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Chapter 34: Warburton Basin

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Chapter 34: WARBURTON BASIN

CJ Edgoose and TJ Munson

INTRODUCTION

The Warburton Basin is a vast subsurface region occurring mostly in northeastern South Australia and southeastern Northern Territory, with a small portion in southwesternmost Queensland (**Figure 34.1**). It is an Early Palaeozoic pericratonic basin containing an early Cambrian and Ordovician succession, with possible Devonian rocks observed in some areas (Radke 2009). Gravestock and Gatehouse (1995) and Gravestock (1995) defined the basin as comprising only Cambrian and Ordovician volcanic and sedimentary rocks, and considered the overlying post-Ordovician sedimentary succession to be more characteristic of the Amadeus Basin. However, in this chapter, the overlying ?Late Ordovician to Devonian or Early Carboniferous succession is also described.

The basin comprises two parts (**Figure 34.1**): the eastern Warburton Basin (SA), which is separated by the Birdsville Track Ridge from the western Warburton Basin (SA and NT). The eastern Warburton Basin is essentially a fold belt, deformed and uplifted during the 450–300 Ma Alice Springs Orogeny of central Australia (or the equivalent Kanimblan Orogeny of eastern Australia) and subsequently buried beneath the Cooper Basin (SA). Its relatively well studied succession consists of the putative early Cambrian Mooracoochie Volcanics unconformably overlain by a thick, relatively complete middle Cambrian to Middle Ordovician succession of the mixed carbonate–siliciclastic Kalladeina Formation/Dullingari Group, overlain by interbedded shale and sandstone red beds of the Innamincka Formation, in turn overlain by the Mudrangie Sandstone (PIRSA 2012, **Figure 34.2**). Within the early Palaeozoic succession, disconformities are recognised at three stratigraphic levels and are related to tectonic events. Early to late Cambrian intraplate rifting is interpreted to have propagated to the north-northwest. The structural style superimposed by deformation during the subsequent Alice Springs Orogeny follows arcuate northeast trends imposed by northwest-directed thrust faults.

The western Warburton Basin is the larger portion and is situated between Proterozoic terranes of the Gawler Craton to the south, Musgrave Province to the west and Arunta Region to the north. This vast region has attracted little seismic and exploration drilling and is consequently much more poorly known and understood than the eastern part. It was in probable depositional continuity with successions of similar age in the Amadeus Basin to the northwest, eastern Officer Basin to the southwest and eastern Warburton Basin to the east of the Birdsville Track Ridge. Cambrian depositional areas of the Georgina and highly metamorphosed Irindina Province basins to the north might also have been continuous with the Warburton Basin, at least in part. This vast contiguous depositional area formed a large part of the Cambrian–Ordovician Centralian B Superbasin (see **Centralian Superbasin**: **figure 22.6**). In the Northern Territory, the western Warburton Basin overlies poorly known Proterozoic crystalline basement rocks and is entirely concealed beneath the younger Permian–Triassic Pedirka, Mesozoic

