# Automatic Fault Extraction (AFE) in 3D Seismic Data

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**Abstract**

Fault interpretation remains one of the most time-consuming aspects of 3D seismic interpretation. Faults are still most often manually picked as discontinuities in seismic amplitude. There have been several attempts to automate fault interpretation in the past that have failed to deliver acceptable interpretations with less effort in less time than manual methods. In general, these methods have required very high quality data sets with very simple fault geometries and significant user correction. Automatic Fault Extraction (AFE) is designed to automatically interpret fault surfaces from a 3D coherency volume. These surfaces can then be used to help constrain and improve the performance of horizon auto tracking and segmentation algorithms, minimizing problems with miscorrelation across faults in the data.

**Introduction**

Traditionally faults are picked in 3D seismic volumes as discontinuities in seismic amplitude on sections and time-slices, or more recently from time-slices of a seismic coherency volume. Interactive tools have been developed to assist the interpreter in this process (e.g., Landmark's F-ZAP and MagicEarth's ezFault). More recently, Hale (2001) has published results of research focused on automatic meshing that could be applied to fault interpretation, and Pedersen et. al. (2003) have described a semi-automatic process for extracting faults using "ant tracking" on a discontinuity volume. However, no generally applicable tool has previously been developed to automatically interpret fault surfaces from 3-D volumes.

Automatic Fault Extraction (AFE) is a process designed to automatically interpret fault surfaces from 3-D seismic coherency volumes. The benefits of this process include:

- Reduced interpreter time spent in 3-D fault interpretation
- Consistent and accurate interpretation of 3-D fault surfaces
- Improved horizon auto tracking by providing interpreted fault surfaces as a constraint

Several processing steps are applied to the coherency volume to improve the imaging of fault surfaces, followed by processes to automatically track the fault polylines on vertical and horizontal slices through the volume. These fault polylines are then either manually or automatically linked into named fault surfaces.

This process may be applied at the start of interpretation to pick the major fault surfaces throughout the volume prior to horizon auto tracking and geobody segmentation. It may also be applied later in the interpretation process to portions of the volume of particular exploration and development interest. Depending on the quality of the input data, and the focus of the automatic fault extraction, the selection of input parameters will typically vary.

**Workflow**

AFE uses signal processing technology combined with intelligent geologic rule based steps and a suite of automatic and interactive tools to enable automated and semi-automated fault interpretation in less time and with much less effort than completely manual methods. The input to AFE is a 3D volume of seismic data that has been processed to show discontinuity rather than reflection amplitude. The output is a volume of relative fault probability, fault polylines and fault surfaces. Any discontinuity attribute may be used for input. The examples used in this paper show results from a 3D seismic surveys offshore Indonesia and in the North Sea in areas of complex faulting.

The workflow in AFE is comprised of a combination of batch and interactive processes:

- Coherency (discontinuity) calculation
- Residual acquisition footprint removal and lineament enhancement attribute
- Fault enhancement attribute and extraction of fault polylines on horizontal slices
- Extraction of fault polylines on vertical slices
- Linking fault polyline into named fault surfaces

The first three steps are performed in a batch mode after parametric tests have been conducted to optimize control parameters for each step. The coherency calculation, lineament enhancement and fault enhancement steps all produce attribute volumes that are themselves useful in the interpretation process. The final three steps may be automatic or highly interactive depending on the specific data set and interpretation problem.

**Input – Coherency**

Coherency was publicly introduced to the industry by Amoco (Bahorich and Farmer 1995). The method outlined used cross correlation techniques on a 3D volume of seismic data. The coherence attribute shows the similarity at each point in a seismic volume to the neighboring points. This attribute accentuates discontinuities in the input 3D amplitude volume. Discontinuities may indicate faults, channels, angular unconformities, pinch outs, the edge of the survey, changes in lithology, pore fluid, pore pressure or elastic properties. The technique also illuminates survey, acquisition and processing problems. The initial process has been improved over time through the implementation of a semblance measure (Marfurt et al 1998), a Modified EigenStructure algorithm (Marfurt et al, 1999, and high-resolution eigen algorithm. An example of the Modified EigenStructure algorithm versus a correlation algorithm is shown in Figure 1 on data from offshore Indonesia.

