AAPG HEDBERG CONFERENCE
"NATURAL GAS GEOCHEMISTRY: RECENT DEVELOPMENTS, APPLICATIONS, AND TECHNOLOGIES"
MAY 9-12, 2011 – BEIJING, CHINA

Carbon and Hydrogen Isotope Systematics of Natural Gases from the Perth Basin, Australia

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From the beginning of petroleum exploration in the Perth Basin, the importance of the Early Triassic marine Kockatea Shale was recognised as the principal source for liquid petroleum in the onshore northern Perth Basin (Powell and McKirdy, 1976). Thomas and Barber (2004) constrained the effective source rock to a Early Triassic, middle Sapropelic Interval in the Hovea Member of the lower Kockatea Shale. In addition, Jurassic and Permian sourced-oils (Summons et al., 1995) demonstrate local effective non-Kockatea source rocks. However, evidence for multiple effective gas source rocks is limited. This study utilizes the molecular composition and carbon and hydrogen isotopic compositions of 34 natural gases from the Perth Basin, extending the previous study (Boreham et al., 2001) to the offshore and includes hydrogen isotopes and gases. It shows the existence of Jurassic to Permain gas systems in the Perth Basin.

Gaseous Hydrocarbons

Most onshore Perth Basin gases were originally believed to be quite dry and sourced from Lower Permian coals (Owad-Jones and Ellis 2000). However, with more recent discoveries, wet gases are the norm (Fig. 1a) and the strong depletion in ^{13}C of the C_1−C_5 gaseous hydrocarbons (Fig. 1b) for the majority of the natural gases is more consistent with an isotopically depleted Early Triassic Kockatea Shale source (Summons et al., 1995). Gases derived from older and younger source rocks are more enriched in ^{13}C (Fig. 1b). In comparison, the hydrogen isotopic compositions of the C_1-C_5 gaseous hydrocarbons show no strong source-age resolution.

Support for active gas generation from Permian strata comes from isotopically heavy gas (Fig. 1b; Boreham et al., 2001) in Elegans-1, also reservoired within the Permian Irwin River Coal Measures. Alternatively, Thomas and Barber (2004) suggest a mixed Permian-Early Triassic source for Elegans gas. Therefore, it is important to geochemically distinguish between an overmature Kockatea Shale gas source, which may become increasingly enriched in ^{13}C with maturity, and a ^{13}C-enriched gas from a Permian source of lower maturity. The recent Redback South-1 gas provides the key. It is a dry gas (Fig. 1a) but the C_1−C_5 hydrocarbons are depleted in ^{13}C indicative of a Kockatea source (Fig. 1b). Nevertheless, it represents a locally sourced gas where the Kockatea Shale is overmature at ~ 2.0 %Ro. Therefore, maturity has a weak control on the ^{13}C of the C_1−C_5 hydrocarbons for Kockatea Shale-sourced gases. Furthermore, *neo*-pentane shows little dependency on maturity (Fig. 1b; Boreham and Edwards, 2008). Given the ^{13}C

enrichment in *neo*-pentane for the Elegans-1 gas (Fig. 1b) a Permian source is considered most likely.

Burial history modelling by Thomas and Barber (2004) suggested the timing of gas and oil generation from the Kockatea Shale-Hovea Member-Sapropelic Interval is virtually coincident with gas generation from the underlying Irwin River Coal Measures. The outcome of the modelling is that in some areas the gas and oil charge from the Early Triassic is in direct competition with any gas being generated from the Permian. An example of this dual source is with the Dongara gas field. The gas is relatively dry and the methane is more enriched in ^{13}C compared to gas co-generated with oil. At Dongara, the Permian charge is mainly isotopically heavy methane, which has added to a wet gas from the isotopically light Sapropelic Interval source. The hydrogen isotopes are more diagnostic, with methane now isotopically heavier than ethane with input of D-enriched methane from the Permian.

The very recent gas discoveries in Jurassic strata (e.g. Gingin West-1 gas reservoired in the mid-Jurassic Cattamarra Coal Measures and Warro-3 gas from the Late Jurassic Yarragaradee Formation) also show enriched in ^{13}C (Fig. 1b) for the C_1–C_5 hydrocarbons and are considered to be locally derived from the Jurassic source rocks. Interestingly, *neo*-pentane from Jurassic sources is enriched in ^{13}C, which distinguishes it from a slightly more ^{13}C-depleted Permian source with further ^{13}C depletion to an Early Triassic source (Fig. 1b).

