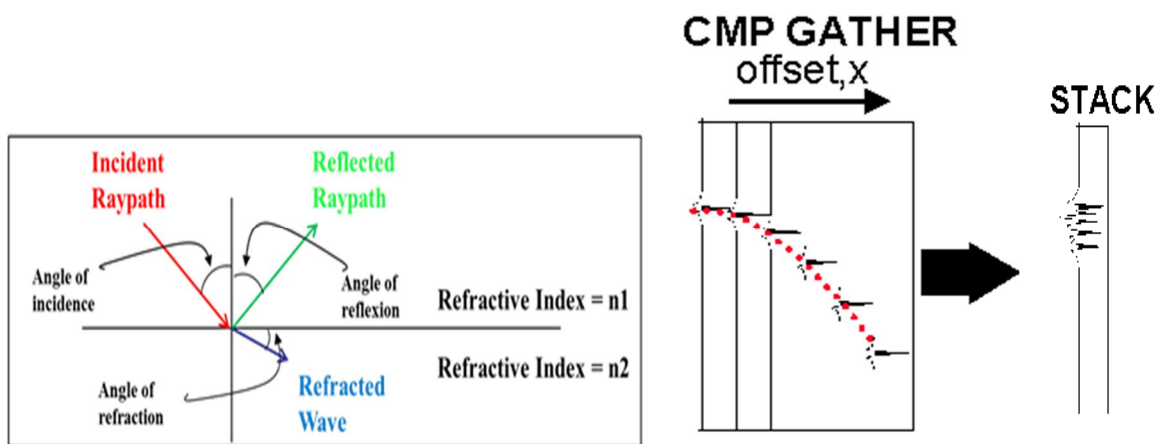


OIL & GAS / HOW TO...

ANALYSE INCIDENCE ANGLES WITH ISATIS



AVO (Amplitude Versus Offset) and AVA (Amplitude Versus Angle) studies require angle stacks where the Common Middle Point (CMP) gathers are stacks according to the incidence angle at the main reflector. The incidence angle analysis provides maps to help the geophysicist assisted by the geologist to perform this stacking process. Areas of sub-stacks (typically near, mid, far) are defined from the angles and transcribed in offsets for effective implementation.

Our current workflow is based on the Walden approximation to transform offset to incidence/reflection angle. Maps of extreme incidence angle related to mute function and fold map for sub-stacks are built. Each extreme angle is determined by a mute function which eliminates noise and/or possible refractions overlapping reflections.

Walden formula: $\theta = \arcsin \{ \mathbf{V}_{DIX} / \mathbf{V}_{RMS} * \sin [\arctan (\text{Offset} / (\mathbf{T} * \mathbf{V}_{RMS}))] \}$

Where: θ is the incidence angle, offset is the trace offset, T is the time, \mathbf{V}_{RMS} is the stacking velocity provided and \mathbf{V}_{DIX} is the Dix velocity computed as follows:

Dix formula: $v_{Dix} = [(t_2 v_{rms2}^2 - t_1 v_{rms1}^2) / (t_2 - t_1)]^{1/2}$

where t1 and t2 is the seismic time from stratum between two reflectors.

1. Input Data and Parameters

- RMS Velocities 2D or 3D
- Horizons in time
- Data of mute: To minimize air waves, ground roll and other early-arriving noise by removing the corresponding part of the signal. Low-frequency traces and long-offset traces are typical targets for muting. Within the gather two types of mute laws are used:
 - Internal mute law, used to determine the min offset to use
 - External mute law, used to determine the max offset to use.
- offset: distance between seismic source and receiver.

