Physical modeling of an anisotropic thrust

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ABSTRACT

A physical model of a fold-fault system has been constructed using fibreglass resin in a cloth weave. The material is approximately transversely isotropic with Thomsen anisotropy parameters $\varepsilon = 0.39$ and $\delta = 0.01$. Construction of the model in a layered manner enabled it to be curvilinear, which better represents geology than piecewise linear models previously used in the modelling laboratory. Zero-offset data collected across the model successfully demonstrate the integrity of the construction technique, and isotropic time migration of the zero-offset data imaged targets within the model. A full complement of seismic data sets (2D, 3D, 3C) will be acquired over the model and will be available to test processing algorithms, particularly migration.

INTRODUCTION

Physical seismic models are useful to test seismic data processing algorithms and methods, since the geometry and physical properties of a model are known almost exactly. Data from physical seismic models are also useful to compare and benchmark numerical modeling solutions, particularly for complex 3D models and where wave propagation may be complex, such is anisotropic media.

At the University of Calgary, CREWES supports the seismic physical modeling laboratory, where acoustic and elastic seismic acquisition experiments are conducted. Acoustic surveying facilities were described by Cheadle et al. (1985), and development of elastic modeling capabilities was described by Lawton et al. (1989). The modeling facility has been used extensively by CREWES to assist the development and testing of data processing flows for converted-wave (*P-S*) as well as conventional P-wave seismic data. Both 3C-2D and 3C-3D surveys have been undertaken over models of interest.

Recently, the physical modeling facility has been used extensively in studies of seismic anisotropy (e.g. Ferguson and Margrave, this volume). Anisotropic models have been constructed from phenolic laminate, which has anisotropy parameters that are similar to those encountered in shale-prone clastic sequences. However, a limitation of existing models is that they have been constructed from slabs of phenolic laminate, which have been cut and assembled to make 2D models (e.g. Leslie and Lawton, 1998), and it has not been possible to have curved interfaces in these models.

In order to make more geologically realistic models, a new approach to model-building has been evaluated, using fibreglass. In this process, layers of fibreglass resin are laid sequentially over a mold, with linen weave enabling the resin to harden in non-flat layers. It was expected that the weave-resin construction would result in the final model possessing transverse isotropy with the axis of symmetry perpendicular to the layering.

THE MODEL

The model constructed was that with a fold-fault geometry, similar to that found in the Rocky Mountain Foothills. Figure 1 shows a schematic diagram of the model, and a photograph of it is shown in Figure 2. It is approximately symmetric along strike.

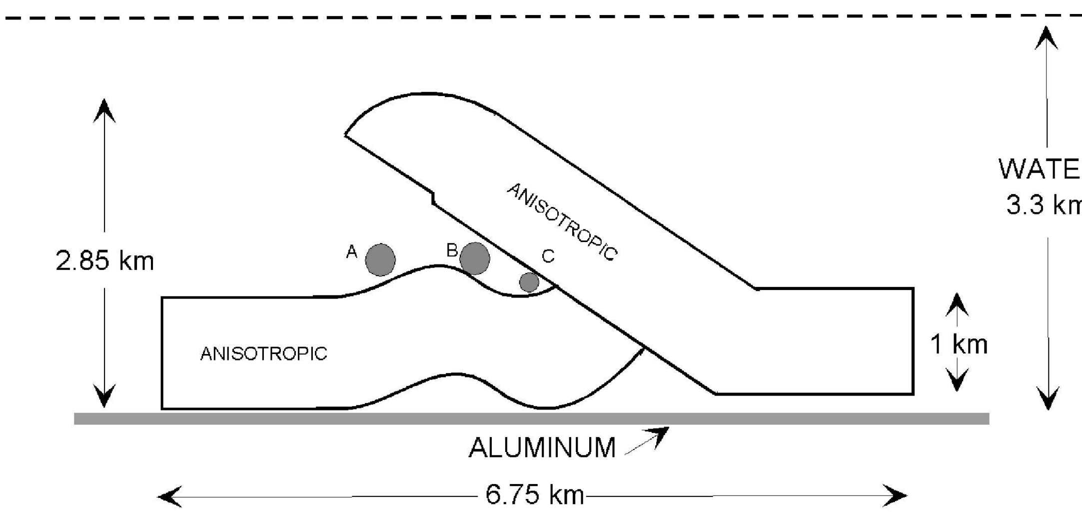


Fig. 1. Schematic cross-section of the anisotropic thrust model. Target rods marked A, B, C were placed in the model for three different surveys.

