Utilizing Seismic attributes and the Microseismic response to characterize a region of the Horn River Basin

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Summary

We present a case study of the integration of microseismic event detection with the 3D seismic volumes of most positive curvature, p wave acoustic impedance, and brittleness index. This case study focuses on two horizontal wells located in the Horn River Basin, BC which were hydraulically fractured in a multi-stage slickwater treatment to target the Muskwa and Evie shale formations. Microseismic event clouds displayed a variety of growth patters, despite similar treatment parameters. The curvature volume shows considerable variation for both target formations with high value ligaments interacting wellbore paths as well as running parallel. This suggest small scale faulting which could explain the downward growth and stunted lateral growth exhibited by some stages. The P impedance suggests geological discrepancies surrounding the wells and it appears that the MS events are unable to transition between different impedance zones, resulting in another constraint on the clouds. Brittleness values show that both wells were drilled into brittle regions in their respective formation and the BRI seems to correlate to the drilling logs which indicate variable values of clay content.

Introduction

Unconventional hydrocarbon plays continue to increase in importance to fill the energy needs of North America. This is mostly due to the technological advances of horizontal drilling and multi-stage hydraulic fracturing treatments. These techniques allow for greater well-bore contact with the formation and can create economical flow rates from reservoirs traditionally overlooked due to low porosity, such as the shale formations in the Horn River Basin in NE, BC. Covering nearly 1.1 million hectares of land in North-east British Columbia, the basin is expected to become a large player in the Canadian natural gas mix with the BC Oil \& Gas commission estimating that the HRB contains 22% of the remaining gas reserves in the province, or 11.3 Tcf [BC Oil & Gas Commission, 2014]. A case is made of two wildcat wells partially treated with a non-standard fracking technique, short interval re-injections, located in the HRB. Both a 3D seismic volume and the resulting microseismic event clouds were collected which can be used as a proxy to understand how a hydraulic fracturing treatment is stimulating a reservoir [Warpinski, 2009] The MS event clouds for the two wells reveal the high potential for reservoir heterogeneity as there was considerable variation in event count, azimuthal growth directions which typically deviated from the expected values; and length, width, and height of growth even with very similar treatment parameters. It is necessary to utilize the seismic volume in order to better understand how the heterogeneous aspects of the formations affected completions, and therefore production, in addition to the variation that the SIR treatment brought. For SIR treatments, a short shut-in period on the order of hours is completed and followed by a re-injection into the same area [Inamdar et al., 2010].Post stack seismic attributes, such as curvature, can be used to visually enhance small scale reservoir heterogeneity that could affect the completion of planned wells. Discrepancies in the p-wave impedance derived from post-stack inversions can also suggest a geological transition and finally the elastic parameters of the formation can be derived though pre-stack seismic inversion to determine the reservoirs brittleness which can highlight areas that are more `frack-able'. By integrating these techniques, it is possible to interpret the current state of the reservoir, which will allow for a better optimized placement of any future wells.

Background

The 3D seismic volume used for case study shows pre-development conditions of the area as it was completed before the wells were drilled. A velocity model was created from the sonic logs from the four wells in the case study which was assumed to be valid for the entire seismic volume. Unfortunately, there are no additional well ties within the seismic volume and very few in the general area. There are four wells in the data set, two horizontally drilled gas wells and their corresponding monitor wells; the wells will be known as Well A, Monitor A, Well C, and Monitor C and are located in separate fields, several kilometres apart. Well C targeted the Muskwa formation with a 9 stage perf and plug slickwater HF treatment, with the exception of the first stage at the toe of the well which was through a hydraulic port. Across all the stages, 3219 events were detected and located but only seven MS events were recorded for stage 1. As such, stage 1 has been removed from all interpretations past this point. Stage 3, 5, and 8 were treated with the SIR technique and stage 6 also has events from an acid treatment included. Well A is a three stage perf and plug slick water HF of a horizontal well intended to stimulate the Evie formation. 6190 events were located and detected with the bulk of the events being attributed to the SIR treatment of stage 3.

