Mudgas Isotope Depth Profiles across Western Canada

Daniela Vlad*
Shell Canada Energy, 400 4th Ave SW, Calgary, AB, Canada T2P 2H5
Daniela.Vlad@shell.com

and

Karlis Muehlenbachs
Department of Earth and Atmospheric Sciences, University of Alberta, 1-26 Earth Sciences Bldg., Edmonton, AB, Canada T6G 2E3

Summary

Carbon isotope and molecular compositions of Cretaceous mudgases have been examined from several depth profiles across the undisturbed Western Canada Sedimentary Basin (WCSB). The complexity of the isotopic profiles shows numerous inflections and deviations of the carbon isotope values and wetness index with depth that suggest a correlation with the stratigraphic framework and can be explained in terms of the origin and alteration of the gases. However, combined evidence from a multidisciplinary approach suggests that isotopic variability of WCSB gases is only partly induced by source maturity. The main shifts of carbon isotope ratios are likely to be related to the physical properties of the rocks, differences between organic precursors, total organic carbon (TOC) content, gas biodegradation and mixing. Mudgas geochemistry is best employed in conjunction with petrophysical analysis and conversion into mineralogy, for defining details of transition zones and reservoir compartments.

Introduction

A mudgas carbon isotope depth profile represents carbon isotope analyses of gases (containing light hydrocarbon gases - C_1, C_2, C_3, C_4, C_5 – and other gases), extracted from drilling muds during drilling of a new well. One of the biggest advantages of carbon isotope mud gas depth profiles is that they provide essentially continuous gas samples from the surface down to the total well depth, through potential production horizons and the intervening shales, silts and coals. One can therefore look at the variation of gases within a reservoir, across the overlying and underlying potential seal rocks (which may also be gas sources) and into the next successive reservoir rocks. With this information one can observe sharp transitions in isotopic ratios at some formation boundaries (effective seals/baffles), no change in isotope ratios across other formation boundaries (ineffective seals/baffles), or mixing trends of carbon isotope ratios across a seal (partially effective seal/baffle). Within each gas package (including those separated by seals and those within the seals themselves) one can gain information about the source, maturation, alteration, and mixing of gases.

Theory and/or Method

The interpretation derived from the geochemical analyses of mudgases is integrated within a sequence stratigraphic framework, with the wireline logs quantifications and petrophysical approach, and the regional flow of formation waters. Carbon isotope values show a strong correspondence to stratigraphic position: major shifts in their trends occur at key sequence stratigraphic surfaces: subaerial unconformities (SU), ravinement surfaces (RS), and maximum flooding surfaces (MFS) (Figure 1). Such boundaries are loci of preferential fluid flow and appear as anomalies on geochemical depth profiles. Other inflections in the trends of the isotopic ratios with depth occur within major stratigraphic formations, suggesting intra-formational compartmentalization of the gas.