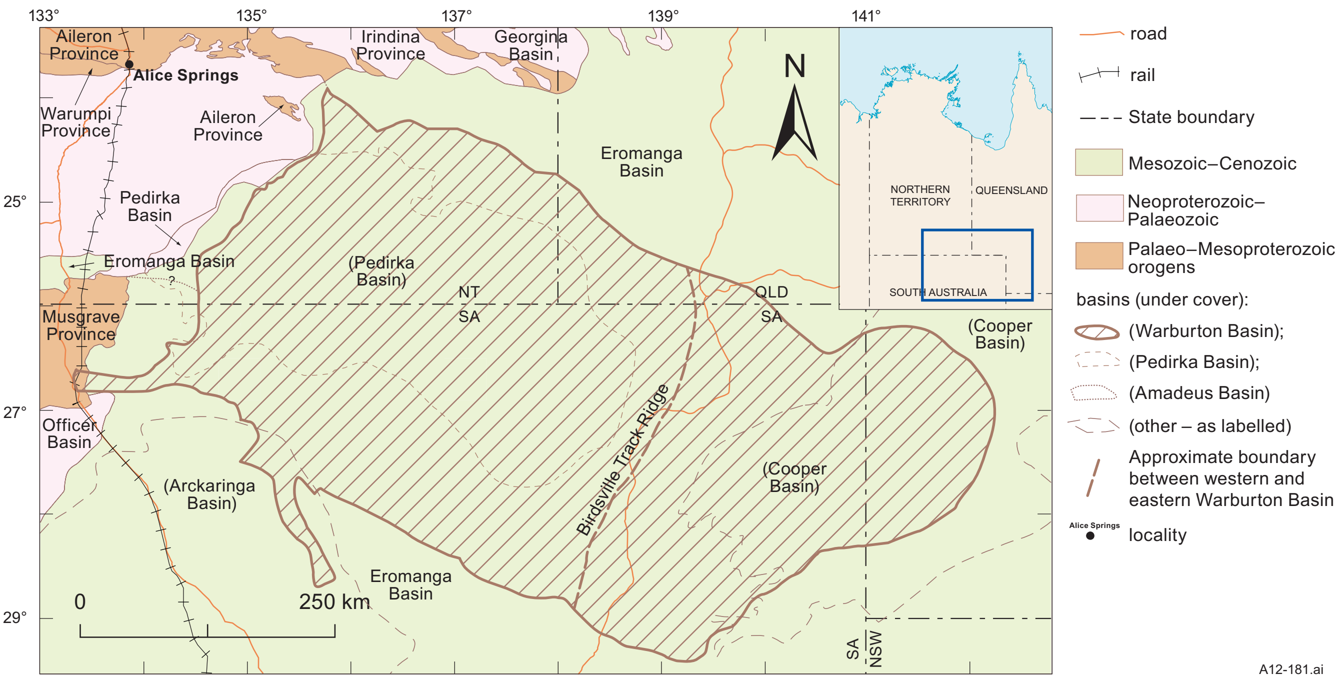

Figure 34.1. Regional geological setting of Warburton Basin. Extent of eastern Warburton Basin in Qld and SA is approximate; boundary between eastern and western Warburton Basin follows Birdsville Track Ridge and is after Ambrose (2008). NT geological regions slightly modified from NTGS 1:2.5M geological regions GIS dataset. Queensland geological regions simplified and slightly modified from Denaro and Dhnaram (2009) and Geoscience Australia (GA) Geological Regions National Geoscience Dataset. SA geological regions simplified and slightly modified from Department for Manufacturing, Innovation, Trade, Resources and Energy (DMITRE), South Australia Resources Information Geoserver (SARIG: **http://www.sarig.dmitre.sa.gov.au/**) and from GA Geological Regions National Geoscience Dataset. Cenozoic covering strata (eg Lake Eyre Basin) not shown.

Eromanga and Cenozoic Lake Eyre basins (see **Cenozoic geology and regolith**). An interpreted basement high, the Andado Ridge, separates the contiguous Warburton and Amadeus basins (**Figure 34.3**). Much of the Cambrian and Ordovician succession can be more readily correlated with units of the Amadeus Basin (**Figure 34.2**), rather than to the known succession of the eastern Warburton Basin. ?Late Ordovician to Devonian or possibly Early Carboniferous strata that overlie these rocks, but underlie the Pedirka Basin, also have affinities with equivalent units of the Amadeus Basin.

Radke (2009) has suggested that the metamorphic effects of the Cambrian Delamerian Orogeny (520–500 Ma) extended over the NT portion of the Warburton Basin, south to just over the SA-NT border and eastwards into Queensland, without affecting the majority of the SA portion of the basin. Some weak metamorphism is recorded in the sedimentary succession intercepted by drilling in the NT, but the age of this interval, and the timing and possible relationship of this metamorphism to known tectono-metamorphic events of the general area is unknown. Large-scale erosion of Warburton Basin sedimentary rocks is postulated for the post-Ordovician period (Radke 2009, Sayers *et al* 2012); however, this is largely deduced from the eastern Warburton Basin and may not be applicable to the western Warburton Basin. From the Permo-Carboniferous to Palaeogene, two major intracontinental downwarps were centred to the southeast of the eastern Warburton depocentre, causing the Warburton succession to tilt gently towards them (Radke 2009). The first downwarp accommodated Cooper Basin deposition in northeastern SA and southwestern Qld. The second downwarp was over a much broader area and resulted in Eromanga Basin deposition concealing all of the Warburton Basin.

From the limited seismic data available, Sayers *et al* (2012) recognised six seismic stratigraphic sequences in the NT part of the basin (**Figure 34.2**), all of which thicken to the east. In the NT, subsurface Early Palaeozoic to Devonian or Early Carboniferous rocks that are ascribed to the Warburton Basin have been intersected in a number of drillholes penetrating the Eromanga and Pedirka basins. Eight petroleum exploration wells record probable pre-Late Carboniferous Palaeozoic intervals: Hale River-1, McDills-1, Thomas-1, Colson-1, Poeppels Corner-1, Simpson-1, Beachcomber-1 and Etingimbra-1 (**Figures 34.3**).

Significant regional studies of the Warburton Basin include Gatehouse (1986), Gravestock and Gatehouse (1995), Gravestock (1995), Sun *et al* (1997, 1998), Radke (2009) and PIRSA 2012.

