

3-D seismic continuity attribute for mapping discontinuities in a target zone: optimum parameters and evaluation

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Abstract: *In this paper, a real 3-D seismic data set was used in establishing optimum parameters for calculating a cross-correlation-based seismic continuity/similarity attribute, with the objective of obtaining an enhanced imaging of geologic discontinuities (low continuities/dissimilarities) in a target zone. The parameters, which were investigated, are the correlation time window, the number of traces in the correlation pattern and the maximum dip-search limit. The quality of the calculated seismic continuity was assessed based on the sharpness and contrast of the interpreted discontinuities, the comparison of the spatial extension of continuity and discontinuity features with that of the corresponding features on seismic sections, and on the sensitivity of the calculated continuity to the noisy parts of the seismic data. Thus the best possible combination of parameters was established and used for calculating 3-D seismic continuity volume. A continuity horizon slice, extracted along the top time horizon of the target zone, was enhanced by applying a median filter (3x3 traces), evaluated and compared to a result obtained from an enhanced dip-magnitude map for the top time horizon of the target zone*

Key Words: *Continuity Attribute, Mapping Discontinuities, Optimum Parameters for 3-D Seismic Data.*

INTRODUCTION

An enhanced imaging of structural and stratigraphic discontinuities in target zones is highly appreciated in many exploration and developments operations such as reservoir delineation, compartmentalisation studies and well placement. The application of 3-D seismic attributes, such as dip-magnitude, dip-azimuth, edge, and continuity/coherence/similarity, to mapping stratigraphic and/or structural discontinuities has been reported in many publications, e.g. Hoetz and Watters (1992), Bahorich and Farmer (1995), Jones and Knipe (1996), Cartwright (1996), Bednar (1998), and Hesthammer (1998).

In addition to being affected by some of the seismic acquisition and processing parameters or to seismic data quality (Hesthammer, 1998), seismic continuity is affected by the calculation parameters, as it is evident when examining the applied cross-correlation formula, which is:

$$\Phi(t, d) = \frac{\sum_{k=t-N/2}^{k=t+N/2} G_k H_{k+d}}{\sqrt{\sum_{k=t-N/2}^{k=t+N/2} G_k^2 \sum_{k=t-N/2}^{k=t+N/2} H_{k+d}^2}}$$

where $\Phi(t, d)$ is the correlation coefficient at time t ms and for a specified geologic dip (dip search limit) d ; ms/trace (milliseconds per trace), G and H are the correlated traces and N is the number of samples in the correlation time window. As the cross-correlation was applied in three different patterns, namely, two traces, four traces and eight traces patterns, where a trace is cross-correlated with the adjacent two, four or eight traces, the calculated continuity is also affected by the selected number of traces in the correlation pattern. Therefore, providing a good quality seismic data one can state that establishing optimum calculation parameters for seismic continuity is a crucial step towards better imaging of geologic discontinuities.

ANALYSIS AND EVALUATION

As discontinuities are manifested in the form of low correlation coefficients, i.e. low continuity, Hesthammer (1998), the minimum correlation coefficient is selected from the obtained two, four, or eight values, depending on the number of traces in the correlation pattern, in order to emphasise discontinuities. The geologic dip is accounted for by specifying a dip search limit, in ms/trace, where each trace in the correlation pattern is shifted up and down within the specified dip limit and the best correlation is used, Landmark Graphics Corporation Poststack/PALUser Guide (1996).

In Figure 1, we portray the effect of using various lengths of the sliding, correlation, time window; 15 ms, 25, 50 and 75 ms for Figures 1a through to Figure 1d, respectively. Discontinuities correspond to light tones of yellow while continuity is displayed in dark tones of blue. Figure 1a manifests the impact of selecting a small correlation window where the sharpness of local discontinuities is greatly diminished by an overall low continuity. As the length of time window increases from Figure 1a through to Figure 1d, major discontinuities as well as the overall continuities are enhanced and the very local discontinuities, which are likely to be noise signatures, are suppressed. However we should be cautious when using large time windows since that may result in vertical expansion of discontinuities and continuities into levels where they are not actually present. The vertical expansion, which is a result of using large time window compared to the average time thickness ($\cong 25$ ms.) of the target zone, evident on image Figure 1d where both the continuity bands as well as the narrow discontinuity (low continuity) features have been vertically exaggerated.

