True-reflection imaging with amplitude correction in dip-angle domain

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Abstract

We compare the new method of amplitude correction in the local dip-angle domain with other correction schemes: the traditional vertical AGC, space-domain correction based on total illumination, and correction in other angle-domains, such as the scattering-angle and receiving-angle domains. For the total strength imaging, amplitude corrections can be considered as applying amplitude gain (AG) factors to the migrated images in prestack depth migration. We analyze the different approximations involved in these schemes and compare their results of amplitude correction for the migrated images of SEG-EAGE salt model. The advantages of the new scheme can be seen clearly. The image quality of subsalt structures is greatly improved and the image amplitudes, especially along the steep faults and the baseline are much more uniformly distributed. In the meanwhile the noises in the same region are depressed.

Introduction

True-amplitude or true-reflection imaging can be considered as applying amplitude gain factors to the migrated images to recover the true local reflection coefficients (or scattering coefficients). The theory and method of true-amplitude imaging were developed originally based on high-frequency asymptotic theory (ray theory) and are traditionally carried out through Kirchhoff prestack depth migration. Since the amplitude corrections have to be done in the locall angle-domain, some effort has been tried to extract common-angle image (CAI) gathers for wave-equation based migration methods from offset related angle gathers or shot related angle gathers (Mosher et al., 1997; Rickett and Sava, 2002). Amplitude correction in angle-domain for wave-equation based migration method is currently a focus of investigation. Wu et al. (2004) proposed a amplitude correction scheme using local image matrix defined in local angle-domain by beamlet decomposition of wave fields and Green's functions. The new theory and method of amplitude correction include both the effects of acquisition system configuration and the propagation through complex overburden. In this paper we will compare the new scheme of amplitude correction in local dip-angle domain with other correction schemes from the viewpoint of amplitude gain control (AGC) factors with different approximations. The SEG/EAGE 2D salt model data are used to demonstrate the effects of different corrections.

Amplitude correction in local dip-angle domain

In order to relate the image field of seismic imaging (prestack depth migration) to the local scattering property of heterogeneity, the image amplitudes of migrated image need to be corrected to eliminate the influences of different factors, such as (1) geometric spreading in complex media, (2) path effects (absorption and scattering losses during propagation), (3) acquisition aperture effects. It turned out that the acquisition aperture effect is the most important one among these factors. It is shown that the acquisition aperture correction must be done in the local angle domain, specifically in the local dip-angle domain (Wu at al., 2004a, b).

To do the amplitude correction in local angle domain, a local image matrix $L(\bar{\theta}_i,\bar{\theta}_g)$ is obtained for each image point in the image space during the migration process, where $\bar{\theta}_i,\bar{\theta}_g$ are the incident and receiving angles respectively. If we define a reflector-normal direction as the direction that bisect the source direction $\bar{\theta}_s=\bar{\theta}_i$ and the receiving direction, as showed in figure 1, we can change $(\bar{\theta}_i,\bar{\theta}_g)$ into $(\bar{\theta}_n,\bar{\theta}_r)$ with $\bar{\theta}_n=(\bar{\theta}_i+\bar{\theta}_g)/2$, $\bar{\theta}_r=(\bar{\theta}_g-\bar{\theta}_i)/2$, where $\bar{\theta}_n$ is reflector-normal angle and $\bar{\theta}_r$ is the reflection angle with respect to the normal. Note that reflector-normal is opposite to the migration-dip in direction, but $\bar{\theta}_n$ is equal to the dip-angle (the angle between X-direction and the dip direction).