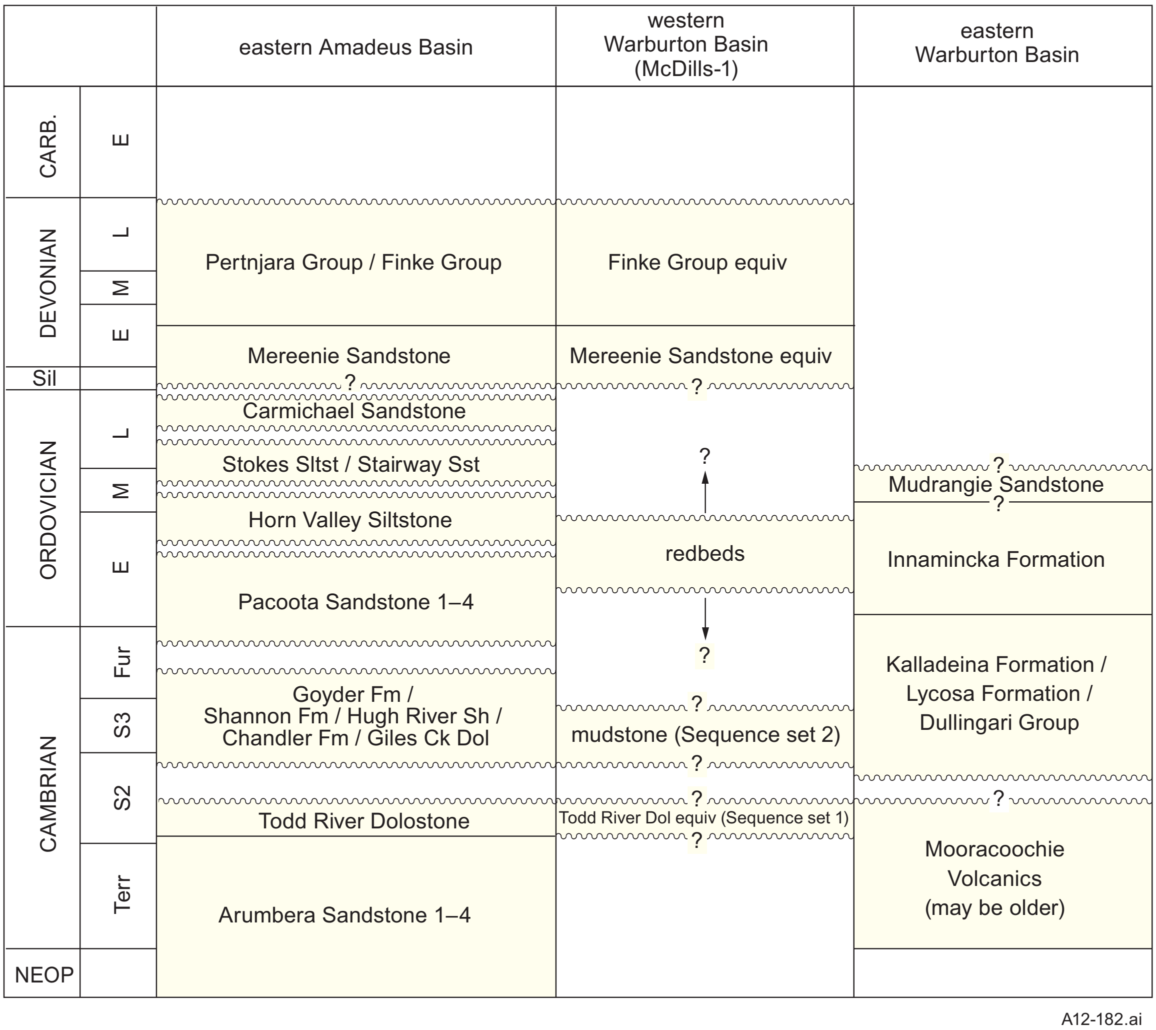

Figure 34.2. Comparative stratigraphic column of interpreted succession in McDills-1in western Warburton Basin, eastern Warburton Basin (PIRSA 2012) and northeastern Amadeus Basin (modified from Sayers *et al* 2012). Abbreviations: Dol = Dolostone; E = Early; equiv = equivalent; Fm = Formation; Fur = Furongian; L = Late; M = Middle; Neop = Neoproterozoic; S2 = Series 2; S3 = Series 3; Sh = Shale; Sil = Silurian; Sltst = Siltstone; Sst = Sandstone; Terr = Terreneuvian.

CAMBRIAN–ORDOVICIAN

Three main Cambrian depositional sequence sets (1–3), typical of the SA Cambrian, are recognised in the western Warburton Basin (Gravestock 1995). Sequence sets 1 and 2 are early Cambrian, and Sequence set 3 is late early to late middle Cambrian in age. In the NT, unnamed successions in a number of drillholes have been tentatively assigned to Sequence sets 1 and 2. There appears to be significant variation between the Warburton Basin successions intersected by drillholes in the NT, making it difficult to correlate units and age from drillhole to drillhole, as well as to specific stratigraphic successions in the adjacent Amadeus, Georgina and eastern Warburton basins.

Sequence set 1

Drillholes McDills-1 and Thomas-1 in the NT are interpreted to intersect Cambrian Sequence set 1. In McDills-1, Sequence set 1 forms the majority of a 452 m-thick carbonate unit of dark grey microcrystalline dolostone with thin bands of light grey microcrystalline limestone and dark shale (Amerada Petroleum 1965, **Figure 34.4**). Gravestock (1995) has suggested from wireline logs that this carbonate unit could be divisible into three sub-units: a lower 147 m-thick sub-unit of micaceous dolostone; a middle 222 m-thick sub-unit of limestone and lesser dolostone; and an upper 83 m-thick sub-unit of featureless grey dolostone. A thin limestone bed within the middle sub-unit bears the small skeletal fossils *Micrina etheridgei* and *'Nisusia' compta* (Gilbert-Tomlinson in Amerada Petroleum 1965, modified), which are characteristic of the early Cambrian Faunal Assemblage 2 of Daily (1956). The carbonate unit can thus be correlated with the Todd River Dolostone of the Amadeus Basin (**Figure 34.2**), which also has elements of this faunal assemblage as well as archaeocyathids and other shallow marine remains (eg Laurie 1986). However,

