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Prestack Depth Migration in the presence of low relief, high velocity layers

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ABSTRACT

Depth migration is more accurate than time migration in that it images seismic data correctly in the presence of lateral velocity changes. However, for mild lateral velocity gradients we often use time migration for reasons of cost and stability; the time spent deriving an accurate velocity field and the increased sensitivity of depth migration to the velocity field make depth migration more difficult to apply. For these reasons, depth migration has often only been used when time migration is perceived to fail to image the data properly. Very often, this means that depth migration is only used in particularly difficult and complex geological environments such as overthrust belts and beneath salt diapirs. Unfortunately, in these environments, depth migration often does not provide a clear image where none existed without depth migration because either the ray paths diverge causing the subsurface not to be illuminated by the recording, or current model building techniques are inadequate for such complicated cases. For example, many model updating techniques assume the starting model is either close to the correct answer, slowly varying or that flat horizons exist.

Experience of imaging beneath the basalts of the Shetland-Faroes basin, the tabular salt of the Gulf of Mexico, the shallow carbonates of N. W Australia and the chalk layer of the North Sea has shown that prestack depth migration can be used to improve imaging substantially beneath these low relief but high velocity layers. In the Shetland-Faroes basin, volcanic flows form a barrier to imaging of deeper sedimentary rocks. PSDM has improved imaging both within and below the multiple lava flows. In the Gulf of Mexico, tabular salt causes significant ray path bending and subsequent distortion of the images of the underlying geology. In the Browse Basin, rugged seabed topography can cause imaging problems that can be addressed with prestack depth migration. In many parts of the North Sea a chalk layer with gentle dips lies above the oil and gas bearing targets. All of these geological environments are characterised by fast velocity layers (for example, the chalk is typically twice the velocity of the overburden) and even low dips at the top and base of these layers cause problems for imaging deeper targets. The ray path bending can either prevent an image being formed at all, distortion of any image that is obtained or loss of resolution. PSDM has been found to be beneficial in all these cases. Prestack depth migration should not be viewed as just a tool for extreme geological cases.

Post stack depth migration may provide better positioning and imaging than post stack time migration. Therefore, in low relief areas, it is tempting to use post stack depth migration instead of prestack. However, the ray path distortion caused by the low relief, fast velocity layers we are considering is significantly offset dependent. This causes image distortion and loss of resolution that cannot be recovered stack. Also, model building via post stack depth migration is subjective – the only test is whether the final image agrees with the interpreter's expectation. Prestack depth migration affords the qualitative test that if the velocity model is correct then the primary events within depth migrated image gathers are flattened and will stack coherently.

CASE HISTORIES

Shetland – Faroes Basalt.

Low relief, volcanic flows characterise large areas of this basin and prevent conventional imaging of deeper sediments. Figure 1 compares a 2D line after prestack time migration and after prestack depth migration. The improvement in imaging of both the deeper layers and also of layering within the basalt pile is apparent. In this instance, the velocity model was derived by iterative, vertical updating. There are no wells within the survey area, so velocities were derived purely from the seismic data. Layer boundaries were interpreted by extrapolation from outside the survey area and by identification of significant velocity contrasts from the seismic data. The velocity model derived not only allows a better image to be formed, but also distinguishes different velocity layers within the volcanics associated with different periods of volcanic activity and also confirms the presence of slower velocity sediments below the volcanics.

Gulf of Mexico Tabular Salt.

Figure 2 shows an example of 3D sub-salt imaging from the Gulf of Mexico. The velocity model was derived from seismic stacking velocities picked after prestack time migration. No layers were used within the salt overburden. The top salt structure was derived from post stack migration, whereas the salt base was derived after prestack depth migration with a model flooded with salt velocity below the top salt. Not only is the general structural image below the salt much improved, but also detailed faulting has been revealed.

Offshore Australia.

Figure 3 shows an example of 3D prestack depth migration located offshore Australia. The data is characterised by fast near surface velocities with shallow velocity anomalies within this layer. Figure 3a shows an example of 3D PSDM with a velocity model derived by vertical updating. In this instance, the shallow velocity anomalies are not fully resolved because of the lack of far offsets in the shallow data. 3D reflection tomography using a maximum entropy technique was used to improve the velocity model resolution in the shallow data. This method performs a global inversion of all travel times. Thus, it can use the fact that ray paths to the later reflections travel through the shallow anomalies and can capture the shallow velocity information from deeper reflections as well as shallow ones. Figure 3b shows an improved PSDM section after deriving the model with the tomographic method.

