast horizons, anhydrite nodules
965.8 – 966.2 m. Anhydrite: chicken-wire texture grading to nodules in mudstone matrix
966.2 – 969.0 m. Dolostone: grey, argillaceous, flat laminated, anhydrite nodules and interbeds, minor chicken-wire texture
969.0 – 988.5 m. Mudstone: grey and green near top, grading to brown with green reduction spots below 973 m, dolomitic near top, siltstone to very fine-grained sandstone interbeds, flat laminated, current ripple laminations near top
988.5 – 997.8 m. Sandstone: light brown to green, mostly medium to coarse grained, moderately to well sorted, rounded, variable porosity, flat bedded to cross-bedded, current ripple laminations, possible glauconite, mudstone interbeds
997.8 – 1003.5 m. Dolostone: reddish-brown, ferruginous, stromatolitic at 997.8 – 1000.5 m, stylolitic, locally vuggy, oolitic grainstone in lower half, porous, medium to coarse grained sandstone interbed in centre
1003.5 – 1005.9 m. Sandstone: light green, medium to coarse grained, well sorted, rounded, subfriable in parts, slightly porous, flat bedding
1005.9 – 1007.0 m. Mudstone: red, flat laminated, fine-grained sandstone interbeds
1007.0 – 1012.0 m. Dolostone: reddish-brown, stromatolitic at 1008.3 – 1010.0 m, stylolitic, recrystallized grainstone at top and base, common intraclasts near top, anhydrite nodules
1012.0 – 1025.1 m. Sandstone: light reddish-brown to white, medium to coarse grained, moderately to well sorted, rounded, subfriable in part, porous in part, flat bedded to cross-bedded, thin mudstone interbeds in central part
1025.1 – 1027.1 m. Dolostone: reddish-brown, stromatolitic at 1025.3 – 1025.7 m, 1026.5 – 1027 m, stylolitic, sandy in part
1027.1 – 1029.0 m. Sandstone: brown, coarse grained, dolomitic and intraclastic near base
1029.0 – 1031.1 m. Dolostone: reddish-brown, wavy laminations, ooids near base, minor silicification, stylolitic
1031.1 – 1037.5 m. Dolostone, sandstone, and mudstone: mostly reddish-brown, lithologies interbedded, possibly stromatolitic dolostone 1033.2 – 1033.5 m, 1035.0 – 1035.4 m, stylolitic, local chert nodules, local ooids
1037.5 – 1040.0 m. Sandstone: light green, medium grained, moderately to well sorted, rounded, subfriable, slightly porous, flat bedded
1040.0 – 1041.0 m. Dolostone: brown, argillaceous, flat laminated
1041.0 – 1043.0 m. Sandstone: brown, medium to coarse grained, moderately to poorly sorted, dolomitic, mudstone, interbeds in lower part, flat bedded, desccation cracks near base
1043.0 – 1045.3 m. Dolostone: brown, argillaceous, chicken-wire anhydrite near top, locally sandy, stylolitic, flat laminations
1045.3 – 1047.8 m. Sandstone: light brown to green, medium to coarse grained, moderately sorted, sub-angular grains, slightly porous horizons, flat to ripple cross-laminations, mudstone interbeds
1047.8 – 1051.8 m. Dolostone: brown, flat laminated, anhydrite and chert breccia near top, possible stromatolites in lower part, stylolitic, partly silicified ooid grainstone near base
1051.8 – 1059.5 m. Sandstone: mostly grey, medium to coarse grained in lower part, poor to well sorted, sub-angular to rounded grains, cross-bedded
1059.5 – 1062.2 m. Mudstone: red and brown, flat to ripple cross-lamnated, desiccation cracks, sandstone interbeds in upper part
1062.2 – 1068.0 m. Dolostone: brown, mostly flat laminated, local microbial laminations, stylolitic, abundant intraclastic breccia near base, anhydrite and chert nodules, dolomitic sandstone interbed near top
1068.0 – 1069.7 m. Mudstone: brown, dolomitic, sandstone interbeds, flat to ripple cross-laminations, desiccation cracks, intraclastic horizon at base
1069.7 – 1070.3 m. Dolostone: brown, flat laminated, anhydrite, halite pseudomorphs, erosive top
1070.3 – 1121.6 m. Mudstone: reddish-brown and lesser green, calcareous in upper half, graded siltstone to very fine sandstone interbeds, flat and current rippe laminations, desiccation cracks, anhydrite nodules
1121.6 – 1124.5 m. Dolostone: grey, partly replaced by chert, fractured, some fractures filled with anhydrite or gypsum, intraclast horizons in upper part, ooids present in lower part, stylolitic
1124.5 – 1134.1 m. Mudstone: mostly reddish-brown, minor green layers and reduction spots, dolomitic in part, mostly massive, sparse anhydrite
1134.1 – 1135.4 m. Dolostone: grey, partly replaced by chert, fractured in lower part, interbeds of anhydrite or gypsum
1135.4 – 1140.8 m. Mudstone: as for 1124.5 – 1134.1 m
1140.8 – 1143.1 m. Dolostone: grey, partly replaced by chert, strongly fractured, stromatolitic between 1141.2 – 1142.0 m, interbed of anhydrite or gypsum near base, stylolitic
1143.1 – 1154.5 m. Mudstone: as for 1124.5 – 1134.1 m
1154.5 – 1157.0 m. Dolostone: grey, partly replaced by chert, fine-grained ooid grainstone between 1155.8 – 1156.2 m, anhydrite nodules near top, stylolitic
1157.0 – 1165.9 m. Mudstone: as for 1124.5 – 1134.1 m, anhydrite more abundant as thin stringers and vertical veins up to 3 m, thin dolostone interbed near base
1165.9 – 1167.1 m. Dolostone: grey, interbeds of anhydrite or gypsum, intraclast horizons, partly brecciated
1167.1 – 1175.2 m. Mudstone: as for 1124.5 – 1134.1 m
1175.2 – 1175.7 m. Dolostone: pink to brown, flat-laminated, argillaceous, recrystallized, small chert nodules possibly replacing anhydrite
1175.7 – 1195.1 m. Mudstone: as for 1124.5 – 1134.1 m, irregular and disrupted laminations, anhydrite more abundant, minor fine-grained sandy horizons
1195.1 – 1195.3 m. Anhydrite: bands of small nodules, partly replaced by chert and chalcedony, hosted by brown mudstone
1195.3 – 1197.0 m. Mudstone: as for 1124.5 – 1134.1 m
1197.0 – 1201.9 m. Mudstone: as for 1124.5 – 1134.1 m, scattered sand grains and medium- to coarse-grained sandstone interbeds, mudstone intraclasts in basal sandstone bed

