A Method to Assess Potential Induced Seismicity Hazard With Application to the Duvernay

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Summary

A workflow comprising steps of increasing sophistication is described that may be used to assess the potential for induced seismicity hazard. The steps span easy-to-implement simple analytical screening tools to the application of newly-developed research. The methodology is applied to a 7-well pad in the Duvernay where microsesimic monitoring was conducted. A good qualitative match was achieved between estimated and observed microseismic events and energy release. Using the existing pad as a calibration point, the method may then be applied to new areas ahead of well pad completion to devise operational procedures to identify the potential risk of induced seismicity.

Introduction

In 2015, Apache drilled a vertical Duvernay pilot well followed up by a 7 well pad in the Kaybob area. The company successfully acquired data necessary to build a robust geomechanical model. The data set included: core, full set of logs, OBMI, DFIT, microseismic with moment tensor inversion on larger events. In 2016, a major review was undertaken to integrate learnings from the pad with the new geomechanical model in order to develop a workflow to assess induced seismicity (IS) hazard. This paper describes the sequential application of various methodologies – each with increasing detail and sophistication – to assess this hazard.

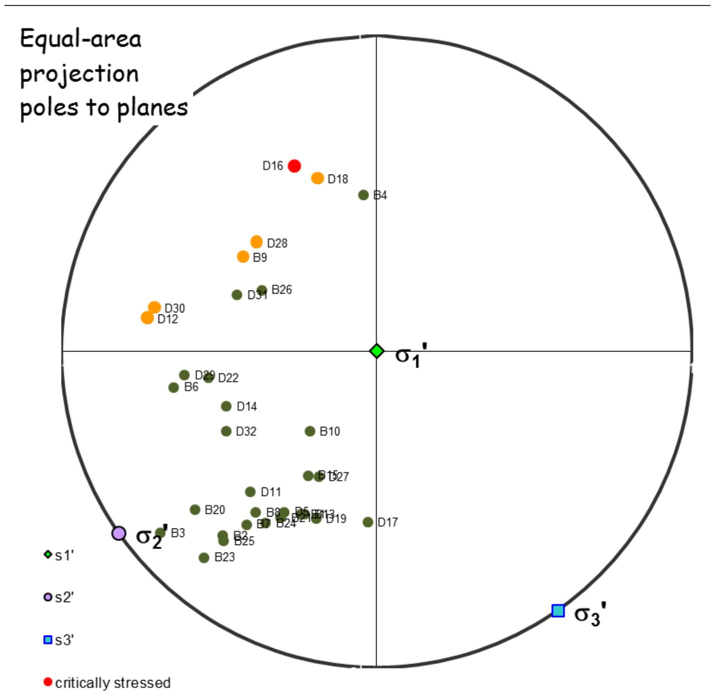

Figure 1: Mapped faults from 3D seismic shown in a lower hemispherical plot color-coded for fault slippage propensity

Method

Well-based geomechanical analyses were first undertaken to develop a description of stresses and formation pressure that honored the available core and drilling-induced or measured data. Geophysical interpretations mapped the observable faults; this was supplemented by seismic attribute analysis to infer the presence of faults at a scale smaller than direct seismic detection. Faults were classified depending upon whether they were contained wholly within the Duvernay or whether that extended down into the Basement. The first level of IS hazard assessment took a simplified fault description (constant dip and strike) and determined the normal stress change required for the fault to become critically stressed (Figs. 1 & 2). Limited portions of a small number of faults were determined to be critically stressed within the prevailing regional stress field. This permitted a ‘traffic light’ screening of faults depending upon their shear stress ratio and the normal stress change required to cause slip.

