Fingerprinting reservoir sandstone provenance in the Canning Basin using detrital zircons

by P. W. Haines and M. T. D. Wingate

Abstract

Detrital zircons have been dated from potential sandstone hydrocarbon reservoirs in the Willara (Acacia Sandstone Member), Gap Creek, and Carranya Formations of the Canning Basin. Two discrete detrital-zircon source areas are recognized, which are most probably the North Australia Craton and adjacent Neoproterozoic sedimentary basins or their source terrain. Significant differences between zircon age spectra in the Acacia Sandstone Member in petroleum exploration wells Looma 1 and Acacia 2 suggest that either this unit is not a single entity, but several discrete sandstone bodies of similar age fed from different sediment input points during relative low stand(s) of sea level, or that provenance switching during deposition led to provenance stratification within the unit. Each has important implications for predicting reservoir distribution and lateral facies changes.

KEYWORDS: zircon, geochronology, hydrocarbons, Ordovician, Canning Basin, Willara Formation, Acacia Sandstone Member, Gap Creek Formation, Carranya Formation, Western Australia.

Introduction

The Canning Basin (Fig. 1) is Western Australia's most extensive onshore hydrocarbon province, but is significantly underexplored. The Ordovician strata of this basin (Fig. 2) contains adequate hydrocarbon source rocks and displays significant oil and gas shows, but is yet to produce a commercial field. A major challenge for explorers is locating good quality hydrocarbon reservoirs. One promising reservoir unit is the locally developed Acacia Sandstone Member of the Willara Formation (Fig. 2), from which good reservoir quality and hydrocarbon shows have been reported locally, but its distribution and regional facies trends are poorly constrained.

Detrital zircon dating is an important tool for establishing sediment provenance and distribution pathways. In cases like the Canning Basin sandstone reservoirs, such studies may be able to provide additional constraints on the deposition of these units by linking well or outcrop control points to possible sediment input points along the basin margin. It may also test the continuity of the sandstone unit between control points, for example, determining if it is a single homogeneous entity or, alternatively, several discrete sandstone bodies linked to separate input points. Such techniques have not previously been applied in the Canning Basin.

Acacia Sandstone Member and possible correlative

The Acacia Sandstone Member, a local component of the limestone-dominated upper Willara Formation, is known from several drillholes on the Barbwire Terrace, eastern Broome Platform, and Mowla Terrace of the Canning Basin (Fig. 1). The unit comprises several shallowing- and sanding-upward cycles capped by horizons of clean, well-sorted, and fine- to medium-grained sandstone deposited under energetic shallow-marine conditions. Deposition was probably in response to a relative low stand or series of low stands of sea level, perhaps localized by tectonic activity, allowing basinward progradation of shoreface and shoreline sands. A similar-aged sandstone unit outcropping near the top of the Gap Creek Formation (Prices Creek Group) in the Prices Creek area (Figs 1 and 2) is here considered a possible correlative of the Acacia Sandstone Member.

Samples

Samples of white medium-grained sandstone from the Acacia Sandstone Member were collected from drillcore in petroleum exploration wells Looma 1 (2026.4 – 2028.4 m, GSWA 136069) and Acacia 2 (1174.6 – 1175.3 m, GSWA 136057).

