UNCONVENTIONAL RESOURCES TECHNOLOGY CONFERENCE
FUELED BY SPE • AAPG • SEG

URTeC Control ID Number: 1579996

Forensic Chemostratigraphy in Geosteering Multilateral Wells: An example from Devonian to Carboniferous-aged sequences in Southern Alberta

Heather Stilwell[1*], Nahysa Martinez[1], Gemma Hildred[1], Brian Zaitlin[2]
1. Chemostrat, Houston, TX, United States.
2. Native American Resource Partners, Calgary, AB, Canada.

Summary

The results presented in this study test the efficacy of using whole-rock elemental data to characterize the stratigraphy penetrated when drilling lateral wells and use this information along with comparisons to a vertical offset well to stay in zone. This approach is tested in the Alberta Bakken Petroleum System (ABPS) in Southwestern Alberta, Canada, focusing on the Banff, Exshaw, Big Valley, and Stettler formations (Hildred et al 2013, Zaitlin 2013). Data and interpretations are presented from vertical well 11-35 and its associated lateral, which were drilled along the flank of a seismically defined anticlinal structure, making geosteering using wireline data difficult.

The target zone within the Big Valley Formation comprises a ~5m thick dolomite interval underlain by anhydrite and overlain by limestone. The dolomitic interval is geochemically identified by high MgO/CaO, Th/Al_2O_3 and MnO values, all of which decrease in the underlying anhydrite. It is differentiated from the overlying limestone cap by lower CaO values. Using the chemostratigraphic type section devised from the vertical offset well, it is possible to identify all of the previously defined stratigraphic units. Due to the sinuosity of the wellbore and probable faulting, some units are encountered several times along the well path; chemostratigraphic analysis has the ability to independently define the target zone when encountered.

The application of chemostratigraphy outlined in this study is relevant to many other scenarios where lateral well placement is critical. Beyond the stratigraphic use of geochemical data, it is also possible to derive the relative brittleness of the target zones in order to better identify zones for completion and the placement of frac stages, thereby making exploitation of resource plays more cost effective.

Introduction

The Alberta Bakken Petroleum System (ABPS) is one of the latest play areas being evaluated in the quest to capture early entry, contingent, light tight oil (LTO) resources. The structural fabric of the Williston Basin and the foreland basin of southern Alberta and Northern Montana is dominated by the presence of large scale divergent wrench fault systems that were initiated at early Proterozoic time and continue to be active throughout the tectonic history of these basins. These structures are characterized by the presence of several pull-apart basins that acted as the focal point for the deposition of thick sections of the Bakken/Three Forks and Exshaw/Big Valley packages. These unique structural features form the prime location for the exploitation of these emerging resource plays. The main basinal difference is that the ABPS is part of a thermocline stratified ramp whereas the Williston Basin is part of low energy interior basin setting.

The ABPS comprises, from base to top, a 0–50m thick mixed carbonate and clastic interval of Devonian and Mississippian Stettler/Big Valley – Exshaw – Banff Formations (Figure 1). The ABPS is a proven play based on production and is characterized by: pervasive petroleum saturation, abnormal pressure (high, lack of down dip

water), low permeability, low matrix porosity reservoir, and is self-sourcing. The play can be divided into a continuous resource play in the deeper part of the trend and as a conventional migrated oil play at shallower depths, similar to the Williston Basin.

The Deep Basin or basin-centered ABPS is characterized by a continuous accumulation of hydrocarbons found in the Basal Banff limestone, Exshaw (Middle Bakken) siltstone to silty dolomitic unit or overlying Big Valley (Lodgepole). The analog to this play is the North Dakota Bakken and Three Forks/ Sanish play. The Shallow Exshaw (Bakken) conventional play shows local accumulations of oil either stratigraphically or structurally trapped in porous Banff limestone, Exshaw siltstone or Big Valley limestone. This zone is expected to be normally pressured, but above-average dolomitization and/or porosity development or fracturing could lead to high-rate wells. The analog to this play is Saskatchewan's Viewfield Bakken area.