Origin of CO_2

The Perth Basin gases show a wide range in $\delta^{13}C$ CO_2 from to -16.2 ‰ to -1.6 ‰ (Fig. 2). The majority of the gases with CO_2 > 1.7 mol% are consistent with an inorganic CO_2 source while those gases with lower CO_2 mol% are more depleted in CO_2 than -10 ‰ and most likely have a contribution from an organic source associated with thermogenic gas generation. Mixing between these two-end members is one mechanism to explain the positive relationship between CO_2 mol% and $\delta^{13}C$ (Fig. 2). An alternative explanation is where the free CO_2 composition is altered by mineral trapping, similar to that suggested by Tenthorey et al. (2010) for adjacent Carnarvon Basin gases, where the CO_2 in the natural gas reacts with reactive minerals in the reservoir rocks and with the accompanying precipitation of carbonate systematically altering molecular and carbon isotopic compositions of the free CO_2.

The distinction between a carbonate and volcanic/magmatic source is ambiguous given the high degree of overlap between respective source isotopic fields for carbon (Wycherley et al., 1999). Given the uncertainty in the origin of CO_2 above, independent evidence is therefore required. Helium isotopes ($^3He/^4He$) can provide more clarity given their distinctive crustal and magmatic compositions (Pinti and Marty, 2000). For Perth gases with CO_2 < 4 mol%, helium is crustal in origin with Rc/Ra close to 0.02, which lends support to a carbonate source for the CO_2. However, for gases with higher CO_2 mol% there is an increasing magmatic contribution with increasing CO_2 content. The strong helium mantle contribution to the Perseverance-1 gas (Rc/Ra = 0.60; $\delta^{13}C$ CO_2 from -5.4 to -4.8 ‰ in Fig. 2) is in accord with its location in the offshore Abrolhos Sub-basin interpreted with a high density of volcanic plugs (Anderson et al., 2006). The extremely high CO_2 content in Perseverance-1 is undoubtedly of a predominately volcanic/mantle origin.

AAPG Search and Discovery Article #90134©2011 Hedberg Conference Natural Gas Geochemistry, Beijing, China, 9-12 May 2011.

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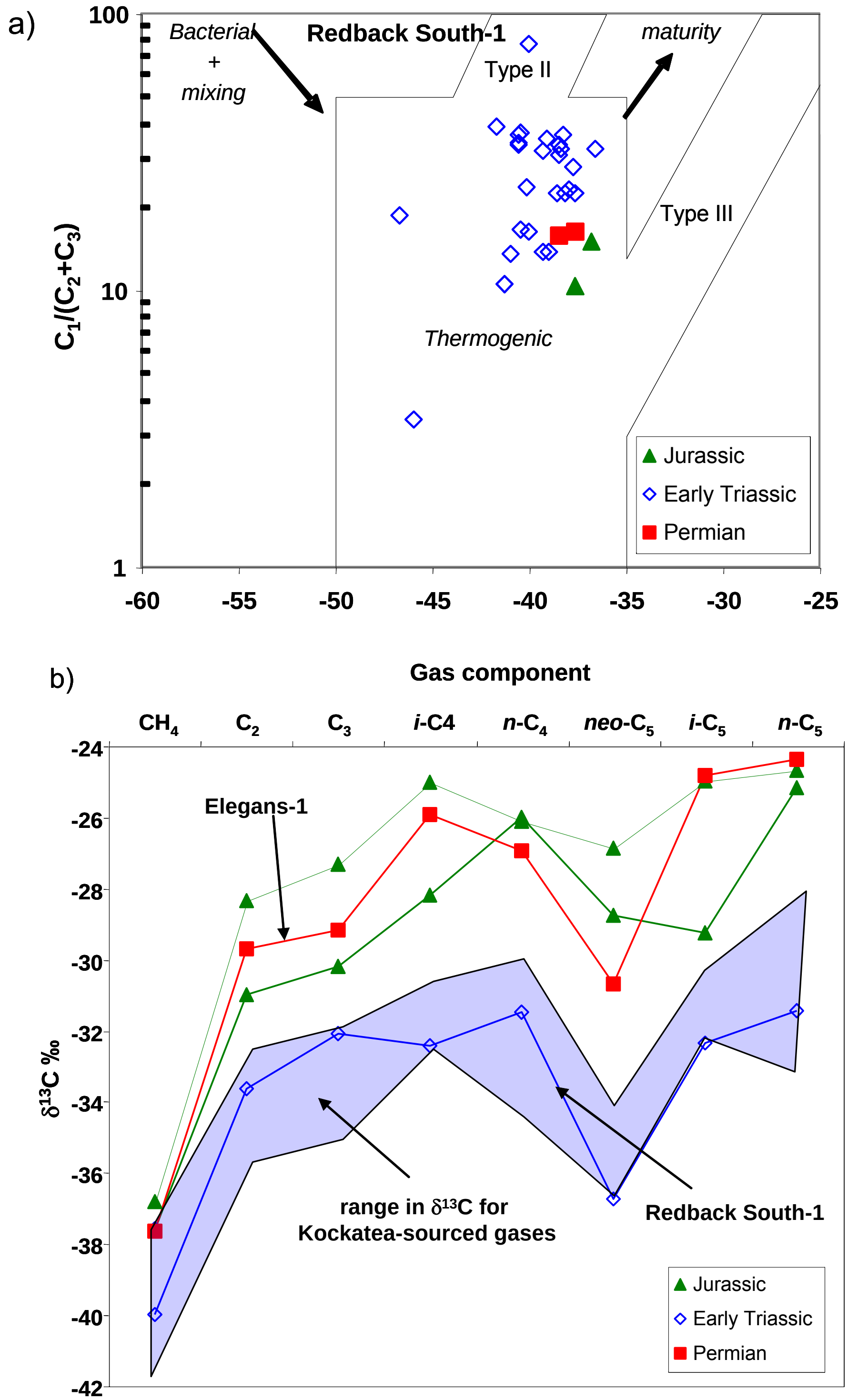

