ASEG-PESA 2015
Geophysics and Geology together for Discovery
24th International Geophysical Conference and Exhibition
15 – 18 February 2015 Perth, Western Australia

Improving Imaging through Specular Amplitude Enhancement in the Local Angle Domain

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SUMMARY

We present a method to improve imaging in the local angle domain (LAD) decomposition and imaging system. This system uses the entire recorded data to generate true-amplitude, angle-dependent or angle and azimuth dependent imaging gathers (Koren and Ravve 2011). These gathers have the ability to distinguish the wavefields by their directional components: Specular (continuous structural surfaces) and diffraction (discontinuous objects such as small-scale fractures and faults). The high-energy values associated with the specular directions can be used to enhance the continuous objects to obtain a diffraction-free, sharpened image of highly complex areas. We propose that the specular enhancement in the LAD system be used to re-evaluate existing land and marine (including narrow-azimuth legacy) seismic data to obtain more detailed high-resolution images without the need to acquire additional 3D data about existing assets.

Key words: Depth Imaging, Reflection Angle Gather, True Amplitude Imaging, Specular Imaging

INTRODUCTION

The importance of generating subsurface angle domain common image gathers rather than surface-offset image gathers has been widely recognized, especially in complex geological areas where the wavefield includes multi-pathing. Although the theory of angle domain imaging is well established (Beylkin and Burridge, 1990), its implementation remains extremely challenging. Koren et al. (2002) introduced common reflection angle migration (CRAM) as its implementation for large-scale 3D models in complex geological areas. Unlike conventional ray-based imaging methods, ray tracing is performed from the image points up to the surface where one-way diffracted rays are traced in all directions (including turning rays), forming a system of ray pairs for mapping the recorded surface seismic data into reflection angle gathers (Figure 1).

The full-azimuth angle domain decomposition, imaging, and characterization system known as EarthStudy 360 is the extension of CRAM. In the full-azimuth decomposition, each ray pair maps the surface recorded data into the 4D LAD angles: Dip and azimuth, opening angle and opening azimuth (Figure 2) at a given subsurface point. These generate two different full-azimuth angle gathers: Reflection and direction. Full-azimuth reflection gathers are most suited to highly accurate velocity model determination (full-azimuth RMO analysis and full-azimuth tomography) and seismic characterization (full-azimuth AVA, or AVAZ). Full-azimuth direction gathers, on the other hand, contain directivity-dependent information at each subsurface point (Figure 3). This allows the creation of enhanced feature images by applying a different specular/diffraction weighted filter to create a specular/diffraction weighted stack. The complete theory of directional gathers is explained in Koren and Ravve (2011) and Ravve and Koren (2011).

We propose that the specular enhancement in the subsurface angle-domain decomposition and imaging system be used routinely to re-evaluate existing land and marine data. We will present two field examples that improve the quality of seismic images that have been challenged by the presence of irregular water bottom, steep slope and salt. The first example is a complex basin in offshore Australia, where drilling activities based on previous depth images resulted in dry wells. The second example is subsalt imaging from the Northwest Germany marine-land transition zone where the image was unclear and difficult to interpret due to sparse and low-quality data.

THEORY

LAD decomposition consists of two stages: Ray tracing and decomposition. The ray tracing stage involves shooting a fan of one-way diffraction rays from image points up to the surface. The take-off angles are measured around a given local normal to the background reflection surface. Ray attributes, such as traveltime, ray coordinates, slowness vectors, amplitude and phase factors, are stored for each ray. The decomposition stage involves forming a combination of ray pairs indicating incident and reflected/diffracted rays. Each ray pair maps a specific seismic data event recorded on the acquisition surface into a 4D local angle domain space in the subsurface. The term "ray pair normal" refers to an apparent normal (also called migration dip vector) computed from Snell's law for any isotropic or anisotropic velocity model, where both incident and scattered slowness directions are known. This is a normal to a vertical surface formed by the incident and scattered rays. Note that the specular direction indicates the special case when the ray pair normal coincides with the normal to a physical reflection surface. The details of the LAD technique are explained in Koren and Ravve (2011).

The creation of Gaussian Beams in the LAD domain is implemented in this approach, where beams are performed on-the-fly throughout the decomposition/imaging stage, associating every beam with traveltime, shot-receiver areas and directivity. This approach is theoretically more accurate than standard beam migrations, where beam construction is uniformly performed prior to the migration.

To apply specular enhancement in the full-azimuth decomposition and imaging system, a specular weighted filter is applied on the full-azimuth directional gathers to create a specular weighted stack. For common reflection angle migration (CRAM), different specular enhancement parameters are used during the migration stage to produce angle-domain gathers with specular enhancement.

EXAMPLES

Example 1: Imaging a Hidden Structure in a Complex Basin

Figure 4 shows an example of imaging in a complex basin in offshore Australia. Using specular energy weighting, we were able to detect and image a structure that had previously been completely hidden due to a noisy diffracted component.

Example 2: Improving the Quality of Transition Zone 3D Data in Northwest Germany

Figure 5 shows two depth migrated sections from a 3D land-marine transition zone in Northwest Germany (owned by RWE-Dea AG and Wingershall AG) following the creation of directional angle gathers. Figure 5(a) shows the direct stack of the directional angle gathers, and Figure 5(b) shows the specular energy weighted stack of the same gathers. The high energy values associated with the specular directions sharpened the image of the structure, and the improvement in the continuity of the structural information throughout the volume is seen clearly in Figure 5(b).

