# 10. Seismic Stratigraphy

Reflection seismology is compartmentalized into **acquisition, processing and interpretation.** Seismic stratigraphy deals with interpretation. It is the study of seismic data for the purpose of extracting stratigraphic information.

Seismic stratigraphy is often divided into several sub-areas:

♥ Analysis of **seismic sequence**
Separating out time-depositional units based on detecting unconformities or changes in seismic patterns;

♥ Analysis of **seismic facies**
Determining depositional environment from seismic reflection characteristics;

♥ Analysis of **reflection character**
Examining the lateral variation of individual reflection events, or series of events, to locate where stratigraphic changes occur and identify their nature; the primary tool for this is modeling by both synthetic seismograms and seismic logs.

## ♥ Amplitude

Reflection amplitude has to do with seismic wave height and is a function of the energy of seismic waves. On a seismic record, amplitude is measured as the distance from the mid-position of a wave to the extreme position. Amplitude is directly proportional to RC. It is also affected by the spacing between reflecting surfaces. Where bed spacing is optimum, lower energy responses are phased together constructively (constructive interference) to intensity or amplify the reflected energy and thus increase amplitude.

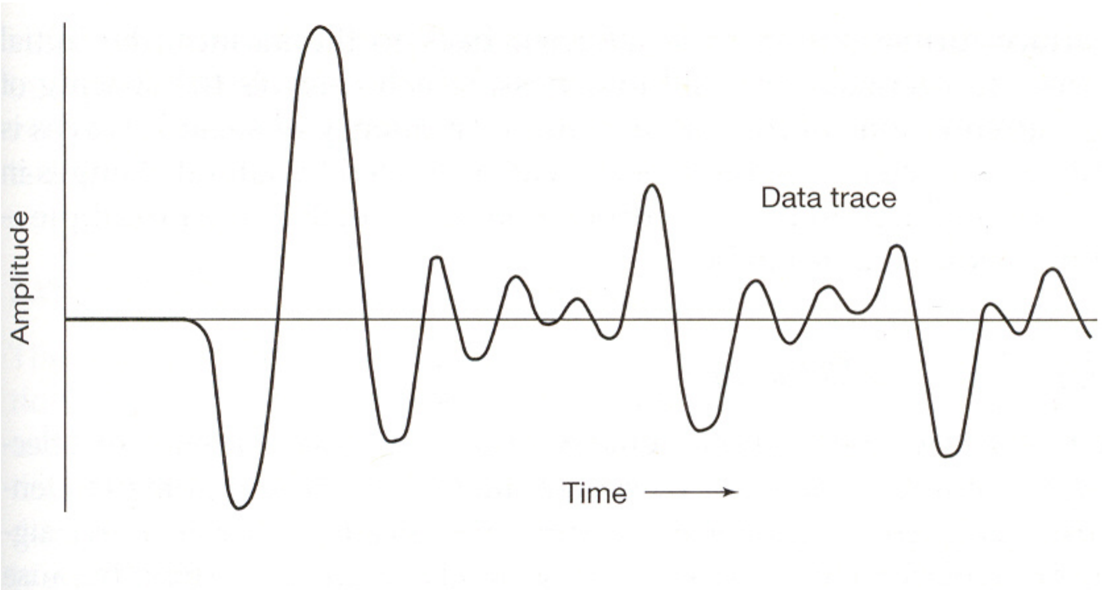



**Figure 14.10**
Schematic representation of the amplitude of seismic waves. The amplitude is the vertical distance above or below the mid-point line drawn through the wave traces. Time refers to arrival time of the waves at the seismic detector. [After Neidell, N. S., 1979, Stratigraphic modeling and interpretation: Geophysical principles and techniques: Am Assoc. Petroleum Geologists Education Short Course Notes 13. Fig. p. 31, reprinted by permission of AAPG, Tulsa, OK.]

Boggs (2001), p.497

## ♥ Polarity

Positive RC produces a positive reflection, by definition and negative RC produces a negative reflection. Determine polarity from known impedance boundary, for example the water bottom (positive).

**Where to Pick?** Actual onset of reflection corresponds to impedance contrast or geological boundary in **Minimum Phase Data**. Data can be processed to **Zero Phase** such that peak amplitude of a symmetrical wavelet lies over impedance contrast. In any case you pick on the peak because that is what is easy and in the case of minimum phase data, make any necessary adjustment for the distance between the reflector and the geologic boundary. Most, if not all, seismic sections are displayed in minimum phase data.
(Definitions: **Minimum phase**: a characteristic of waveforms which have their energy concentrated early in the waveform; **Zero phase**: a characteristic waveforms which are symmetrical.)

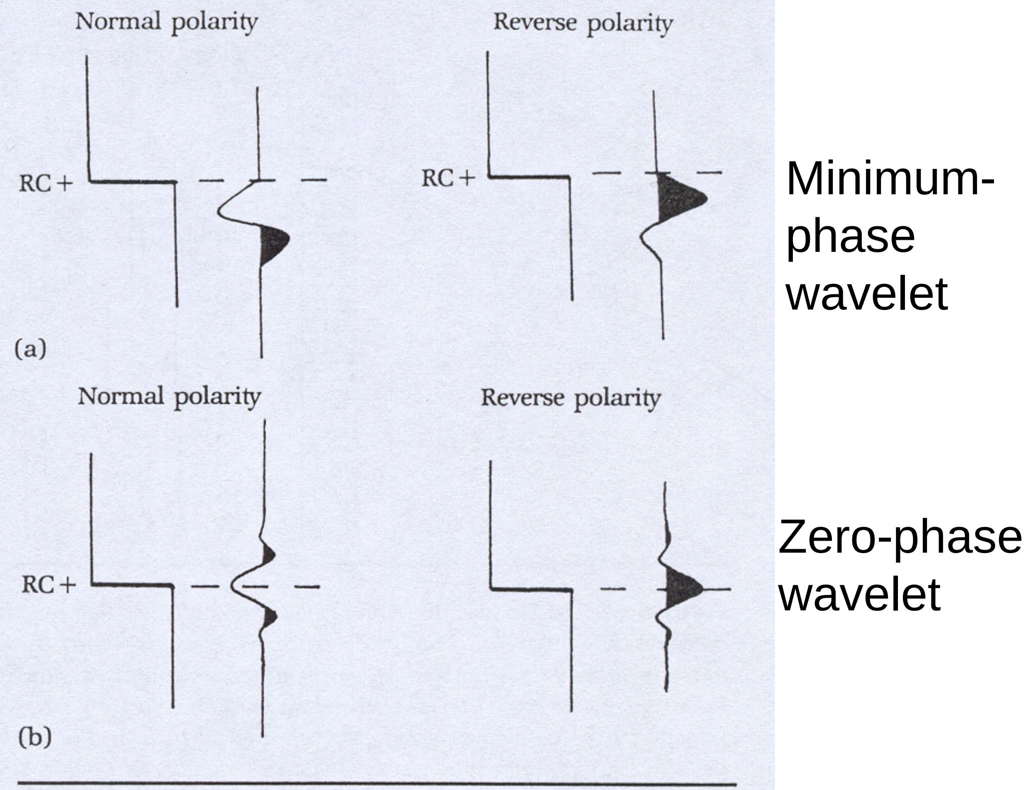



**FIGURE 2.6** *Examples of idealized normal and reverse polarity for (a) minimum- and (b) zero-phase wavelets at an acoustic-impedance boundary with a positive reflection coefficient.*

Badley (1985), p.9

**Frequency:** The frequency spectrum of the acoustic signal generated varies according to the energy sources.

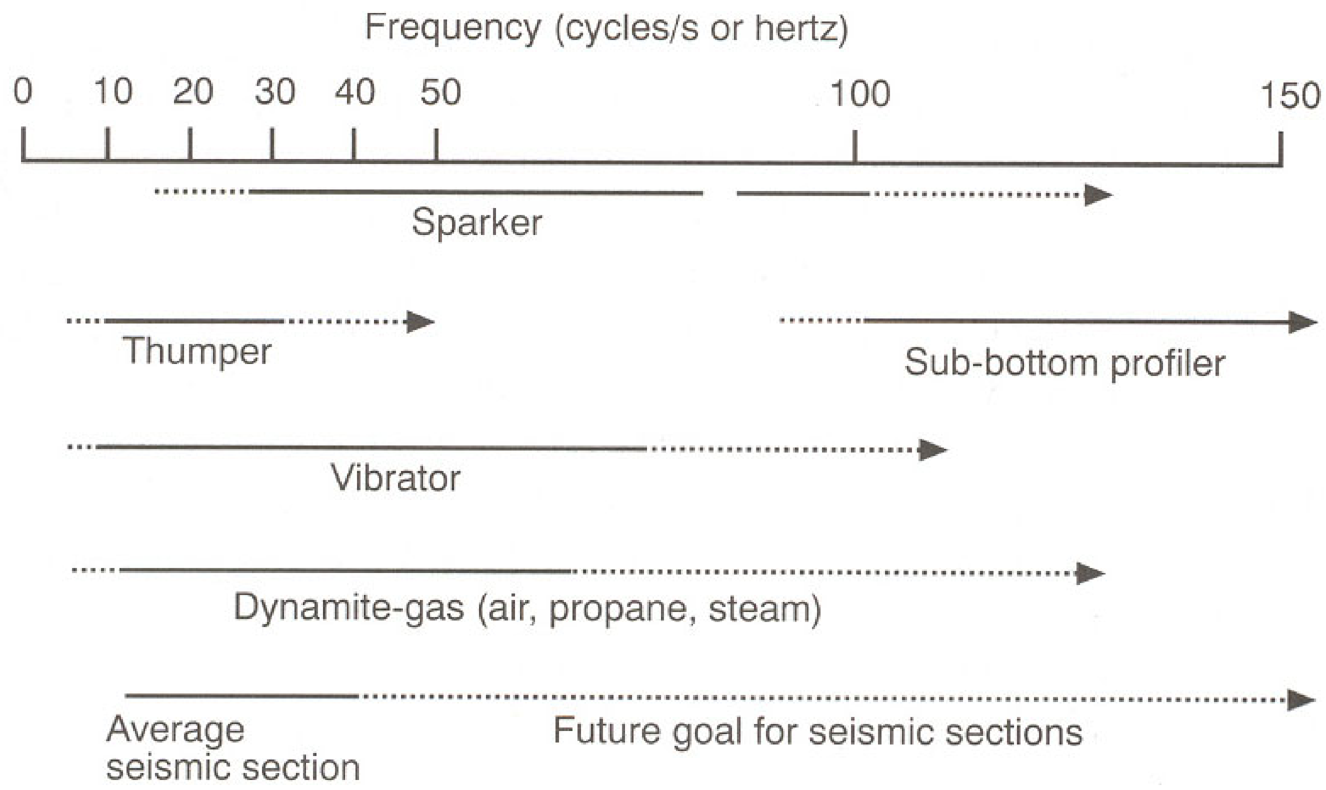



***Figure 10.6*** *A frequency spectrum acoustic signal from 0 to 150 Hertz (cycles per second) showing frequency ranges for different energy sources. [Modified from: Tucker (1974)]*

Doyle and Bennett (1998), p.284

# 10.3 Chronostratigraphic significance of seismic reflections

Primary seismic reflections follow chronostratigraphic (time-stratigraphic) correlation patterns rather than time-transgressive lithostratigraphic (rock-stratigraphic) units. In other words, seismic reflectors in many cases are time lines. They cut across <u>major</u> lithologic boundaries, especially those defined by outcrop sections or wells.