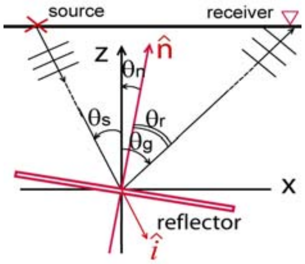


Figure 1, the definition of reflection and dip angles

Depending on the purpose of the final image, the amplitude correction can be done to different image gathers:
(1) CRA (Common Reflection-Angle) imaging:
In this case the amplitude correction is done for each dip-angle in a CRA gather. True amplitude CRA image gathers can be used for local AVA (amplitude vs. angle) analysis.
(2) Total Strength imaging:
In this case the amplitude correction can be done to CDA (common dip-angle) images (see Wu et al., 2004b):

$$|I(\vec{x})|^2 = \sum_{-\theta_1 \le \theta_n \le \theta_2} \left[\sum_{\theta_r} |L(\vec{x},\bar{\theta}_n,\bar{\theta}_r)|^2\right] / \left[|D(\vec{x},\bar{\theta}_n)|^2 + \varepsilon\right] \quad (1)$$

where ε is a damping factor for regularization, $-\theta_1$ and θ_2 form the angle-span for the dip-angle summation, and $D_a(\vec{x},\bar{\theta}_n)$ is the dip correction factor of the acquisition system:

Comparison of different approximations for image amplitude correction

In this paper we concentrate on the total strength imaging. In this case amplitude corrections can be considered as applying amplitude gain (AG) factors to the migrated images in prestack depth migration. We will compare four different schemes with different degrees of approximation:

1) Correction in local dip-angle domain

For amplitude correction in local dip-angle domain, the amplitude gain (AG) factor is a dip-angle and space dependent function $A(\vec{x},\bar{\theta}_n)=1/D_a(\vec{x},\bar{\theta}_n)$ as can be seen from equation 1. The correction can be rewritten as

$$|I(\vec{x})|^2 = \sum_{-\theta_1 \le \theta_n \le \theta_2} |I_m(\vec{x},\bar{\theta}_n)|^2 \, A(\vec{x},\bar{\theta}_n)^2, \qquad (2)$$

where $|I(\vec{x},\bar{\theta}_n)|$ is the raw migrated image field in local dip-angle domain (common dip-angle image gathers),

$$|I_m(\vec{x},\bar{\theta}_n)|^2 = \sum_{\theta_r} |L(\vec{x},\bar{\theta}_n,\bar{\theta}_r)|^2. \qquad (3)$$

2) Correction in other local angle domains

If we do not apply the correction in dip-angle domain, and instead work on common scattering-angle (or reflection-angle) image gathers, the correction then becomes

$$|I(\vec{x})|^2 = \sum_{-\theta_1 \le \theta_r \le \theta_2} |I_m(\vec{x},\bar{\theta}_r)|^2 \, A(\vec{x},\bar{\theta}_r)^2, \qquad (4)$$

In the same way we can apply the correction to common receiving-angle image gathers or other gathers. However, these corrections cannot correctly handle the acquisition aperture effects, because the aperture effect is mainly dip-dependent.

3) Correction in space-domain alone

If we totally neglect the angle dependence of aperture correction, the AG factors are only space dependent

$$|I(\vec{x})| = |I_m(\vec{x})| \, A(\vec{x}), \qquad (5)$$

where

$$|I_m(\vec{x})|^2 = \sum_{-\theta_1 \le \theta_n \le \theta_2} |I_m(\vec{x},\bar{\theta}_n)|^2. \qquad (6)$$

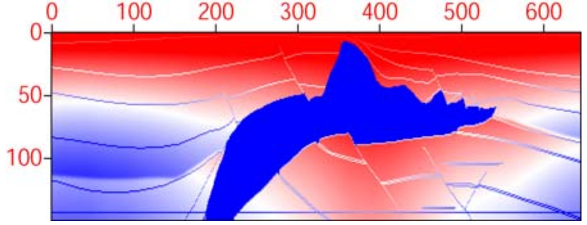
4) Correction by vertical AGC

The conventional AGC is the simplest amplitude correction, which has an AG factor dependent only on z:

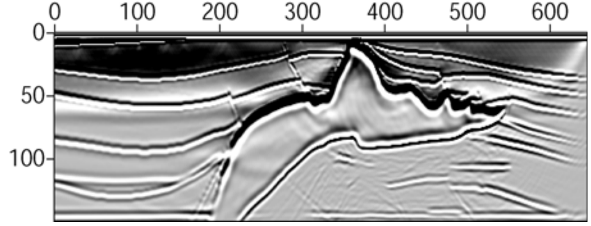
$$|I(x,z)| = |I_m(x,z)| \, A(z), \qquad (7)$$

Application to the imaging of SEG/EAGE salt model

We apply various image amplitude gain factors defined in the previous section to prestack depth migration for the SEG/EAGE salt model. Local cosine beamlet (LCB) prestack migration method (Wu et al., 2000; Wang and Wu, 2002; Luo and Wu, 2003) is employed for the imaging. The velocity model and the raw image of prestack depth migration are shown in Figure 2.