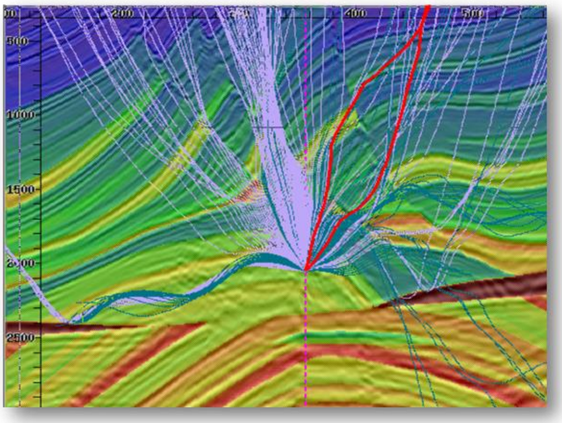

Figure 1: Local Angle Domain illumination of an event in a complex subsurface.

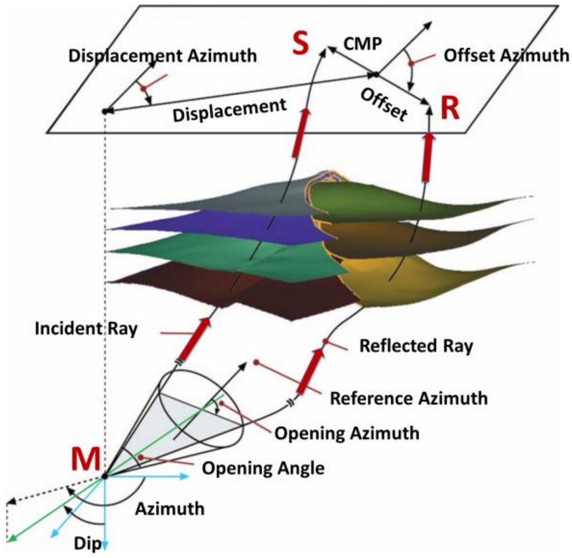

Figure 2: Subsurface-to-surface and surface-to-subsurface ray-based mapping. Each ray pair maps a specific seismic data event recorded on the acquisition surface into a 4D local angle domain space in the subsurface – dip and azimuth of the ray pair normal, opening angle and opening azimuth.

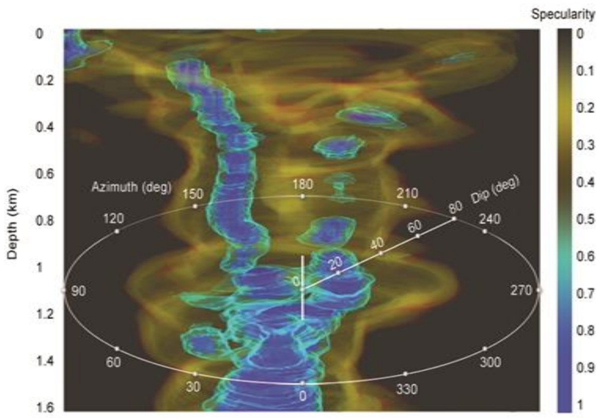

Figure 3: Full-azimuth directional gathers showing the specular directions at different depth points.

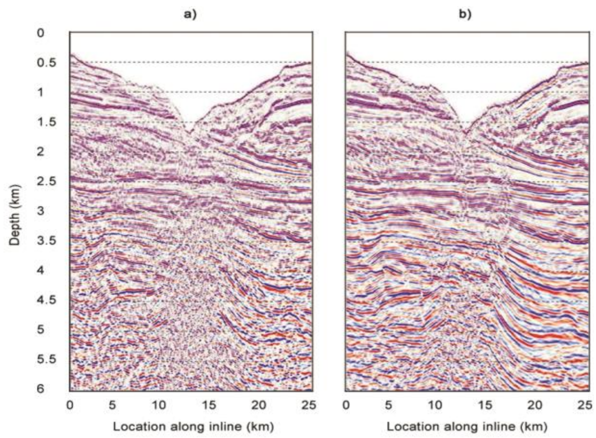

Figure 4: Imaging a "hidden" structure in offshore Australia. (a) Directional angle decomposition followed by

normal stack. (b) Image in the same area with specular energy weighted stack applied.

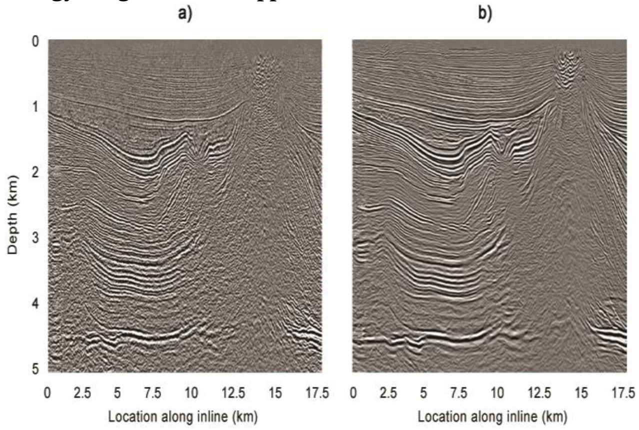

Figure 5: Depth migrated section from a 3D land-marine transition area, Northwest Germany. (a) Directional angle decomposition followed by normal (no weighting) stack. (b) Image in the same area with specular energy weighted stack applied.

CONCLUSIONS

The new subsurface angle domain decomposition and imaging system generates true amplitude angle-dependent or angle and azimuth-dependent gathers that contain the directivity information. This information is used to create high-resolution specular enhancement images. This technology is applicable to any existing land and marine (including narrow-azimuth legacy) data to enhance the quality of continuous reflectors. Two field examples form the area of complex geological structures (an irregular water bottom and a transition zone) show how specular enhancement better defined the subsurface areas of interest, leading to accurate well planning and a better explanation of the outcome of existing wells.

ACKNOWLEDGMENTS

We thank colleagues at Paradigm for their contributions to this expanded abstract.

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