SEQUENCE STRATIGRAPHY WORKSHOP

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Book 1.
Course notes
Sequence Stratigraphy Concepts

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THE TECHNIQUES OF

SEQUENCE STRATIGRAPHY

(Shelfal Accommodation and Types of Stratigraphic Cycles)

BY

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THE TECHNIQUES OF SEQUENCE STRATIGRAPHY

PART 2: SHELFAL ACCOMMODATION AND THE STRATIGRAPHIC RECORD

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- (II) Stratal (reflection) Patterns and Depositional Environments (Fig. 5)
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(II) Stratal Termination Patterns (Fig. 35)

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COLOR CODE FOR SEQUENCE STRATIGRAPHY

Element:	Line Type: (ChartPak #'s)	Color Pencils:	Color Pens:	Color Tape/Zip: (ChartPak #'s)
(SB1 or SB2) Sequence Boundary (HST) HIGHSTAND SYSTEMS TRACT	(BG1251M)	Orange #1295	Orange	Orange (FT3105)
(mfs) Maximum Flooding Surface (cs) Condensed Section (TST) TRANSGRESSIVE SYSTEMS TRACT	(12533T & TL867AA)	Light Green #1284	Light Green	Lt. Green (3116)
(LST) (TLS) Top Lowstand Surface (pc) Prograding Complex (tbt) Top bottom-set(shingled)turbidites	(TL54M)	Rose #1296	Rose	Rose (FT3108)
(LST) (tsfs) downlap surface on Slope Fan (sfc) SLOPE FAN COMPLEX	(TL876AA)	Brown #1272	Brown	Brown (3114M)
(LST) (tbfs) downlap surface on Basin Floor Fan (bfc) BASIN FLOOR FAN COMPLEX	(TL873AA)	Yellow #1279	Yellow	Yellow
(TLS) Top lowstand surface (SMST) SHELF MARGIN SYSTEMS TRACT	(TL54M)	Lavender #1293	Lavender	

Correlations	Thin solid line	Carmine Red #1277	Red	Red (FT3102)
Reflection Terminations	arrow	Carmine Red #1277	Red	Red (FT3102)
Parasequence Surfaces	Thin solid line	Blue #1276	Blue	Blue (3103M)
Coherent Noise		Purple #1282	Purple	
Carbonate-Prone Facies		Light Blue #1283	Light Blue	
Sand-Prone Facies: transgressive, prograding, and channel sands sand-prone mounds		Yellow #1279	Yellow	
Incised Valley Fill	—	Pink #1288	Pink	••

(NOTE: The upper boundary of a systems tract should be the same color as the fill color of the systems tract)

Pencils: Faber Castell COL-ERASE   Tapes: Chartpak pressure sensitive graphics tape

MICRO-STRAT INC 1 90 ©

Fig. 1-1

WELL LOG SEQUENCE STRATIGRAPHY INTERPRETATION CHART COLOR CODE

LITHOLOGIES

SAND	Yellow -1279
SHALE	Green - 1278
SILT	Light Gray - 1290
LIMESTONE	Blue - 1276

HYDROCARBON INDICATORS

GAS	Carmine Red - 1277
OIL	Green - 1278

PALEOWATER DEPTHS

INNER NERITIC	Yellow - 1279
MIDDLE NERITIC	Light Green - 1284
OUTER NERITIC	Green - 1278
UPPER BATHYAL	Light Blue - 1283
MIDDLE BATHYAL	Blue - 1276
LOWER BATHYAL	Lavender - 1293
ABYSSAL	Purple - 1282

MICROFOSSIL ABUNDANCES

BENTHIC FORAMS	Light Gray - 1290
COMBINED FORAMS	Terra Cotta - 1273
PLANKTONIC FORAMS	Blue - 1276
ALL NANNOFOSSILS	Green - 1278

SEQUENCE BOUNDARIES AND SYSTEMS TRACTS

SEQUENCE BOUNDARY	Orange - 1295
MAXIMUM FLOODING SURFACE	Light Green - 1286
TOP LOWSTAND PROGRADING COMPLEX	Rose - 1296
TOP SLOPE FAN	Brown - 1272
TOP BASIN FLOOR FAN	Tuscan Red - 1275