The effect of the dip-search limit parameter, which is designed for accounting for the average geologic dip in ms/trace, is realised as we inspect Figure 2a, 2b, 2c and Figure 2d for search limit of 0, 4, 8, and 12 ms., respectively. Discontinuities, which are marked with arrows in Figure 2a are actually the result of not accounting for the geologic dip as a dip search limit of zero millisecond was specified. Those geologic dip-related discontinuities are greatly subdued (Fig. 2a, b, c, d) and a dipping continuity seem to be the sensible interpretation.

In Figure 3a, 3b and 3c, the use of different correlation patterns is shown. For a given correlation window and dip search limit, a correlation pattern of two traces is by far more efficient in imaging discontinuities as it is manifested when comparing Figure 3a with either of Figure 3b and Figure 3c. This can be explained by the fact that when having four or eight correlation coefficients, (Figs. 3b and 3c), from which the minimum value is assigned to the central

sample in the correlation window, we have a greater chance of both picking smaller value for the minimum and having more gradual change in the correlation coefficients than when using two values, (Fig. 3a). Therefore, one can state that using more than two traces in the correlation pattern leads to reducing the overall continuity and to a poor identification, i.e. low sharpness and contrast, of discontinuities.

Figure 4 is the result of using a correlation time window of 35 ms, correlation pattern of two traces and a dip search limit of 8 ms/trace. The parameters used for Figures 3 and 4, in the author's view, represent the best possible combination for mapping discontinuities in the target zone using continuity attribute minimum.

A continuity attribute horizon, extracted using the top time horizon of the target zone and the 3-D seismic continuity volume, from which a section is shown in Figure 4, is displayed, Figure 5 in grey-scale with illumination from the upper right corner. The extracted continuity horizon is interpreted as disrupted by three main trends of linear discontinuity (low relief); a regional trend (E), a northwest trend (A-B-C) and a north-south trend (D). Figure 5a is dominated is dominated by noise (N), in particular on the Eastern part where the target zone is pinching out as shown on Figure 7. The majority of the noise discontinuity signatures can be identified as circular and (curvi) linear features (Hesthammer, 1998 and 1999). Applying median filter (3x3 traces) to Figure 5a resulted in image Figure 5b on which the three interpreted main trends are in higher contrast with the less noisy background. Figure 6 is a result of applying edge-detection which amount to calculating the derivative of dip, (Jones and Knipe, 1996), sharpens some features such as C, yet a quite noisy background is evident when compared with the image in Figure 5b. On a cross-plot of the measured time thicknesses against X co-ordinates (Fig. 7), it is evident that the three interpreted discontinuities trends are associated with local thickness anomalies, marked with arrows. Thus cross-plots of measured time thickness can help increasing the credibility of interpreted structural and/or stratigraphic discontinuities.

CONCLUSION

As a conclusion of applying different lengths of the time window, various numbers of traces in the cross-correlation process, testing for the effect dip-search limit, and evaluating the results based on; i) sharpness and contrast of the interpreted discontinuities, ii) on the comparison of the spatial extension of continuity and discontinuity features with that of the corresponding features on seismic sections and iii) on the sensitivity of the calculated continuity to the noisy parts of the seismic data, we recommend the fol-