2. Workflow

In the case of tabular environments, the determination of the angles can be performed at any point in space by applying the Walden formula from a velocity field (V_{RMS}), from a DIX velocity field and from the definition of the internal and external mute laws ($offset_{min}$ and $offset_{max}$):

$$\Theta_{min}(X,Y,T) = \text{Walden}[T, V_{RMS}(X,Y,T), V_{DIX}(X, Y, T), offset_{min}(X,Y,T)]$$

$$\Theta_{max}(X,Y,T) = \text{Walden}[T, V_{RMS}(X,Y,T), V_{DIX}(X, Y, T), offset_{max}(X,Y,T)]$$

Θ_{min} Θ_{max} are assigned at target horizons:

$$\Theta_{min}^{horizon} = \text{Walden}(T^{horizon}, V_{RMS}^{horizon}, V_{DIX}^{horizon}, offset_{min}^{horizon})$$

$$\Theta_{max}^{horizon} = \text{Walden}(T^{horizon}, V_{RMS}^{horizon}, V_{DIX}^{horizon}, offset_{max}^{horizon})$$

Flowchart:

- Data Quality control: horizons (2D) and V_{RMS} (3D)
- Dix Velocity calculation
- Velocity extraction at target horizons: V_{RMS} and V_{DIX} .
- Specification of $offset_{min}^{horizon}$ and $offset_{max}^{horizon}$
- Angle determination with Walden Formula
- Fold map extraction
- Output maps analysis

3. Data Quality Control

The first step consists in checking the concordance between velocity cube V_{RMS} and horizons.

This step is essential when dealing with seismic data. Data control analysis allows detecting potential artifacts, problems of support, acquisition and interpolation during different processing steps. The first task is to carry out a proper data investigation:



→ Statistics → Exploration Data Analysis

- Display of a data basemap, in order to validate the data location; check the concordance between horizons and velocity cube.
- Compute a histogram to check the homogeneity of the statistical distribution of V_{RMS} and time horizons and between them.
- Control the statistical characteristics: the mean (or average tendency) and the variance that measures the dispersion of the values around the mean for time and velocity data.
- Investigate correlation between several variables through the display of the scatter diagram.

The second task is to estimate large or medium scale structures in the velocity cube V_{RMS} .

- Calculation of the velocity trend:

→ Interpolate → Quick Interpolation → Least Square Polynomial fit

More explanation about trend is given in the file "How to compute quickly a reliable Trend" that you can download from the Geovariances website.

- Calculation of residual velocities:

→ File → Calculator

$$\text{Residual velocities} = \text{Raw Data} - \text{Trend velocities}$$

The variogram analysis is important to check the presence of potential anisotropies or if we need filtering some artifacts. For more information about filtering, please refer to white paper about filtering or the file "How to remove quickly structured noise from a seismic" that you can download from the Geovariances website.

4. Dix Velocity

- Calculation of the Dix velocities:

→ File → Calculator

$$VDix(x,y,[t_{n-1};t_n]) = \text{sqrt} \{ [(VRMS^2(x,y,t_n) * t_n) - (VRMS^2(x,y,t_{n-1}) * t_{n-1})] / (t_n - t_{n-1}) \}$$

where t_{n-1} and t_n ($n=1 \dots \text{max reflector}$) are reflection arrival times, in our case the sample time.

5. Extraction of RMS and Dix velocities at horizons:

→ Tools → Time Sampling → From Volume...

A simple verification of Dix velocity can be done with the ratio $VDix/VRMS$ calculated with calculator. This ratio has to be between 1 and 2.

6. Determination of extremes offset

The mute law is provided by the geophysicist and defines $offset_{max}$ and $offset_{min}$, therefore the offset range for each X,Y,T position. The mute law is defined in order to discard the traces of poor quality, knowing that the signal degrades near limit angle (angle beyond which waves are refracted):

- External Mute or $offset_{max}$:
 - $offset_{max} = \text{constant}$
for deep and ultra-deep environment (depth at which we have critical angle).
 - $offset_{max} = f(\text{Time})$
for shallow environment (the trace at a given offset is only reliable below a given time).
 - $offset_{max} = f(x,y,\text{Time})$
for shallow environment with highly sloped seafloor (all offset are available only from a certain depth that varies with the seafloor).
- Internal Mute or $offset_{min}$:
 - $offset_{min} = f(\text{Time})$
for shallow environment (the trace at a given offset is only reliable above a given time).
 - $offset_{min} = f(x,y,\text{Time})$
for shallow environment with highly sloped seafloor (all offset are available only until a certain depth that varies with seafloor).

The selected offset values are used in angles determination formula.