Fig. 1-2

THE TECHNIQUES OF SEQUENCE STRATIGRAPHY

PART 2: SHELFAL ACCOMMODATION AND THE STRATIGRAPHIC RECORD

A) INTRODUCTION

SEISMIC SECTION SHOWING STRATAL PATTERNS AND STRATAL DISCONTINUITIES OFFSHORE NORWAY

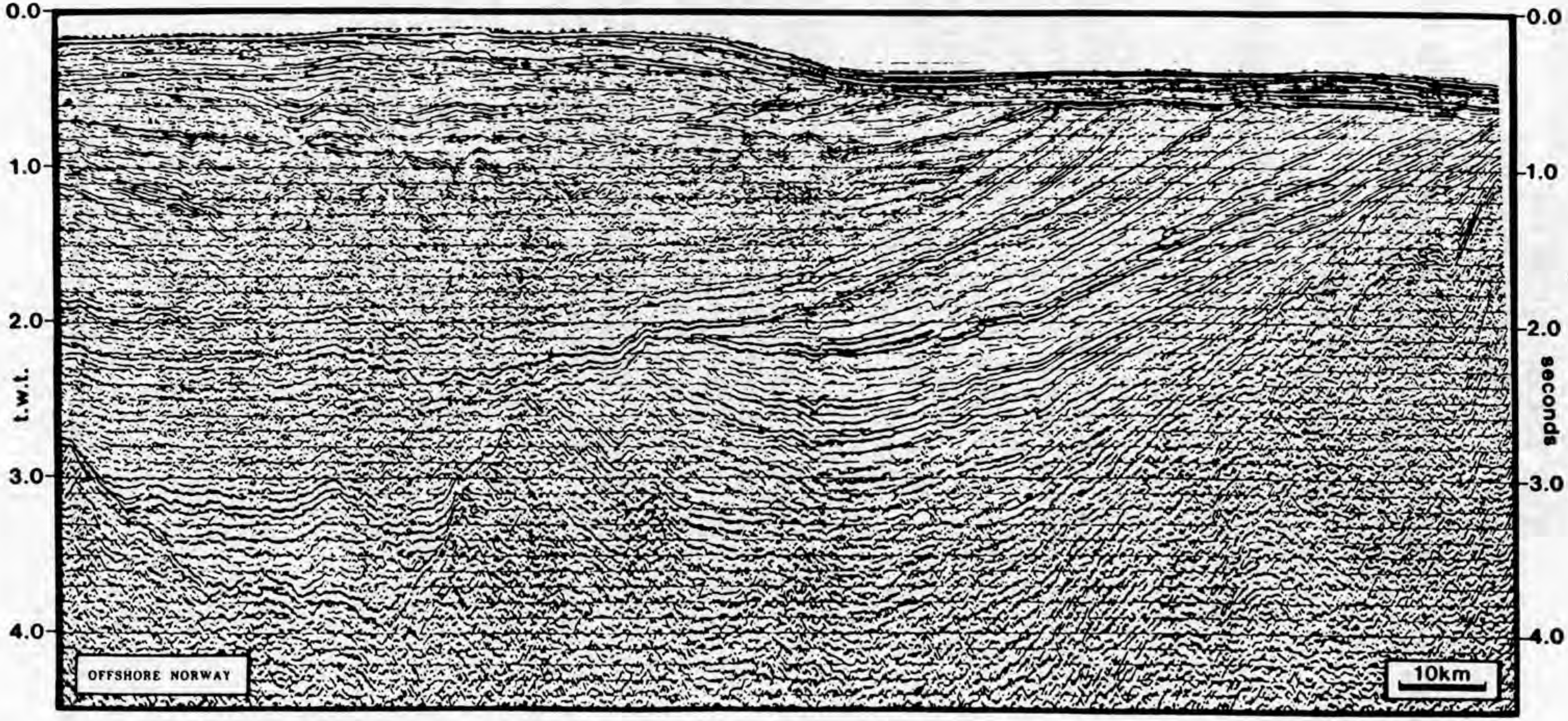


Fig. 2-1

P.VAIL

B.DUVAL
C.CRAMEZ

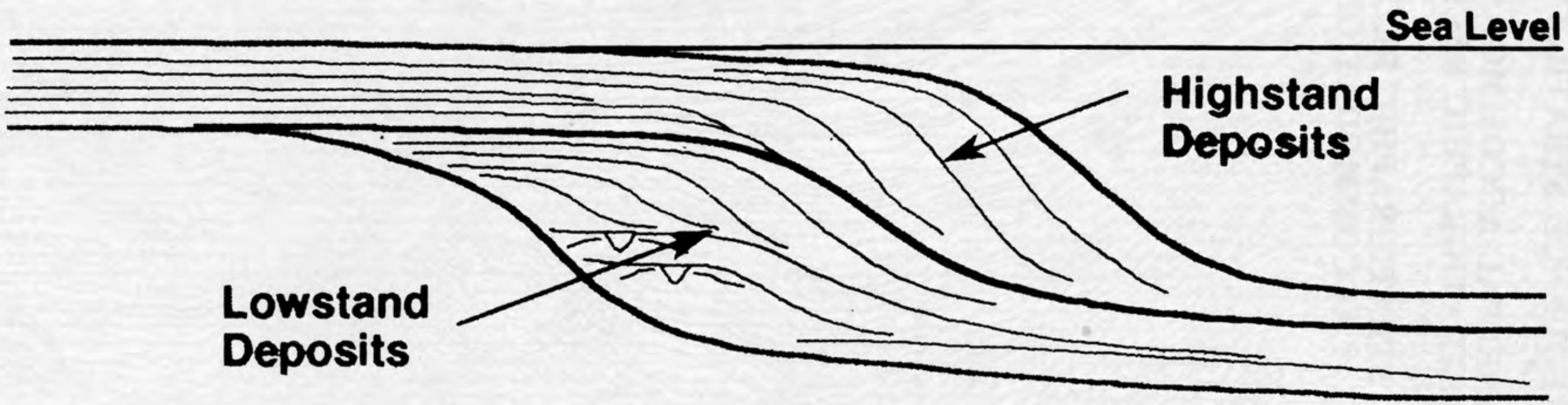
THE TECHNIQUES OF SEQUENCE STRATIGRAPHY

