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Estimation of the displacements among distant events based on parallel tracking of events in seismic traces under uncertainty

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ABSTRACT

The method we propose in this paper seeks to estimate interface displacements among strata related with reflection seismic events, in comparison to the interfaces at other reference points. To do so, we search for reflection events in the reference point of a second seismic trace taken from the same 3D survey and close to a well. However, the nature of the seismic data introduces uncertainty in the results. Therefore, we perform an uncertainty analysis using the standard deviation results from several experiments with cross-correlation of signals. To estimate the displacements of events in depth between two seismic traces, we create a synthetic seismic trace with an empirical wavelet and the sonic log of the well, close to the second seismic trace. Then, we relate the events of the seismic traces to the depth of the sonic log. Finally, we test the method with data from the Namorado Field in Brazil. The results show that the accuracy of the event estimated depth depends on the results of parallel cross-correlation, primarily those from the procedures used in the integration of seismic data with data from the well. The proposed approach can correctly identify several similar events in two seismic traces without requiring all seismic traces between two distant points of interest to correlate strata in the subsurface.

1. Introduction

A significant proportion of the geophysical prospecting data is obtained from seismic surveys. These data are processed to produce graphical interpretations of the subsurface. A migrated seismic section or volume may reveal geological formations, outlined with reflections. Some of these formations may represent either mineral deposit or petroleum reservoirs (Davies et al., 2004). An experienced interpreter can mark the horizons over the images to determine the boundaries of a stratum that could represent a mineral deposit. Moreover, the automatic methods for tracking horizons are useful to interpreters because they can simplify the work involved and reduce uncertainty in the interpretation of profiles (Totake et al., 2017). Nevertheless, a suitable parameterization of the tracking method and of an increase of the signal-noise rate is necessary (Nicoli et al., 2002; Brown, 2005; Porsani et al., 2010).

There are different horizon tracking methods (Schneider and Backus, 1968; Howard, 1991; Glinsky et al., 2001; Chopra and Marfurt, 2007; Yan et al., 2013), including methods based on cross-correlation, whose metric allows quantification of the similarity between portions based on seismic traces and the displacement among seismic events. Displacement estimation can be useful in estimating the dip angle, thickness and depth of certain structures. The data used in estimation are from 2D or 3D seismic surveys and from synthetic seismic traces at a well (Darling, 2005). Data from vertical seismic profiling (VSP) are used to tune the seismic data and the synthetic seismic traces of a well (Serra, 2008). However, such data is not always available, so in this study we proposes an alternative way of solving this problem.

The cross-correlation of parallel seismic events that we propose in this paper searches for similar events in only two seismic traces at different locations. In order to determine the displacements of the events, the first seismic trace shall be close to a well, and the second trace close to the point where the displacements in depth will be estimated. However, some difficulties and issues emerge before the estimation of displacements can be achieved. For instance, since an event from the second seismic trace could be similar to the standard event, what criteria could be used to relate them? It is also difficult to determine whether an event or events in the first seismic trace share any traces with the second seismic trace, or whether they simply disappear due to destructive interference in the migration process or in a low signal-noise rate (Cooper, 2004). All of these factors introduce uncertainty in the seismic trace data. The tracking methods can overcome

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some of these difficulties, but the tracking can be complex in a seismic volume with irregular distribution of traces. One way to simplify the identification of events is through a parallel search of events in the two seismic traces, and by including geometric constraints.

Now, how can the identified events be related to the strata in the well log? One way is through the preparation of suitable synthetic seismic traces to compare with real seismic traces (Schlumberger, 1998; Darling, 2005; Serra, 2008). However, there are several factors that make this task uncertain. Among these factors are the unknown frequency and shape of the seismic source wavelet, the well log errors and the changes when processing real seismic traces, among others. To address this issue, we propose an adaptation under uncertainty for the cross-correlation between the seismic trace from a 3D survey and a synthetic seismic trace prepared using the sonic and density logs of a well. Furthermore, we propose procedures for estimating the depth of events with information extracted from the well logs and seismic signals.

2. Parallel cross-correlation of events of two seismic traces

In seismic reflection an "event" is a wave reflected at an interface between two layers (Chapman, 2004). Thus, several events may occur in a single recorded seismic trace. Supposing that such an interface is extended up to subsurface, the reflections with similar characteristics will appear in other seismic traces in the same survey. In this section, our purpose is to work with a set of events ordered and chosen according to their energy E, defined as:

$$E_e = \sum_{l=i_e}^{f_e} g(l)^2 \Delta t_s, \tag{1}$$

where $g(l)$ is the digital seismic signal or seismic trace, Δt_s is the sampling rate of the seismic signal, i_e and f_e are the indexes of the start and end of the event and, for practical purposes, the event is redefined as the positive part of a cycle (or half of the wave longitude). Two examples of seismic traces with several events can be seen in Fig. 1. The negative part of a cycle can also be used to define an event. This depends on the wave form generated by the source of vibrations or the information contained in the traces. In any case, we examine the events with greater energy E_e in the other seismic trace.

