Petroleum geochemistry of the Amadeus Basin

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Introduction

The Amadeus Basin in central Australia contains commercial petroleum fields and has the potential to host undiscovered resources. Current production is from Ordovician reservoirs in the Mereenie oil and gas field, the Palm Valley gas field and until recently, the Surprise oil field (Heugh *et al* 2012), in addition to the Neoproterozoic Dingo gas field (**Figure 1**). Despite this production, most of the greater Amadeus Basin is largely considered to be a greenfields basin (Marshall 2005, Munson 2014). The majority of exploration drilling has been undertaken near the Central Ridge and has focused on Ordovician plays where source rocks, presumably within the Horn Valley Siltstone, have generated and expelled petroleum into reservoirs within the Pacoota and Stairway sandstones (Korsch and Kennard 1991, **Figure 2**).

The granting of licenses for the construction of a gas pipeline to the east coast of Australia (Onshoregas 2016) has focused new interest in the Amadeus Basin for both conventional and unconventional petroleum exploration and production (Carr *et al* 2016). The discovery of light sweet crude in Surprise 1 by Central Petroleum is evidence that the Horn Valley Siltstone contains an abundance of both oil and gas reserves (Munson 2014). Furthermore, in the southwestern part of the basin, helium-rich gas has been discovered in the Tonian Heavitree Quartzite at Magee 1 (6 mol% He: Palmer and Ambrose 2012, Wakelin-King and Austin 1992) and Mt Kitty 1 (5.8 mol% He: Palmer and Ambrose 2012).

The Onshore Energy Systems Section at Geoscience Australia has undertaken a comprehensive geochemical study of the Amadeus Basin. One component of the study is the Australian Source Rocks Mapping Project in which newly acquired and legacy total organic carbon (TOC) and Rock-Eval pyrolysis screening data (total number of samples with data is 1177) are used to determine the distribution, type, quality, maturity and generation potential of source rocks in the basin. The second component of this study uses compound-specific stable carbon and hydrogen isotopic analysis to conduct gas-oil and oil-source rock correlations to better define the basin's petroleum systems. Analyses of Cambrian and Neoproterozoic source rocks are sparse even though oil and gas shows have been identified in these older sections that are unlikely to have been derived from the Horn Valley Siltstone. In this study, we highlight some of the results of this ongoing research.

