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Structural uncertainty of time-migrated seismic images

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ABSTRACT

Structural information in seismic images is uncertain. The main cause of this uncertainty is uncertainty in velocity estimation. We adopt the technique of velocity continuation for estimating velocity uncertainties and corresponding structural uncertainties in time-migrated images. Data experiments indicate that structural uncertainties can be significant even when both structure and velocity variations are mild.

1. Introduction

The usual outcome of seismic data processing is an image of the subsurface (Yilmaz, 2001). In the conventional data analysis workflow, the image is passed to the seismic interpreter, who makes geological interpretation, often by extracting structural information, such as positions of horizons and faults in the image. Hidden in this process is the fact that structural information is fundamentally uncertain, mainly because of uncertainties in estimating seismic velocity parameters, which are required for imaging. Apart from the trivial case of perfectly flat seismic reflectors, which are positioned correctly in time even when incorrect stacking or migration velocities are used, seismic images can be and usually are structurally distorted because of inevitable errors in velocity estimation (Glogovsky et al., 2009).

Understanding and quantifying uncertainty in geophysical information can be crucially important for resource exploration (Caers, 2011). The issue of structural uncertainty in seismic images was analyzed previously by (Pon and Lines, 2005; Thore et al., 2002). Tura and Hanitzsch (2001) studied the impact of velocity uncertainties on migrated images and AVO attributes. Bube et al. (2004a,b) studied the influence of velocity and anisotropy uncertainties on structural uncertainties.

In this paper, we propose a constructive procedure for estimating the degree of structural uncertainty in seismic images obtained by prestack time migration. The basis for our approach is the method of velocity continuation (Burnett and Fomel, 2011; Fomel, 1994, 2003a,b; Hubral et al., 1996), which constructs seismic images by an explicit continuation in migration velocity. Velocity continuation generalizes the earlier ideas of residual and cascaded migrations (Larner and Beasley, 1987; Rocca and Salvador, 1982; Rothman et al., 1985). In addition to generating accurate time-migration images, it provides a direct access to measuring the structural dependence (sensitivity) of these images on migration velocities. We define structural uncertainty as a product of velocity picking uncertainty and structural sensitivity.

We use a simple data example to illustrate our approach and to show that structural uncertainty can be significant even when both structure and velocity variations are mild. Although the proposed approach is directly applicable only to prestack time migration, it can be extended in principle to prestack depth migration using velocity-ray approaches for extending the velocity continuation concept (Adler, 2002; Duchkov and De Hoop, 2009; Iversen, 2006).

2. Velocity continuation and structural sensitivity

Velocity continuation is defined as the process of image transformation with changes in migration velocity (Fomel, 1994, 2003b). Its output is equivalent to the output of repeated migrations with different migration velocities (Yilmaz et al., 2001) but produced more efficiently by using propagation of images in velocity (Hubral et al., 1996). If we denote the output of velocity continuation as $C(t,x,v)$, where t and x are time-migration coordinates and v is the migration velocity, the time-migrated image is simply

$$I(t,x) = C(t,x,v_M(t,x)), \tag{1}$$

where $v_M(t,x)$ is the picked migration velocity. Fig. 1 shows the velocity continuation cube $C(t,x,v)$ generated from a benchmark 2-D dataset from the Gulf of Mexico (Claerbout, 2005). Migration velocity $v_M(t,x)$

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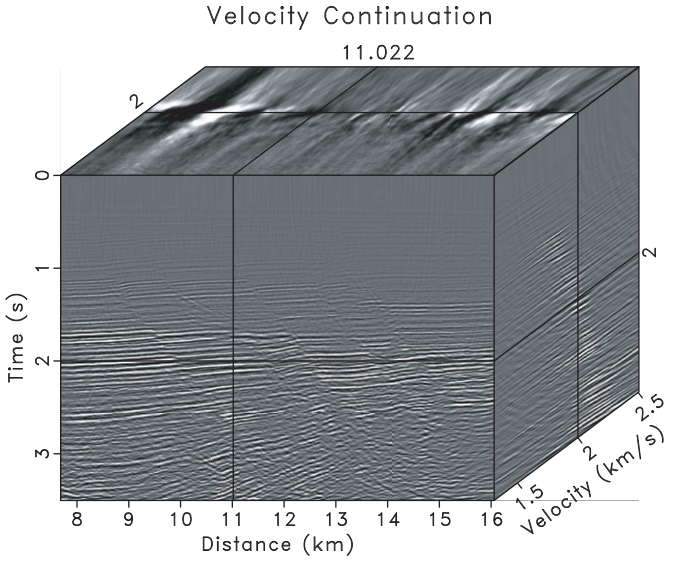

Fig. 1. Velocity continuation cube for prestack time migration of the Gulf of Mexico dataset.

picked from the semblance analysis is shown in Fig. 2. The velocity variations reflect a dominantly vertical gradient typical for the Gulf of Mexico and only mild lateral variations, which justifies the use of prestack time migration. The corresponding migration image $I(t,x)$ is shown in Fig. 3 and exhibits mild, nearly-horizontal reflectors and sedimentary structures.

