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Rapid automatic velocity images from long-offset seismic data

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Introduction

We present a new method for analysing refraction seismic data, which results in a velocity image in depth or two-way-time being transformed directly and automatically from the data itself. The method is particularly suited for use with long-offset two-ship data, which may be picked automatically by exploiting its geometrical configuration in three dimensions (Nicola-Carena, 1999, 2000). Such images have potential for direct geological interpretation, for use as a starting model for seismic inversion, for superimposition onto conventional reflection images, or for input into pre-stack depth migration and other processing routines. The method captures sub-basalt turning wave energy at long offsets and focuses it into a structural velocity image that carries significant geometrical information about deeper structure.

Velocity imaging

The method produces a two-dimensional velocity image of the subsurface by mapping travel time events from the time-offset domain into the tau-velocity-turningpoint domain (Barton & Edwards, 1999; Barker, Barton & Nicola-Carena, 2000). Each arrival pick is mapped individually from time-offset to intercept-slowness (tau-p) domains, and the 'true' velocity is obtained from the two apparent velocities recorded by reciprocated – reversed - raypaths. Each reciprocated tau-velocity pair is plotted initially at the shot-receiver midpoint, then migrated laterally to an approximate turning point using simple geometry. Using two-ship data, it is straightforward to create equal spatial sampling in the shot and receiver domains, and the 'reversal' can be achieved by comparing gathers along reciprocal raypaths in the two domains. To quantify uncertainty in the velocity and tau values obtained, extra curves are fitted through the travel time data and their associated pick errors, to give a range of possible values of tau and p for each data point. Whilst the uncertainty in tau is dependent on the pick error, it also varies with the shot-receiver offset of the data: each individual pick error produces a far greater tau-error where the shot-receiver offset is large. This error estimation technique is used for filtering the data points to remove those with unacceptably large tau or velocity errors prior to depth conversion.

Depth conversion

The tau-velocity-turningpoint data obtained from the transformation is first fitted into a matrix of binned values, and arranged in vertical columns. As tau is the vertical component of total travel time, tau and velocity can be converted into incremental layer thicknesses using the geometric expression for refracted arrivals, with the offset term set to zero. Before these columns of data can be converted into depth, any data points that produce a velocity inversion are removed. Points that contain a large uncertainty in tau (> ± 0.3 s) are discarded; where several points existed within any particular binned square, the point with the least uncertainty is used; and isolated points are also removed. Depth conversion is carried out on each vertical column of data in turn, beginning with a surface velocity of 1.5 km/s, and continuing down the column. Conversion from depth into two-way reflection time was achieved simply using the depths and velocities down vertical columns. The whole process is extremely fast.

Discussion

On the tau-time section, first order changes in velocity with depth are marked by a gap in tau between one set of arrivals and the next. These gaps are closed when the section is converted to depth, thus confirming their origin. Gaps between layers that remain after depth conversion must be a consequence of there being no data from that depth range, and this is most commonly due to a velocity inversion preventing turning waves reaching the surface from that interval. The velocities in these unsampled regions may be extrapolated from the layers above or beneath (generally resulting in too high a velocity being used, causing pull-down on the depth section), or a more realistic assumed velocity may be inserted into the depth conversion algorithm.

Each picked travel-time maps onto a single velocity point on the tau map independently of other points, except inasmuch as surrounding points are necessary for the determination of slope (apparent velocity) and intercept time (tau). The velocity image sorts arrivals automatically into phases, grouped on the basis of geometry and velocity, and no subjective allocation of

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arrivals to seismic phases is necessary. The map also picks out layers with high velocity gradient (densely sampled on plot) and low velocity gradient (sparsely sampled on plot). Such phase allocation and relative subsurface geometry could be fed back into forward modelling or inversion schemes such as *Jive3D* (Hobro, 1999). Secondary arrivals such as multiples and converted waves may also be identified and distinguished from the primaries by their spatial distribution and velocities.

Applications

The method has been tested on both synthetic and real datasets, producing excellent results, including velocity structure in the sub-basalt region. Comparison of the results obtained using this new method with a conventional stack of a long offset two ship dataset showed good correlation between the velocity field and the reflectivity structure, demonstrating the potential for pre-stack depth migration using a high resolution velocity field obtained by this independent method. The next stage in the development of this technique will be its application to full-wavefield data, making the picking of the data unnecessary: this approach is described by Jones (2000).

References

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