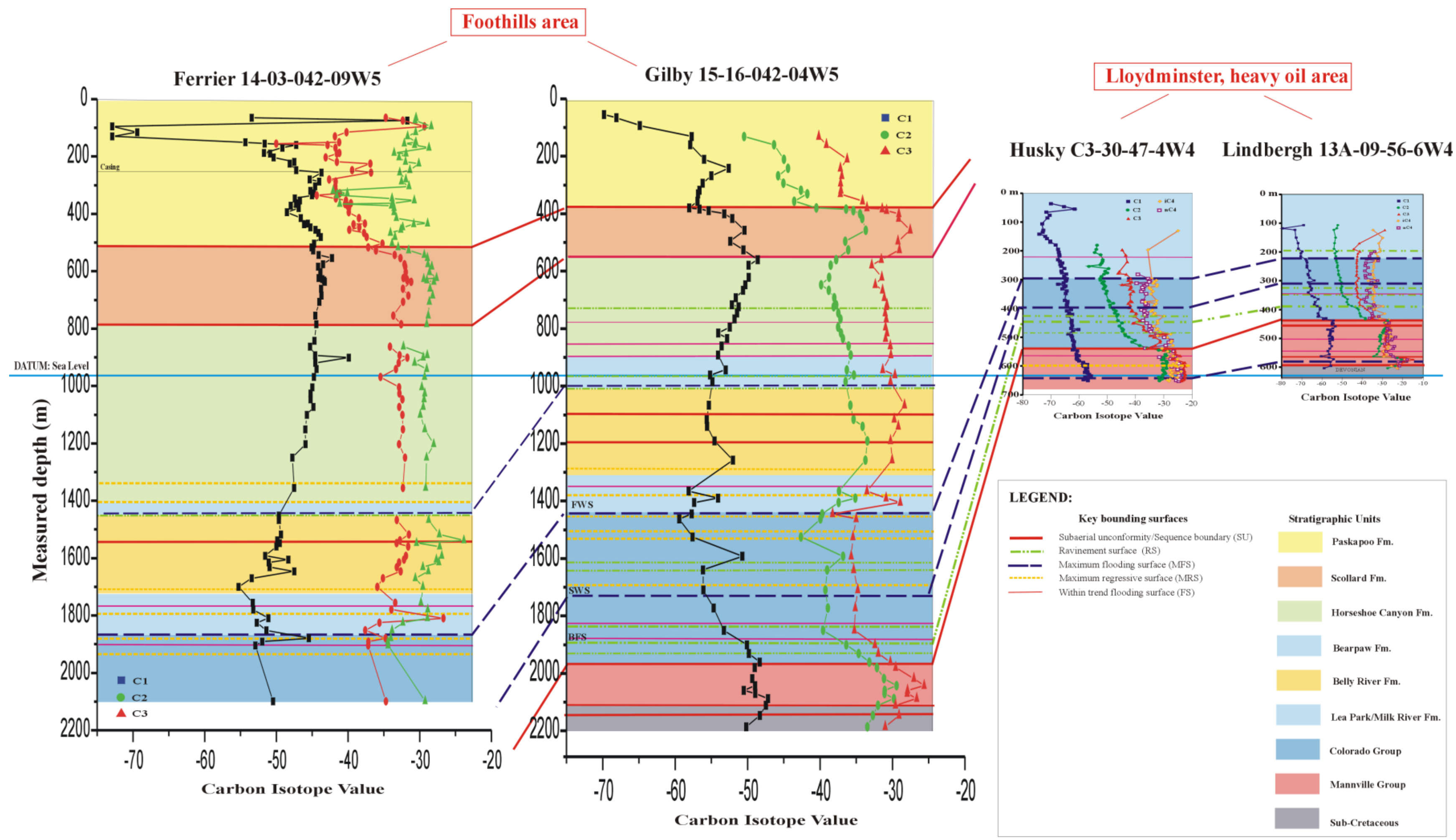

Figure 1: SW to NE stratigraphic cross -section showing carbon isotope depth profiles from four wells across the Western Canada Sedimentary Basin. Datum is Sea Level. The stratigraphic units used in the study are correlated across the four wells. Each well includes isotope profiles for methane, ethane, propane; normal-, and isobutane are added for the two Lloydminster wells.

The analysis of the wireline data and conversion into mineralogy by a matrix algebra solution, demonstrates that a number of shifts in geochemical signature appear to be related to the presence of some horizons with sealing properties (high shale content and/or low porosity, diagenetic layers). Among shales, only the presence of highly compacted, montmorillonite - rich layers, or shales with different composition (mainly illite, montmorillonite, chlorite), but with a very low porosity, seems to influence the trend of the carbon isotope ratios on mudgas profiles. Their presence segregates several packages of gases, with distinct isotopic and molecular composition, and with distinctive biodegradation and/or mixing signatures.

