C003
Subsalt Velocity Analysis by Combining Wave Equation Based Redatuming and Kirchhoff Based Migration Velocity Analysis
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SUMMARY
Due to the geometrical complexity of the typical Gulf of Mexico (GOM) velocity models, with embedded salt bodies of any shapes, wave equation migration is used preferentially over Kirchhoff methods for subsalt velocity model building. This preference is based on the ability of wave-equation based migrations to overcome the need for tracing complex ray paths through the salt bodies and for a better handling of multi-path arrivals via wavefield reconstruction. Subsalt velocity analysis uses prestack wave equation migration scans that are created from perturbed velocity models: this is an accurate albeit expensive and time consuming approach that requires multiple runs of prestack migrations. To make this process more efficient, we present in this paper an alternative methodology to perform subsalt velocity analysis. For those cases where sediment velocity structure is relatively simple, we perform a single one-time redatuming to the base of salt (BOS), using existing prestack wave equation tools. By redatuming, we remove the complexity of the wavefield caused by the salt bodies. Once having obtained a simplified wavefield by stripping off the effects of the complex overburden, we can employ less expensive Kirchhoff imaging algorithms for performing subsalt velocity model building.
Introduction

Due to the geometrical complexity of the typical Gulf of Mexico (GOM) velocity models, wave equation migration is used preferentially over Kirchhoff methods for subsalt velocity model building. Although the most recent attempts at using the wave equation based migration scan techniques for subsalt velocity updating (Wang et al., 2006) are promising, the cost of generating migration scans is still very high. A migration scan is a set of PreSDM stack images that are produced from a set of locally scaled velocity models. The cost of producing a set of scans becomes prohibitively high, when a large scan range is needed.

In order to allow for a more detailed subsalt velocity analysis using a larger number of scans we presented last year two alternative methods to the full PreSDM scan technique. These two alternatives are totally complementary, each of them being applicable to different subsalt situations. The first approach (Wang et al.; 2005a) is based on focusing analysis. In the second approach (Wang et al.; 2005b), we first use the current “best” velocity model to produce a single PreSDM stacked subsalt image. The stacked subsalt image is then demigrated to the base of salt to produce demigrated zero-offset data in the time domain, then post-stack instead of prestack wave equation migration is used to generate subsalt scan.

In this paper, we describe another somewhat more general approach for reducing the time and computational effort of subsalt velocity analysis. For typical offshore Gulf of Mexico data sets, the complexity of the surface seismic wavefield is due primarily to the multi-pathing and illumination effects caused by seismic wave propagation through salt bodies. Naturally, by using wave equation based migration algorithms, we model more adequately the wave propagation effects. Wavefield redatuming has been described by various authors: Berryhill (1984), Bevc and Popovici (1998) and Luo and Schuster (2004). In this paper, we describe a scalable algorithm for performing an SR (source-receiver), wave equation based redatuming that is suitable to velocity model building. Our algorithm completely removes the salt-sediment overburden effects, and redatums the surface seismic data to a flat arbitrary subsalt datum. At this datum, the wavefield has been simplified and we can employ less expensive Kirchhoff imaging algorithms for performing subsalt velocity model building. For simplicity, we use the 2D Sigsbee data set to illustrate the method and will discuss the implications and complexity of the 3D redatuming process.

Scalable wave equation based SR redatuming

The direct SR (source-receiver) redatuming is a modification of the SR migration algorithm and is conceptually simple. Also, like SR migration it is not as easily scalable as would be required for large 3D surveys. As a consequence, we developed an algorithm that is equivalent to SR redatuming, but is fully scalable. To solve the scalability problem, we work with a single shot record at a time.

Let us assume we want to redatum the seismic data from the surface to a flat subsurface BOS (Base Of Salt) datum. As illustrated in Figure 1, we first downward continue the receiver wavefield, for each shot record, from the surface to the BOS datum. After finishing the downward continuation of the receiver wavefield from the surface to the BOS for all the shot records, we sort the data to common receiver gathers. Now for each common receiver gather, the receiver is located at the BOS datum, while the shots are still located at the surface. By invoking the principle of reciprocity, we perform a similar operation as in the previous step, for each common receiver gather, that is now equivalent to a “new” shot record: we downward continue the “old” source wavefield (that is now a “new” receiver wavefield), from the surface to the BOS datum. With this procedure, we have essentially achieved SR redatuming, with one single large extrapolation step in depth, as opposed to the many small steps used in SR migration.
Removing BOS topography

The BOS interface may have variable topography: to be able to redatum the wavefield to a flat datum surface (a requisite of most extrapolation algorithms), while at the same time removing the effects of the salt bodies, we perform the following operations.

As shown in Figure 2, we first define two flat horizontal surfaces Zmin and Zmax, with Zmin at the minimum depth of the BOS topography, and Zmax at the maximum depth of the BOS topography. We then use two velocity models in our redatuming algorithm: one with the original salt bodies in place, the second one with a replacement of the salt velocity with the sediment velocity (or a fixed constant velocity) within the salt bodies, between Zmin and Zmax. Now, each step of downward continuation from the surface to the Zmin datum will be split into two substeps: in a first substep, we use the original model, with all the salt bodies, to downward continue the “receiver” wavefield from the surface to the Zmax datum. Then, in the second substep, we use the second model, with the replacement by the sediment velocity, to upward continue the “receiver” wavefield from the Zmax datum to the Zmin datum. There, we obtain the wavefield at the Zmin datum, as if the velocity in the salt bodies between datum Zmin and Zmax had been effectively and legitimately replaced with the sediment velocity (or a constant velocity), as shown by Figure 3: an otherwise classic layer replacement but in a new context. At this stage of the redatuming process, there is no need to know precisely the subsalt velocity. However, the geometry of the salt bodies and the salt velocity must be accurate in the first model, and the replacement velocity in the salt bodies, in the second model, should be left untouched in the subsequent iterations of the velocity model building. This datuming plus layer replacement simplifies the wavefield reconstituted at the Zmin datum.

