

# Application of Pulsed Neutron Elemental Spectroscopy Measurements in Heavy Oil and Shale Gas Reservoir Evaluation

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## Introduction

A new generation elemental spectroscopy tool (Formation Lithology Explorer<sup>sm</sup>) which utilizes a pulsed neutron source permits the measure of gamma rays emitted by the interactions with the neutrons in both the inelastic and capture energy spectra. Additional elements are able to be quantified by measurement of both spectrums including Mg, Al and C. The Rockview<sup>sm</sup> 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 have applications for Heavy Oil and shale gas reservoir evaluation.

## Theory and/or 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. 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)<sup>sm</sup> is able to uniquely provide a formation weight percentage of elemental carbon (C) in the formation as well as much

more robust measures of Magnesium (Mg) and Aluminium (Al) 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 RockView<sup>sm</sup> 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 RockView<sup>sm</sup> interpretation is based solely on the measured geochemistry and does not require input from other wireline logging devices. The RockView<sup>sm</sup> expert system can be easily modified to account for unique basin or formation lithologies or mineralogy. The resulting mineralogy from RockView 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 FLEX<sup>sm</sup> tool. Carbon may occur as part of the dry rock matrix or in the pores. The RockView 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 Examples

Athabasca Tar Sand – Canada Examples

Bitumen Plugging – Canada Examples

## **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.

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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 81<sup>st</sup> 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 48<sup>th</sup> 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 53<sup>rd</sup> 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 22<sup>nd</sup> Annual Logging Symposium, Mexico City, 1981.
6. Chase D.M., Schmidt, M.G., and Duchek, M.P.: "The Multiparameter Spectroscopy Instrument Continuous Carbon/Oxygen Log – MSI C/O," Canadian Well Logging Society 10<sup>th</sup> 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 62<sup>nd</sup> 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 74<sup>th</sup> 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 41<sup>st</sup> Annual logging Symposium, Dallas, 2000.
11. Lock, G.A. and Hoyer, W.A.: "Natural Gamma-Ray Spectral Logging," Paper AA, Trans., SPWLA 12<sup>th</sup> 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 16<sup>th</sup> Annual Logging Symposium, 1975
13. Pemper, Richard, Page, Geoff, and Prati, Enrique: "A New Generation Natural Gamma Ray Spectroscopy Logging System," Paper E027, Trans., 17<sup>th</sup> 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, 2<sup>nd</sup> 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
19. Ahmed, M. R., Demidov, A. M., et al., 1978, "Atlas of Gamma-Ray Spectra from the Inelastic Scattering of Reactor Fast Neutrons", Atomizdat, Moscow
20. Lone, M.A., Leavitt, R. A., and Harrison, D. A., 1981, "Prompt Gamma Rays from Thermal-Neutron Capture," *Atomic Data and Nuclear Tables*, Volume 26, pp. 511-559.
21. Firestone, R. B., Choi, H. D., et al., 2004, "Database of Prompt Gamma Rays from Slow Neutron Capture for Elemental Analysis," Lawrence Berkeley National Laboratory.
22. Lofts, J.C., 1993, "Integrated Geochemical- Geophysical Studies of Sedimentary Reservoir Rocks," Ph.D. Dissertation University of Leicester, Department of Geology.
23. Chakrabarty, T. and Longo, J. M.: "A New Method for Mineral Quantification to aid in Hydrocarbon Exploration and Exploitation," *The Journal of Canadian Petroleum technology* (Dec. 1997), Volume 36, pp. 15-20
24. Moore, B. R. and Dennen, W. H.: "A Geochemical Trend in Silicon-Aluminum-Iron Ratios and the Classification of Clastic Sediments," *Journal of sedimentary Petrology* (1970), Volume 40, pp. 1147-1152
25. Wendlandt, R. F. and Bhuyan, K.: "Estimation of Mineralogy and Lithology from Geochemical Log Measurements," *The American Association of Petroleum Geologists Bulletin* (June, 1990), Volume 74, pp. 837-856.
26. Rollinson, H. R., 1993, "Using Geochemical Data: Evaluation, presentation, Interpretation," Addison Wesley Longman, Essex, England.
27. Weaver, C. E. and Pollard, L. D. < 1973, "The Chemistry of Clay Minerals," Elsevier, Amsterdam.
28. Bhatia, M.: "Plate Tectonics and Geochemical Composition of Sandstones," *Journal of Geology* (1983), Volume 91, pp. 611-627

29. Gromet, P.L., Dymek, R.F., Haskin, L. A., and Korotev, R. L.: "The North American Shale Composite: Its Composition, major and Trace Element Characteristics," *Geochimica et Cosmochimica Acta* (1984) , Volume 48, pp. 2469-2482.
30. Land, L.S., Milliken, K. L., and McBride, E. P.: "Diagenetic Evolution of Cenozoic Sandstones, Gulf of Mexico Sedimentary Basin," *Sedimentary geology* (1987), Volume 50, pp. 195-225
31. Land, L.S., Milliken, K. L., and Lynch, F. L.: "Burial Diagenesis of Argillaceous Sediment, South Texas Gulf of Mexico Sedimentary Basin: A Reexamination," *G.S.A. Bulletin* (1997), Volume 109, pp. 2-15
32. Armstrong-Altrin, J.S., Lee, Y. I., Surendra V. P., and Ramasamy, S.: "Geochemistry of sandstones from the Upper Miocene Kudankulam formation in Southern India: Implications for Provenance, Weathering, and Tectonic Setting," *Journal of Sedimentary Research* (2004), Volume 74, pp. 285-297