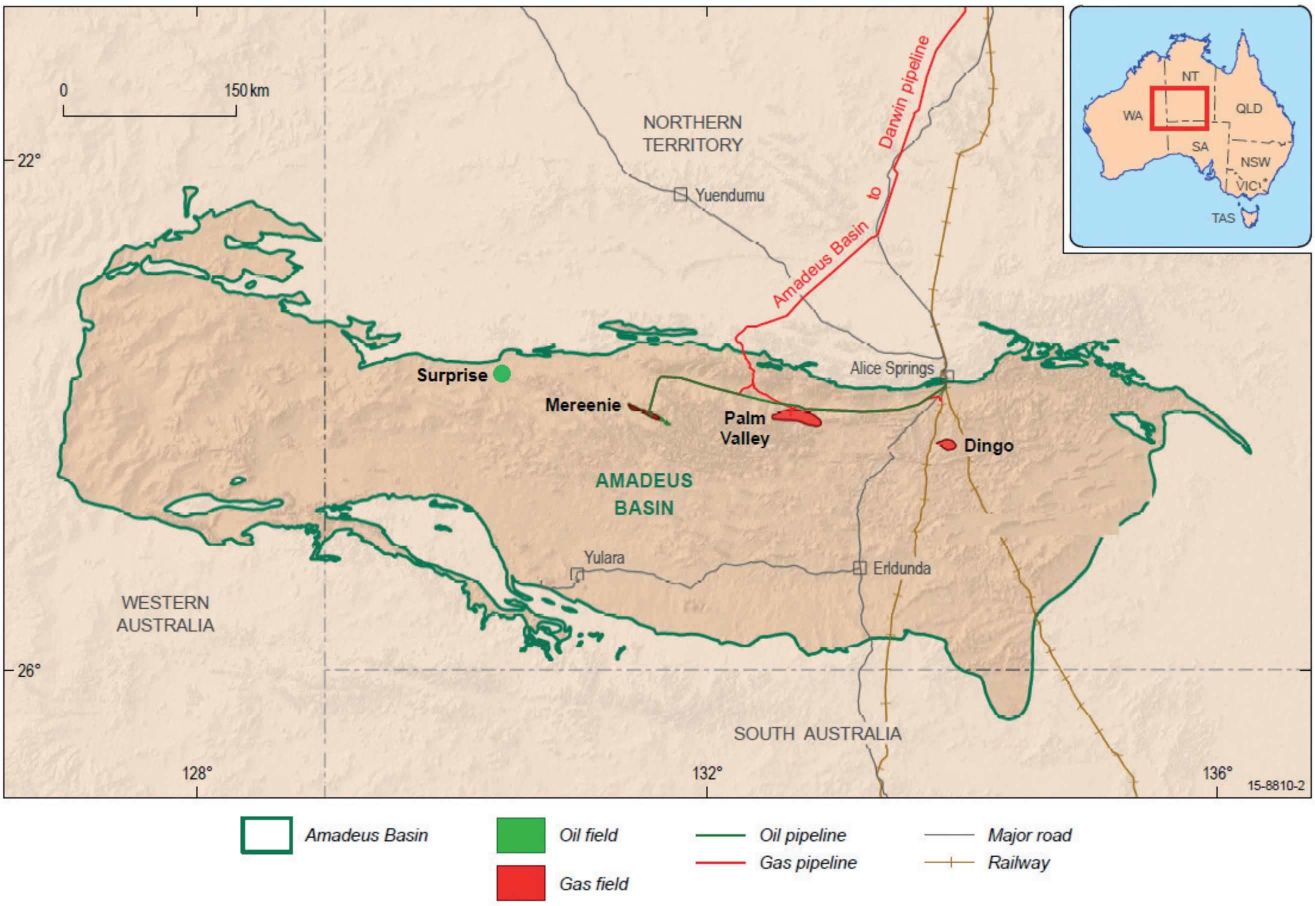

Figure 1. Hydrocarbon accumulations in the Amadeus Basin.

