Part 1

Essentials of Seismic Interpretation

Chapter 4

Seismic Stratigraphic Interpretation
Seismic stratigraphy refers to extracting stratigraphic information from seismic data.

Seismic stratigraphy is divided into:

1. **Seismic sequence stratigraphy**: separating time-depositional units based on unconformities
2. **Seismic facies analysis**: determining depositional environments
3. **Direct hydrocarbon detection**: using seismic direct hydrocarbon indicators (DHI) to detect hydrocarbons, especially gas

Facies refers to features characterizing the depositional environment of a sedimentary unit. These features include:

- Sedimentary structures, forms, and orientation
- Unit shape and continuity
- Unit thickness and thickness variations
The central concept of sequence stratigraphy is that sediment deposition is controlled by four factors:

1. **Crust subsidence (isostasy)** due to tectonic and/or isostatic (sediment loading) reasons. It creates accommodation space.
2. **Sediment inflow** that fills the accommodation space.
3. **Eustasy**: rises and falls of absolute sea level
4. **Climate**: which determines the sediment nature. For example, carbonate deposition dominates in warm climates.

The following are consequences of sequence stratigraphy:

- Seismic reflections represent mainly geologic-time surfaces rather than facies surfaces.
- Therefore, seismic reflections are the result of either:
  - Sediment deposition (forming layer boundaries) at the same time or
  - Erosion (forming unconformities) during the same time period.
Geophysical concepts

Seismic sequence stratigraphy

Depositional models of sequence stratigraphy include:

1. **Lower-boundary reflections**: These include:
   - **Onlap**: reflections terminate against (an angle with) an originally dipping boundary. They indicate proximal deposition (close to sediment source).
   - **Downlap**: reflections terminate down onto (parallel to) an originally horizontal boundary. They indicate distal deposition (far from sediment source).
   - **Concordance**: reflections do not terminate but are parallel to a boundary. They can occur with upper and lower boundaries.

2. **Upper-boundary reflections**: These include:
   - **Toplap**: reflections terminate from above parallel to a boundary of non-deposition.
   - **Erosional truncation**: reflections are truncated from above by an angular (type I) or parallel (type II) unconformity.
Fig. 24.1 Classification of bed terminations likely to be observed on seismic data. Stratigraphic terminations are fundamental components of seismic stratigraphy using 2D seismic data.
Fig. 24.6 Common stratigraphic truncations associated with lower boundary (arrow) of a sediment package. All data from SE Asia. (A) Concordance of the upper or lower boundary means strata do not truncate against the boundary. (B) Onlap is a situation where strata terminate against an originally dipping surface. (C) In Downlap the beds terminate down onto an originally horizontal surface, indicating the edge of sediment transport.
Fig. 10.23 Shale flowage. (Courtesy of Exxon.) (a) CMP section with vertical exaggeration of 5× to 8×, decreasing with depth; (b) interpretation indicating the attitude of reflections (which have not been correlated except for the angular unconformity $U$). With depth the faults die out in flowage of the overpressured shale into shale diapirs $D$.

Sheriff and Geldart (1995)

Fig. 24.5 Seismic sequence stratigraphy is an interpretation method that extracts stratigraphic information from long 2D seismic lines. These three panels illustrate the common stratigraphic truncations associated with the upper boundary (arrow) of a sediment package. Data from West Africa (A) and SE Asia (B,C). (A) An angular unconformity cutting deeply into layered sediments. The featureless zone above the unconformity is likely a section of deep water shale. (B) A more subtle unconformity is evidenced by rough surface scattering and gradual truncation of the beds below. (C) Toplap is indicated by beds truncating from below into a surface of nondeposition.

Liner (2004)
Geophysical concepts

Seismic sequence stratigraphy

A sequence is a sediment package that lies between two unconformities or their correlative conformities.

Steps for mapping a seismic sequence are:
1. Mark reflection angularities.
2. Draw unconformities using onlaps, downlaps, toplaps, and truncations.
3. Continue unconformities to their correlative conformities.

