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Image segmentation for tracking salt boundaries

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ABSTRACT

Image segmentation can be used to track salt boundaries when the salt boundary amplitude is greater than any other local reflections. We apply a modified version of the normalized cut image segmentation method to partition seismic images along salt boundaries. In principle our method should work even when the boundaries are not continuous, and conventional horizon tracking algorithms may fail. Our implementation of this method calculates a weight connecting each pixel in the image to each pixel in a local neighborhood. The magnitude of the weight is inversely proportional to the size of the maximum instantaneous amplitude along the shortest path between the two pixels. This method is demonstrated to be effective on two simple models and 2D seismic section.

INTRODUCTION

Salt boundaries are often the brightest, most prominent reflections in a seismic image. For many processing applications, this boundary needs to be tracked. However, this reflection can be discontinuous, making it difficult for traditional amplitude based auto-pickers to track. Here, we present a tracking method that can handle these issues.

Hale and Emanuel (2003, 2002) applied the normalized cut image segmentation method developed by Shi and Malik (2000) to paint a coherency based reservoir model. Our approach is very similar. This image segmentation technique creates a matrix containing weights relating each pixel to every other pixel in a local neighborhood. The matrix is then used to cut the image where the normalized sum of weights cut is minimized. We have modified the weight calculation to be inversely proportional to the absolute value of the complex trace (instantaneous amplitude) of the seismic. This makes the weights very weak at salt boundaries, causing the segmentation algorithm to cut along the boundary.

In this paper, we give a very general overview of the normalized cut segmentation technique. We then describe how we modified it for application to salt dome seismic data. We test this technique on simple models illustrating its efficacy with discontinuous salt boundaries. We also apply this method to a 2D field section where the amplitude is inconsistent and challenging to pick. Methods for dealing with noisy data are also presented.

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SEGMENTATION METHODOLOGY

The normalized segmentation method described by Shi and Malik (2000) is designed to look for clusters of pixels with similar intensity. To do this, it first creates a weight matrix relating each pixel to every other pixel within a local neighborhood. The strongest weights will be between pixels of similar intensity and close proximity to each other. The method then seeks to partition the image into two groups, A and B, by minimizing the normalized cut:

$$\mathrm{N_{cut}} = \frac{\mathrm{cut}}{\mathrm{total_A}} + \frac{\mathrm{cut}}{\mathrm{total_B}} \tag{1}$$

where cut is the sum of the weights cut by the partition. $total_A$ is the total number of weights in Group A, and $total_B$ is the total number of weights in Group B. Normalizing the cut by the total number of weights in each group prevents the partition from selecting overly-small groups of nodes.

The minimum of N_{cut} can be found by solving the generalized eigensystem:

$$(\mathbf{D} - \mathbf{W})\mathbf{y} = \lambda \mathbf{D}\mathbf{y} \tag{2}$$

created from the weight matrix ($\mathbf{W}$) and a diagonal matrix ($\mathbf{D}$), with each value on the diagonal being the sum of each column of $\mathbf{W}$. The eigenvector ($\mathbf{y_2}$) with the second smallest eigenvalue is used to partition the image by taking all values greater than zero to be in one group, and its complement to be in the other.

Application to seismic

To apply this segmentation method to seismic data, the weight calculation needs to be modified. Rather than looking for clusters of pixels with similar intensity, we are now looking for groups of pixels on each side of the bright amplitude salt boundary. Therefore, we want the weights connecting pixels on either side of the salt boundary to be low and the weights connecting pixels on the same side of the salt boundary to be relatively high. Taking the negative of the maximum amplitude along the shortest path between two nodes as the weight would insure that the weights connecting pixels on either side of the salt boundary will be low. However weights on the same side would be alternating from low to high as they go from peak to trough on the seismic data. This could make the grouping more uncertain. To correct this problem, we take the negative of the maximum of the absolute value of the complex trace (instantaneous amplitude) along the shortest path between two nodes.