Inorganic whole rock geochemical data has been used to define stratigraphic correlations in the petroleum industry for over a decade (Ratcliffe et al. 2010 and references cited therein). The stratigraphic technique of chemostratigraphy is based on the recognition of variations in elemental concentrations through time and the use of those to model changes with respect to geological events, such as changing lithology, paleoclimate (Pearce et al. 2005, Ratcliffe et al. 2010) and provenance (Ratcliffe et al. 2007, Wright et al. 2010). Published datasets using this methodology are largely on fluvial or shallow marine sequences successions, where only vertical wells are considered (e.g. Pearce et al. 2005, Ratcliffe et al. 2006, Ratcliffe et al. 2010, Wright et al. 2010, Hildred et al. 2010).

In this study, chemostratigraphic techniques are applied to the lithologically variable sequences of the Alberta Bakken Petroleum System (ABPS) in Southern Alberta to test if this methodology can be reliably used to help characterize lateral wells and relate the intervals encountered to a vertical type section.

Methodology

Fifty-seven core samples were selected at an average of 1m spacing (with samples taken at a higher resolution of every 20cm through the Lower and Upper Exshaw members) from the vertical section of well 11-35, which penetrated the Banff, Exshaw, Big Valley, and Stettler formations. Additionally, 109 cutting samples were selected at 10m intervals along the length of the 11-35 lateral. In total, 166 samples were subjected to whole rock geochemical analysis using ICP/MS-OES (Inductively-coupled Plasma with Mass Spectroscopy-Optical Emission Spectroscopy) techniques via a Li-metaborate fusion procedure (Jarvis and Jarvis 1995). Data is subsequently provided for 10 major elements, 26 trace elements and 14 rare earth elements. Precision error for the major element data is greater than 2%, and is near 3% for high abundance trace-element data derived by ICP-OES (Ba, Cr, Sc, Sr, Zn and Zr) techniques. The remaining trace and rare earth elements are determined from the ICP-MS analyses, with precision error in the order of 5%.

Chemostratigraphic differentiation of the Stettler, Big Valley Dolomite, Big Valley Limestone, Exshaw and Banff Formations in a vertical pilot well

In order to be able to provide a useful characterization within a lateral well, it is important to be able to relate its chemostratigraphic features back to a vertical type section. In this study, core samples analyzed from the vertical portion of well 11-35 are used to define a chemical type section that relates the chemical characterization to the lithostratigraphic units within the vertical part of the study interval (Figure 1). Using variations in a series of key elements and elemental ratios, it is possible to subdivide the study interval into 10 unique chemostratigraphic "Packages" (Figure 1) which are defined using the following criteria:

Stettler Formation – Samples from the Stettler Formation are anhydrite-rich and are all assigned to P1 (Package 1). P1 is characterized by lower MnO values than all overlying packages and lower MgO/CaO values than overlying P2 (Package 2).

Big Valley Formation – The Big Valley Formation is comprised of a lower dolomite member and an upper limestone member. P2 represents the dolomite member and is characterized by generally higher MgO values than all other samples in the study interval as well as higher MgO/CaO values than P1 and P3 (Package 3). P3 is the limestone member and is characterized by higher CaO values and lower MgO/CaO values than P2.

