Model-based decimation of input data for delayed-shot/plane-wave migration for the purpose of subsalt velocity model building

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**Summary**

The process of subsalt velocity model building often makes use of wave-equation migration scans using a series of perturbed velocity models. As these methods require significant computer resources, reducing the cost is a concern to the depth imager. Historically and from a practical point of view, decimation of the input data using a regular or random pattern of data selection is frequently applied but does not make use of any available illumination criteria. In this paper, we present an alternative methodology that offers a way to optimize the decimation criteria according to P-values for delayed-shot/plane-wave type migrations. Local Tau-P analysis of wave equation de-migrated seismic events is used to drive the P-value selection and honor illumination effects.

**Introduction**

Due to the complexity of typical Gulf of Mexico velocity models that include salt body emplacements, wave equation migration is preferentially used for subsalt velocity model building. In a standard workflow, multiple wave equation migrations are performed either to test different base of salt interpretations or to scan for subsalt sediment velocities.

For the purpose of subsalt velocity model building, the primary goal of producing multiple wave equation migrations is to identify which velocity model yields the best subsalt image. Since we do not yet aim to produce the final “best” migration image and only wish to focus on noticeable subsalt image quality differences, the input data may be decimated to reduce the overall computation cost. The most commonly used decimation scheme is based on regular decimation.

Delayed-shot or plane-wave migrations (Whitmore, 1995; Rietveld, 1995; Duquet et. al., 2001; Liu et. al., 2002, 2004; Zhang et. al., 2005) present alternative migration schemes that first synthesize linear or planar source records by linear superposition of different shot records according to given P values. The cost of these migration schemes is directly proportional to the number of synthesized common P records (or P-values).

Recently there have been some discussions (Stock and Kapoor, 2004; Etgen 2005; Zhang et. al., 2005) regarding the required number of P-values for optimal imaging using delayed-shot or plane-wave migration and the impact of regular decimation on image quality. Regular decimation is a simple and effective way to reduce computation cost for velocity model building purposes. However, useful signals as well as noise may be thrown away indiscriminately. Under some anticipated circumstances, the illumination of the subsalt target may already be very poor; necessitating the preservation of useful signals in order to obtain optimal illumination at the target levels.

In this paper, we present a methodology for improved selection and subsequent decimation of P-values. The goal is to preserve the precious signals reflected from subsalt targets. Synthesis of different common P gathers amounts to designing a number of different numerical experiments, and therefore is analogous to an acquisition design problem. Similar to the task of optimizing acquisition design, and for the purpose of improving the illumination of subsalt targets, model-based forward modeling can be used.

Two key ingredients of our methodology are wave equation based poststack demigration, and a subsequent local Tau-P analysis of the demigrated seismic data. For simplicity, we use the Sigsbee2a data set as an example to demonstrate our methodology. We also restrict ourselves to the use of a simple 2D FFD imaging algorithm to illustrate the benefits of the proposed method.

**Wave equation based poststack demigration of prestack migrated images**

In our previous work, we demonstrated that poststack demigration of prestack migrated images is a useful tool for subsalt velocity model building (Wang et. al., 2005; 2006). As we mentioned in our previous papers, there is a mismatch between the complex forward-modeling operator (the true seismic wave propagator) and the much-simplified one-way wave equation based migration operator. Any wave-modes not modeled by the one-way wave-equation operator contribute to coherent noise in each partial image after migration.

Conceptually, poststack demigration is used in our current work in the same way as conventional forward modeling tools are used for acquisition design. As the poststack demigration is using the same one-way wave propagation operator as the prestack migration process and the same velocity model, it removes the velocity model dependence and recovers the kinematic information of the true
reflection events. We therefore propose to use wave equation demigration only for the part of the prestack image that is targeted for update, which in the context of this paper is the subsalt area.

Figure 1 shows an example of a demigrated subsalt event for the Sigsbee 2a model. The corresponding illumination plot is shown in Figure 2 illustrating the complex wave propagation in the model. It is easy to understand that a dip analysis of the demigrated data in Figure 1 will reveal the P-value range that is required to image the modeled event. The same analysis can be performed for any subsalt event and indeed for the totality of all subsalt events by analyzing the demigrated section of an initial subsalt prestack image.

