ABSTRACT

One of the difficulties in seeing beneath salt is that the migration velocity in the salt and above is often not well known. This can lead to defocusing of migration images beneath the salt. Both reduced-time migration (RTM) and interferometric migration (IM) can mitigate this problem. The RTM method shifts the data with a time difference between the calculated and natural arrival times of a reference reflection. The IM method on the other hand requires: 1) extrapolation of the surface data below salt using the natural arrival times of the subsalt reference reflector, and 2) migration of the extrapolated data below the salt. The synthetic and field CDP data tests indicate that both RTM and IM can remove the kinematic effects of the overburden without knowledge of the overburden velocity.

PRINCIPLE

1. Reduced-time Migration

The left figure illustrates a reference reflector located just below the salt, the reflection events from the reference and oil interfaces with respective natural arrival times are denoted by \( t^r \) and \( t^g \). The velocity model below the reference is known exactly, except in the overburden salt. This means that the timing errors for calculating the reference-reflection time \( t^r \) are the same as those for the oil-reflection time \( t^g \) for raypath segments nearly coincident in the salt. With this approximation, RTM suppresses the timing error caused by an uncertain overburden velocity in three steps: 1) Pick the reflection times \( t^r \) associated with the reference reflector from the data.

2. Shift the data by the picked reference reflection time.

3. Migrate the reduced data with the RTM migration formula:

\[
r(x, y) = d(x, y) e^{i k(x-y)}
\]

where \( e_{xs} \) without the tilde indicates the calculated reflection time for an assumed velocity model; \( \omega \) denotes the angular frequency; and symbols s and g represent the source and geophone indicies.

2. Interferometric Migration

The IM removes the kinematic effects of the salt by 1) the natural downward continuation of the surface data through the salt to the reference layer:

\[
d(x', y') = \sum \sum d(x, y) e^{i \omega (t^r(x, y) - t^r(x', y'))}
\]

2) migration of the redatumed data:

\[
m(x) = \sum \sum \sum \sum d(x, y) e^{i \omega (t^r(x, y) - t^g(x, y))}
\]

To simplify the computation, we replace the diffraction times with the specular times by applying Fermat's principle:

\[
m(x) = \sum \sum \sum \sum d(x, y) e^{i \omega (t^g(x, y) - t^g(x', y'))}
\]

where the subscript o denotes the positions on specular rays and \( t^g \) for the data after waveform residual static corrections, and \( t^g \) for the data before residual static corrections, and \( t^g \) for interferometric migration with semi-natural Green's functions. The migration velocity model is estimated by the NMO velocity. Both RTM and IM images are not strongly affected by the overburden velocity errors.

CONCLUSIONS

Both RTM and IM migrations remove the kinematic defocusing effects caused by the errors in the overburden velocity model by using the natural Green's functions from the data. RTM is as inexpensive as standard Kirchhoff migration because it does not extrapolate the data but rather applies a natural static shift to the data and then undoes this with a calculated static shift. This removes most of the timing error effects of the overburden which lead to defocusing in migration images. The IM with the semi-natural Green's functions is almost as efficient as RTM because it implements IM with a semi-natural Green's function instead of the explicit data extrapolation. Test results on synthetic and field data show that RTM and IM can mitigate the timing error effects associated with the shallow structures and provide focused images below the reference layer. Synthetic tests also indicate that RTM and IM can focus the structures below the reference layer using only a rough estimate of the reference layer's geometry.

NUMERICAL RESULTS

1. Synthetic data

Figure 1. True velocity model (left) and the migration velocity model (right). The migration velocity model is a smoothed version of the true model. The bottom of the salt located at a depth of 0.8 km is chosen as the reference layer.

Figure 2. Kirchhoff depth migration image (a), RTM image (b), and IM image with the migration velocity model shown in Figure 1 (c). Due to the errors in the overburden velocity model, standard migration cannot remove the kinematic effects without the tilde indicates the calculated reflection time for an assumed velocity model; \( \omega \) denotes the angular frequency; and symbols s and g represent the source and geophone indicies.

Figure 3. RTM image with the reference layer located at (a) 0.8 km (50 m above its true depth); (b) 0.9 km (50 m below its true depth); and (c) a sinusoidal undulating horizon with a 20 m maximum vertical deviation. The subsalt structures are still focused in all cases, although they are shifted or distorted due to the errors in the reference position.

Figure 4. IM image with the reference layer located at (a) 0.8 km (50 m above its true depth) and (b) 0.9 km (50 m below its true depth). The subsalt structures are still focused in all cases, although they are shifted or distorted due to the errors in the reference position.

Figure 5. The stacked section. The event located at about 0.72 seconds is chosen as the reference layer in RTM and its reflection traveltimes are picked from 6 km to 12 km along the horizontal direction.

Figure 6. Time migration images for (a) standard Kirchhoff migration with the data after waveform residual static corrections, (b) reduced-time migration with the data before residual static corrections, and (c) interferometric migration with semi-natural Green's functions. The migration velocity model is estimated by the NMO velocity. Both RTM and IM images are not strongly affected by the overburden velocity errors.