(1)

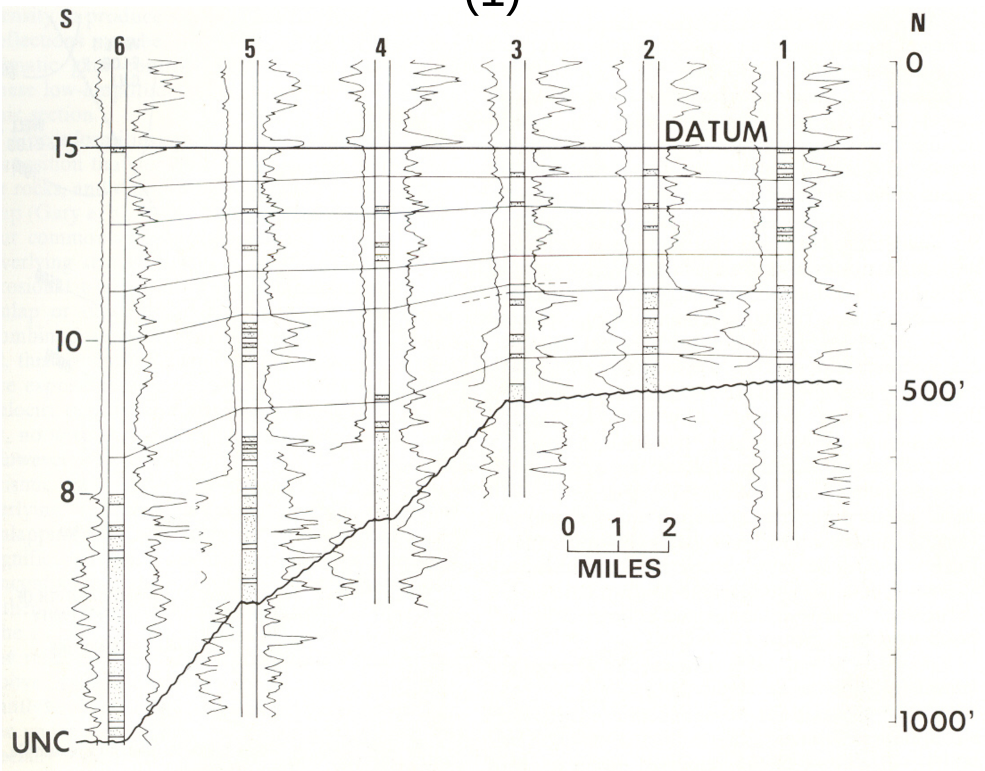



FIG. 2—Geologic cross section showing electric-log correlations, Tertiary example, South America. Stippled pattern in well bore represents sandstone. Key horizons indicated on left.

Vail et al. (1977) in AAPG Mem.26, p.102

(2)

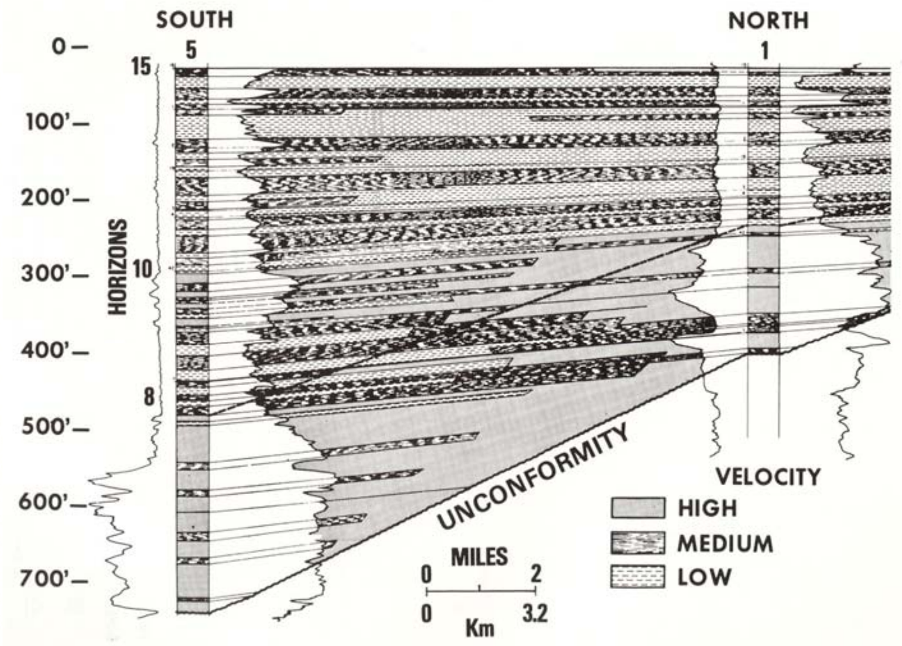
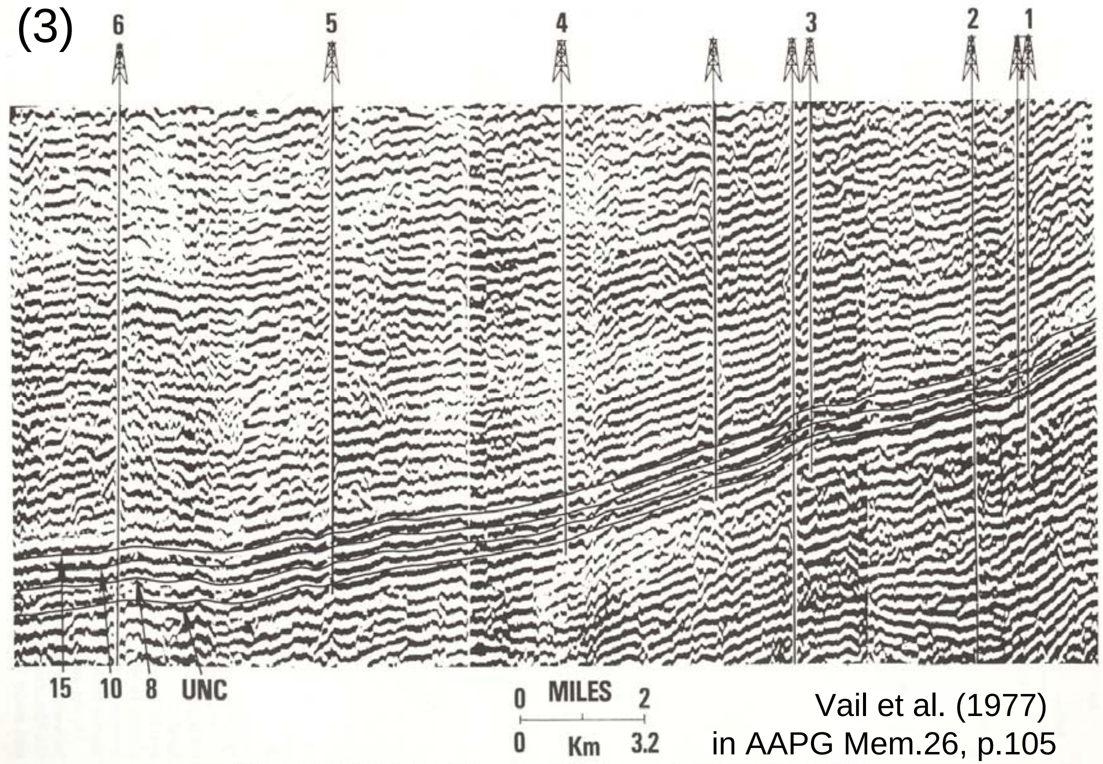



FIG. 3—Distribution of velocity for Tertiary example, South America. Velocity was obtained from CVLs for wells 5 and 1 and distributed laterally using stratal surface correlations.

Vail et al. (1977) in AAPG Mem.26, p.103

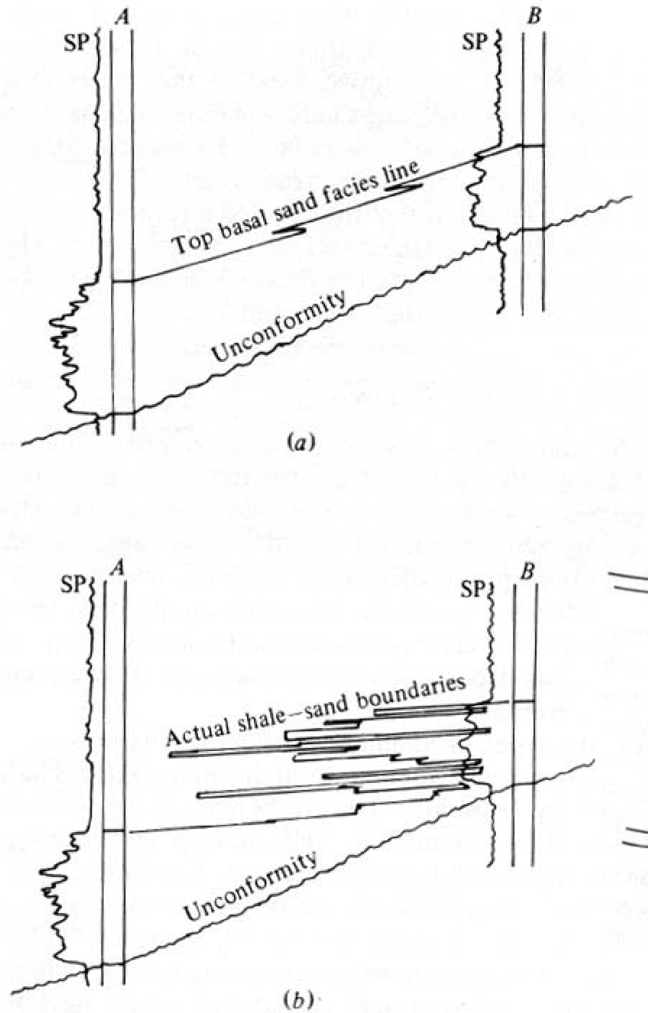
Another example showing the chronostratigraphic significance of seismic reflections (Sherrif and Geldart, 1995, p. 403)

(3)




Vail et al. (1977)
in AAPG Mem.26, p.105

FIG. 6—Single-fold VDF magnetic tape seismic section from a Tertiary basin in South America.



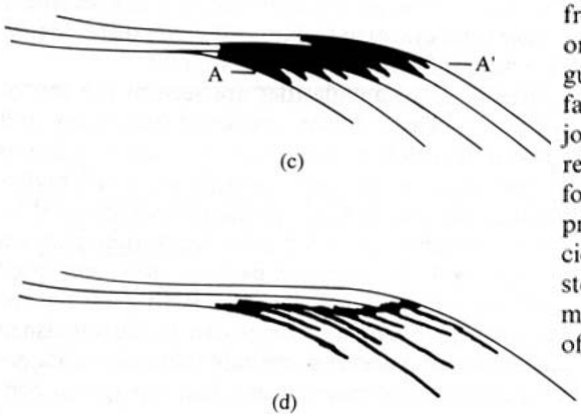




Fig. 10.55 The nature of facies surfaces. (Data for a and b from Vail, Todd, and Sangree, 1977b.) (a) Facies surface based on data from two wells 17 km apart; the *SP*-log curves distinguish the sand from surrounding shale. (b) Redrawing of the facies surface based on intervening well-control points; the major portions parallel stratal or time surfaces. Seismic data show reflections parallel to the time surfaces onlapping the unconformity. (c) Classical picture of sand-rich sediments in a prograding/aggrading system suggests a reflection along the facies boundary *AA'*, which does not show. (d) Occasional major storms and other catastrophic events rework the sand-rich sediments and spread them along time surfaces, which is the attitude of reflections.