Numerical example

We use the Sigsbee2a data set to illustrate the acceptability of the simplified wavefield after redatuming from the surface to a flat datum at a depth of 4550 m. Figures 4A to Figure 4C compare the original CMP gathers at the surface with the CMP gathers obtained after redatuming to a datum level 4550 m. In the original CMP gathers the subsalt events exhibit very complex moveouts, weak amplitude, and they are sometimes completely overwhelmed by the strong events of the salt boundaries. After redatuming, the wavefield is much simplified. The shallow strong events have disappeared to “negative” times, and the subsalt events now exhibit more or less hyperbolic move-out shapes. Figures 4A also shows the variability with offset of the illumination for the subsalt targets: the redatuming removed the kinematic imprint of the complex overbuden, but did not remove totally its dynamic (illumination) imprint.

Now that after redatuming we have at hand a much simplified wavefield, the use of less expensive Kirchhoff migration algorithms is warranted. This renders velocity analysis very practical and effective in updating the subsalt half-space of the velocity model. Figure 5A shows the Kirchhoff migration image obtained with the redatumed data. Figure 5B shows the Kirchhoff migration image obtained from the original data at the surface. We observe that the migrated image with redatumed data is greatly improved, and exhibits less coherent noise. It even compares quite favorably with the image obtained by wave equation migration at the surface, Figure 5C, even in the subsalt zone.

Feasibility of 3D redatuming

With current “narrow” azimuth 3D marine acquisition, there is a potential “data explosion” problem in the intermediate step of redatuming. Since we need to add significant migration aperture in both the inline and crossline directions, the data are allowed to expand toward wider azimuths. If the implementation is not carefully done, the intermediate data volume after redatuming of the receiver wavefield could be 10 times larger than the original input data.

In order to reduce this “data explosion” problem, we have taken into account the following factors. First, by moving sources and receivers closer to the subsalt target, the effective maximum offset in both the
inline and cross-line directions decreases. Second, after redatuming, the record length is reduced and fewer time samples are needed. Third, since the redatuming surface lies below the rugose TOS (Top Of Salt), now the receiver wavefield can be sampled at a coarser interval in the inline direction. Fourth, due to attenuation effects, the signal bandwidth decreases, thus allowing the use of a larger time sampling interval. After taking into account these factors, the data explosion problem in the intermediate step can be largely contained.

It is worth pointing out that after completion of the redatuming process, the redatumed data volumes are usually smaller than the original input data volumes: generally the output redatumed survey has a similar geometry as the original input one, but with significantly reduced offset range and recording time. There are other benefits of redatuming, in addition to generating a much simpler wavefield. First, redatumed data are regularized. Second, there is the possibility of reprocessing the redatumed data. Even simple routine pre-processing steps such as muting, filtering and amplitude rebalancing can significantly improve the final image. There are also new opportunities for the application of advanced algorithms to the redatumed data such as new demultiple algorithms, etc. For future wide azimuth marine surveys, we foresee a tremendous potential for the application of wave equation redatuming techniques as described in this paper, to provide significant subsalt imaging quality improvements by taking full advantage of the natural richness of azimuth information in such datasets.

**Conclusions**

The hybrid redatuming workflow described in this paper makes use of the right algorithm for the right purpose. Wave equation based migration methods are used for handling complex salt geometries, while Kirchhoff based methods are used for detailed velocity analysis, for the generation of prestack gathers, and migration velocity scans. The scalability of our workflow and redatuming algorithm is important for large 3D surveys. In general, 3D redatuming of narrow azimuth surveys requires large temporary disk space to store the intermediate data volumes. However, we suggest a careful implementation that can largely reduce this “data explosion” problem. Redatuming also provides the opportunities to re-process the redatumed data, which in general will result in a better final image. For future wide azimuth surveys the intermediate data will be proportionally less voluminous, thereby improving the overall efficiency.

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**References**

Figure 1: Schematic diagram showing the downward continuation of the receiver wavefield from the surface to the BOS datum.

Figure 2: Schematic diagram showing the BOS topography and the flat datum surfaces at Z_{min} and Z_{max}.

Figure 3: Schematic diagram showing the velocity model as seen at the new datum, after redatuming in two steps using two velocity models. The new acquisition at the Z_{min} datum sees only sediment velocity below Z_{min}.

Figure 4A: CMP gathers at location 950, left: CMP gather at the surface, right: CMP gather after redatuming.

Figure 4B: CMP gathers at location 1205, left: CMP gather at the surface, right: CMP gather after redatuming.

Figure 4C: CMP gathers at location 1580, left: CMP gather at the surface, right: CMP gather after redatuming.

Figure 5: Comparison of subsalt migration images: A) Kirchhoff migration of redatumed data; B) Kirchhoff migration of surface data; C) wave equation migration of surface data.