RESERVOIRS and SEALS

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Chapter 10

INTRODUCTION

The Officer Basin contains a number of reservoirs with excellent porosity and permeability. These are generally sandstones of fluvial or aeolian origin, and were originally feldspathic, but dissolution of the feldspars has led to extensive secondary porosity development, in some cases with permeabilities over 8 darcys (8000 md). Reservoir potential also exists in carbonates (vuggy porosity). The only previous core analysis for reservoir properties carried out by industry was for Comalco in the early 1980s, which concentrated on the Ungoolya Group reservoirs (Weste, 1984), but MESA has since obtained data from all available cored sandstone reservoirs as part of the South Australian Exploration Initiative (106 samples; Sansome and Gravestock, 1993). In addition, some analytical work was initiated by university student projects (Gaughan, 1989; Kamali, 1995b).

FORMATION DESCRIPTION

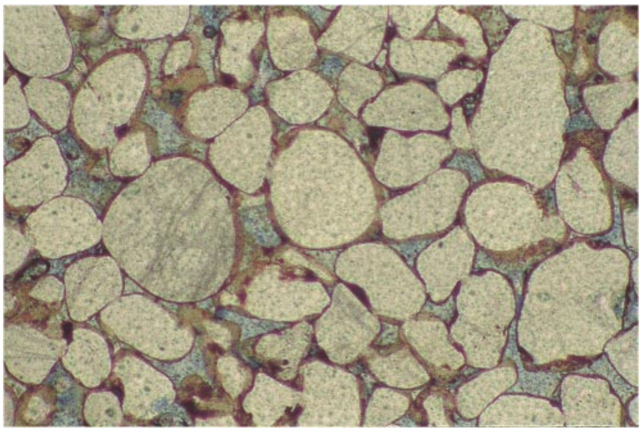
Pindyin Sandstone

Distribution

Pindyin Sandstone crops out in the Birksgate Sub-basin but in the subsurface it has only been intersected by Giles 1. The formation is, however, presumed to be widespread in the deeper, undrilled parts of the basin. The thickness ranges from 100 to 200 m.

Petrophysics

Twelve samples from Giles 1 range from 3.8 to 22.5% porosity with an average of 11.8%, and permeability values reach 1538 md. The porosity–log permeability (phi log k) plot is linear (Fig. 10.1). Calculated shale volume (V_{shale}) rarely exceeds 5% and the Gamma Ray is generally between 20 and 40 API units (Fig. 10.2). Wireline log porosity is readily calculated from the density log using a quartz matrix density of 2.65 g/cm^3. The Pindyin Sandstone aeolian facies is the cleanest potential reservoir in the basin.



Aeolian sandstone of the Pindyin Sandstone at 1291.36 m in Giles 1. Quartz grains are evenly coated with haematite. Porosity is coloured blue; core porosity from a nearby sample was 22.6% and permeability was 1538 md. Plane polarised light; field of view is 1.6 mm. (Photo 44393)

Seal

Siltstone and evaporites of the Alinya Formation may act as a semi-regional seal for the Pindyin Sandstone on the northern margin of the Murnaroo Platform.

Tarlina Sandstone

Distribution

Tarlina Sandstone is distributed over the Murnaroo Platform, Manya Trough and may possibly extend to the

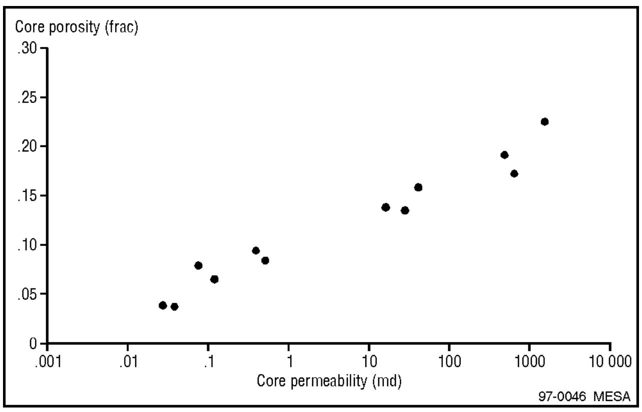


Fig. 10.1 *Porosity–log permeability plot, Pindyin Sandstone; Murnaroo Platform depth range 1291–1326 m.*

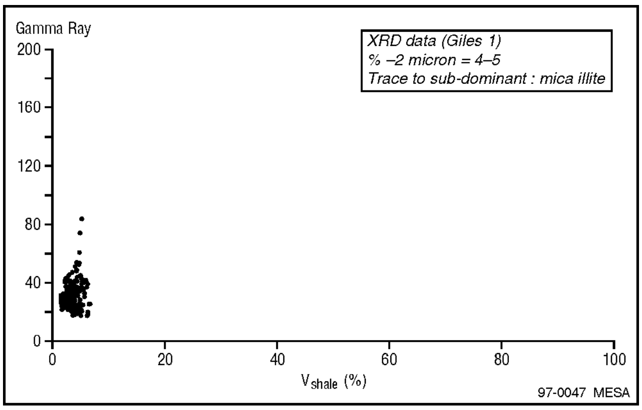
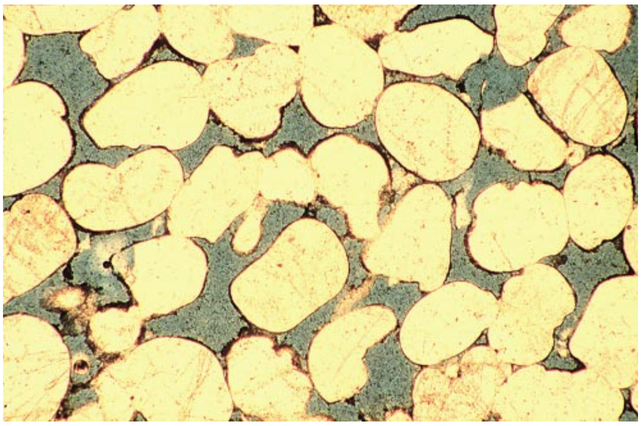