If two pixels happen to be adjacent to each other, then it doesn't make sense to take the minimum of the two as the weight. This would make the weight connecting pixels within the boundary itself extremely weak, causing the segmentation algorithm to fail. Our solution is to set the weight equal to unity for adjacent pixels. This puts emphasis on the relative difference between weights calculated from pixels that are not adjacent to one another.

Alternatively, for pixels that are adjacent to one another, we can make the weight a function of similarity in intensity, similar to the standard implementation of the segmentation method.

For instance, the weight connecting two adjacent pixels, $Pixel_1$ and $Pixel_2$ can be calculated as:

$$\text{Weight}(1,2) = 1 - \sqrt{(\text{Amplitude}(\text{Pixel}_1) - \text{Amplitude}(\text{Pixel}_2))^2}. \quad (3)$$

This causes weights parallel to the reflections to be stronger, making it more likely to partition along reflections. Thus far, both of these approaches give similar results.

TEST CASES

We applied this segmentation technique to two simple models of salt boundaries and a 2D field seismic section. The first model tests a simple continuous salt boundary. The second model introduces a discontinuity into the salt boundary that would cause conventional auto-trackers to fail. Finally, the 2D seismic section tests this method on real data with a salt boundary that would be difficult for conventional trackers to follow.

Simple Amplitude Boundary

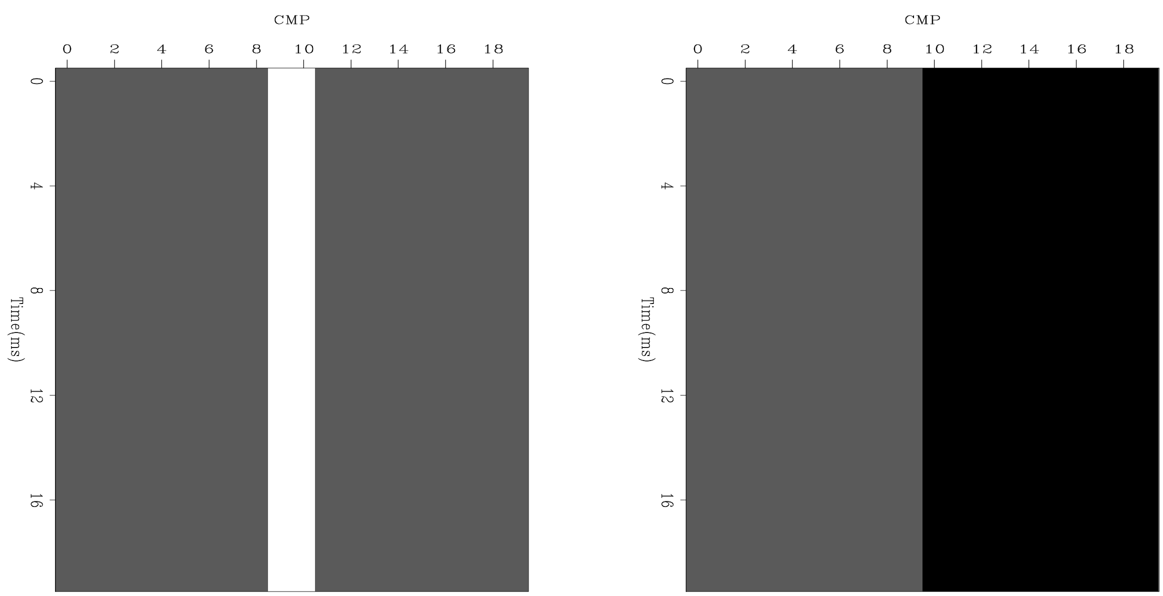

Figure 1: Left is a simple model of a high amplitude salt boundary. Right is the partitioned output of the segmentation method. jesse1-mod1 [ER]

On the left in Figure 1 is a simple model of a salt boundary. The vertical stripe in the middle is the high amplitude salt reflection. The results of the segmentation method can be seen on the right. The pixels have been partitioned into two groups, one on either side of the boundary.