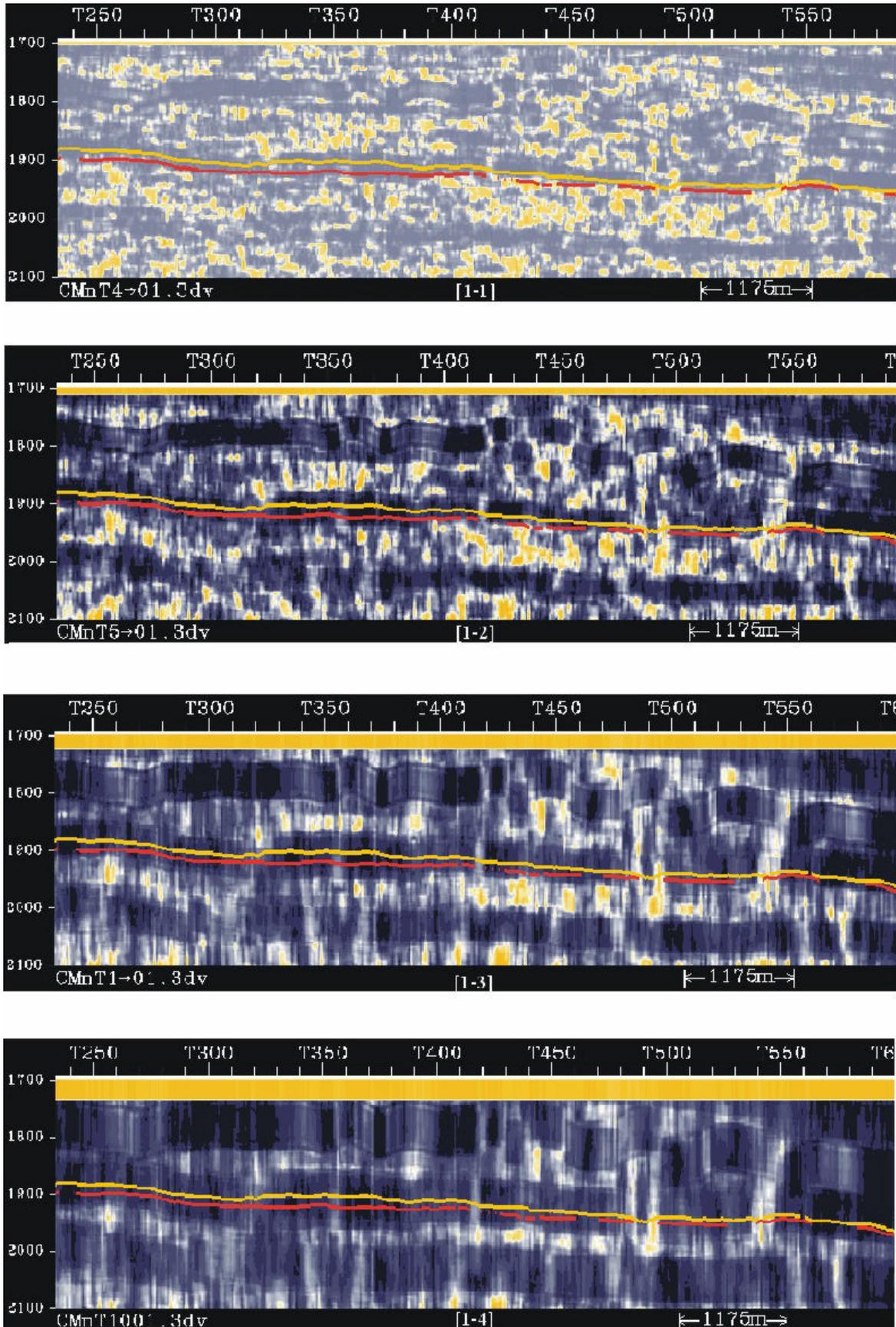


FIG. 1. Continuity-discontinuity attribute section formed by selecting the smallest (minimum) correlation coefficient and using a two-traces correlation pattern, a maximum dip-search of 0, normalisation value=0.55, and correlation time window of 15, 25, 50 and 75 ms for (1-1, a), (1-2, b), (1-3, c) and (1-4, d), respectively.