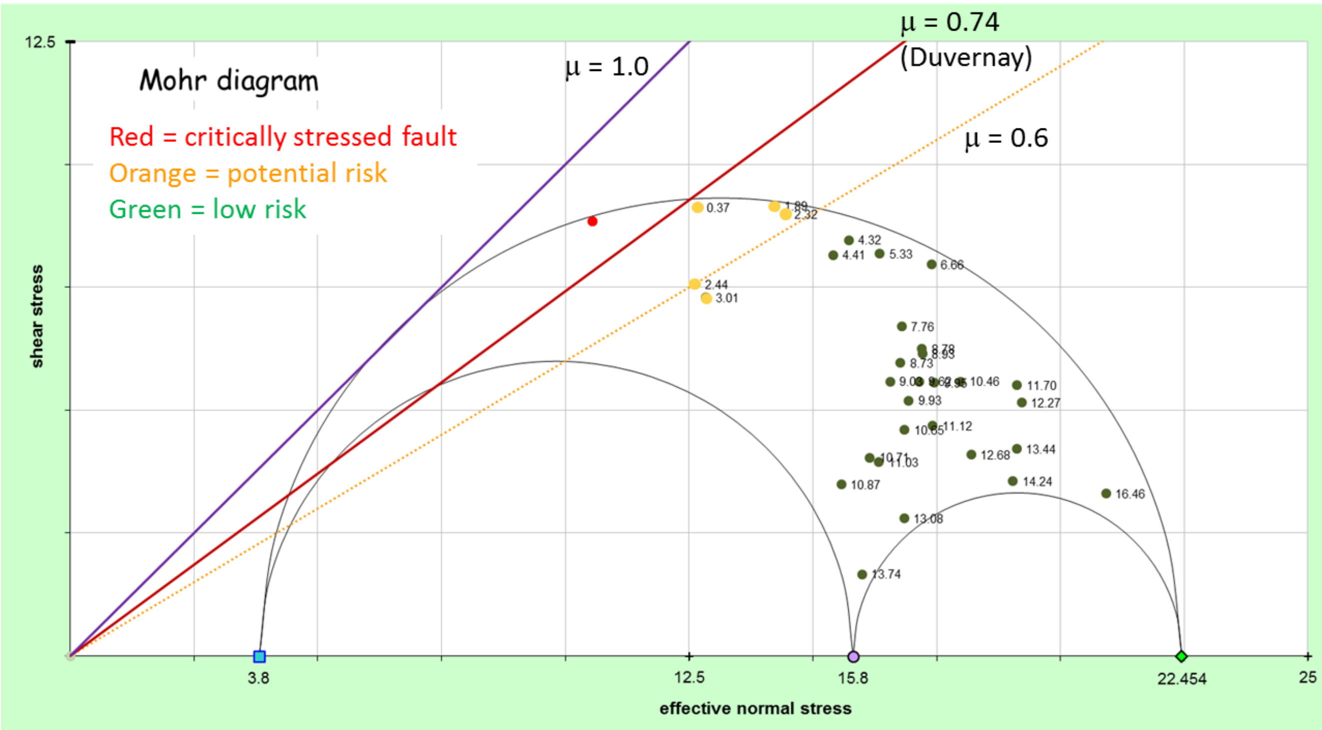

Figure 2: Fault representation in a Mohr diagram showing normal stress change required to achieve a critically stressed state

From this starting point, the analyses were extended to incorporate the seismically-mapped surface topography of the faults (varying dip and strike). This permitted a more detailed analysis of fault patch areas potentially subject to slip (Fig. 3) and generated a statistical description of fault properties for use in subsequent probabilistic modeling. At this point in the analysis the impact of perturbations in stress and pressure in the local area caused by hydraulic fracturing operations (or from produced water reinjection, where applicable) is assessed. These effects include both stress changes due to the elastic response of the rock from hydraulic fracturing and pore pressure changes due to hydraulic diffusion. Both are regarded as impacting IS propensity in recent studies (e.g. Ref.1). The general procedure is to approximate these changes through computational analysis of the ‘stress shadow’ effect or by simulation of water injection. By inferring pre- and post-fracturing stress states on faults the scale of the perturbation can be calculated – some areas experiencing an increased shear stress whereas others are reduced. Having identified the area of the fault with potential to slip, the maximum size of a possible triggered IS event is then estimated using standard Kanamori-Anderson relationships. The estimated energy release may also be compared with cumulative estimates of energy release from microseismic monitoring to provide a verification, or calibration, where necessary, to the predicted maximum-size event.

To extend this necessarily simplified deterministic assessment of fault slip potential to a more probabilistic approach, Apache is investigating the use of newly-developed research into the collective properties of injection-induced earthquake sequences (Refs. 2&3). This new model couples a fracture mechanics description of 1-D fault rupture with fractal stress heterogeneity and the evolving stress and/or pore pressure distribution around a well, or wells, either due to water injection or hydraulic fracturing. By evaluating the extent of possible energy source regions (once slip is triggered) with energy sink regions, the fault rupture size is thus estimated (Fig. 4). This is evaluated in terms of the Gutenberg-Richter a and b values to estimate the appropriate magnitude frequency distribution of potential IS events. (This presently is a work in progress and more detailed results will be available at the time of the geo**convention**.)