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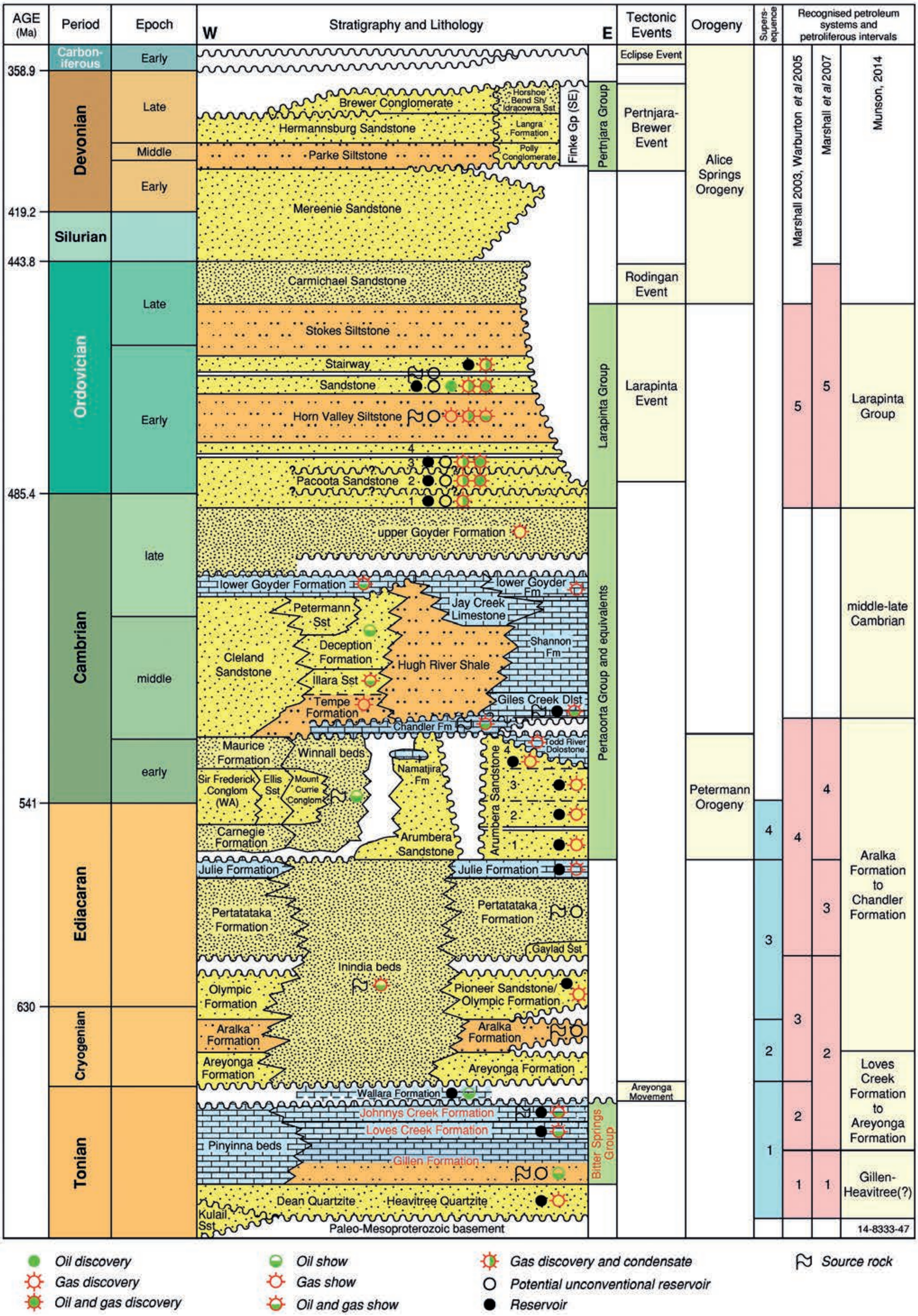

Figure 2. Amadeus Basin stratigraphy (Carr *et al* 2016).

Source rock geochemistry

The Amadeus Basin contains carbonate and siliciclastic source rocks with variable organic richness and quality (**Figure 3**). According to the classification of Peters and Cassa (1994), three source rock units exhibit excellent organic richness (TOC >4%), namely the Ordovician Horn Valley Siltstone, the Cambrian Tempe Formation and the Tonian Johnnys Creek Formation (lithostratigraphic nomenclature after Normington *et al* 2015 and Carr *et al* 2016). A further five units have good organic richness (TOC 2–4%): the Cryogenian Aralka and Areyonga formations; Ediacaran Pertatataka Formation; and the Cambrian Chandler Formation and Jay Creek Limestone (**Figure 2**).

In the past, emphasis has been placed on the Horn Valley Siltstone, long considered to be the main source of hydrocarbons produced from the basin's Ordovician reservoirs (Kurylowicz *et al* 1976, Jackson *et al* 1984; Summons and Powell 1991). Detailed analysis of this formation reveals that its fossiliferous shale units are typically organic-rich (TOC up to 11%) and contain Type II kerogen, whereas those barren of fossils have lower TOC contents (<0.5%) and contain predominantly 'Type III kerogen' (Gorter 1984, Marshall 2005). Other workers have divided the Horn Valley Siltstone into ten members consisting of four main lithologies: brown to black laminated siltstones and mudstones, laminated calcilutite, marls, and fossiliferous coquinas, with the variations in facies resulting from a marine transgression and regression (Elphinstone 1989, Edgoose 2013). Elphinstone (1989) also showed that laminated siltstones have the highest TOC and hydrogen index (HI) values and that only one unit (HV7) contains fossil evidence for *Gloeocapsomorpha prisca* (*G. prisca*), found in Ordovician oil-prone shales (Guthrie and Pratt 1995).

