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Vertical Displacement on Faults Extracted from Seismic, Offshore Nigeria Case Study

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SUMMARY

The determination of the vertical displacement, or throw, of horizons across a fault surface is important to identify potential sealing fault surfaces within a volume. This paper presents a workflow for fault identification, extraction of fault surfaces onto which a fault throw distribution image is projected. This method involves the use of technology that interprets every horizon within a 3D seismic volume to produce a fault throw attribute cube. This paper includes a comparative analysis of traditional fault detection and fault throw imaging methods. The case study describes the faults and their throw distributions extracted from a dataset offshore Nigeria, where this method is applied. When compared to more traditional methods of fault surface picking and imaging the fault throw distribution, this method provides a sensible fault surface and improved spatial imaging of the throw distribution projected onto the fault surface in a time efficient manner.

Introduction

Traditionally, seismic interpretation is a labour-intensive process of manual picking or auto-tracking single horizons within a seismic volume. The method presented in this paper is based on an initial interpretation by PaleoScan™, already used on off-shore seismic data (Gupta et al, 2008). A continuous geo-model is constructed using an algorithm that automatically tracks every horizon within the seismic volume (Figure 1). This optimisation algorithm correlates the seismic trace and moves in directions that lead to a global lower minimum to produce an optimum seismic model. Discontinuity and continuity constraints such as faults or manually picked horizons may be added in order to improve the geo-model horizon tracking (so that the geo-model converges), connect fault blocks and enhance fault positions. The resolution of the automatic horizon extraction of the geo-model is limited by faults and noise in the volume.

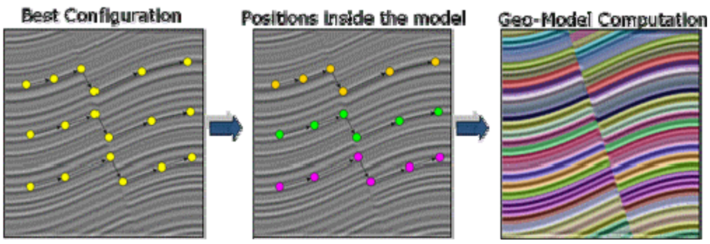

Figure 1: *Extraction of the Geo-Model using an optimisation algorithm.*

A 3D fault throw attribute is one of various independent attributes that may be produced from the geo-model in PaleoScan™. The algorithm used to map the fault geometries in 3D is based on a 'geo-model time differential analysis' method where the throw break points greater than a defined threshold parameter are mapped as an independent fault throw attribute volume in two-way-time (Gupta et al, 2008). The faults in the fault throw attribute cube can be identified as linear features, where the values of throw along these fault features are determined from the vertical displacement of horizons in the geo-model (Figure 2). The fault throw attribute cube produces values of throw in milliseconds. Fault throw calculations on dipping horizons with shallow slopes close to the fault plane are identified and filtered in order to remove the slopes and interpolate the horizon up to the fault plane. The minimum fault throw threshold detected by the algorithm can be parameterised and applied to the volume, dependent on the quality of the seismic. The algorithm threshold permits larger faults to be mapped whilst aiming to avoid the identification of noise that may be mistakenly interpreted as smaller faults, and also allows for the effects of diffraction at the fault edges that may have been left behind due to incomplete migration.

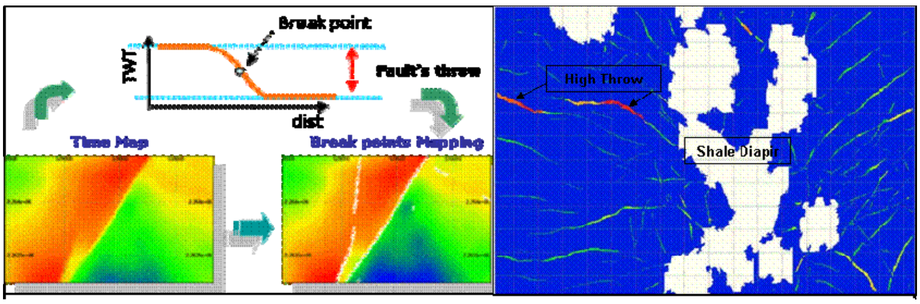

Figure 2: *Geo-Model time differential analysis. Left: throw break points are mapped as an independent fault throw attribute, Right: a time slice through the fault throw attribute cube.*

Method

PaleoScan™ is the first procedure used in this workflow to create a fault throw attribute cube. Ant Tracking is applied directly to the fault throw attribute cube (Pedersen et al., 2003). The automatic fault extraction tool rapidly tracks the faults using either passive or aggressive ants due to the clarity of the attribute cube and the ability of the agents to track coherent fault with little deviation. This direct application does not require any pre-conditioning or stacking of the volume that is often essential when Ant Tracking is used directly on a seismic cube (Carrillat et al., 2004).