Fig. 10.2 *V_{shale} versus Gamma Ray for Giles 1, Pindyin Sandstone.*



Pindyin Sandstone aeolianite at 445.4 m in Watson Siding 1a. Plane polarised light; field of view is 3.2 mm. *(Photo 44429)*

Tallaringa Trough. The formation is up to 183 m thick to the south of the basin on the Murnaroo Platform, but may be up to 373 m in Manya 5. It may not be present on the northern margin of the basin due to facies changes.

A section corresponding to the Murnaroo Formation in Manya 5, as originally interpreted by Gravestock and Sansome (1994), has been revised. Moussavi-Harami (1994) and Moussavi-Harami and Gravestock (1995) now consider that the Murnaroo Formation is underlain by the Tarlina Sandstone. This interpretation better fits the burial history of this well.

Petrophysics

Twenty-one samples from Giles 1 and Manya 5 have porosities ranging from 9 to 19.6% with low permeabilities which average 1.0 md. The porosity–log permeability plot is clustered and there is no discernible difference between Murnaroo Platform and Manya Trough samples of the Tarlina Sandstone, supporting the reinterpretation of Manya 5 stratigraphy as discussed above (Fig. 10.3).

Calculated V_{shale} in Giles 1 is mainly 10–20% with few values exceeding 30%. Gamma Ray (Fig. 10.4) is generally 60–90 API units in Giles 1, reflecting the feldspar content. Scattered high values to 150 API are attributed to slumped mudclast horizons. Porosity from the wireline density log (quartz matrix) correlates reasonably well with measured values (Fig. 10.5). The relatively low permeability values, despite good porosity, suggest that pore-bridging clays may be responsible.

Seal

Mudstone of the Meramangye Formation may act as a seal for the Tarlina Sandstone in the northern Murnaroo Platform where it reaches a thickness of 195 m in Giles 1. The Meramangye Formation may disappear towards the basin margins, resulting in stacked reservoirs. The Tarlina Sandstone is overlain by Murnaroo Formation in Lake Maurice East (southern Murnaroo Platform) and Manya 5 (Manya Trough).

Murnaroo Formation

Distribution

The Murnaroo Formation is a key petroleum reservoir target. The formation is widespread on the Murnaroo Platform (maximum thickness 391 m) and extends to the Manya Trough where it was fully cored in Manya 5 (246 m thick). In Marla 9, however, the formation is represented by a thin condensed section. It underlies the Dey Dey Mudstone (Murnaroo Platform and Marla Overthrust Zone) and Cambrian Relief Sandstone (Manya Trough), and overlies the Meramangye Formation or Tarlina Sandstone.

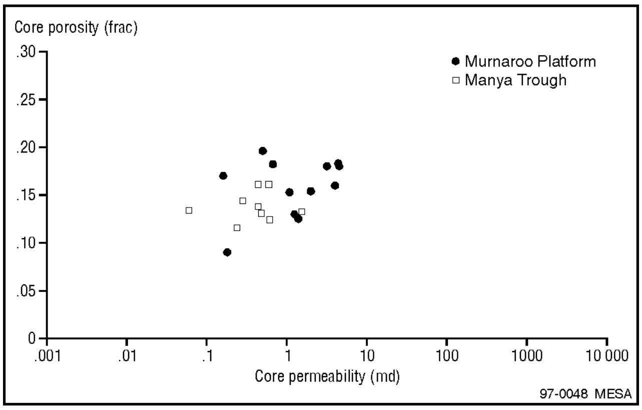


Fig. 10.3 *Porosity–log permeability plot, Tarlina Sandstone; Murnaroo Platform depth range 1064–1230 m; Manya Trough depth range 715–1053 m.*