# 10.4 Seismic sequence analysis

The procedures for interpreting stratigraphy from seismic data involve three principle stages: (1) seismic sequence analysis, (2) seismic facies analysis, and (3) interpretation of depositional environments and lithofacies (Vail, 1987).

**Seismic sequence (or a depositional sequence):** A stratigraphic unit composed of a relatively conformable succession of genetically related strata and bounded at its top and base by unconformities or their correlative conformities.

A depositional sequence has chronostratigraphic significance because all the rocks of the sequence were deposited during the interval of geological time defined by the ages of the sequence boundaries where they are conformities.

---

FIG. 1—Basic concepts of depositional sequence. A depositional sequence is a stratigraphic unit composed of relatively conformable successions of genetically related strata and bounded at its top and base by unconformities or their correlative conformities.

**A.** Generalized stratigraphic section of a sequence. Boundaries defined by surfaces A and B which pass laterally from unconformities to correlative conformities. Individual units of strata 1 through 25 are traced by following stratification surfaces, and assumed conformable where successive strata are present. Where units of strata are missing, hiatuses are evident.

**B.** Generalized chronostratigraphic section of a sequence. Stratigraphic relations shown in **A** are replotted here in chronostratigraphic section (geologic time is the ordinate). Geologic-time ranges of all individual units of strata given as equal. Geologic-time range of sequence between surfaces A and B varies from place to place, but variation is confined within synchronous limits. These limits determined by those parts of sequence boundaries which are conformities. Here, limits occur at beginning of unit 11 and end of unit 19. A sechron is defined as maximum geologic-time range of a sequence.)

↓ next page



Sequence Stratigraphy
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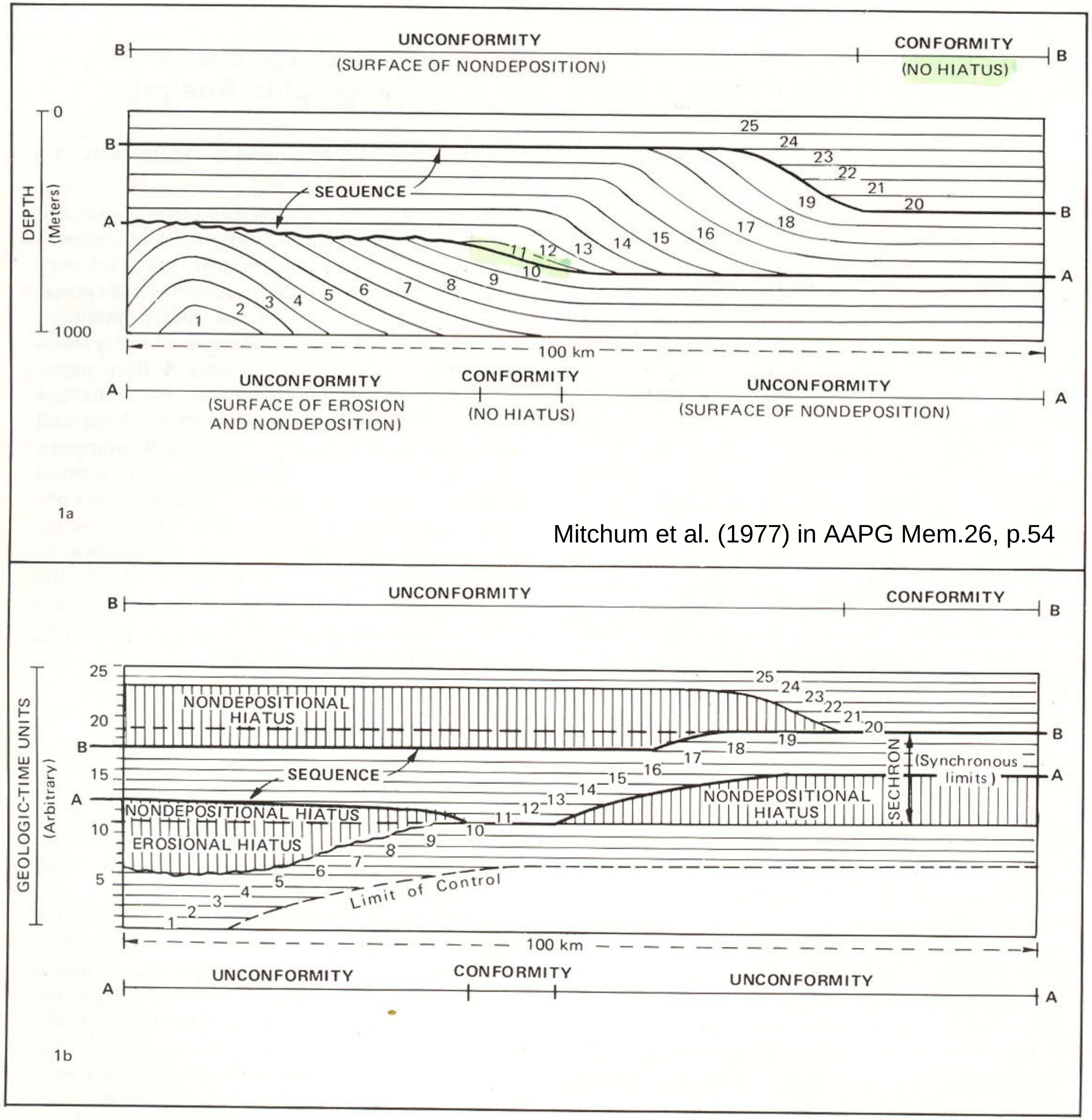
Basic concept of a depositional sequence




Mitchum et al. (1977) in AAPG Mem.26, p.54

## An idealized sequence

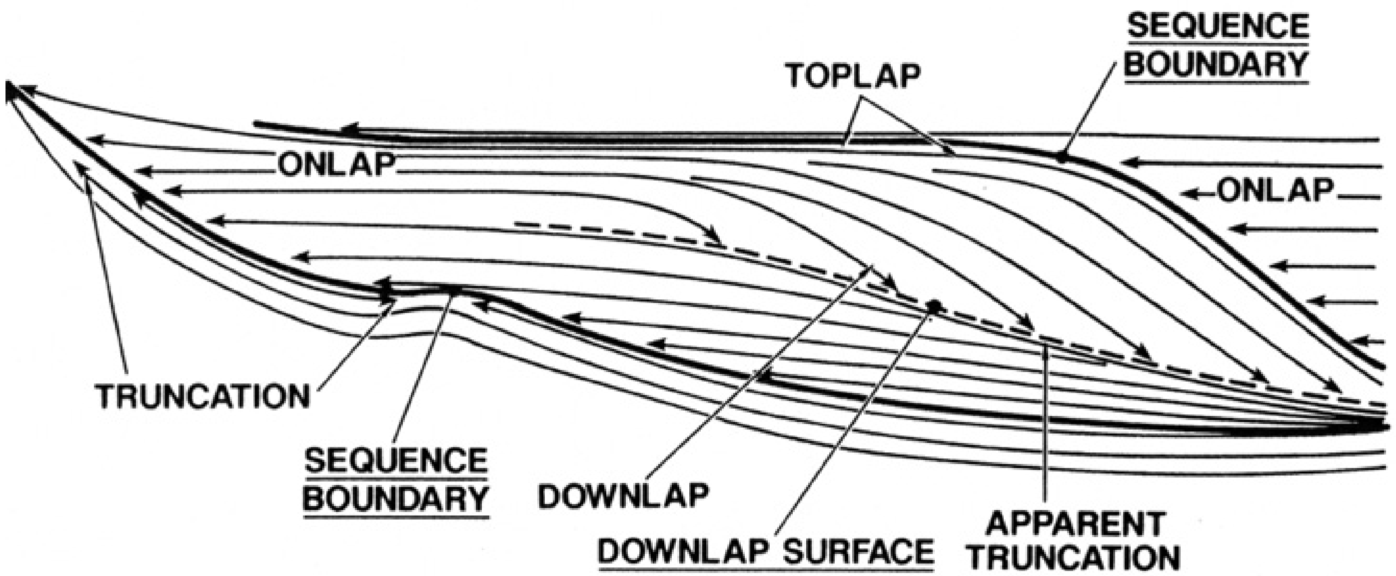



**Figure 1.** Diagram showing reflection termination patterns and types of discontinuities. Discontinuity names are underlined.

Vail (1987)

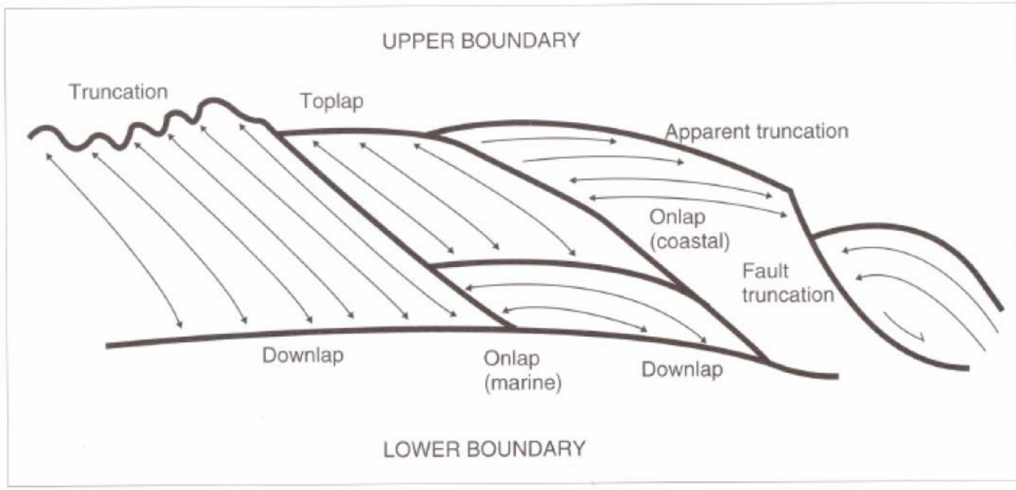
Seismic sequence analysis involves identification of major reflection "packages" that can be delineated **by recognizing surfaces of discontinuity**. Discontinuities may thus be recognized by interpreting systematic patterns of reflection terminations along the discontinuity surfaces.

