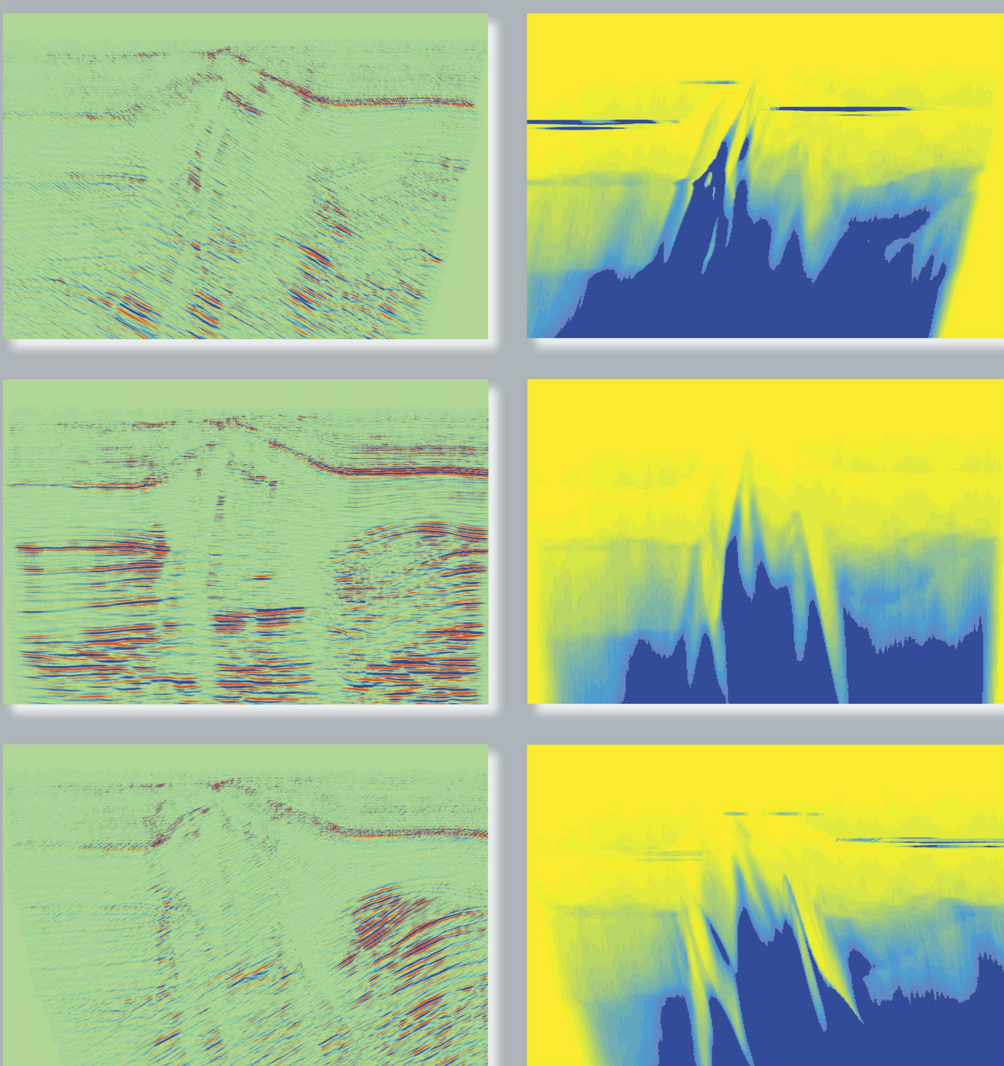
3D PreSDM: AVA-ready data in depth

Restored amplitude depth imaging for amplitude versus angle analysis

A new Geovista feature



See the depth from the best angles.

The benefits of **AVO** analysis for lithology and fluid identification are widely recognized.

The benefits of **preSDM** for complex structural imaging are equally well known.

The next step? Combine the two!

Processing

Restored amplitude depth imaging for amplitude versus angle analysis

CGG's new preSDM directly produces angle gathers, the natural starting point for amplitude variation with angle (AVA) studies. The true scattering angle is determined during the migration, avoiding the assumptions about reflector dip made during time-domain amplitude variation with offset (AVO) analysis. Careful attention to amplitudes during the migration ensures that the data are truly AVA ready.

Kirchhoff migration and angle gathers

In Kirchhoff migration, the reflection coefficient is expressed as a weighted sum of data taken from a traveltime surface. For 3D prestack data, the surface is associated with 4 coordinates, 2 defining the source surface position and 2 for the receiver location. The Kirchhoff migration involves summing data over all of these coordinates. In angle domain migration, we change the coordinate system from the surface coordinates just described to a system defined at each depth point in the subsurface image. We still have 4 coordinates, but now they are angles defined by the directions of the ray paths from source to image point and image point to receiver.

Figure 1 shows the terminology. We call two of the angles "scattering angles" since they describe the relationship between the incident and scattered energy. The other two are the "illumination angles", which describe the direction of the subsurface illumination.