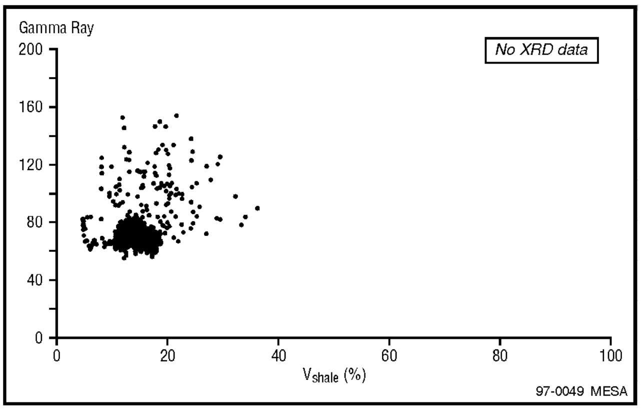


Fig. 10.4 *V_{shale} versus Gamma Ray for Giles 1, Tarlina Sandstone.*

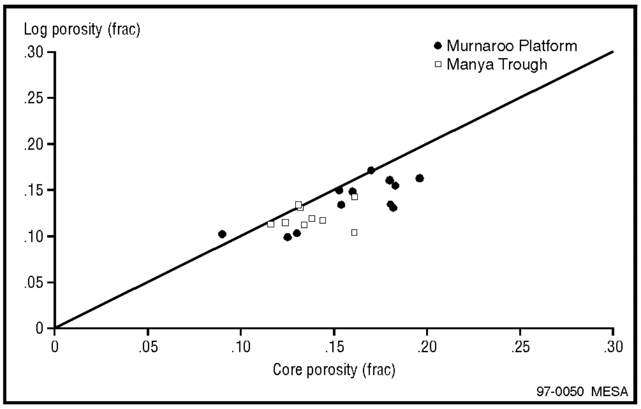


Fig. 10.5 *Core porosity versus porosity calculated from the density log, Tarlina Sandstone.*

Petrophysics

The reservoir quality is variable, ranging from 3 to 20% in the three sampled wells (Giles 1, Munta 1, Manya 5; n = 28). The porosity–log permeability plot shows that permeability can reach 200 md and is generally greater than 1 md (Fig. 10.6). Slightly higher porosity but lower permeability values in Manya 5 near the Marla Overthrust Zone may be related to early cementation by illitic clay prior to burial.

On average, however, there is no great difference in porosity distribution between Manya 5 (Manya Trough) and the other two wells (Murnaroo Platform; Fig. 10.7). In Giles 1, the Gamma Ray varies from 20 to 200 API probably due to the feldspar, mica, heavy mineral and glauconite composition. V_{shale} ranges up to 40% but is predominantly 20% or less (Fig. 10.8).

Water saturation

Three samples from Manya 5 were submitted for air–mercury capillary pressure curve analysis. Two curves from the Murnaroo are very similar, whilst the one Tarlina Sandstone sample indicates that a higher injection pressure is required for the same saturation. Calculations from capillary pressure data (assuming a 100 000 ppm brine) indicate that, for the Murnaroo Formation, a 120 m vertical height above an oil–water contact yields an irreducible water saturation (Sw_{irr}) of 22%. In contrast, the Tarlina Sandstone would yield an Sw_{irr} of 43% under similar conditions. This result is consistent with the low permeability measurements for the Tarlina (Fig. 10.3).

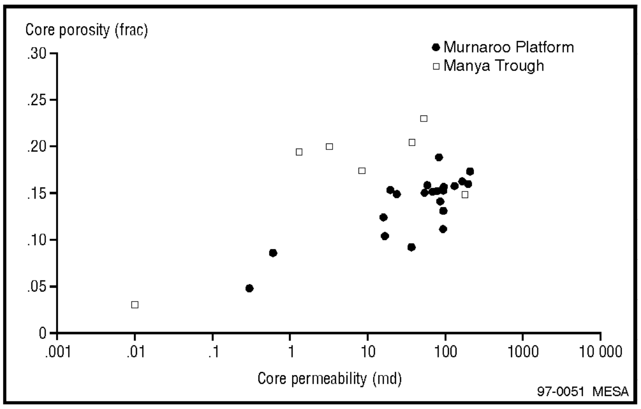


***Fig. 10.6** Porosity–log permeability plot, Murnaroo Formation; Murnaroo Platform depth range 593–1985 m; Manya Trough depth range 458–686 m.*

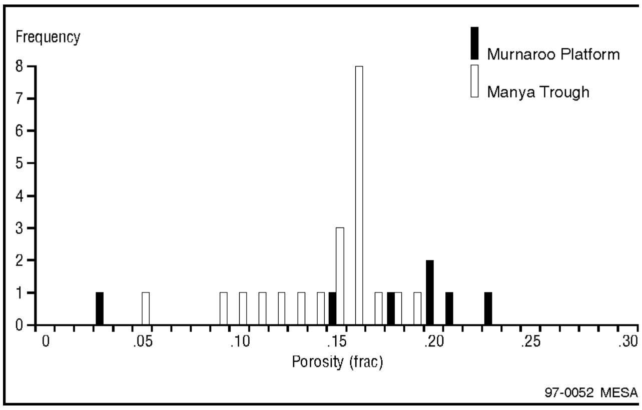


***Fig. 10.7** Porosity histogram of pore distribution, Murnaroo Formation.*

Seal

On the Murnaroo Platform and in the Marla Overthrust Zone, the Murnaroo Formation is sealed by the Dey Dey Mudstone. Thickness of the Dey Dey Mudstone ranges from 86 m to possibly 900 m, in the Munyarai Trough. In the Manya Trough, seals are absent, resulting in stacked reservoirs, with the Cambrian Relief Sandstone overlying the Murnaroo Formation.

Relief Sandstone

Distribution

The Relief Sandstone has been intersected on the Murnaroo Platform and in the Manya Trough (thickness ~100 m). It is overlain conformably by, and intertongues with, the Ouldburra Formation (transitional, with halite interbeds), and is overlain conformably to disconformably by the Observatory Hill Formation. In Manya 5, however, the Relief Sandstone is overlain by the Ordovician Mount Chandler Sandstone due to Delamerian erosion.