# Three main types of reflection discordance

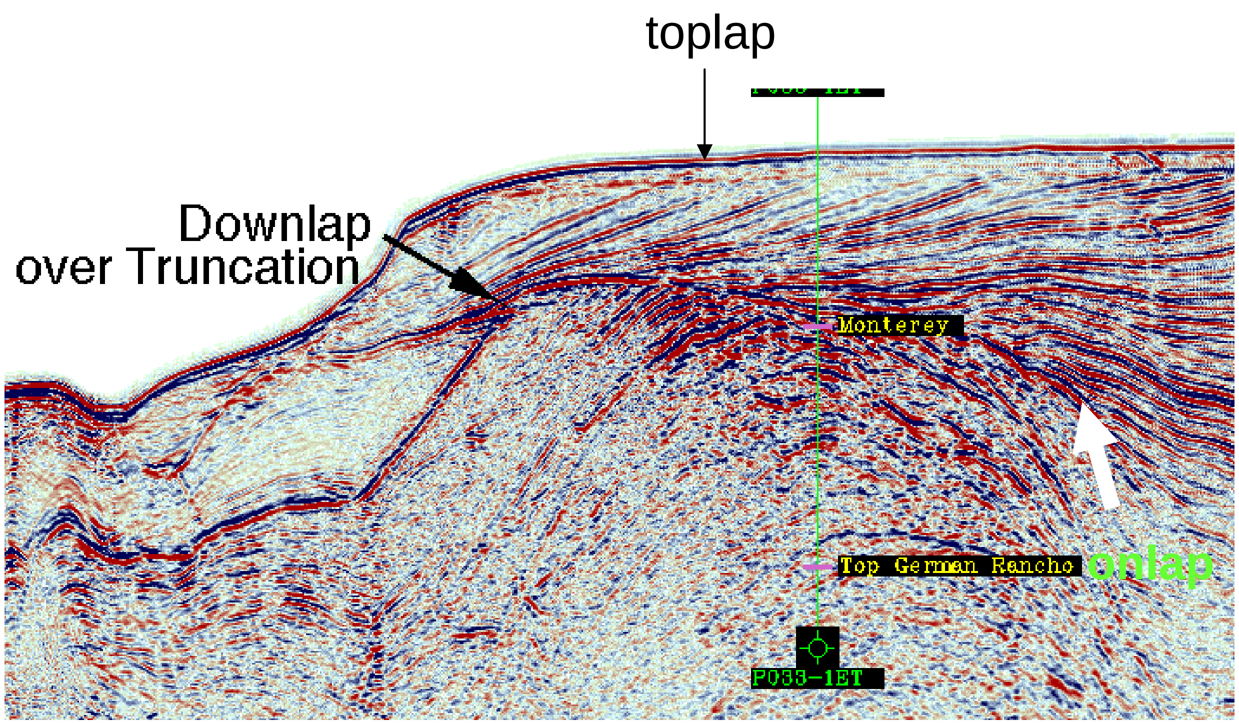
1. Erosional truncation

2. Apparent truncation

3. Lapout
   - baselap
     - onlap
     - downlap
   - toplap



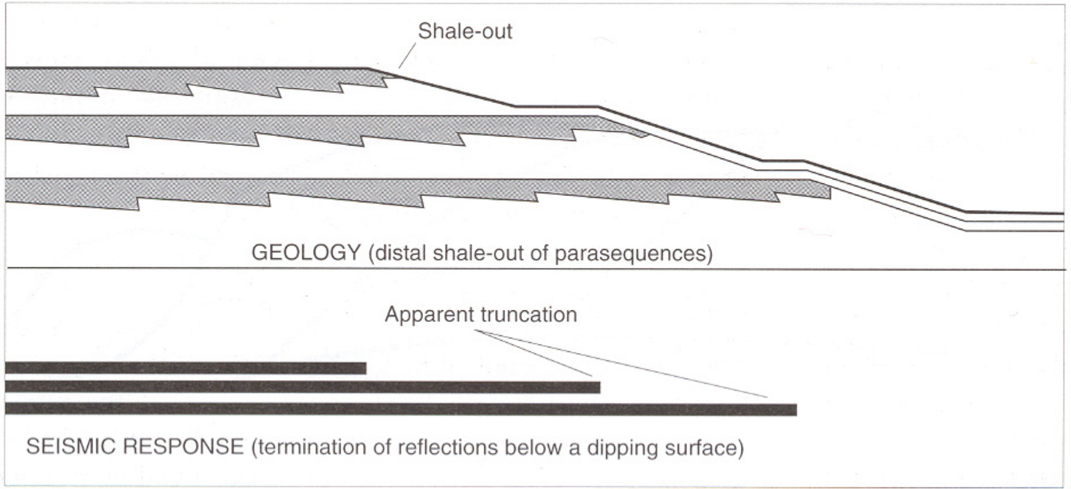

Emery & Myers (1996), p.53




**Erosional truncation** is the termination of strata against an overlying erosional surface.

http://ic.ucsc.edu/~casey/
eart168/Lec.SeisStrat.htm

**Apparent truncation** is the termination of relatively low-angle seismic reflections beneath a dipping seismic surface, where that surface represents marine condensation.




Emery & Myers (1996), p.54

**Fig. 3.9** Apparent truncation; the termination of reflections against an overlying surface, which looks like erosional truncation, but represents the original depositional limit of the strata

**Lapout** is the lateral termination of a reflection (generally a bedding plane) at its depositional limit.

**Baselap** is the lapout of reflections against an underlying seismic surface (which marks the base of the seismic package). Baselap can consist of **onlap** or **downlap**.

**Onlap** is recognized on seismic data by the termination of low-angle reflections against a steeper seismic surface. Two types of onlap are recognized: **marine onlap** and **coastal onlap**.

**Downlap** is baselap in which an initially inclined stratum terminates downdip against an initially horizontal or inclined surface. The surface of downlap represents a marine condensed unit in most cases.


Santa Cruz terrace deposits downlapping onto unconformity.

**Toplap** is the termination of inclined reflections (clinoforms) against an overlying lower angle surface, where this is believed to represent the proximal depositional limit.

Other term:

**Offlap:** A conformable sequence of inclined strata, deposited during a marine regression, in which each stratum is succeeded laterally by progressively younger units (a **clinoform**).

http://ic.ucsc.edu/~casey/eart168/Lec.SeisStrat.htm

Clinoforms merging into toplap. Peru, a temperate water carbonate of Miocene age.



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# 10.5 Seismic facies analysis

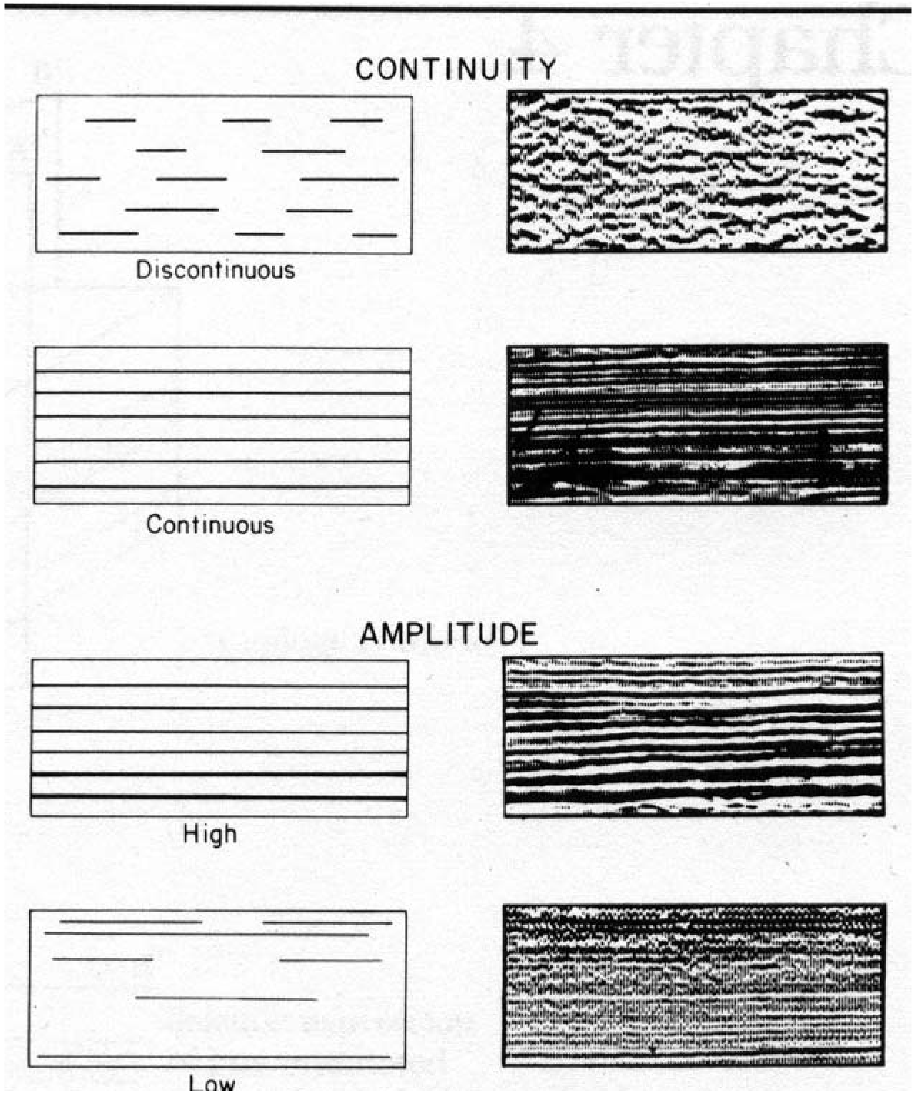
Seismic facies analysis takes the interpretation process one step beyond seismic sequence analysis by examining within sequences smaller reflection units that may be the seismic response to lithofacies.

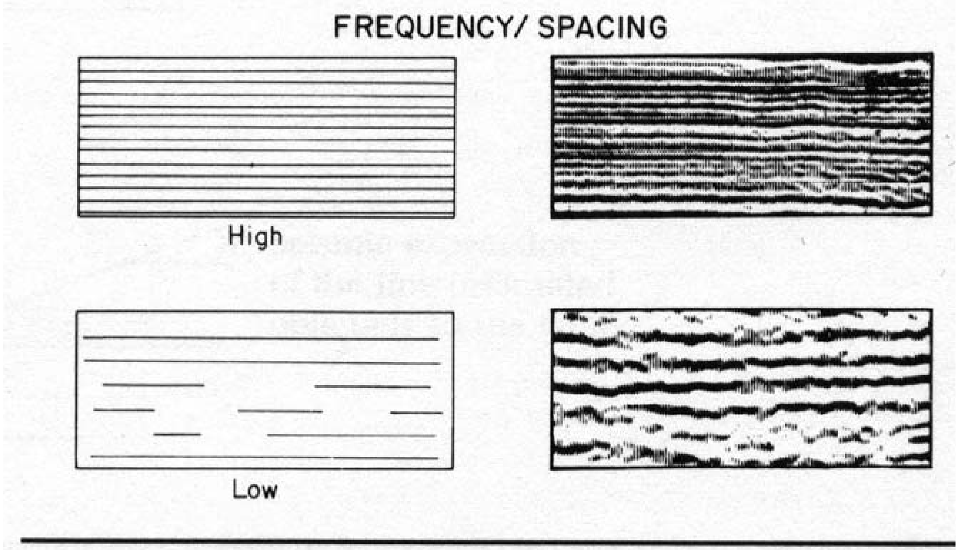
Seismic facies are packages of reflectors with a set of seismic characteristics differing from adjacent units (similar to definition of a “formation”-must be distinguishable from adjacent units and mappable on earth's surface).

**Keystones in seismic facies analysis** (Sangree and Widmier, 1979):

1. An understanding of the effects of lithology and bed spacing on reflection parameters: **amplitude, frequency, continuity of reflections**.

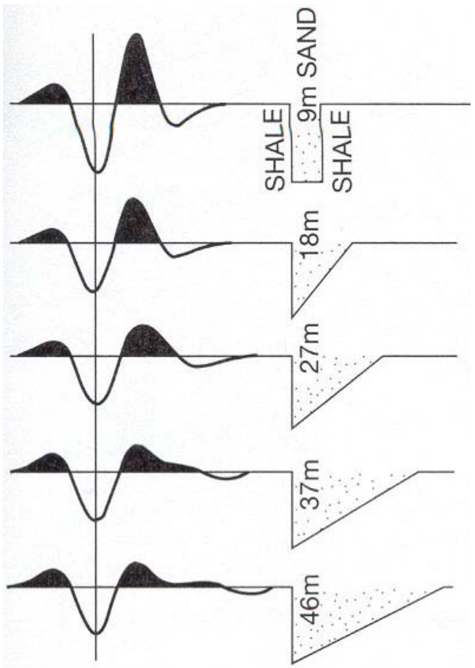
| Feature of Reflectors | Geological Interpretation (Sangree Widmier, 1979) |
|---|---|
| **Amplitude** | Impedance (velocity-density) contrasts, Layer spacing (cause constructive and destructive interference), Fluid content |
| **Frequency** | Bed spacing, Fluid content |
| **Continuity** | Beddding or layer continuity, depositional processes |




***Reflection attributes: continuity, amplitude, frequency/spacing.*** (from Badley (1985) p. 72 )

Presence of gas may cause “bright spots” effect.