- Figure 1 (left) shows the scattering angles. θ is the opening angle between the incident energy, $\vec{S}$, and $\vec{S}+\vec{G}$. φ defines the azimuth of the local diffraction plane formed by these two slowness vectors.
- Figure 1 (right) shows the illumination angles (λ,ψ), for instance latitude and longitude, that define the direction of illumination, given by the sum of the two slowness vectors $(\vec{S}+\vec{G})$.

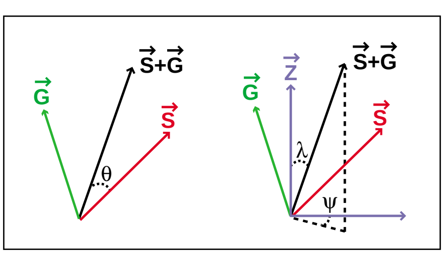


Figure 1: Scattering angles (left) and illumination (dip) angles (right).

It is therefore possible to check what is really reconstructed at the imaged depth point. The usual Kirchhoff summation over input traces thus becomes a multiple summation over these four angles $(\theta,\varphi\ \lambda,\psi)$.

3D acquisition datasets generally provide multiple coverage of the subsurface (various θ and φ). Migrating the whole dataset altogether (summing over mixed θ and φ) would produce only an average reflection coefficient, which is not physically interpretable. Instead, common scattering angle gathers (fixed (θ, φ)) are produced during pre-SDM migration. Within each gather, the illumination is regularised so that the Kirchhoff integral becomes a simple summation over the illumination angles (λ,ψ), for fixed (θ, φ). This yields an output proportional to the reflection coefficient $R(\theta, \varphi)$ required for AVA analysis (see Figure 2).

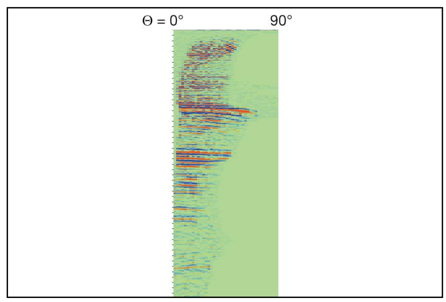


Figure 2: CRP-gather in the scattering angle domain. Each trace comes from the stack of a restored amplitude subgather like the one in figure 3 (right).

Regularising the illumination

One of the keys to a successful AVA analysis is careful treatment of the amplitudes in the migration. Acquisition effects and a complex overburden both cause the range and distribution of scattering and illumination angles to vary from place to place in the subsurface. This results in amplitude artefacts if not corrected.

To achieve the correction for a particular subsurface location, we can think of a small sphere centred at that position. We divide its surface into bins of equal area, and for each bin we count the number of contributions to the migration contained in that angular range. The resulting table of hits per bin supplies an amplitude normalising factor for each of the angular bins.

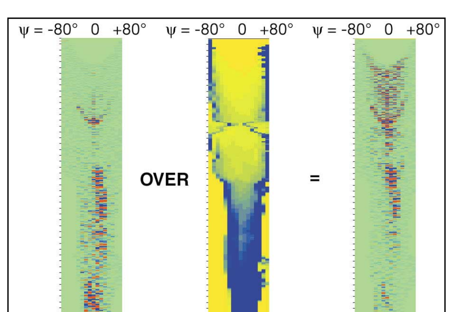


Figure 3: Sub-gathers for a constant scattering angle θ = 10 degrees. Each trace corresponds to a given illumination angle. Left: unweighted migrated traces; centre: hitcount table; right: migrated trace with regularized illumination.

Figure 3 illustrates the effect for a subgather of data. The scattering angle for this subgather is held fixed at 10 degrees, and each trace represents a different illumination dip. After dividing each sample of the subgather by its corresponding hitcount, all of the traces in this subgather are stacked to obtain one trace of the common reflection point gather in the scattering angle domain.

Amplitude correction

The illumination regularisation is not the only factor in restoring amplitudes. Weighting factors are included in the migration to correct the effects of geometric spreading and transmission amplitude loss during propagation. For efficiency, these factors can be computed directly from the traveltime maps.

Improvement in both AVA analysis and structural imaging

Although the restoration of amplitude with hitcount correction was designed for true amplitude and AVA analysis, it brings more general benefits, for instance, to structural imaging. Figure 4 shows how the simple application of the hitcount correction of Figure 2 significantly changes the structural image inside the salt body.

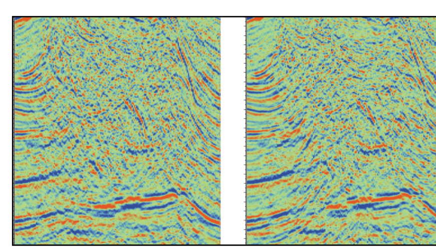


Figure 4: Close-up of images, without hitcount correction (left), and with hitcount correction (right). Images have been equalized for qualitative comparison.

Front cover figure: Partial images for a constant scattering angle = 10 degrees. Each row corresponds to a specific illumination dip angle.
Top row: -20 degrees, middle row: 0 degree, bottom row: +20 degrees.
Left column: unweighted migrated images.
Right column: corresponding hit-count tables.

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