Petrophysics

Porosity is secondary; Gaughan and Warren (1990) cited one sample from Observatory Hill 1 with a permeability of 4839 md. Gravestock and Sansome (1994) reported a sample from Giles 1 with a permeability of 8033 md. Five samples from Giles 1 (40 m interval) exceed 1400 md and five samples from Meramangye 1 (17 m interval) are in the 2607–6297 md range. In contrast, the Relief Sandstone in Manya 6 rarely exceeds 0.08 md (Gravestock and Sansome, 1994).

The porosity histogram shown on Figure 10.9 (three wells from the Marla Overthrust Zone and Manya Trough, n =19; two wells from the Murnaroo Platform, n =25) clearly illustrates the bimodal porosity distribution pointed out by Gaughan and Warren (1990). The porosity–log permeability plot illustrates the marked difference between the two regions (Fig. 10.10). Two trends are evident — one related to high secondary porosity and low compaction in the Marla Overthrust Zone and Manya Trough, the other related to low secondary porosity and high compaction on the Murnaroo

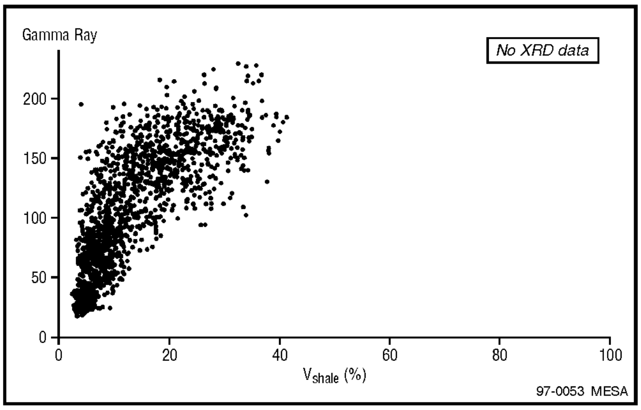


***Fig. 10.8** V_{shale} versus Gamma Ray for Giles 1, Murnaroo Formation.*

Platform and related to Carboniferous depth of burial (Gravestock and Sansome, 1994).

The Gamma Ray (Giles 1) ranges from 20 to 80 API with scattered higher readings to 200 API. V_{shale} remains generally between 10 and 30% (Fig. 10.11). V_{shale} from neutron logs run in Marla, Manya and Byilkaoora wells are unreliable because of uncalibrated substandard readings. Core to log correlation is poor (Fig. 10.12).

The Relief Sandstone reservoir quality is superb on the Murnaroo Platform due to high dissolution and low compaction effects. Porosity in the Marla Overthrust Zone

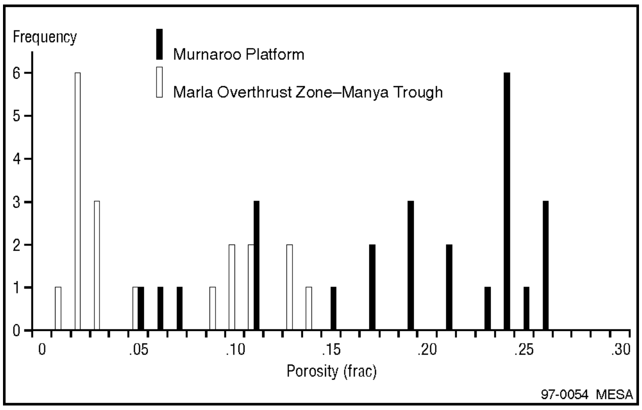


Fig. 10.9 *Porosity histogram of pore distribution, Relief Sandstone.*

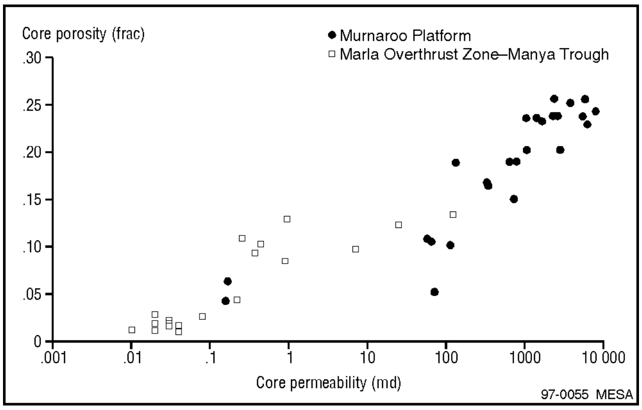


Fig. 10.10 *Porosity–log permeability plot, Relief Sandstone; Murnaroo Platform depth range 304–447 m; Marla Overthrust Zone and Manya Trough depth range 405–1755 m.*

Relief Sandstone at 178.9 m in Observatory Hill 1. Porosity, coloured blue, is ~20%. Plane polarised light; field of view is 6.8 mm. *(Photo 44385)*

and Manya Trough should not be written off as it is only poor in deeply buried footwall situations. In hanging wall structures, porosity reaches 13% and permeability reaches 124 md. In Manya 5 (Manya Trough), porosity reaches 10.9% with a permeability of 0.44 md. Commercial reservoirs may be found in all areas (Gravestock and Sansome, 1994).

