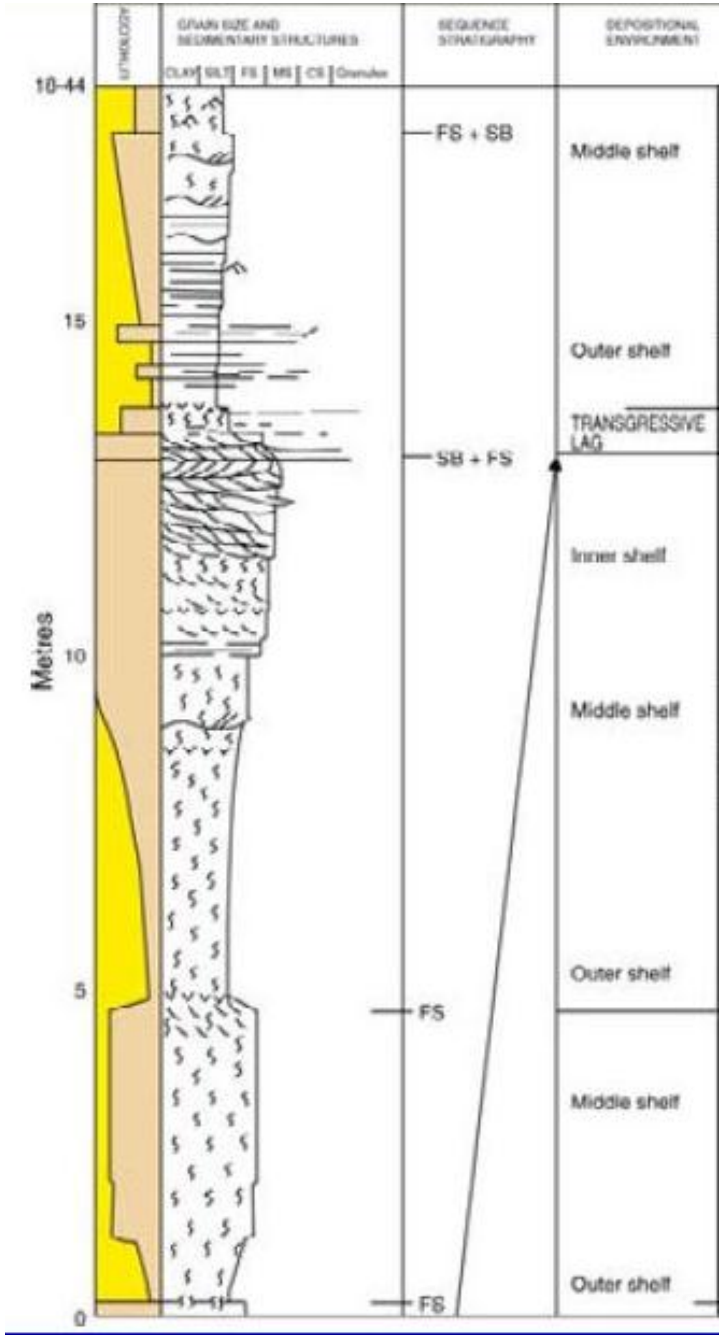
Lecture on Sunday
15-3-2020

About the terminology of sequence stratigraphy

- Parasequence: A relatively conformable, genetically-related succession of beds or bedsets bounded by marine-flooding surfaces or their correlative surfaces.

- If the rate of sediment supply to a shoreline area exceeds the rate of water deepening as a result of subsidence and/or sea level rise, then sediments will prograde basinward.

- Most siliciclastic parasequences are progradational in nature, resulting in an upward-shoaling (upward-coarsening and -cleaning).


LITHOLOGY
GRAIN SIZE AND SEDIMENTARY STRUCTURES
CLAY SILT FS MS CS Granules
SEQUENCE STRATIGRAPHY
DEPOSITIONAL ENVIRONMENT
10-44
15
10
5
0
Metres
FS + SB
SB + FS
FS
FS
Middle shelf
Outer shelf
TRANSGRESSIVE LAG
Inner shelf
Middle shelf
Outer shelf
Middle shelf
Outer shelf