PART 2: SHELFAL ACCOMMODATION AND THE STRATIGRAPHIC RECORD

B) STRATIGRAPHIC RECORD OF ACCOMMODATION

CHANGES IN SHELFAL ACCOMMODATION CAUSE:

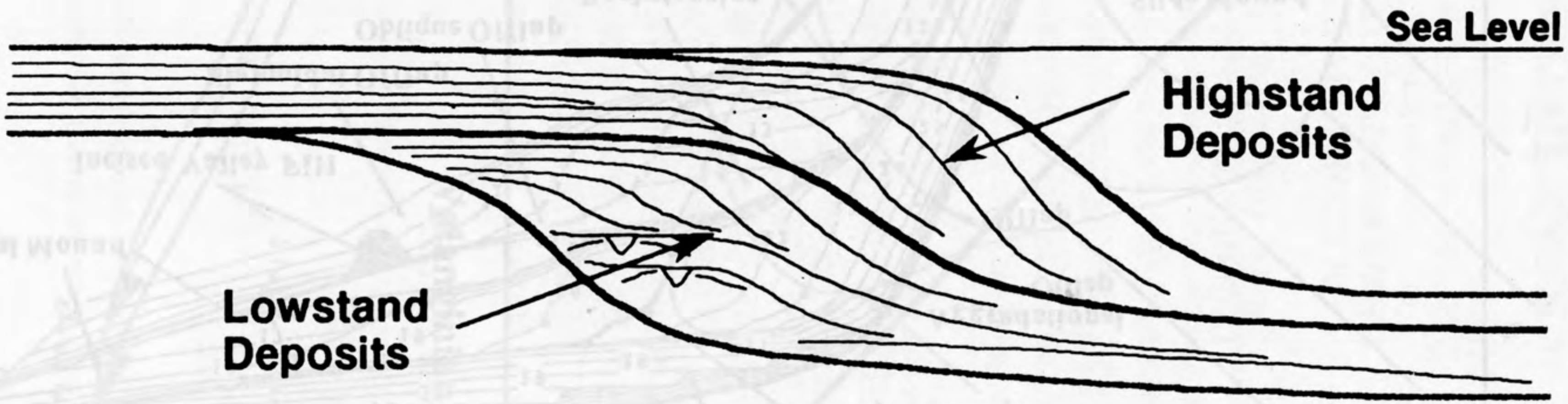
- Highstand and Lowstand Deposits
- Large Scale Stratal Patterns
- Stratal Discontinuities
- Facies Stacking Patterns
- Transgressions and Regressions



