Summary

When we derive a velocity field for migration, we assume that the derived values are meaningful in some way. However, before we can assess the ‘meaning’ of these values, either in terms of accuracy or precision, we need to understand what assumptions and approximations have been made in both their derivation, and in the underlying physical model we have taken to represent the process of elastic wave propagation.

In this keynote address, we will investigate the nature of the assumptions and approximations made in the analysis of various physical processes, and note the misconceptions that can arise as a consequence.

These observations will be extended to the industrial practice of velocity model estimation and migration, and comments made as to what is ‘fit for purpose’ and what we should expect from any given approach.

We will commence with a review of the consequences of moving from an analog form of any signal, to the digital representation of that signal: the inherent limitations on resolution brought about by this discrete sampling will be discussed.

Following this review, we will move-on to consider the manifestation of the physical properties of materials governing elastic wave propagation, and the simplification required for tractable algorithmic solutions of associated geophysical problems. We will look at anisotropic behaviour, and other effects which mimic anisotropy, including ray bending and its effect on lateral positioning in migrated images.

Finally, we will assess the impact of choice of migration algorithm on the resultant image, in terms of what set of simplifications the algorithm is based on, and the physical consequences of using such a scheme, vis-à-vis the images it will produce.

Introduction

At the outset of any imaging project, as we set-out to build a velocity-depth model of the subsurface, there is an expectation that we are measuring something meaningful in order to produce a reliable image. It is instructive to step back and assess what we are actually measuring in our ‘velocity’ estimation procedures, what the limits on its accuracy are, and how the subsequent imaging algorithm sets-out to use these values to construct an image.

The work of Al-Chalabi (1973, 1994, 1997) gives great insight into the meaning of the term ‘velocity’ and how the measured quantity relates to both the underlying rock properties, and the processing parameters we need for routines such as stacking and also for migration. It is clear that what we call ‘velocity’ as measured from surface seismic data bears little direct resemblance to the speed of sound within a localized volume of rock. In figure 1, we see a well sonic profile and an overlay of the seismically derived migration velocity function. The well velocity measures transit times (in microseconds per foot) on a length scale of a few centimeters, in the direction of the well bore (assume for simplicity that it is vertical). The imaging velocity on the other hand, is a large scale average over many cubic kilometers of rock through which the seismic energy propagated: the direction of propagation changes continuously as the wavefield refracts and reflects; hence the perceived velocity as a function of direction also changes. For anisotropic media (Thomsen, 1986, Alkhalifa 1997, Alkhalifa and Tsvankin 1995), we are thus at worst averaging
vector quantities to derive a scalar, and at best deriving a simplified version of the directional properties of ‘velocity’ (via Thomsen’s anisotropic coefficients).

Before we even get to the stage of making a measurement, we also have to understand the effect of having sampled the data digitally. Sampling theory tells us about the effects of discretizing analog data. We limit the resolution, and introduce the transfer functions of the sampling procedures into our data (Bracewell, 1978). These put limits on the accuracy of what we can measure. A cartoon of a parabolic Radon transform is shown in figure 2. This is similar in nature to the transforms involved in velocity analysis where we look at moveout behavior as a function of offset (or angle). Having sampled: we smear. Having smeared, we limit resolution. In addition, in certain parts of the data, the window functions severely limit our resolving power: in the shallow, direct arrivals obscure the events of interest, so a harsh mute is used limiting the number of traces to analyze. In the deeper data, the acquisition lateral aperture window limits the angular coverage, so the resolving power of our analysis decays with depth (or time).

These limits on resolution and their associated measurement errors, especially in the shallow overburden have an effect on vertical depth lateral positioning in the migration. In figure 3, we see a suite of migrations from a simple three-layer model...
where we have altered the velocity of the first layer by 3% and 8%. The magnitude of these errors would not be atypical for the very shallow section, and their effects can be significant.

Once we have the set of measurements representing the velocity of the subsurface, with all the limiting assumptions mentioned above, we are now faced with the approximations inherent in the migration algorithms we use. At very least, we assume that the rocks in the earth are all liquid (the acoustic approximation), and then we approximate the shapes of the propagating acoustic wavefronts with various tractable algorithmic representations of complex equations (Pelissier at al, 2007).

In figures 4 we see a ‘velocity model’ (and here ‘velocity’ represents the near-vertical anisotropic P wave velocity function, used in conjunction with epsilon and delta values), and three different acoustic 3D pre-stack anisotropic depth migration results: each using the same data and same model. They are respectively a Kirchhoff integral formulation, a one-way differential solution using a split-step Fourier plus interpolation scheme, and a two-way reverse time migration.
Fig. 4. with the same velocity model and the same input data, different approximate solutions to the (acoustic) wave equation produce very different images.

Conclusions

We need to assess what parameters we need for imaging versus what we actually measure. We need to understand the limits of accuracy in the measurements we make, and finally, we need to know the limitations on the migration algorithms vis a vis these parameters we provide.

This knowledge must be set against the objectives and expectations made for a given project, in order to assess what velocity estimation and migration techniques are ‘fit for purpose’ for the project in-hand. A mismatch between expectations and techniques used will result in unsatisfactory results.

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Background Reading

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