1201.9 – 1478.9 m BROWNE FORMATION (277 m thick)

1201.9 – 1297.7 m Lancer Member (95.8 m thick)

1201.9 – 1242.0 m. Sandstone: reddish-brown, medium grained, mostly well sorted, well rounded, subfriable, porous, quartzose, large foresets to 11 m with dips to 25°, minor irregularly flat-bedded horizons, sandstone dykes along small-scale faults
1242.0 – 1261.0 m. Sandstone: as for 1201.9 – 1242.0 m, but average grain size increases to borderline coarse sand, increased proportion of finer moderately sorted irregularly flat bedded horizons, foresets to 3 m
1261.0 – 1279.0 m. Sandstone: as for 1201.9 – 1242.0 m, foresets to 3 m with dips to 27°
1279.0 – 1297.7 m. Sandstone: as for 1201.9 – 1279.0 m, but irregularly flat bedded horizons become dominant over 1 m-scale foreset horizons, fine to coarse grained, moderately to well sorted, inclined open fractures common, 60 cm green sandstone at base
1297.7 – 1301.9 m. Sandstone: basal 80 cm green grading to reddish-brown above, medium grained and moderately sorted at base grading upward to fine-grained and poorly-sorted muddy sandstone above, irregular laminations
1301.9 – 1322.0 m. Sandstone: mostly reddish-brown with local green interbeds, fine to very fine grained (rarely medium) with high mud content, poorly sorted, irregular laminations
1322.0 – 1323.4 m. Sandstone: reddish-brown, medium grained with coarse interbeds, moderately sorted, subangular grains, cross-bedded

1323.4 – 1357.7 m Woolnough Member (34.3 m thick)

