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Fractures – enemies or friends? How to answer this and navigate with DWM to increase production and mitigate hazards

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Summary:

For the oil and gas industry to survive and flourish we must find a way to maintain production rates at reduced costs and be environmentally friendly. Over the last 20 years advancements in horizontal drilling and fracking technology have provided the opportunity to increase recovery rates in very mature basins around the world. Our experience shows that a more complete understanding of the faults and their associated fracture systems is critical to improved production recovery rates and a reduction in encountered drilling hazards.

Future oil production will come from increasing the percentage of recoverable hydrocarbons in place from existing reservoirs. Some of this increase in production will come through an improved understanding of the fluid flow paths and barriers within the reservoir, and some will come from creating increased permeability using fracking operations. Continued fracking operations and associated wastewater injection are needed to enable this increased production, however, the danger of induced seismicity is also increased, therefore, a complete and careful study of the existing fault/fracture systems is required to both enhance production and avoid negative outcomes. We must be more aware that wastewater injection operations may open and lubricate existing fault/fracture systems which in turn may produce induced seismicity events, and it will make future nearby fracking operations more likely to become invaded by water from the injection reservoir site.

To increase recoverable production efficiently and safely from existing reservoirs geophysicists and geologists must improve their ability to build a model of all sizes of faults and fractures from the basement to the reservoir level and above. We believe that the fault systems that exist in the deeper formations play a significant role in determining the location and probability of the fault systems within the reservoir. Also, we believe that the existence of the fault/fracture systems play a much greater role in the success or failure of efficient reservoir production than previously believed. Therefore, if we wish to increase recovery rates in mature basins (such as the WCSB and others), we need to locate regional fault lineaments and all associated and none associated faults must be identified from the Precambrian up to the reservoir.

We need to improve our ability to delineate subtle, zero throw, vertical and sub vertical faults and their associated fracture swarms. We believe that a key component to the solution is to utilize the unique properties of Duplex Wave Migration (DWM) technology to build a comprehensive fault/fracture model as a routine procedure to assist in the planning of new drilling locations.

Theory:

A recent book entitled "Numerical modeling of seismic responses from fractured reservoirs by the grid-characterization method" by V. Leviant, I. Kvasov, and I. Petrov (2019) indicates that subtle fluid-saturated faults and fracture systems can produce a detectable seismic response (published by SEG). The upper row of images in Figure 1 are taken from this publication and during the presentation we will briefly overview the results of their work.