Fig 2. Photograph of the anisotropic thrust model.

It consists of a fault-bend fold, with a layer of anisotropic fibreglass that is carried as a hangingwall flat above a thrust fault. The same unit forms the footwall of the structure, in which a footwall syncline/anticline pair represents a subthrust target. In the experiments reported here, the model was immersed in water, and acoustic surveys were run. Also, cylindrical steel rods were placed at various positions in the footwall of the model (Figure 1) as additional targets for imaging purposes.

Anisotropy parameters

The Thomsen anisotropy parameters were measured on samples of the fibreglass that were cut from the model. These were determined from measurements at 0, 45 and 90 degrees to the laminations, as described by Cheadle et al. (1985), although additional measurements were taken at 30 and 60 degrees to the laminations to better visualize the slowness surface. For these initial determinations, the weak anisotropy assumption was invoked, although it may only be marginally valid in this case for the computation of δ. Velocities measured are shown in Table 1.

Table 1: Velocities of fibreglass from model

Azimuth (degrees)	Velocity (m/s)
0	2584
30	2650
45	2860
60	3050
90	3606

From these velocity measurements the Thomsen anisotropy parameters (Thomsen, 1986) were determined to be $\varepsilon = 0.39$ and $\delta = 0.01$.

SURVEYS

Data acquisition

Initial experiments undertaken were zero-offset surveys, using a scaling factor of 1:10,000 for distance and time, and a velocity scaling factor of unity. The model was immersed in water and lines were recorded in the dip direction across the model, with a trace spacing of 30 m (scaled). A time sampling interval of 2 ms (scaled) was used during data acquisition. Panametrics model V103 transducers were used as source and receiver. These are flat-faced transducers, each with an active element that has a diameter of 12.6 mm (126 m scaled). During the surveys, the active element was immersed just below the surface of the water.

Four surveys were run along the same line. The first survey was run as a baseline experiment with no target rods present, in order to characterize the model. For the subsequent three surveys, a target aluminum rod was placed at various locations in the footwall of the thrust, as shown in Figure 1.

Processing

Processing of the data consisted of a global scaling correction for spherical spreading, followed by 70 degree *f-k* time migration using a constant velocity of 1480 m/s (water velocity). The scaled sections for the four experiments are shown in the upper part of Figures 3 through 6, and the migrated equivalents are shown in the lower part of each of the figures.

Interpretation

Figure 3 shows data for the baseline model, with no target rods present. The upper surfaces of the hangingwall and footwall parts of the model are clearly imaged, as are the basal parts of these layers where they are nearly flat. The event at approximately 4.5 seconds is the table upon which the model rests. At the crest of the structure, there are overlapping scattered events on the raw data (Figure 3a), which have been collapsed after migration (Figure 3b). The pattern of diffractions which follow immediately after the hangingwall reflection is thought to be caused by the impression of the fabric weave of the fibreglass in the surface of the model. Details of the geometry of the footwall are not clear in either the raw or migrated data due primarily to low energy of events from this part of the model. It is anticipated that these features will be better imaged after migration with a more refined velocity model.

Raw and migrated sections with a target rod present are shown in Figures 4, 5 and 6. In each case, the migrated section shows a weak image of the rod (solid arrow); the location of the rod for each survey is shown in Figure 1 (locations A, B and C respectively). The base of the hangwall sheet has been imaged quite well, indicated by the dashed arrow.