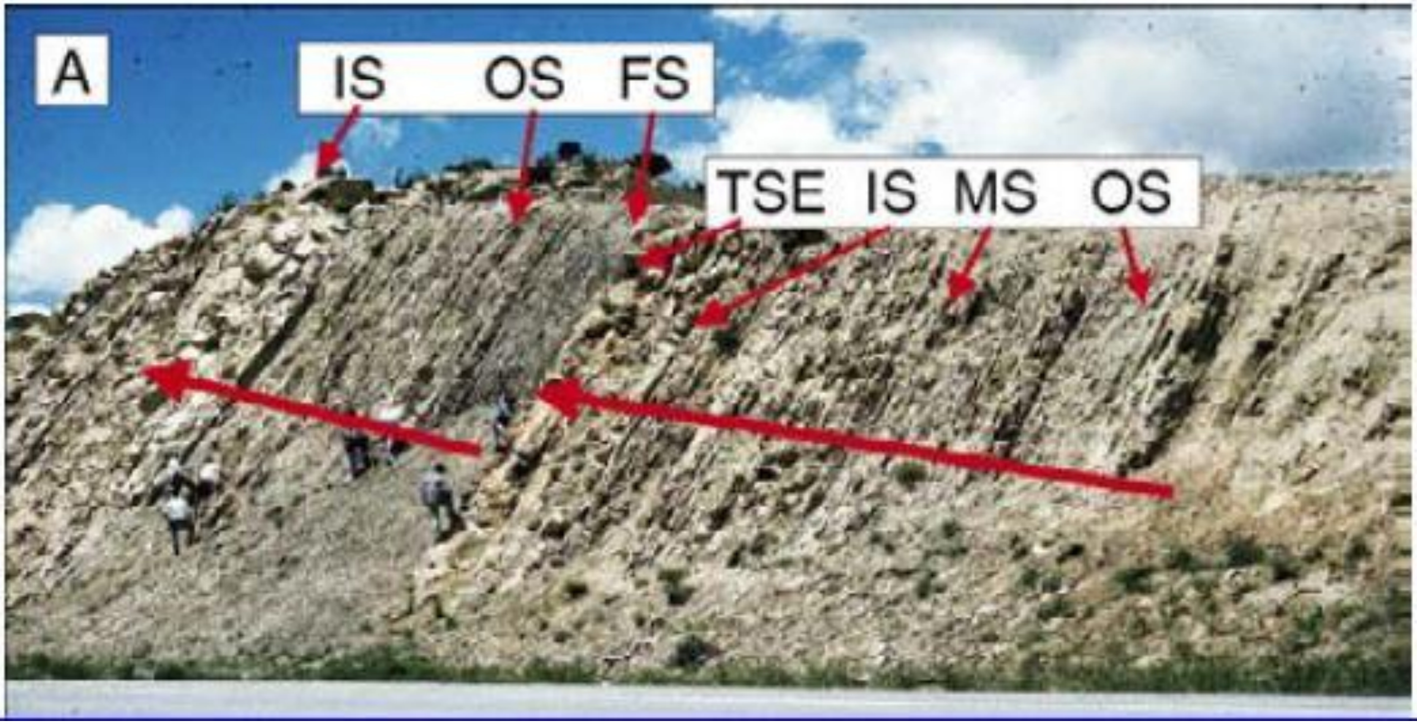
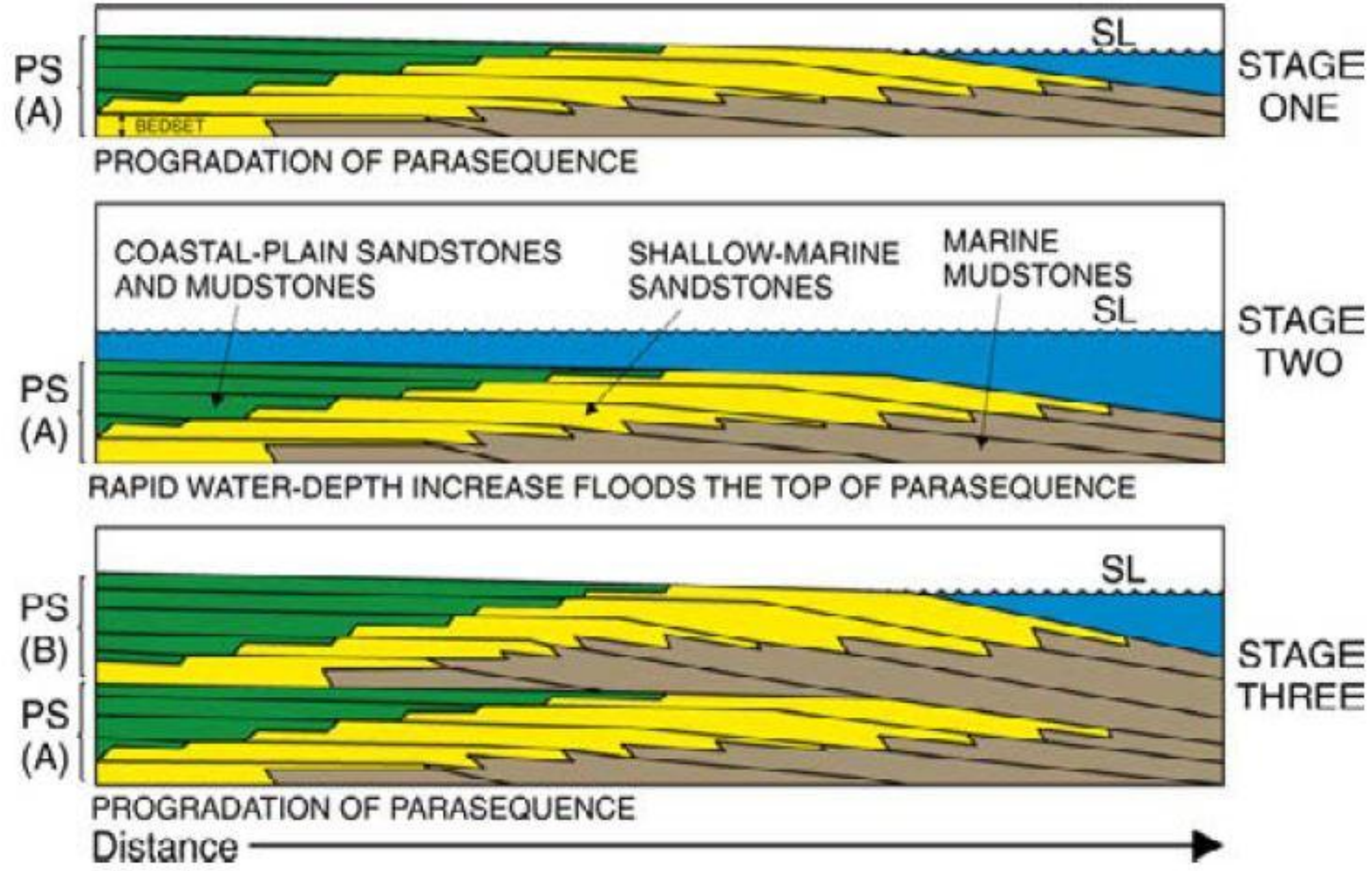