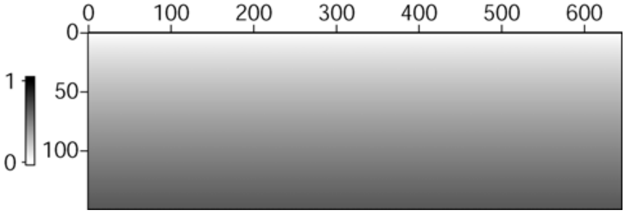
(a) 2D SEG/EAGE salt model



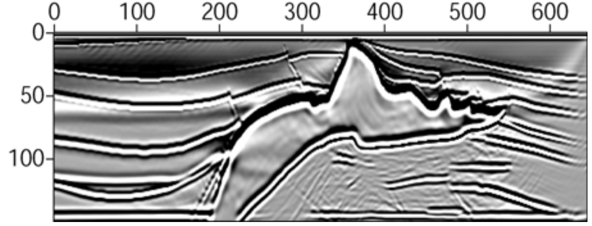
(b) Raw image of prestack depth migration

Figure 2, the 2D SEG/EAGE velocity model and its raw prestack depth migration image by LCB method

We start from the simplest vertical gain control AGC factor *A* (z). Figure 3 gives the AG factor distribution and the image after the AGC correction. We see that although image amplitudes are increased for the deep targets, but the noise background is also amplified at depth. More important is the fact that the shadow zones still exist and the images for steep faults are still weak.



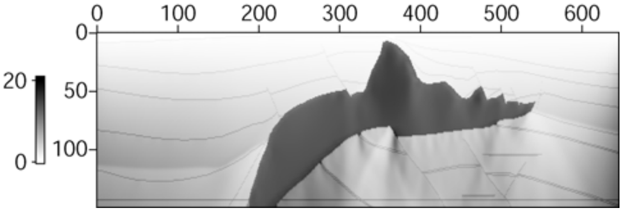
(a) AG factor for AGC



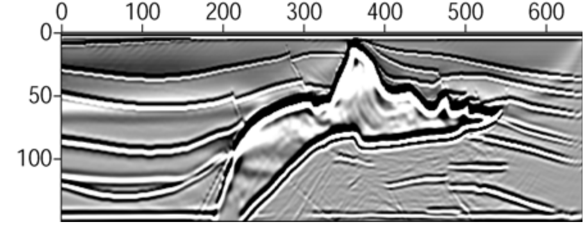
(b) Image after AGC

Figure 3, AG factor and the image after AGC

Figure 4 gives the corresponding results for the correction on total strength (equation 5). This correction corresponds to a spatially varying AGC, which extends the vertical AGC to include the laterally variation of acquisition and propagation effects. We see that the amplitude balance and image quality have been improved. However, the signal and noise are enhanced simultaneously in the weak illuminated areas.