1323.4 – 1325.6 m. Dolostone: light reddish-brown, stromatolitic at 1323.5 – 1324.1 m, 1324.6 – 1325.6 m, interbedded with mudstone
1325.6 – 1331.9 m. Mudstone and dolostone: multicoloured, interbedded lithologies, flat laminations and ripple cross laminations, possible desiccation cracks, vertical anhydrite veins
1331.9 – 1333.8 m. Dolostone: reddish-grey, argillaceous, stromatolitic, stylolitic, vertical anhydrite vein
1333.8 – 1345.9 m. Mudstone and dolostone: reddish-brown and grey, interbedded lithologies, flat to current ripple laminations, desiccation dracks, intraclast horizons, minor medium to coarse grained sandstone, anhydrite layers and veins
1345.9 – 1347.3 m. Dolostone: brownish-grey, microbially laminated and stromatolitic
1347.3 – 1357.7 m. Dolostone: brownish-grey, stromatolitic at 1348.8 – 1350.9 m, 1351.3 – 1351.7 m, 1353.7 – 1355.3 m, sandy at top, locally argillaceous, grainstone and intraclastic horizons, vertical anhydrite vein, minor mudstone interbeds

1357.7 – 1478.9 m lower Browne Formation (123.6m thick)

1357.7 – 1378.0 m. Mudstone: red with common green reduction spots and mottles, weakly dolomitic, massive to irregularly laminated
1378.0 – 1382.2 m. Mudstone: as for 1357.7 – 1378.0 m, but with thin horizons containing scattered fine to medium sand grains, massive
1382.2 – 1386.5 m. Mudstone: as for 1357.7 – 1378.0 m, but with anhydrite or gypsum in veins and filling pseudomorphs after probable halite, massive
1386.5 – 1390.0 m. Mudstone: as for 1357.7 – 1378.0 m, but with poorly sorted and lithic medium to coarse grained sandstone horizons, irregularly laminated, minor anhydrite or gypsum
1390.0 – 1408.5 m. Mudstone: reddish-brown, green reduction spots, dolomitic, dolostone interbeds, sparse medium to coarse sandy horizons, flat to irregular and current ripple laminations, desiccation cracks, anhydrite or gypsum, halite pseudomorphs
1408.5 – 1414.9 m. Mudstone: reddish-brown, green reduction spots, dolomitic, dolostone interbeds, mostly massive, halite rimmed by anhydrite or gypsum, nodular anhydrite layers between 1414.4 – 1414.9 m
1414.9 – 1440.8 m. Mudstone: reddish-brown, green reduction spots, dolomitic, massive to weakly laminated, rare sandy interbeds, common clear halite as isolated crystals, crystal clusters and veins
1440.8 – 1447.0 m. Halite: orange, interbeds and lenses of flat-laminated dolomitic mudstone
1447.0 – 1450.0 m. Mudstone: reddish-brown, flat laminated. Halite: orange, thin beds and isolated crystals
1450.0 – 1451.0 m. Halite: as for 1440.8 – 1447.0 m
1451.0 – 1451.6 m. Mudstone: reddish-brown, dolomitic, flat laminated, isolated halite
1451.6 – 1456.5 m. Halite: as for 1440.8 – 1447.0 m
1456.5 – 1457.4 m. Mudstone: brown, flat laminated, dolomitic, isolated halite, grey argillaceous dolostone at top
1457.4 – 1463.4 m. Halite: as for 1440.8 – 1447.0 m, grey dolostone interbeds in lower half
1463.4 – 1465.1 m. Dolostone: grey, argillaceous, halite beds and isolated crystals
1465.1 – 1466.2 m. Halite: as for 1440.8 – 1447.0 m
1466.2 – 1467.0 m. Dolostone: as for 1463.4 – 1465.1 m
1467.0 – 1469.6 m. Halite: as for 1440.8 – 1447.0 m
1469.6 – 1471.4 m. Dolostone: as for 1463.4 – 1465.1 m, minor black intervals, minor fine-grained sandstone interbeds
1471.4 – 1472.4 m. Halite: as for 1440.8 – 1447.0 m
1472.4 – 1475.2 m. Dolostone: as for 1463.4 – 1465.1 m, minor black horizons, sandy interbeds
1475.2 – 1478.9 m. Sandstone interbedded with conglomerate, dolostone, and mudstone: brown, grey, and black, 10 cm basal sandy conglomerate over erosional surface, minor halite and anhydrite, bedding dips 2°

1478.9 – 1501.2 m ?CORNELIA SANDSTONE (>22.3 m thick)

1478.9 – 1501.2 m. Sandstone: bluish-grey, medium grained, minor coarse interbeds, sparse small pebbles, moderately sorted, subrounded, minor clay matrix, feldspathic, micaceous, well cemented, cross-bedded; 1 cm mudstone interbed dips 4°

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