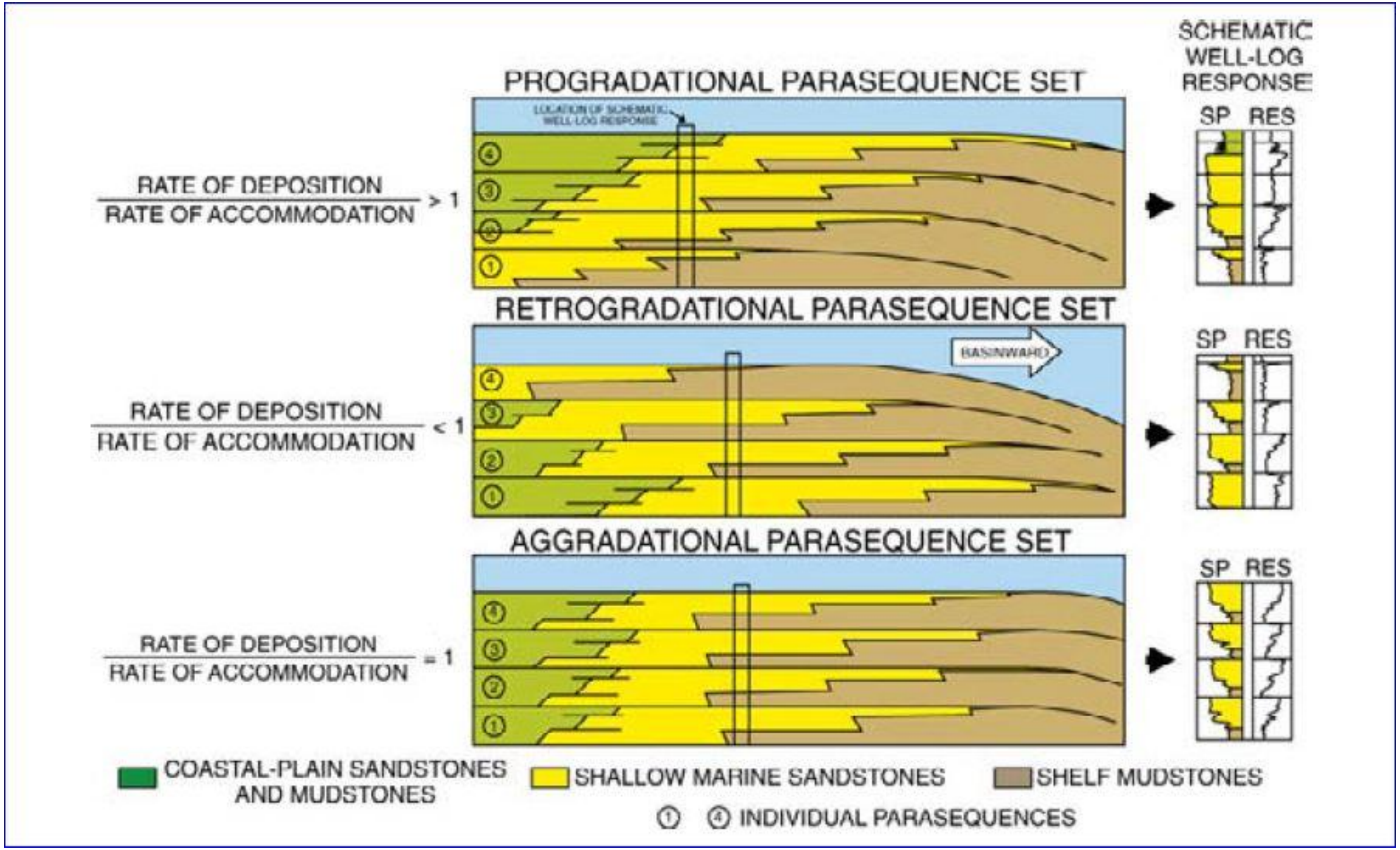
Fig. 11.11. (A) Two shoreface parasequences in Cretaceous strata of Utah. OS – outer shelf, MS – middle shelf, IS – inner shelf, TSE – transgressive surface of erosion, FS – flooding surface. The transgressive surface of erosion is characterized by a relatively coarse-grained lag, abundant burrows, and the presence of shark teeth. Net sandstone content increases from OS to MS and IS. Large arrows point toward coarsening- and thickening-upward


SL
PS
(A)
BEDSET
STAGE
ONE
PROGRADATION OF PARASEQUENCE
COASTAL-PLAIN SANDSTONES
AND MUDSTONES
SHALLOW-MARINE
SANDSTONES
MARINE
MUDSTONES
SL
STAGE
TWO
PS
(A)
RAPID WATER-DEPTH INCREASE FLOODS THE TOP OF PARASEQUENCE
SL
PS
(B)
PS
(A)
STAGE
THREE
PROGRADATION OF PARASEQUENCE
Distance

- If water depth increases more rapidly than sediment can be supplied, then marine waters will flood landward over the preceding parasequence, forming a condensed section/marine flooding surface that marks the base of a new parasequence.

- If the rate of sedimentation then exceeds that of relative sea level rise, another progradational parasequence will form, giving rise to two progradational parasequences bounded by a shaly condensed section (which can vertically isolate the two sandstone intervals

- **Parasequence set**: A succession of genetically related parasequences forming a distinctive stacking pattern bounded by major marine-flooding surfaces and their correlative surfaces.


PROGRADATIONAL PARASEQUENCE SET
LOCATION OF SCHEMATIC WELL-LOG RESPONSE
RATE OF DEPOSITION / RATE OF ACCOMMODATION > 1
RETROGRADATIONAL PARASEQUENCE SET
BASINWARD
RATE OF DEPOSITION / RATE OF ACCOMMODATION < 1
AGGRADATIONAL PARASEQUENCE SET
RATE OF DEPOSITION / RATE OF ACCOMMODATION = 1
SCHEMATIC WELL-LOG RESPONSE
SP RES
COASTAL-PLAIN SANDSTONES AND MUDSTONES
SHALLOW MARINE SANDSTONES
SHELF MUDSTONES
① ④ INDIVIDUAL PARASEQUENCES

- **A *progradational parasequence set*** forms when
- a set of individual parasequences are deposited because the rate of deposition exceeds the rate of accommodation. In this instance, each parasequence progrades progressively farther basinward than does the preceding parasequence.

- This pattern can be recognized on a well log as a set of sandstones that become progressively thicker-bedded and with fewer shale interbeds upward.

- LST – HST????

- **A *retrogradational parasequence set*** forms when the rate of deposition is less than the rate of accommodation. In this instance, each parasequence steps (retrogrades) farther landward than does the preceding parasequence.

- This pattern can be recognized on a well log as a set of sandstones that become progressively thinner-bedded and more highly interbedded with shale upward.

- TST?????

- **An *aggradational parasequence set***

- forms when the rate of deposition is approximately equal to the rate of accommodation. In this instance, each parasequence extends basinward about the same distance as does the preceding parasequence.

- This pattern can be recognized on a well log as a set of sandstones that are of equivalent thickness, separated by shales of equivalent thickness; sedimentary facies are also similar among the sandstones.

- LST-HST??????