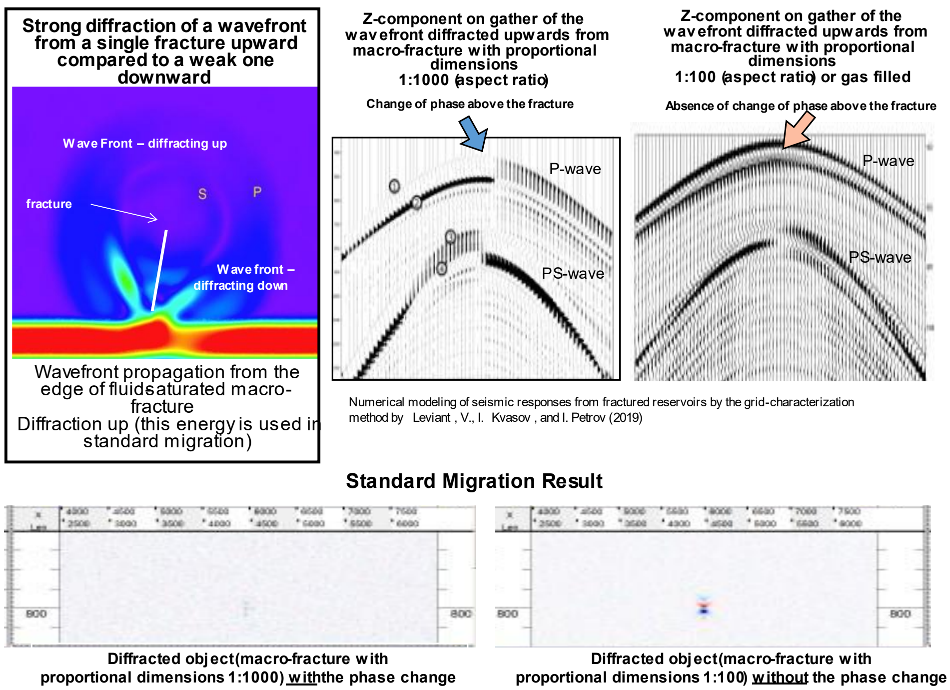

Figure 1: The fact that fractures can produce a significant response to seismic wave energy indicates that we should further investigate direct fracture detection methods such as DWM.

Method:

During the past 15 years we have utilized DWM to delineate subtle fluid filled, zero or near zero throw faults in several carbonate and shale projects around the world. DWM is a pre-stack depth migration that images only the seismic response energy that is produced by a second reflection (duplex waves) thereby imaging only vertical (+ or – 30 degrees) boundaries. The method eliminates primary wave (single reflection) energy using the unique kinematics of duplex waves thereby enabling this much weaker energy to be clearly imaged. We have consistently found that the amplitude of the DWM response is directly proportional to the permeability as measured by fluid flow rates at the wells. Also, experienced interpreters estimate that they can delineate the lateral location of fluid filled fracture systems within 25 meters at depths of thousands of meters. Figure 2 illustrates a DWM amplitude map in an area with several wells for validation of all conclusions made in a paper published in the January 2011 issue of the EAGE First Break. During this presentation we will briefly compare the performance of DWM technology to commonly used conventional methods such as coherency, curvature, Ant Tracking, diffraction migration, and others.

