Anomaly detection and visualization using color-stack, cross-plot, and anomalousness volumes.  
Tracy J. Stark*, Stark Reality Inc.

Summary

The search for hydrocarbons can be viewed as an anomaly detection and isolation problem. In general the largest anomalies have already been found; the large bright spots, flat spots and structures. Tools and methodology to find the smaller anomalies are now required.

This presentation discusses a general technique of using cross-plot, anomalousness and color-stack volumes in combination with visualization software to help detect, and isolate anomalies that might otherwise “slip through the cracks”. The visualization software performs real-time volume sculpting by modifying the opacity lookup table of the anomalousness volume (which is used as a classification volume).

The techniques will be illustrated using partial and full stack data over a 1000 ms window from a marine 3D data set. These partial and full stack volumes will be used to create the color-stack, cross-plot, and anomalousness volumes, which in turn will be used in visualization software for the anomaly detection. The methods discussed are not limited to the type of data used in this presentation, but with this type of data, more than one class of AVO anomaly is detectable.

Introduction

This paper has four main topics. I will start with a review of how to generate a color-stack volume. This will be followed by a discussion of how the cross-plot and anomalousness volumes are generated. The majority of the presentation time (but not of this abstract) will be spent on the visualization techniques applied to these volumes such that we are able to better detect and visualize anomalies. I will wrap up with how these techniques might be expanded.

Color-Stack Generation

It has been over twenty years since a color-stack section was first shown at an SEG (Onstott et al, 1984). Unfortunately, few have probably been seen since, so I will provide a brief review of its generation. Figure 1 contains a representative full-stack crossline from the 3D data volume used for this presentation. The line contains 507 traces with 1000 ms of data. This data are displayed using a gray scale. There are 1192 such lines in this volume, which covers a little over 300 km².

In figure 2 the near, full, and mid stack data are displayed using the primary colors of red, green, and blue respectively. The color scale used is symmetrical about zero, which obscures the event polarity. Onstott et al overcame that problem by making the troughs appear as dashed events. However, dashed events do not work that well when generating an entire volume of color-stack sections, particularly when this volume will be displayed using volume visualization software. Since modern visualization software and hardware allow for the interactive modification of the color table, this functionality can be used to easily identify the data polarity.

In figure 3 the individual partial and full stacks of figure 2 are stacked in color. Events that are white and gray are of equal strength on all three stacks. Events that are red to yellow are stronger on the near stack than they are on the mid stack, while events that are blue to cyan are stronger on the mid stack than they are on the near stack. The magenta events are those that are strong on both the near and mid stacks, but weak on the full stack; therefore magenta events imply polarity reversals.

Notice that the cyan flat event is much more pronounced on the color-stack of figure 3 than it is on any of the other displays. As the cyan color implies, this event is not present on the near stack volume.

There are other applications of the color stack besides AVO anomaly detections. The color-stack is also good for identifying velocity problems; residual moveout causes an event to have color fringing at the zero crossing. In addition, there often will be an event, or a set of events, that exhibit a distinct color that can be used in correlating across faults.

Cross-plot and anomalousness volumes

Generating and using cross-plots to identify anomalies, particularly AVO anomalies, is not new. However, the types of 3D cross-plot volumes I am generating have a few differences from the ones described by Ross and Sparlin (2000), whom I believe are the first to promote the generation of a volume of cross-plots.

Figure 4 contains a volume of 2D cross-plots generated from the near and mid stacked volumes. The x and y dimension of the volume in Figure 4 are each 256, representing the 256 amplitude values of the 8-bit seismic data. The vertical dimension is 250 points, representing the 250 time samples of the partial stacked volumes. Each time slice in the cross-plot volume of figure 4 corresponds to a time slice in the near & mid volumes. The values (i.e. colors) contained in this cross-plot volume represent the
number of times that particular near-mid amplitude combination occurred on that particular time slice. This cross-plot volume is displayed such that all amplitude pairs with less than 10 occurrences are rendered transparent. The crenulations on this cross-plot “worm tube” are related to the vertical changes in geology.

There are three main differences between this volume of cross-plots and the ones generated by Ross and Sparlin. First, I use a time slice instead of a time window from an inline or cross-line. Therefore these displays highlight vertical changes in AVO behavior versus the lateral changes that Ross and Sparlin were illustrating. Second, my cross-plot space is a 256 by 256 matrix to correspond to the input 8-bit amplitude volume. This produces some limitations, but it allows for my third difference. The third difference is that I am able to easily keep track of the number of times a particular amplitude pair is found within the time slice used to generate the cross-plot. As a result, I am able to use this cross-plot volume to build a classifier volume to interactively hunt for the AVO anomalies.

The large “arms” on figure 4 are caused by the flat event seen in figure 2. The “spikes” are due to the differential mute on the near and mid partial stack volumes. There are some traces that only appear on the near stack, while there are others that only appear on the mid stack.

A top down view of this volume (figure 5), and a slight change in the rendering parameters show that there are other anomalies besides the large “arms” and spikes.

The cross-plot volume is used to generate an anomalousness cross-plot volume, which is then used to generate an anomalousness seismic volume. This anomalousness seismic volume will have the same dimensions as the seismic volume, but its attribute value at each point is related to the anomalousness measure.