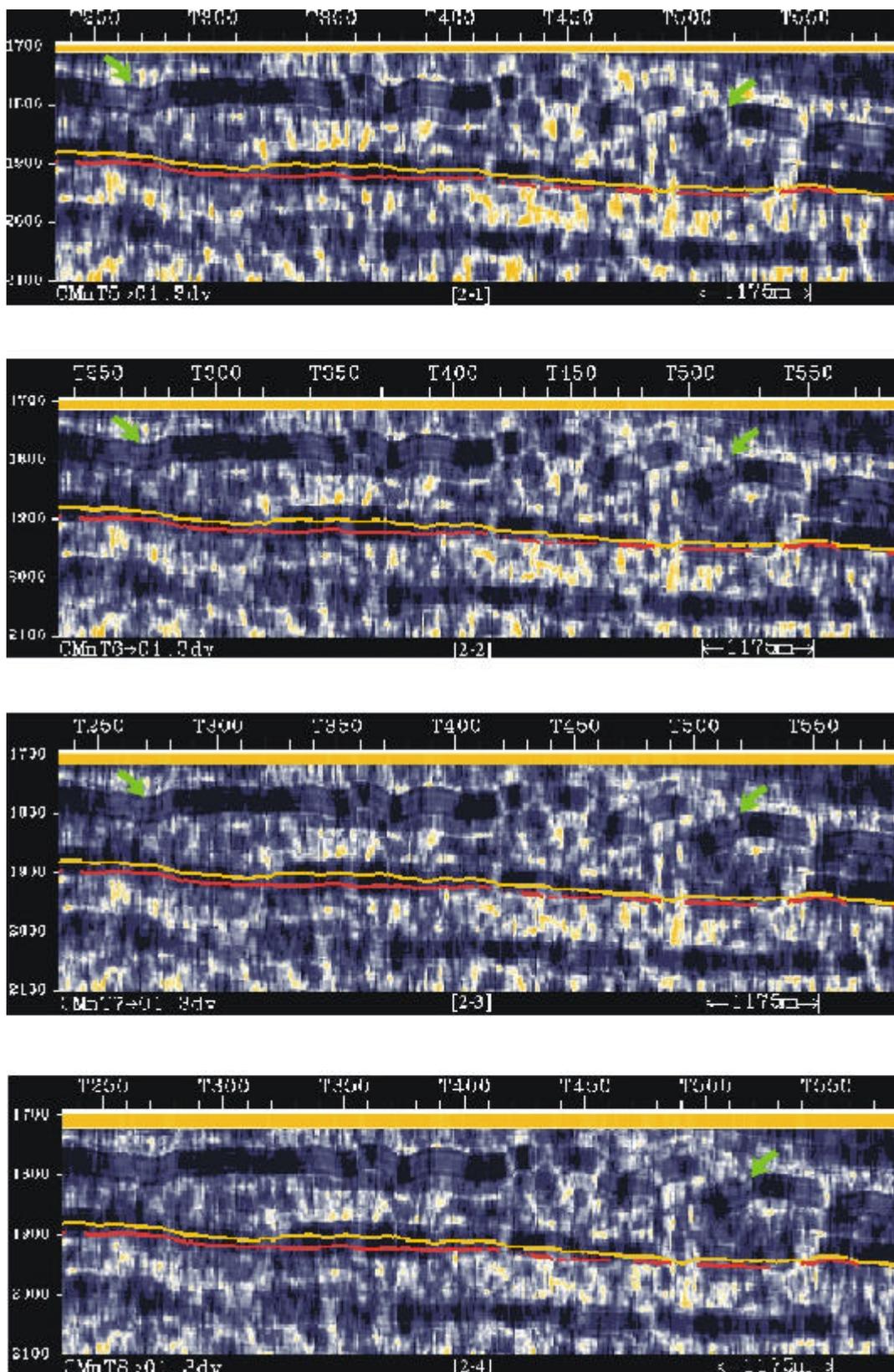


FIG. 2. Continuity-discontinuity attribute section formed by selecting the smallest (minimum) correlation coefficient and using a two-traces correlation pattern, normalisation value=0.55, and correlation time window of 25 ms, and maximum dip-search of 0, 4, 8 and 12 ms for (2-1, a), (2-2, b), (2-3, c) and (2-4, d), respectively.