Thank You

Lecture on Sunday

22-3-2020

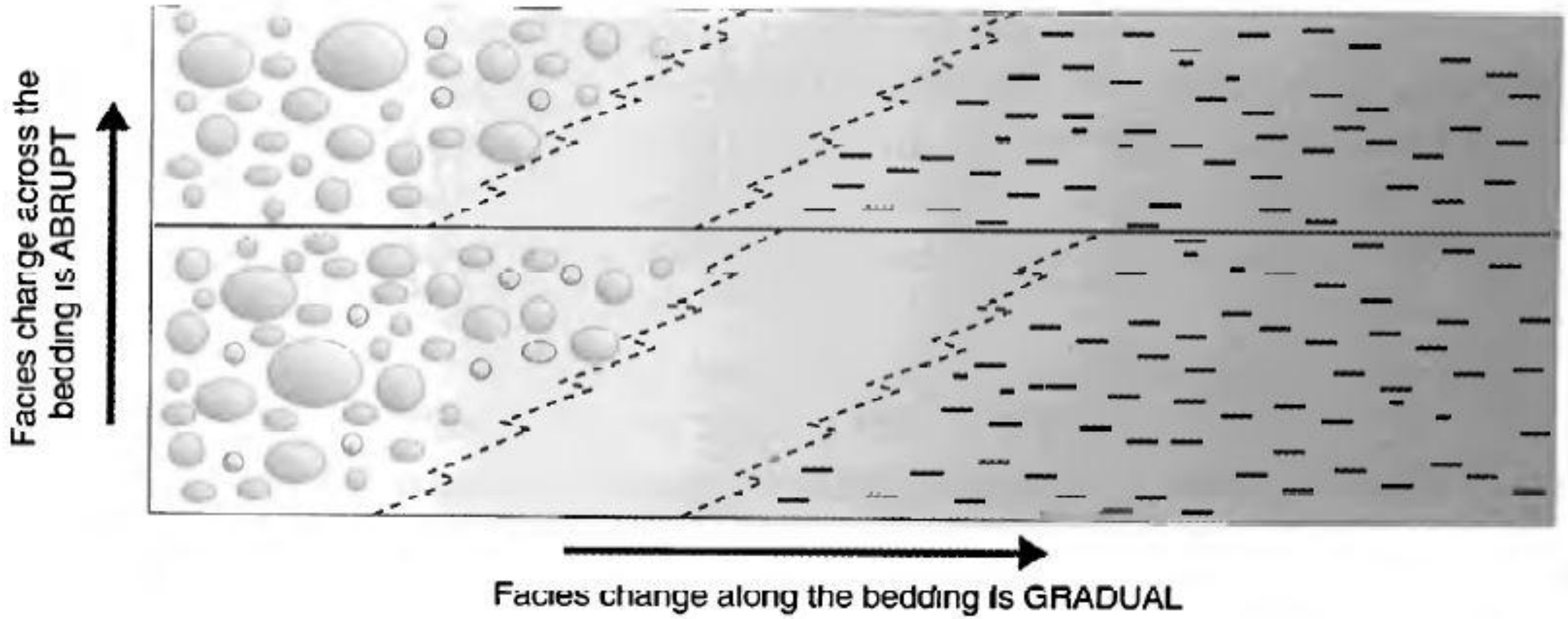
About seismic stratigraphy

3.1 Seismic interpretation

3.1.1 Principles of seismic stratigraphic interpretation

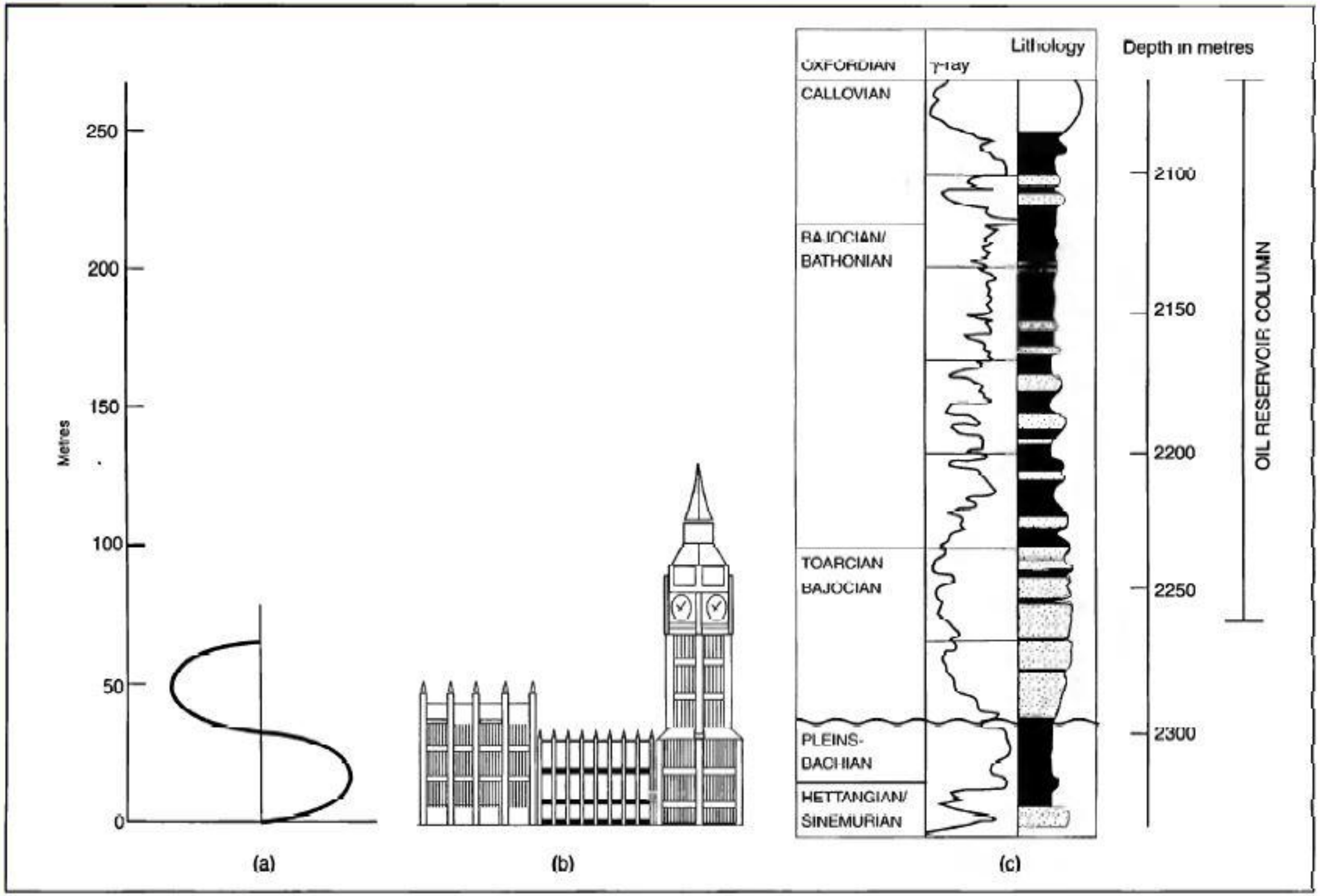
Seismic stratigraphy is a technique for interpreting stratigraphic information from seismic data. Together with its offspring sequence stratigraphy, it is acknowledged as being among the most significant developments in the earth sciences in the last 30 years. The ideas behind the technique were introduced in a number of papers in Association of American Petroleum Geologists (AAPG) Memoir 26 (Vail *et al.*, 1977a,b,c).

