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Locating Microseismicity in Three-Dimensionally Heterogeneous Reservoirs

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Summary

This study describes the methodology for locating microseismic events in three dimensional media. Most velocity models are formed as one-dimensional parallel blocks, to ease the computational burden of ray tracing to model the first arrival traveltimes. The three-dimensional technique we describe relies on the fast marching algorithm to rapidly evaluate the traveltime field as well, and determination of hypocentral locations is not significantly slower than for one-dimensional ray-based techniques after an initial one-time computation. We investigate the artefacts that this less accurate assumption makes by showing how events located in a parallel block model move when a fully three-dimensional velocity model is considered.

Introduction

Microseismic monitoring has become an increasingly utilized tool in the petroleum industry assessing: the geometry of induced fractures from hydraulic treatment of unconventional reservoirs, monitoring caprock integrity, assessing the growth of steam chambers in CSS and SAGD, and in many other applications. Many of these plays occur in simple geological settings where the stratified nature of the sedimentary units makes it natural to simplify the geometry to a one-dimensional velocity model. Such an approximation has the benefits of reducing the complexity in ray-tracing to find a solution for the first-arriving wavefield from an event to a sensor.

Many reservoirs, on the other hand, feature more complex structure and, would be inaccurately modeled by flat-layered geology. These structures can be introduced in a particular depositional environment or deformation such as folding or faulting. . Although rays may still be traced in these volumes, they exhibit a more chaotic behaviour, especially as propagation distances increases (Keers et al., 1997). As such, the problem of determining the wavefield in the medium is more conveniently cast in terms of tracking the evolution of the wavefront with time.

In this paper, we discuss how 3D velocity models are constructed, the implementations, and the application in a laterally heterogeneous setting. Using a case study, we assess the differences that are incurred by approximating the three-dimensional structure with parallel blocks.

Implementation

Construction of a three-dimensional velocity model involves a synthesis of a number of data-types. For example, the sonic logs that are the basis of velocity model building in simpler geometries, remain an important component for the three-dimensional case, as they constrain model velocities around different wells in the region. These data are combined with accurate maps of the lithological discontinuities to produce the more accurate results. Tying the sonic logs to these discontinuities allows for the *P*- and *S*-

wave velocities to be assigned to a depth range representing a layer in the model. Depending on the quantity of sonic logs available, these velocities may be interpolated through the grid such that the layer velocities vary laterally. Similarly, assigning one velocity to all depths in the layer is a oversimplification: the next highest-order of approximation is to interpolate both velocities and velocity gradients in each unit. The location algorithm requires just the ~~the~~ velocities at gridpoints, and so there is no restriction on how the structures can vary inside a lithological unit.

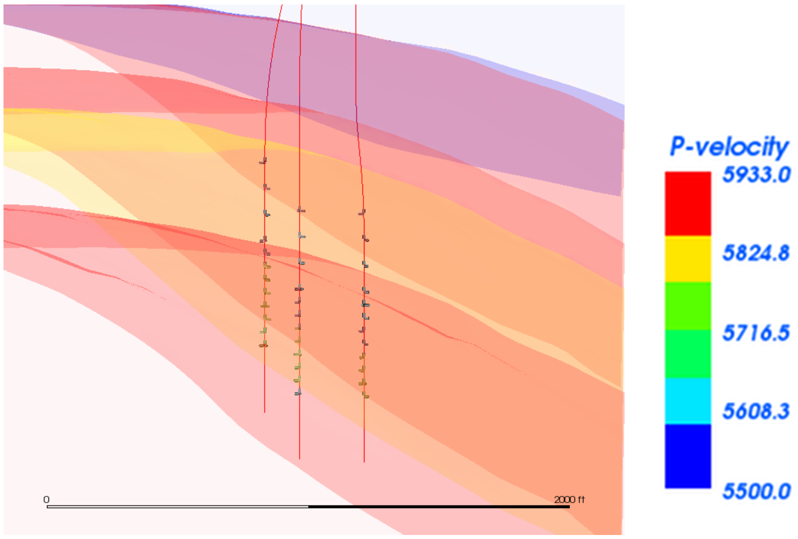

Figure 1: The laterally heterogeneous model where the *P*-wave velocity has been colour-coded to the lithological top of each unit (in ft/s). The microseismic monitor wells are denoted by red lines with each 3-component sensor shown as a triad of grey cylinders. Blue wells show other wells in the vicinity of the monitors.

We construct a model for a treatment zone on the flank of an anticline, shown in Figure 1. A dipole sonic log is used to estimate the velocities of each layer formation, which are themselves bounded by lithological tops interpreted from seismic cross-sections.