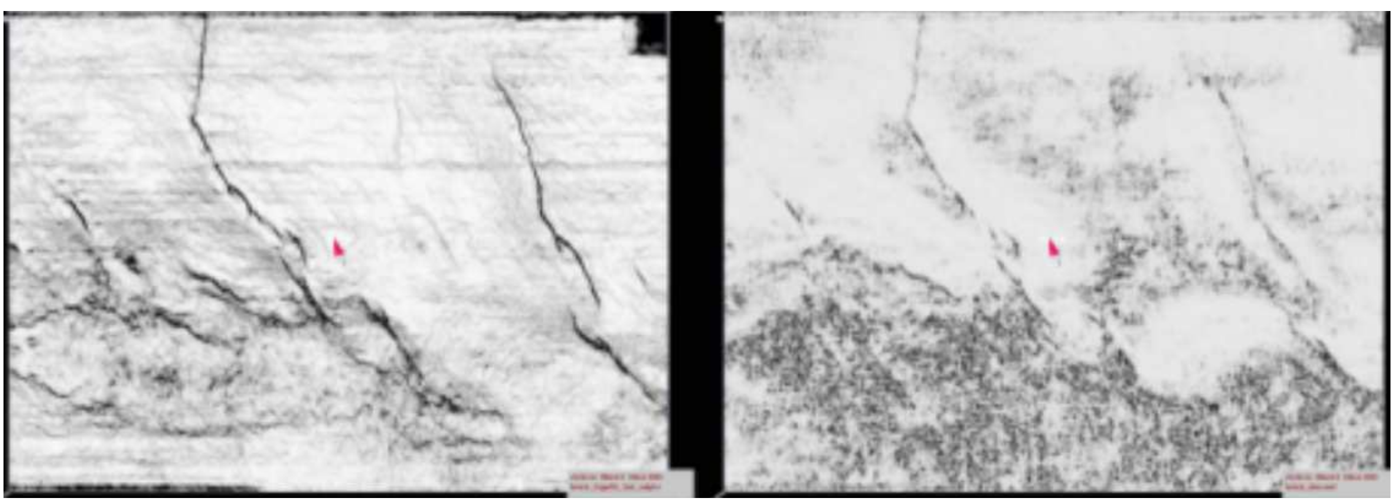

Figure 1: Modified EigenStructure on the left versus competitive “discontinuity” at right for time slices at 600 ms.

**Automatic Fault Extraction**

Coherency volumes will typically show some acquisition footprint as stripes on time and depth slices. The first step in the AFE workflow estimates the remnant acquisition footprint by applying a classical de-striping operator to estimate and remove any stripes on each time or depth slice. The output represents the de-striped coherency of the input.

This volume is then processed to enhance linear features on each time or depth slice. A linear feature associated with a fault is expected to display some minimum length where the continuity value is low. Each sample in a slice is examined with a window of adjacent samples to see if a linear segment can be created that links the samples of low continuity to form a line segment. The output of this step is a relative probability volume, where each sample represents the relative probability that it belongs to a horizontal linear feature. Filters can be set to limit the azimuth range or to exclude linear features that fail to reach a suitable length. This volume can be viewed and quality controlled by any 3D interpretation system. Examples are shown in Figure 2 for a 3D survey in the Wytch Farm field, offshore, UK.