On the left in Figure 2 is the same simple model as Figure 1 yet with a discontinuity. Notice that the output result on the right partitions the image across the discontinuity. Although only

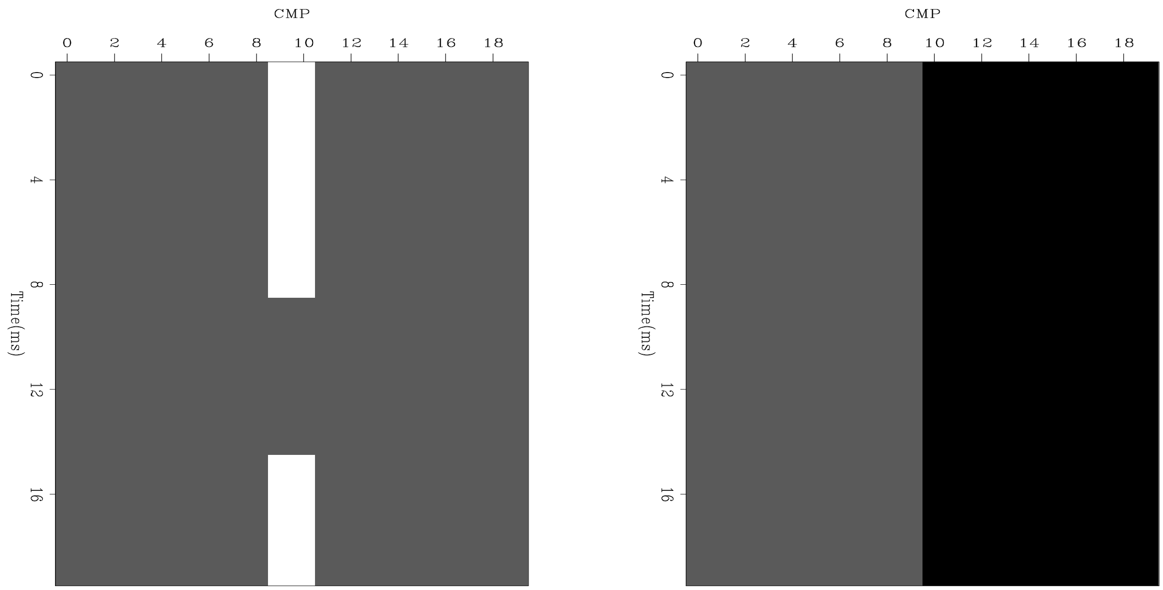

Figure 2: Left is a simple model of a high amplitude discontinuous salt boundary. Right is the partitioned output of the segmentation method. jesse1-mod2 [ER]

a simple test case, this demonstrates that this segmentation method can successfully partition data where the amplitude is discontinuous.

The resulting $\mathbf{y_2}$ eigenvector for the discontinous model is shown on the left in Figure 3. It is this eigenvector that is used to partition the data. The splitting point is at zero. All values greater than zero will be in one group and all values less than zero in the other group. However, a practical measure recommended by Shi and Malik (2000) is to calculate the normalized cut at several splitting points across the eigenvector and take the minimum. On the right in Figure 3 is a contour plot of the $\mathbf{y_2}$ eigenvector. Each contour can be thought of as the partition for a different splitting point. Notice that the contours are spread out in the area of the discontinuity. Here the algorithm is unsure of where to track the salt boundary and basically opts for the shortest distance.

Field Data

We applied this normalized cut method to the Unocal Gulf of Mexico field data shown in Figure 4. The salt boundary is at approximately 3200 ms. The instantaneous amplitude is shown is Figure 5. Notice that it isn't too obvious where to pick the salt boundary near Cmp 13500.

