# Understanding subsalt uncertainty with illumination analysis

*Joanne Wang*, Duane Dopkin*
*Paradigm*

**Summary**

Illumination analysis provides valuable information in understanding subsalt uncertainty. Using examples from the deep water Gulf of Mexico, we examine and analyze the illumination effects of acquisition geometry, subsurface model and complex salt distribution.

**Introduction**

Geoscientists have been facing great challenges in subsalt exploration. Presence of salt bodies coupled with imperfect seismic acquisition, affects subsurface illumination and therefore seismic data quality and reliability. Uncertainties are present in every step of seismic processing, imaging and interpretation. Illumination provides a tool to assess the uncertainties of structural and stratigraphic interpretations made below a complex overburden. The objectives of an illumination study are to better understand how factors such as the subsurface model, seismic acquisition geometry, and seismic imaging parameters affect subsurface illumination.

**Methodology**

Ray tracing provides a mechanism to map seismic data recorded at the earth's surface to subsurface image points. When this ray tracing is carried out in the local angle domain (Koren, et. al., 2011), a rich set of point diffractor operator parameters (e.g. ray paths, slowness vectors, traveltimes, geometric spreading, and phase rotation) can be evaluated as a system of polar angles (Fig 1).

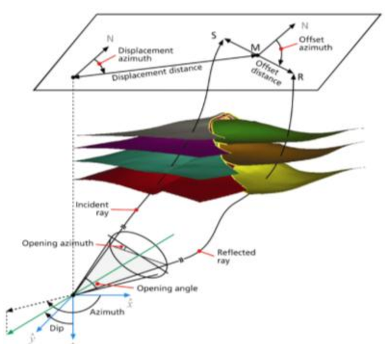


Fig 1

Illumination analysis gathers and organizes all the information and provides detail ray attribute information at any selected subsurface location(s) including challenging subsalt horizons.

**Examples**

Acquisition geometry

Acquisition geometry affects the subsurface illumination rate. Fig 2a displays a deep water Gulf Mexico model. We observe differences in the illumination rate using different acquisition azimuths. Fig 2b shows illumination hit count maps, ray fan trajectories and ray attribute polar maps with zero (0) degree azimuth on the left and forty-five (45) degree azimuth on the right. The surface color represents hit count (red color represents a low hit count while the blue color represents a high hit count). There are noticeable differences in hit count along the slope where the ray fan is shot. Ray fan trajectories and related ray fan attribute maps reveal the details from the same subsurface location. Comparing the ray fan and ray attributes from different azimuths, we notice better ray coverage as well as a higher hit count from the zero (0) degree azimuth. Clearly, acquisition coverage around the zero azimuth direction will contribute to a better image of the slope and will be the favorable acquisition orientation if the slope is the target.

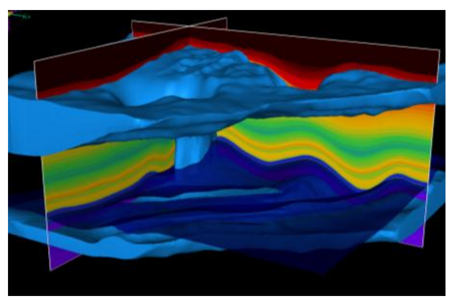

Fig 2a a deep water GOM model with salt

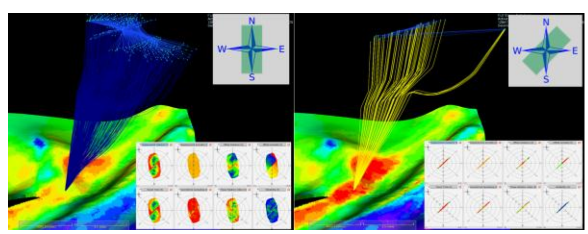


Fig 2b Hit count map shows the effects of acquisition azimuth. Ray fan trajectories and ray fan attribute maps reveal the details at a subsurface location.

## Understanding subsalt uncertainty with illumination analysis

Subsurface Model

A subsurface model represents a geoscientist's understanding of the structure, stratigraphy, and distribution of velocities in the study area and plays an important role in the success of seismic exploration. The complexity of a model varies from a simple isotropic model to a complicated anisotropic model with significant lateral and vertical variations. One of the determining factors of seismic imaging quality is the accuracy of both the velocity parameterization and topology of the model. Since ray trajectories and attributes are governed by the model, ray tracing can be used to quickly analyze the effects of different models. Fig 3a shows a ray fan trajectory and corresponding travel time polar map through an isotropic velocity model while Fig 3b shows the same by ray tracing through an anisotropic model. Notice that ray fan trajectories and the travel time maps are different from different models. The difference in travel time at small reflection angle indicates that position in depth domain is different if the travel time is preserved.

