Anisotropic prestack depth migration: A case study
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Summary
The Latimer County, Oklahoma, area is characterised by severe thrust faulting producing dipping sediment packets. The objective of the depth migration is to improve the accuracy of the lateral positioning of the target below these anisotropic sediments. We parametrise the anisotropy using the standard Thomsen formulation. To obtain flat CDP gathers and a reasonable depth tie at the wells requires values of $\delta$ around 0.16. Analysis of $\varepsilon$ is rather more problematic. We find that the upper part of the image is affected by the choice of $\varepsilon$, but at the target level the CDP gathers are extremely insensitive to this parameter. Fortunately the dips at the target level are low, and hence the lateral positioning accuracy is also relatively insensitive to the value of $\varepsilon$. In default of further information, we estimate $\varepsilon$ in the shallow part of the data and propagate it through the model in a geologically consistent manner.

Anisotropic model building
The area of interest in Latimer County, Oklahoma, is characterized by severe overthrusting of the sediments. Figure 1 shows a typical depth section migrated using the isotropic velocity model shown in figure 2. There are two main thrusts marked on the velocity model. We observe that the wells do not tie with the main events of interest.

We attempt to image the data using an anisotropic velocity model. This is parametrised by the short-spread velocity and the Thomsen parameters $\varepsilon$ and $\delta$ (Thomsen, 1986). The shales in the thrust blocks are clearly strongly tilted by the tectonics, and hence we assume that the symmetry axis of the anisotropy is reasonably modelled by taking the local normal to the bedding planes. Because of the high dips (up to 70° in places) the tilt is far from negligible, and using a vertical symmetry axis would itself result in significant lateral positioning error.

The model building process consists of constructing first a migration velocity field, optimised by flattening the short-spread image gathers, then achieving correct depth calibration by adjusting an effective $\delta$. We then attempt to scan for effective $\varepsilon$ by flattening the long-offset image gathers. The difficulty here is that the depth calibration and $\varepsilon$ scan have in effect assumed a vertical symmetry axis of anisotropy. The model is updated by fitting a slowness coincidence with the target event, marked with the arrow.

In fact the sediment packets in the thrust zones are known to be anisotropic. This has caused difficulties in previous attempts at depth imaging in the area, and in particular there is considerable uncertainty in the lateral positioning of events at the target level.

Figure 1: Dip line migrated using isotropic preSDM. The maximum depth shown is about 20000 ft. Four wells are marked, but nowhere does the well depth coincide with the target event, marked with the arrow.

Figure 2: Isotopic velocity model. Layer 1 is the upper thrust wedge, layer 2 the central wedge, and layer 3 is below that.

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Anisotropic preSDM case study

surface defined by a TI model having a symmetry axis normal to the local dip to the slowness surface defined by our effective parameters assuming vertical symmetry. The fitting is performed over an angle range consistent with the migration aperture. This methodology makes it possible to construct a geologically plausible model consistent with the given seismic and well data. It is applied in a layer-stripping approach to obtain the final model.

In practice, we found that the $\varepsilon$ scan could not resolve $\varepsilon$ at the target depth. Increasing the migration aperture caused a considerable increase in noise content without improving the resolution of $\varepsilon$. On the other hand, there are steeply dipping shallow events for which $\varepsilon$ is well-resolved. The geological interpretation of the thrusts indicates that the same sediments are repeated in the different thrust blocks. These sediments have been buried more deeply then uncovered, and therefore we expect relatively little effect of compaction on the anisotropy parameters. For these reasons, it is plausible to interpolate the well-resolved values of $\varepsilon$ from the shallow data along the geological dips.

Results

The model is divided into 3 layers conforming to the main thrust faults. Dips vary from about 70° to less than 20° across the section shown in figure 1, which is essentially a dip line.

Figure 3 shows an image gather from a scan for $\varepsilon$ at a location about 2/3 of the way along the line in layer 3. The left hand gather is the result of the isotropic migration. The remaining gathers show the result of varying $\varepsilon$ in layer 3 between 0.07 and 0.27. The value of $\delta$ was held fixed throughout layer 3 at a value of 0.17. It is clear that, while changing $\delta$ has altered the target depth, there is little evidence of any variation of the gathers over the range of $\varepsilon$ which was scanned. From this and similar analyses throughout the volume, we conclude that $\varepsilon$ is not resolvable at the target.

Displaying the travel time map (fig 4) gives additional support to the conclusion. This shows the one-way travel times from a surface location to subsurface points, with $\varepsilon = 0.27$ in layer 3. The size of the migration aperture is clear from the boundaries of the travel time map, and it is clear that the dip limitation caused by the restricted aperture causes a loss of resolution. The difference between travel time maps for $\varepsilon = 0.07$ and $\varepsilon = 0.27$ (fig 5) is an additional indication of this lack of resolution. In fact looking at the difference between stacked migrations for $\varepsilon = 0.07$ and $\varepsilon = 0.27$ (fig 6) shows that there are differences between those results, but an objective measure of quality is problematic since both parameter models fit the seismic and well observations equally well (fig 7).

Figure 3: Image gather scan for $\varepsilon$ in layer 3: from left to right, isotropic, $\varepsilon = 0.07, 0.12, 0.17, 0.22, 0.27$. The target event is marked by the arrow. The target depth changes from the isotropic to the anisotropic cases.

Figure 4: One-way travel time map for a fixed surface location. The migration aperture is indicated by the limits of the map.
Anisotropic preSDM case study

Figure 5: Difference between travel time maps for $\epsilon = 0.07$ and 0.27. At the target depth, no difference is discernible. The colour scale ranges from –10 msec (dark blue) to +30 msec (red).

Figure 6: Difference between anisotropic migrations for $\epsilon = 0.07$ and $\epsilon = 0.27$ in layer 3.

Figure 7: Anisotropic migration showing the well locations. The wells and seismic now give a reasonable tie.

Lateral uncertainty

It was seen above that, although $\epsilon$ is poorly resolved, in fact its value has little effect on the seismic image of the target. At that level, dips are relatively moderate and therefore the lateral positioning is controlled by the tilt of the anisotropy symmetry axis, as well as details of the velocity field. Figure 8 shows the lateral shift in image position due to varying tilt axis for a range of values of $\epsilon$ and $\delta = 0.16$. The shift is expressed as a fraction of the vertical bed thickness. With $\epsilon = 0.16$ the shift reaches about 20% at a tilt angle of around 50°. This calculation does not incorporate the rotation of the effective parameters but simply keeps $\epsilon$ and $\delta$ fixed. Hence the shift is larger than it would be if we performed the rotation process described above.

Figure 8: Lateral shift in image position expressed as a fraction of bed thickness for $\delta = 0.16$ and varying $\epsilon$ and tilt angle.
Anisotropic preSDM case study

Conclusions

We have observed that for this particular data set, migration with a tilted axis TI model is necessary to achieve a reasonable result. The vertical velocity and short-spread velocity were obtainable from the seismic and well data. However, the third parameter, $\varepsilon$, could not be resolved at the target level. We therefore estimated it where possible in the shallow, steeply dipping data, and interpolated those values elsewhere in the model in a manner consistent with the geological dip. This methodology appears to be robust and give geologically plausible models where parameters are not resolvable.

The estimates of uncertainty in lateral position are certainly pessimistic. The small faults imaged in the seismic at the target level appear to be located correctly relative to the well positions which are relatively dense in some parts of the survey area. Further work is required to refine the seismic uncertainty estimates.

References


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