Summary

This paper presents an effort toward interactive migration. A prestack depth-domain fast beam migration algorithm is implemented. To achieve efficiency, only picked events are migrated. Picked events in the time domain form a new dataset which is a small fraction of the original dataset in terms of volume. Furthermore, events are migrated wavelet by wavelet instead of sample by sample. The wavelet is mapped into depth domain in the format of a patch. Coherent noise and migration artifacts in migration image are reduced by multi-path migration and intrinsically used dipping information. The idea of multi-path algorithm is borrowed from the Gaussian beam migration technique, but only picked events with certain p values (event slowness) are migrated. The resulting Sigsbee image using fast beam migration is superior to that of conventional Kirchhoff migration with a speed-up of at least one order of magnitude.

Introduction

It is well known that subsalt seismic imaging is a challenge which arises from the fact that signals containing subsalt information are usually weak, and subsalt illumination is generally poor and non-uniform. More often than not is the identification of salt base problematic. Poor subsalt images make subsalt seismic interpretation a difficult job to perform. Since subsalt regions are the most important targets for oil/gas exploration, research efforts are on the way to provide the solutions to such subsalt imaging problems.

One such solution could be to provide an interactive approach to the subsalt model building whereby different velocity models are tested and validated over a short time period. However, turnaround and cost constraints with current imaging technology make any iterative model building a time consuming and costly exercise. Most of today’s PSDM work is therefore based on a single pass of model building.

In order to make interactive migration become reality, imaging algorithms need at least to become an order of magnitude more efficient than existing migration techniques, while retaining good subsalt imaging capabilities. Prestack depth-domain Kirchhoff type migration has been established as a powerful and robust seismic imaging tool (e.g., Xu and Lambare, 2004). To improve the efficiency of Kirchhoff migration, Sun et al. (2000) implemented 3-D prestack Kirchhoff beam migration with an efficiency of an order higher in production data processing. Hua and McMechan (2001, 2003) developed parsimonious migration techniques, resulting in a speed-up at least one order of magnitude. Sun and Schuster (2001) implemented a 2D wave path migration, which performed an order of magnitude faster than conventional Kirchhoff migration. These techniques were all developed to solve the efficiency problem while retaining reasonable/good image quality; however, their subsalt imaging capabilities are not fully demonstrated.

To improve subsalt image quality, in addition to good picking, we borrowed ideas from Gaussian beam migration (e.g., Hill, 1990, 2001; Gray, 2005), and also used directional attributes to suppress coherent noise and migration artifacts. To allow multi-pathing, we use similar techniques as are employed in Gaussian beam migration where ray-based extrapolated times are used for the migration process.

In our implementation of a fast beam migration we image a set of events that have been identified and picked in the recorded time data. These events form a new dataset that is a fraction of the size of the original recorded time data. The picking is considered a pre-processing step of the migration. Time attributes (the location of events in time domain) and directional attributes are determined in the picking process. For this, groups of traces are selected in the common shot and common receiver domain to form beams. Picking is performed in Tau-p domain (Hua and McMechan, 2001), and the events are determined using both amplitude and semblance spectra. Once all significant events are picked and stored, they can be re-used repeatedly for migration runs using different velocity models in a very fast and efficient way.

Methodology

Event picking and discrimination

The goal of the picking process is to determine the time slope and position of locally coherent events within a beam of traces in the recorded time domain on common shot and common receiver gathers. Once computed, such a local time slope can be translated into a ray emergent angle at the receiver location and a ray emitting angle at the source location if the velocity in the vicinity of the source and the receiver is known. The ray angles in the common shot and receiver domain are defined as the directional attributes of an event. One main assumption of this method is that we assume the local wave front to be planar.
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Picking is performed in the Tau-p domain and both semblance and amplitude spectra are used to determine the event location in time and the event slope. In addition to simultaneous picking in common source and receiver domains, optionally picking can also be performed in the common offset domain to help improve the picking accuracy. Once events have been identified around a given time sample within a beam they are removed using a matching pursuit approach (Wang and Pann, 1996) to allow for accurate picking of multiple events arriving within a very short time window.