Seismic response for a sand with a gradational base, which results in lower amplitude. The 9-m thickness is about 1/8 wavelength.

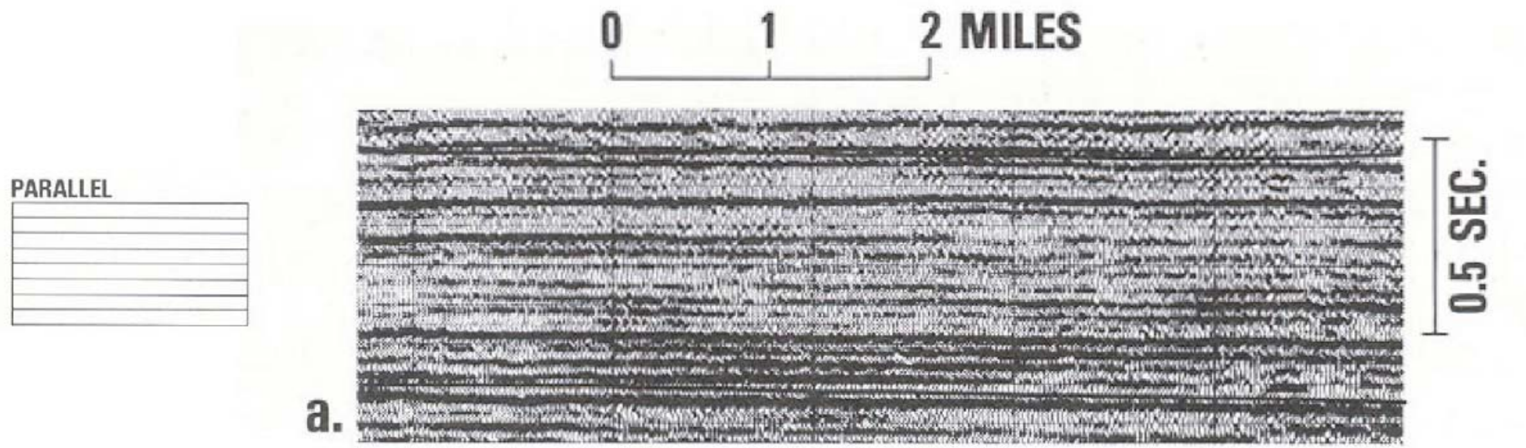
2. Parallelism of reflection cycles to gross bedding, and therefore, to physical surfaces that separate older from younger sediments :
**Reflection configurations**.

Reflection configuration refers to the gross stratification patterns identified on seismic records.

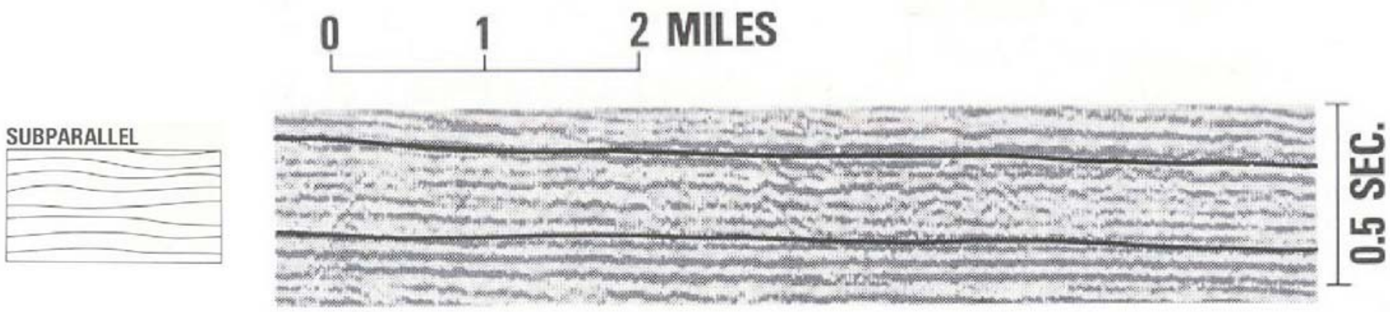
| **Feature of Reflectors** | **Geological Interpretation** (Sangree Widmier, 1979) |
|---|---|
| **Reflection Configuration (pattern)** | Stratification patterns, Depositional processes, Erosion and paleotopography |
| **External form** and **areal association** of seismic facies units | Gross depositional environment, Sediment source, Geologic setting |

**Principle reflection patterns**

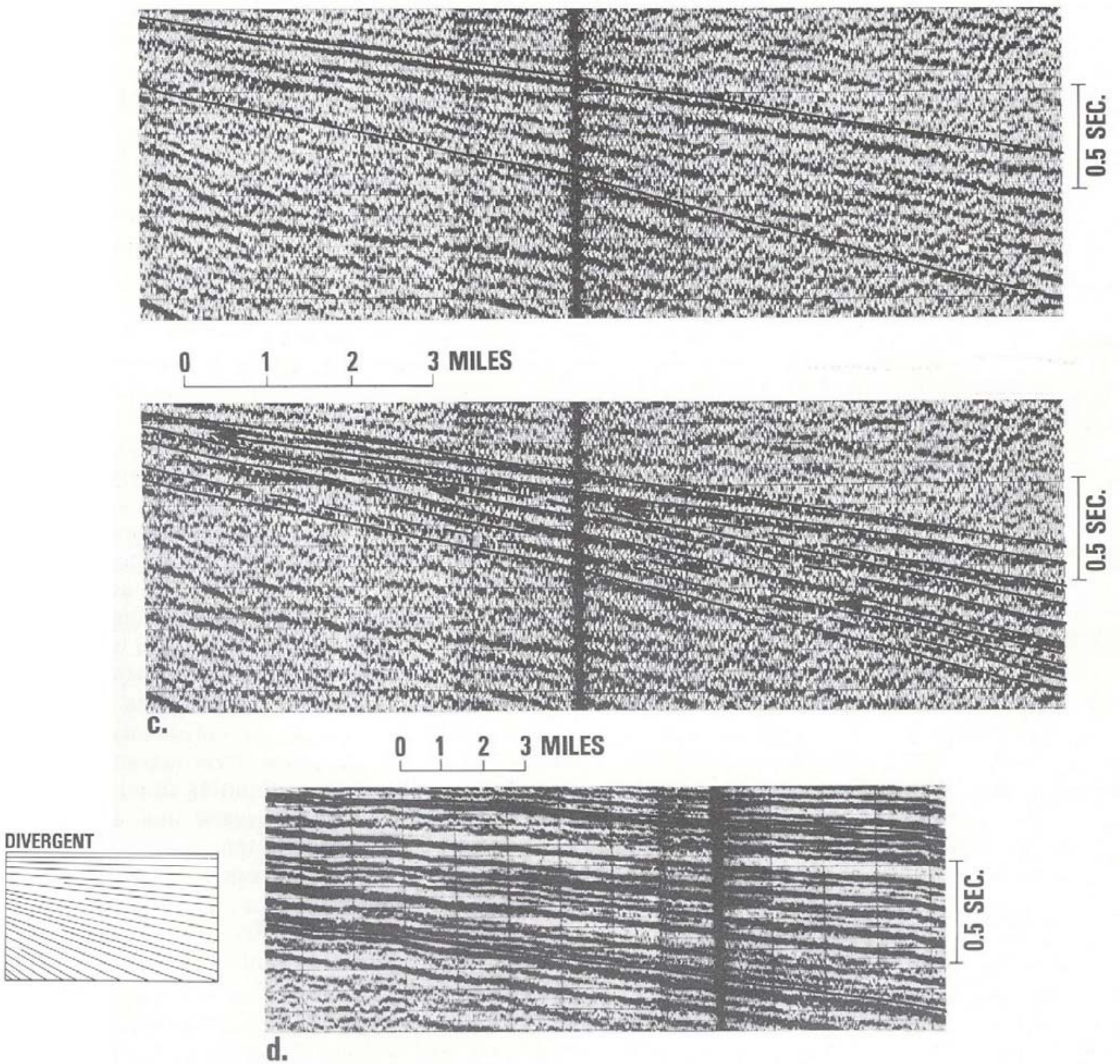
1. **Parallel and subparallel**: generated by strata that were probably deposited at uniform rates on a uniformly subsiding shelf or in a stable basin setting.




Parallel configuration with good continuity and high to medium amplitude




Subparallel configuration with good to fair continuity and high to medium amplitude




Divergent configurations, with thickening of individual reflection cycles in direction of divergence.

**2. Divergent**: Divergent configurations are characterized by a wedge-shaped unit in which lateral thickening of the entire unit is caused by thickening of individual reflection subunits within the main unit. Divergent configurations are interpreted to signify lateral variations in rates of deposition or progressive tilting of the sedimentary surface during deposition.

**3. Prograding**: Generated by strata that were deposited by lateral outbuilding or progradation to form gently sloping depositional surfaces called clinoforms. Prograding reflection configurations may include patterns of **sigmoid** (superposed S-shaped reflectors) and **oblique, complex sigmoid-oblique, shingled, hummocky.**

