Microseismic Event Location Accuracy Enhancement using Anisotropic Velocity Models

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Summary

Microseismic monitoring of hydraulic fracture treatments often provides the only opportunity of determining any reliable information about the geometry of the fracture network formed by that treatment. This type of survey is becoming more and more widely used to monitor fracture treatments in horizontal wells and/or unconventional reservoirs. Useful interpretation of the results requires accurate location of the monitored microseismic events, which in turn requires an accurate and suitable velocity model.

In most real-world cases the velocity model is built from sonic logs in nearby vertical wells, with possible additional information from VSP or walkaway VSP data and the monitoring of perforation shots from the monitoring array. Unfortunately such data sets seldom contain any information about the TI nature of the rock between microseismic event and receiver. Wireline logs generally measure vertical slownesses, along the length of the borehole, and the monitoring of perforation shots, in general, provides neither adequate constraints to invert for a depth-variant anisotropy nor the ability to solve for both ε and δ. A a very significant proportion of HFM surveys are performed in rocks which are expected to exhibit strong variations between vertical and horizontal velocities (especially in shale gas reservoirs and their geological environs. Accurate event location requires a velocity model which contains, and uses, the TIV parameters. Failure to correctly estimate, and subsequently use, the anisotropic parameters can lead to large errors in event locations (eg. Warpinski et al. 2009).

Introduction

Two horizontal wells were drilled into a shale sequence and the high-rate slickwater frac was monitored from a vertical monitor well between the two horizontals. Many hundreds of events were detected and located for each stage of the fracture treatment, and in particular for stages 1 and 7 in the same well. These two stages are at a similar distance from the monitor well, though on opposite sides of it. The microseismic events and wells are shown in Fig. 1. It can be seen that for each stage the microseismic 'cloud' clusters in two parts, one at the vertical level of the well, and the other somewhat higher and closer to the monitor well. The correct interpretation of this type of picture is of fundamental importance since it could

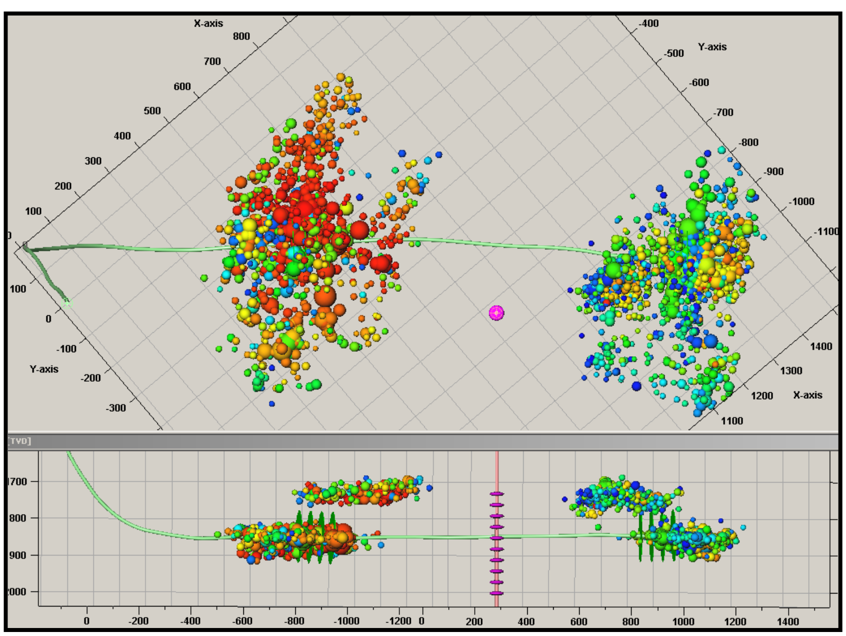

Figure 1: Microseismic Events from stages 1 and 7

indicate significant vertical fracture growth ‘out of zone’ and the creation of fluid-flow pathways leading outside the reservoir formation.

The semi-symmetrical appearance of the vertical event distribution about the monitor well suggests that the vertical distribution may owe some of its character to systematic location errors, probably stemming from the velocity model.

Velocity Model

The initial velocity model, and the logs from which it was derived, are shown in Fig 2. Although the model is fairly smooth, there are some clear large scale variations. The Vp/Vs ratio of the zone containing most of the receivers is quite different from the reservoir section itself, suggesting a significantly different rock, although both are shales and therefore have the potential for large intrinsic anisotropy. After the perforation shots were recorded a global value of 0.12 was selected for the parameter γ, governing the shear anisotropy.