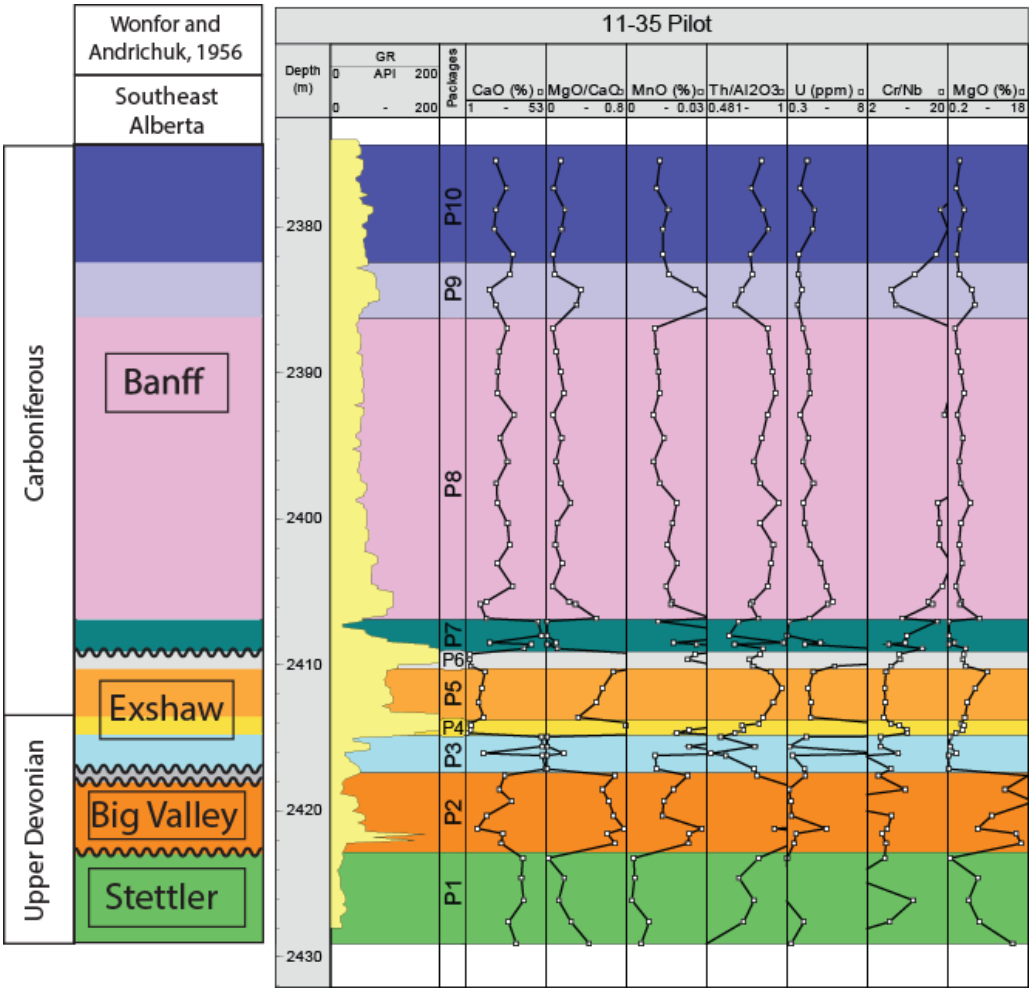

Figure 1. Characterization of the 11-35 vertical pilot well using whole-rock element data relative the stratigraphic formations defined within these sequences. Individual sample points are represented by gray squares. (Modified from Hildred et al. 2013).

Exshaw Formation – Samples from the Exshaw Formation are subdivided into three packages (P4, P5 and P6). Both P4 (Package 4) and P6 (Package 6) are organic-rich shales and are characterized by high U values compared to the other samples in the study interval. Differentiation between P4 and P6 is more subtle, however; P4 has marginally lower Th/Al_2O_3 values than P6. P5 (Package 5) is defined between P4 and P6, with this interval being characterized by lower U and higher CaO values than P4 and P6, and generally higher MnO values than the over and underlying packages.

Banff Formation – Samples from the Banff Formation are subdivided into four packages (P7, P8, P9 and P10). P7 is a carbonate-rich sequence and is characterized by higher CaO values than overlying packages. Although superficially P3 and P7 may appear similar, as they are both carbonates, P7 is clearly differentiated from P3 by higher Cr/Nb values. P8 and P10 are both characterized by very high Cr/Nb values compared to other packages, with P9 being defined by higher MnO and lower Cr/Nb values than P8 and P10.

Within the study's parameters, the target zone of the Big Valley Formation varies in thickness from 5m to 20m thick. Based on the characterizations detailed previously and illustrated on Figure 1, the P2 interval can be readily identified and differentiated from over and underlying packages.

Tying the chemostratigraphic characterization from a vertical to a lateral well

The lateral well bore from well 11-35 has been drilled along the flank of a seismically defined anticlinal structure that may contain small-scale faulting. Using the chemostratigraphic type section derived from the vertical core study (Figure 1), it is possible to identify previously defined stratigraphic units as they are penetrated along the

length of the lateral. This characterization is shown in Figure 2. Due to the sinuosity of the wellbore and probable faulting, some units are encountered several times along the well path (Figure 2). Additionally along the build section of this lateral at approximately 2500 m MD, a normal fault is interpreted to be present based on the geochemical interpretation.