The fundamental principle of seismic stratigraphy is that within the resolution of the seismic method, seismic reflections follow gross bedding and as such they approximate time lines. It is important to realize that this statement does not deny in any way the physical fact that the seismic reflections are generated at abrupt acoustic impedance contrasts, nor does it dispute the fact that variations in impedance contrast will produce reflections of varying amplitude (impedance is the product of rock density and seismic velocity). The key message is that the correlative impedance contrasts represented on seismic data come


Facies change across the bedding is ABRUPT
Facies change along the bedding is GRADUAL

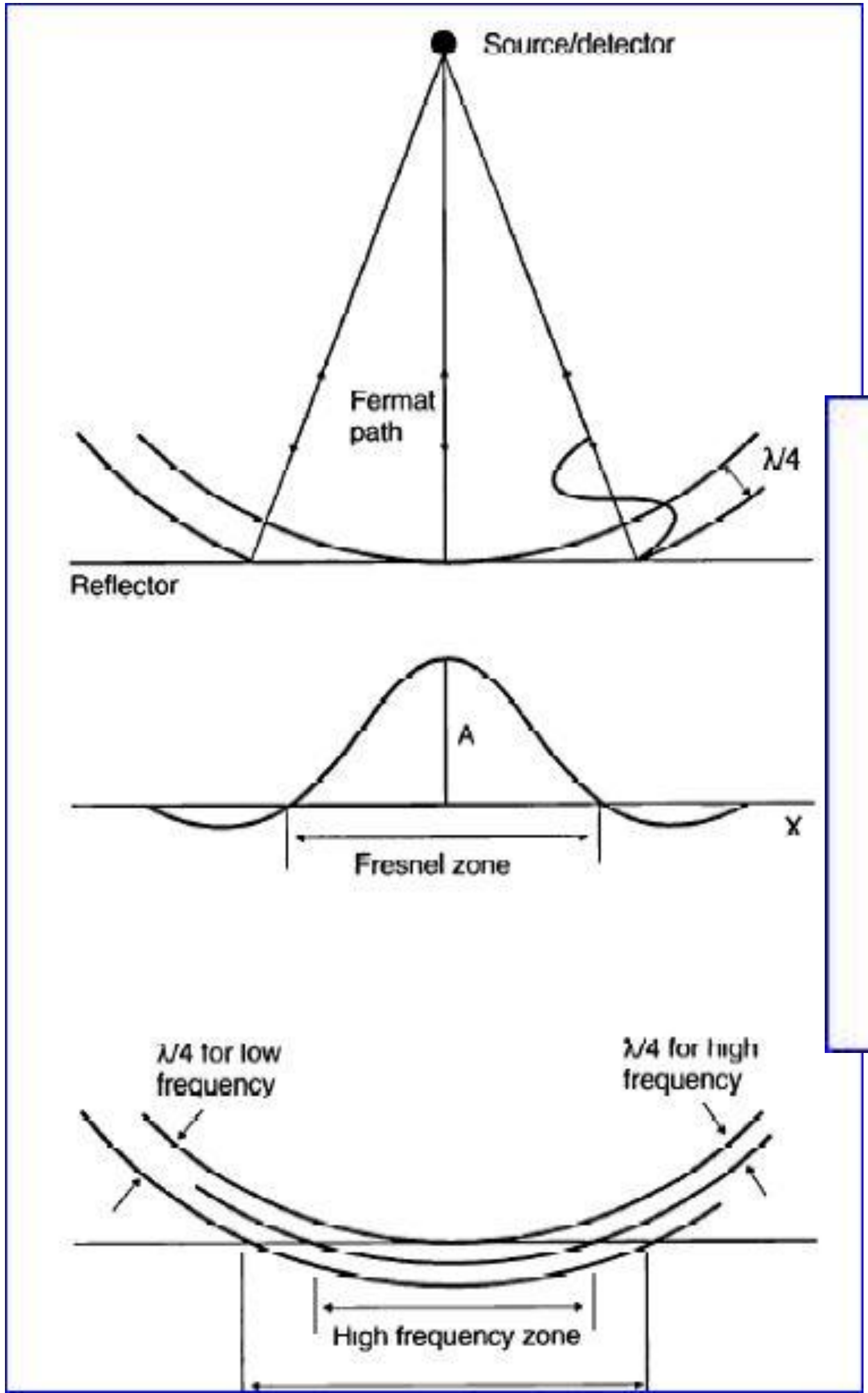
Vertical resolution

This can be defined as the minimum vertical distance between two interfaces needed to give rise to a single reflection that can be observed on a seismic section. In a single noise-free seismic trace this is governed by the wavelength of the seismic signal. At its simplest the shorter the wavelength (and hence the higher the frequency) the greater the vertical resolution. Seismic data are acquired and processed to produce as wide a range of frequencies as possible.