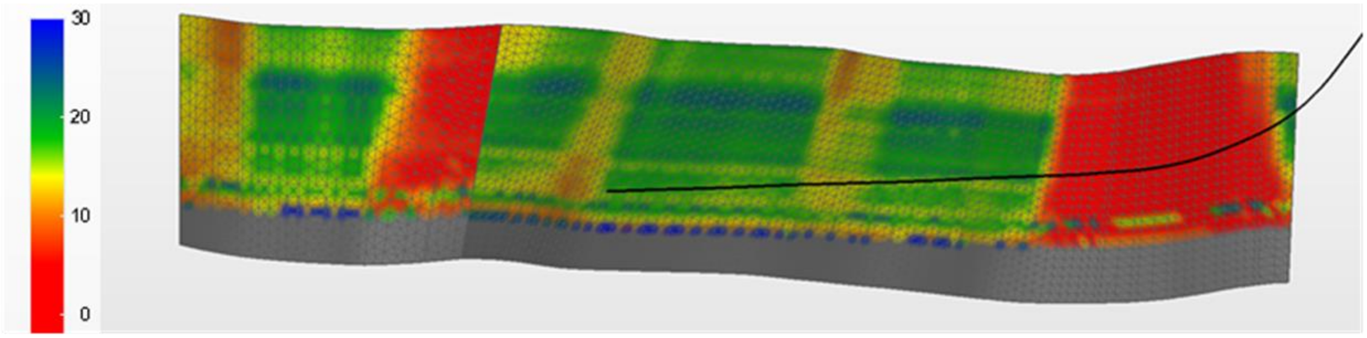

Figure 3: 3D fault stability model (for a hypothetical stress state) – colors show stress change in MPa required for fault slip

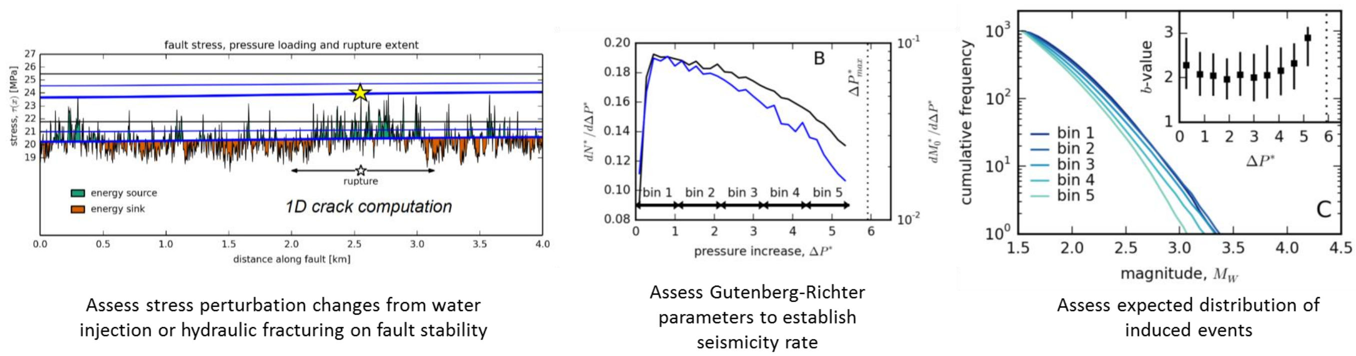

Figure 4: Schematic description of the advanced fault slip & IS event potential workflow of Dempsey & Suckale (2016)

Case Study

The Duvernay team selected an area of interest (6×6 km) covered by 3D seismic to first test the workflow. A total of 32 faults were picked over the area of interest. The interpreted faults have different orientations, dips and size. The stress state was determined from the geomechanical model that was calibrated to well-testing data. Initial screening was able to position the fault segment into a Mohr diagram by computing effective normal shear stresses for each of the segments. A coefficient of friction of 0.74 (determined from geomechanical testing) is used to identify faults with the potential to be critically stressed (i.e. higher possibility of slip) and a coefficient of friction of 0.6 is used to flag moderate risk faults (Figs 1&2). Most faults are positioned below the 0.6 line and are ranked as low risk. Of the interpreted faults, the D16 segment (Figs 1&2) is the only one that was identified as having the potential to be critically stressed. It is oriented subparallel to the maximum horizontal stress direction (about 55 deg). Stresses predicted to be caused by hydraulic fracturing were imposed on these faults – e.g. by evaluating the pre- and post-stimulation state of stress on discretized fault areas such as shown in Fig.3. The cumulative fault area subjected to increased effective shear stress causing slip could thus be identified, and from this this energy release and equivalent single event magnitude could be estimated by assuming a suitable event stress-drop on the fault patch. The estimated cumulative energy release from the geomechanical analysis (0.178 gigajoules) was in good qualitative agreement with that estimated from a summation of monitored microseismic events (0.118 gigajoules). The Duvernay team is presently extending this analysis using the Dempsey & Suckale (2016) workflow to better define the IS hazard in a more probabilistic manner.

Conclusions

The study allowed the team to develop a detailed workflow describing fault architecture and stress state from which the fault-patch slip area due to imposed stress perturbations caused by hydraulic fracturing operations could be estimated. The methodology was verified through application on a 7-well pad drilled in the Kaybob area of the Duvernay. More advanced analyses are underway. Upon completion of our additional analysis using the Dempsey & Suckale (2016) workflow, it is anticipated that a robust IS screening methodology will exist and be implemented on all operational activities elsewhere in the Duvernay.

Acknowledgements

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References

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