



An Update on the use of Pulsed Neutron Elemental Spectroscopy Measurements in Heavy Oil and Shale Gas Reservoir Evaluation

Grant D. Ferguson
Baker Hughes, Calgary, Canada
grant.ferguson@bakerhughes.com

David Jacobi, Matt Bratovich, Brian LeCompte
Baker Hughes, Houston, USA

Summary

At last years convention we presented on a new open hole logging service offering comprised of our Formation Lithology Explorersm wireline tool and the RockViewsm processing software built to convert the elemental measurements made with the FLEX tool into a robust mineralogical estimate of the formation.

This year we are now able to present our first released Canadian Shale gas examples utilizing this service as well as provide more complete core to log comparisons of the oil sand wells shown previously including Dean Stark comparisons to the Excess Carbon output from Flex and RockViewsm.

Introduction

Formation Lithology Explorersm is a new generation elemental spectroscopy tool which utilizes a pulsed neutron source and provides a measure of gamma rays emitted by the interactions with the neutrons in both the inelastic and capture energy spectra. The RockViewsm service utilizes the results from the FLEx device and Spectralog II to determine formation lithology and mineralogy. In certain types of reservoirs the amount of elemental carbon measured exceeds the amount necessary for the mineralogy of the rock itself and is presented as 'Excess Carbon'. The measurement of carbon and excess carbon along with mineralogy determination has applications for Heavy Oil and Shale Gas reservoir evaluation.

Methodology

Pulsed neutron tools have been ran in the cased hole environment for estimating hydrocarbon content in the formation since Dresser Atlas a predecessor company of Baker Atlas introduced the technology to the industry in 1963. The theory of the measurement is well known and in common use in the Industry so only a brief discussion of the theory of the measurement will be given.

The application of this technology in a wireline tool designed for use in open hole permits the use of a much larger detector to improve the count rates of the gamma rays emitted from the elements present in the formation as a result of their interaction with the neutrons with which the tool 's source bombards the formation. The energy levels of the gamma rays are characteristic of the element from whose nucleus it is emitted. In the open hole environment where the sonde is placed immediately opposite the formation and shielding is applied to the tool minimizing borehole effects this measurement is representative of the elemental weight percentages of the formation. Detailed information on the tool theory, design and processing can be found in the Pemper et al paper "A New Pulsed Neutron Sonde for Derivation of Formation Lithology and Mineralogy", SPE 102770, presented in San Antonio in 2006.

From the inelastic spectrum the new Formation Lithology Explorer (FLEX)sm is able to uniquely provide a formation weight percentage of elemental carbon (C) in the formation as well as much more robust measures of other elements such as Magnesium (Mg) than were previously available to the industry. These measures when combined with the elements that are quantifiable through the use of the capture spectra permit for a more robust estimation of the lithology and mineralogy of the formation.

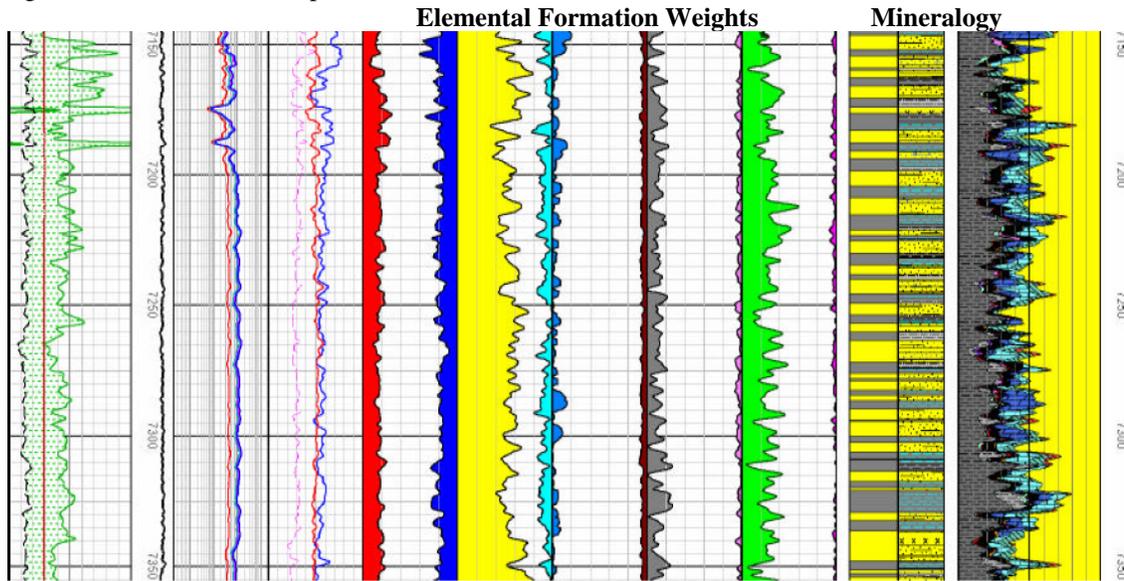
The RockViewsm interpretation system differs from previous methods in that it uses a sequential approach which systematically builds upon initial conclusions. Using the elemental weight fractions as input, the interpretation system first defines a general lithology for each record, then follows by a more detailed classification of a specific lithology. Mineralogy is then systematically determined for each record by sequentially using the measured elemental weight fractions that are available. The process obeys the principles of mineral stoichiometry. The RockViewsm expert system can be easily modified to account for unique basin or formation lithologies or mineralogy. The resulting mineralogy from RockViewsm can then be further incorporated with additional logging measurements for further petrophysical evaluation and reservoir characterization.

