Investigation of Fluid Migration Pathways Using Volumetric Seismic Damage Zone Analysis

Helen Basford, Gaynor Paton, ffA, Aberdeen.

Introduction

Detailed analysis of the geometry of damage zones and seismic properties in the immediate vicinity of faults is required to aid interpretation of fluid migration pathways. This level of analysis can be greatly facilitated by combining manually guided fault slicing with 3D seismic attribute driven Fault Damage Zone geobody delineation to generate fault based attributes, Allan diagrams and throw maps that accurately reflect the underlying data.

A critical input to such a Fault Analysis workflow is the fault surfaces. To create simple models, fault surfaces are often created by linking small scale faults as a single fault surface leading to greatly simplified representations of the true fault geometries resulting in important fluid migration pathways being overlooked.

A Fault Analysis workflow that avoids the issues of over simplification and allows more complete interrogation of the underlying data is presented by showing the results of applying the workflow to a highly faulted dataset from the Norwegian North Sea.

Workflow

The main objective of the workflow is to generate Allan diagrams and fault throw maps that best represent the information contained in the available seismic data and horizon interpretation. The key components of the workflow are set out in Figure 1. The input to the workflow is a Fault Attribute that represents the position within the seismic data of the faults of interest. As the seismic character associated with faulting can change from fault to fault, the workflow permits a range of fault attribute inputs to be considered and if required a single volume can be created based on a combination of different fault attributes. From the input fault attribute a volumetric 3D network is generated via a ridge detection operation where faults are represented by voxel thick lineations (Fault Detection).

Fault extraction is performed by fitting patches to the 3D fault network and then grouping these patches based on their azimuth, dip and separation. This can be performed on a regional basis, or in this example, on specific faults of interest. User interaction is such that the impact of varying these parameters on the connectivity of patches and therefore lateral extent of the extracted fault can be easily examined. For simple models of bulk faulting it is often useful to allow relatively widely separated fault patches to be grouped; however for detailed analysis of fluid migration pathways it is important to avoid this level of simplification and in such cases more stringent parameters should be used. The fault throw maps and Allan diagrams generated in the next stage of the workflow can be used as a quality check that the interpreter can use to determine the most likely solution.

In order to generate the fault throw maps and Allan diagrams, a 3D representation of the Seismic Damage Zone (SDZ) is required. This is generated via user defined fault slicing or by using a deformable surface growing algorithm. The deformable surface growing algorithm allows a purely data driven definition of the SDZ geometry. To generate a deformable surface representing the edge of the SDZ, the fault surface acts as a seed point and growth occurs away from that fault surface. The growth of the SDZ is controlled by a seismic attribute that represents the extent of seismic damage associated with the fault. Figure 2a shows the position of a fault (red line) and associated SDZ surface (black line) that has been generated. The projection of horizons (Figure 2b) from the point at which they intersect the SDZ on to the fault surface is used to generate the Allan diagram and fault throw map.

