Assessing preferential orientations of fracture reactivation by iterative-statistical stress inversion from earthquakes in Taranaki, New Zealand

Introduction

The determination of present-day stress field orientations is of key importance in reservoir studies, because it can help understand borehole stability for drilling and assist production by improving understanding of subsurface fluid flow through fractures and faults. Stress fields can be calculated from earthquake moment tensor decomposition and direct stress inversion of the resulting focal planes. However, the fault-auxiliary plane uncertainty needs to be confronted: which focal plane represents the true fault plane and which represents the auxiliary plane? (e.g., Yin 1996, Busetti et al. 2014) Here, an iterative-statistical stress inversion of earthquake data from Northern New Zealand is used to calculate the local present-day stress field using a novel Monte Carlo stress inversion method. The stress field is then used to predict the likelihood of fractures to slip and dilate in the Maui Field area, Taranaki Basin.

Method

Initially, 10,000 stress inversions were performed from 253 earthquake moment tensors from around New Zealand, collated from Centroid Moment Tensors (Trabant et al. 2012) and The Global Centroid-Moment-Tensor (CMT) Project (Dziewonskie et al. 1981, Ekström, 2012). In each inversion, the calculation randomly chooses one of the two focal planes of the earthquake as the fault plane and uses the corresponding slip vector to estimate the stress field (direct inversion method, Angelier 1990). To refine this estimate, the focal planes that were used for the initial stress inversion were then evaluated to determine whether or not they were critically stressed under the calculated stress field and likely to fail.

Planes that were found to be critically stressed and were in failure were then used to refine the initial stress field calculation. Quality estimators were used to identify the best fitting stress tensors and shape ratios out of the entire pool of the Monte Carlo results. These estimators include Ratio of Failed Fractures, Average RUP (average ‘ratio upsilon’ defined by Angelier, 1990) and N1 Ratio (number of fractures where the RUP values are greater than 75%, Angelier 1990). This provided a more accurate estimate of principal stress orientations ($\sigma_1$, $\sigma_2$, $\sigma_3$) and shape ratios (differential stress ratios).

Initial results, filtering and final results

With the iterative-statistical approach, complex stress scenarios can be identified. In this case, the resulting statistical distribution for the 253 earthquakes, with its spread of shape ratios and two maxima (around 0.16 and 0.98, see Figure 1a) suggested that the input data represents events that have been produced as a result of at least two different stress fields.

To filter out interference from other stress fields, the input data were revised to 39 earthquakes restricted to the North Island of New Zealand with locations shallower than 70 km. Results from 10,000 stress inversions of the 39 earthquakes indicated a N36E (+/-10°) $\sigma_{\text{Hmax}}$ orientation, with minimised fault-auxiliary plane uncertainty (Figure 2). This is compatible with the NW-SE extension orientation indicated by other studies in the area (e.g., Rajabi et al. 2016).
Figure 1 Results of initial 10,000 iterative-statistical stress inversions from 253 earthquakes from around New Zealand. a) Shape ratio (differential stress ratio) frequency distribution. The data is explained by at least two stress fields (two maxima). b) Resulting principal stress orientations plotted on a stereonet ($\sigma_1 =$ maximum stress orientation, $\sigma_2 =$ intermediate stress orientation, $\sigma_3 =$ minimum stress orientation).

Figure 2 Results of 10,000 iterative-statistical stress inversions from 39 earthquakes restricted to the North Island with locations shallower than 70 km. a) Shape ratio (differential stress ratio) frequency distribution. The data can be explained by a single stress field. b) Resulting principal stress orientations plotted on a stereonet. Dashed circles represent the orientations of the best quality results according to quality estimators (Ratio of Failed Fractures, Average RUP and N1 Ratio).
Applying inverted stress field to assess slip and dilation tendency

The Maui Field is located in the immediate footwall of the Cape Egmont Fault, a multi-phase fault which has a present day throw at the main reservoir levels (Palaeocene-Eocene Sandstones) of 1.5-2km (Reilly et al, 2015). The displacement on the fault was kinematically modelled and the resultant strain, captured at every point, used to build a Discrete Fracture Network in the main Palaeocene (Farewell Formation) reservoir. The present-day stress field, calculated by iterative-statistical stress inversion, is then applied to the Discrete Fracture Network. Fractures dipping 50 to 80 degrees towards NW and SE (striking NE) are found to have the highest slip and dilation tendency and are therefore preferentially orientated to act as fluid flow conduits at present (Figure 3).

Figure 3. Discrete Fracture Network created over the Maui Field in the footwall of the Cape Egmont Fault (CEF) coloured for Slip and Dilation Tendency under the stress field calculated using the iterative-statistical stress inversion carried out here.

Conclusions

The work highlights the usefulness of the iterative-statistical stress inversion procedure to reduce the uncertainty linked with stress inversion from earthquake data. Worldwide available moment tensor data can be incorporated into exploration workflows, for example to predict preferential orientations of fluid flow linked with fracturing.

Acknowledgments

This article makes use of data from IRIS DMC Data Products, Centroid Moment Tensors (Trabant et al. 2012) and from the The Global Centroid-Moment-Tensor (CMT) (Dziewonskie et al. 1981, Ekström, 2012). We want to acknowledge the work of Heike Broichhausen and the rest of the Petroleum Experts team (Broichhausen et al. 2017) on developing the software code used as a base for the work presented here.
References