Central N.Sea Chalk.

The last example is from the central N. Sea where the Tertiary section consists of approximately flat layers of similar velocities. This section is approximately 3s thick and overlies a low relief Cretaceous chalk wedge. The chalk has a velocity that is typically twice the velocity of the Tertiary overburden and it also has a strong vertical velocity gradient within it. The main hydrocarbon targets in this region are beneath the chalk in sediments of lower velocity and typically are thought to be moderately well imaged by time migration. However, the sharp contrast in velocity associated with the chalk means that even the modest dips at the top and bottom of the chalk can cause a significant lateral velocity gradient.

Figure 4 compares a typical vertical cross-section through the chalk and zone of interest after prestack and post stack depth migration. Both depth migrations used the same velocities but the structural depths of the models differ. The post stack depth migration was produced as the final step in model building i.e. the velocities had already been updated and the post stack depth migration was produced to allow the interpreter to update the geological structure of the final model. The pre stack depth migration used this final model. The near flat structure of the shallow layers meant that several iterations of velocity updating were possible from the top downwards without previously updating the structural picks. (The reflection time picks were frozen so that as interval velocities changed, the associated depths changed automatically.)

The post stack depth migration in figure 4 was identified as being a significant improvement on the previous time migration, but it is clear that the pre-stack depth migration yields a substantial further improvement. Deep events can now be identified that were not clear before and the continuity of events at the zone of interest is enhanced. Figure 5 shows an enlargement of another section from the same survey. The data shown is from below the chalk at the reservoir level. The pre stack depth migration shows clear evidence of faults with small throws that extend from deep in the section up to and into the Cretaceous. This faulting cannot be identified on any earlier result including the shown post stack depth migration. The improvement in resolution and continuity shown in the previous example are typical of pre-stack depth migration results in the general area.

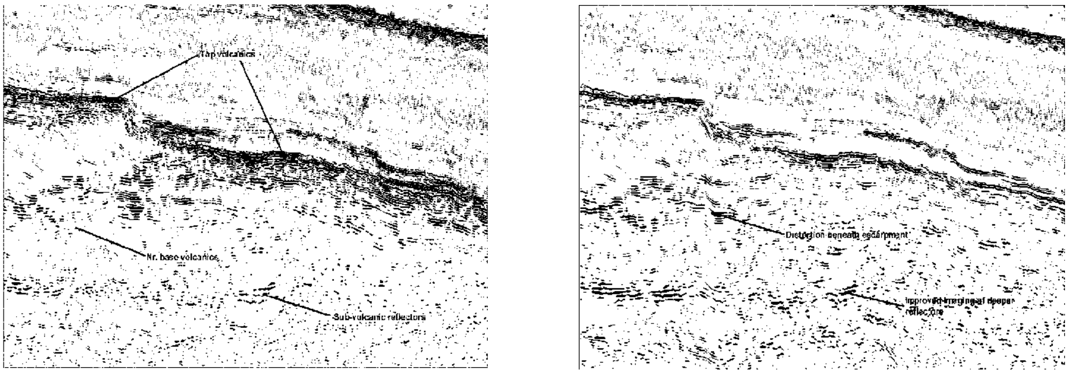
CONCLUSIONS

Case histories have been used to illustrate the benefits of prestack depth migration in the presence of strong vertical velocity gradients and mild dip. Substantial improvements in image continuity and interpretability have been demonstrated. Also, the resolution has been shown to be improved and this allows the identification and interpretation of small scale faulting that can be vital for understanding fluid flow within a reservoir.

In the geological environments examined in this paper, the model building for depth migration is a relatively straightforward procedure. The model can be built layer by layer from the top downwards mainly by simple velocity picking. It is essential to work with the main velocity boundaries rather than geological markers.

The above results suggest that pre stack depth migration should be used far more widely than is currently the case and that in many geological environments improved imaging can be achieved in a robust and straightforward manner.

Figure 1



a) b)

Comparison of sub-basalt imaging in the Shetland_Faroes basin using a) 2D prestack time migration and b) 2D prestack depth migration.

Figure 2

a) b)

Comparison of sub-salt imaging in the Gulf of Mexico using a) 3D prestack time migration and b) 3D prestack depth migration.