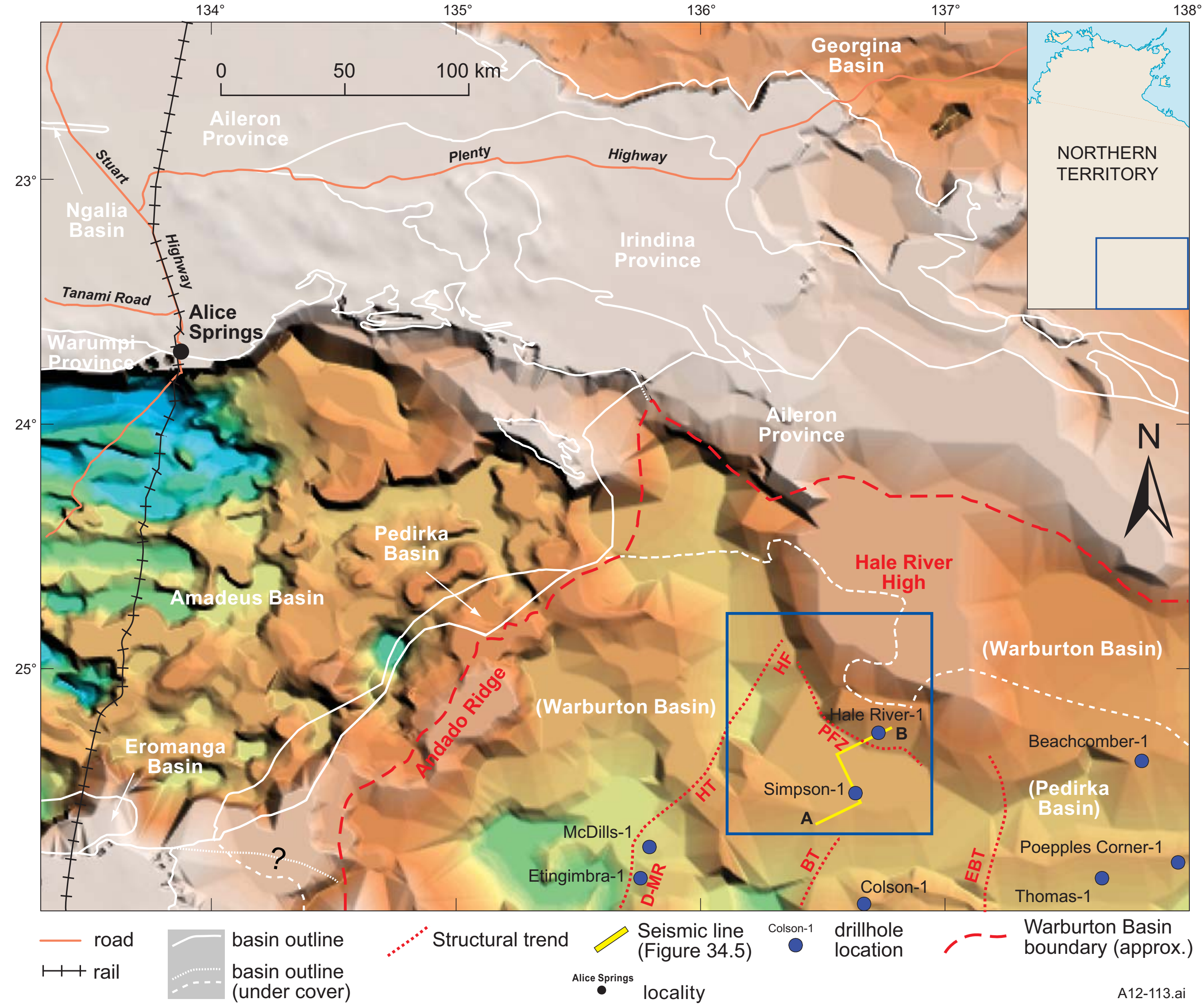

Figure 34.3. SEEBASE™ depth-to-basement image (after Pryor and Loutit 2005) with NT geological region boundaries for reference, showing probable extent of subsurface Warburton Basin in the NT, location of drillholes intersecting Warburton Basin strata and seismic line of **Figure 34.5**. Yellow–brown tones are interpreted Proterozoic basement highs; blue–green tones are interpreted depocentres. Northerly limits of Warburton Basin deposition follow southern margins of Arunta Region. Interpreted boundary between Amadeus and Warburton basins is positioned along Andado Ridge. Box shows location of **Figure 34.9**. Location of structural trends is approximate: D-MR = Dalhousie-McDills Ridge; HT = Hallows Trend; HF = Hector Fault; PFZ = Pellinor Fault Zone; BT = Border Trend; EBT = East Border Trend (see also **Pedirka Basin**: **figure 38.2**).

Gravestock (1995) has suggested that there might be a disconformity between the middle and upper sub-units and that it is therefore possible that the upper sub-unit may instead be equivalent to the younger Chandler Formation or Giles Creek Dolostone of the Amadeus Basin. In Thomas-1, 157 m of indurated, hard, steeply-dipping, silty, dolomitic and calcareous fine sandstone, with quartz veins and quartzite intervals, was intersected below the Pedirka/Eromanga basins succession (Wiltshire 1982). These sedimentary rocks were interpreted to represent low-energy, shallow shelf environments, and were considered to be correlatives of late Neoproterozoic or early Cambrian successions of the Amadeus and Georgina basins.

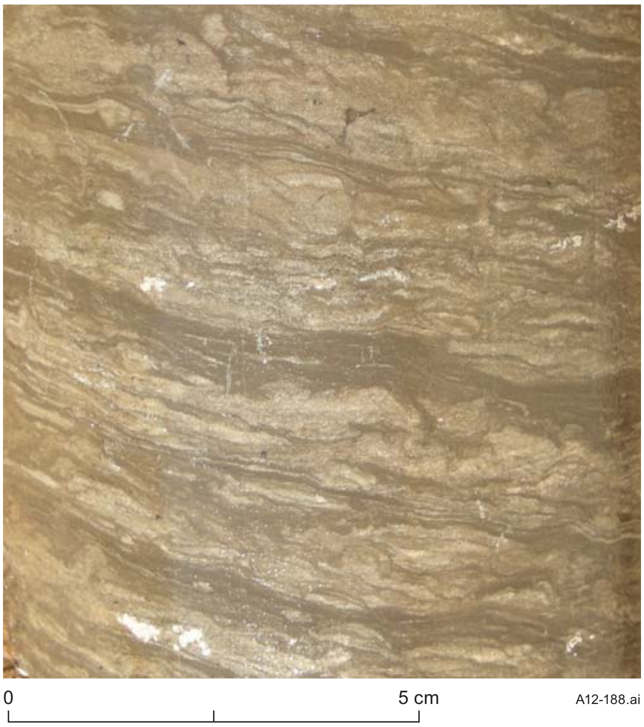

Figure 34.4. Laminated calcareous siltstone from Todd River Dolostone equivalent unit in core from drillhole McDills-1 at 2935.8 m.