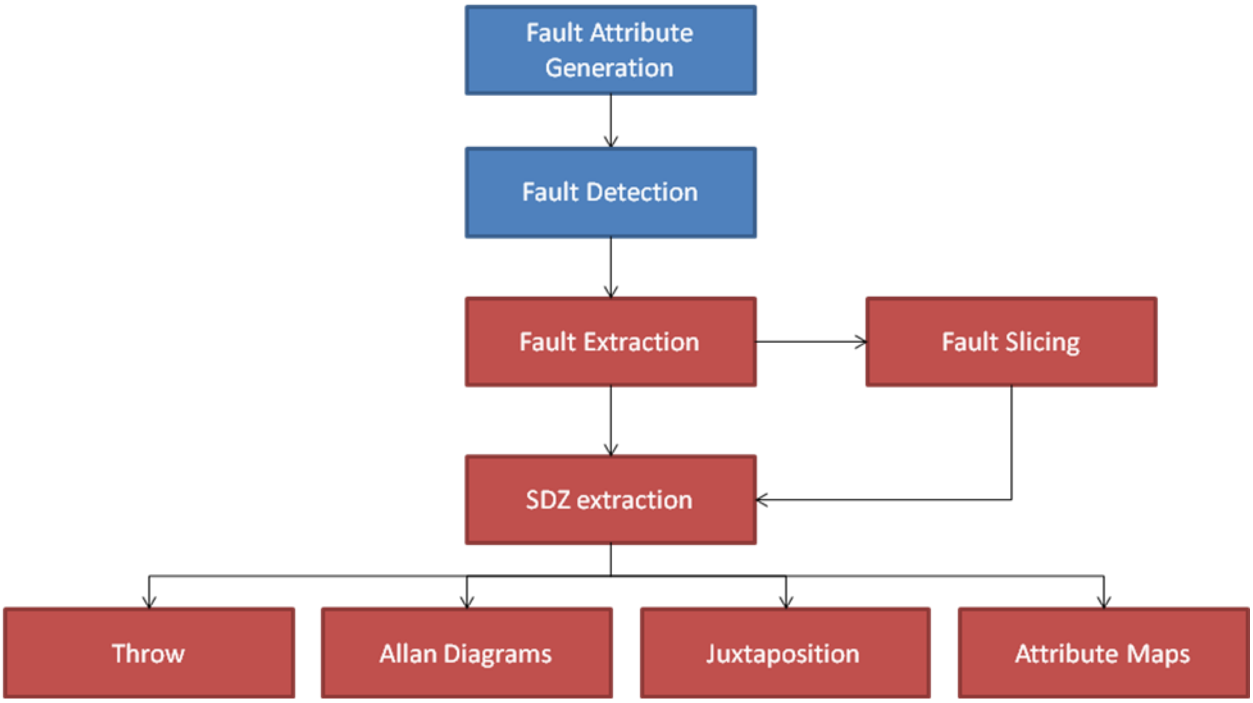

Figure 1 *Workflow for the generation of surface based Fault Analysis. Blue represents the volumetric component of the workflow and Red represents the surface component of the workflow.*

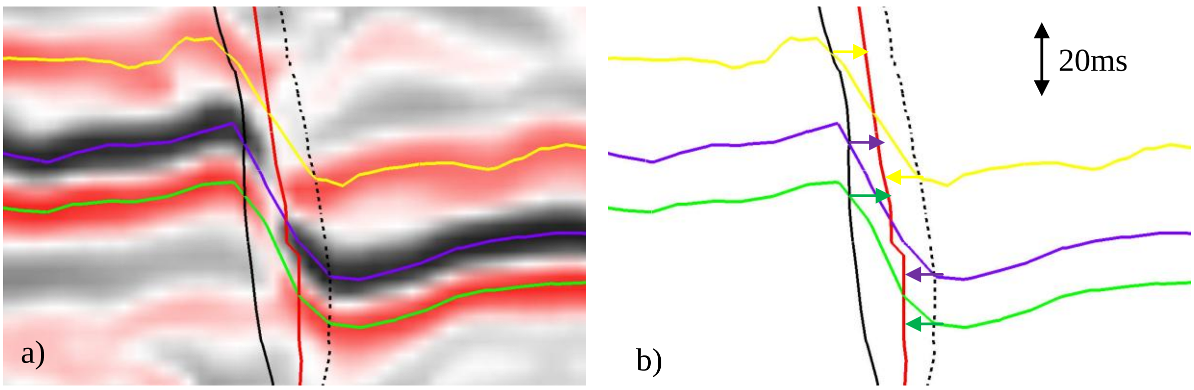

Figure 2 *IL3368 1300m by 100ms. Seismic Damage Zone (SDZ) associated with the fault surface (red line). Solid black line represents the outer limit of the SDZ on the footwall and the dashed black line represents the outer limit of the SDZ on the hanging wall b) The intersection of horizons with the SDZ is used to calculate the Allan diagram and fault throw map.*

Case Study

Figure 3 shows a typical scenario from the Norwegian North Sea where automatic extraction of Normal faults has led to either a single large fault (Model 1) or two smaller faults (Model 2). By considering both the fault throw map and Allan diagram for Model 1(Figure 4) it can be seen that the fault throw goes to zero in the centre (Zone B) of the proposed fault in Model 1. This does not fit classic models for normal faults which see the largest amount of throw in the centre of the fault reducing to zero at the tips (Cowie and Roberts 2001), suggesting instead that it is more likely that we are dealing with two separate faults (Model 2).

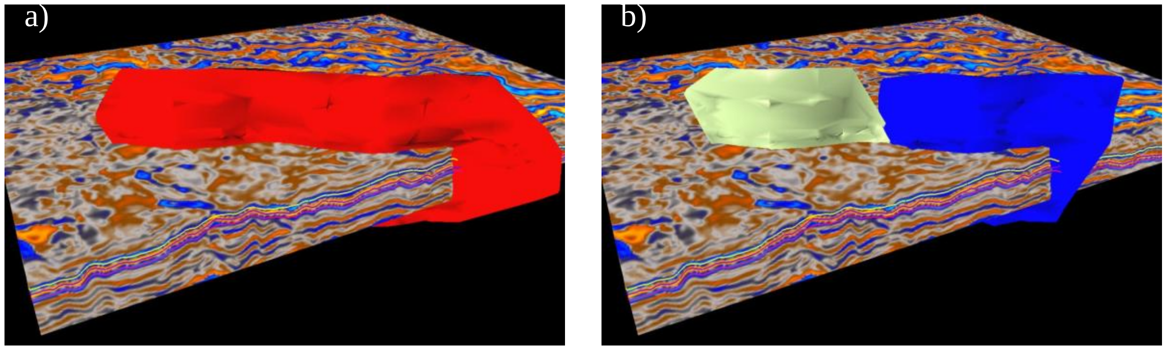

Figure 3 *Extracted fault surface showing a) Model 1 (Fault 1) and b) Model 2 (Faults 2 and 3)*