T. JACQUIN 10/92

THE STRATIGRAPHIC RECORD OF SHELFAL ACCOMMODATION

* Highstand and Lowstand Deposits



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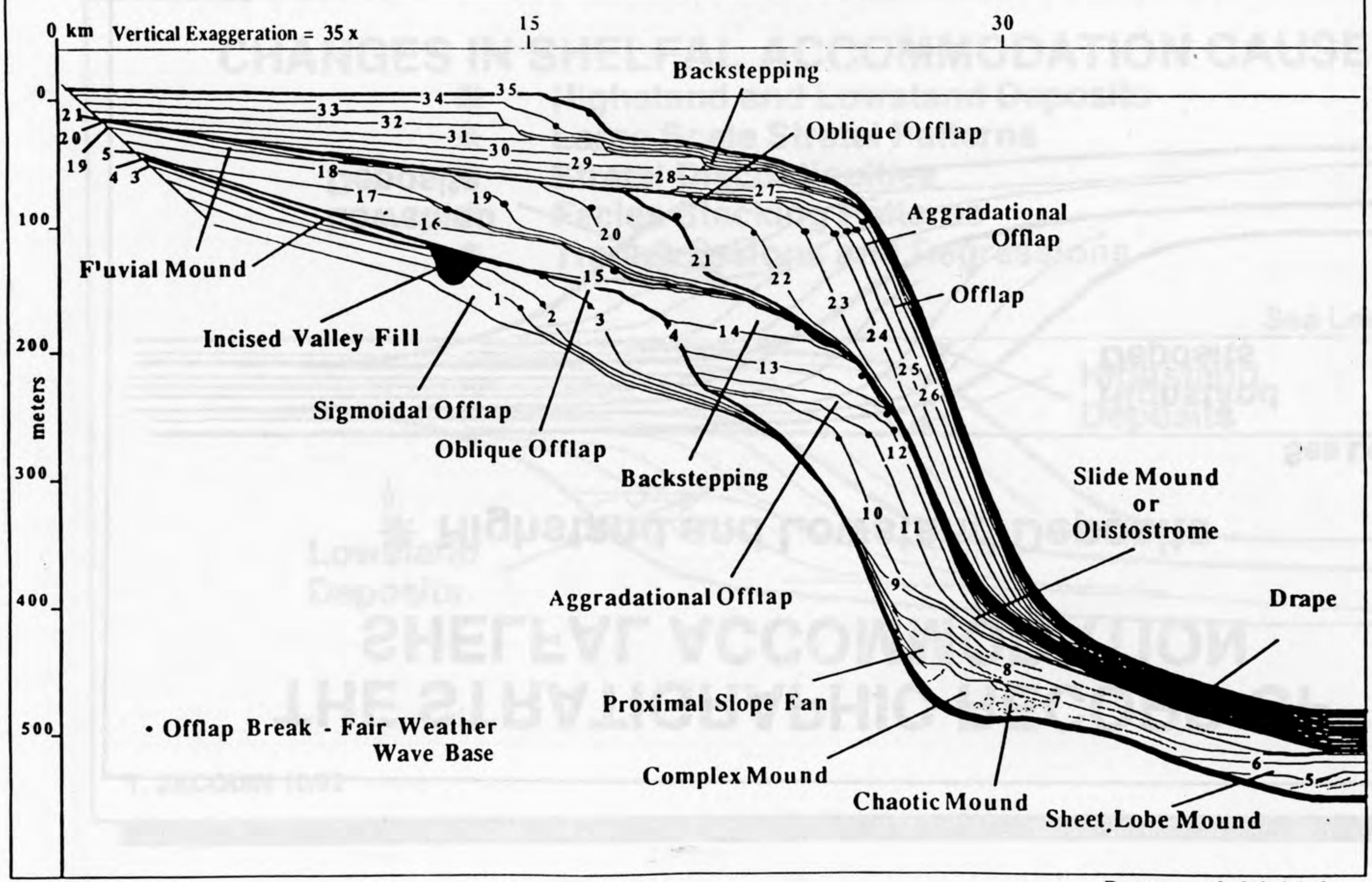
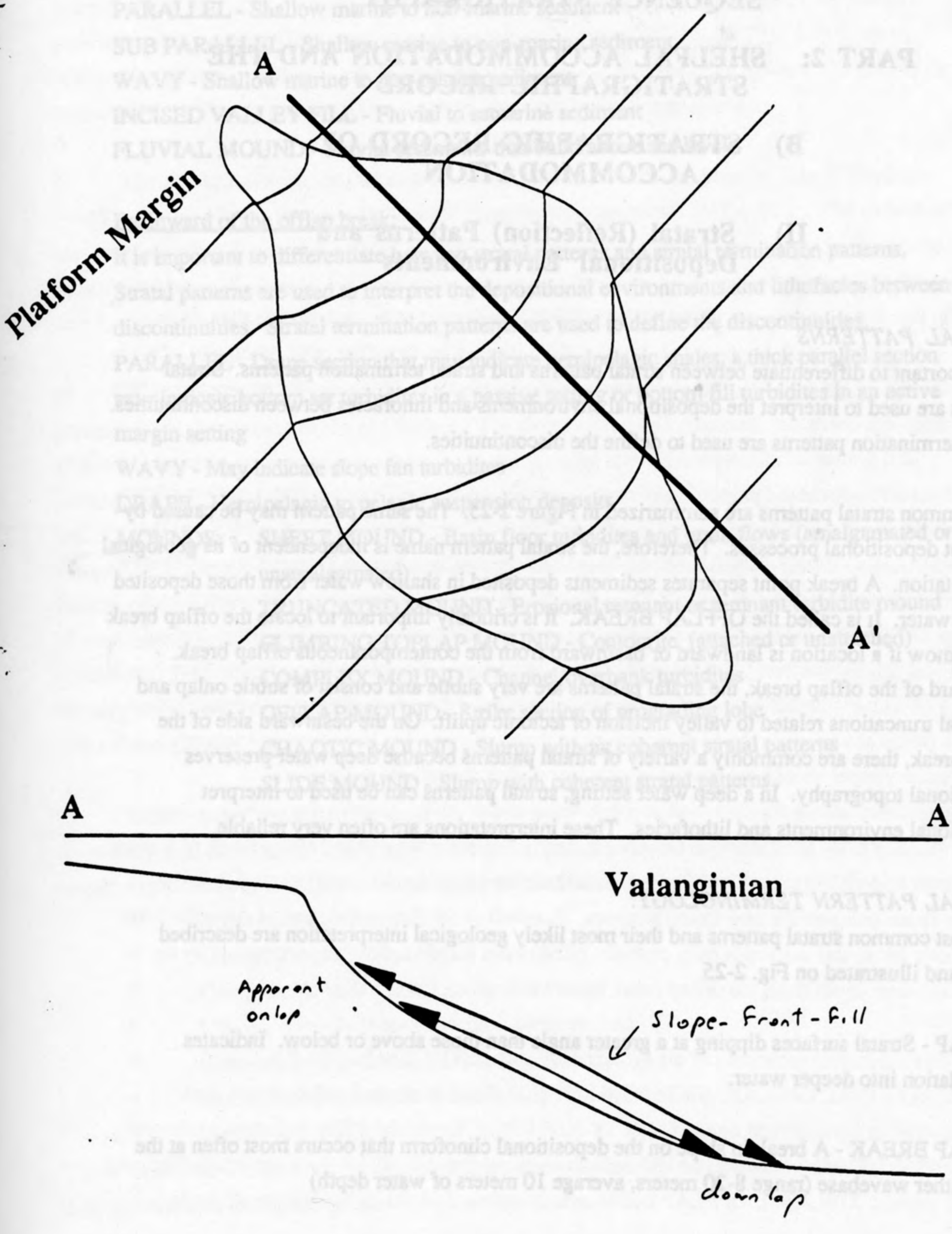
Stratal Patterns