Figure 34.5. Basalt in core from drillhole Hale River-1 at 1694–1697.7 m.

A minimum 298 m thickness of claystone, volcanigenic conglomerate, tuffaceous agglomerate and interlayered basalt flows (**Figure 34.5**), intruded by feldspathic dykes and possible andesitic sills, intersected in drillhole Hale River-1, was interpreted as ?Proterozoic basement by Amerada Petroleum (1966), but may be the early Cambrian Mooracoochie Volcanics or a correlative. The Mooracoochie Volcanics of the eastern Warburton Basin (**Figure 34.2**) comprise acid–intermediate volcanic rocks, tuff and agglomerate, but there are no mafic volcanic rocks in this succession, as have been described from Hale River-1. Other potential correlatives are rift-related Cambrian mafic rocks of the Irindina Province to the north, which have been subsequently metamorphosed to granulite facies so that their intrusive or extrusive origin cannot be determined, or the Late Devonian volcanigenic succession that was intersected in Poeppels Corner-1 (see below).

Sequence sets 2 and 3

Sequence set 2 is interpreted to be an equivalent of the Chandler Formation and Hugh River Shale of the Amadeus Basin, and in McDills-1 is represented by mudstone overlying dolostone of Sequence set 1 (Gravestock 1995), or possibly by the upper sub-unit of the underlying dolostone succession (see above). Cambrian Sequence set 3 is correlated with the middle Pertaoorrta Group of the Amadeus Basin (**Figure 34.3**), but has not been described from any of the drillholes in the NT.

Unassigned strata

In Colson-1, 42 m of muscovite-chlorite phyllite or slate with an interpreted structural cleavage was intersected below the Permian succession of the Pedirka Basin (Beach Petroleum 1979). This low-grade metamorphosed sedimentary interval is difficult to correlate with any units of the Amadeus or Georgina basins, and may represent an older succession. Similarly, Beachcomber-1 intersected 39.5 m of siliceous metasedimentary rocks with biotite, pyrite and vein quartz at its base (Dee 1988), and this succession may also represent basement rather than Warburton Basin sedimentary rocks. However at present, both of these drillholes sit within the interpreted margin of the western Warburton Basin.

In McDills-1, a succession of red beds overlies the Cambrian succession (**Figure 34.6**) and is probably equivalent to red beds of the Innamincka Formation of the eastern Warburton Basin. It also probably correlates with either the Ordovician Pacoota Sandstone (Larapinta Group), or the slightly younger Stairway Sandstone of the Amadeus Basin (**Figure 34.2**). This succession comprises about 247 m of coarse (lower part) to fine (upper part) white, red-brown, tight to indurated sandstone, locally gypsiferous, with minor red and green shale intervals.

?LATE ORDOVICIAN–DEVONIAN OR EARLY CARBONIFEROUS

In McDills-1, approximately 340 m of red-brown to orange, fine- to coarse-grained, friable sandstone, which is cross-bedded and locally calcareous (**Figure 34.7**), overlies the Ordovician succession, and is considered equivalent to the ?Upper Ordovician–?Upper Devonian (but most likely Silurian) Mereenie Sandstone of the Amadeus Basin (**Figure 34.2**). Overlying this succession is just over 1000 m of sedimentary rocks that probably correspond to the Devonian Finke Group of the Amadeus Basin, with equivalents of all four formations (Polly Conglomerate, Langra Formation, Horseshoe Bend Shale, Idracowra Sandstone) present. In Etingimbra-1 to the south-southeast, an intersection of just over 250 m was assigned to the Finke Group by Osborne and Edwards (1990); this succession comprises an upper 41 m of sandstone and claystone attributed to the Idracowra Sandstone, and a lower 218 m of massive sandstone with minor claystone correlated with the Langra Formation section in McDills-1. A disconformity, related to the absence of a unit equivalent to the intervening Horseshoe Bend Shale, has been described between these two units. Approximately 50 m of shale, and interbedded kaolinitic and pebbly sandstone above the basal volcanic succession in Hale River-1 (Amerada Petroleum 1966) is also considered to be equivalent to the Devonian Finke Group, deposited as synorogenic detritus in dominantly fluvial conditions. A thin (1.2 m) andesite with 207 m of associated agglomerate in Poeppels Corner-1 (Arco Australia 1985) has yielded a K-Ar date of 384 ± 3 Ma (Late Devonian). The andesite and agglomerate dip at about 30°, and were interpreted to be a response to uplift and erosion in the Late Devonian–Carboniferous, as constrained by an angular unconformity with the overlying Permian succession of the Pedirka Basin. It is possible that the undated volcanic succession in Hale River-1 (see Sequence set 1 above) is actually a correlative of Devonian volcanic rocks dated in Poeppels Corner-1. In Simpson-1, an interval of red-brown to grey-brown silty shale marks the top of the Warburton Basin succession, and is in sharp contact with overlying well sorted ?aeolian sandstones with very poor porosity (Central Petroleum 2009).