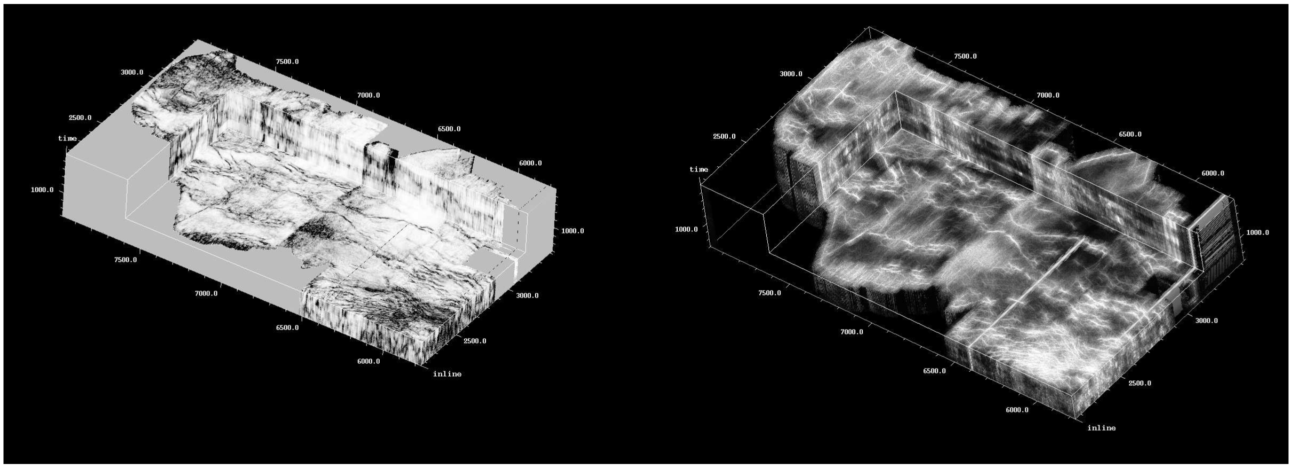

Figure 2: Left is a Coherency volume. Right is a line enhanced relative probability volume.

The output volume from line enhancement is then input to the fault enhancement process which performs similarly, except linear features are traced in time or depth as well as azimuth. This step filters out linear features due to channel boundaries, pinch outs, and unconformities, none of which have substantial vertical extent. This step produces the fault enhanced volume with a scale of relative probability that each sample belongs to a dipping fault surface (e.g., Figure 3, for the data from Wytch Farm).

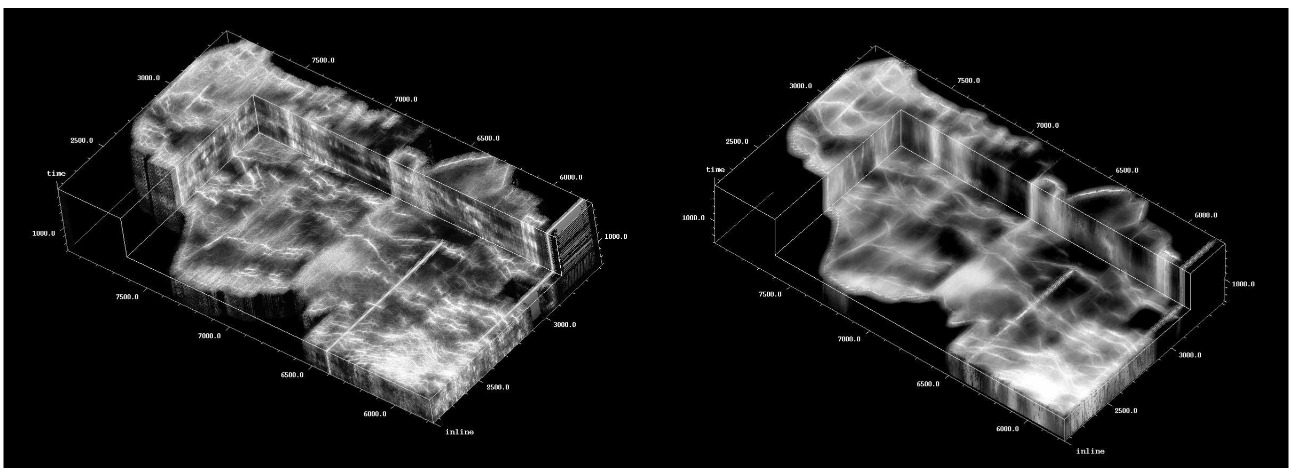

Figure 3: Left is a line enhanced relative probability volume. Right is a fault enhanced relative probability volume. Notice in particular the improved continuity and signal to noise ratio for faults on the vertical sections in the volume.

Coherency is frequently discontinuous on vertical sections. The relative fault probability volume enhances the apparent continuity along fault planes. Another result is to remove patches of low coherency that are not planar or that fail the size test.