The case study focuses on two separate members of the Devonian aged Horn River Group shales on the Western edge of the Horn River Basin (HRB). The basin is delineated by the Bovie fault zone to the west, the coeval Keg River and Slave point formation reef carbonates in the East and South, and by the provincial boundary to the Northwest Territories to the North. The Horn River Group thickness increased westward towards the Bovie fault zone with a range of 30 to 240m for all the members with a total organic content of 1-5% and a porosity of 3-6%. The Muskwa is a black bituminous shale which is characterized by a high radioactivity on well logs. The Evie formation, which is a fissile black bituminous pyritic shale, can also can be distinguished on well logs by high levels of gamma radiation. The Evie shale is thought to have been deposited during two large-scale transgression-regression cycles of the Western Interior Seaway while the Muskwa shale is understood to be a record of an abrupt sea level rise or transgression across the Western Canadian Sedimentary Basin with reefal restraints [Gray and Kassube, 1963].

Seismic attributes consist of a subset of seismic information which is focused on to allow for interpretation [Chopra and Marfurt, 2007]. While there is a host of different attributes available, the focus will be on curvature, *K*. *K* is the rate of change of the dip and azimuth and quantifies the degree to which the quadratic surface that best describes the area in question deviates from a planar geometry [Barnes, 2016]. While technically not a fundamental *K* [Rich, 2008] most positive *K* is used in geophysical interpretation due to its inferred relationship to fractures. It is thought that brittle rock structures are more likely to fracture in areas of folding, which can be seen in positive *K* maps as both anticlines and the up-thrown side of faults [Barnes, 2016].

Inversion problems are the process of determining the initial condition from the results, and in geophysics this typically is the determination of the geological setting from the resulting seismic wave reflections. All inversion models suffer from uniqueness issues, and addition data is required to constrain the solution and increase the success of the interpretation [Russel, 1988]. With post stack seismic inversion it is possible to determine the P-wave impedance, Z_p. This can allow for the identification of geological changes that relate to a changing P-wave velocity or density. Pre-stack seismic inversion can take the interpretation one step farther by looking at individual traces instead of an aggregate for a specific subsurface location. It can be used to estimate the elastic parameters of Young's Modulus, E, and Possion Ratio, PR, [Yin et al.,2015] which are the ratio of stress to stain and the negative ratio between transverse and longitudinal strains respectively. These geomechanical properties are of great concern to HF stimulation plans as they can highlight brittle sections. These brittle areas can dictate the direction of fracture growth as shown by the MS cloud, regardless of the well perforation placements, into areas interpreted as being brittle [Perez and Marfurt, 2013]. Rocks with a higher E and a lower PR are considered to be brittle.

Examples

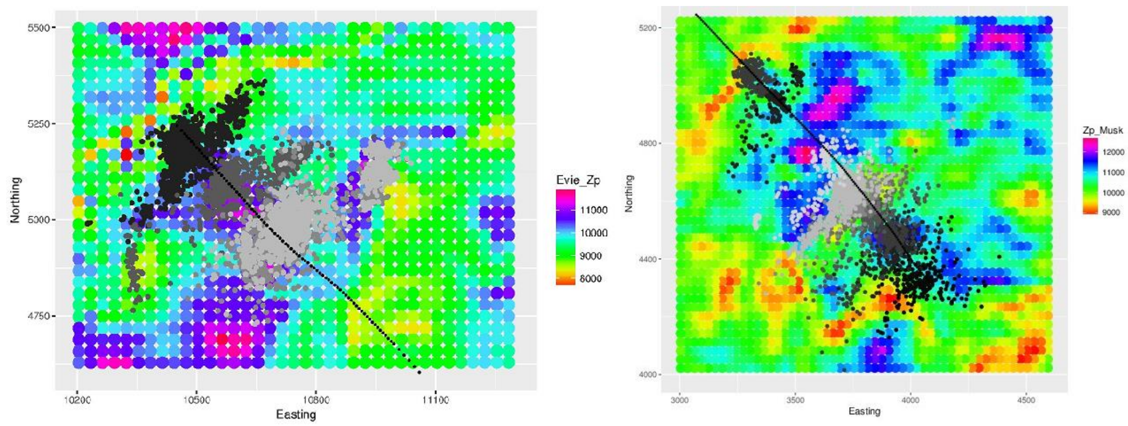

Figure1: Overview of the p wave impedance of the two different formations with the Evie and Well A on the left and the Muskwa targeted by Well C to the right and the respective MS events for the well shown.