Multi-pathing

To allow for multi-pathing in the fast beam migration we used ray times instead of pre-computed time tables to migrate the picked events into depth domain, in a fashion very similar to Gaussian beam migration. Two rays are shot from source and receiver location using the directional attributes of an event. Dip and spatial image location of the event are computed using ray extrapolated travel times (Zhang and Qin, 2004). This process eliminates the usage of any time table which is not efficient to be loaded into memory, and suppresses coherent noise due to the mismatch between the arrival types of the picked event and pre-computed time table.

Event Migration

Once the location and dip of an event are computed, each event can be either mapped to depth domain using a standard Ricker wavelet (Figure 1) or migrated by smearing energy along time iso-chrons, depending on picking quality. By mapping, the width of the wavelet is determined by local velocity and the dominant frequency, and the mapping length is determined by the width of the local Fresnel zone. Using this method, the picked events are migrated wavelet by wavelet instead of sample by sample (Wang and Pann, 1996). Since the energy of the mapped events is relatively localized in space, the swing noise in the migration is greatly reduced, which becomes very apparent when the beam migration results are compared to classical Kirchhoff images (Figure 2). An additional advantage of the mapping method is the fact that it can be implemented with great efficiency. If preferred, the standard Ricker wavelet can be replaced by a real stacked wavelet.

An interactive model building/evaluation example

To demonstrate the ability of the proposed fast beam migration implementation to image steeply dipping structure and to produce good subsalt images, we use migration examples from the Sigsbee 2a dataset. Although the model is only 2D it features structurally complex enough salt body to test the imaging capability of our migration algorithm. For the migration tests 5 traces were used to form a single beam, which resulted in a total of 30064 beams being migrated. Time domain events were picked in common shot, common receiver and common offset domain. After final event discrimination which is critical for subsalt image quality, each beam was comprised of less than 100 events.

To simulate the process of interactive model building and model validation the true Sigsbee velocity model was altered by removing some salt in the areas of maximum salt thickness (Figure 3).

For both new models, depth images were produced rapidly to assess the resulting subsalt images. As expected, the image of the salt body is deformed the most when the most salt is removed. Interestingly, we can observe that some subsalt sediment reflections to the right of the deep salt keel in the center of the salt body are still migrated in approximately the correct locations and have not experienced significant deformation due to removing large amounts of salt above. This indicates that these subsalt events are imaged through the sediments rather than the salt, and a comparison of the two images would provide interpreters valid information as to where to change the model and where not.

This small example demonstrates the potential benefits of providing multiple migrated images for a range of different models to the interpreter in order to facilitate a better and faster velocity model building process.

Discussions and Conclusions

We developed a fast beam migration that is composed of beam forming, time domain event picking and discrimination followed by an event migration or mapping into the depth domain. Event picking and discrimination are the critical steps for good migration images, and they are expensive. However, they are done only once prior to interactive migrations. Multiple images can be computed...
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very rapidly using the same event database. This makes testing of a large number of alternative velocity models a real possibility.

Our results demonstrate that the proposed fast beam migration produces superior subsalt images (Figure 2) compared to any published Kirchhoff images on the Sigsbee 2a dataset.

The presented method provides a real alternative to classical Kirchhoff imaging and opens the door to true interactive velocity model building.

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References

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Figure 2. Close-up of an image from the Sigsbee 2a model produced using the presented fast beam migration (left) and a classical Kirchhoff migration (right). The image from the beam migration is characterized by less migration artifacts and swing noise.
Figure 3. Simulation example of interactive migration. The same picked time domain events were used in the fast beam migration to produce the three images on the left hand side. The corresponding different velocity models are displayed on the right.