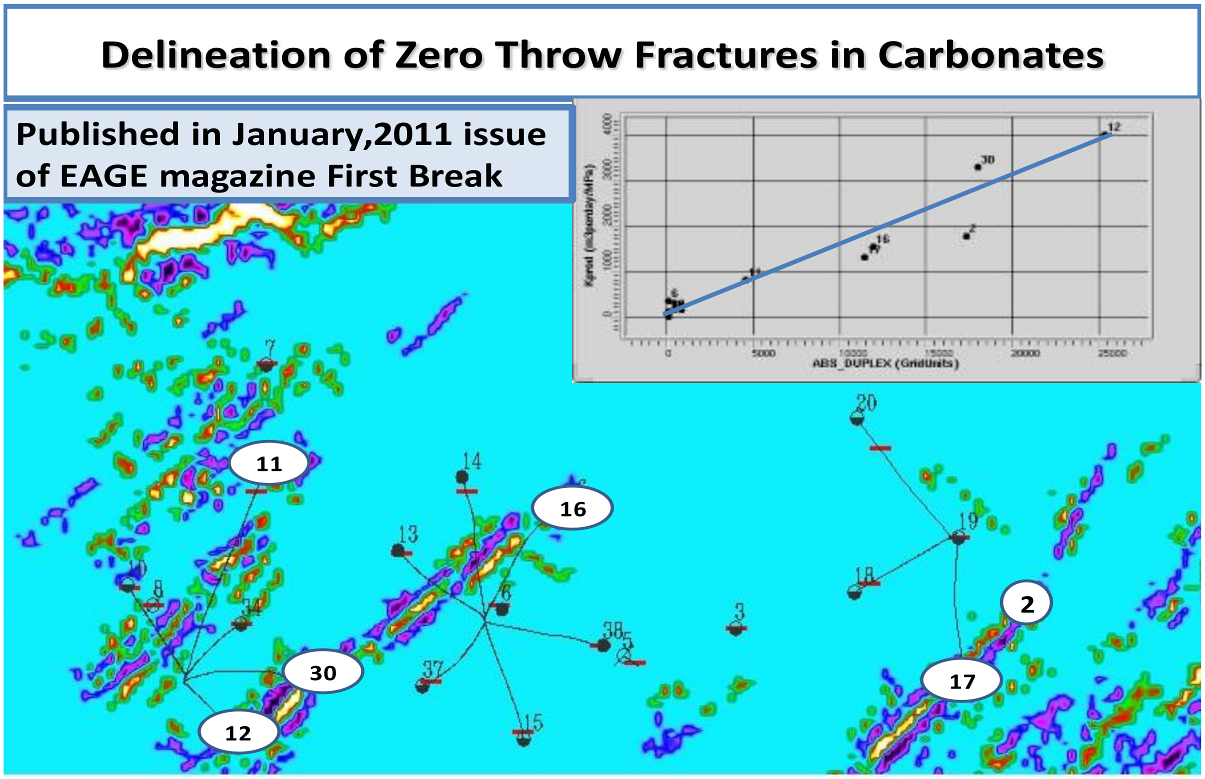

Figure 2: This is a DWM amplitude map that has delineated the location of permeable fracture systems within an accuracy of 25 meters. Note that the graph of DWM amplitudes versus measured permeability (total fluid flow rates of water plus oil measured at each producing well) is linear. This indicates that DWM provides a reliable predictor of fluid content and permeability within the fault/fracture system.

Workflow:

DWM is a pre-stack depth migration that is run after conventional PSTM or PSDM imaging and interpretation has been completed. Since DWM is a depth migration it does require a depth model which is used to compute travel times from the surface down to a near horizontal base boundary plus the travel time to a possible sub vertical boundary, plus the travel time from the sub vertical boundary to the surface. We can also image duplex wave energy that reflects from the sub vertical boundary first followed by the reflection from the horizontal boundary – this enables the ability to determine the tilt away from vertical of the sub vertical boundary. The specular reflection from the fault face is imaged thereby providing us with a direct detection method to enable the characterization of the fault/fracture system. Figure 3 explains how DWM can be utilized in the workflow.