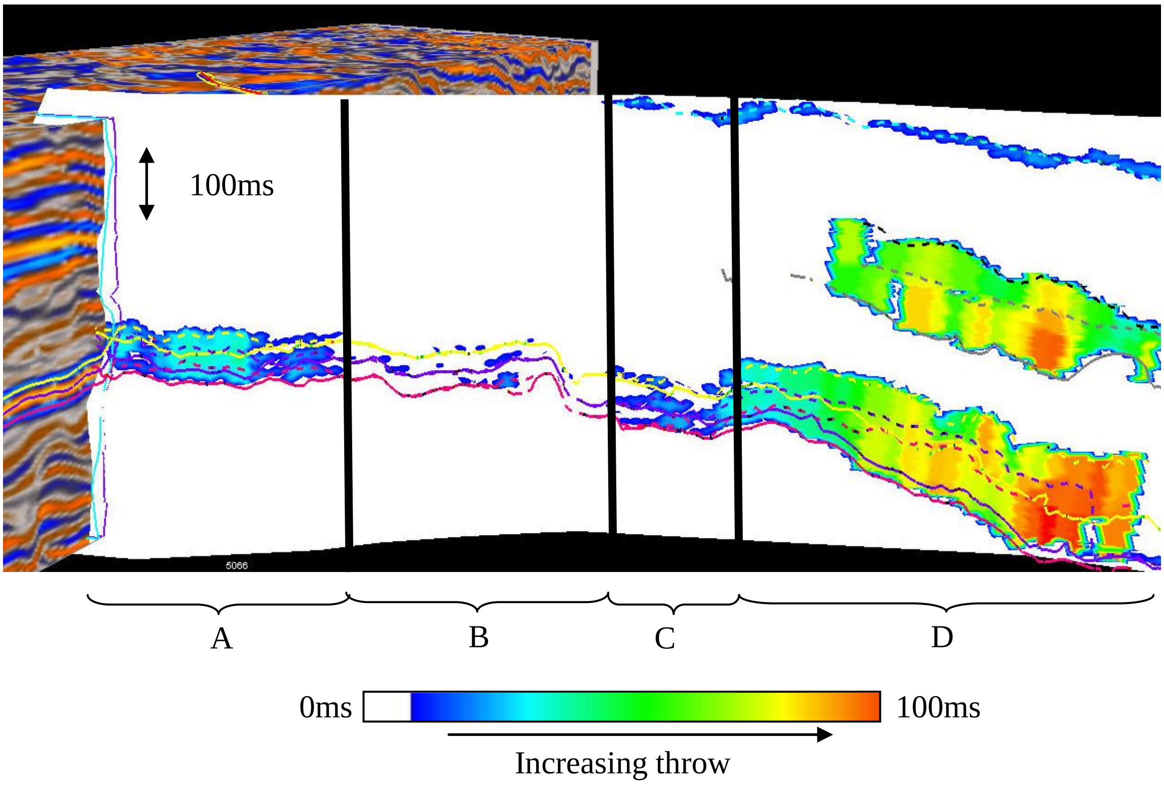

Figure 4 *Combined fault throw map and Allan diagram for the single fault (Fault 1) shown in Figure 3a. Zones A and C represent areas of small throw with partial reservoir contact across the fault. Zone B shows an area of no throw and full contact of reservoir across the fault and Zone D shows a region of large throw with no reservoir contact across the fault. Solid lines represent the intersection of a horizon with the hangingwall and dashed lines represent the intersection of a horizon with the footwall.*

Figure 4 can also be used to interpret juxtaposition based fault seal potential by highlighting areas suitable for fluid migration. Zones A and C both show partial reservoir contact across the fault and therefore some potential for fluid migration. Zone B shows no throw, full reservoir contact and thus high potential for fluid migration. Zone D shows a high throw with no reservoir contact across the SDZ and therefore a high potential for juxtaposition based sealing.

Conclusions

Examining the Seismic Damage Zone surrounding faults and generating fault throw maps and Allan diagrams can be used as a successful workflow methodology for improving the interpretation of faults, their lateral extent and potential to act as a seal or provide a fluid migration pathway. The reduction of throw in the centre of the single fault in Model 1 is clear evidence to suggest that the 2 individual faults in Model 2 are the most likely scenario. Taking this analysis further it is possible to divide the length of the entire faulted zone in to four smaller zones (A – D) of varying seal potential. This information is essential for the detailed understanding and input to reservoir models.

References

Cowie, P.A., Roberts, G.P., 2001. Constraining slip rates and spacings for active normal faults: *Journal of Structural Geology 23, 1901–1915.*

Roberts, G.P., Michetti, A.M., 2004. Spatial and temporal variations in growth rates along active normal fault systems: an example from The Lazio–Abruzzo Apennines, central Italy*: Journal of Structural Geology 26, 339–376*