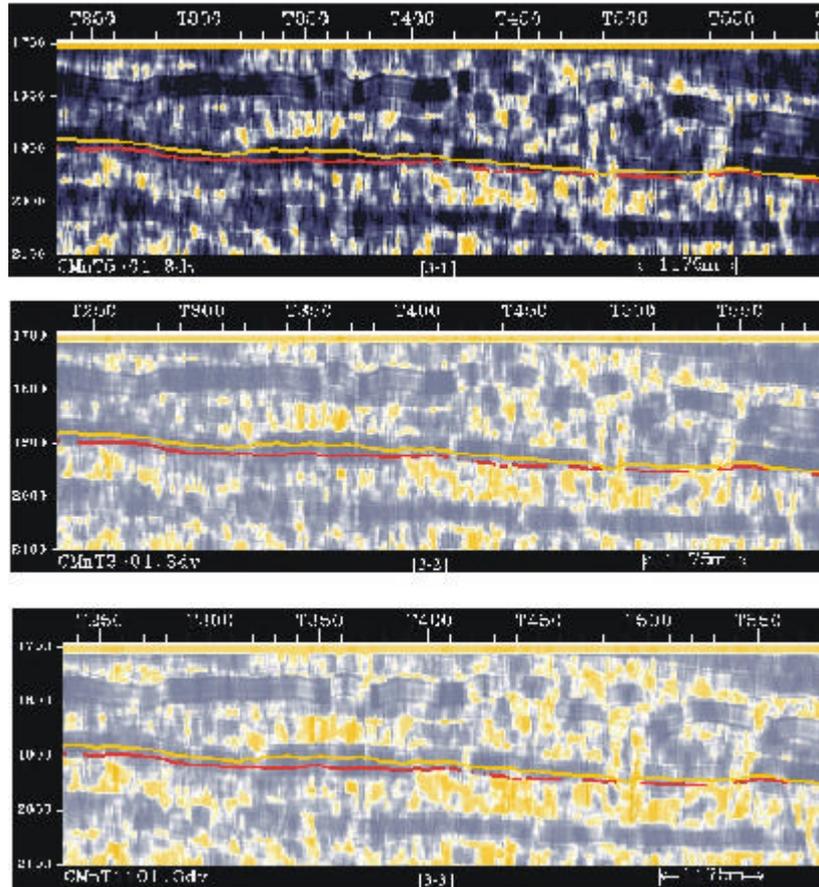


FIG. 3. Continuity-discontinuity attribute section formed by selecting the smallest (minimum) correlation coefficient and using correlation time window of 25 ms, maximum dip-search of 0 ms, normalisation value=0.55, and correlation pattern of two, four and eight traces for (3-1, a), (3-2, b) and (3-3, c), respectively.

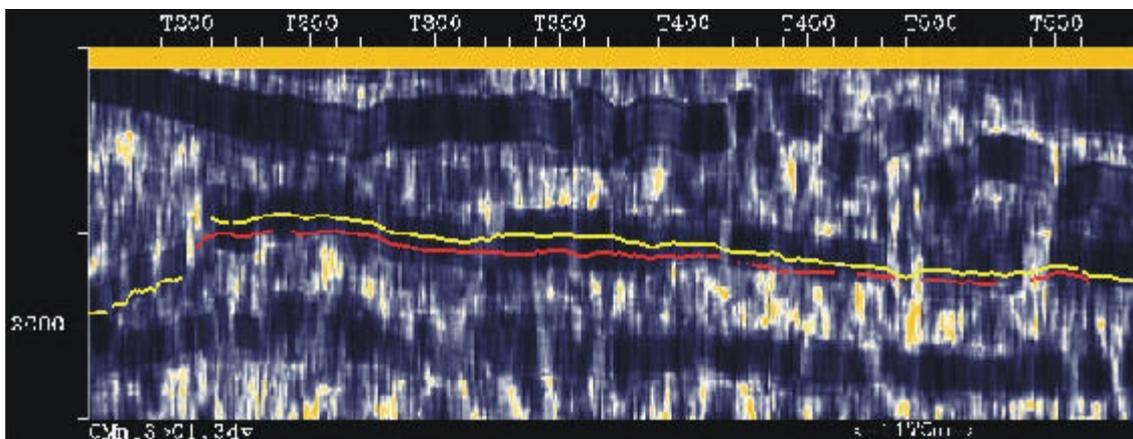


FIG. 4. Continuity-discontinuity section for minimum correlation attributes. Parameters: No of traces=2, window=35 ms, MDS=8, normalisation value=0.55.