Seal

The Ouldburra and Observatory Hill Formations may act as seals for the Relief Sandstone. The Relief Sandstone intertongues with the Ouldburra Formation, possibly due to relative sea-level changes. At low relative sea level, the Relief Sandstone progressed basinwards over the Ouldburra

Relief Sandstone at 416 m in Emu 1. *(Photo 44384)*

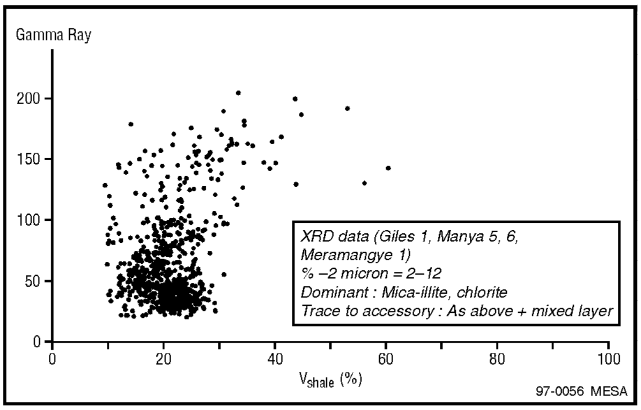


Fig. 10.11 *V_{shale} versus Gamma Ray for Giles 1, Relief Sandstone.*

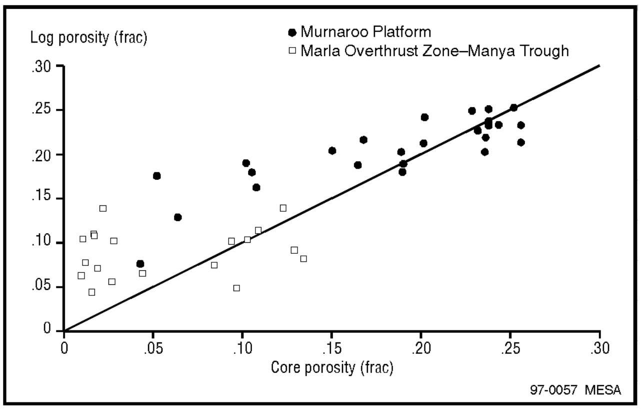


Fig. 10.12 *Core porosity versus porosity calculated from the density log, Relief Sandstone.*

Formation, while high relative sea level led to flooding of the hinterland, causing carbonate buildup (Ouldburra Formation) thus forming a seal to the Relief Sandstone (Gravestock and Hibburt, 1991). In the Marla Overthrust Zone, the Cadney Park Member of the Observatory Hill Formation might provide a seal to the Relief Sandstone.

Ouldburra Formation

Distribution

The Ouldburra Formation has been intersected in the Marla Overthrust Zone and Manya and Tallaringa Troughs. The maximum thickness is in the Manya Trough (987 m in Manya 6). However, the Ouldburra is absent on the eastern margin of the Manya Trough in Manya 5. The maximum thickness in the Tallaringa Trough is 486 m in Wilkinson 1. Magnetic data suggest that the formation in the Tallaringa Trough thickens towards the Karari Fault, which is interpreted as a reverse or thrust fault (Milton, 1974).

The Ouldburra is predominantly carbonate but it does contain sandstone reservoir potential. As an example, in Manya 3 (Middle Bore Ridge) there are 30 stacked sands (Dunster, 1987a) with an average thickness of 3.8 m comprising 100 m of sandstone in 639 m of section (16%). The average separation between the stacked sands is 17.8 m (Gravestock and Hibburt, 1991).

The Ouldburra Formation is overlain conformably by the Observatory Hill Formation. It overlies and intertongues with the Relief Sandstone (Gravestock and Hibburt, 1991). In Wilkinson 1, the Ouldburra is underlain by Relief Sandstone and unconformably overlain by Permian Stuart Range Formation. Hence, the true thickness of the Ouldburra is unknown in the Tallaringa Trough.

Petrophysics

Reservoir quality in the Ouldburra Formation is variable with porosity ranging from 3 to 27% and permeability ranging from 0.005 to 1640 md. Dolomitisation has resulted in substantial secondary porosity in the carbonates (Kamali *et al.*, 1995). Carbonate reservoir porosity averages 15.0% while the clastic reservoirs average 13.8%. The porosity–log permeability plot has a poor correlation, with significant scatter for carbonate reservoirs, whilst the sandstones are in good agreement and plot on a semi-log trend with minor scatter (Fig. 10.13). In this respect, the intra-Ouldburra sandstones behave like other siliciclastic reservoirs in the Officer Basin. Kamali (1995b) identified that the better carbonate reservoirs are composed of sucrosic dolomite with intercrystalline porosity. Subaerial exposure in the early stages of diagenesis of the carbonates has largely contributed to the Ouldburra's good reservoir quality. The extent and distribution of these higher quality carbonate reservoirs is yet to be determined.

While no samples have been taken from Wilkinson 1, a 3 m sandstone described as very porous and vuggy was intersected at a depth of 460 m. Another ~1 m thick sandstone with a visual porosity of 10% was intersected at 704 m. The carbonates have been described as mainly micritic and have no visible porosity (Gatehouse, 1979).