Bowman 9.26.91.3

Fig. 2-25

Submarine Onlap



B-3/4

20d

THE TECHNIQUES OF SEQUENCE STRATIGRAPHY

PART 2: SHELFAL ACCOMMODATION AND THE STRATIGRAPHIC RECORD

B) STRATIGRAPHIC RECORD OF ACCOMMODATION

II) Stratal (Reflection) Patterns and Depositional Environments

STRATAL PATTERNS

It is important to differentiate between stratal patterns and stratal termination patterns. Stratal patterns are used to interpret the depositional environments and lithofacies between discontinuities. Stratal termination patterns are used to define the discontinuities.

The common stratal patterns are summarized in Figure 2-25. The same pattern may be caused by different depositional processes. Therefore, the stratal pattern name is independent of its geological interpretation. A break point separates sediments deposited in shallow water from those deposited in deep water. It is called the OFFLAP BREAK. It is critically important to locate the offlap break and to know if a location is landward or basinward from the contemporaneous offlap break. Landward of the offlap break, the stratal patterns are very subtle and consist of subtle onlap and erosional truncations related to valley incision or tectonic uplift. On the basinward side of the offlap break, there are commonly a variety of stratal patterns because deep water preserves depositional topography. In a deep water setting, stratal patterns can be used to interpret depositional environments and lithofacies. These interpretations are often very reliable.

