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Applications of Mud Gas Isotope Logging in Petroleum Systems Analysis

Daniel Dawson and Andrew Murray
Woodside Energy Ltd., Perth, Australia

Natural gas has rapidly become the "fuel of choice" for both economic and environmental reasons. The demand for gas has increased markedly in recent years, and it is important to develop and apply new technologies in natural gas exploration and development to help better understand and exploit this important, non-renewable resource.

Geochemistry is an important tool in the understanding of the formation, migration and accumulation of hydrocarbons. The origin and sub-surface behaviour of natural gas is not as well understood as that of coal and oil. Historically, the reasons for this include (i) the relative infrequency with which gas samples have been taken and preserved compared with liquids samples and (ii) the relatively simple composition of natural gas presents fewer opportunities for detailed gas-source, gas-liquid and gas-gas correlation.

During the last decade, new sampling techniques have been developed to acquire subsurface gas samples for geochemical analysis. Mud gas – the gas entrained in the drilling mud and returned to surface - has long been used as an indicator of the presence and composition of hydrocarbons in the sub-surface. The gas wetness of the mud gas in combination with petrophysical logs can provide information about the hydrocarbon fluid type (gas vs. oil) or the liquids content (e.g. CGR or GOR). However, the extent to which mud gas components permeate into the mud is influenced by operational factors such as rate of progress (ROP) and mud weight. Furthermore, traditional gas traps are often inefficient in capturing the wet gases (C2-C5). These factors can result in non-representative mud gas compositions. Recently developed advanced mud logging systems (e.g Schlumberger "Flex-Flair") include more advanced gas traps and heated gas extractors, allowing for more accurate mud gas compositions and the ability to analyse a wider boiling range. Real-time stable carbon isotope analysis of the mud gas is also possible but this is still a relatively immature technology and only methane isotopes can currently be recorded.

"Mud gas isotope logging" (MGIL) is a term coined to describe the technique of monitoring variations in the stable carbon isotope composition ($\delta^{13}C$) of C1-C5 to interpret the nature of hydrocarbon shows and connectivity through a well (Ellis et al., 2003). Samples can be collected in bags, as the headspace of cuttings in glass jars or most conveniently in "Isotubes" which are small aluminium containers placed in-line with the rig-site gas chromatograph. The original application of MGIL was in exploration, ie. the determination of the origin of discovered gas and its distribution through the stratigraphy of an exploration well. However, the low cost and convenience of Isotubes allows high density of sampling which opens up the possibility for within-reservoir characterisation of gases. This has proven very useful in the appraisal and development of gas fields. This is important when, increasingly, discovery and appraisal are carried out in a single campaign and it is not feasible to wait for the results of detailed geochemical analyses. This paper will show examples of the collection and interpretation of mud gas isotope data in gas and oil field appraisal.

The first criterion for the successful use of MGIL is that the results are concordant with those of conventional down-hole samples. Figure 1 shows a comparison of $\delta^{13}C$ of methane obtained from mud gas in Isotubes and that from bottom hole samples, taken from both thermogenic and secondary biogenic hydrocarbon accumulations. Deviations occur typically where there are low net-to-gross units where locally-sourced "shale gas" can mix with low concentrations of migrated gas (if any) and perturb the isotope values. A comparison of MGIL profiles for two wells drilled ~400m apart will be shown in this presentation. This is evidence of the reproducibility of the data obtained from one well to another through similar stratigraphic sections.

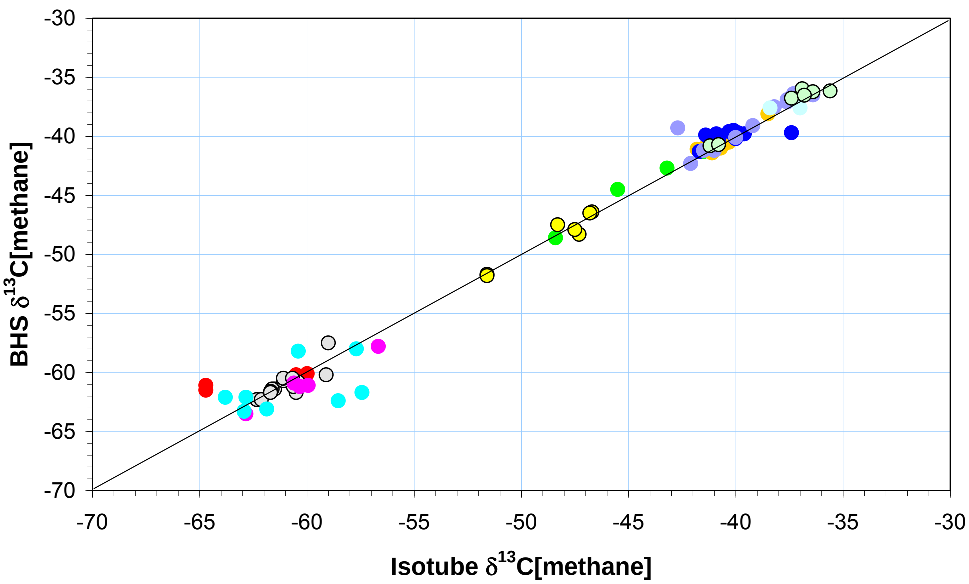

Figure 1: Comparison of the stable carbon isotope composition ($\delta^{13}C$) of methane obtained from mud gas samples (Isotubes) vs. bottom hole gas samples (n = 95).