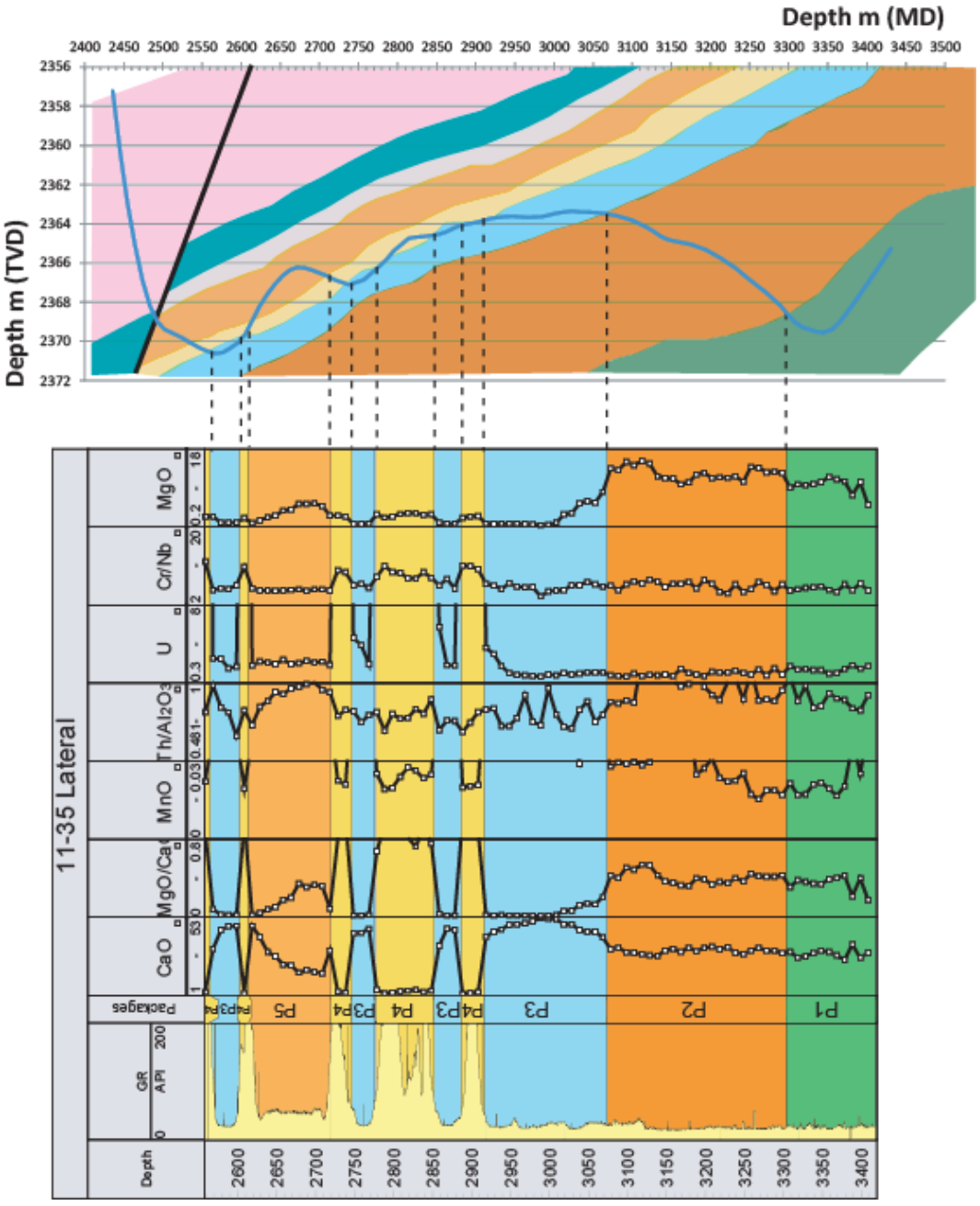

Figure 2. Characterization of the 11-35 lateral penetration using whole-rock elemental data plotted relative to the well path and schematic stratigraphic interpretation. Individual sample points are represented by white squares, the well path is represented by a blue line and dashed black lines tie the chemostratigraphic characterization based on the chemical changes to the well path. Faults are interpreted based on chemostratigraphic interpretations and are shown as solid black lines along the well path. The elements, elemental ratios and scale bars are the same as those shown in Figure 1. Sample depth positions are plotted in meters and measured depth. (Modified from Hildred et al. 2013)