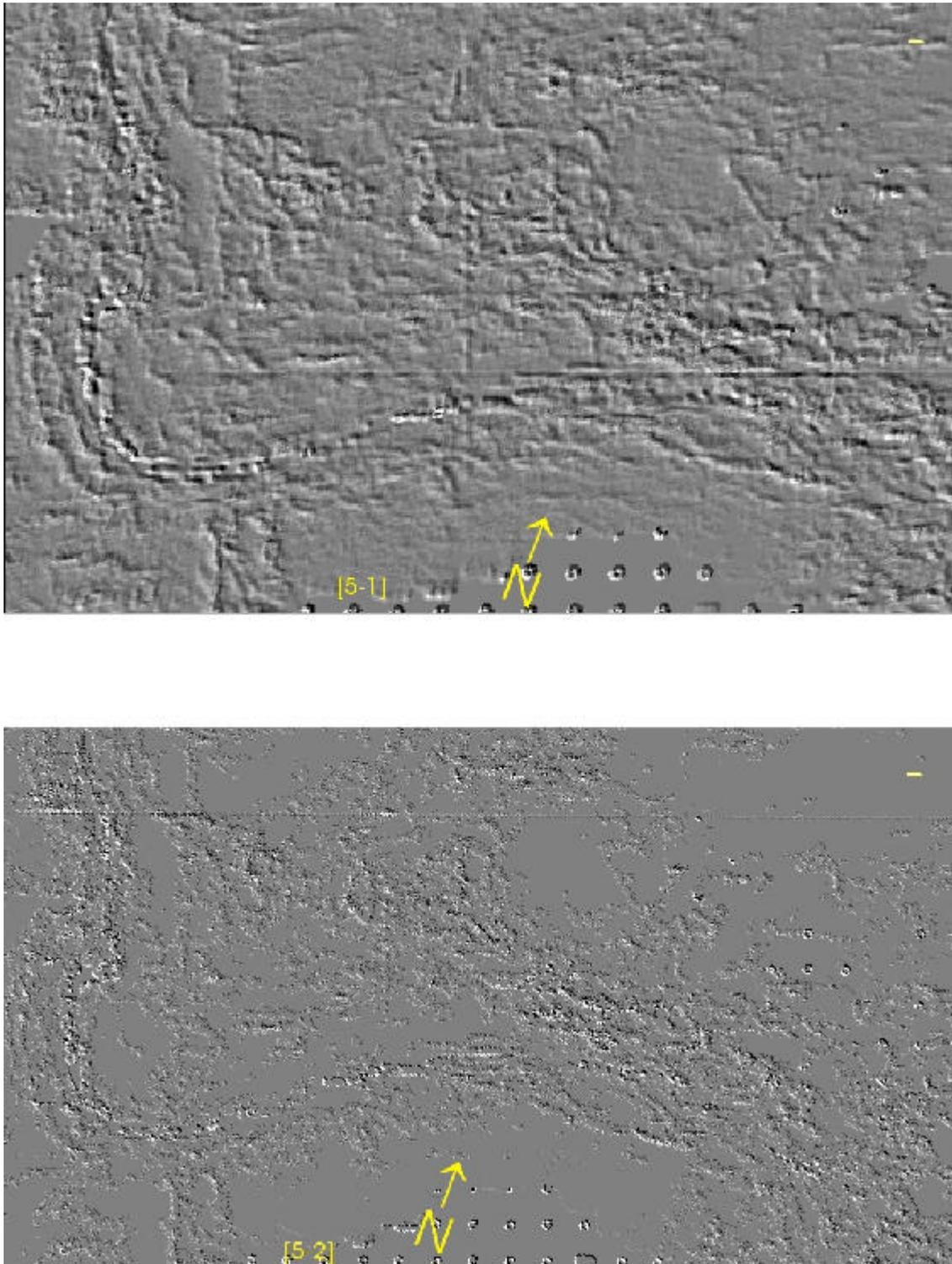


FIG. 5. Continuity-discontinuity horizon map, extracted from a continuity volume with best parameters (No of traces=2, window=35 ms, maximum dip-search=8 ms, and normalisation value=0.55) for calculating minimum correlation attributes, before (5-1, a) and after (5-2, b) applying a 3x3 traces median filter. A, B, C, D and E are interpreted discontinuities and N is noise.