Fault surfaces are generated from the Ant Tracking performed on the fault throw attribute cube. These automatically extracted fault patches are then manually merged to form fault surfaces. This is performed in 3D using a picking tool and a dip-azimuth polar plot utility to merge the fault patches (Pedersen et al., 2003). The merged fault patches are then converted to fault surfaces using a convergent interpolation algorithm.

The faults identified in the PaleoScan™ fault throw attribute cube have a value of throw related to the vertical displacement of every horizon in the geo-model volume. This method allows the fault throw values from the fault throw attribute cube to be projected onto the 3D fault surfaces at points across the entire fault surface. In order to capture the maximum throw values within the deformation zone, a search criterion for the maximum throw is applied within a specified time shift of the fault surfaces. The throw attribute is directly imaged or projected in 3D onto the fault surfaces where the throw range is relative only to the throw values on each individual fault. Imaging of individual faults with throw attributes can be examined in order to comment on the resolution of the fault throw.

The fault surface in terms of location (x, y, and two-way-time) and throw attribute value at each point can be exported for statistical analysis. The fault throw values on each fault surface may be imported into graphical software and plots can be made of the throw values across the entire surface. These statistical plots can be used to identify relationships between the fault surface areas represented by the dimensions of the fault (number of points extracted) with the fault throw values. The statistics and improved visual projection of the fault throw distributions onto the fault planes using every horizon from the geo-model can be compared to other current trapping application software that analyse the fault throw distribution statistics along just a few selected horizons.

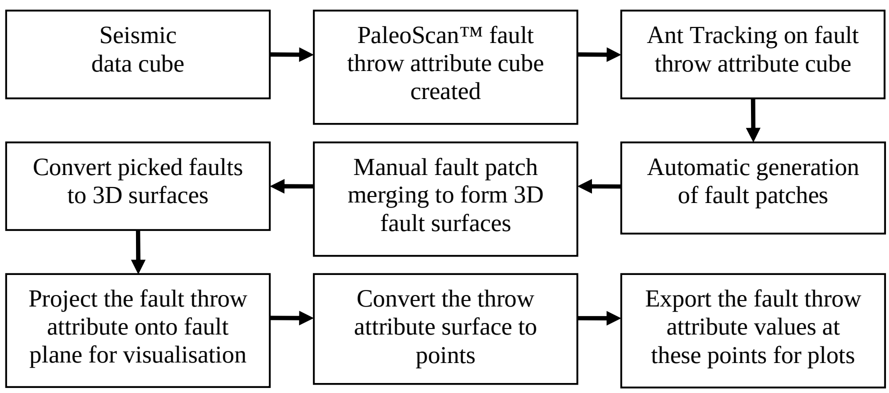

Figure 3: *Flow chart of the methodology for fault surface extraction and fault throw imaging*

Example Case Study Offshore Nigeria

The method of fault surface extraction and throw projection to analyse the vertical displacement across fault surfaces was performed on a 3D seismic data cube, located on the Niger Delta. The quality of the fault throw attribute cube was evaluated, with the purpose of interpreting the faults and the throw distributions within the cube and comparing the results to traditional methods of attribute analysis and throw imaging. The seismic data cube was characterised by discontinuity features such as normal faulting, gas chimneys, and a large shale diapir that makes seismic imaging difficult. A geo-model of the offshore Nigeria seismic data cube and fault throw attribute cube were created using PaleoScan™ (Gupta et al., 2008). The fault throw attribute cube was compared to traditional discontinuity detection attributes like curvature, coherency and similarity applied to the seismic cube. The fault throw attribute cube produced a cleaner cube of identified faults.

The Ant Tracking and merging fault patch extraction process generated fault surfaces that were directly compared with surfaces generated from manually picked faults. Quality checks against the manual interpretation included the accuracy of the locations and dimensions of the fault surfaces, and continuity with the original seismic volume. This workflow generated the fault surfaces over a shorter time period than manual interpretation.