On Figure 2, data are plotted from the deepest true vertical depth to total depth (TD). As the well path starts to climb back up, stratigraphically the elemental data suggests that P3 and P4 are repeatedly penetrated until a depth of 3075 m MD is reached. Geochemically, this alternation of P3 and P4 is expressed as sharp changes from the high CaO, low U carbonate of P3, to the low CaO, high U organic-rich shale of P4. The only interruption to this repetitive sequence is between 2615m MD and 2715m MD, where P5 is interpreted to be present due to its characteristically high Th/Al_2O_3 values. After 3075m MD, the geochemical signature changes to reflect a more dolomitic composition, with high MgO and MgO/CaO values recorded. The interval between 3075m MD and 3300m MD is interpreted to be P2 (Big Valley Fm.), which is the target zone for this well. After 3300m MD MgO values drop, indicating that the well bore has penetrated P1, where it remains until TD.

In order to match both the elemental data and the well path information in this lateral it becomes clear that the strata must dip in a pervasively southward direction.

Modeling mineralogy from elemental data

Once the chemostratigraphic characterization of the vertical 11-35 pilot well was completed, 43 samples that were previously analyzed for their mineralogical composition using XRD (X-ray Diffraction) analyses were selectively high-graded in order to properly represent each chemostratigraphic package and comprehensively calibrate the geochemical data to the mineralogical profile for each section (Figure 3a).

An important aspect to understanding these study intervals is appreciating the lithological changes that occur over a relatively thin stratigraphic interval (e.g. moving from anhydrite to dolomite to carbonate over a 10m vertical thickness). Interpretations presented in Figures 1 and 2 are based on elemental data alone; however, in order to confidently relate changes in elemental composition to changes in geology and existing stratigraphic assignments in this area, the mineralogy must also be considered. Based on the comparative logs shown on Figure 3, the following interpretation can be made:

- CaO wt% = a proxy for the carbonate content
- Na_2O wt % = a proxy for the plagioclase content
- K_2O wt % = a proxy for K-feldspar and clay content
- Al_2O_3 wt % = a proxy for clay content in general
- MgO wt % = a proxy for dolomite content
- Fe_2O_3 wt % = a proxy for pyrite content

Another way to look at the relationship between geochemistry and mineralogy is to use publicly-available software packages that automatically calculate mineralogy from geochemistry (ModAn, Sednorm and Minlith) (Paktunc, 2010, Rosen et al., 2004). Figure 3b displays a comparison of directly measured mineralogy obtained by XRD analyses and calculated mineralogy using Minlith software. This dataset clearly shows that for most key minerals, the calculated mineralogy closely matches the directly measured mineralogy. This method provides a good indication of bulk mineralogy and is derived from the same dataset that has been obtained primarily for stratigraphic correlations. Once mineralogical data is available, it is then possible to use that data to model a range of rock properties, including a relative brittleness value.

Conclusions

In this study, it has been demonstrated that chemostratigraphy can be successfully used to characterize a vertical pilot well, which can in turn be used as a “type section” to understand and interpret which stratigraphic interval a related lateral has penetrated. This approach is especially useful where gamma signatures are not diagnostic and where cutting samples from different units appear visually similar.

Furthermore, it is also possible to use elemental data to model the mineralogy within this dataset, which allows a relative brittleness model to be produced for the study wells. The application of chemostratigraphy as demonstrated in this study is readily transferable to other plays where lateral well placement is important both during drilling and post-drill for completions.