The cross-plot volume can be used as the anomalousness cross-plot volume without any modification. Alternately, the shape of the histograms can be used to produce an anomalousness cross-plot volume. One way to generate such a volume is to model the histogram on each slice, and use the difference between the model and actual values as the anomalousness measure. Such a procedure (as well as the removal of most of the differential mute caused spikes) was used to generate the volume shown in figures 6 & 7. All amplitude pairs in this volume have been assigned anomalousness values. In figure 7, only the points with the highest anomalousness values are opaque, while the low anomalousness values are semi-transparent. The opacity curve, based on the anomalousness value, is used to determine which of the points are displayed.

Once the anomalousness cross-plot volume is generated, it is used to generate an anomalousness seismic volume. The value for each inline, crossline, traveltime location in the anomalousness seismic volume is determined by the value in the anomalousness cross-plot volume associated with the near-mid amplitude combination of that point. In essence the anomalousness cross-plot volume is used as a large look-up table to assign the appropriate values to all of the locations in the anomalousness seismic volume.

Classification volume visualization

Now to tie all of this together. The anomalousness seismic volume just generated can be volume visualized to identify the spatial positions of the different AVO anomalies. However, a straightforward visualization of this volume does not produce the optimum results. Depending upon how the anomalousness was defined, there can be several locations that have the similar anomalousness values, but belong to different AVO classes. By combining the anomalousness volume with the color stack volume and using a modified version of the opacity classification technique described by Stark 2004, the anomalies can be isolated and the AVO attributes identified.

For visualization purposes, a volume containing four 8-bit fields is generated. In this case three of the fields contain the near, full and mid trace stacks, while the fourth field contains the anomalousness values. The anomalousness values are used as a classification volume and they determine the opacity of the resultant display, while the other three fields are used to determine the color of the displayed points. If the opacity of each anomalousness value is either on or off (transparent or opaque), then the color of the visible points will indicate where they reside in AVO space (i.e. color-stack space).

Figure 8 is such a display. Only the most anomalous points for a portion of the volume are shown. The predominant cyan color indicates that these points are strong on the full and mid stack, but essentially absent on the near stack. Their spatial geometry indicates that they are laterally pervasive. Since this is a map view, it is not possible to discern the different travel times of the cyan and other AVO anomalies. Motion (or better yet stereo displays) of the rendered volume allows the interpreter to distinguish the spatial locations of the different anomalies. As the amount of anomalousness is relaxed, simply by changing the opacity curve, more points become visible. If desired, this can be accomplished in near real-time by using an appropriate volume graphics hardware and software combination.
Anomaly detection and visualization

Conclusions and Discussion

In this presentation near, full and mid partial stack volumes were used to identify AVO anomalies. Near, mid, and far partial stack volumes might have been a better choice, but they were not available. The color-stack technique works best with three volumes, but can also be used with just two volumes. If near, mid, and far partial stacks are available, the cross-plot volume could be extended to a 3D volume per time slice. Depending upon how the anomalousness is generated, this could provide a much better identifier of the anomalies. Other volumes typically used in AVO work (such as A-B or slope-intercept) could be substituted for the near and mid stacks used to generate the cross-plot volume.

The method was described using partial stack volumes, but any two or three attribute volumes could also be used. The interpretation of the results would of course be different.

In the interest of time, not much time was devoted to how the anomalousness was calculated. For the end results this is a crucial step, but for the discussion of the current anomaly detection technique the particular method employed is generally immaterial. A whole other paper could be devoted to different anomalousness calculation methods. Any particular method should be tailored to the data used to generate the cross-plot volume. The more the modeling technique “understands” or includes the changing background trend with travel time, the better the results.

The modeling used to generate background and therefore the anomalies also contains information. Depending upon how it is generated, it could be giving information on the general change in geology (i.e. rock properties) with travel time.

In general, I believe that generating the cross-plot per time slice is better than per inline or per crossline. This assumes that the background trend is significantly more dependent upon travel time than spatial position. As a result, the anomalies will be easier to detect from time slice generated cross-plots.

For this particular study, a TeraRecon Volume Pro 1000 volume rendering graphics board was used in a Sun Blade 1000 and a Sun Blade 2500. Implementation of the real-time anomalousness volume sculpting was relatively easy using this hardware combination. Implementation effort using other hardware combinations is unknown.

References


Acknowledgements

Forest Oil provided the data used in this presentation. Sun Microsystems provided workstations on which this work was performed and TeraRecon provided VolumePro 1000 boards that allowed the real-time volume sculpting based on the classification volumes. STARK Research provided the funding and technology.
Anomaly detection and visualization

Figure 2: 32% squeezed version of individual lines used to generate the color stack shown in figure 3. The near range stack is shown in red, the full stack in green, and the mid range stack in blue. These three displays are “stacked” in color to generate figure 3.

Figure 3: Dual polarity color stack using the near, full and mid partial stack volumes. The polarity is currently obscured due to the color scale utilized. Note the flat cyan event – it represents an event that is strong on the full and mid stacks, but not present on the near stack. See text for more description of the colors.

Figures 4 and 5: Perspective (left) and top down (right) views of the near-mid cross-plot volumes. The vertical axis of the perspective figure represents travel time. In the top down figure, the mid stack amplitudes are plotted on the horizontal axis while the near stack in on the vertical axis. The colors represent the number of times a particular amplitude pair was found.

Figures 6 and 7: Anomalousness cross-plot. This volume was derived from the cross-plot volume shown in figures 4 and 5. The anomalousness is calculated based on the trend of the data in each time slice using a simple model of the 2D histogram. The figure on the right shows how the most anomalous points are isolated using opacity filtering.

Figure 8: Map view of a portion of the anomalousness filtered color-stack volume. Only the most anomalous points in this portion of the volume are rendered opaque. The color stack of the opaque parts helps identify the types of AVO anomalies.