Geoscience Australia is currently geochemically characterising these facies using stable isotopes and biomarkers to determine their generation potential and whether they are oil- or gas-prone; characteristics that are essential to accurately define play fairways and sweet spots. These source rock units are also being correlated to the oils and condensates found within the Ordovician reservoirs of the producing fields. This study demonstrates that numerous potential source rocks are present within the Precambrian, Cambrian and Ordovician successions. Rigorous quality control of TOC and Rock-Eval pyrolysis data was undertaken using the methodology of Hall *et al* (2016). The results of the revised source rock data interrogation are presented in **Figure 4**. Only in the case of the Horn Valley Siltstone are there sufficient data to undergo statistical analysis. For all the other potential source rocks there are either limited data (<6 samples) or, in the case of the Jay Creek Formation and Johnnys Creek Formation, no reliable Rock-Eval analyses, highlighting the need for further data acquisition.

The Horn Valley Siltstone has HI values within the range 5 to 664 mg HC/g TOC, indicating that source rock quality is variable. Although the better-quality samples contain oil-prone Type I to Type II kerogen, many have HI values <150 as a consequence of poor preservation of their microbial algal organic matter and/or elevated thermal maturity.

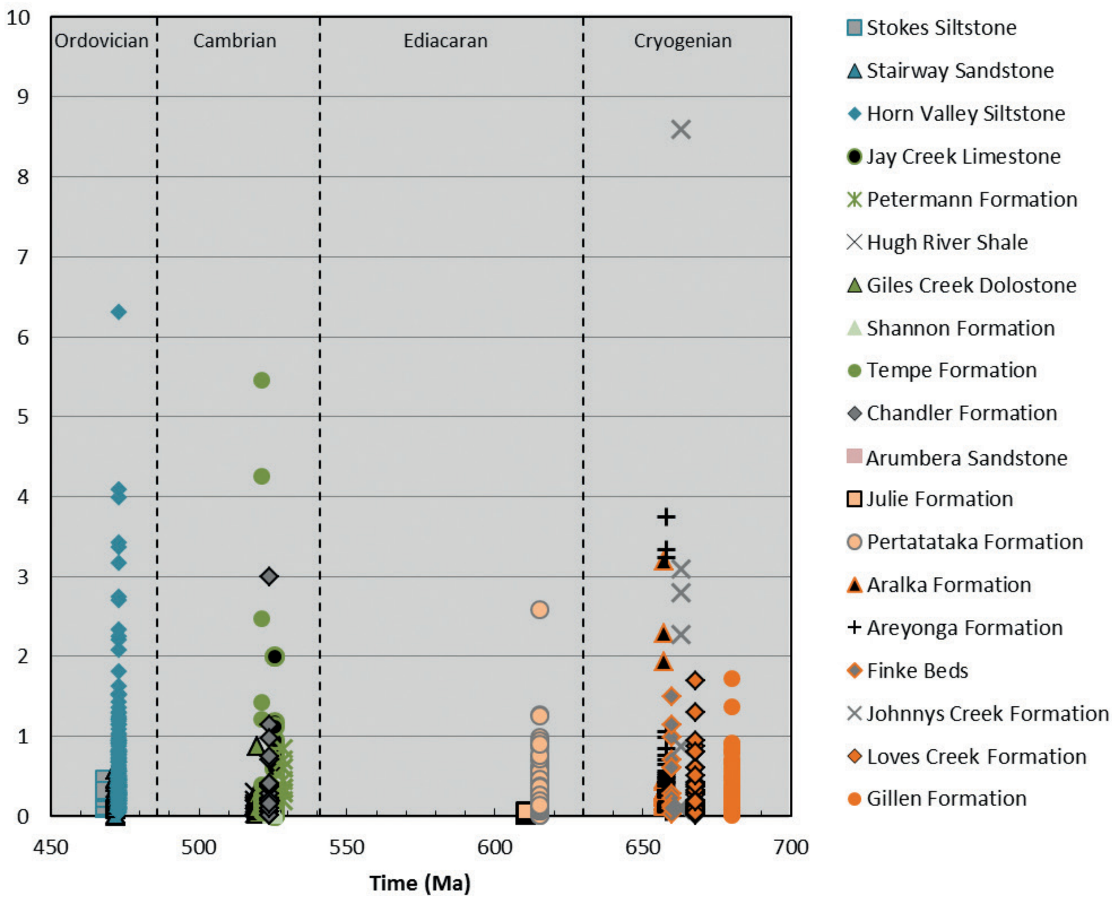

Figure 3. Secular variation of TOC content in the Amadeus Basin.

Fluid isotope geochemistry

Stable carbon isotopic signatures ($\delta^{13}C$) of the bulk saturated and aromatic hydrocarbon fractions were used to identify differences between the produced oils and oil stains recovered from Ordovician reservoirs. In a single oil family, the $\delta^{13}C_{sat}$ and $\delta^{13}C_{arom}$ values typically do not deviate more than 1–2‰ (Sofer 1984, Edwards and Zumberge 2005). The oils and condensates of the Mereenie and Palm Valley fields cluster into distinct families suggesting that they are derived