Recent seismic surveys in the NT portion of the western Warburton Basin have shown the existence of a carbonate rimmed platform (Erec Carbonate Platform Complex), which is up to 750 m thick, and reef complex (Pellinor Barrier Reef Complex), which is up to 1700 m thick, beneath the Eromanga and Pedirka basin successions (Ambrose 2008, Central Petroleum 2011, Ambrose *et al* 2012, **Figure 34.8**). Various elements of the carbonate complexes, including platform, rim, reef, channel and fan facies, occur at depths in the range 2300–3500 m. The age of the Warburton Basin succession in this area is conjectural, but the presence of mild uplift and erosion at the pre-Permian unconformity is clearly recognised on seismic sections and corresponds to mild epeirogenesis during the 450–300 Ma Alice Springs Orogeny (Ambrose 2008). The carbonate platform is pre-Permian as it underlies Early Permian stratigraphic units; Ambrose (2008) and Ambrose *et al* (2012) speculated that it may be equivalent to Devonian carbonate build-up/reef successions in the Canning and Bonaparte basins. However, the age of this interval is equivocal and it is also possible that it represents

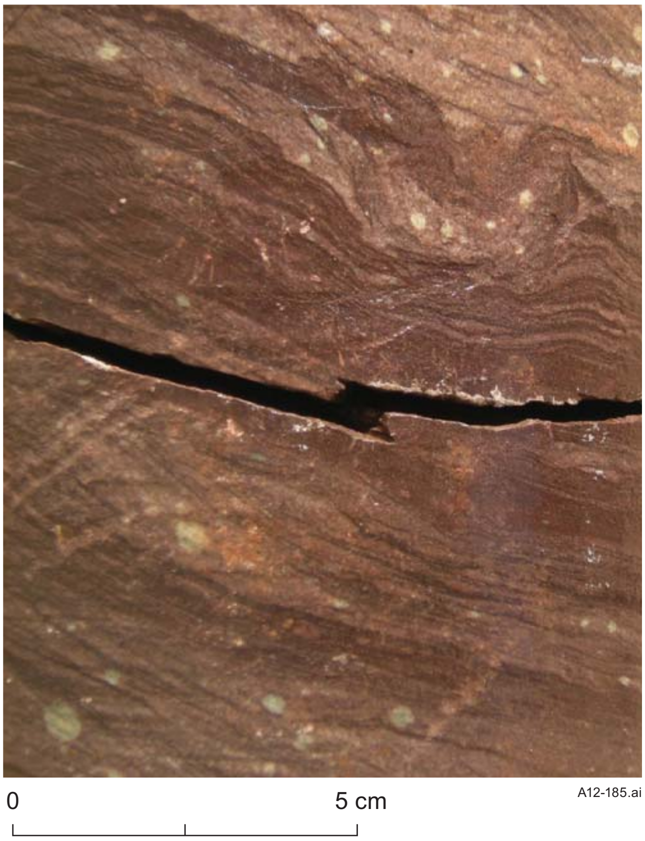

Figure 34.6. Laminated red siltstone and fine sandstone from the un-named unit overlying Todd River Dolostone equivalent unit in core from drillhole McDills-1 at 2725.8 m.

Figure 34.7. Characteristic red medium-grained sandstone from Mereenie Sandstone equivalent unit in core from drillhole McDills-1 at 2471.9 m.

an older carbonate succession, possibly Ordovician in age (Sayers *et al* 2012, J Sayers, Central Petroleum Ltd, pers comm 2012). Unexposed Ordovician carbonate reefs are also known from the Canning Basin.

STRUCTURE AND TECTONIC HISTORY

The western Warburton Basin succession has been folded into a number of northeast- to north-trending anticlinal structural ridges (trends), separating or segmenting the main depocentres of the overlying basins (see **Pedirka Basin: figures 38.2**, **38.3**, **Figure 34.3**). Some of the more significant of these include, from west to east, the collinear Dalhousie-McDills Ridge, Hallows Trend and Hector Trend, and the Border, Colson, Macumba-Bejah, East Border and Poolowanna-Thomas trends. These structural ridges are reflected by gravity anomalies and are interpreted to be composed of folded and faulted pre-Permian sedimentary rocks (Questa 1990, Hibburt and Gravestock 1995). They are flanked by reverse faults that, with the exception of the ridges immediately to the east of the Eringa Trough (Pedirka Basin), are mostly downthrown to the east (Questa 1990). These structural ridges were most likely to have been formed during the later stages of the 450–300 Ma Alice Springs Orogeny, by analogy with the probable Carboniferous age of deformation in the eastern Warburton Basin (Gravestock *et al* 1995, Apak *et al* 1995). Many of the marginal faults also experienced Mesozoic and Cenozoic reverse movements, but they have a long history and there is evidence that they have been repeatedly reactivated during the Phanerozoic. A series of northwest-trending, down-to-basin normal faults, the Pellinor Fault Zone (**Figures 34.3**, **34.9**; see **Pedirka Basin**), flank the southern margin of the Hale River High and may have controlled deposition in the northern Warburton Basin during the Devonian–Carboniferous. These faults were reactivated as steep reverse faults in the Miocene (Ambrose 2008, Ambrose *et al* 2012).