7. Angles determination

This step allows defining the two angles used to characterize the fold map. Use the Walden formula to calculate the minimum and maximum angles depending on $offset_{max}$ and $offset_{min}$.

- Angle calculation:

➔ [File](#) ➔ [Calculator](#)

$$\Theta_{min} = \text{asin} (V_{DIX} / V_{RMS} * \sin (\text{atan} (\text{Offset}_{min} / (T * V_{RMS}))))$$

$$\Theta_{max} = \text{asin} (V_{DIX} / V_{RMS} * \sin (\text{atan} (\text{Offset}_{max} / (T * V_{RMS}))))$$

This can be done in 2D for each target horizon (where T is the horizon) or in 3D where T is the seismic time.

8. Output maps analysis

In 3D, we can do an extraction at the target horizon:

- The angle min is extracted at shallow horizon and the angle max is extracted at deep horizon. If deep horizon is not available we extract a horizon calculated as follow $H = \text{Top} + \text{thickness of the target (ms)}$.

→ Tools → Time Sampling → Time Sampling → From Volume...

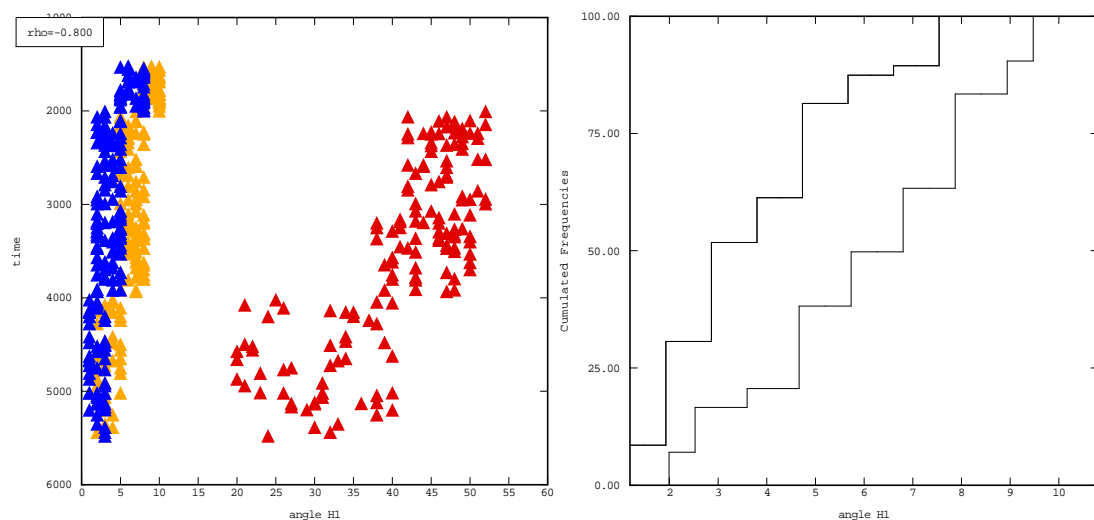
In theory, the minimum of Θ_{\max} ($\min(\Theta_{\max})$) and maximum Θ_{\min} ($\max(\Theta_{\min})$) angles define the interval from which to create sub-stacks (corresponding incidence angle ranges). Generally in practice, these statistics are not chosen as they often lead to a too low angle range, which limits the operational definition of sub-stacks.

It is the geophysicist, in collaboration with the geologist in charge of the interpretation of the data, who decides the angle $\min(\Theta_{\max})$ and $\max(\Theta_{\min})$ values on the basis of the analysis of $\Theta_{\min}^{\text{horizon}}$ and $\Theta_{\max}^{\text{horizon}}$ maps.

To help the decision making, cumulative curves are used to quantify the percentage of points discarded for the selected angles.

- Cross plot angles / time, to position the envelope curves min and max.

→ Statistics → Exploration Data Analysis: crossplot and / or cumulated histogram



Minimum angle: 10% of H0 and 50% of H1 values are above 6°.

For more information, let us help you assessing the quality of your data and implementing this workflow.

Contact our consultants at consult-oil@geovariances.com.