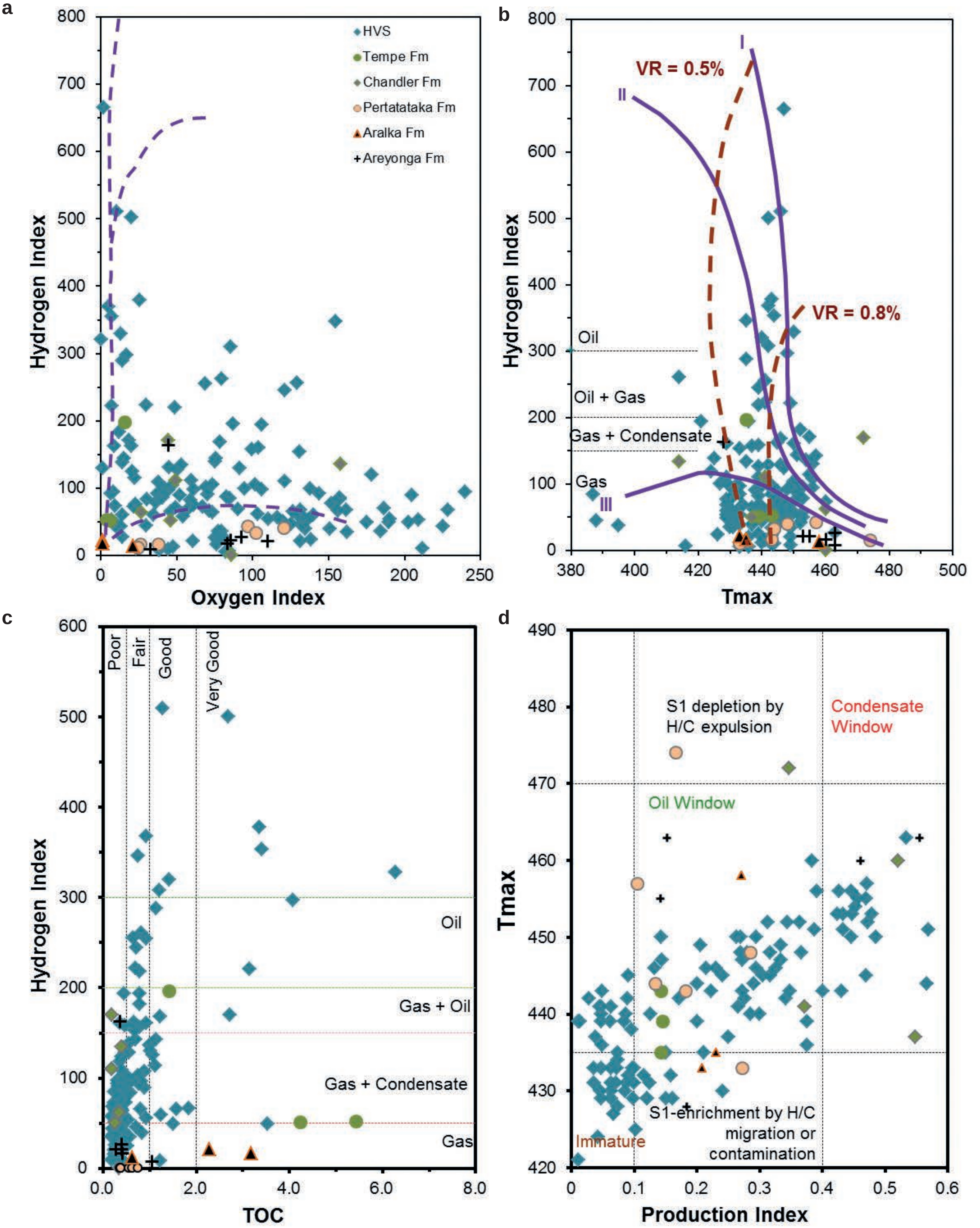

Figure 4. Geochemistry of source rocks in the Amadeus Basin. HVS = Horn Valley Siltstone. **(a)** Hydrogen Index (mg HC/g TOC) versus Oxygen Index (mg CO_2/g TOC).**(b):** Hydrogen Index (mg HC/g TOC) versus Tmax (°C). **(c)** Hydrogen Index (mg HC/g TOC) versus TOC (wt %). **(d)** Tmax (°C) versus Production Index.

from several different source units (**Figure 5**). The Surprise oil is strongly differentiated from those in the Mereenie and Palm Valley fields on the basis of its heavier $\delta^{13}C_{sat}$ value, whereas an oil stain in core of the Cambrian Giles Creek Dolostone from Alice 1 (McKirdy 1977, McKirdy *et al* 1983) is isotopically indistinguishable from the Mereenie crudes.

The carbon and hydrogen isotopic signatures of individual *n*-alkanes are a useful method for determining oil-oil and oil-source rock correlations (Boreham *et al* 2004, Edwards *et al* 2013). **Figure 6** illustrates the $\delta^{13}C$ and δD profiles of the C_{7+} *n*-alkanes in oils and condensates from the Mereenie, Palm Valley and Surprise fields, with the shaded area showing the isotopic variation within the Horn Valley Siltstone, a result of source and maturity differences. Comparison of the $\delta^{13}C$ profiles of these Ordovician-reservoired oils with those of a Cambrian and a Neoproterozoic oil stain, as reported by Boreham and Ambrose (2005) and Jarrett (2014), reveals that the oil stains are more depleted in ^{13}C, reflecting a different biological input to their respective source rocks. *n*-Alkane $\delta^{13}C$ and δD profiles have not yet been obtained for Cambrian source rocks due to the low organic richness of the samples analysed. However, strong hydrocarbon staining throughout the Alice 1 core is evidence for initial expulsion from the Chandler Formation into the Giles Creek Dolostone reservoir (Boreham and Ambrose 2007). A correlation between an oil stain and source beds within the Aralka Formation in drill core from BR05DD01 has been confirmed using *n*-alkane compound-specific analysis, hydrocarbon biomarkers and stratigraphic relationships (Jarrett 2014).

Conclusion

The Onshore Energy Systems Section at Geoscience Australia is undertaking a detailed geochemical study of the Amadeus Basin to better understand the hydrocarbon prospectivity of the basin and to reduce exploration risk. Screening of the available source rock data has shown that further work is required to determine the hydrocarbon potential of the Cambrian and Neoproterozoic sections since not all fluids in the basin can be correlated to the effective source rocks of the Ordovician Horn Valley Siltstone.