The main operational advantage of Isotubes over bottom hole samples is that a large number of samples can be taken rapidly and at relatively low cost, so the sample coverage is much greater than that of a typical bottom hole sampling program. MGIL has numerous technical advantages over conventional mud gas analysis. For example, the isotope data provides genetic information about the hydrocarbons (source type and thermal maturity), and the isotope profile through a well can give insight into reservoir continuity as well as seal capacity. The large number of data points from high resolution sampling allows for a detailed examination of gas behaviour and communication through a well (e.g. Figure 2).

One of the first and most valuable pieces of information obtained from MGIL is an indication of whether a gas show is primary biogenic or thermogenic in origin. This is based primarily on the carbon isotope composition ($\delta^{13}C$) of methane, but also on the presence, quantity and isotope composition of the wet gases (C2-C5). The ability to differentiate between background primary biogenic and migrated thermogenic gas is important for determining whether or not the section penetrated by a well has been exposed to significant charge from a source rock. This is particularly useful for evaluating gas shows in "dry" wells (i.e. those with only low hydrocarbon saturations), because it helps determine if lack of charge is the reason for failure. If there is evidence of hydrocarbon charge from a mature source rock, further exploration

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may be warranted. Examples of the differentiation between biogenic and thermogenic gas and the advantages of this distinction will be shown using exploration and appraisal wells.

Aside from the effect of hydrocarbon source and maturity, isotopic fractionation can occur during migration through tight rock. Large fractionations (> 5 per mil and up to 30 per mil) of methane isotopes have been reported to occur during migration (e.g. Prinzhofer and Pernaton, 1997). High resolution MGIL has enabled this phenomenon to be observed in recently drilled wells (e.g. Figure 2). The extent of diffusion and the amount of isotopic fractionation occurring above a trap can be used to estimate the length of geologic time over which diffusion has been occurring, allowing for a better understanding of the age a and viability of a petroleum system (Zhang and Krooss, 2001).

Finally, mud gas isotopes have been used for fluid property assessment and prediction in an Australian oil field. Geochemical studies of mud gas, together with oil, free gas and solution gas, were used to determine the reasons for fluid property variation and to allow effective prediction of fluid properties away from well control.

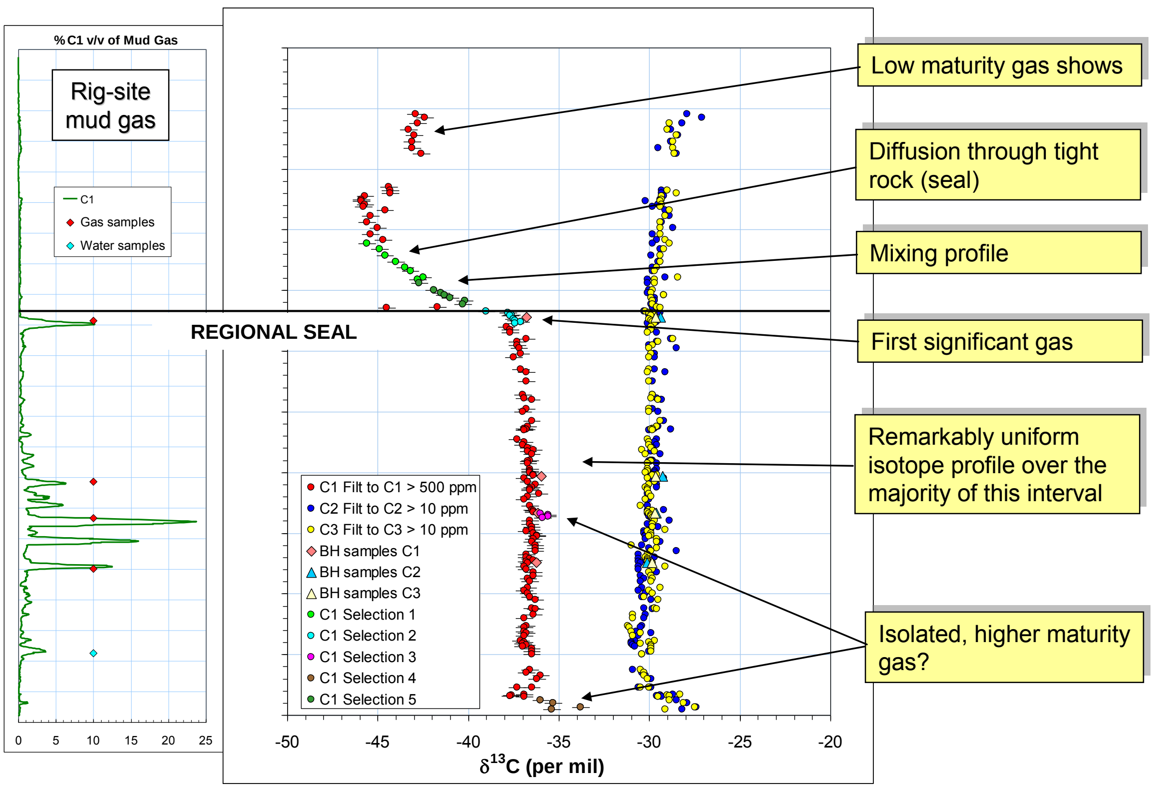

Figure 2: Mud gas isotope log (MGIL) in combination with a rig site mud gas log (C1 only) gives insight into the subsurface behaviour of natural gas.

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