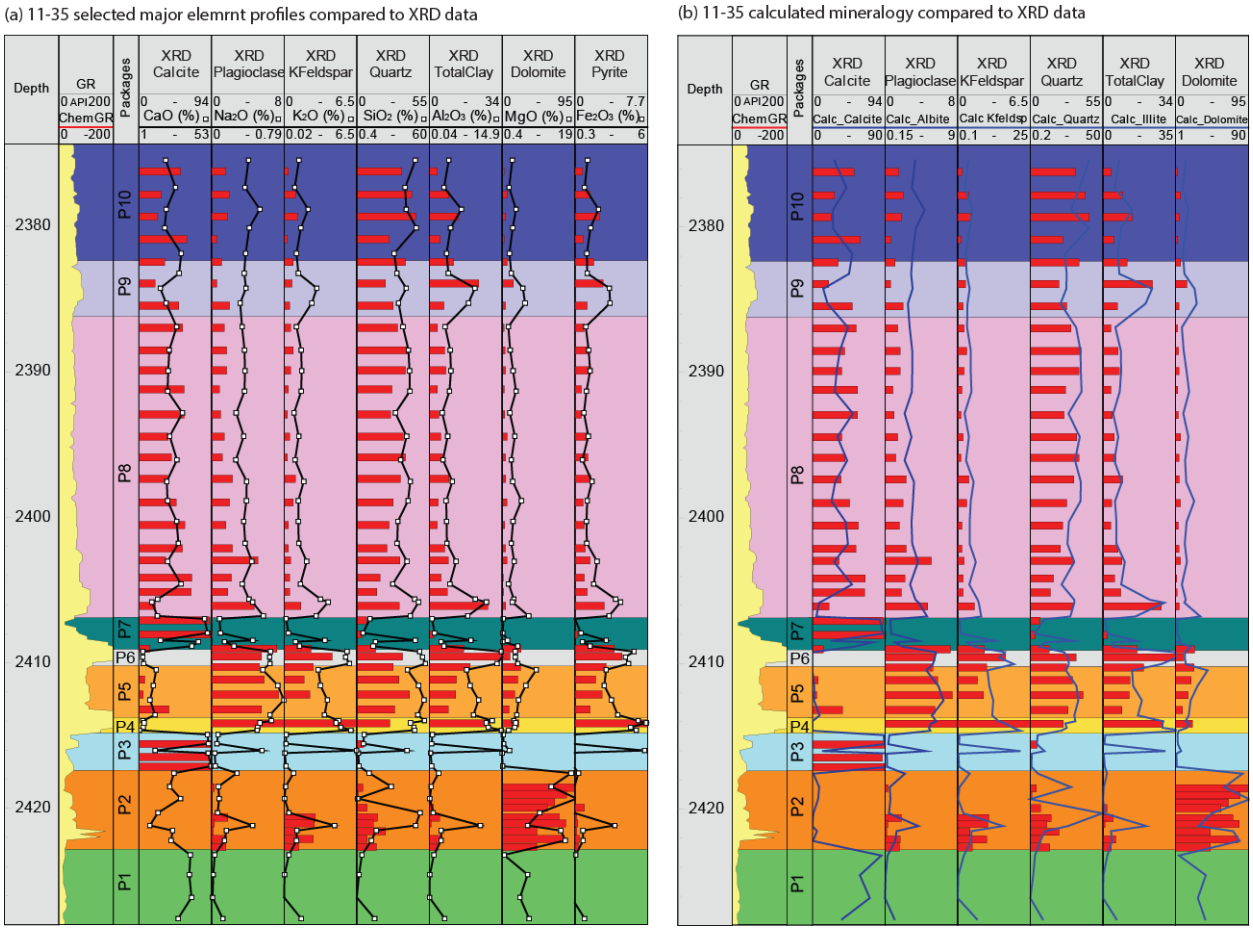

Figure 3. (a) Shows the comparison between measured XRD data and selected elemental data for vertical well 11-35 (b) Shows XRD data compared to mineralogy calculated from elemental data for vertical well 11-35. XRD data are represented as red bars, elemental data are shown as gray squares and calculated mineralogy is shown as a blue log relative to depth. (Modified from Hildred et al. 2013)

Acknowledgments

The authors would like to thank Kainai Energy, Native American Resource Partners and Chemostrat, Inc. (in particular, Milly Wright) for permission to release this paper, in addition to the Kainai Technical Team (Scott Lovett, Christine Robertson, Garry McCarroll, Karen Brawley-Rodgers, Grazina Palmer, Tim Bird, Odette Abaco and Elin Holvik).