**Local Tau-P analysis of demigrated seismic data**

In order to compute the main dip components in the demigrated time data we perform a local Tau-P transform. An amplitude-weighted histogram is computed based on the data distribution in Tau-P space. With the knowledge of the surface velocity the computed P values can be easily converted into surface angles. Using this process, either surface P-value or surface angle distribution plots can be generated for the demigrated dataset. These distribution plots provide the necessary information to determine the optimum P-value range in order to generate the best image of the target reflectors.

Using the same subsalt reflector element as presented in Figures 1 and 2, a P-value distribution plot can be computed (Figure 3). The horizontal axis represents the surface (emergence) angle. Figure 3 clearly indicates that the majority of energy illuminating the subsalt target is recorded between surface locations at 12 and 16.5 km, with surface angles in the range of -15 degrees to -35 degrees (a negative sign indicating here a dip to the right hand side of the model). Since the histogram plot not only provides surface angle distributions but also lateral distributions, it would be even more appropriate for model-based decimation as input to any beam-type migration, which uses local P instead of global P estimates for the migration process. For comparison, Figure 4 shows the illumination map based on demigration of a steep dip salt boundary for the Sigabee2a model. Figure 5 is the corresponding surface angle distribution plot, which indicates that the dominant energies illuminating this portion of steep dip salt boundary come from surface locations between 16 and 22 km and from surface angles in the range of positive 30 degrees to 55 degrees.

**Model-based selection of P values for subsalt migration velocity analysis**

As previously stated at the subsalt velocity analysis stage, the salt geometry modeling is assumed to be completed and fixed in the model. The primary imaging goal is aimed at generating an improved image of the subsalt sediment targets.

Whereas a wide range of P values are necessary to produce a good image of the steep dipping salt boundaries, subsalt sediments are usually characterised by moderate dips and require only a limited number of P-values for optimal imaging.

To illustrate this we have performed a surface angle distribution analysis of the demigrated subsalt prestack image for the Sigsbee 2a dataset. Based on this analysis we estimated the optimum angle range to be between -35 and +20 degrees.

Figure 6 shows an image based on 7 surface angle (P) values only, which were chosen to be between -10 and +10 degrees, representing approximately the center of the determined useful angle range.

Figure 7 represents the image achieved with 24 surface angles, spanning the whole precomputed surface angle range from -35 to +20 degrees.

A comparison of Figures 4 and 5 reveals that 7 surface angles, although from within the desired angle range, are not enough to produce an acceptable image. However, using 24 surface angles results in a much improved subsalt image.

For further comparison, Figure 8 shows a single arrival Kirchhoff migration image and Figure 9 shows the shot profile migration using all 500 available shots.

Using all the data, both Kirchhoff and wave equation migration produced good steep-dip salt boundary images. However, compared with the Kirchhoff result, the image produced by only 24 surface angles is much cleaner in the subsalt area and hence better suited for any velocity updating procedure. According to sampling theory (Zhang et al., 2005), we would expect to require about 240 P values in order to produce an image without losing any information through the decimation process. We observe that different P values will illuminate different portions of subsurface targets. Large amounts of high degree surface angle common P gathers contribute predominantly to the illumination of the steep dip salt boundaries as shown in Figures 4 and 5, which are not critical for the purpose of subsalt velocity model building.

**Conclusions**

The methodology described in this paper offers a potential way of reducing the cost of wave equation based subsalt image scanning by computing the required effective surface
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angle range needed for optimum subsalt imaging. The optimum P-values range is computed by dip analysis of poststack demigrated data. The selection of P values may be different depending on the stage of velocity model building and the imaging objective. The method offers an inexpensive way of linking forward modeling through demigration with the practical aspects of data selection and image optimization.

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References


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Figure 4: Illumination plot for demigration of a steep dip salt boundary.

Figure 6: Migration of 7 P gathers in the range of –10 to +10 Degrees.

Figure 5: Surface angle distribution plot corresponding to Figure 4.

Figure 7: Migration of 24 P gathers, with surface angle range between –35 to +20 degree.

Figure 8: Kirchhoff migration result of all 500 shots.

Figure 9: Wave equation based shot profile migration of all 500 shots.