Drill sections record some effects of the 450–300 Ma Alice Springs Orogeny in the western Warburton Basin, with moderate to steeper dips recorded in some of the Palaeozoic succession (eg in Thomas-1). However, the lack of outcrop and widely spaced drill data make it difficult to assess the nature of any deformational effects. Ambrose (2008) reported only minor Miocene rejuvenation on steep, bounding normal faults and no significant folding of the Palaeozoic succession during the Alice Springs Orogeny in the region of the ?Devonian carbonate-reef platform. The presence of a thick succession of the synorogenic Devonian Finke Group equivalent in McDills-1, Hale River-1 and Etingimbra-1, indicates that at least part of the basin acted as a foreland trough at this time, analogous to the southeastern Amadeus Basin. The absence of the Cambrian–Ordovician sedimentary succession in Hale River-1 suggests the loss of a significant section prior to the ?Devonian to Permian along the southwest flank of the structure on which the well is located, and this could be attributed to early phases of the Alice Springs Orogeny (Amerada Petroleum 1966).

Although the western Warburton Basin is temporally analogous to the Amadeus and Georgina basins,

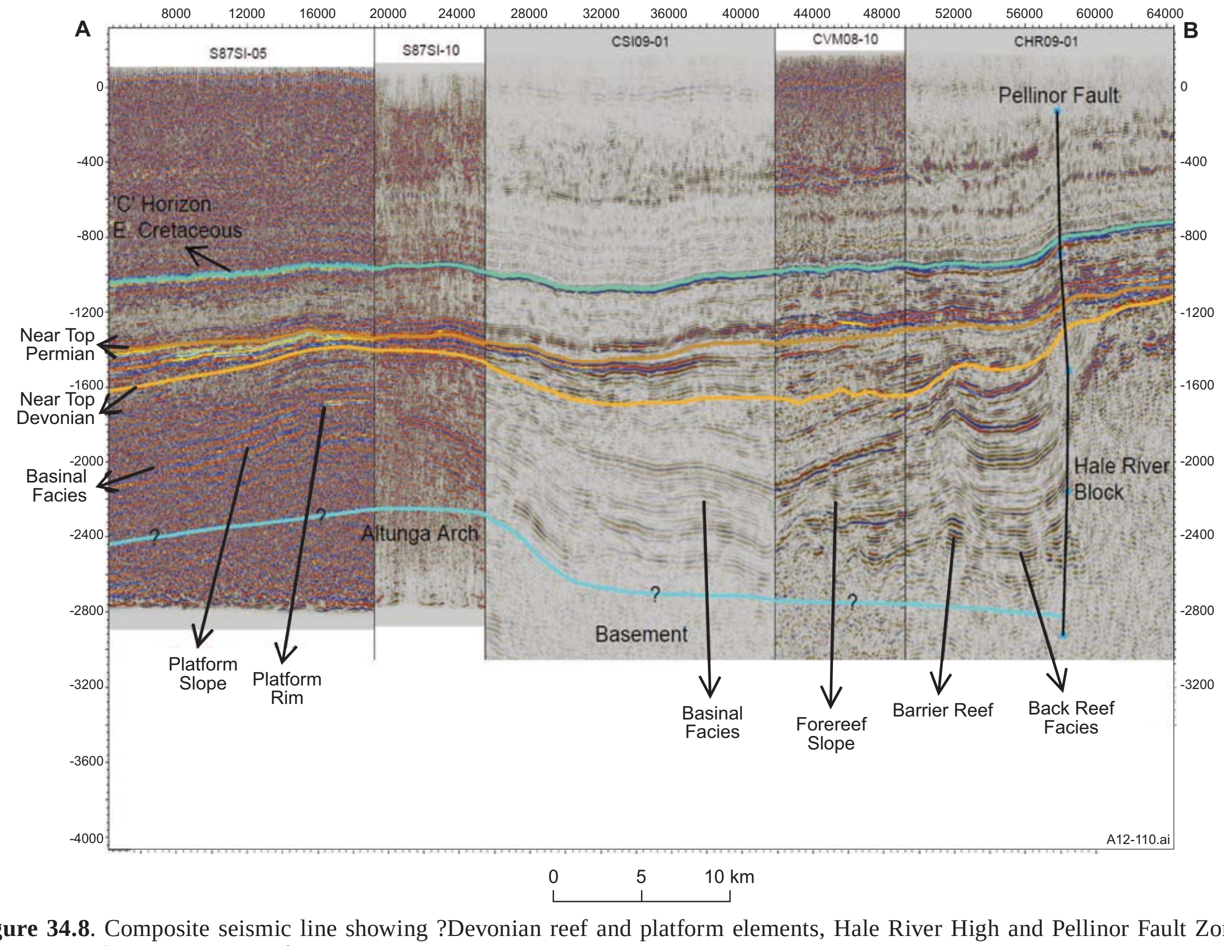

Figure 34.8. Composite seismic line showing ?Devonian reef and platform elements, Hale River High and Pellinor Fault Zone (after Ambrose *et al* 2012). Location of line shown in **Figure 34.3**.

particularly during the Cambrian and Ordovician, and there is significant stratigraphic correlation across the three basins, there also appears to be some marked contrasts in basin history. If the presumably rift-related mafic volcanism recorded in Hale River-1 is early Cambrian in age, it has no equivalents in either the Amadeus or Georgina basins. Possibly the Warburton Basin may have been the locus of rifting associated with the Cambrian extension recorded in these two basins, although the presence of thick Cambrian deposits in the southern Georgina Basin suggest that this area may have been the main locus of Cambrian deposition (see **Georgina Basin)**. Voluminous Cambrian mafic rocks attributed to a rift setting do occur in the now highly metamorphosed Irindina Province of the Arunta Region to the north of the Warburton Basin (**Figure 34.3**), interpreted as a deeply buried and subsequently exhumed deep depocentre of the Amadeus-Georgina basins depositional system during the late Neoproterozoic–Cambrian.