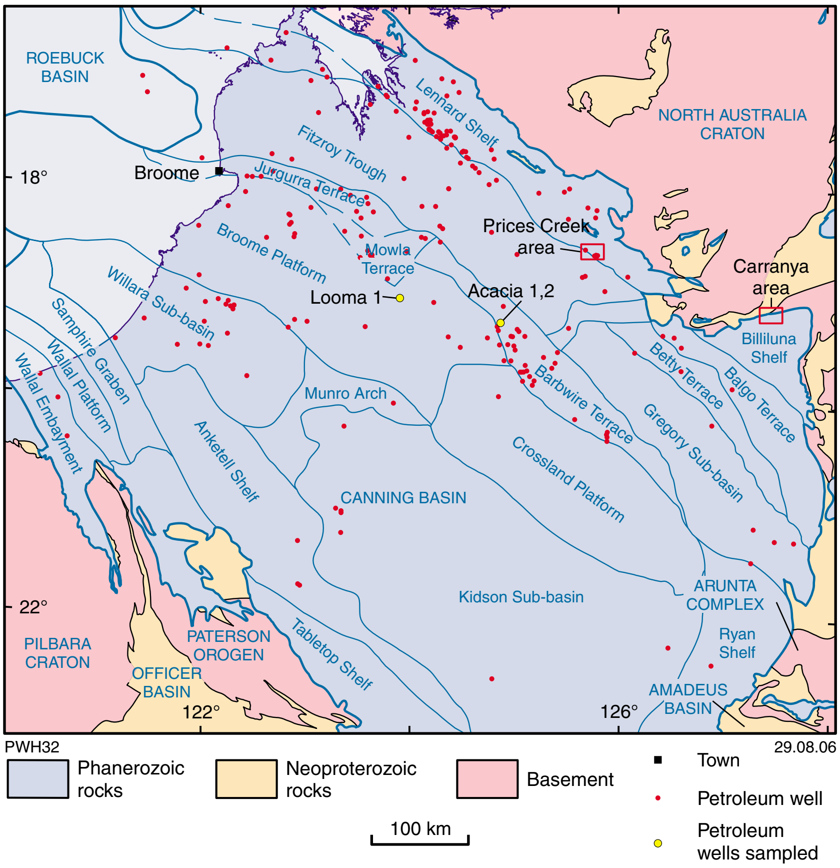

Figure 1. The Canning Basin, showing tectonic elements, petroleum wells intersecting the Acacia Sandstone Member of the Willara Formation, and sample localities in the Gap Creek and Carranya Formations

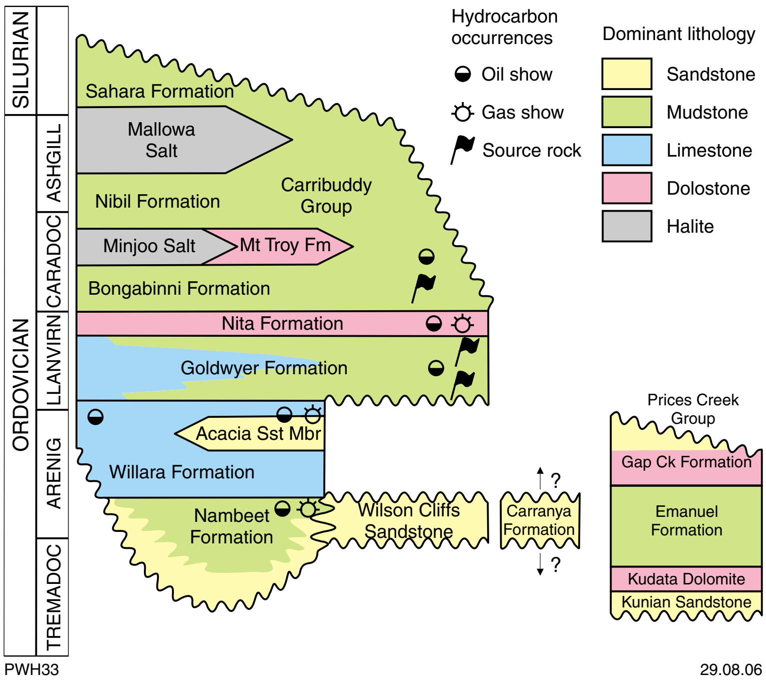

Figure 2. Ordovician–Silurian stratigraphy of the Canning Basin with stratigraphic position of source rocks and major hydrocarbon shows

These wells are 107.5 km apart on the Broome Platform and Barbwire Terrace respectively (Fig. 1). An outcrop sample from near the base of the sandstone unit in the Gap Creek Formation was collected in the Prices Creek area (Fig. 1; 18°37'45.29"S, 125°55'12.14"E; GSWA 184268). Sandstone from outcrop of the Lower Ordovician deltaic Carranya Formation, 15 km northwest of Carranya Homestead on the Billiluna Shelf (Fig. 1; 19°9'52.98"S, 127°39'3.12"E; GSWA 184269), was also collected to provide comparison with a possible Ordovician sediment input point. Although this unit may be of similar age to the Acacia Sandstone Member, it is more likely to be somewhat older based on tentative regional correlations (Fig. 2).