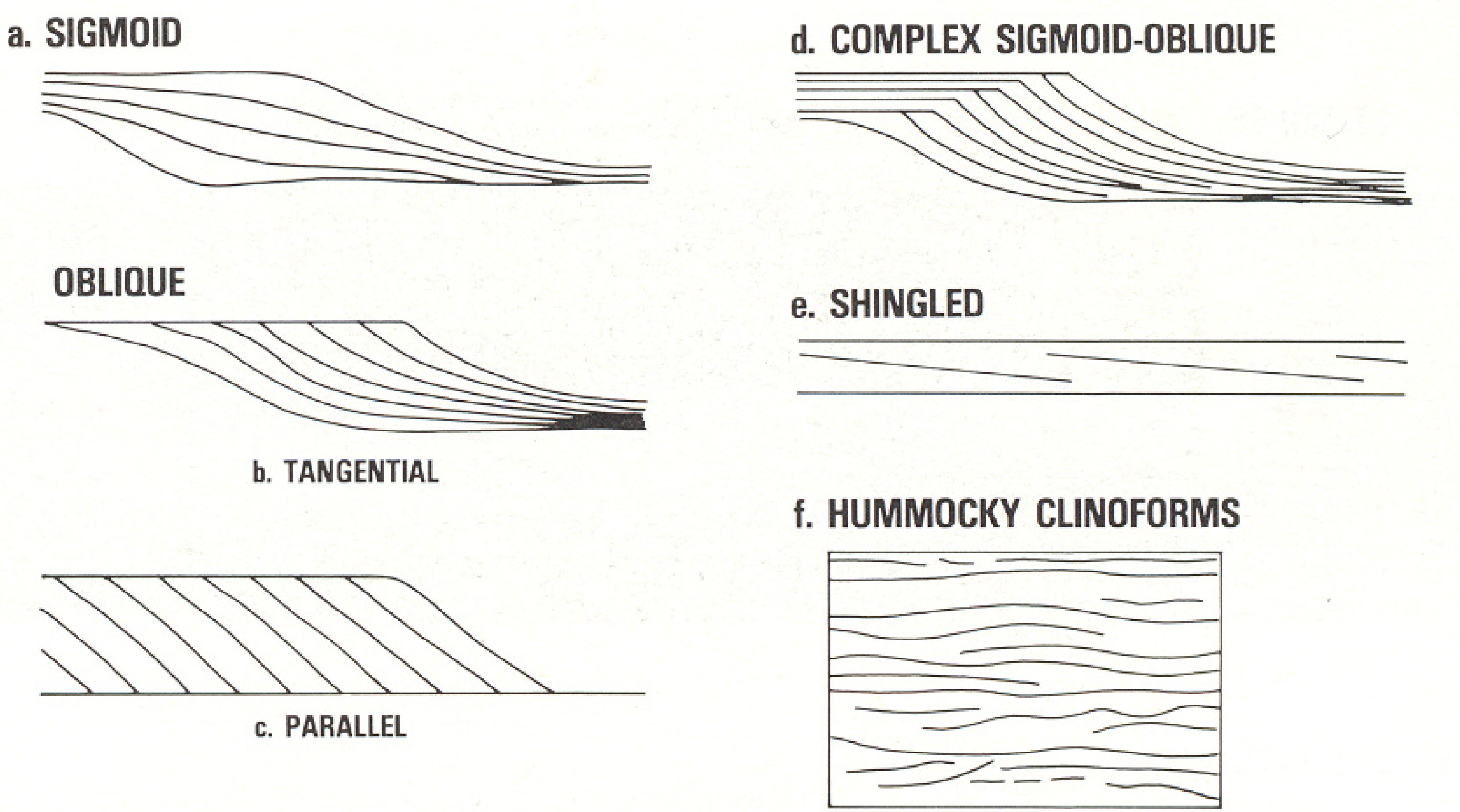
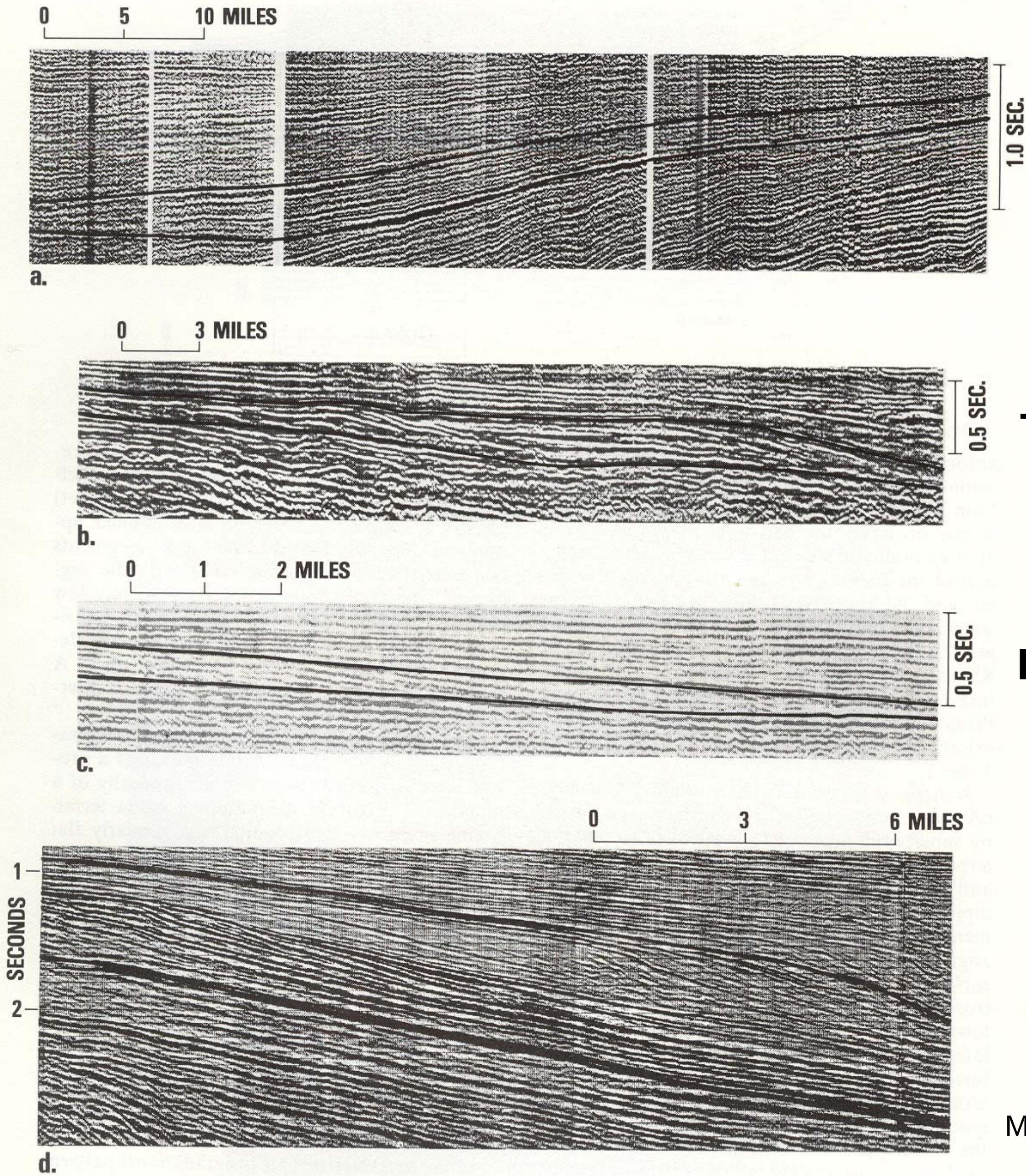



FIG. 6—Seismic reflection patterns interpreted as prograding clinoforms.

Mitchum et al. (1977), p.125

Examples of prograding configuration pattern




**Sigmoid**

**Tangential oblique**

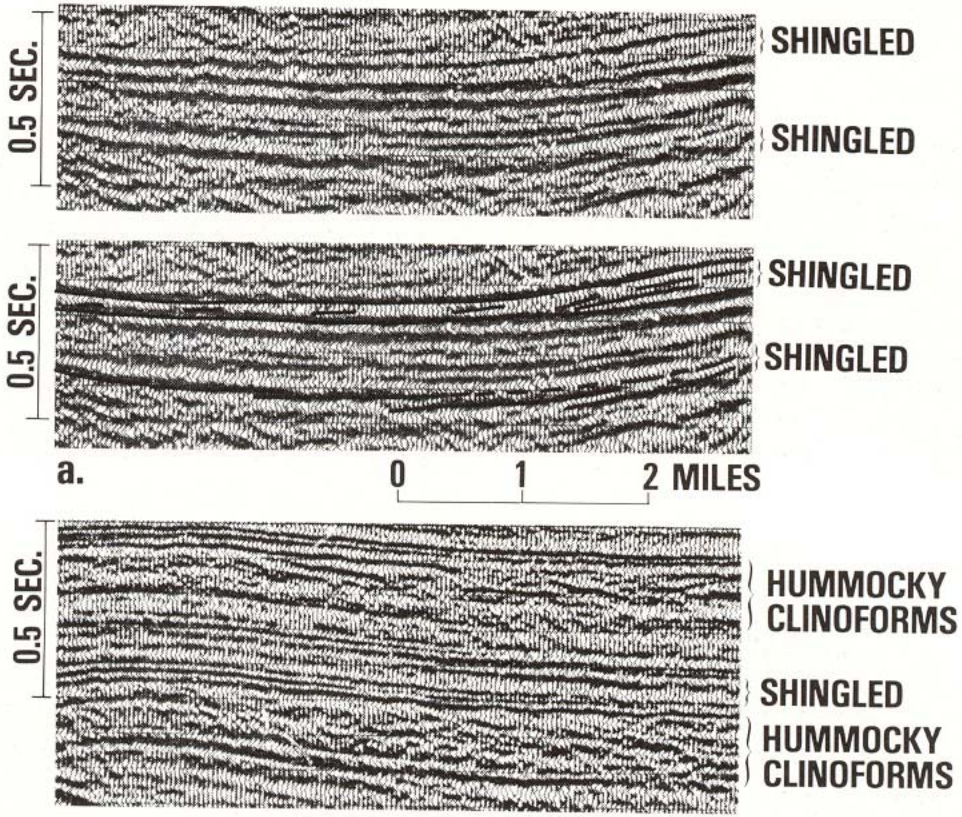
**Parallel oblique**

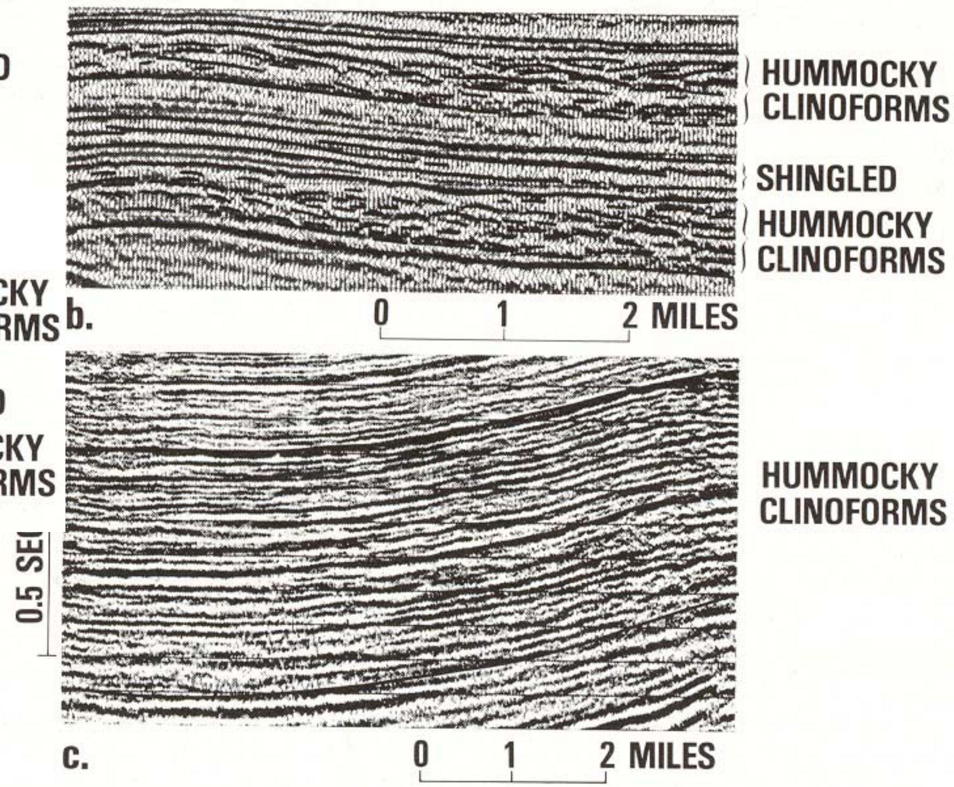
**Complex sigmoid-oblique**

Mitchum et al. (1977), p.126

FIG. 7—Examples of sigmoid, oblique, and complex sigmoid-oblique seismic reflection configurations: **a** is sigmoid, **b** is mostly tangential oblique with some sigmoid, **c** is mostly parallel oblique, **d** is complex sigmoid-oblique.