Figure 1. Relationships between a) methane/(ethane + propane) and carbon isotopic composition of methane (modified after Bernard et al., 1976), and b) carbon isotopic composition of C_1–C_5 gaseous hydrocarbons.

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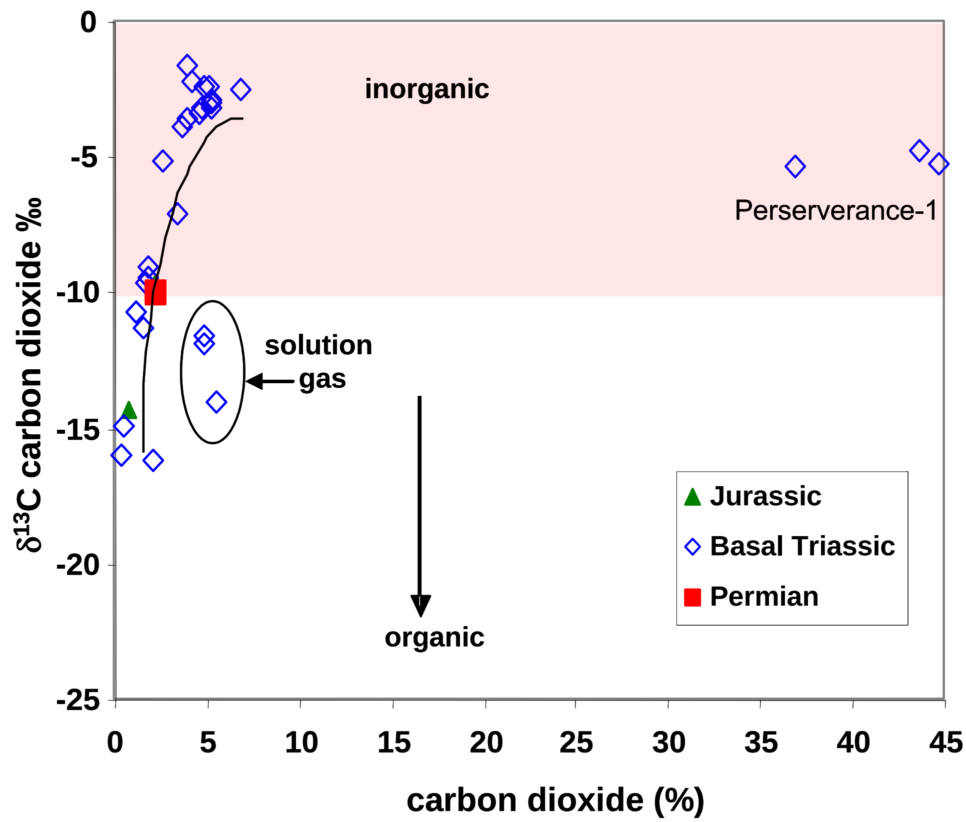

Figure 2. Molecular and carbon isotopic compositions of CO_2 in Perth Basin gases.