Method and results

Zircons were separated by standard procedures before dating of between 58 and 68 grains per sample with the sensitive high-resolution ion microprobe (SHRIMP) at Curtin University of Technology, Perth. Full analytical results, including data tables, are available in Wingate (in prep.a–d). All plotted data with ages older than 1000 Ma for individual analyses are based on $^{207}Pb/^{206}Pb$ ratios, whereas those younger than 1000 Ma are based on $^{238}U/^{206}Pb$ ratios. Although it was intended that the dated crystals be as representative as possible of the population from each sample, some bias is inevitable because crystals with abundant cracks and inclusions were avoided, and a few very high uranium crystals (>1000 ppm ^{238}U) were not dated because it was likely that they would yield discordant (and unusable) results. With about 60 grains dated per sample, no fraction of a population comprising more than 0.087 of the total will be missed at the 95% confidence level (Vermeesch, 2004).

Of the zircons from Looma 1, 65% plot as a single peak with a weighted mean age of 1850 ± 4 Ma (95% confidence, MSWD = 1.1; Fig. 3a). Similarity in appearance and tightly grouped Th/U ratios of between 0.1 and 0.9 suggest that the majority were

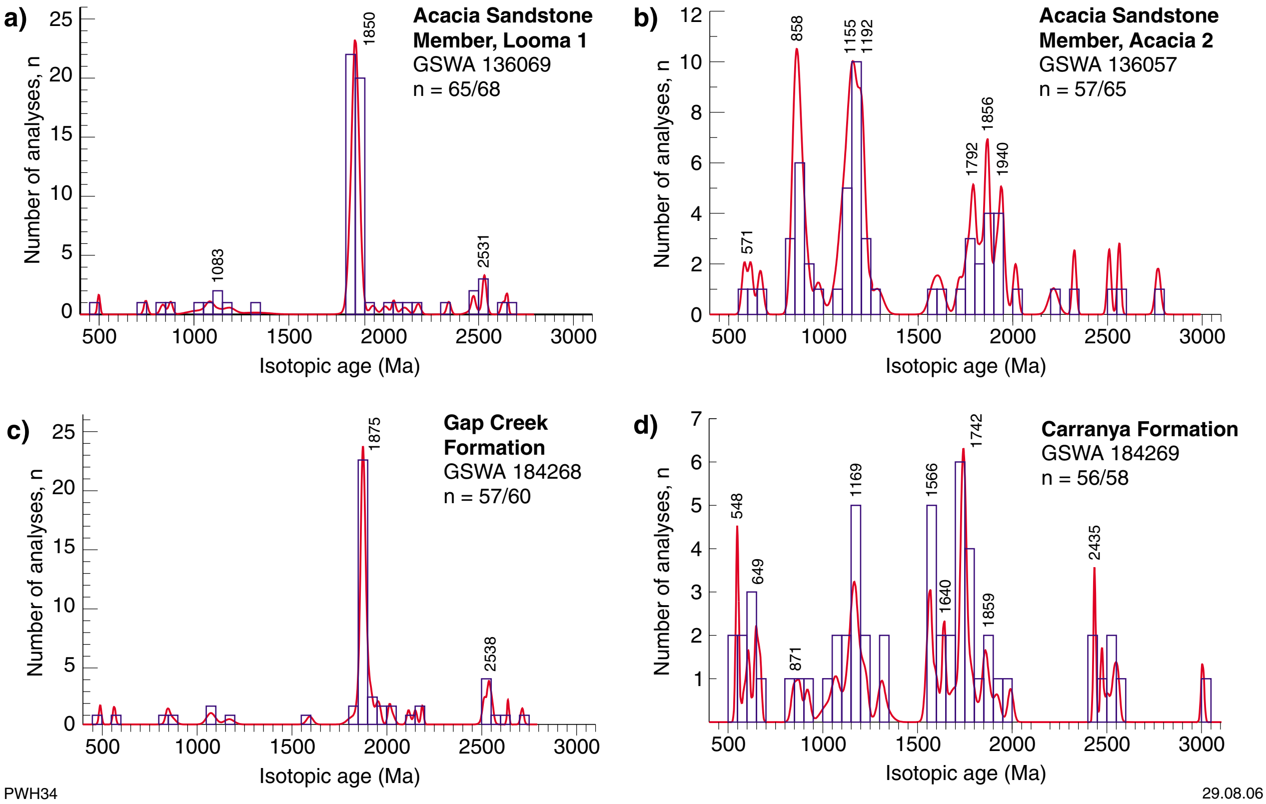

Figure 3. Probability density and histogram plots (50 Ma bins) of zircon isotopic ages for samples from a) Looma 1; b) Acacia 2; c) Gap Creek Formation; and d) Carranya Formation. Ages older than 1000 Ma are based on $^{207}Pb/^{206}Pb$ ratios, and those younger than 1000 Ma on $^{238}U/^{206}Pb$ ratios. Data more than 10% discordant are not plotted; n = number of concordant grains/total grains. Mean ages of major probability peaks are indicated