With respect to Well C, several observations become clear by looking at the P impedance within the Muskwa layer, which shows are large variability suggesting geological heterogeneity. MS event cloud growth appears to be dictated by impedance zones with the highest event counts of 474 and 602 being from stages 5b and 6b respectively. They are both located in the mid to low range zone sandwiched between two high Z_p zones that cut across the well-bore. It also appears that MS events are preferentially growing into this midrange impedance zone. This can be seen in several stages including the asymmetrical growth of stage 2 and 5b to favour the LHS and away from the cooler colours, how the events of 6b appear to near perfectly follow the impedance transition as well as exhibit preferential growth to the LHS, and the MS events for stage 5a where the transition into cooler colours appears to also be prohibitive. Stage 3 is the only stage where the perforation was in a high Z_p zone and both the first and second stage of the SIR treatment had limited linear growth, with their event clouds bearing a more circular shape. Both stages 8a and 8b exhibited small lateral growth and are also located in a mid to high range of impedance. Unfortunately, the second section of the well bore that has the largest impedance values cross cutting it was avoided for unrelated reasons, limiting the interpretation. Stage 9 is uniquely located in the hot coloured low impedance, but this also appears to limit growth. This can somewhat be also seen in how stage 2 failed to grow significantly to the LHS. The region of the Evie that was completed with Well A is mostly located in a higher impedance trend, with the exception being the first stage which is the only stage that exhibits similar growth in either direction. The majority of the events for stage 2, 3a, and 3b are confined to higher zones with the exception of the isolated cluster from stage 2 to the NW corner. It is worth noting that a majority of the events for all 4 stages are in round clusters, with the exceptions of the isolated clusters that form secondary regions. This appears to reinforce the difficulty of the MS events to transcend an impedance transition.

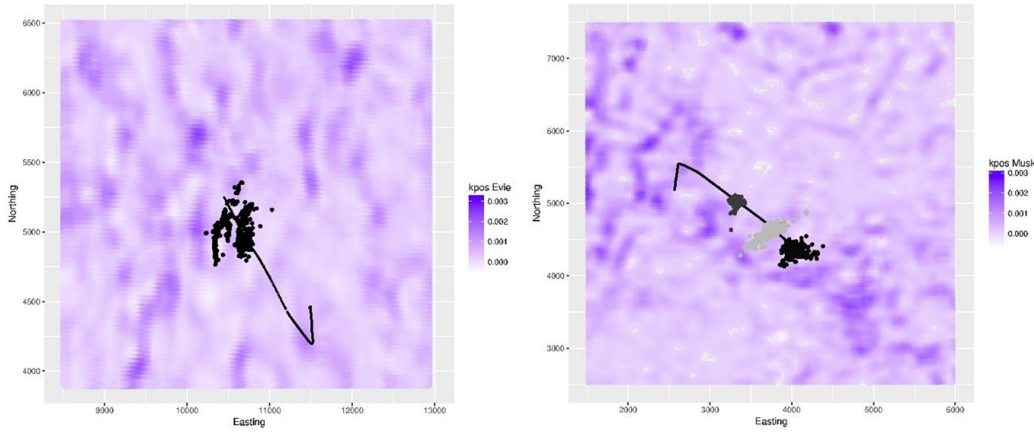

Figure2: The positive curvature of the Evie formation near Well A with only deep MS events shown to the LHS. To the right, the positive curvature of the Muskwa formation with the the MS events for stages 2, 6a, 6b, and 9 of Well C are overlaid for reference