The resulting $\mathbf{y_2}$ eigenvector is shown in Figure 6 and a contour plot is shown in Figure 7. Notice that the contours are spread in areas where the amplitude of the salt boundary is low and the tracking is therefore less certain.

Lastly, Figure 8 shows the instantaneous amplitude with the partition with the minimum

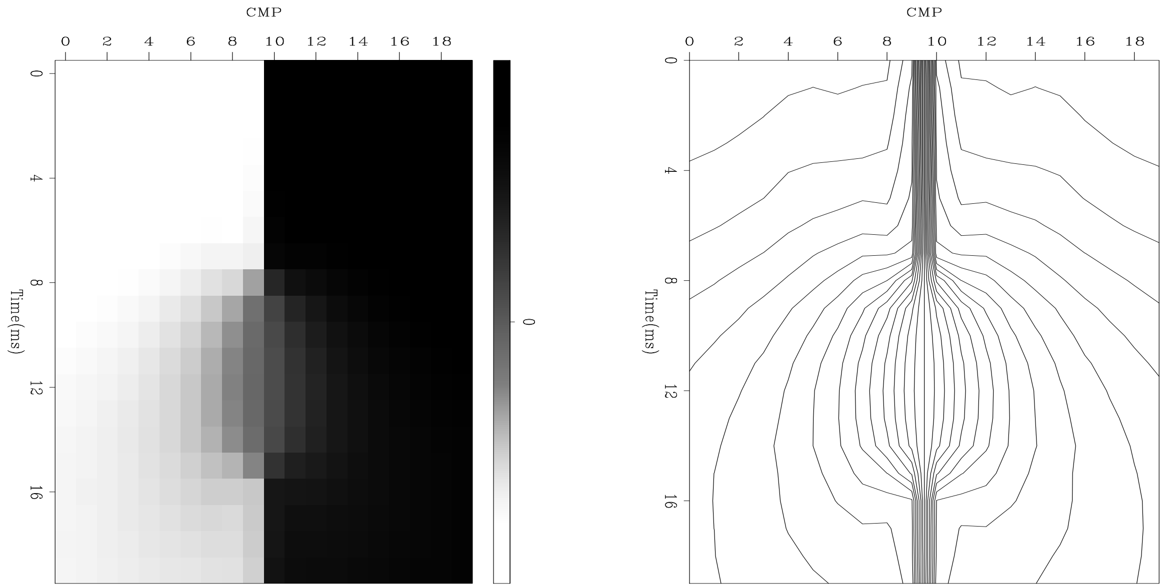

Figure 3: Left the $\mathbf{y_2}$ eigenvector of Figure 2. Right is a contour plot of the $\mathbf{y_2}$ eigenvector. jesse1-y2_2 [ER]