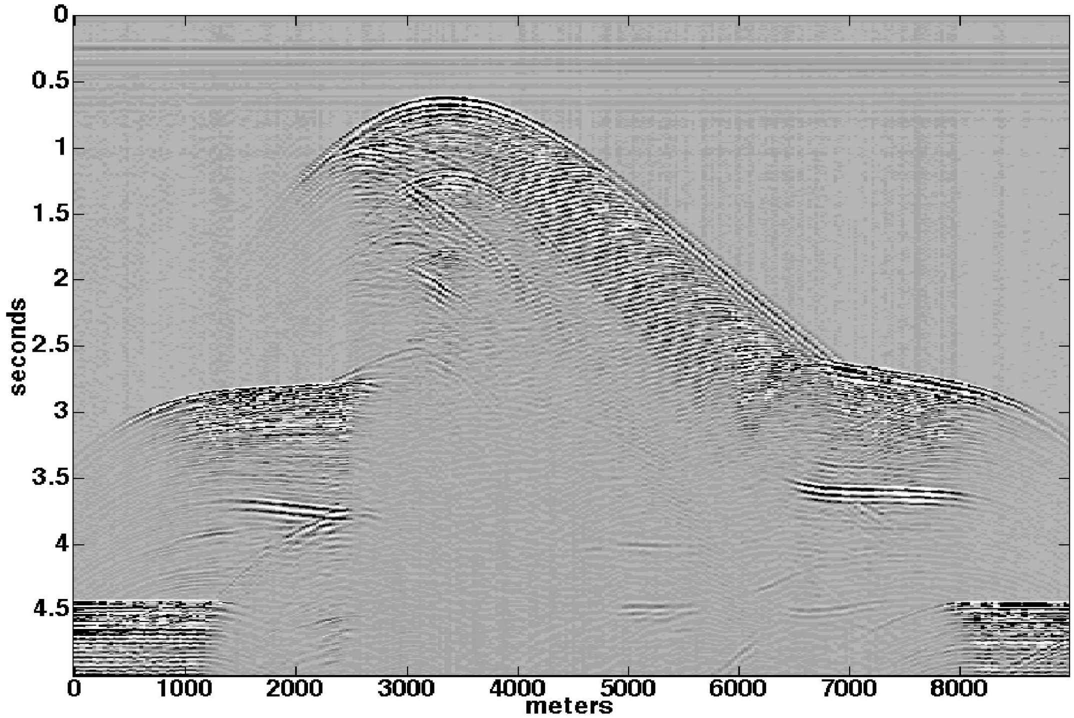
PLANNED EXPERIMENTS

Plans for continued experiments with this model include:

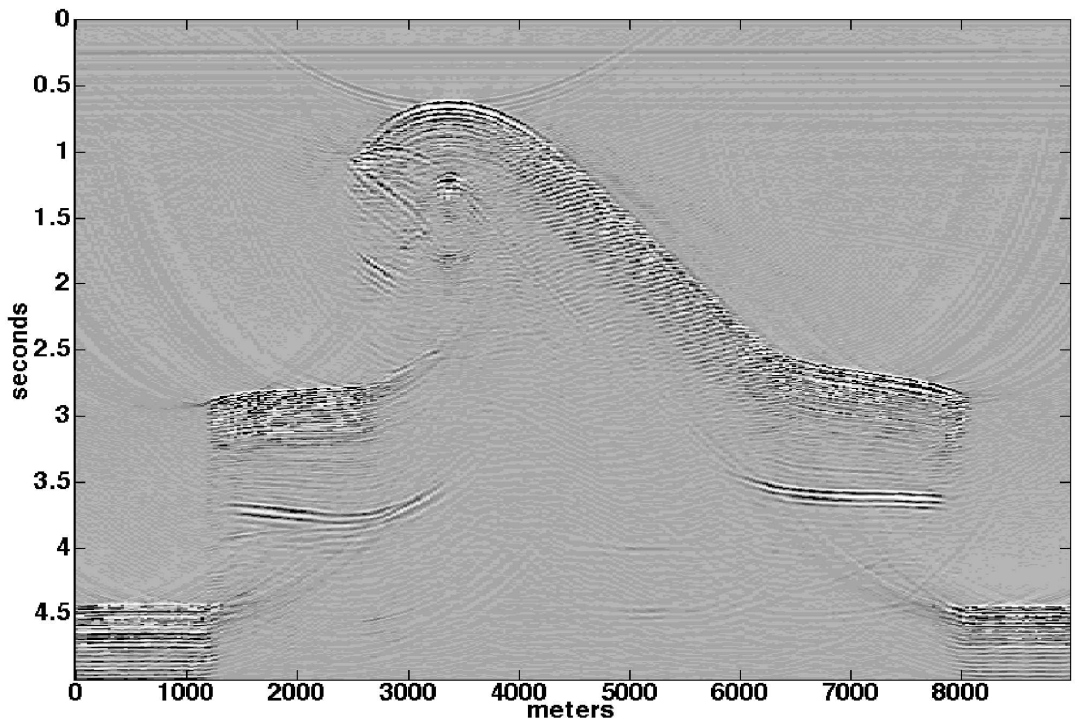
- Acoustic 3-D surveys over both parts of the model to map their geometries,
- An acoustic 3-D survey of the assembled model,
- Encase model in an elastic host material and run 3D-3C surveys for different sub-thrust targets,
- Perform 2D-3C surveys oblique to the structural dip of the model.