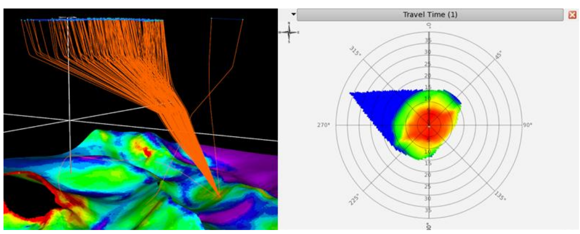


Fig 3a. A ray fan trajectory on the left and the travel time polar map on the right. The ray tracing is carried out with with an isotropic model

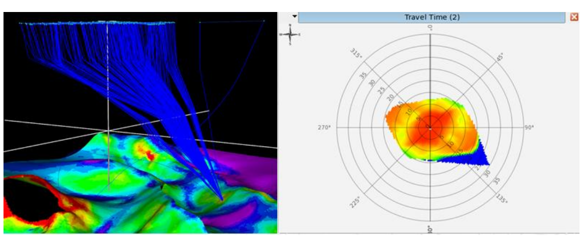


Fig 3b. A ray fan trajectory on the left and the travel time polar map on the right. The ray tracing is carried out with an anisotropic model

Complex Salt Geometry

Salt spatial distribution and geometry could greatly affect the seismic data quality and reliability. The importance of understanding the uncertainties of structural and stratigraphic interpretations below a complex overburden cannot be over-emphasized. Illumination analysis provides a mechanism to assess such uncertainties. Figure 4 shows a complex, multi-structure Gulf of Mexico salt model with dramatic changes in shape, thickness and distribution. Below the salts, it is the target surface.

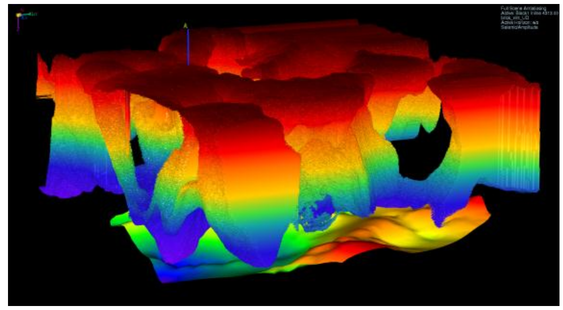

Fig 4. A multi-structure salt model from the Gulf of Mexico

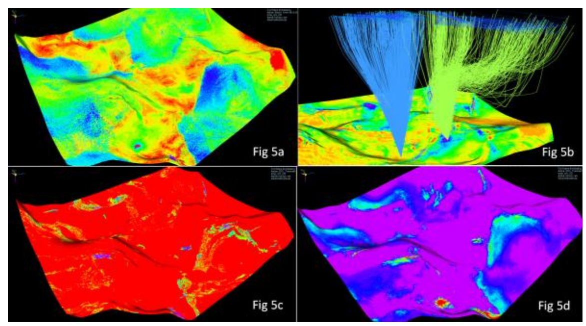


Fig 5 Examples of illumination attribute maps below salt structures.

Illumination analysis by ray tracing generates a variety of kinematic and dynamic attributes which provide insights in understanding seismic quality and reliability. Shown in Fig 5 are some examples of these attributes.

The Maximum Aperture (Fig 5a) maps the maximum displacement distance along the horizon, given the ray shooting parameters and the model. This attribute can be used to understand the effect of aperture, and further to optimize it in order to balance the imaging quality and the throughput. Azimuth discrepancy (Fig 5b) measures the difference between the surface azimuth (acquisition geometry) and the subsurface azimuth (local angle domain). A complex overburden can cause severe distortion of the ray paths, which results in large discrepancies between the surface and the subsurface azimuth. The Minimum opening angle (or offset) (Fig 5c) is an important attribute which identifies the areas that are missing near angle/offset data. In these areas, AVO technique may not be feasible and velocity analysis carries large uncertainty. The reliability factor quantifies and qualifies the ray field at any given location and direction. Seismic data quality is directly related to the reliability factor. Shown in Fig 5d is "Average Reliability" in which the bright color zones are low in reliability.

## Conclusions

Subsalt exploration is challenging. Many factors affect seismic data quality, such as acquisition geometry, accuracy of a subsurface model and the presence of the salts and their complexity. Illumination analysis enables geoscientists to effectively evaluate these factors and assess the uncertainties of structural and stratigraphic interpretations made below a complex overburden.