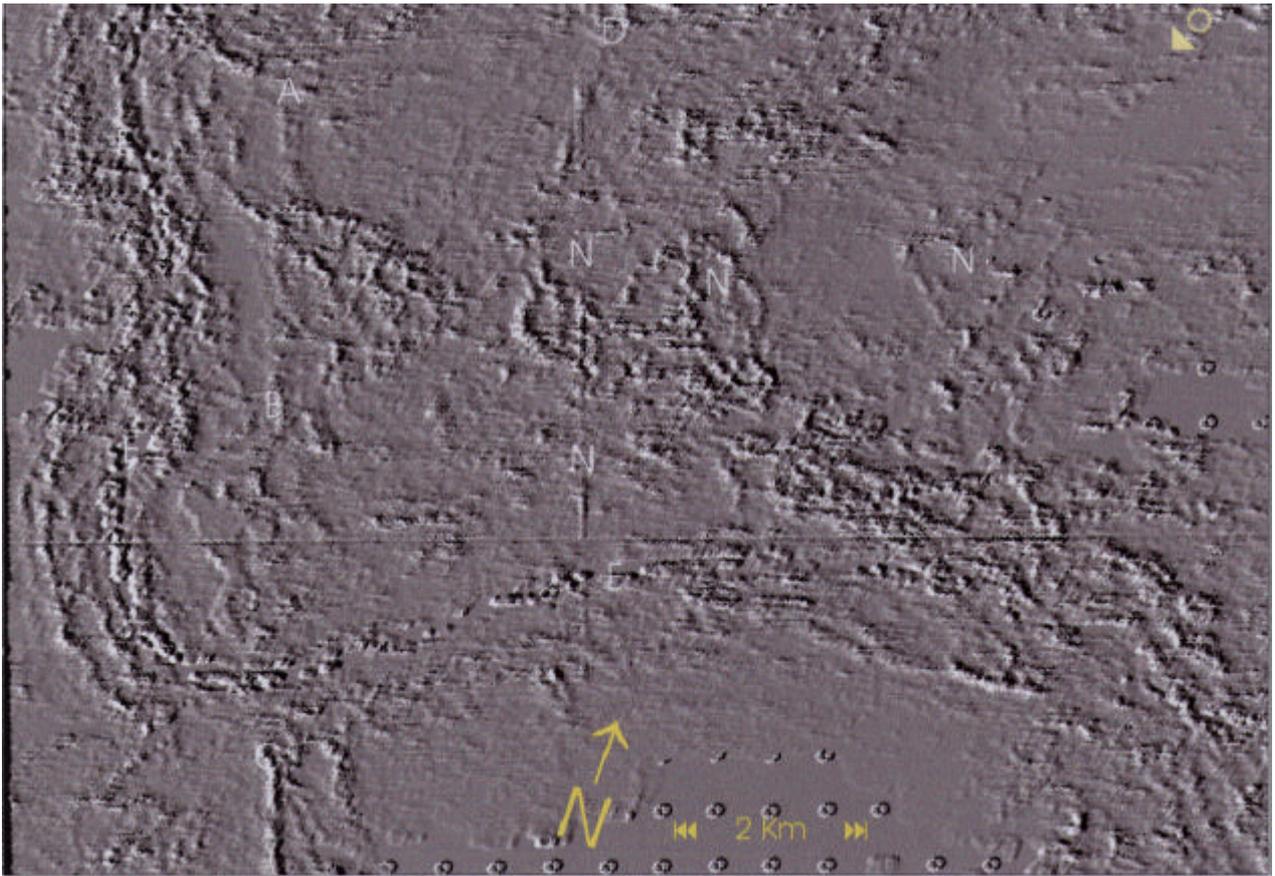


FIG. 6. Grey-scale time-dip map illuminated from upper right corner, for the top horizon of the target zone. A, B, C, D and E are interpreted discontinuities and N is noise.