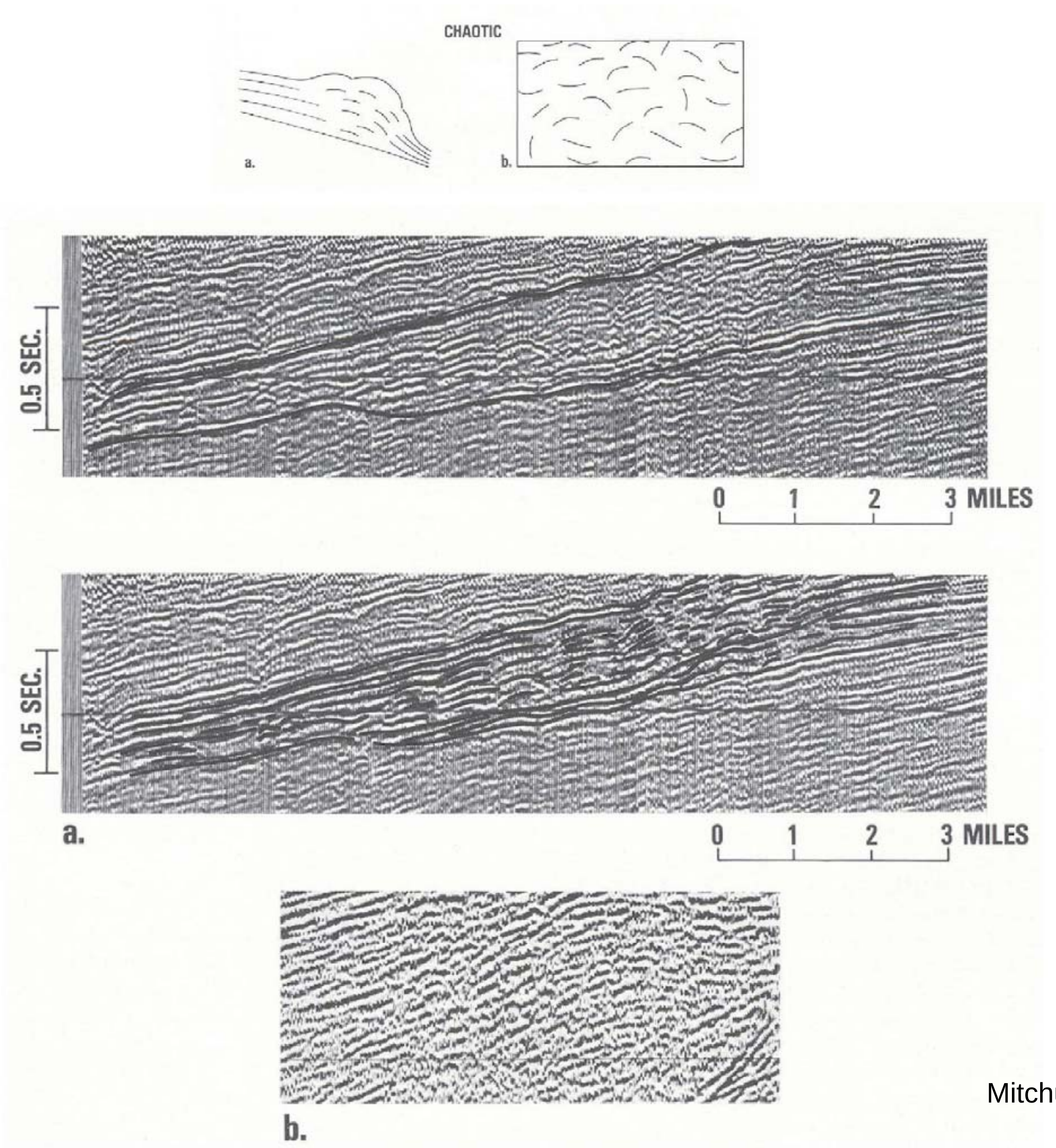
# Examples of prograding configuration pattern




Mitchum et al. (1977), p.127

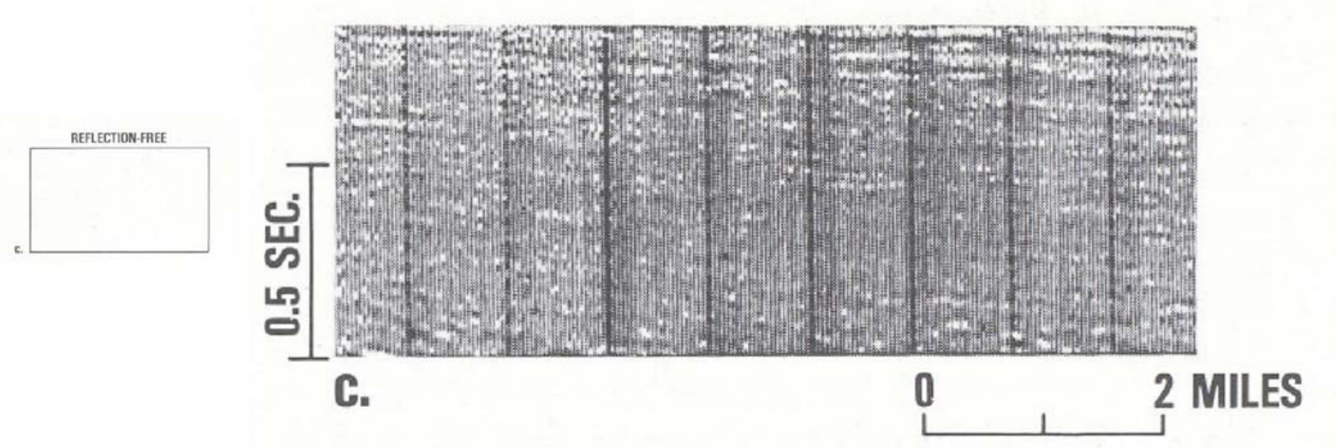
FIG. 8—Examples of shingled and hummocky clinoform seismic reflection configurations: **a** is a shingled configuration; **b** is hummocky clinoform configuration with minor shingling; **c** is hummocky clinoform configuration. Both configurations are interpreted as strata deposited in small clinoforms with relief approaching, or at, the point of seismic resolution. Clinoforms of **a** and **b** are slightly larger than those of **c** with correspondingly better resolution. Second sections of pairs **a** and **b** shows interpretation.




**4. Chaotic**: This pattern is interpreted to represent a disordered arrangement of reflection surfaces owing to penecontemporaneous, soft-sediment deformation, or possibly to deposition of strata in a variable, high-energy environment.

Mitchum et al. (1977), p.129

Chaotic seismic configuration. In (a) reflections may be interpreted as contorted stratal surfaces; in (b) no stratal patterns may be reliably interpreted.




**5. Reflection-free**: This pattern may represent homogeneous, non-stratified units such as igneous masses or thick salt deposits, or highly contorted or very steeply dipping strata.

Reflection-free seismic configuration, where no or very few reflections occur in seismically homogeneous shale.

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## Modifying terms

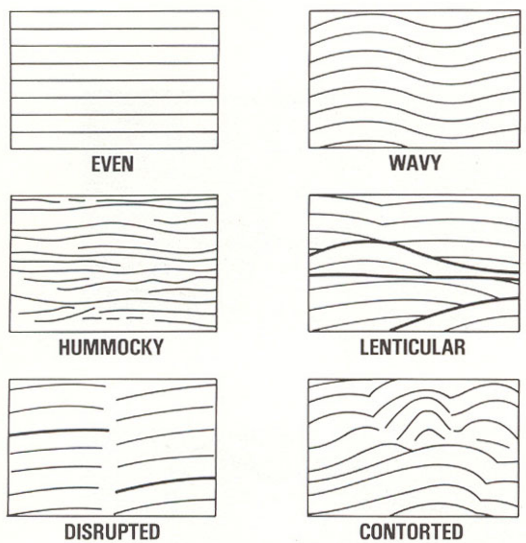
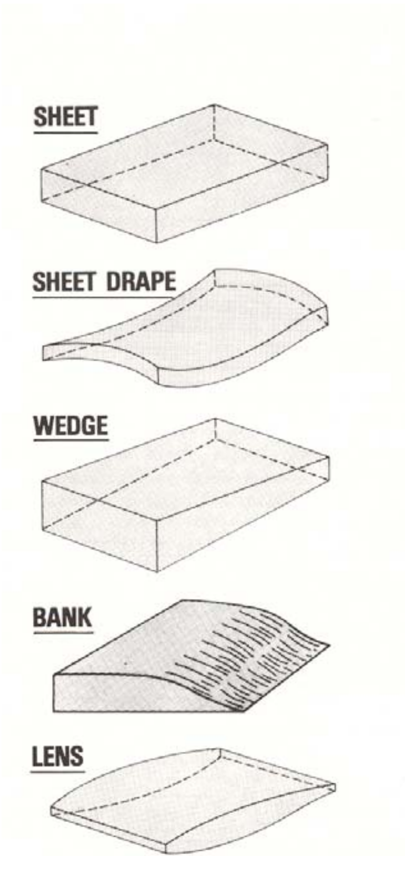
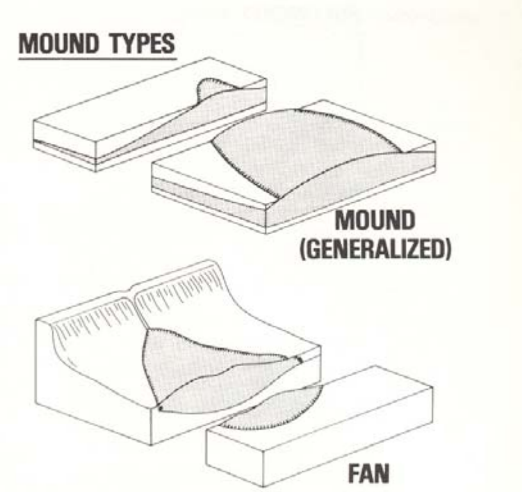


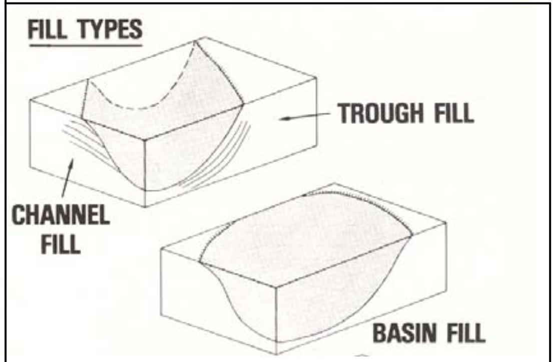

FIG. 11—Some modifying seismic reflection configurations.