Both formations have clear *K* variations throughour the volume and around the wells. Focusing in on the C wells and the Muskwa formation, there is a distinct high positive *K* trend that runs parallel to the horizontal tajectory of the well bore which eventually would have crossed the well path if it had been drilled longer. This trend is directly perpendicular to the ideal lateral growth of fracture stages, and few events seems to transcend across this feature. The events of stage 2, both of the injection cycles of stage 6, and the 9^{th} stage are used to highlight this. The trends seen in the Evie formation near Well A appear to run parallel to the Bovie fault, as the general trend of NE-SW oriented high positive *K* values. These linear *K* trends cut across the bore path of Well A which could account for the high amount of downward growth for both stage 2, 3a, and 3b from Well A. There was almost 700 MS events at a depth greater than 100m below the target depth and these events also appear to follow strikingly similar linear trends to the positive *K*. As the feature is perpendicular to the well-bore, it follows the predicted MS growth for the region.

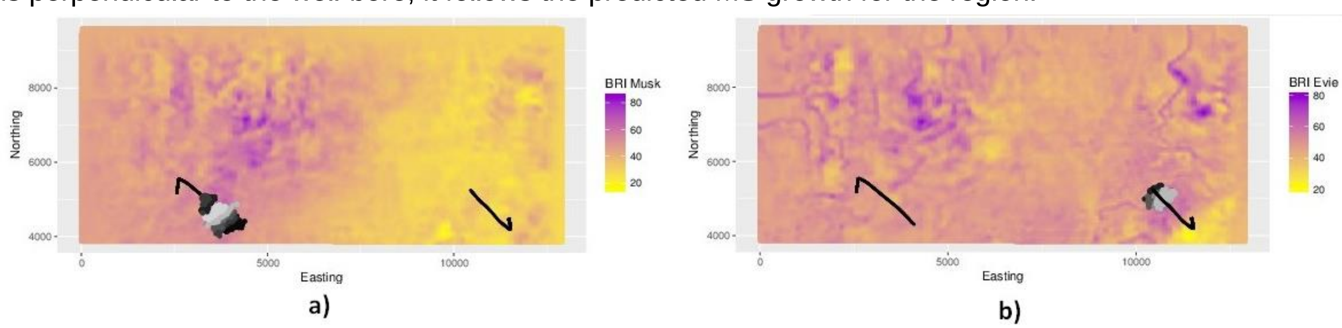

Figure3: Overview of the brittleness of the two different formations with the Muskwa on the left (a) and the Evie to the right (b) and the respective MS events for the well shown in the correct formation. The second wells are added for reference.

In general terms, both Well C and Well A were drilled in brittle areas for their respective formations, as purple colours indicate a more brittle rock fabric. However, well C's completions skip the most brittle area between stage 7 and 8 as noted earlier. Well A, however, seems to be ideally placed to take advantage of highly brittle areas, albeit with very few stages. While both the toe and the heel are located in less brittle regions, the bulk of the well-bore transcends a highly brittle area. Both formations show a wide variance in the computed brittleness index which correlates well to the drill logs which stated a changing clay content over the horizontals. This is best validated with the two zones Well A appears to be in as the logs stated an increasing clay content from toe to heel resulting in a more ductile and less brittle regime.

Conclusions

All three aspects considered show a high variability over both the scale of the entire volume and the regions surrounding the well bores which could be factors into the discrepancies in MS event cloud growth and distribution. A transition in Z_p as well as high values of positive curvature appears to be a hindrance to bi-wing fracture growth that is classically expected and they therefore limit the contact that the generated fractures have with the formation. This would likely result in lower production from these stages. It appears that ideal stages for future wells in this section would be wise to be placed in regions with a moderate impedance gradient and little curvature perpendicular to desired growth. With respect to brittleness, the Muskwa should only be targeted on the LHS of the volume while the Evie is, in general, brittle over the whole section displayed with the exception of the SE corner.

Acknowledgements

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