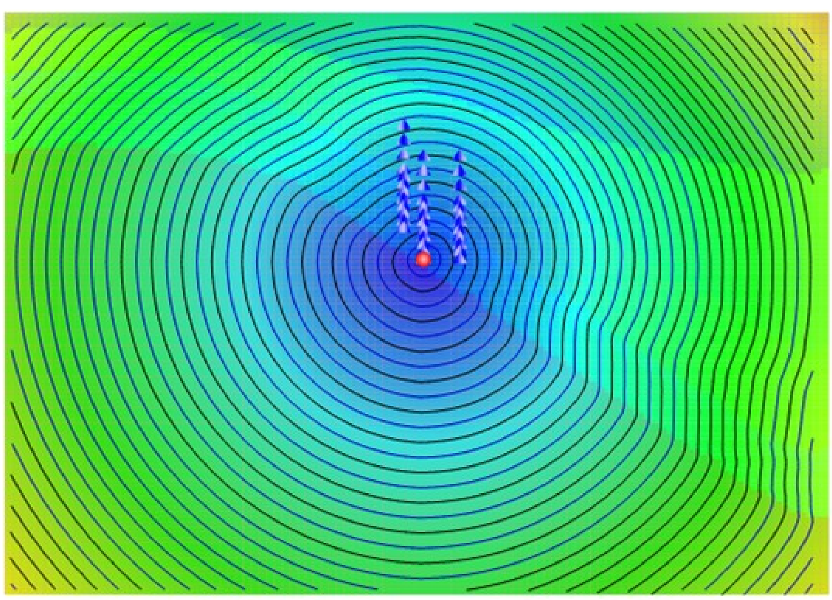

Figure 2: A depth view of wavefronts (blue curves) and traveltime field (blue-yellow contours) propagating from a source (red circle) to receivers (triangles) in the velocity model shown in Figure 1. The three-dimensional lithology is highlighted by changes in contrast of the traveltime field.

To locate a microseismic event, the travel times between each preliminary location and each sensor is calculated by propagating the *P* and *S* wavefronts with a fast-marching algorithm (Sethian and Popovici, 1999). The implementation, discussed by Trifu and Shumila (2010), takes advantage of source-receiver reciprocity to reduce the computational expense. The traveltime from each point in the medium to each sensor is computed by propagating a wavefront from each of these sensors and recording the traveltime to all the grid points into a table. Figure 2 shows a number of these wavefronts in the model presented in Figure 1. The traveltime to each point in the medium from each receiver is stored as a large grid file. Although the initial procedure to generate this lookup table is relatively computationally expensive, it only needs to be performed once. Hypocenters are determined through minimization of these modeled traveltimes with respect to the candidate event locations by searching through these traveltime files.

Application

For the setting described above, three monitor wells with 12 geophone levels each are deployed to monitor a steam injection. Due to the proximity of the steam injection to the wells, routine location of the events near the observation array is accommodated through a velocity model where the geological layers are dipping. For events further away, a horizontal model was used as this was deemed more representative of the fact that the dominant velocity structure at this scale was the air-ground interface. Recognizing that this solution was not optimal, a three-dimensional velocity model was built to locate the regional events with more accuracy. Figure 3 shows how a number of regional events relocated upon implementing the three-dimensional model for hypocenter determination.

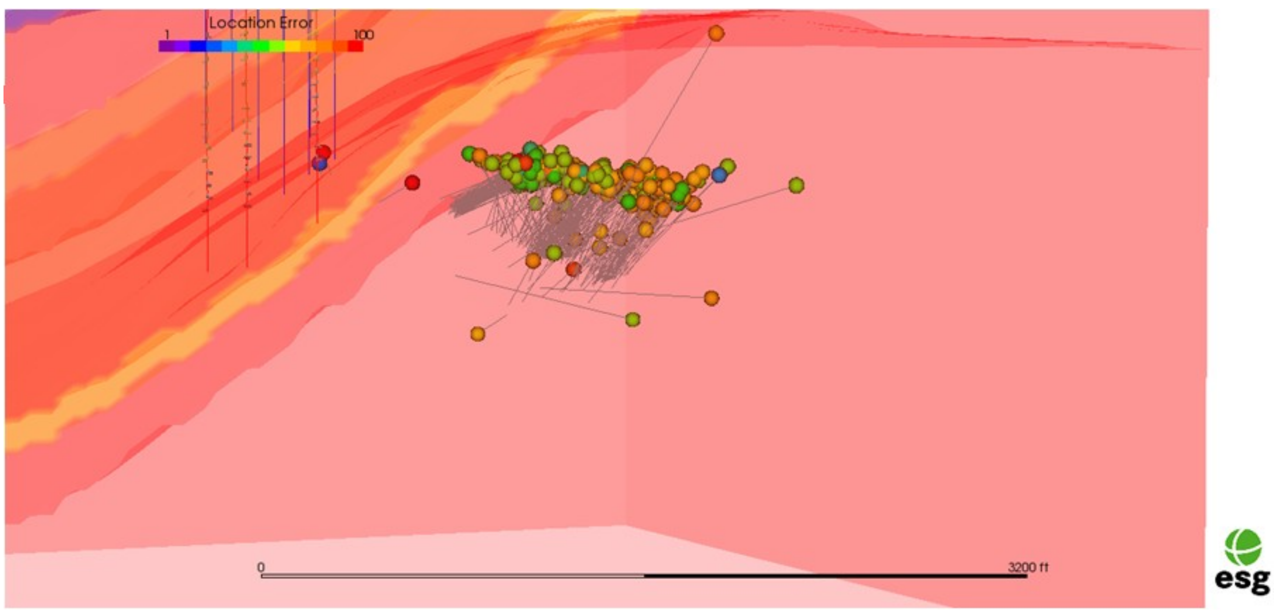

Figure 3: Events, initially located in a parallel block velocity model, are relocated with a 3D velocity model of figure 1. The events themselves are shown with their final locations are colourscaled by location error (in ft) and the trajectory of the relocated events is denoted by the grey lines.

The events dominantly relocate up-dip from the flat-layer locations and align along a potential fault plane. For illustrative purposes, a few events closer to the monitor wells were also relocated and show much less movement from the original locations.

Conclusions

Accurate location of microseismic events in complex geological models requires a location methodology capable of incorporating geological structures. This technique relies on the fast marching algorithm to propagate wavefronts in the velocity models and determine the traveltimes from each point in the model to each sensor. A case study was used to illustrate the relocation of events from a flat-layered model to this fully three-dimensional model with results that show significant changes in location and overall interpretation.

References

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