Seal

Halite is an effective stratigraphic seal across the Ouldburra–Relief interface, while intraformational seals are provided by micritic carbonates. In Manya 3, for example, these carbonates average 17.8 m in thickness, while the thinnest carbonate beds are 1 m thick. Locally, thin breccia beds may lower the seal efficiency of some carbonates but are not considered a major risk.

Arcoeillinna Sandstone

Distribution

The Arcoeillinna Sandstone is a southwest-thickening unit (60–172 m) which extends through the Manya and Munyarai Troughs. It reaches a maximum thickness in Munta 1 on the Murnaroo Platform. The Arcoeillinna Sandstone occurs between the Observatory Hill Formation (source rock) and the dolomitic mudstone seal of the Apamurra Formation.

Petrophysics

As with the older Relief Sandstone, the porosity distribution between the Marla Overthrust Zone–Manya Trough areas and the Murnaroo Platform is bimodal, the latter having a very high average porosity value of 21%. However, the Arcoeillinna in the Marla Overthrust Zone and Manya Trough has quite high porosity values averaging 13.7% and ranging up to 19% (Fig. 10.14).

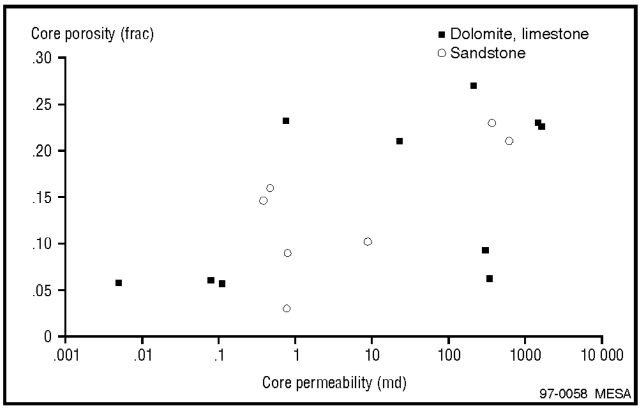


Fig. 10.13 *Porosity–log permeability plot, Ouldburra Formation; Marla Overthrust Zone and Manya Trough depth range 187–1471 m (raw data from Kamali, 1995b).*

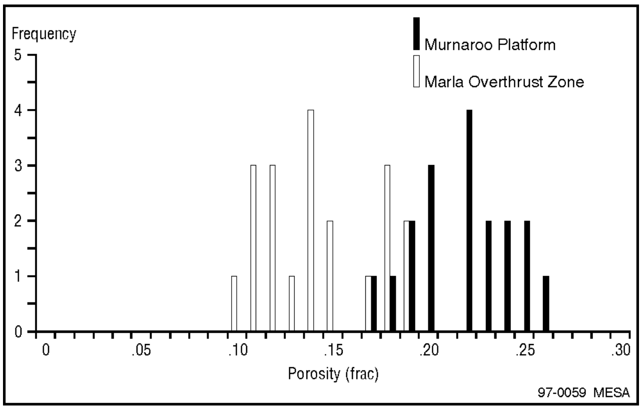


Fig. 10.14 *Porosity histogram of pore distribution, Arcoeillinna Sandstone.*

The porosity–log permeability plot (Fig. 10.15) is remarkably linear, with Marla Overthrust Zone and Manya Trough permeability values ranging between 0.1 and 50 md, and Murnaroo Platform permeabilities averaging 291 md with a maximum exceeding 1700 md.

Gamma Ray and V_{shale} values are very high (Fig. 10.16) but two fields can be distinguished on the porosity–log permeability plot. One, which comprises mostly sandstone (with muddy laminae), has a 'low' Gamma Ray and very high V_{shale}. Abundant mica may be responsible. The other, which comprises mostly mudstone, has a very high Gamma Ray and low to moderate V_{shale}. These observations must be taken with caution because of the poor quality logging in the basin. Because of its abundant thin muddy interbeds, the Arcoeillinna Sandstone is not a high quality reservoir but could be considered a potential secondary target.

The formation is a fine to medium-grained, immature micaceous arkose with numerous muddy laminae and mudstone interbeds. Benbow (1982) provided the following sandstone composition: quartz (50%), K-feldspar (35%), minor plagioclase, lithic grains (10%), and muscovite and biotite (5%). His interbedded siltstone and claystone composition is: quartz and feldspar (35%), muscovite and biotite (35%), and chlorite (30%). This heterogeneous composition is confirmed by XRD data (Gravestock and Sansome, 1994).

Seal

The widespread, seismically mappable Apamurra Formation (Benbow, 1982; Stainton *et al*., 1988) is a potential regional seal above the Arcoeillinna Sandstone or older reservoirs.

Trainor Hill Sandstone

Distribution

The Trainor Hill Sandstone was originally widespread but was thinned and locally removed in the Marla Overthrust Zone by Delamerian erosion. Maximum thickness in Marla 10 is 316 m but exceeds 440 m on the Murnaroo Platform, reaching a maximum preserved thickness of 520 m in Lairu 1. Where preservation is more complete it thus rivals the Murnaroo Formation in thickness.

