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Target Zone Identifier (TZI): An Integrated Approach To High-grade Zones in Unconventional Reservoirs

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Summary

We have developed a target zone identifier (TZI) which can be used to place horizontal wells and hydraulic stimulation treatments within unconventional reservoirs. Our index relies on four inputs: (1) rock fabric, (2) rock composition, (3) rock compaction, and (4) stress difference. Rock fabric is defined by the degree of laminations/heterogeneities present in the reservoir. Rock composition is defined by the bulk mineral volumes of the reservoir. Rock compaction is defined by the over-consolidation-ratio (OCR); the ratio of maximum previously experienced vertical effective stress, σvmax divided by the present effective vertical stress, σv (Holt et al. 2011). Stress difference equals the difference between vertical stress (overburden) and closure stress. The stress difference input is specific to the reservoir of study and is related to the existing stress state. The workflow aims to understand how fabric and composition relate to stress anisotropy and pore pressure. The TZI employs all factors in conjunction with each other to predict the best zone(s) to complete. A well interval displaying the Montney reservoir is used as a case study to present our identifier.

Workflow

The workflow starts by running quantitative log analysis to solve for lithology, porosity, water saturation, and permeability. If the reservoir contains organic matter, then TOC must also be accounted for. The solved for petrophysical parameters are then used to reconstruct sonic and density logs. This step removes bad hole and gas effects from the logs so that accurate water-filled rock mechanical properties can be calculated. The process also corrects for organic matter volume which affects the logs. In addition, reconstruction is routinely used to create missing logs, where needed. The authors have covered these topics with past papers – please see references for additional information.

Next, the reconstructed logs are used to calculate rock elastic properties, and subsequently converted to static values, using static triaxial core data where available, or established correlations in the absence of core data.

Once reservoir parameters and mechanical properties have been solved for using quantitative log analysis, the target zone identifier is calculated. Rock fabric is the first input to calculate for the TZI. The inclusion of this term is based on the idea that layer interfaces, which in shale most commonly take the form of laminations, are features which create anisotropy within a rock mass (Teufel et al. 1984). When an interface is unbonded, tensile strength will be minimized, and failure is likely (Teufel et al 1984). In addition, an increase in the frequency of interfaces will result in an increase in the stress state, due to formation heterogeneity.

Rock fabric is calculated by running a discrete curve to identify layers with distinct characteristics (bulk volume of clay, quartz, carbonate and organic matter for example). Once layers have been identified with a set of discriminators, the number of layers per meter, for a given zone is calculated. The number of layers per meter per zone equals the rock fabric input number for the zone.

Rock composition, the second input to the TZI is based on bulk mineral volumes, calculated from quantitative log analysis. These volumes should, if possible, be calibrated to core data. The rock composition input relates rock brittleness to mineralogical components, by calculating the ratio of brittle components to ductile components, after Walles et al. 2010. The inclusion of this term is based on the theory that areas of higher brittleness are expected to fail easier than areas of higher ductility.

Rock compaction, the third input to the TZI is defined by the OCR; the ratio of maximum previously experienced vertical effective stress divided by the present vertical effective stress (Holt et al. 2011). This term estimates the degree of past effective vertical stress by relating sonic compressional velocity to rock compaction/consolidation. Present day vertical stress is calculated via integration of the bulk density log, at the increment of the LAS file, from shallowest log reading to the target interval depth. However, before the bulk density log can be used, it must be corrected for abnormally low data caused by bad hole, coal, etc. The other issue is that the bulk density log will usually not have readings to surface. To remedy, a depth function is used to assign bulk density values from surface to the shallowest log reading, and to remove abnormally low bulk density values. Once these steps have been completed, the corrected bulk density log is used to calculate vertical (overburden) stress. Pore pressure is then subtracted from this term to calculate effective vertical stress ratio.

Stress difference, the last input to the TZI, is the difference between present day vertical stress, σv and minimum horizontal stress, σhmin. The total stress equation, along with mechanical properties and pore pressure are used to calculate σhmin. For accurate results, stress must be calibrated to field measured values, with a strain or stress correction factor. Strain corrected models are generally preferred by completion engineers. The inclusion of this term is based on the theory that a hydraulic fracture will preferentially propagate to areas along the wellbore with a lower stress state (Warpinski 2011). High stress makes breaking down the formation more difficult, and fractures will be more likely to close rapidly following stimulation (Norton et al 2011).

Data suggest that pore pressure is coupled to closure stress; an increase in pore pressure causes an increase to closure stress, by 60-80 percent of the increase in pore pressure. Therefore, contrary to uncoupled modeling predictions, a decrease in stress difference (σv-σhmin) will occur with increased pore pressure (Hillis 2000). Both decreased stress difference and increased pore pressure are believed to be detrimental to a complex hydraulic fracture network. This is particularly true in a reservoir such as the Montney, where the stress regime is highly anisotropic and approaching a thrust fault regime. Although it is difficult to calculate the overall stress state, due to inaccuracies in estimating maximum horizontal stress (σHmax), σhmin is used to examine the potential shifts in stress regime.

Together, these four inputs are used to calculate the TZI. The TZI thereby accounts for the effects of fabric, mineralogy, compaction and stress difference when determining where to place a well or completion. TZI moves beyond the simplified idea that a highly brittle interval equates to the best completion zone.

Conclusions

The mechanical stratigraphy of an unconventional reservoir plays an important role with regards to hydraulic stimulation design and placement, for both horizontal and vertical wellbores. Our target zone identifier can be used to locate optimal intervals in unconventional reservoirs to initiate hydraulic stimulation.

Reservoir fabric is an important element to consider when placing a hydraulic fracture. Natural fractures and laminations which interact with the hydraulic fracture can induce shear failure and link together a complex network of natural and hydraulic fractures. However, a high degree of laminations may also inhibit fracture growth – and we aim to understand which degree of reservoir heterogeneity is optimal.

Rock composition has a strong influence on the propagation of hydraulically induced fractures. Zones with a higher proportion of quartz and carbonate tend to be stiffer and more susceptible to stimulation.

The OCR input is calculated by estimating maximum previously experienced vertical effective stress and comparing to present day vertical effective stress. OCR is related to the rock's burial history and subsequent removal of overburden due to erosion and uplift.

Knowing the difference between vertical stress and minimum horizontal stress prior to stimulation is very important. Increased pore pressure during stimulation can shift the overarching stress regime and limit fracture growth. By targeting zones with lower pore pressure and lower minimum horizontal stress, we avoid areas where σhmin is approaching the overburden stress, and therefore approaching the transition from strike-slip to reverse stress regime. Within a reverse stress regime, pancake (horizontal) fracture patterns are more likely to occur and may lead to a lower stimulated reservoir volume (SRV).

There is potential for re-fracturing of wells which were previously stimulated with equal perforation spacing. The TZI is a viable method for designing differential spacing and fluid / proppant volumes, based on the interfaces between higher and lower TZI values.

The same fracture and stress mechanisms are present in both vertical and horizontal well cases.

It is important to note that the TZI does not directly address potential fracture networks, which may have a large influence on completion success. Burial, hydrocarbon generation, diagenesis, and tectonics all affect the mechanical character and in-situ stress state of the reservoir as well, and these topics are beyond the scope of this paper.

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