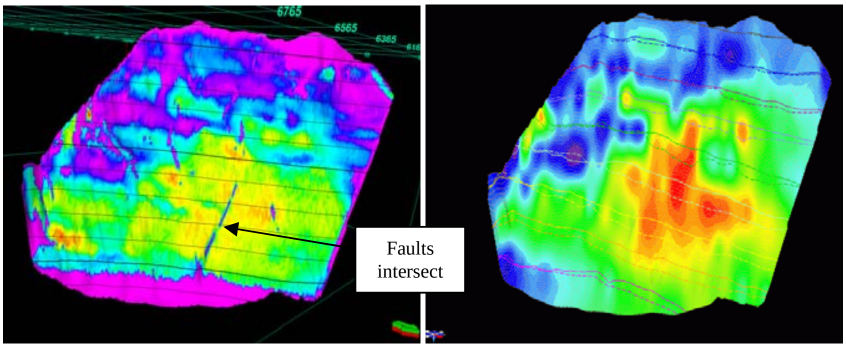

Figure 4: *Left: Fault surface with throw distributions extracted using the workflow. Right: Fault with throw distribution created traditionally using a number of horizons and interpolation in TrapTester. Hot colours (red) represent high relative throw values to colder (blue/purple) low throw values.*

The resolution of the fault throw distributions as projected images onto the fault surfaces using all the horizons tracked by the PaleoScan™ geo-model, were compared to an analysis using traditional method of fault throw projection that interpolated the throw between a limited number of horizons (Figure 4). The fault throw distribution images had better vertical and horizontal resolution across the fault plane when compared to conventional methods. Furthermore, the throw distribution could also be directly measured in any orientation at any location on the fault to aid accurate well planning. The throw images characterised in this cube featured intersecting faults, reactivation evidence and clusters of maximum throw nucleations suggesting that the region is structurally complex.

The statistics of the fault throw distributions were investigated for relationships between the fault size and maximum fault throw values, and statistical correlations between faults in the cube (Bailey et al., 2005). A frequency plot where the throw is extracted at points over the entire fault surface area using the current workflow is compared to a plot of the maximum throw related to the fault length along selected horizons (Figure 5). The traditional method generates numerous plots for fault seal analysis where the faults length is measured along the selected horizons, but the area method produces a clear single fault throw distribution plot for each fault.

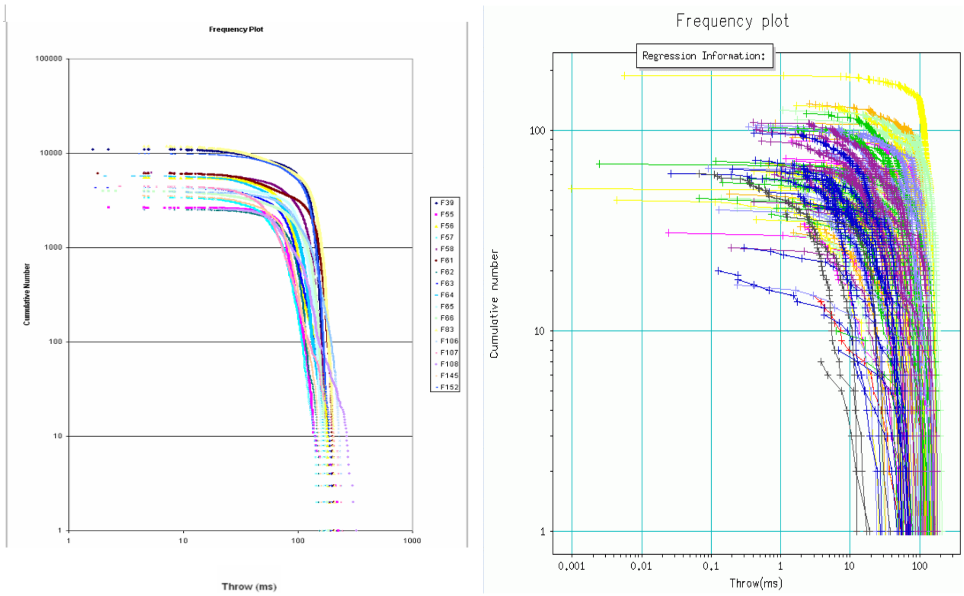

Figure 5: *Frequency plots, a statistical comparison of the throw of 17 faults. Left: throw extraction points over the entire fault surface, Right: TrapTester throw extraction along selected horizons.*

Conclusions

This case study showed valid time-efficient fault surface extraction, improved spatial resolution of the fault throw distribution image projected onto the fault surfaces and concise statistical analysis when compared to alternative current methods. These improvements are due to the method in which the fault throw attribute cube is obtained from the geo-model onto which Ant Tracking is directly applied. This result suggests that the workflow may be useful for projects where detailed fault throw analysis is required to identify potential sealing faults, in geo-steering and well placement applications.

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