A system tract is a part of a sequence deposited during a single eustatic change. It includes the following types:
- **Lowstand (LST)**: deposited during a rapid eustatic fall.
- **Transgressive (TST)**: deposited during a rapid eustatic rise.
- **Highstand (HST)**: deposited during a period spanning late eustatic rise, stillstand, and early fall.
Fig. 10.54 Changes in relative sea level. (a) Assumed eustatic variation, which is rapid compared with tectonic subsidence (b). Tectonic subsidence is nearly linear over this short time span, although logarithmic over a long time. The sum of these two (c) gives the relative change of sea level that provides the accommodation space for sediments. The weight of deposited sediments will produce further subsidence by isostatic adjustment, also a long-term process. System tracts (§10.7.5) are indicated at the bottom.

Fig. 24.4 System tracts and the seismic patterns that indicate sea-level changes. Coastal onlap is evidence of a rise of sea level, a seaward and downward shift in onlap is evidence of a fall of sea level, and a landward movement of sediment packages is evidence of transgression. (a) Types of reflection terminations. (b) System tracts; a stratigraphic sequence begins with a sea-level fall at the end of a highstand tract (HST) and ends with the next highstand tract. A lowstand tract (LST) is the first unit after a large sea-level fall, lying on top of a type 1 sequence boundary (SB1). It is subdivided into basin-floor fan (bf), slope fan (sf), and lowstand wedge (lsw). A rapid rise of sea level produces a transgressive tract (TST), at the top of which there lies the maximum flooding surface (mfs) and a thin, fossil-rich condensed section. The first unit after a sea-level fall that does not fall below the shelf edge (type-2 sequence boundary, SB2) is a shelf-margin tract (SMST). (From Vail, 1987, 2, 4.) (Figure and caption from [165])
Reading Assignment: Read the article in this link:
http://www.aseg.org.au/publications/articles/mul/ss1.htm?print=1
Fig. 10.59 Picking reflection terminations to indicate sequences. (a) Section on east coast of New Zealand (from Loutit et al., 1988); and (b) section from Midland Basin, Texas, showing reflection terminations (arrows) used to locate sequence boundaries (from Sarg, 1988).
Fig. 24.7 Systems tracts seen in offshore data from West Africa. (A) This long 2D line shows a classic prograding delta depositional sequence composed of systems tracts. The sigmoidal sequence boundaries are also called clinoforms. (B) Detail view.
Fig. 10.53  Section showing prograding unit $AA'$ with toplap where reflections pinchout at the top of the unit and downdip where reflections converge at the base. Note also the channel at
Geophysical concepts

Seismic facies analysis

It is the study of the internal and external forms of a group of reflections within a sequence in order to establish the depositional environment of this group of reflections.

Internal forms include:

1. Reflection configuration including:
   - Parallel and sub-parallel
   - Divergent
   - Chaotic
   - Reflection-free
   - Prograding, which includes: sigmoid, oblique, hummocky, and shingled.

2. Reflection amplitude (high, low, variable)
3. Reflection continuity (high, low, variable)
4. Reflection frequency: thickness of each layer
5. Interval velocity
Geophysical concepts

Seismic facies analysis

External forms include:
- Sheet
- Sheet drape
- Wedge
- Bank
- Lens
- Mound
- Fill

Reading assignment
Here is a table of some associations of seismic characters and depositional environments:

<table>
<thead>
<tr>
<th>Seismic character</th>
<th>Depositional environment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sheet of high continuity and amplitude</td>
<td>Marine</td>
</tr>
<tr>
<td>Sheet of low continuity and variable amplitude</td>
<td>Non-marine</td>
</tr>
<tr>
<td>Mound of local reflection void</td>
<td>Reef</td>
</tr>
<tr>
<td>Oblique internal reflections</td>
<td>High depositional energy and sediment supply</td>
</tr>
<tr>
<td>Sigmoid internal reflections</td>
<td>Low depositional energy and sediment supply</td>
</tr>
<tr>
<td>Sheet drape</td>
<td>Low-energy deep marine</td>
</tr>
</tbody>
</table>
Representative collocated chirp images at crossing the edge of a buried fluvial channel. The 1-15 kHz data were used as a guide for interpreting significant seismic boundaries, while the 1-4 kHz data provided more detail of the seismic facies.

http://www.ig.utexas.edu/research/projects/geoclutter/geoclutter.htm
Geophysical concepts

Direct hydrocarbon indicators (DHI)

- It is the study of changes in the amplitude and polarity of reflections in order to relate them to changes in pore-fluid phase (i.e., liquid versus gas).
- Its basis stems from the relation between rock velocity and pore-fluid velocity (e.g., time-average equation).