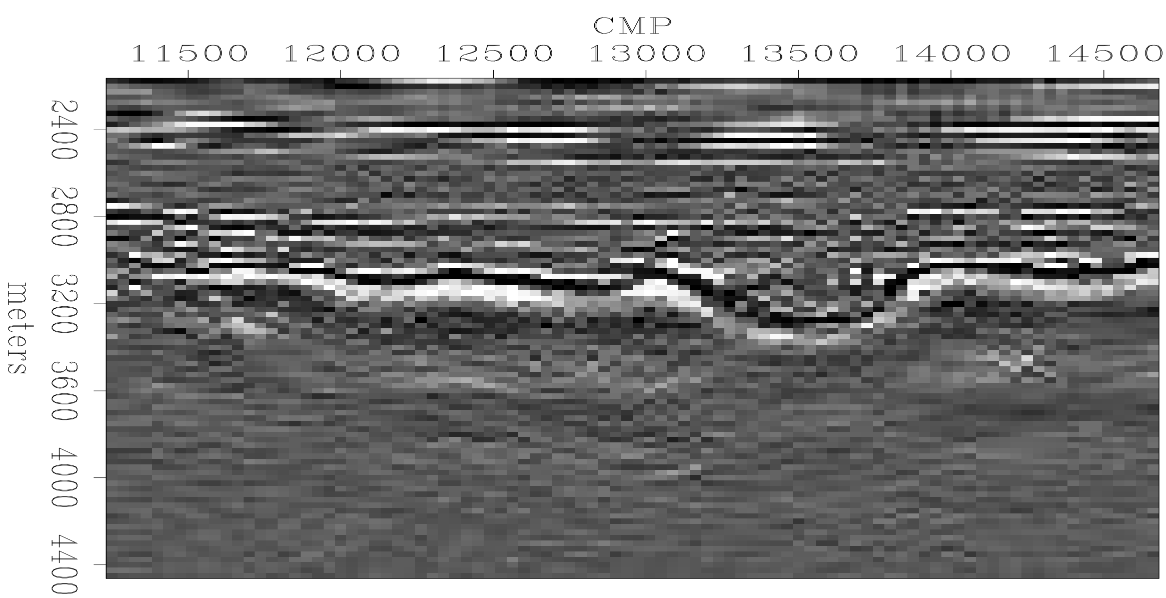

Figure 4: A 2D seismic section from Unocal. The major reflection at 3200 ms is the salt boundary. jesse1-unocal [ER]

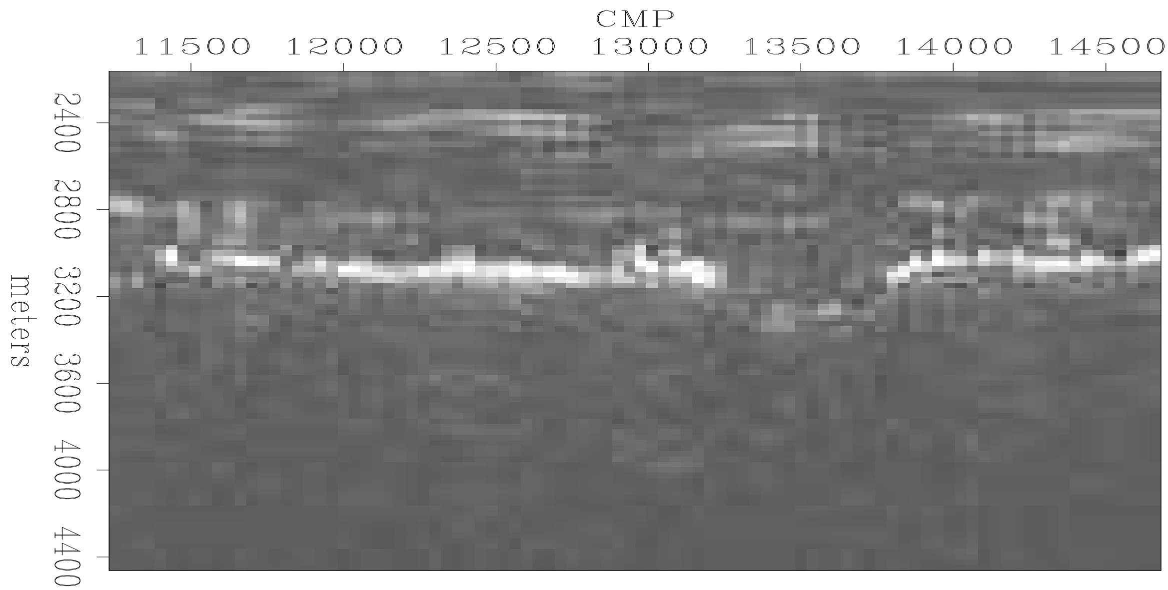

Figure 5: This is the instantaneous amplitude of the seismic section in Figure 4. jesse1-unocal.amp [ER]