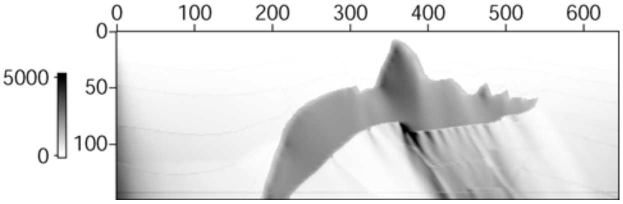


(a) AG factor for total strength

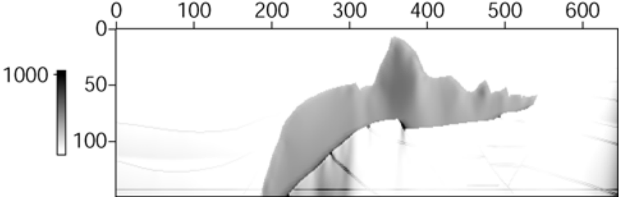


(b)Image after the total strength correction

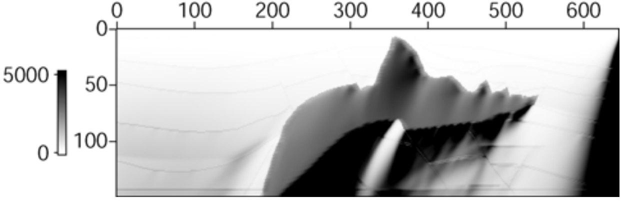
Figure 4, AG factor and corrected image for the total strength



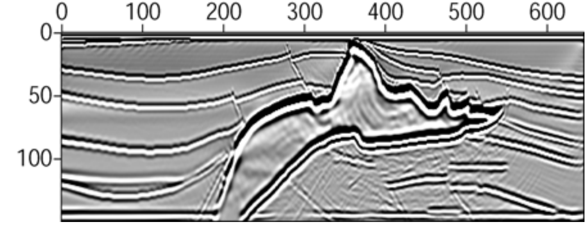
(a) AG factors corresponding to θ_g=-45°



(b) AG factors corresponding to θ_g=0°



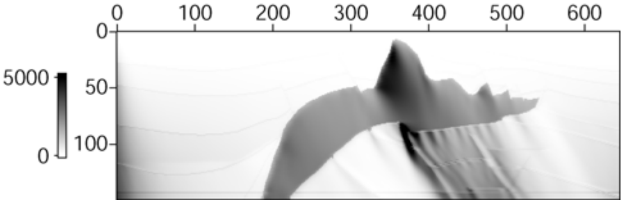
(c) AG factors corresponding to θ_g=45°



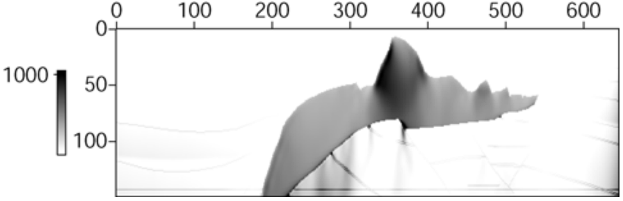
(d) Image after receiving angle domain correction

Figure 5, AG factors and corrected image for correction in receiving-angle domain

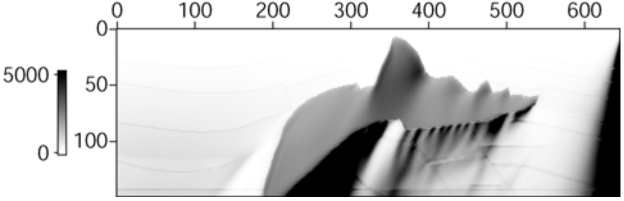
Next we show the results of amplitude corrections in local angle-domain. To calculate the correct AG factors, the effects of acquisition aperture to local reflectors with different dips must be taken into account. Without this consideration, even corrections in angle domain, such as that for offset plane waves, or the correction in receiving angle-domain for common-shot migration, will not give the correct AG factors for the purpose of true-reflection imaging. Figure 5 shows the results for the amplitude corrections in local receiving-angle domain. Figure 5a,b and c show the AG factors for the corresponding -45°, 0°, and 45° common receiving angle-gathers. Figure 5d gives the amplitude corrected image. We have tested also the case of correction in common scattering-angle domain. The results are similar. We see that even though the image quality and amplitude balance are significantly improved, however, the signal-to-noise ratio in the subsalt region is still low.