Analyzed gases reflect a complicated suite and mixture of (a) gases that evolved at higher temperatures during the time of maximum burial and (b) gases that evolved at lower temperatures during the more recent period of uplift and erosion. They represent both thermogenic gases, and mixtures of thermogenic (in-situ and migrated) and bacteriogenic gases. The gas migration mechanisms are likely to be related to free gas phase passage through porous media, diffusion, and solution/exsolution processes related to the presence and influence of groundwater flow systems. Indigenous bacterial gas seems to be present in immature to marginally mature Upper Cretaceous-Tertiary rocks close to the Cordilleran deformation front of WCSB, and in the Upper Cretaceous Colorado-Lea Park section of the eastern side of the basin. Thermogenic gases are present throughout the entire stratigraphic section, in both studied areas – as indigenous, mixed, and migrated gases. Indigenous thermogenic gas (source rocks $R_o<0.65\%$) is present in the entire Cretaceous sedimentary section, from Mannville Group up to Scollard Formation. Migrated thermogenic gases can be recognized particularly in shallow reservoirs where contributions from local sources appear small (e.g. Belly River gases).

Examples

Carbon isotope analyses of production gases and gases extracted from drilling muds can provide valuable information related to reservoir appraisal. High density sampling of gases from drilling muds can lead to recognition of reservoir compartmentalization and seal identification, and prediction of the depth range of vertical continuity within a reservoir. Discontinuity of the reservoir between two wells can be detected by dissimilar isotope compositions of the gases produced from each well. Detailed carbon isotope mudgas profiles obtained in the Lloydminster heavy oil field operated by Petro Vera Resources Ltd. are presented as a case study. The compositional differences between individual intervals within the Mannville Group suggest the absence of vertical continuity. Observed range of propane carbon isotope values is huge, indicating that these data can be used as a natural tracer of fluid variability (Figure 2).

Mud gas isotopes can also be used to assess the presence or absence of lateral reservoir continuity between wells. The presence of similar carbon isotope values for certain zones in two or more wells indicates the presence of lateral reservoir connectivity within those intervals. In contrast, the significantly different carbon isotope values for certain zones indicates the absence of lateral reservoir connectivity within those intervals.

Conclusions

The carbon isotopic mud gas profiles represent a powerful tool that provides information about the compartmentalization of the gas, the effectiveness of low permeability barriers, the origin, alteration and maturity of gases, and the regional gas dynamics. However, this geochemical information is but one part of the puzzle in the investigation of regional gas dynamics, and should be integrated with geological information, lithostratigraphic-, and sequence stratigraphic information, petrographic information and geophysical data.

These results may have important implications for understanding the role of gas geochemistry in characterization of actual prospects. This allows for more accurate mapping of likely oil and gas migration pathways, which can be used for prospect risking and for the ranking of exploration plays. In addition, carbon isotope depth profiles are inexpensive and require no additional rig time for sample collection.