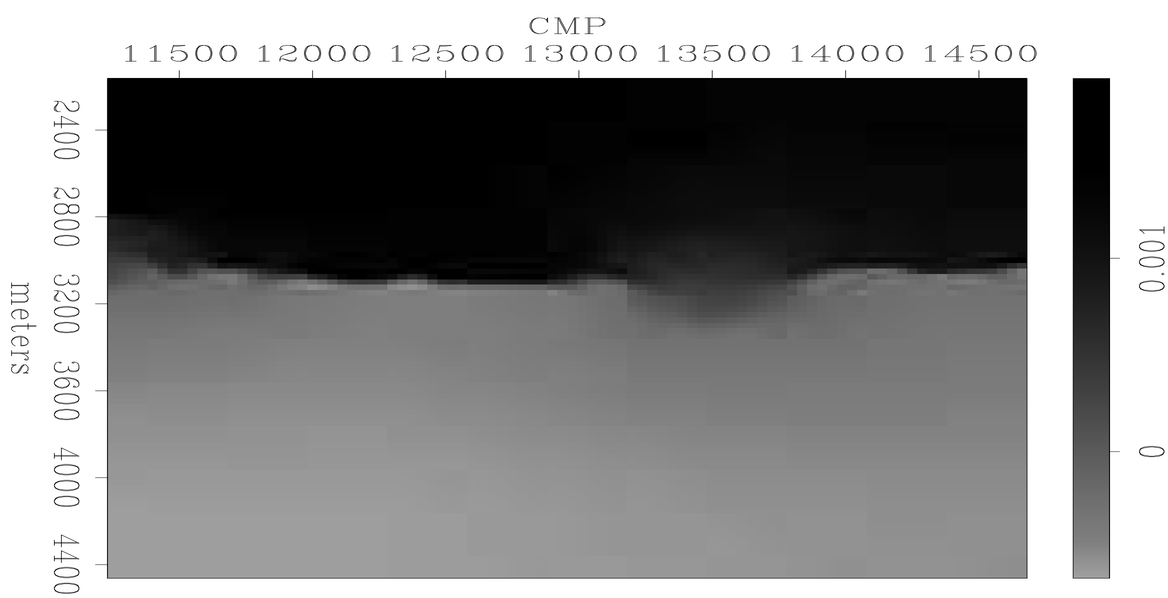

Figure 6: $\mathbf{y_2}$ eigenvector calculated from the data in Figure 5. jesse1-out_y [ER]