Petrophysics

Like the preceding Arcoeillinna and Relief Sandstones, porosity distribution of the Trainor Hill is bimodal (Fig. 10.17). Mean porosity values are very good — 15% in the Marla Overthrust Zone and Manya Trough and 22% in the Murnaroo Platform. Permeability values on the porosity–log permeability plot (Fig. 10.18) are high, usually tens to hundreds of millidarcies in the Marla Overthrust Zone and up to 5249 md on the Murnaroo Platform (Ungoolya 1, depth 667 m). Core-log porosity correlation (calcite matrix density) is good (Fig. 10.19). Gamma Ray values reach 300

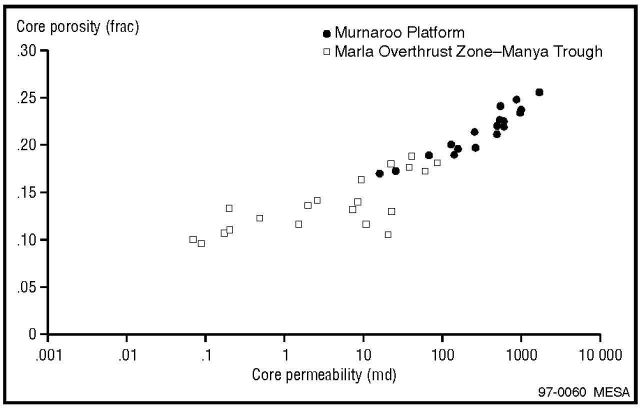


Fig. 10.15 *Porosity–log permeability plot, Arcoeillinna Sandstone; Murnaroo Platform depth range 959–1200 m; Marla Overthrust Zone depth range 106–566 m.*

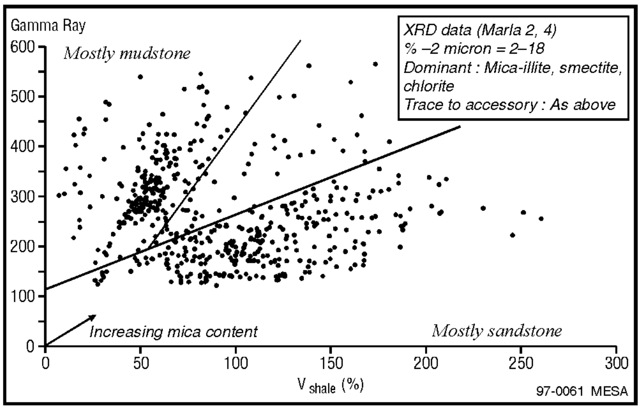


Fig. 10.16 *V_{shale} versus Gamma Ray for Marla 4, Arcoeillinna Sandstone.*

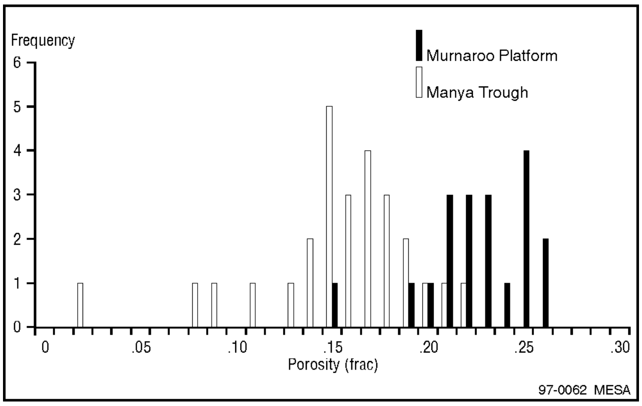


Fig. 10.17 *Porosity histogram of pore distribution, Trainor Hill Sandstone.*

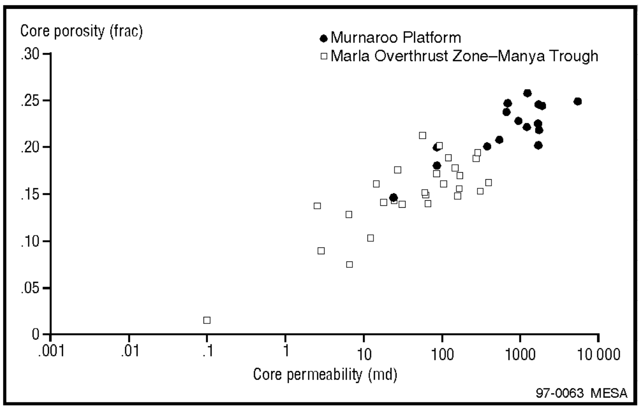


Fig. 10.18 *Porosity–log permeability plot, Trainor Hill Sandstone; Murnaroo Platform depth range 472–907 m; Marla Overthrust Zone depth range 105–459 m.*

API and V_{shale} is predominantly in the range 5 to 80%. Values >100% on Figure 10.20 are spurious and related to a correction factor for poor logs.

Upper levels of the Trainor Hill Sandstone in outcrop are calcareous and dolomitic, but the abundant kaolin reported from outcrops (Benbow, 1982) is not matched by the XRD data from cores (Gravestock and Sansome, 1994). The near-surface kaolin results from a Tertiary weathering event which affected sandstones as young as Jurassic (Algebuckina Sandstone) and is evident in most of the upholes drilled for velocity data in the region. Feldspar content is usually low but in outcrop it ranges up to 35%; biotite is lacking in contrast to the Arcoeillinna (Benbow, 1982).