Fault polylines are automatically picked from these volumes, and are output to the fault interpretation repository and may be used by any 3D interpretation system. The next steps link these polylines up in 3D space, segregate them into separate faults, and produce named fault surfaces. Each of these steps may be performed automatically or interactively in a 3D interpretation program. The automatic process filters polylines by azimuth ranges, removes polylines less than a given size and joins polylines that are almost co-linear. The process is repeated on vertical sections to create a polyline set for in-lines, cross-lines or both. These polyline sets can also be filtered using dip masks, length criteria and nearly co-linear polylines can be joined. The last step links the polylines from horizontal and vertical slices to form fault surfaces. These surfaces may be filtered to remove faults with a vertical size or a horizontal size less than a user-defined threshold. The results of this process are shown in Figure 4 for the data from offshore Indonesia.

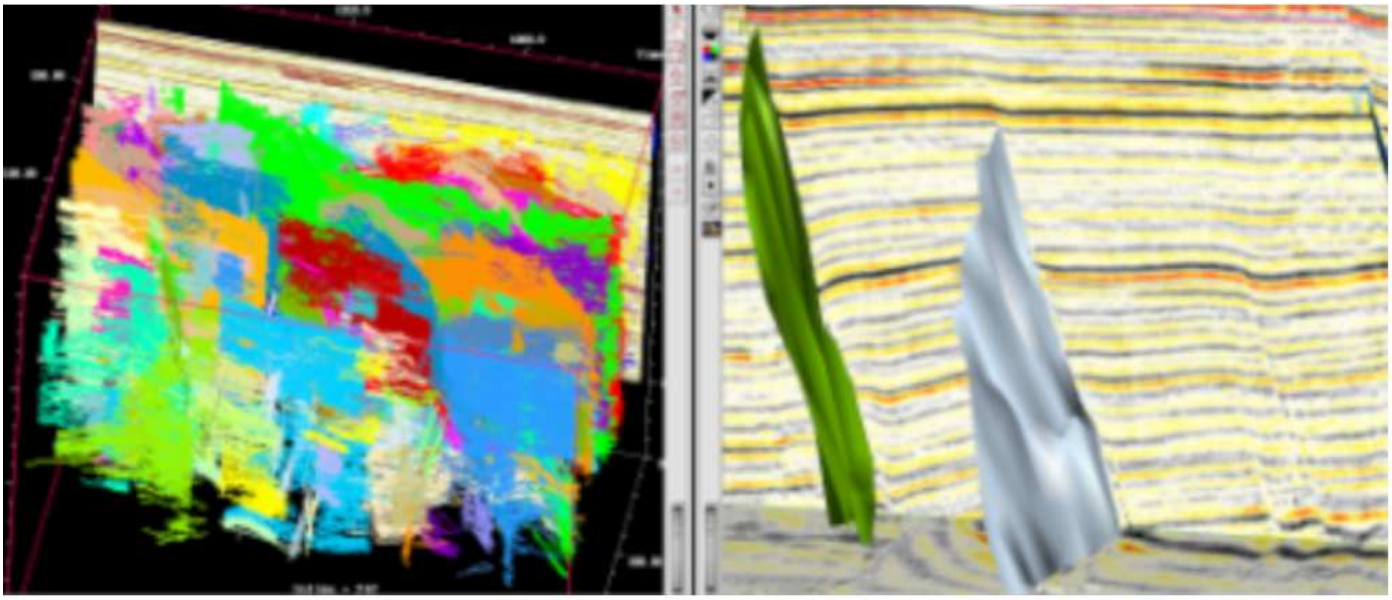

Figure 4: Left, all fault picks. Right, two selected fault surfaces.

## Conclusions

By using AFE to prepare fault probability volumes, interpreters can automatically pick faults in 3D. The faults are well-defined, which supports improved automated horizon picking, which in turn can help with interpretation of more minor faults. Automatic interpretation of faults is a very complex process, but by using Automatic Fault Extraction, the interpreter can produce reliable, detailed 3D fault interpretations.


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