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A practical review of migration issues and solutions

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Summary

The two key steps in any imaging project are the model building and the migration. However, a confusing plethora of different techniques is available in the industry today, for both the migration and model building phases of a project. Here we will review the issues involved in imaging, and describe the various aspects that need to be addressed, showing examples of each for both the migration and model building phases.

Introduction

There are numerous migration schemes in widespread use which can be classified in two broad categories, both of which are numerical solutions to the wave equation. These two categories are the integral methods (including Kirchhoff and beam techniques), and the differential methods, which use wavefield extrapolation to solve the migration equations (these include reverse time migration (RTM) and wavefield extrapolation migration (WEM), also referred to by some as being 'wave equation migration', which is a bit misleading as all the methods attempt to solve the wave equation). Many of these migration techniques can in-turn be applied in various 'domains' on different input-data collections: e.g. time domain, frequency domain, and common shot, common azimuth, or common offset data, etc, and can also be solved with several different numerical techniques, such as finite difference (FD), phase shift, phase screen, etc. Current-day techniques solve what is called the acoustic wave equation: that is to say, they ignore all shear modes and mode conversion at interfaces: this is equivalent to treating all the rocks in the earth as liquids! (Jones, et al., 2008).

It is also instructive to question what kind of pre-stack depth migration (preSDM) is required for a given geological environment. Once we have concluded that time migration may not be appropriate for the complexity of the problem in-hand, we still need to decide what kind of preSDM algorithm to use. Also, the method of velocity model building must be tailored to the type of depth migration algorithm we intend to use. We nowadays commonly have available Kirchhoff, beam, one-way 'wave equation' extrapolation (WEM), and two-way reverse-time migration (RTM) approaches to depth migration.

The 'issues' involved in selecting an algorithm can be summarized as primarily including:

- amplitude preservation
- lateral velocity variation
- dip response
- noise handling
- honouring the velocity field
- multi-pathing
- two-way propagation

In the discussion, we'll consider these issues so as to familiarize the reader with some of the limitations of various migration algorithms, and the related effects in velocity model update (Robein, 2003). It should be noted that the algorithm we intend to use for producing the final image should be linked in performance to how we build the velocity model. For example, if we have steep geological structures, and we correctly selected a migration algorithm with a good dip response for the final imaging step, then it would be foolish to use a model building route that was in some way dip limited, as it could not correctly represent the steep structures in the velocity model. Hence the subsequent migration would be in error, even though the migration algorithm itself had the potential to image the structures.

Also, the scale-length that we try to invert for in the model building should be tuned to the scale-length of feature of interest in the data, but within the limits of ray theory if we are using a ray-based tomography. For example, figure 1 shows an offshore India thin channel sand body associated with an erosional episode on an unconformity (Fruehn, et al., 2008). Using tomographic inversion with a coarse cell size (500m*500m*100m) is

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unable to resolve the velocity associated with this feature. However, reducing the tomographic cell size to (200m*200m*20m) resolves the feature successfully (figure 2).

Discussion

Apart from the above technical aspects related to how algorithms function, there is also a difference in the way we need to work. Historically, when time migration was being used, the oil company interpreters would at best monitor the processing, and wait until the pre-processing was finished, the velocities picked, and the time migration run, before beginning the interpretation process. What was then passed-on to the interpreter was the final product from the view point of the geophysicist. Interpretations of layers from the time migrated volume would be made and later converted to depth using wells for calibration. Thus, the process was purely sequential. Conversely, depth imaging is an iterative multi-disciplinary effort, involving ongoing input from the oil company interpreter during several of perhaps many iterations of model update and (depth) migration. The interpretation may evolve during this process, as understanding of the prospect changes and is refined. Conversion from geophysical depth to geological depth may still need to be made (either on the interpreted depth horizons, or the depth volume), depending on whether we've been able to adequately address anisotropic effects, or localized heterogeneities.

Hence the complexity of the velocity model can evolve not simply because of the inversion update process being used, but also due to changes in any preconceptions that the interpreters might have, and additionally, their practical geological insight may also rule-out implausible inversion results. Due to the various limiting assumptions of the migration schemes available, it is important to couple the complexity of the algorithm to the complexity of the geological problem, and also to ensure that the velocity model building scheme is based on comparable (compatible) assumptions to the migration scheme.

As a final comment, we need to be aware that different migration algorithms make differing assumptions about the behaviour of the subsurface, and are based on varying mathematical simplifications of the acoustic wave equation. These limiting assumptions may have unacceptable consequences if we are using a given algorithm as part of the model update loop in an imaging project. We need to match the performance of the algorithm we select to the complexity of the subsurface model we expect to build.

References

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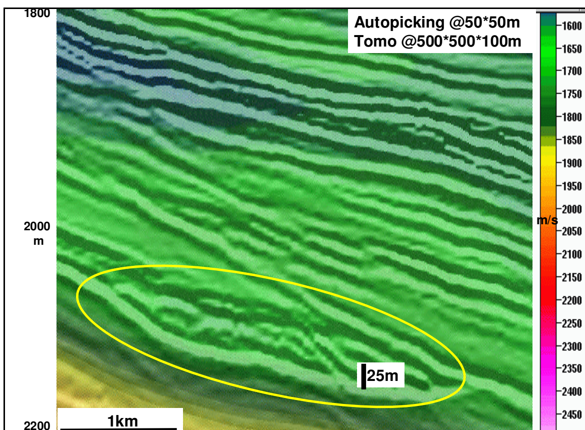

Fig.1: standard cell size tomography does not resolve the thin channel feature

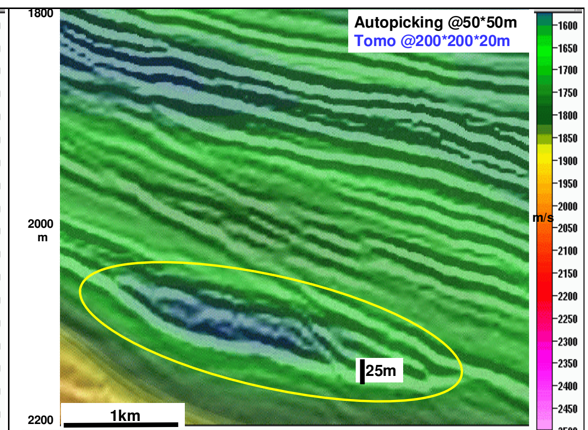

Fig.2: high-resolution cell size tomography resolves the channel feature