Seal

The Trainor Hill Sandstone is usually overlain disconformably by the Ordovician Mount Chandler Sandstone. The Delamerian unconformity at the top of the Trainor Hill Sandstone is a moderate reflector but due to muting and near-surface noise, coupled with the weight-drop technique, picking the reflector in the basin is quite difficult (Mackie, 1994; Rudd, 1995). The overlying Mount Chandler Formation is sandy and does not provide a stratigraphic seal. However, in Devonian thrust zones, there is a good chance of fault seal and of juxtaposition against potential Cambrian source rocks. In this scenario, the Trainor Hill Sandstone would be in the footwall and sealed by rocks in the hanging wall.

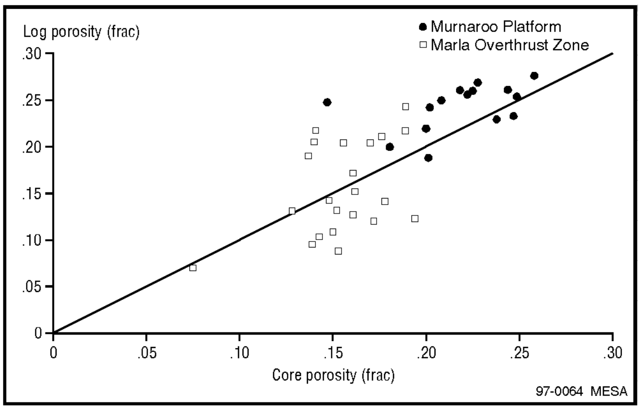


Fig. 10.19 *Core porosity versus porosity calculated from the density log, Trainor Hill Sandstone.*

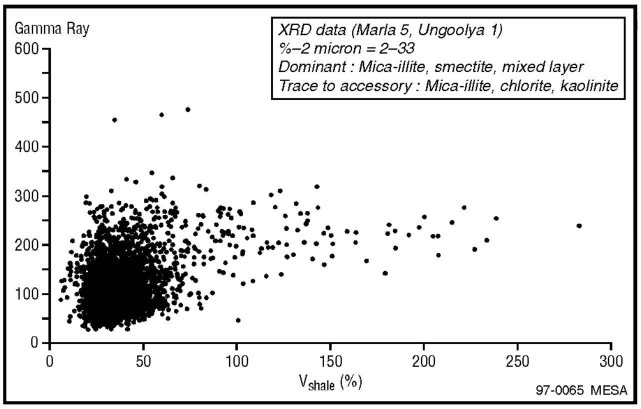


Fig. 10.20 *V_{shale} versus gamma ray for Lairu 1, Trainor Hill Sandstone.*

Mount Chandler Sandstone

Distribution

This Ordovician sandstone is widespread and once thickened northwards over the Musgrave Block before being eroded during the Alice Springs Orogeny. Maximum drilled thickness ranges from 212 m in the Marla Overthrust Zone (Byilkaoora 2) to 472 m on the Murnaroo Platform (Karlaya 1) but may be >600 m thick in outcrop (Benbow, 1982).

Petrophysics

There are too few samples from the Murnaroo Platform to compare porosity distribution but the porosity–log permeability plot (Fig. 10.21) indicates consistently high porosity (up to 25.4%) and permeability (up to 238 md). Log porosity data agree well with core data (Sansome and Gravestock, 1993) using a quartz matrix density of 2.65 g/cm^3 (not calcite — this was an error in the above abstract). Gamma Ray and V_{shale} values are correspondingly low.

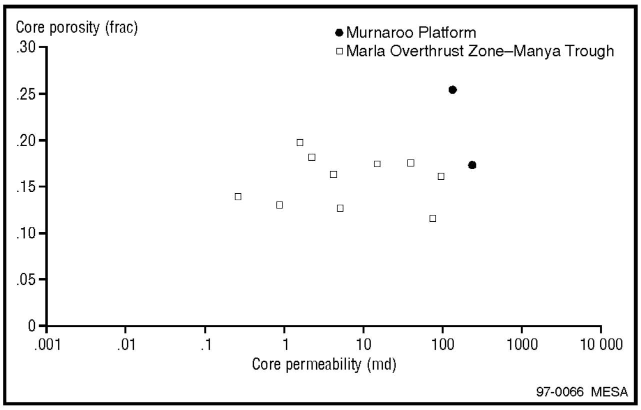


Fig. 10.21 *Porosity–log permeability plot, Mount Chandler Sandstone; Murnaroo Platform depth range 323–400 m; Marla Overthrust Zone and Manya Trough depth range 63–192 m.*

Seal

The Mount Chandler Sandstone is locally sealed in the northern Munyarai Trough–Mount Johns region by the Indulkana Shale. The shale reaches a thickness of 60 m in the Indulkana Range (Krieg, 1973) and may be quite widespread east of the Marla Overthrust Zone based on aeromagnetic evidence (Hamer, 1994). However, in the Marla Overthrust Zone, the sandstone requires hanging wall fault structures for seal. The Mount Chandler and stratigraphically younger Blue Hills Sandstone (not studied) also run the risk of being breached by Permian erosion. Despite its excellent reservoir qualities, the Mount Chandler Sandstone is thus unlikely to be a major target for petroleum.