CONCLUSIONS

Experiments on the model show that the fibreglass construction has integrity and that realistic geological models can be developed. Data sets from this model will be used to develop and test processing routines, particularly anisotropic *P-S* mapping and migration.

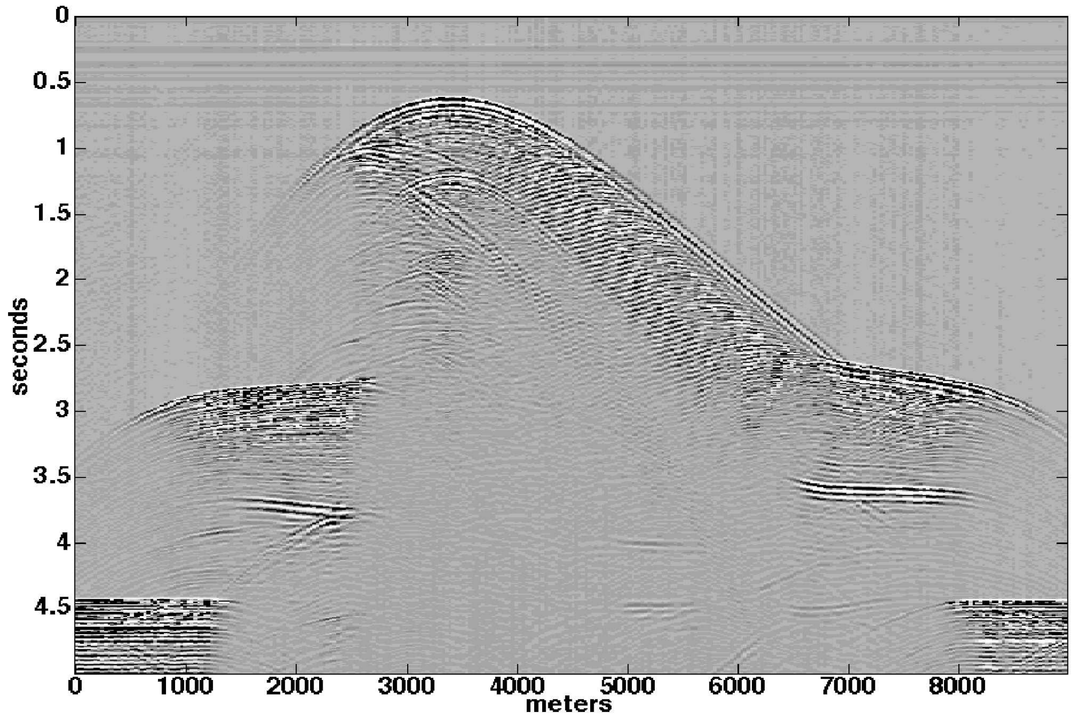


(a)