References

Hildred, G.V., Martinez-Kulikowski, N., and Zaitlin, B.A., 2013, Forensic chemostratigraphy: a tool to determine lateral well bore placement, 2013 CSPG GeoConvention.

Hildred, G.V., Ratcliffe, K.T., Wright, A.M., Zaitlin, B.A., and Wray, D.S., 2010. Chemostratigraphic applications to low-accommodation fluvial incised-valley settings; an example from the Lower Mannville Formation of Alberta, Canada. Journal of Sedimentary Research, v. 80, p. 1032-1045.

Jarvis, I. and Jarvis, K.E. 1995. Plasma spectrometry in earth sciences: techniques, applications and future trends, in Jarvis, I., and Jarvis, K.E., *eds.*, Plasma Spectrometry in Earth Sciences: Chemical Geology, v. 95, p. 1–33.

Paktunc, A.D. 2001. MODAN; a computer program for estimating mineral quantities based on bulk composition; Windows version. Computers & Geosciences, Vol. 27, Issue 7, pp. 883-886

Pearce, T.J., Wray, D.S., Ratcliffe, K.T., Wright, D.K. and Moscarello, A. 2005a. Chemostratigraphy of the Upper Carboniferous Schooner Formation, southern North Sea. In: Carboniferous hydrocarbon geology: the southern North Sea and surrounding onshore areas. In: Collinson, J.D., Evans, D.J., Holliday, D.W. and Jones N.S. (eds) Yorkshire Geological Society, Occasional Publications series, 7, 147–64.

Ratcliffe, K.T., Hughes, A.D., Lawton, D.E., Wray, D.S., Bessa, F., Pearce, T.J. and Martin. J. 2006 A regional chemostratigraphically-defined correlation framework for the late Triassic TAG-I in Blocks 402 and 405a, Algeria. Petroleum Geoscience, 12, 3–12.

Ratcliffe, K.T., Morton, A., Ritcey, D. and Evenchick, C.E. 2007. Whole rock geochemistry and heavy mineral analysis as exploration tools in the Bowser and Sustut Basins, British Colombia, Canada. Journal of Canadian Petroleum Geology, 55, 320–37.

Ratcliffe, K.T., Wright, A.M., Montgomery, P. Palfrey, A. Vonk, A. Vermeulen, J. and Barrett, M. 2010. Application of chemostratigraphy to the Mungaroo Formation, the Gorgon Field, offshore Northwest Australia. APPEA Journal 2010 50th Anniversary Issue p. 371 – 385.

Rosen, O.M., Abbyasov, A.A.; Tipper, J.C. 2004. MINLITH; an experience-based algorithm for estimating the likely mineralogical compositions of sedimentary rocks from bulk chemical analyses. Computers & Geosciences, Vol. 30, Issue 6, pp. 647-661

Wonfor, J.S. and Andrichuk, J.M. 1956. The Wabamun Group in the Stettler area, Alberta. Journal of the Alberta Society of Petroleum Geologists, v. 4, no. 5, p. 99-111.

Wright, A.M., Ratcliffe, K.T., Zaitlin, B.A. and Wray, D.S. 2010. The application of chemostratigraphic techniques to distinguish compound incised valleys in low-accommodation incised-valley systems in a foreland-basin setting: an example from the Lower Cretaceous Mannville Group and Basal Colorado Sandstone (Colorado Group), Western Canadian Sedimentary Basin. In: Ratcliffe, K.T. and Zaitlin B.A. (eds) Application of Modern Stratigraphic Techniques: Theory and Case Histories SEPM SP PUB no 94

Zaitlin, B.A., 2013, An emerging Unconventional Hybrid Light tight Oil Play within the Southern Alberta Bakken – Exshaw Petroleum System ,2013 Williston Basin Conference