Metres
250
200
150
100
50
0
(a)
(b)
OXFORDIAN
CALLOVIAN
BAJOCIAN/
BATHONIAN
TOARCIAN
BAJOCIAN
PLEINS-
BACHIAN
HETTANGIAN/
SINEMURIAN
γ-ray
Lithology
Depth in metres
2100
2150
2200
2250
2300
OIL RESERVOIR COLUMN
(c)

Lateral resolution

Seismic energy travels through the subsurface and comes into contact with the reflecting surfaces over discrete areas much in the same way that a spot-light travels through the darkness and illuminates a particular area. The energy travels as wave fronts and the region on the reflector where the seismic energy is reflected constructively is known as the *Fresnel Zone* (Sherrif, 1977). Lateral resolution is determined by the radius of the Fresnel Zone, which itself depends on the wavelength of the acoustic pulse and the depth of the reflector (Fig. 3.4). Thus in non-migrated seismic data, lateral resolution is dependent on the seismic bandwidth, on the interval velocity and on the travel time to the reflector (Fig. 3.5). The procedure of migrating seismic data considerably enhances resolution. For two-



Hence, the Fresnel zone width is frequency (or wavelength) dependent The higher the frequency (and shorter the wavelength), the narrower the Fresnel zone and higher the lateral resolution

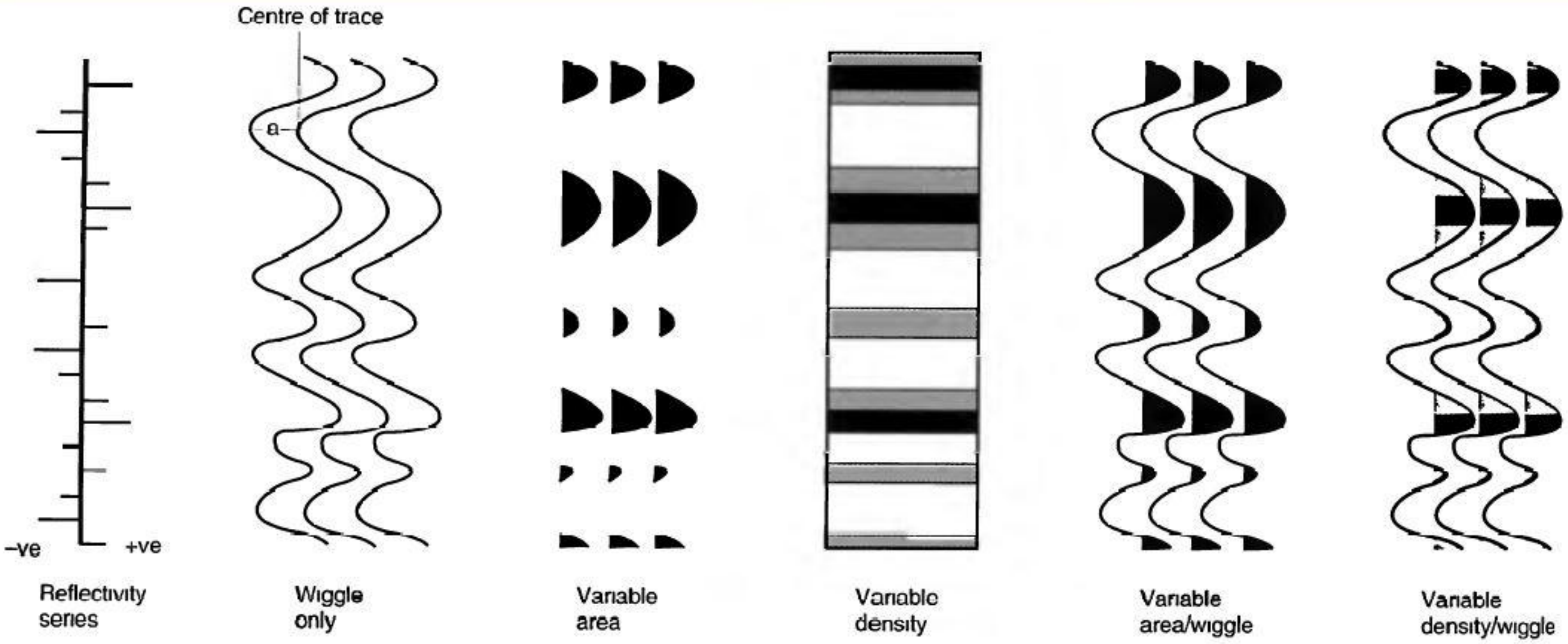


Fig. 3.6 Examples of various types of seismic trace display. a, amplitude

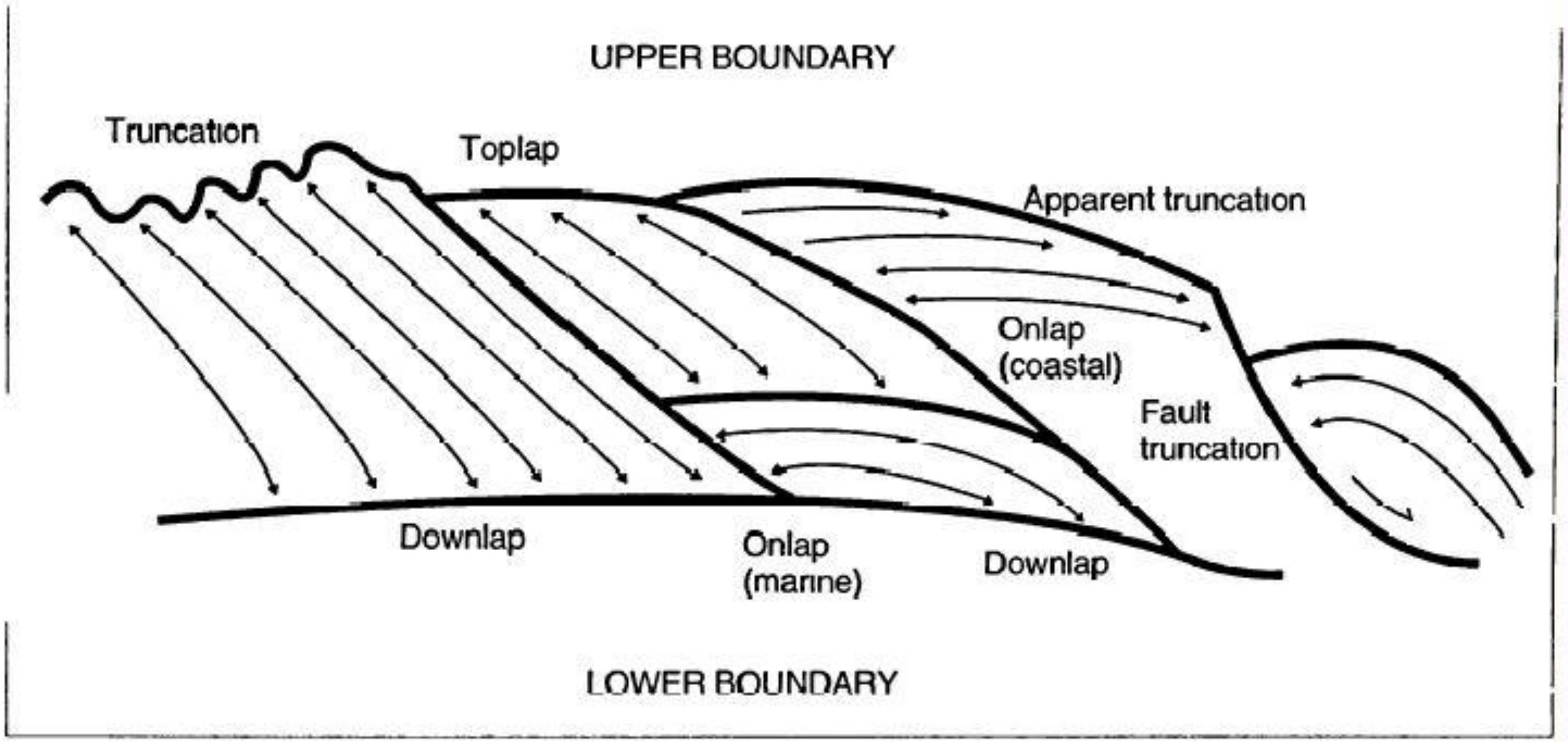
Table 3.1 Seismic stratigraphic application of seismic attributes (after Sonneland *et al.*, 1989).