According to the Nyquist sampling theorem (Yarlagadda, 2009), it is possible to deduce that the minimum number of samples in a cycle will be equal to two. However, a small number of samples is statistically insufficient for representing an event. For that reason, the algorithm of parallel cross-correlation of events will vary the number of samples in order to find the best correlation possible in each event. Thus, the cross-correlation coefficient c_{ije} for an event is calculated with the following expression:

$$c_{ije}(\Delta i_e) = \frac{\sum_{l=l_1}^{l_1+nc} (g_i(l) - m_i)(g_j(\Delta i_e + l) - m_j)}{\left(\sum_{l=l_1}^{l_1+nc} (g_i(l) - m_i)^2 \sum_{l=l_1}^{l_1+nc} (g_j(\Delta i_e + l) - m_j)^2\right)^{1/2}} \tag{2}$$

where c_{ije} varies between -1 and $+1$; thus, when closer to $+1$, the correlation among events is greater. The indexes i and j indicate the first and second seismic trace, respectively. The averages of the patch of signals are represented by m_i and m_j. The parameter nc is the number of correlated samples, and l_1 is equal to the initial index i_e of the standard event. The index Δi_e is the displacement of the event trace j in relation to the trace i. Using that index, it is possible to estimate the position of the initial index j_e of the similar event, in the second seismic trace, as follows:

$$j_e = i_e - \Delta i_e. \tag{3}$$

The relationship between the number of samples nc and the indexes of eq. (3) can be seen graphically in Fig. 2.

The index Δi_e is varied to find the maximum value of c_{ije} inside a range. The range of the first displacement Δi_1 ($e = 1$) is defined as follows:

$$-\Delta i_\theta \le \Delta i_1 \le i_2 - f_1, \tag{4}$$

where the index i_2 is the start of the second event; f_1 is the final index of the first event; and $-\Delta i_\Theta$ is the value of the lower limit of the first range. The absolute value of that limit is calculated with the following geometric expression:

$$\Delta i_\theta = \frac{d_{gi,gj} \tan\theta}{V_1 \Delta t_s}, \quad 0^o \le \theta \le 45^o, \tag{5}$$

where $d_{gi,gj}$ is the distance between the seismic traces; V_1 is the medium

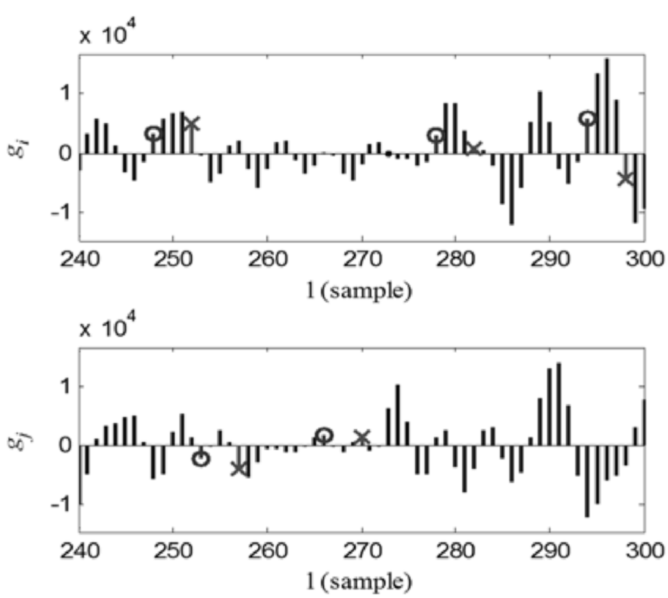

Fig. 1. Examples of two traces from a migrated section. The three events on the upper trace are standards. There might be similar events in the lower trace. The symbol 'o' indicates the start and 'x' the end.

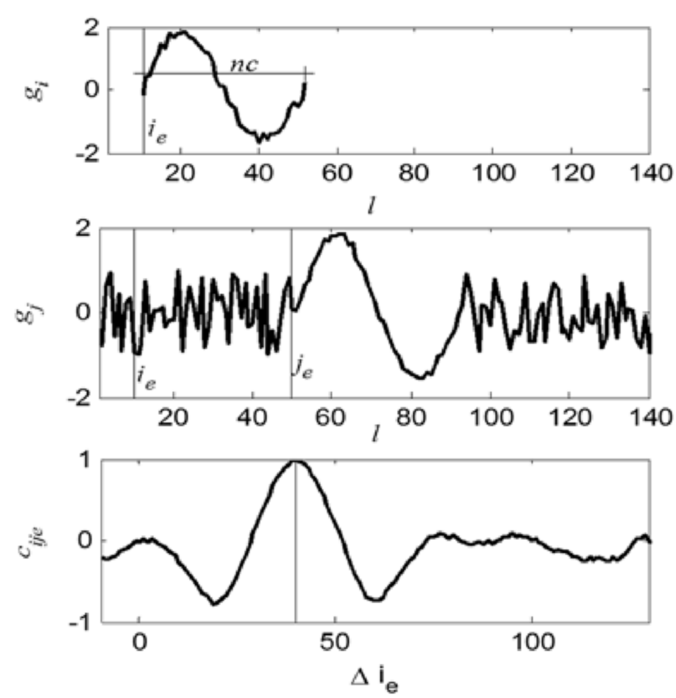

Fig. 2. A cross-correlation example for an event; the upper part shows curve g_i with the standard event, then trace g_j, while the lower part shows the variation of the cross-correlation coefficient c_{ije}.