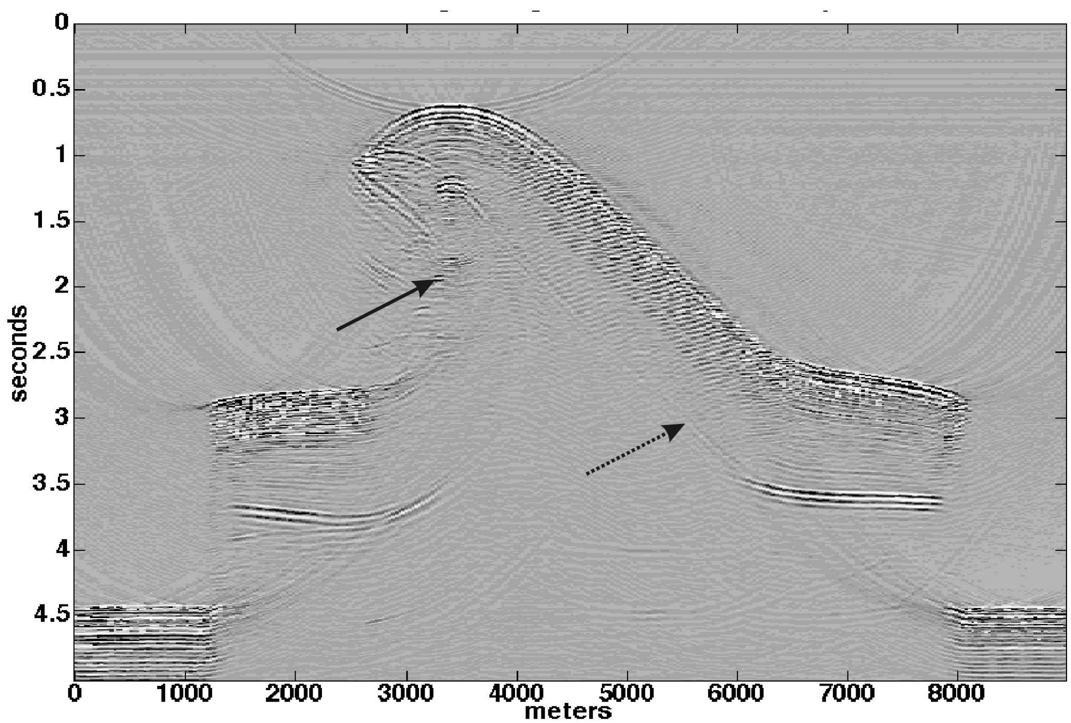


(b)

Fig. 3. Raw (a) and migrated (b) data from the baseline survey across the anisotropic thrust model. The migration was performed using a constant velocity of 1480 m/s (water velocity).



(a)



(b)

Fig. 4. Raw (a) and migrated (b) data from the survey across the anisotropic thrust model with target rod A (identified by solid arrow). The migration was performed using a constant velocity of 1480 m/s (water velocity). Location of rod A is shown in Figure 1. Dashed arrow is fault plane reflection.