Attribute	Application
Instantaneous frequency	Bed thickness Lithological contrasts Fluid content
Instantaneous phase	Bedding continuity
Cosine of instantaneous phase	Bedding continuity Identifying sequence boundaries
Reflection strength	Lithological contrast Bedding continuity Bed spacing

Aim

- To define different seismic packages (**Sequences**), their boundaries and their internal classification (**Systems Tracts**) depending on the **key seismic surfaces.**

Seismic reflection termination patterns


UPPER BOUNDARY
Truncation
Toplap
Apparent truncation
Onlap
(coastal)
Fault
truncation
Downlap
Onlap
(marine)
Downlap
LOWER BOUNDARY

Lapout is the lateral termination of a reflector (generally a bedding plane) at its depositional limit, whereas *truncation* implies that the reflector originally extended further but has either been eroded (erosional truncation) or truncated by a fault plane, a slump surface, a contact with mobile salt or shale, or an igneous intrusion (Mitchum *et al*., 1977a,b).

Baselap is the lapout of reflections against an underlying seismic surface (which marks the base of the seismic package). Baselap can consist of *downlap*, where the dip of the surface is less than the dip of the overlying strata, or *onlap*, where the dip of the surface is greater (Fig. 3.8).

Downlap commonly is seen at the base of prograding clinoforms, and usually represents the progradation of a basin-margin slope system into deep water (either the sea

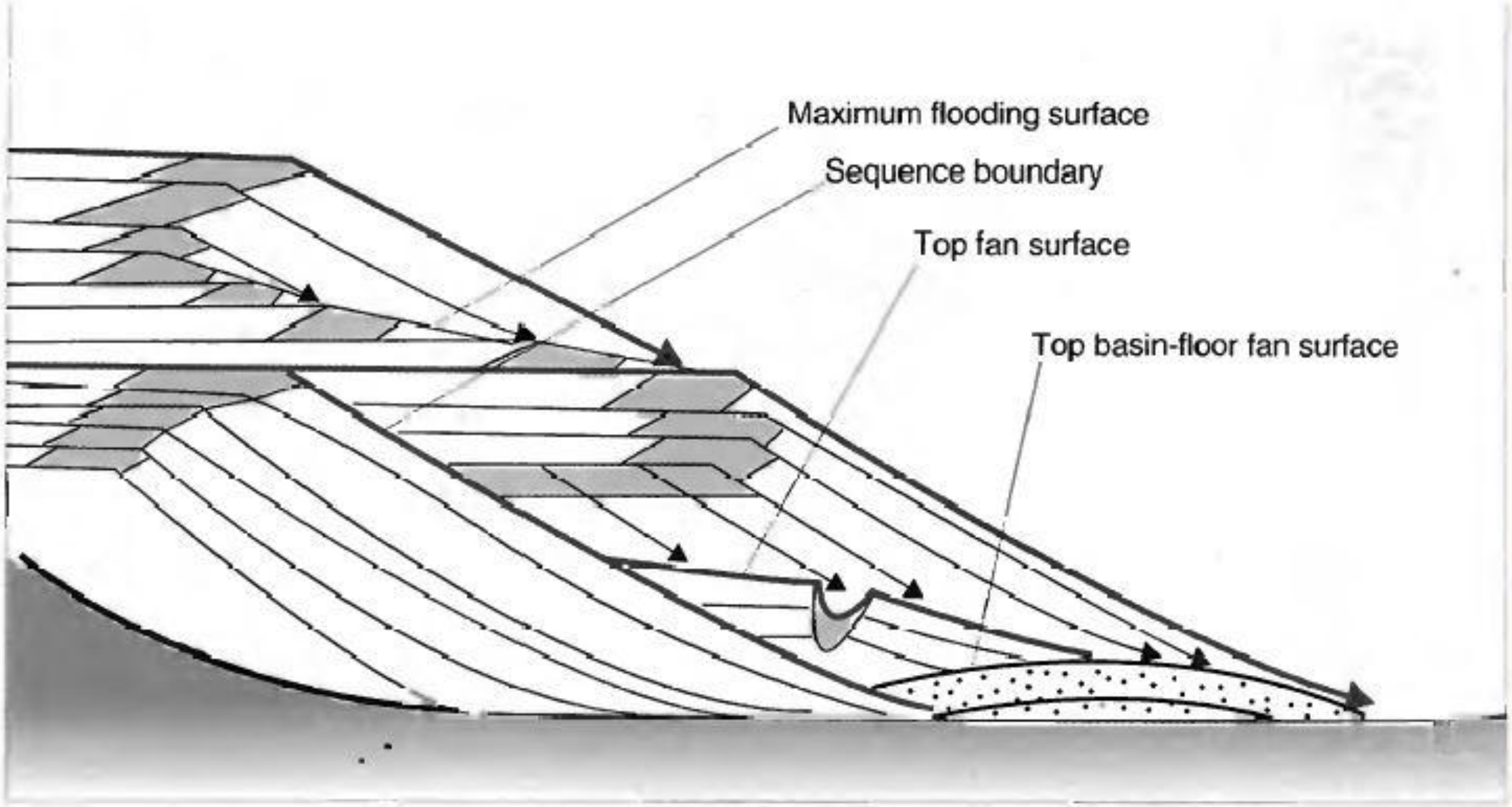
Toplap is the termination of inclined reflections (clinoforms) against an overlying lower angle surface, where this is believed to represent the proximal depositional limit. In marginal marine strata, it represents a change from slope deposition to non-marine or shallow marine bypass or erosion, and the toplap surface is an unconformity. An apparent toplap surface can occur, where the clinoforms pass upwards into topsets that are too thin to resolve seismically. In a deep marine setting, an apparent toplap