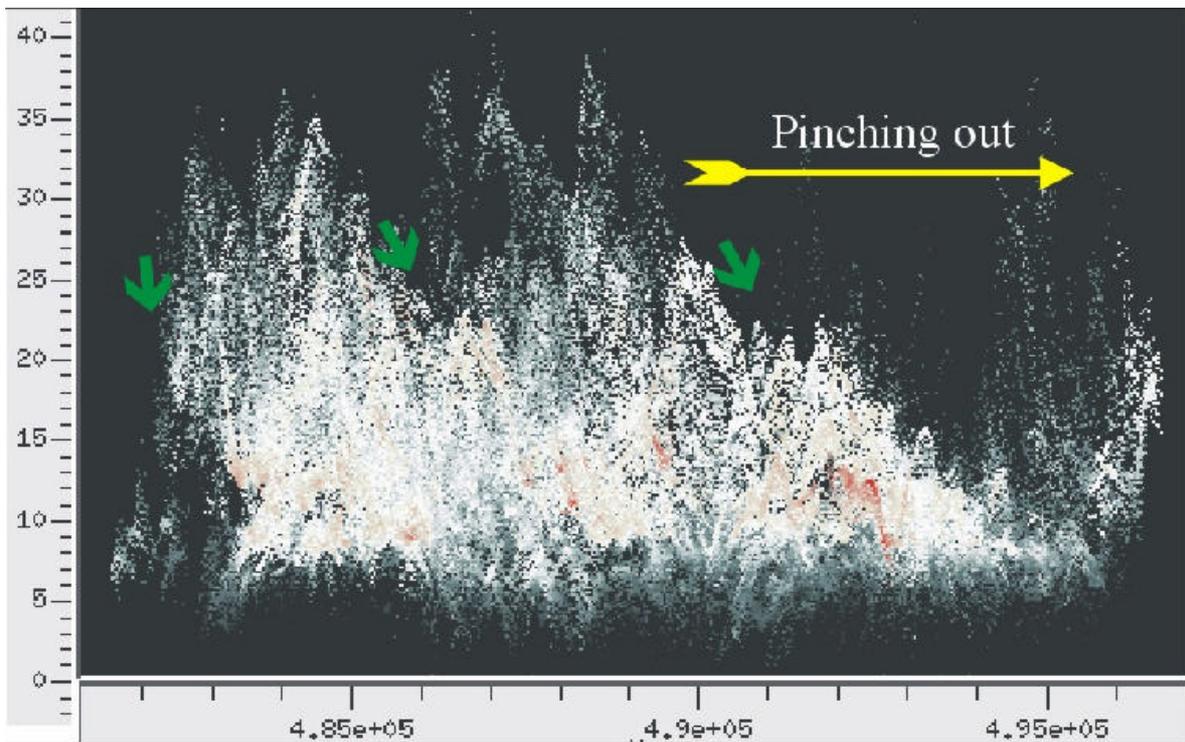


FIG. 7. A cross-plot of time thickness against the X-coordinate (the horizontal dimension in all maps) revealing a regional thinning (marked with green arrows) associated, from left to right with E, A-B-C and D trends on Figures 5 and 6.

lowing: using two traces correlation pattern, dip search-limit equal to the average geologic dip in ms./trace, and a window size that is not greater than one and half times the time thickness of a target zone,

(1) examining vertical continuity section in order to help better distinguish geologic discontinuities that would likely have considerable spatial dimensions when compared to localised (curvi)linear noise signatures,

(2) integrating with other discontinuity-detectors such as time dip and edge (dip-derivative) maps, and (4) using cross-plots of a measured time thickness against cross-line coordinates or in-line co-ordinates, may help verify interpreted geological discontinuities striking at high angles to the in-line or cross-line directions.

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