The Devonian settings of the western Warburton and eastern Amadeus basins seem to be largely analogous during the deposition of the Finke Group, with a full section of rocks equivalent to this Amadeus Basin unit present in McDills-1, and a thinner succession encountered in Hale River-1 and Etingimbra-1. The Finke Group is interpreted to have been deposited in response to largely compressional deformation during the Alice Springs Orogeny. However, the Warburton Basin carbonate reef and platform complex, identified on seismic profiles and interpreted to be possibly Devonian–Carboniferous in age, has no known counterpart in the Amadeus Basin. Ambrose (2008) interpreted that this carbonate complex was controlled by salient basement faults that were largely extensional during the Devonian–Carboniferous, with very large displacements of up to 2 km (eg Pellinor Fault Zone, **Figures 34.3**, **34.9**). An extensional setting during this period is also indicated by Devonian volcanism in Poeppels Corner-1, the most easterly of the drill intersections. These proposed extensional settings are in contrast with the largely compressional deformation of the Alice Springs Orogeny.

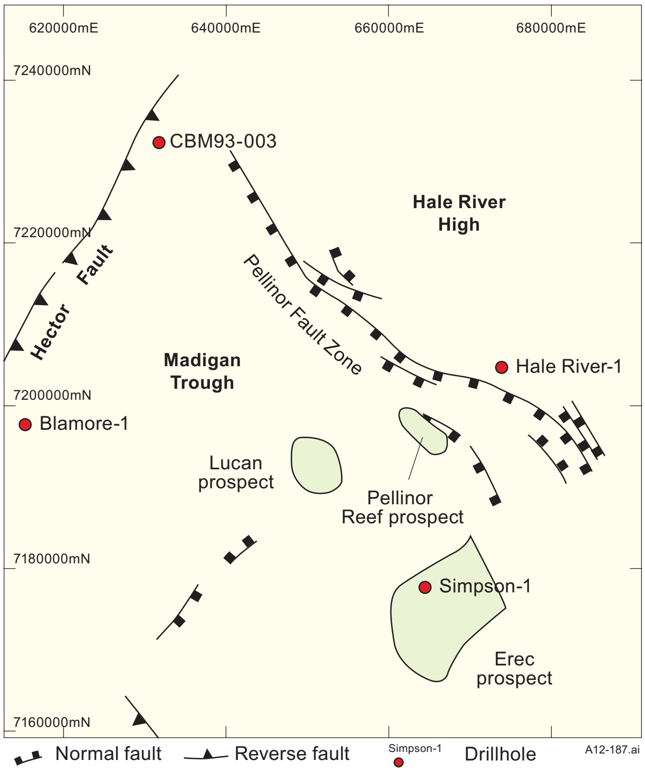

Figure 34.9. Location of Pellinor, Lucan and Erec petroleum prospects (simplified after Ambrose 2008, Ambrose *et al* 2012). Location of map shown in **Figure 34.3**.

MINERAL RESOURCES

Petroleum

Petroleum exploration programs that have encountered the western Warburton Basin succession in the NT have been mostly targeted at overlying Pedirka–Eromanga basin plays and the hydrocarbon potential of this deeply buried basin is therefore largely untested. Potential source rocks, thermal maturity, reservoir rocks, seals and possible trap configurations within the basin have not been properly evaluated and the presence of a Palaeozoic petroleum system, analogous to those of the contiguous Amadeus Basin, is yet to be demonstrated. Nevertheless, the Warburton Basin has significant potential for substantial hydrocarbon accumulations in both its clastic and carbonate successions.

Potential reservoir rocks are relatively common within the Palaeozoic clastic succession. For example in McDills-1, a thick section of alluvial quartz clastic rocks, including conglomerate, sandstone and minor shale, contains potential reservoir rocks at a number of levels, including the Mereenie Sandstone equivalent (Amerada Petroleum 1965, Ambrose 2008). Generative source rocks and effective stratigraphic seals are yet to be identified in the Palaeozoic succession. However, excellent source rocks are present in Permian and younger rocks of the overlying Pedirka and Eromanga basins, and there is some potential for structural traps updip from these source rocks, where they have been juxtaposed against older reservoir rocks by faulting (see **Pedirka Basin**).

The recognition of possible rimmed platform and barrier reef facies in the northern Warburton Basin (Ambrose 2008, Central Petroleum 2011, Ambrose *et al* 2012, Sayers *et al* 2012) allows for a variety of potential petroleum reservoirs and stratigraphic traps that could contain commercial hydrocarbon accumulations. Potential targets are at viable depths of 2500–3500 m and include, for the barrier reef complex (Pellinor prospect, **Figure 34.9**), fringing reef, back reef, barrier reef, channelised fore reef slope and toe-of-slope apron clastic rocks. For the carbonate platform (Erec and Lucan prospects), potential targets include the inner platform, carbonate mound facies, platform rim, fore reef slope and toe-of-slope apron clastic rocks. All of these facies have reservoired hydrocarbons in different basins around the world (Ambrose 2008, Ambrose *et al* 2012). Potential source rocks might be present in basinal, fore reef, back reef and barrier reef facies (Central Petroleum 2011, Ambrose *et al* 2012). Possible reservoir–seal couplets and modes of entrapment include: (1) transgressive marine shales capping barrier reef reservoirs either internally or at the top of the succession; (2) transgressive marine shale/evaporites capping back reef reservoirs; (3) sealing of back reef/fringing reef facies against the Pellinor Fault Zone to the south of the Hale River High; and (4) shale seal isolating fore reef slope clastic rocks from the barrier reef facies (Central Petroleum 2011, Ambrose *et al* 2012).

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