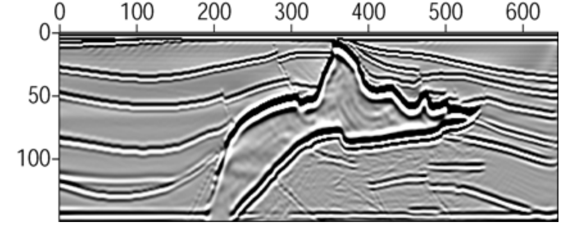
(a) AG factors corresponding to θ_n=-45°



(b) AG factors corresponding to θ_n=0°



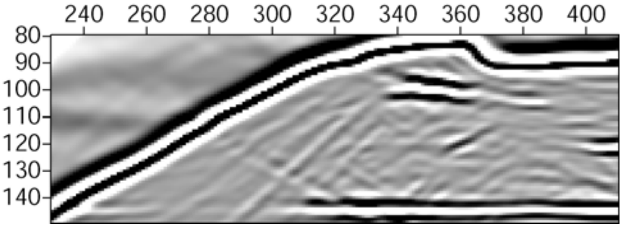
(c) AG factors corresponding to θ_n=45°



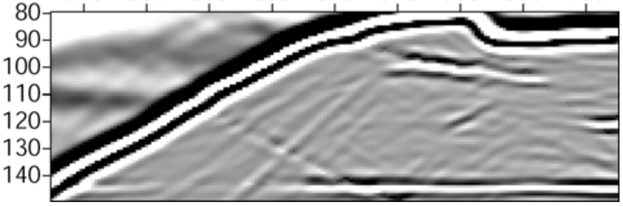
(d) Image after dip-angle domain correction

Figure 6, AG factors and corrected image for correction in dip-angle domain

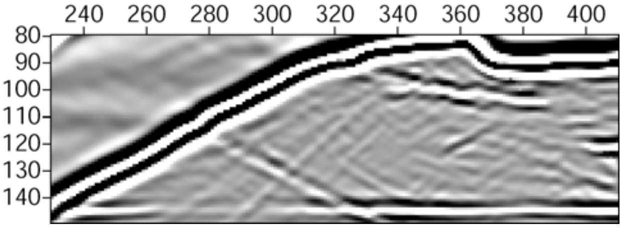
Finally we show the results of corrections in local dip-angle domain in Figure 6. The AG factor for dip=-45°, 0°, and 45° are given in Figure 6a, b, and c. The image after correction is given in Figure 6d. We can see clearly the superior performance of this scheme. While the images of steep reflectors in the subsalt region are enhanced, the noises in the same region are depressed in the same time. The AG factors in Figure 6a for the dip 45°, which is the dip of target reflectors, are the opposite of the dip -45° (Figure 6c), which is the dip of coherent noises in this case. The image quality of subsalt structures is greatly improved by the amplitude correction in local dip-angle domain. The image amplitudes, especially along the steep faults and the baseline are much more uniformly distributed. The last figure (Figure 7) summarizes the comparison of image qualities in a zoomed subsalt region for different amplitude corrections.



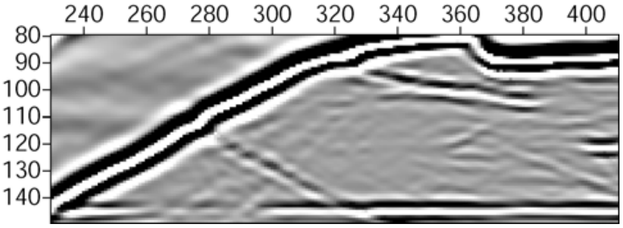
(a) Image of the subsalt region after AGC



(b) Image of the subsalt region after total strength correction



(c) Image of the subsalt region after receiving angle domain correction



(d) Image of the subsalt region after dip-angle domain correction

Figure 7, comparison of images of the subsalt region by the four kinds of amplitude corrections

Conclusions

We compared the new method of amplitude correction in local dip-angle domain with other schemes that have various degrees of approximations: traditional vertical AGC, space-domain correction based on total illumination, and correction in other angle-domains, such as the scattering-angle and receiving-angle domains. Through the tests with the SEG-EAGE salt model, we see clearly the superior performance of the new dip-angle domain correction scheme. Not only the images of steep reflectors in the subsalt region are enhanced, but also the noises in the same region are depressed. The image quality of subsalt structures is greatly improved and the image amplitudes, especially along the steep faults and the baseline are much more uniformly distributed.

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