The elemental weight fraction of carbon is one output of the FLEXsm tool. Carbon may occur as part of the dry rock matrix or in the pores. The RockViewsm processing determines the amount of the measured carbon that is required as a component of the dry rock mineral components of each record. Any remaining carbon fraction is classified as "excess" carbon. This ability to quantify the amount of carbon and excess carbon can be used in numerous ways depending upon the operator's particular production and formation issues. To date applications that have been discussed and / or utilized are for a prediction of hydrocarbon in place in heavy oil reservoirs, an indicator of total organic carbon content (TOC) in shale gas plays and identification of bitumen plugged zones in gas plays.

Examples

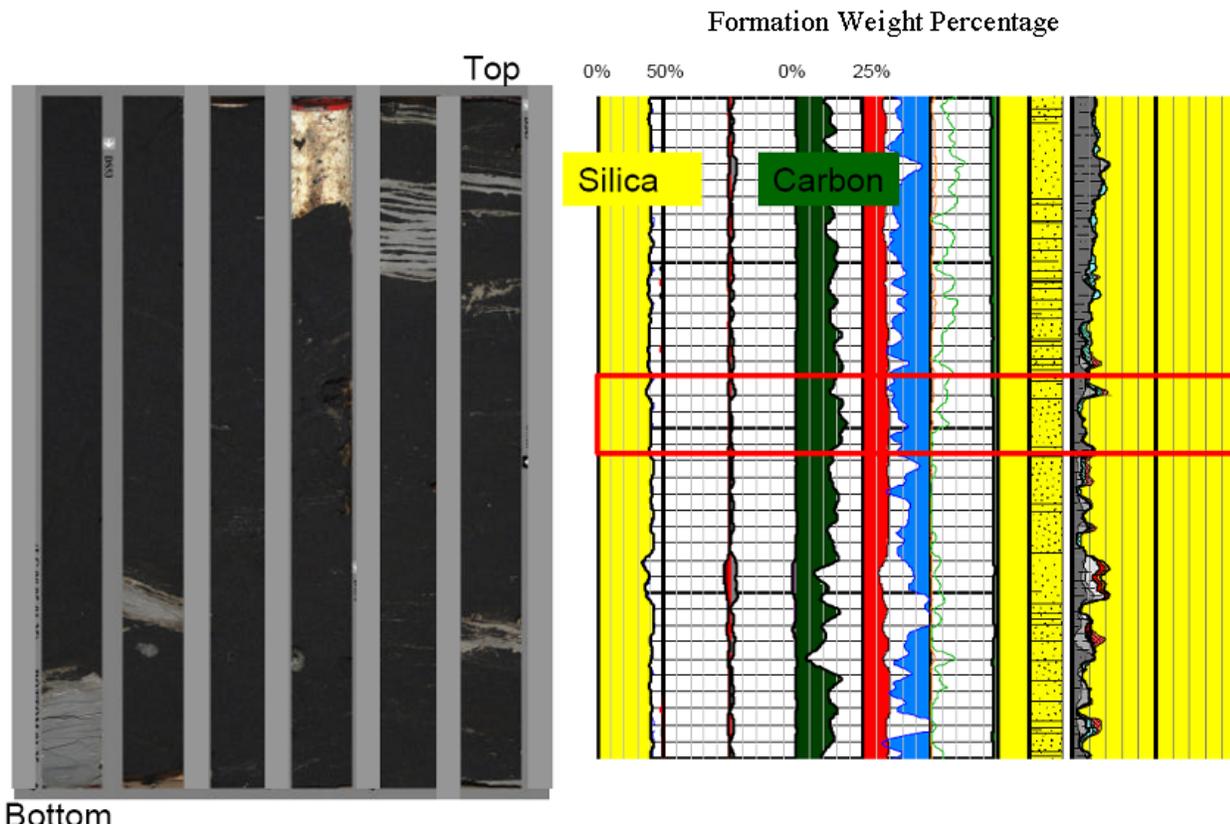
Shale Gas – US and Canada Examples (see one example below)

Figure 1 Barnett Shale Example



Oil Sand - Athabasca Tar Sand Examples (see one example below)

Figure 2 Athabasca Oil Sand Core to Flex comparison



Conclusions

The introduction of a pulsed neutron spectroscopy measurement designed for the open hole environment allows for a more comprehensive measurement of common formation elements. This additional information can be input into a new expert system interpretation software that provides a better definition of the lithology and mineralogy than has been previously available to the industry from wireline measurements.