derived from a single or closely related igneous source(s). Much smaller age components are present at c. 2531 and c. 1083 Ma. The discordant $^{207}Pb/^{206}Pb$ age of c. 2814 Ma is a minimum age for the oldest zircon in this sample, whereas the youngest has a near-concordant $^{238}U/^{206}Pb$ age of c. 498 Ma. Zircons from Acacia 2 show a much broader range of significant age peaks ranging from Neoarchean to latest Neoproterozoic in age. Major age peaks are identified at c. 852, 1155, 1192, 1775, 1792, 1865, and 1940 Ma (Fig. 3b). Of the $^{207}Pb/^{206}Pb$ ages, 29% cluster between 1093 and 1214 Ma. The oldest zircon in this sample has a near-concordant $^{207}Pb/^{206}Pb$ age of c. 2767 Ma.

The Gap Creek Formation sample gives a very similar age distribution pattern to the sample from Looma 1, although the main peak is slightly older at c. 1875 Ma (Fig. 3c). The Carranya Formation sample (Fig. 3d) shows closer similarity to that from Acacia 2, although the ratio of peak heights varies significantly, and the highest peak at c. 1742 Ma is not obvious in the Acacia 2 sample. The c. 852 Ma peak of Acacia 2 is potentially present, but small.

Limited paleocurrent data can be inferred from dipmeter logs over the sampled intervals in both wells (Watson and Derrington, 1982, Appendix VII; Phipps et al., 1998, Appendix 7). In Looma 1 the pattern is bipolar with northwest- and southeast-directed modes, suggestive of tidal channel deposition. In Acacia 2 inferred paleocurrents form a bimodal pattern with transport directions towards the south-southwest and south-southeast over the sampled interval. However, the inferred paleocurrent distribution throughout the entire member is more complex, particularly in the case of Acacia 2, which has currents directed towards all quadrants, with an overall average towards the west. In any case, the complex nature of currents in shallow-marine environments makes it unlikely that there will be any simple relationship between current direction at a particular location and the ultimate source of the sand. No paleocurrent data are available for the Gap Creek Formation, and limited field data for the Carranya Formation show significant variability, but average transport from the north.

Discussion

Igneous rocks dated at c. 1870–1850 Ma are widespread across the North Australia Craton in the Northern Territory and Western Australia. Such basement lies to the north and east of the present (partly tectonic) northeastern margin of the Canning Basin. Detrital zircons in widespread syn- to post-orogenic

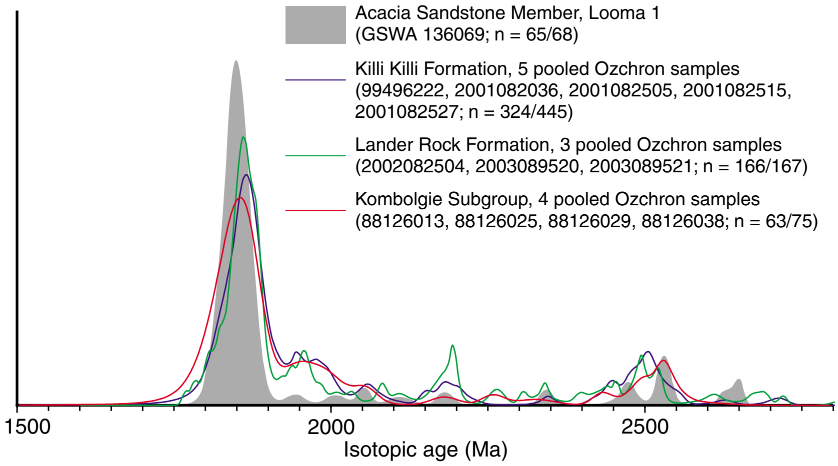

***Figure 4.** Probability density plots for the time interval 1500–3000 Ma, comparing zircon isotopic ages for the Looma 1 sample with pooled results from selected Paleoproterozoic sedimentary and metasedimentary rocks from the North Australia Craton (extracted from OZCHRON; Geoscience Australia, 2006). Ages are based on $^{207}Pb/^{206}Pb$ ratios. Data more than 10% discordant are not plotted; n = number of concordant grains/total grains*