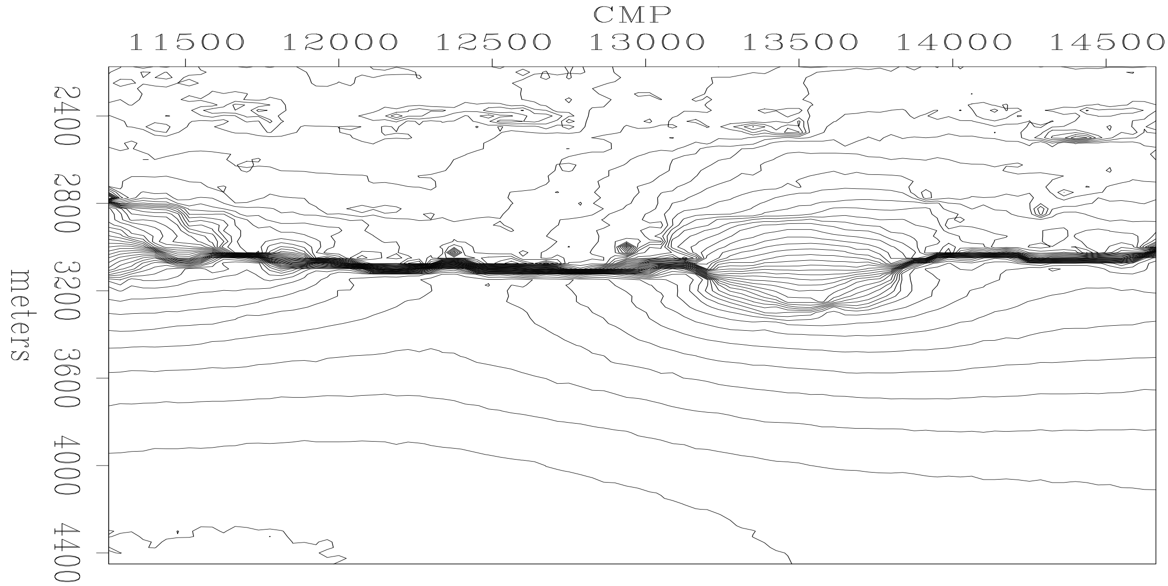

Figure 7: A contour plot of the $\mathbf{y_2}$ eigenvector in Figure 6. Notice the areas of uncertainty where the contours are spreading. jesse1-cont_y [ER]

normalized cut overlain. It tracks the salt boundary even across the challenging area around Cmp 13500.

CONCLUSIONS AND FUTURE WORK

Our modified segmentation method successfully tracked the salt boundaries in all of our test cases. These test cases presented challenges that include a salt boundary that was not continuous and a field data example that had variable amplitude.

Application of this method to 3D datasets is going to be a computational challenge. The normalized cut method has already been applied to paint 3D reservoir models based on coherency data (Hale and Emanuel, 2003). Unfortunately, 3D seismic cubes can have many more data points. However, for our application of tracking the salt boundary, much of the data can be windowed away in the beginning, hopefully making it possible.

ACKNOWLEDGMENTS

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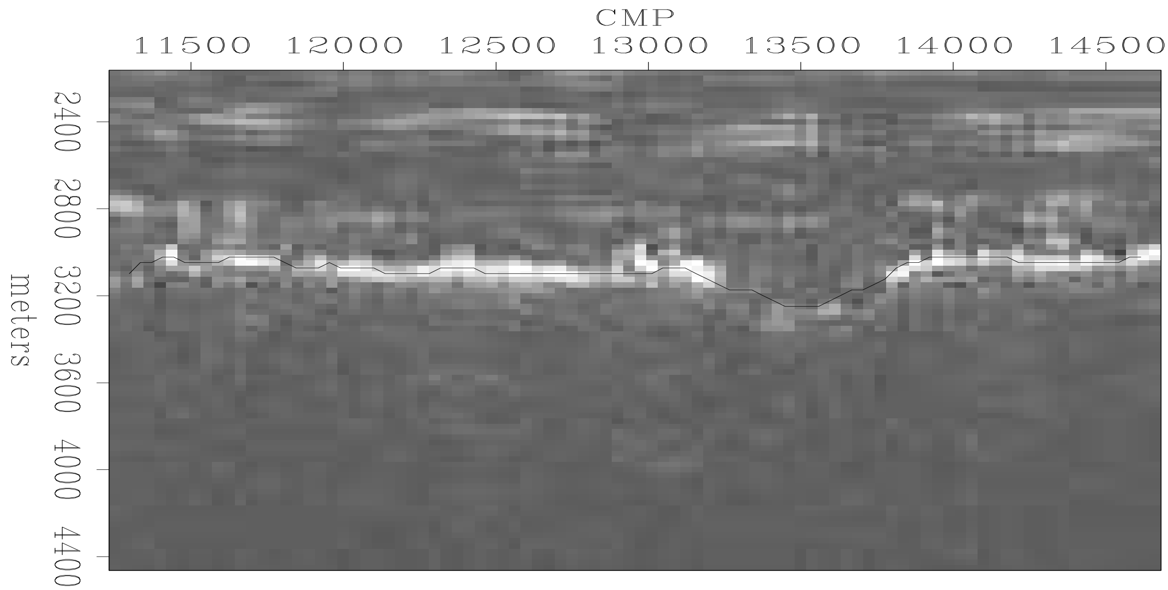

Figure 8: The instantaneous amplitude with the mininum normalized cut overlain. jesse1-horizon [ER]

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