Erosional truncation is the termination of strata against an overlying erosional surfacc. Toplap may develop into

crosional truncation, but truncation is more extreme than toplap, and implies either the development of erosional relief or the development of an angular unconformity. The erosion surface may be marine, such as at the base of a canyon, channel or major scour surface, or a non-marine erosion surface developed at a sequence boundary.

Apparent truncation is the termination of relatively low-angle seismic reflections beneath a dipping seismic surface, where that surface represents marine condensation. The terminations represent a distal depositional limit (or thinning below seismic resolution), generally within topset strata, but sometimes also within submarine fans. Many reflection terminations in marine strata fall under the heading 'apparent', because it is likely that thin condensed units extend beyond the limit of seismic resolution (Fig. 3.9).

Fault truncation represents the termination of reflections against a syn- or post-depositional fault, slump, glide or intrusion plane. Termination against a relict fault scarp is onlap.


Maximum flooding surface
Sequence boundary
Top fan surface
Top basin-floor fan surface

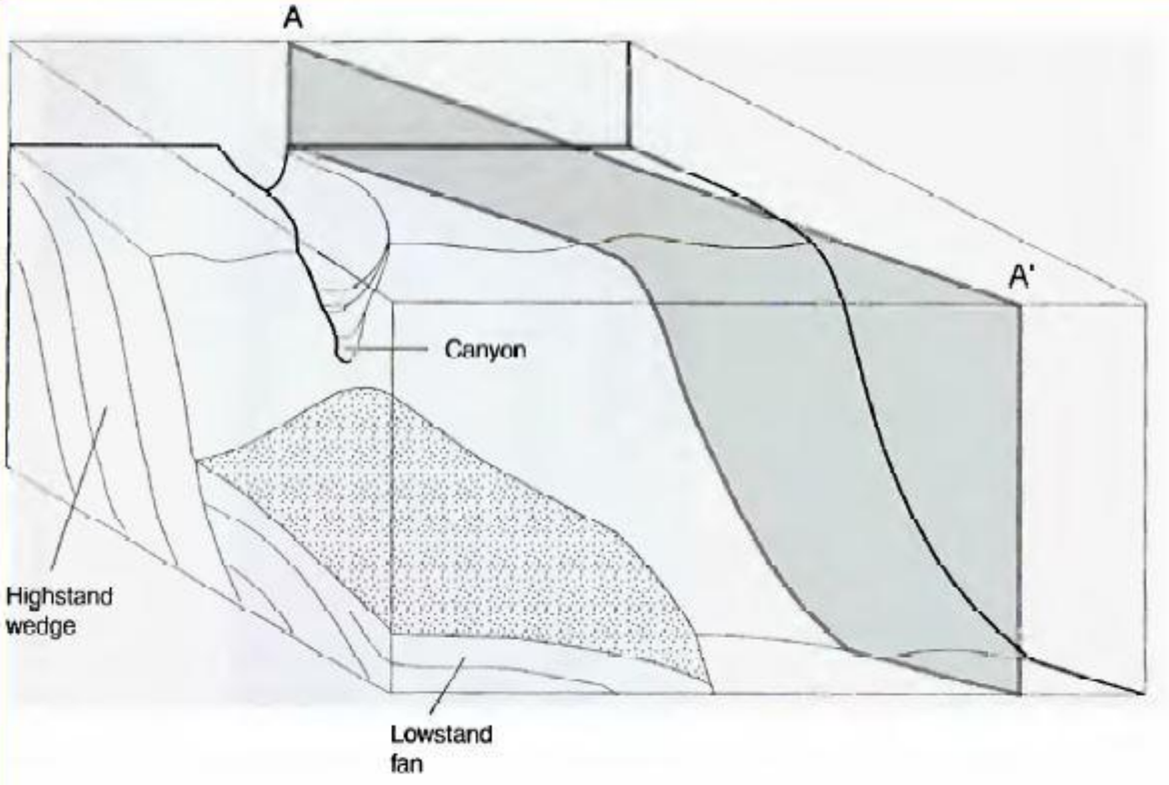


Fig. 3.17 Not every seismic line encounters every systems tract. Seismic line A–A′ here misses the incised valley and lowstand fan

3.4 Pitfalls in interpretation

There are many pitfalls and ambiguities inherent in seismic stratigraphic interpretation. The more important ones are outlined below.

1 Seismic data have a relatively coarse resolution, and stratal relationships in thin successions may be impossible to resolve.

2 Not every systems tract will be present on every line. Any one line may, for example, completely miss the lowstand fan system. This is illustrated in Fig. 3.17, where a lowstand fan is shown developed at the mouth of a canyon incised into a highstand slope. A seismic section along line A–A′ would encounter neither the incised valley nor the lowstand fan.

3 A common mistake is to assume that all seismic surfaces which have been identified by reflection terminations must be sequence boundaries *sensu* Van Wagoner *et al.* (1988).

4 The key to successful seismic stratigraphy is the appreciation of the significance of coastal onlap and being able to recognize it on seismic data. However, it is easy to confuse marine and coastal onlap. Although coastal onlap is confined to topset reflections, it is not always easy to determine which reflections are truly topsets. Topsets can be identified confidently only where they are parallel and lie landward of an offlap break.

5 Fluvial incision and marine canyons may be easily confused. Fluvial incision is an indicator of a sequence boundary; canyon cutting is not necessarily so.

6 In a clinoform succession with extensive bottom sets, it is easy to misidentify the downlap surface. Many of the clinoforms will terminate against older bottomsets, and the true downlap surface is at the bottomset terminations.

Thank You