sedimentary and metasedimentary rocks across the North Australia Craton show a remarkably similar age distribution pattern to the older (pre-1700 Ma) components in the Looma 1 and Gap Creek Formation samples. Figure 4 compares the Looma 1 sample to pooled data from the OZCHRON database (Geoscience Australia, 2006) for selected units across the craton, specifically the Lander Rock Formation (western Arunta Orogen, central Australia), Killi Killi Formation (Granites–Tanami Complex), and the Kombolgie Subgroup (basal McArthur Basin), all from within the Northern Territory. The similarity of zircon age spectra across over a thousand kilometres of the North Australia Craton precludes identifying a unique source location or sediment entry point, but strongly supports derivation of these sediments almost exclusively from this craton.

In contrast, the zircon age spectra obtained from Acacia 2 are broadly similar to those previously observed from Neoproterozoic sedimentary rocks of the Amadeus (Camacho et al., 2002; Buick et al., 2005) and western Officer Basins, including deformed equivalents in the Paterson Orogen (Bagas et al., 2001; Bagas, 2003; Geological Survey of Western Australia, 2005). Most samples from these basins have dominant age components of around 1200–1100 Ma, probably derived from the Musgrave Complex and contiguous domains (Camacho et al., 2002), and a complex of smaller upper Paleoproterozoic peaks, with some other peaks important in individual cases. Maximum ages rarely exceed the latest Archean. The main divergence from the common Neoproterozoic pattern in the Acacia 2 sample is the strong 865 Ma peak of unknown provenance, although sparse zircons of near this age are known in some Neoproterozoic samples. Neoproterozoic sedimentary and metasedimentary rocks border the Canning Basin along its southern and southeastern sides, and are likely to lie beneath at least part of the basin. Scattered Neoproterozoic outcrops are also present east of the Canning Basin, but no detrital zircon age data are available from these rocks. Figure 5 compares the Acacia 2 sample to two widely spaced Neoproterozoic samples from the southern Amadeus Basin (Winnall beds) and northwest Paterson Orogen (Choorun Formation). The Carranya Formation sample is interpreted to be derived from a broadly similar, although not identical source. The significant c. 1743 Ma zircons suggest an additional component, possibly from the Arunta Orogen.

The rarity of Archean zircons in all samples indicates that very little, if any, material was derived directly or via reworking from the Pilbara or Yilgarn Cratons, and zircon age spectra are also dissimilar to

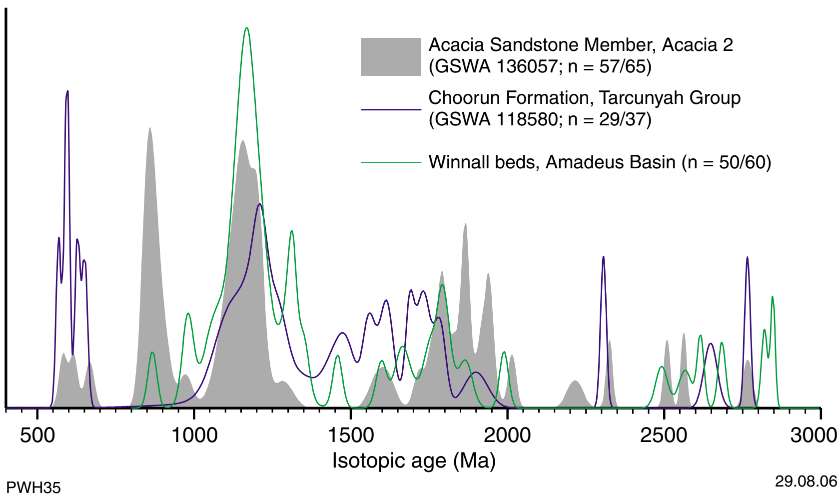

***Figure 5.** Probability density plots comparing zircon isotopic ages for the Acacia 2 sample with Neoproterozoic samples from the Choorun Formation, Paterson Orogen (GSWA 118580, Geological Survey of Western Australia, 2005), and the Winnall beds, Amadeus Basin (Camacho et al., 2002). Ages older than 1000 Ma are based on $^{207}Pb/^{206}Pb$ ratios, those younger than 1000 Ma on $^{238}U/^{206}Pb$ ratios. Data more than 10% discordant are not plotted; n = number of concordant grains/total grains*