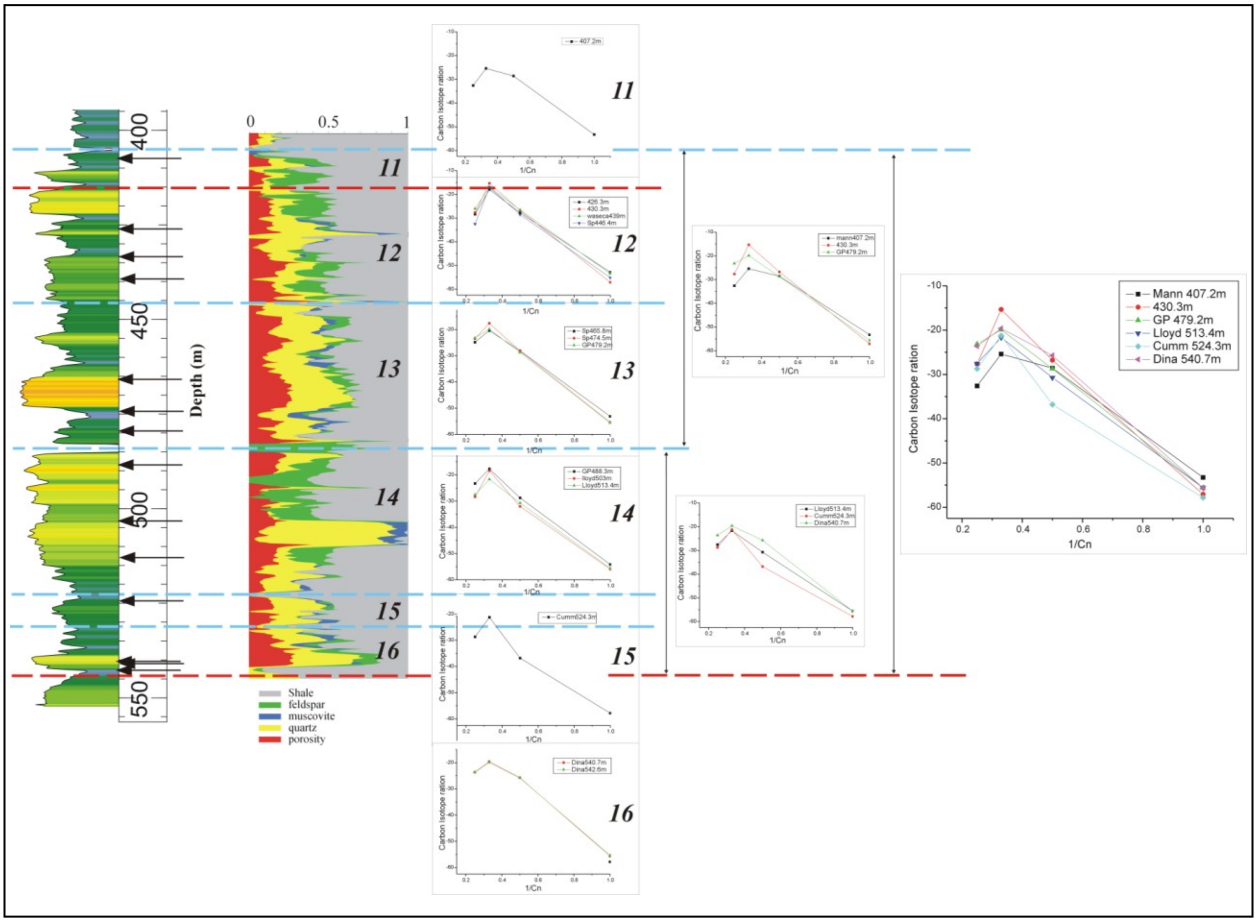

Figure 2. Intra-formational compartmentalization within the Mannville Group, Petrovera 1-25-55-5W4. Gases have similarly shaped δ13C isotopic profiles, but the isotopic differentiation between ethane, propane and butane can reach 10‰.

Acknowledgements

Financial support was provided by the Canadian Association of Petroleum Producers and NSERC. Samples were generously provided by Husky Oil Operations Ltd., Petro-Canada, and Petro Vera Resources Ltd. Bryan Szatkowski of G-Chem Environmental Ltd. at Lloydminster, Alberta, Canada is thanked for his sampling and chemical analyses. We thank Imperial Oil Resources Limited and Petro-Canada for access to their wellsites.

References

Doveton, J.H., 1986, Log analysis of subsurface geology. Concepts and computer methods: John Wiley and Sons, Inc., 273 pp.

Rowe, D., Muehlenbachs, A., 1999, Low-temperature thermal generation of hydrocarbon gases in shallow shales: Nature, 398l, 61–63.

Schoell, M., 1983, Genetic characterization of natural gases, AAPG Bull., 67, 12, 2225-2238.

Tilley, B.J., Muehlenbachs, K., 2006. Gas maturity and alteration systematics across the Western Canada Sedimentary Basin from four mud gas isotope depth profiles: Organic Geochemistry, 37, 1857–1868.

Vlad, D., 2009, Mudgas geochemistry and factors controlling their variability: University of Alberta PhD Thesis.