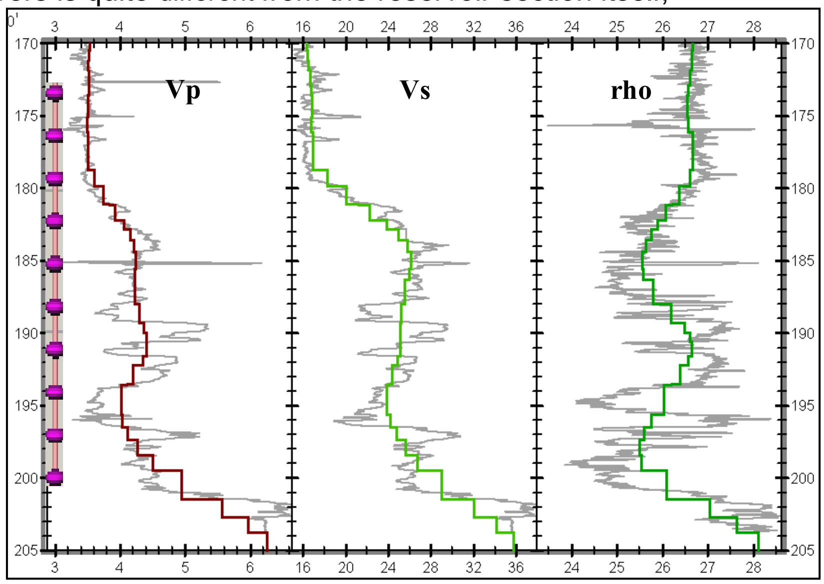

Figure 2: Velocity model

Given a velocity model and a survey geometry, it is possible to estimate the expected accuracy of event location for events located at points within a volume around a selected receiver array. An estimate must be made of the expected time picking discrimination and angular accuracy of the data. The results of such a simulation are shown in Fig 3. The assumed time picking discrimination of 1ms for compressional arrivals and 2ms for shear arrivals is appropriate for data with moderate signal to noise ratios. The modelling result suggests that for an event which occurs at the vertical level of the horizontal wellbore, the maximum uncertainty in its location increases if it is further away. Indeed at a distance of 1,000m the uncertainty is ~10m, which, by inspection of fig 1, is much less than would be needed to move events upwards into the 2 ‘high’ event clusters.

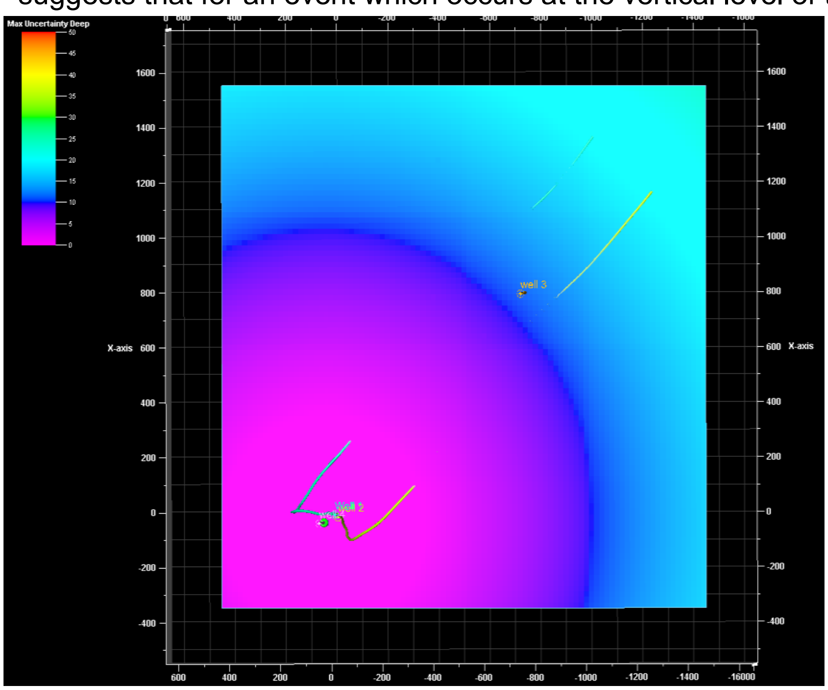

Figure 3: Maximum Uncertainty at borehole level. The dark blue ring represents ~10m uncertainty

A sensitivity test indicated that a depth variable VTI model could focus the two clusters to similar depths and horizontal offsets. The perforation shot relocation as a calibration tool was used to introduce a background ‘gamma’ correction for the shear wave velocities, but the multiple perforation shot s along the horizontal well do not provide enough constraint to uniquely solve simultaneously for all 3 weak elastic anisotropy parameters in a number of vertically distributed zones.

Fortunately some work had been done on a suite of Sonic Scanner[1] logs from a well in a similar geological setting, though some distance from the treatment well discussed here. This suite of logs had been acquired and processed to yield, in addition to Vp and Vs, the shear velocity derived from the Stoneley waves (eg Walsh et al., 2007). This measurement suggests the vertical variation of anisotropy along the log and provides a starting point for finding an anisotropic velocity model which will better locate the microseismic events. Figure 4 shows the horizontal and vertical velocities of the final model used to ultimately locate the events. The main feature is the very large difference between horizontal and vertical velocity in the upper section of the model, covering the top 3 receivers.