The measure of carbon and excess carbon weight fractions gathered through the inelastic spectra coupled with the mineralogy has numerous potential formation evaluation applications.

Acknowledgements

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References

1. Pemper, R., Sommer, A., Guo, P., Jacobi, D., Longo, J., Biven, S., Rodriguez, E., Mendez, F., Han, X.: "A New Pulsed Neutron Sonde for Derivation of Formation Lithology and Mineralogy", Paper SPE 102770, Trans., SPE 81st Annual Technical Conference and Exhibition, San Antonio, Texas, 2006
2. Kenneth Barbalace <http://klbprouctions.com/>. Periodic Table of Elements - Sorted by Cross Section (Thermal Neutron Capture). EnvironmentalChemistry.com. 1995 - 2008.
3. Culver, R.B., Hopkinson, E.C., and Youmans, A.H.: "Carbon Oxygen (C/O) Logging Instrumentation," Paper SPE 4640, Trans., SPE 48th Annual Technical Conference and Exhibition Las Vegas, 1973.
4. Hertzog, R.C.: "Laboratory and Field Evaluation of an Inelastic neutron scattering and capture Gamma Ray Spectroscopy Tool." Paper SPE 7430, Trans., SPE 53rd Annual technical Conference and Exhibition, Houston, 1978.
5. Oliver, D.W., Frost, E., and Fertl, W.H.: "Continuous Carbon/Oxygen (C/O) Logging- Instrumentation, Interpretive Concepts and Field Applications," Paper TT, Trans., SPWLA 22nd Annual Logging Symposium, Mexico City, 1981.
6. Chase D.M., Schmidt, M.G., and Ducheck, M.P.: "The Multiparameter Spectroscopy Instrument Continuous Carbon/Oxygen Log – MSI C/O," Canadian Well Logging Society 10th Formation Evaluation Symposium, Calgary, 1985.
7. Hertzog, R., Colson, L., Seeman, B., O'Brien, M., Scott, H., McKeon, D., Wraight, P., Grau, J., Ellis, D., Schweitzer, J., and Herron, M.: "Geochemical Logging with Spectrometry Tools," paper SPE 16792, Trans., SPE 62nd annual technical Conference and exhibition, Dallas, 1987.
8. Ellis, Darwin V., 1987, *Well Logging for Earth Scientists*, Elsevier, New York, pp. 227-242
9. Gilchrist, W.A., Prati, E., Pemper, R., Mickael, M.W., and Trcka, D.: "Introduction of a new Through -Tubing Multifunction Pulsed Neutron Instrument" paper SPE56803, Trans., SPE 74th Annual Technical Conference and Exhibition, Houston, 1999.
10. Gilchrist, W.A., Pemper, R.R., Trcka, D., Frost, E. Jr., and Wilson, W.: "Initial Field Applications of a New 1.7-Inch Pulsed Neutron Instrument," paper FF, Trans., SPWLA 41st Annual logging Symposium, Dallas, 2000.
11. Lock, G.A. and Hoyer, W.A.: "Natural Gamma-Ray Spectral Logging," Paper AA, Trans., SPWLA 12th Annual Logging Symposium, 1971
12. Wichman, P.A., McWhirter, V. C. and Hopkinson, E. C.: "Field Results of the natural Gamma Ray Spectralog." Paper O, trans., SPWLA 16th Annual Logging Symposium, 1975
13. Pemper, Richard, Page, Geoff, and Prati, Enrique: "A New Generation Natural Gamma Ray Spectroscopy Logging System," Paper E027, Trans., 17th European Formation Evaluation Symposium, Amsterdam, 1996.
14. Sherman, Harold: "Nonfluid-Filled Borehole Logging Apparatus," U.S. Patent 3, 932,747, Schlumberger Technology Corporation, January 13, 1976.
15. Knoll, Glenn F., 1989, "Radiation Detection and Measurement", John Wiley & Sons, New York, 2nd Edition, pp 672-674.
16. Pemper, R. R., Flecker, M. J., McWhirter, V. C., and Oliver, D.W.: "Hydraulic Fracture Evaluation with Multiple Radioactive Tracers," Geophysics (oct., 1988)pp. 1323-1333
17. Hoel, P. G., Port, S. C., and Stone, C. J., 1971, "Introduction to Statistical Theory", Houghton Mifflin, pp. 121-127
18. Draper, N.F. and Smith H., 1966, "Applied Regression Analysis", John Wiley & Sons, pp. 44-85