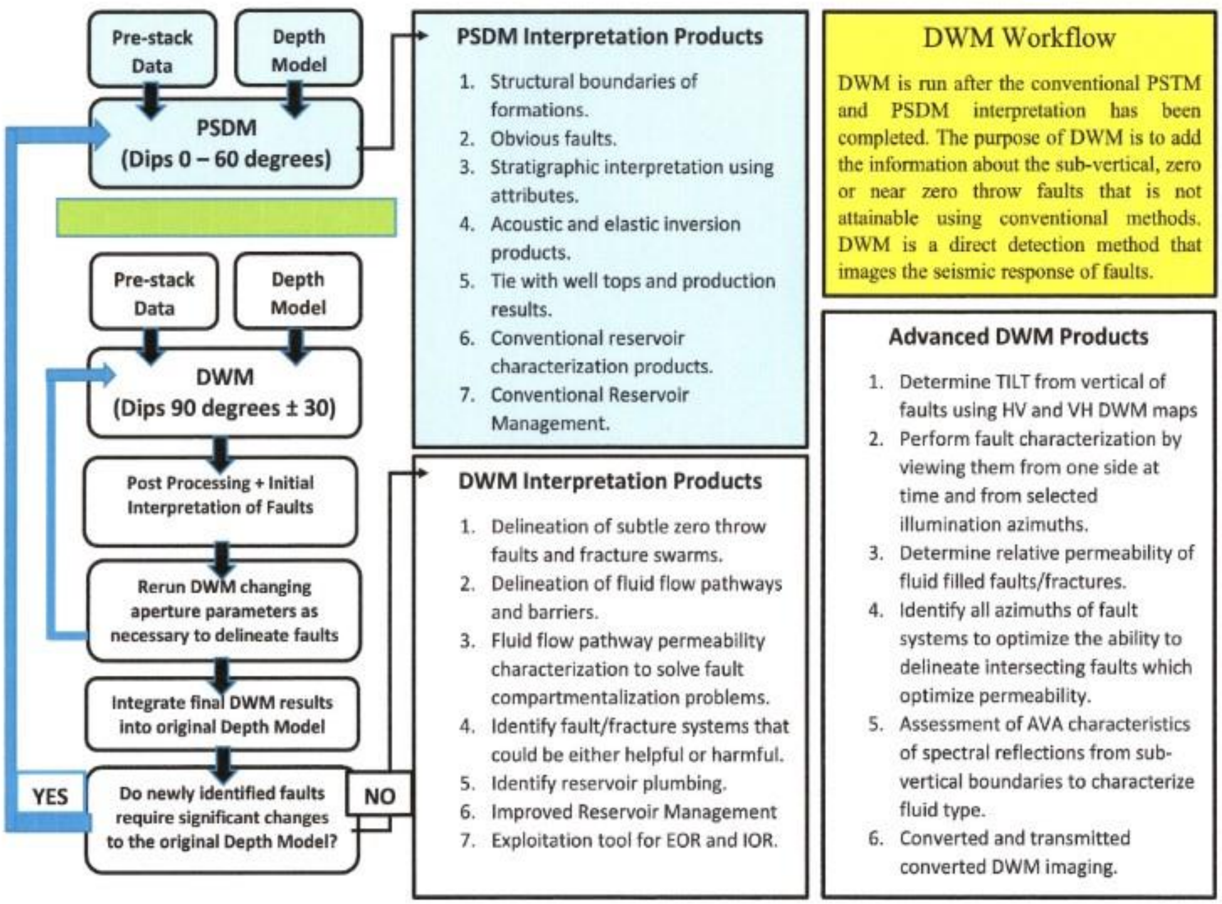

Figure 3: this workflow illustrates the function the DWM process relative to conventional PSTM and PSDM products.

Observations:

The need to define the fault/fracture systems more carefully in the WCSB, and other mature basins around the world, has increased substantially since the hydraulic fracturing method has been introduced and some resulting induced seismicity events have been observed. Alberta researchers have identified the following characteristics of re-activated faults due to fracking operations:

1. A fault line must underlie the shale.
2. Fault orientation must be such that it will slip.
3. Usually need a flow pathway between the Fracking Operation and the underlying fault.
4. Also, faults may be re-activated due to stress changes associated with the elastic response of the rock-mass to hydraulic fracking.
5. Re-activated faults are sub-vertical faults rooted in the crystalline basement that are associated with reef platform initiation.

6. Several induced faults are associated with the edge of the Devonian aged Swan Hills platform.
7. The faults are often related to dolomitization in the carbonates.
8. Often the fault displacement is 0 to 20 meters.

If we can increase our ability to characterize fault and fracture permeability we will be in a much better position to take part in other immerging industries such as selection of sites for geothermal plant locations and the growing mining industry.

Conclusions:

For the oil and gas industry in mature basins to maintain (or increase) production levels with reduced cost per barrel geophysicists must provide geologists and production engineers with a more complete model of the fault and fracture systems. In the past these unidentified fault and fracture systems have caused major drilling and production problems that have often resulted in oil companies leaving what would have been highly successful reservoir development areas. If we can improve our ability to exploit these areas efficiently this will improve the general investment climate for oil and gas companies.

Novel/Additive Information:

DWM is a direct detection method that images the seismic response of the specular reflection from sub vertical fault and fracture systems. The ability of DWM to image this mirror like reflection from the fault surface itself enables explorationists to perform fault permeability characterization studies that provides improved predictability of the result of drilling into those faults. DWM can delineate the lateral location of the fault/fracture system accurately as well as being predictive of its relative permeability.

Acknowledgements

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References

Khromova, I.Y., Link, B.H., Marmelevskyi, M, [2011] Comparison of seismic-based methods for fracture permeability prediction, First Break Vol 29 (1), 11-18