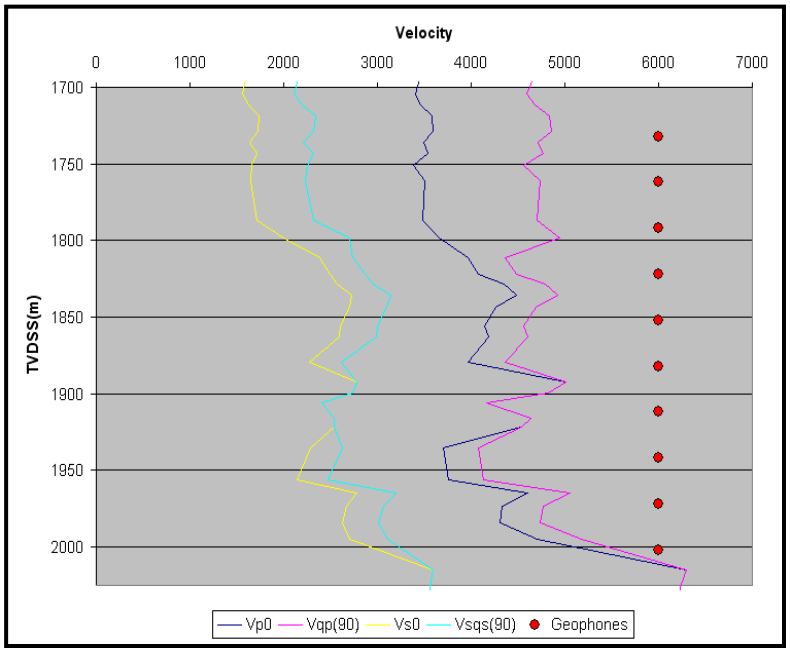

Figure 4: Horizontal and vertical velocities for the 'new' model

Results

The relocated microsesimc events with this velocity model are shown in figure 5. There are 2 major differences between this set of event locations and those of figure 1. These show much better vertical localization and collapse to 'tighter' areas in plan view as a result of using a velocity model which is closer to the actual earth velocities. These locations are more consistent with the expected hydraulic fracture geometries.

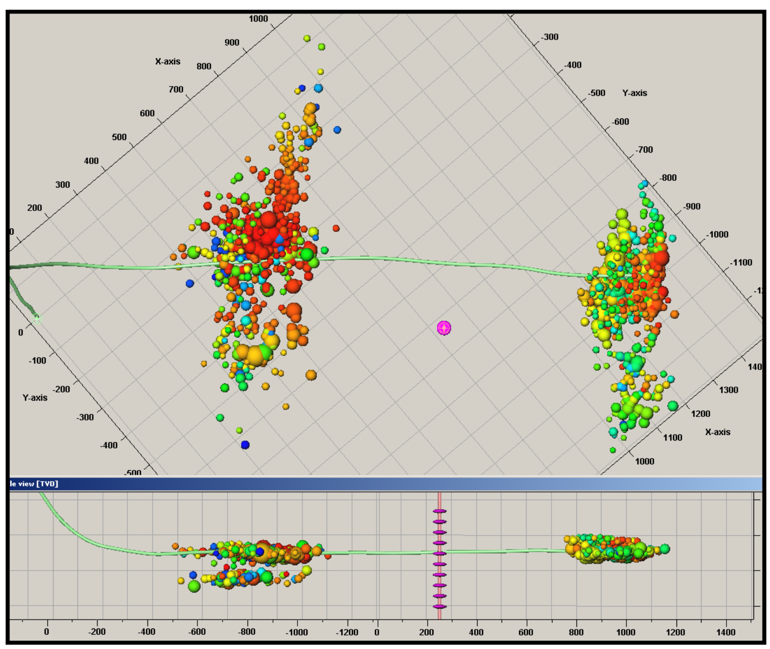

Figure 5: Relocated microseismic events from Stages 1 and 7 using the anisotropic model

Conclusions and Future Work

Inclusion of strong depth-dependent anisotropy has resulted in event locations clustered much more tightly, both vertically and areally. Both isotropic and anisotropic models, with unifrom anisotopy with depth, result in significant event mislocations that could result in

[1] Mark of Schlumberger

erroneous hydraulic fracture interpretations. The resulting event locations correspond to a more reasonable fracture interpretation with differences in height growth apparent between Stage 7 (on the left) and Stage 1 which are no longer mirrored about the borehole. Relocation of synthetic microseismic events from different depths through the velocity model may help to define the differences in locations associated with the different velocity models. At this time there is no attempt to track events between the two sets of computed locations to see differences in arrival time moveouts of events in fig. 5, which locate ‘high’ in Fig 1. This will be an interesting extension of the work on this project.

References

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