Important DHI indicators include the following:

1. **Bright spot**: local-amplitude increase due to the presence of hydrocarbons in the low-impedance formation across an interface.
2. **Dim spot**: local-amplitude decrease due to the presence of hydrocarbons in the high-impedance formation across an interface.
3. **Flat spot**: discordant flat reflector due to GOC or GWC.
4. **AVO anomaly**: changes in amplitude with offset due to gas presence.
5. **Gas chimney**: data deterioration above due to gas escaping from below.
6. **Polarity reversal**: due to gas in slightly higher-impedance reservoir.
7. **P-wave but no S-wave anomaly**: indicating only a pore-fluid change.
Bright-Spot Example

VIC/P60 A-2 Lead

Seismic line GC89A-11, Medium Water (700 to 800 meters)
Showing structure with “Bright Spots” in the Golden Beach Subgroup

http://www.aussieoil.com/site/offshore.htm
Flat-Spot Example

DHI Driven Pliocene Exploration

Pliocene Channel Complex
GWC

http://www.hgs.org/en/art/2219
AVO

Example

Typical Gulf Coast gas sand AVO response
Low impedance

A north-south seismic section illustrating the fault-bounded reef platform and associated gas chimneys rising from the oil reservoir.

Polarity-Reversal Example

Typical Mid-Continent gas sand AVO response
High impedance

Vp Density Poisson's ratio Near Offset Far Offset

Gathers

Amplitude decreases with offset and goes from negative to zero to positive

A gas chimney is a subsurface leakage of gas from a poorly sealed hydrocarbon accumulation, clearly visible in the center of the lower seismic section P-P but not as apparent in the upper seismic section P-S. Section P-P displays conventional P-wave data. Section P-S, however, includes S-wave energy, which improves seismic imaging in areas where the acoustic impedance contrast is small, such as in a gas chimney, because the presence of gas has little effect on S-wave propagation.
Maps of P-P and P-SV amplitude-based seismic facies (top) across a carbonate interval of West Texas and vertical sections through these P-P and P-SV data volumes along inline 67 (bottom). A unique P-SV amplitude facies follows the trend of productive stratigraphic-trap wells (right); the P-P amplitude facies does not (left).

Comparison of deep, depth-equivalent, P-P and P-SV data windows, Gulf of Mexico. These data are a classic example of the principle of elastic-wavefield seismic stratigraphy in that the sequence geometry defined by P-SV features 1 and 2 differs from the P-P geometry.

Guidelines for Good DHI Practice

Questions an interpreter should ask in an attempt to validate hydrocarbon indicators

1) Is the reflection from the suspected reservoir anomalous in amplitude, probably bright?
2) Is the amplitude anomaly structurally consistent?
3) If bright, is there one reflection from the top of the reservoir and one from the base?
4) Do the amplitudes of the top and base reflections vary in unison, dimming at the same point at the limit of the reservoir?
5) Are the data zero phase?
6) Is a flat spot visible?
7) Is the flat spot flat or dipping consistently with gas velocity sag or tuning?
8) Is the flat spot unconformable with the structure but consistent with it?
9) Does the flat spot have the correct zero-phase character?
10) Is the flat spot located at the downdip limit of brightness (or dimness)?
11) Is a phase change (polarity reversal) visible?
12) Is the phase change structurally consistent and at the same level as the flat spot?
13) Do bright spot, dim spot, or phase change show the appropriate zero-phase character?
14) Is there a low-frequency shadow below the suspected reservoir?
15) Is there an anomaly in moveout-derived interval velocity?
16) Is a study of amplitude versus offset on the unstacked data likely to yield further validation evidence?
17) Are any shear wave data available for further validation evidence?