those of the Paleoproterozoic and Mesoproterozoic tectonic units lying between these cratons (see data in Geological Survey of Western Australia, 2005). The zircon age profile of the Lower Ordovician Pacoota Sandstone in the Amadeus Basin (Buick et al., 2005) is also dissimilar to both samples, raising questions about the nature or existence of the hypothetical Larapintine Seaway widely believed to have linked the Canning and Amadeus Basins at this time.

Conclusion

Based on our present data the Acacia Sandstone Member has at least two major provenance areas with zircon age spectra similar to the North Australia Craton and adjacent Neoproterozoic basins, respectively, suggesting that sediment was derived from these sources or at least shared common source terrains. Although any further conclusions must be considered preliminary because of the small sample size in this pilot study, one possibility is that the Acacia Sandstone Member is not a single sandstone unit, but several discrete sandstone bodies of similar age feeding from different sediment input points during relative low stand(s) of sea level. This is important to consider when inferring reservoir distribution and making predictions about lateral changes in facies and reservoir properties. An alternate possibility involves switching of sediment sources during deposition, such that the Acacia Sandstone Member is internally stratified with respect to sand source. Further analyses are warranted.

References

BAGAS, L., 2003, Zircon provenance in the basal part of the northwest Officer Basin, Western Australia: Western Australia Geological Survey, Annual Review 2002–03, p. 43–51.

BAGAS, L., CAMACHO, A., and NELSON, D. R., 2001, Are the Neoproterozoic Lamil and Throssell Groups of the Paterson Orogen allochthonous?: Western Australia Geological Survey, Annual Review 2000–01, p. 45–52.

BUICK, I. S., HAND, M., WILLIAMS, I. S., MAWBY, J., MILLER, J. A., and NICOLL, R. S., 2005, Detrital zircon provenance constraints on the evolution of the Harts Range Metamorphic Complex (central Australia): links to the Centralian Superbasin: London, United Kingdom, Journal of the Geological Society, v. 162, p. 777–787.

CAMACHO, A., HENSEN, B. J., and ARMSTRONG, R., 2002, Isotopic test of a thermally driven intraplate orogenic model, Australia: Geology, v. 30, p. 887–890.

GEOLOGICAL SURVEY OF WESTERN AUSTRALIA, 2005, Compilation of geochronology data, June 2005 update: Western Australia Geological Survey.

GEOSCIENCE AUSTRALIA, 2006, OZCHRON database, Geoscience Australia, Canberra, viewed 20 April 2006, <http://www.ga.gov.au/oracle/ozchron/>.

PHIPPS, J., TRUPP, M., and NOSIARA, M., 1998, Well completion report interpretive volume, Looma-1, EP353, Shell Development (Australia) Pty Ltd: Western Australia Geological Survey, Statutory petroleum exploration report, S20358 A2 (unpublished).

VERMEESCH, P., 2004, How many grains are needed for a provenance study?: Earth and Planetary Science Letters, v. 224, p. 441–451.

WATSON, S., and DERRINGTON, S., 1982, Acacia No. 2 well completion report, Western Mining Corporation Ltd: Western Australian Geological Survey, Statutory petroleum exploration report, S2161 A2 (unpublished).

WINGATE, M. T. D., in prep.a, 136057: quartz sandstone, Acacia 2; Geochronology dataset 655: Western Australia Geological Survey.

WINGATE, M. T. D., in prep.b, 136069: quartz sandstone, Looma 1; Geochronology dataset 656: Western Australia Geological Survey.

WINGATE, M. T. D., in prep.c, 184268: quartz sandstone, Gap Spring; Geochronology dataset 657: Western Australia Geological Survey.

WINGATE, M. T. D., in prep.d, 184269: quartz sandstone, Carranya Homestead; Geochronology dataset 658: Western Australia Geological Survey.