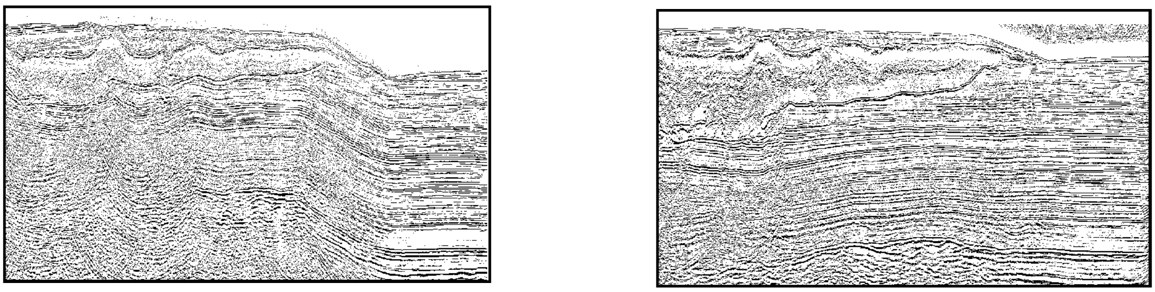
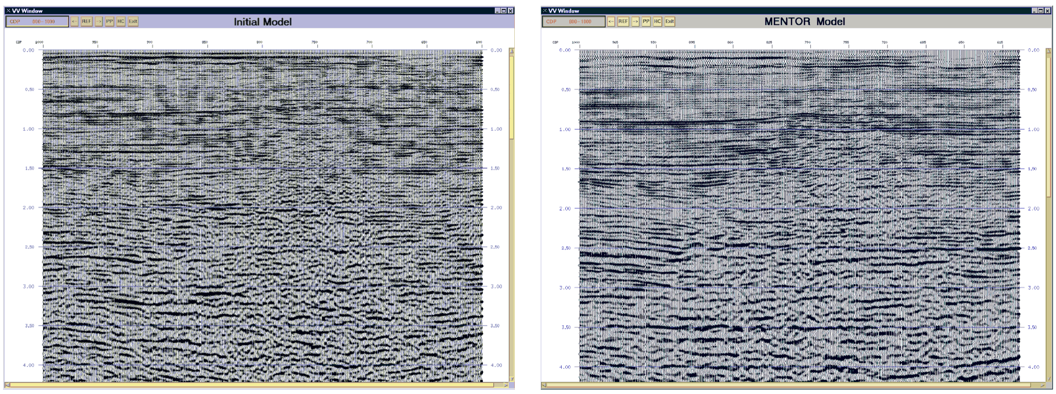
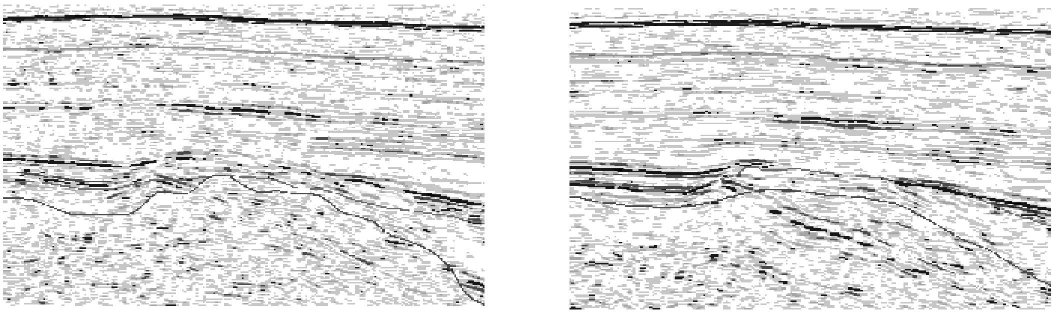


Figure 3



Comparison of prestack depth migration from offshore Australia using a) vertical updating and b) tomographic inversion of reflection travel times.

Figure 4



a) b)

Comparison of a) 3D post stack depth migration with b) 3D prestack depth migration from the central N. Sea. The main zone of interest is beneath the cretaceous chalk.

Figure 5

Enlargement of another portion of the same N. Sea dataset again comparing a)post stack and b) prestack 3D depth migration. The improved resolution achieved by pre-stack depth migration allows the identification of extensive faulting with small throws.