The $\delta^{13}C$ isotopic signatures of the bulk saturated and aromatic hydrocarbon fractions, together with their *n*-alkane $\delta^{13}C$ and δD profiles, indicates that the oils and condensates from the three producing fields (Surprise, Palm Valley and Mereenie) exhibit significant source and maturity-related differences, despite them all being found within Ordovician reservoirs.

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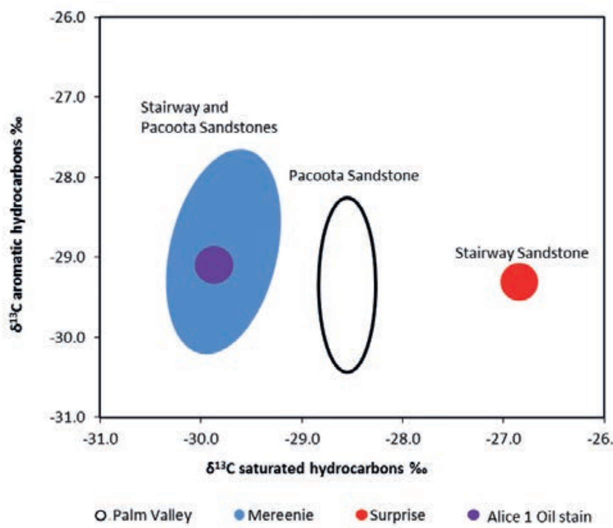

Figure 5. Cross plot of $\delta^{13}C$ signatures of the bulk saturated and aromatic hydrocarbon fractions (‰ VPDB) showing the range of values for oils and condensates in Ordovician reservoirs from the Mereenie (blue oval), Palm Valley (black oval) and Surprise (red circle) fields, and an oil stain (purple circle) from the Cambrian Giles Creek Dolostone in Alice 1.

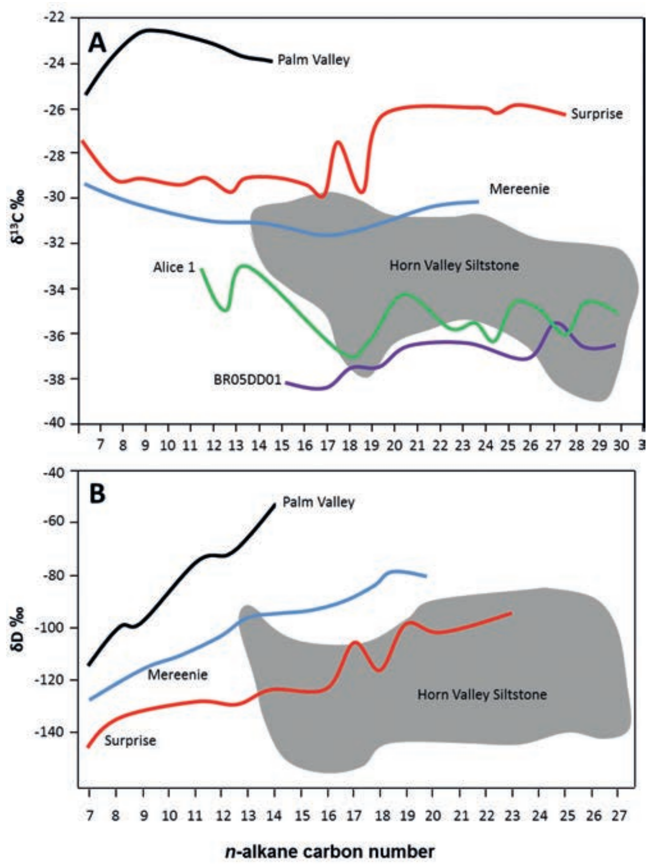

Figure 6. (**a**) Carbon ($\delta^{13}C$, ‰ VPDB) and (**b**) hydrogen (δD, ‰ SMOW) isotopic composition of C_{7+} *n*-alkanes in oils and oil stains (solid line averages for fields with multiple fluid samples). The oil stains are from Alice 1 in the Giles Creek Dolostone and BR05DD01 in the Aralka Formation.

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