The structural sensitivity of an image can be described through derivatives $\partial t/\partial v$ and $\partial x/\partial v$, which correspond to slopes of events in the $C(t,x,v)$ volume evaluated at $v = v_M(t,x)$. These slopes are easy to measure experimentally from the $C(t,x,v_M)$ volume, using, for example, the plane-wave destruction algorithm (Chen et al., 2013a,b; Fomel, 2002). Fig. 4 shows one common-image gather $G(t,v) = C(t,x_0,v)$ for $x_0 = 10$ km and the time slice $S(x,v) = C(t_0,x,v)$ for $t_0 = 2$ s. Measuring the slope of events $\partial t/\partial v$ in this gather and evaluating it at the picked migration velocity produces the slope

$$p_t(t,x) = \left.\frac{\partial t}{\partial v}\right|_{v=v_M(t,x)}. \qquad (2)$$

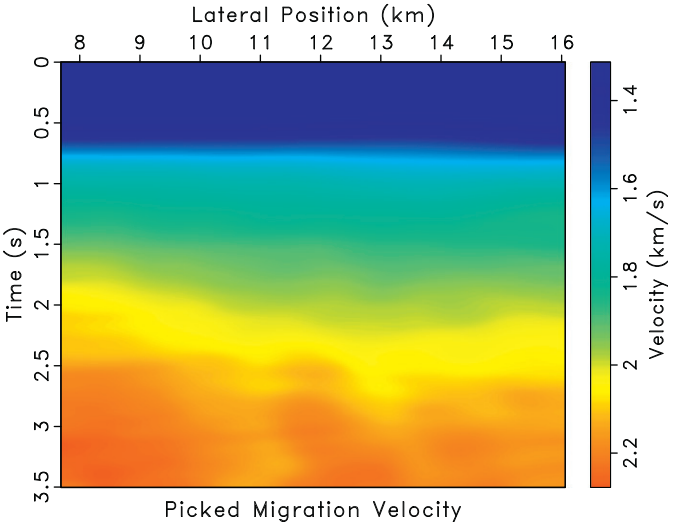

Fig. 2. Migration velocity picked from velocity continuation.

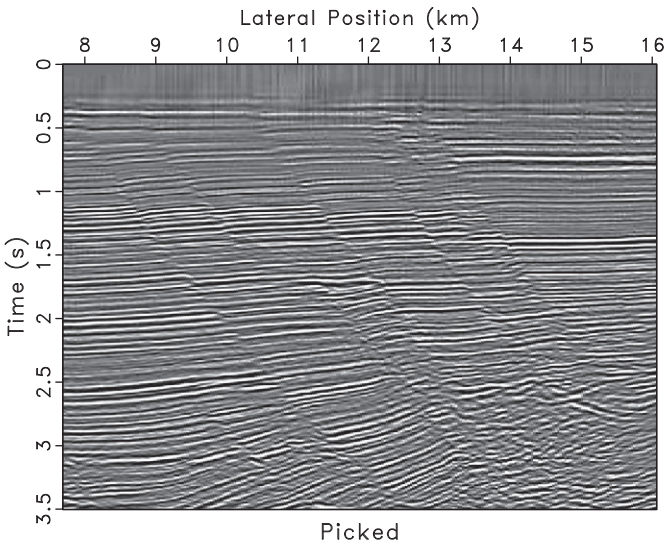

Fig. 3. Seismic prestack time-migration image generated by velocity continuation.

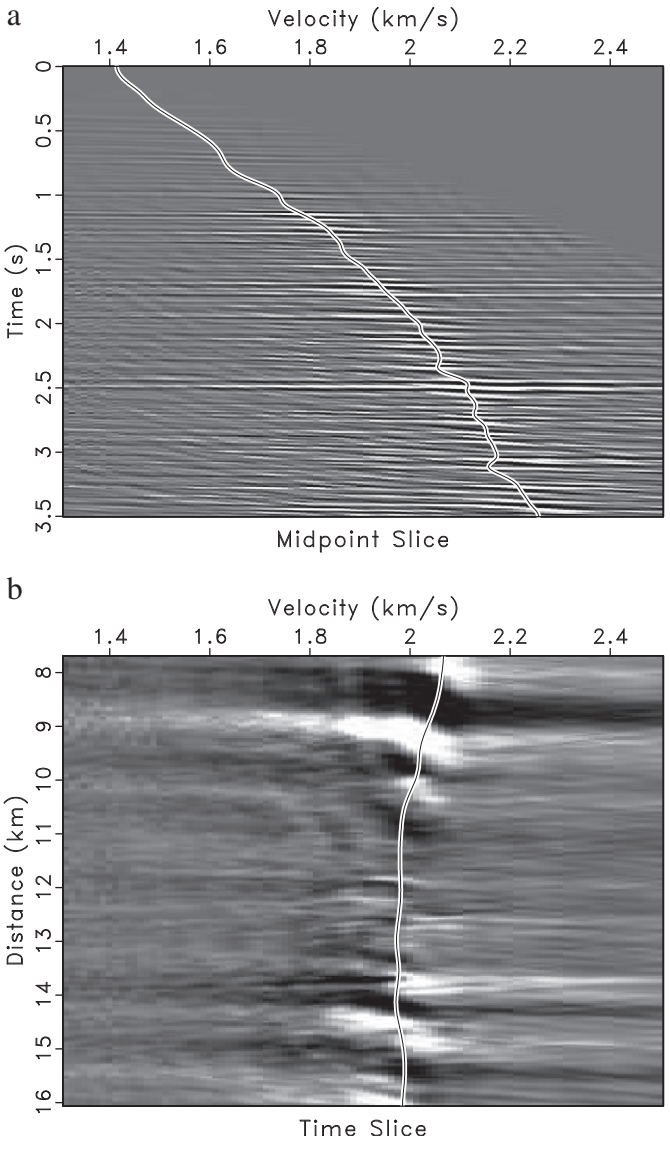

Fig. 4. Common-image gather (a) and time slice (b) from velocity continuation with overlaid time-migration velocity.