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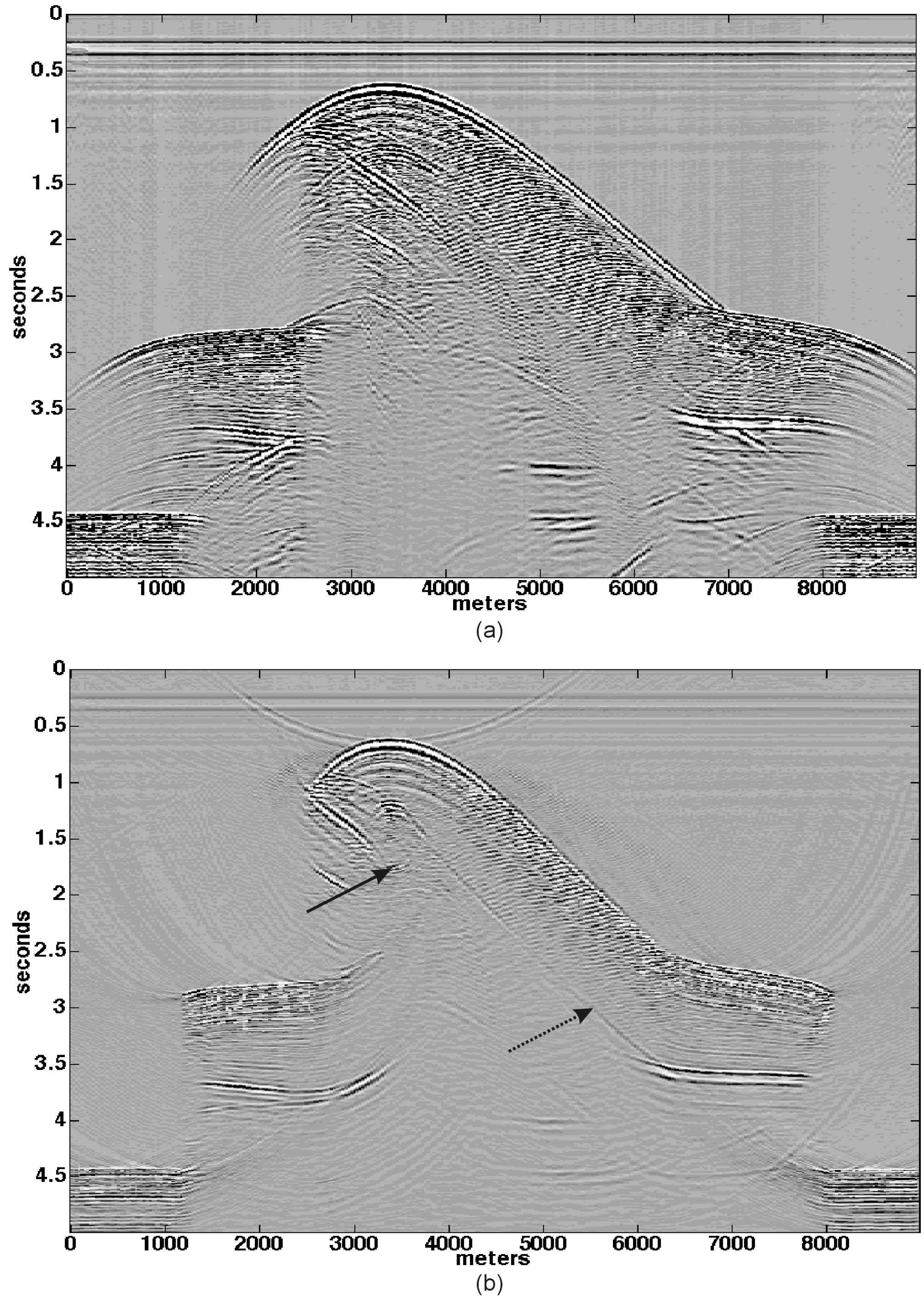
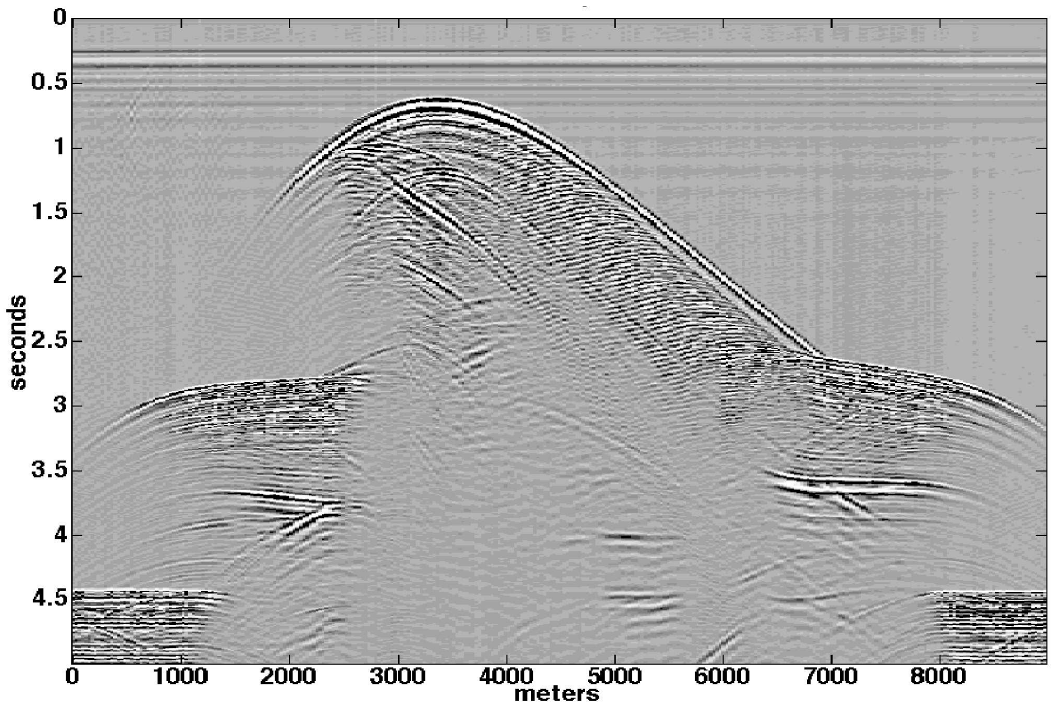
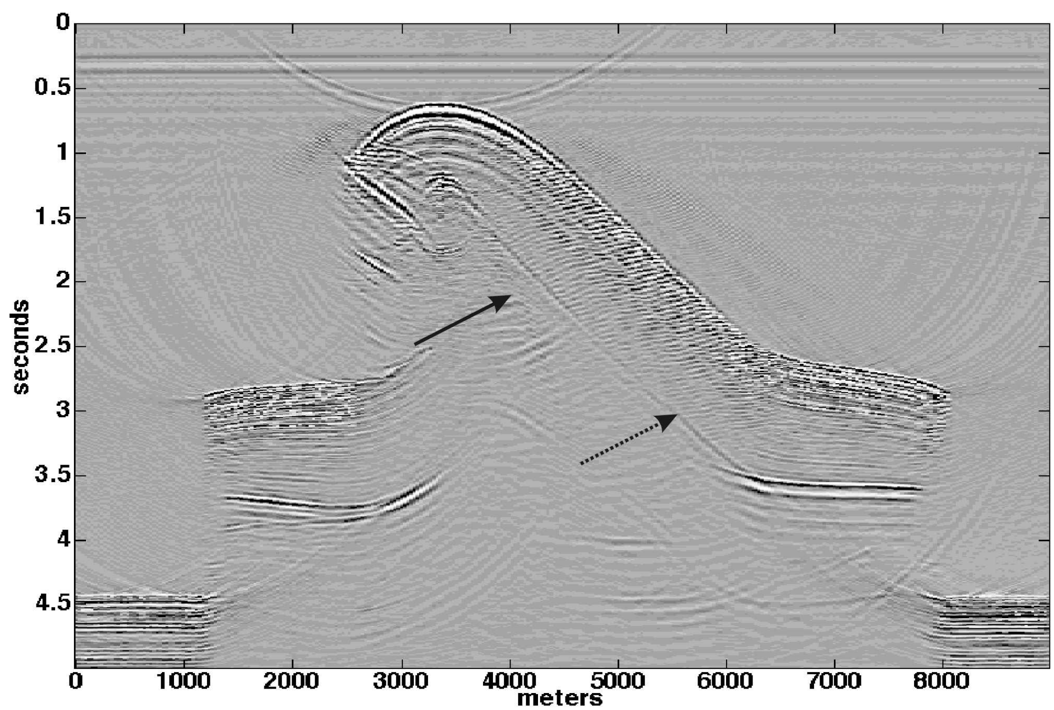


Fig. 5. Raw (a) and migrated (b) data from the survey across the anisotropic thrust model with target rod B (identified by solid arrow). The migration was performed using a constant velocity of 1480 m/s (water velocity). Location of rod B is shown in Figure 1. Dashed arrow is fault plane reflection.



(a)



(b)

Fig. 6. Raw (a) and migrated (b) data from the survey across the anisotropic thrust model with target rod C (identified by solid arrow). The migration was performed using a constant velocity of 1480 m/s (water velocity). Location of rod C is shown in Figure 1. Dashed arrow is fault plane reflection

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