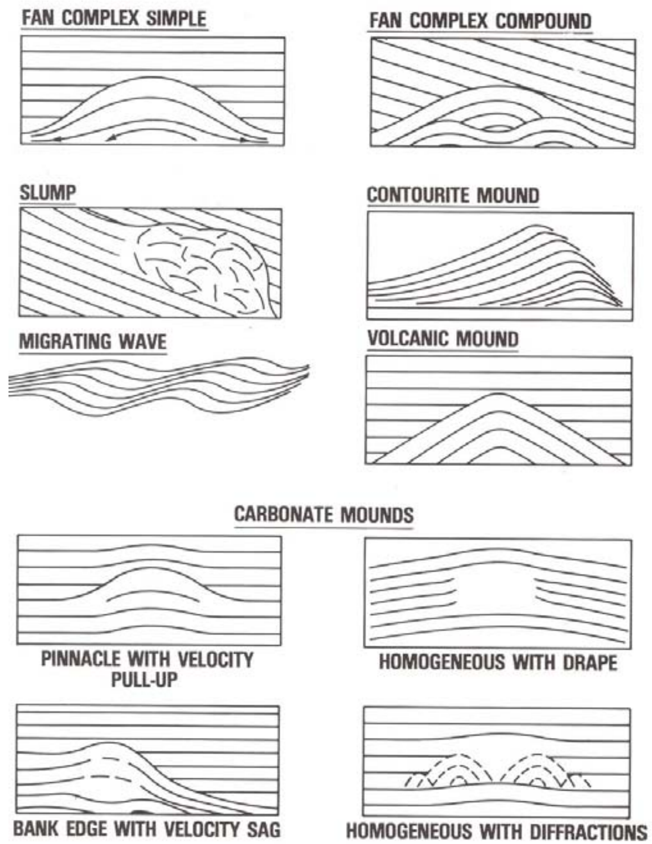
Mitchum et al. (1977), p.130

# External forms of seismic facies units



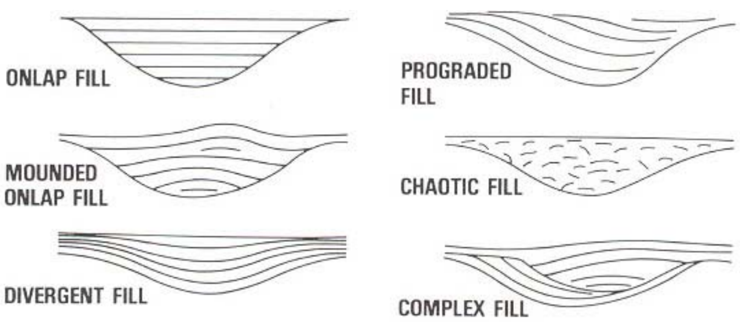




Sediment waves


FIG. 14—Example of migrating-wave seismic reflection configuration.



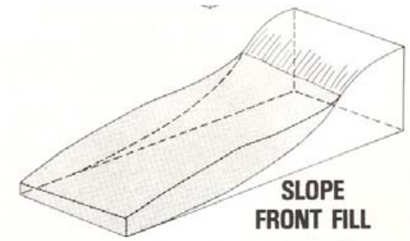




FIG. 15—Some fill seismic facies units.

Mitchum et al. (1977), p.133

# A summary for geological interpretation of seismic facies parameters

**REFLECTION TERMINATIONS (AT SEQUENCE BOUNDARIES)**

- LAPOUT
  - BASELAP
    - ONLAP
    - DOWNLAP
  - TOPLAP
- TRUNCATION
  - EROSIONAL
  - STRUCTURAL
- CONCORDANCE
  - (NO TERMINATION)

**REFLECTION CONFIGURATIONS (WITHIN SEQUENCES)**

- PRINCIPAL STRATAL CONFIGURATION
  - PARALLEL
  - SUBPARALLEL
  - DIVERGENT
  - PROGRADING CLINOFORMS
    - SIGMOID
    - OBLIQUE
    - COMPLEX SIGMOID-OBLIQUE
    - SHINGLED
    - HUMMOCKY CLINOFORM
  - CHAOTIC
  - REFLECTION-FREE
- MODIFYING TERMS
  - EVEN
  - WAVY
  - REGULAR
  - IRREGULAR
  - UNIFORM
  - VARIABLE
  - HUMMOCKY
  - LENTICULAR
  - DISRUPTED
  - CONTORTED

**EXTERNAL FORMS (OF SEQUENCES AND SEISMIC FACIES UNITS)**

- SHEET
- SHEET DRAPE
- WEDGE
- BANK
- LENS
- MOUND
- FILL

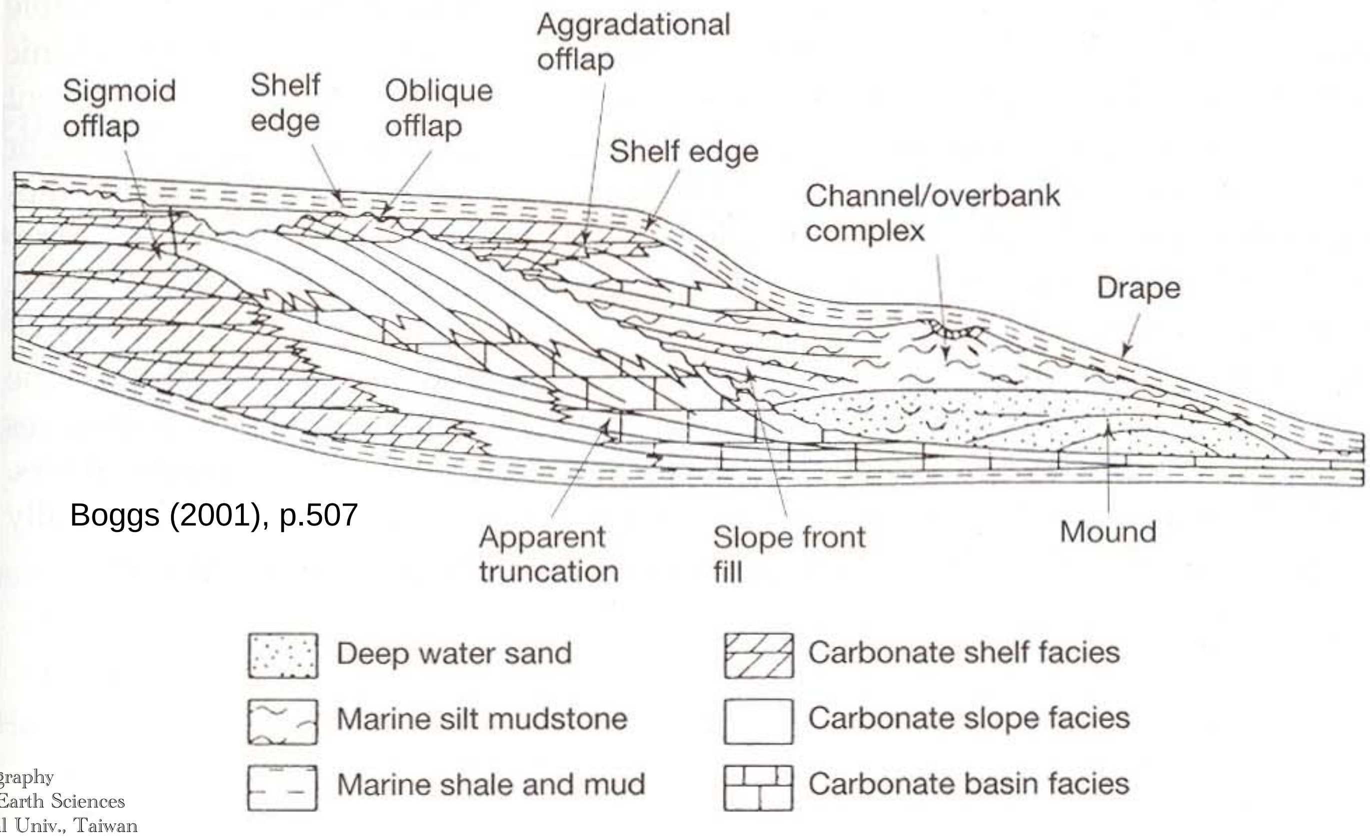
Mitchum et al. (1977), p.118

## Interpretation of lithofacies and depositional environments

Once the objective aspects of delineating seismic sequences and facies have been completed, the final objective is to interpret the facies in terms of lithofacies, depositional environments, and paleobathymetry.

The most useful seismic parameters in seismic faces analysis are the following:

1. The geometry of reflections (reflection amplitude, continuity, frequency) and reflection terminations (onlap, downlap, erosional truncation, toplap…).
1. Reflection configuration (parallel, divergent, sigmoid, or oblique)
2. Three dimensional form.




Boggs (2001), p.507

**Figure 14.20**
Schematic illustration of lithologic and environmental interpretation of the simulated seismic facies patterns shown in Figure 14.18. [From Vail, P. R., 1987, Seismic stratigraphic interpretation using sequence stratigraphy, *in* A. W. Bally (ed.), Seismic stratigraphy: Am. Assoc. Petroleum Geologists Studies in Geology 27, Fig. 9, p. 10, reproduced by permission of AAPG, Tulsa, OK.]

# Seismic facies classification

## "A,B,C technique" for two-dimensional seismic facies analysis (Ramasayer, 1979)

These codes can be marked on a map:

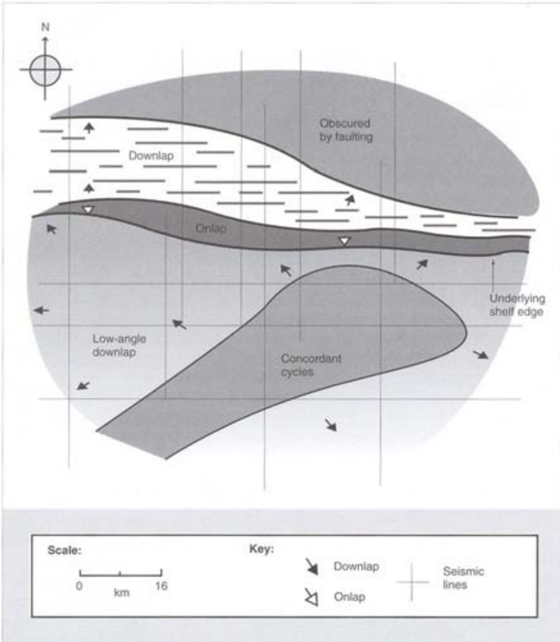



**Fig. 3.11** An example of a seismic facies map (from Mitchum and Vail, 1977). This map shows reflection terminations at the base of a Lower Cretaceous package, offshore western Africa

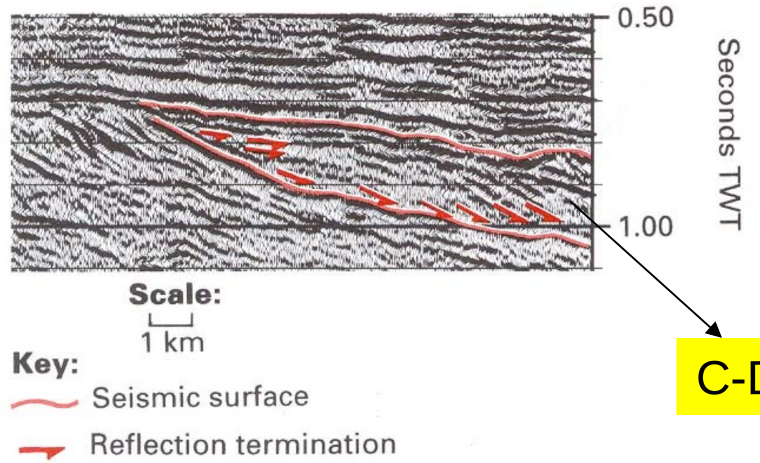
Emery & Myers (1996), p.56

Code system A-B/C

| Upper boundary (A) | Internal configuration (C) |
|---|---|
| Te, erosional truncation | P, parallel |
| Top, toplap | D, divergent |
| C, concordant | C, chaotic |
| | W, wavy |
| *Lower boundary (B)* | DM, divergent mounded |
| On, onlap | M, mounded |
| Dwn, downlap | Ob, oblique progradational |
| C, concordant | Sig, sigmoid progradational |
| | Rf, reflection free |
| | Sh, shingled |

Emery & Myers (1996), p.58

There is no unequivocal link between seismic facies and depositional systems, with the probable exception of the link between clinoforms and slope systems. Continuous flat-lying reflections may, for example, reflect deep-marine shales, coastal-plain topsets, alluvial plain, or lacustrine facies.




C-Dwn/Ob

**Fig. 3.13** A lowstand systems tract on seismic data. On this part of this line, only the lowstand prograding wedge is seen. The underlying sequence boundary is recognized by a downward shift in coastal onlap. Late Eocene, Outer Moray Firth, central North Sea