STRATAL PATTERN TERMINOLOGY:

The most common stratal patterns and their most likely geological interpretation are described below and illustrated on Fig. 2-25

OFFLAP - Stratal surfaces dipping at a greater angle than those above or below. Indicates progradation into deeper water.

OFFLAP BREAK - A break in slope on the depositional clinoform that occurs most often at the fairweather wavebase (range 8-20 meters, average 10 meters of water depth)

Landward of the offlap break:

PARALLEL - Shallow marine to non-marine sediment

SUB PARALLEL - Shallow marine to non-marine sediment

WAVY - Shallow marine to non-marine sediment

INCISED VALLEY FILL - Fluvial to estuarine sediment

FLUVIAL MOUND - Fluvial sediments that build above sea level

Basinward of the offlap break:

It is important to differentiate between stratal patterns and stratal termination patterns. Stratal patterns are used to interpret the depositional environments and lithofacies between discontinuities. Stratal termination patterns are used to define the discontinuities.

PARALLEL - Drape section that may indicate hemipelagic shales, a thick parallel section may indicate bottom set turbidites in a passive setting or bottom fill turbidites in an active margin setting

WAVY - May indicate slope fan turbidites

DRAPE - Hemipelagic to pelagic suspension deposits

MOUNDS:
- SHEET MOUND - Basin floor turbidites and grain flows (amalgamated or unamalgamated)
- TRUNCATED MOUND - Erosional remnant or remnant turbidite mound
- CLIMBING TOPLAP MOUND - Contourite (attached or unattached)
- COMPLEX MOUND - Channel/overbank turbidites
- OFFLAP MOUND - Strike section of prograding lobe
- CHAOTIC MOUND - Slump without coherent stratal patterns
- SLIDE MOUND - Slump with coherent stratal patterns

THE TECHNIQUES OF SEQUENCE STRATIGRAPHY

PART 2: SHELFAL ACCOMMODATION AND THE STRATIGRAPHIC RECORD

E) EXERCISES

I Stratal Patterns

Identification of stratal patterns:

1) On Fig. 2-34 identify the STRATAL SURFACES dipping at a greater angle than those above or below (underline numbers 1-4, 10-13, 18-27 located on the offlapping timelines). This is an indication of depositional dip. The pattern is called OFFLAP and is caused by progradation into deeper water.

2) Place a red dot at the point of maximum curvature on each offlapping stratal surface where the stratal pattern changes from parallel to offlap on the landward side (1-4, 10-13, 18-27). The red dots mark the OFFLAP BREAK. The offlap break generally relates to fairweather wavebase at a depth of 8-15 meters below sea level. The offlap break was previously called the depositional shelf edge or shoreline break. These terms have been dropped because of the confusion created by their use.(see discussion Part L). Draw a dashed red line connecting the offlap breaks. This line is called the OFFLAP PLANE and approximates the position of fairweather wavebase through time. It is not a physical surface in the rock record, but a time-transgressive boundary that separates shallow water (upper shoreface) from deeper water (lower shoreface) sediments.

3) Mentally draw a vertical line downward from a red dot located at the offlap break of surface 4 to the next underlying stratal surface. Landward of this imaginary line, sediments fill all the available space between the two stratal surfaces. Seaward of this line at the time of deposition the space above the stratal surface is only partially filled or not filled at all. This is recorded by an increasing water depth from the offlap break basinward.

4) Three principal variations of the offlap pattern are SIGMOIDAL, OBLIQUE, and AGGRADATIONAL OFFLAP. SIGMOIDAL OFFLAP builds upward and outward, and becomes more progradational upward (1-3, 18-20, 33-35). Sigmoidal offlap indicates a relative rise of sea level during which the rate of rise is decreasing upward. Color the sigmoidal offlapping intervals orange. OBLIQUE OFFLAP builds mostly outward (4, 20-23). Oblique offlap is

associated with toplap and indicates a relative stillstand. Color yellow the oblique offlapping intervals from the offlap plane to the downlap plane. AGGRADATIONAL OFFLAP builds outward and upward and becomes more aggradational upward (10-14, 24-27). It indicates a relative rise of sea level during which the rate of relative rise is increasing upward. Color red the aggradational offlapping intervals from the offlap plane to the downlap plane.

5) Identify stratal surfaces that step landward (14-17, 28-32). In practice it is difficult to identify an offlap break on these backstepping surfaces as explained IN PART F. The pattern of landward stepping is called BACKSTEPPING. Backstepping is caused by progradation where each progradational package does not extend as far into the basin as the previous one. It indicates a very rapid relative rise of sea level. Color green the backstepping strata.

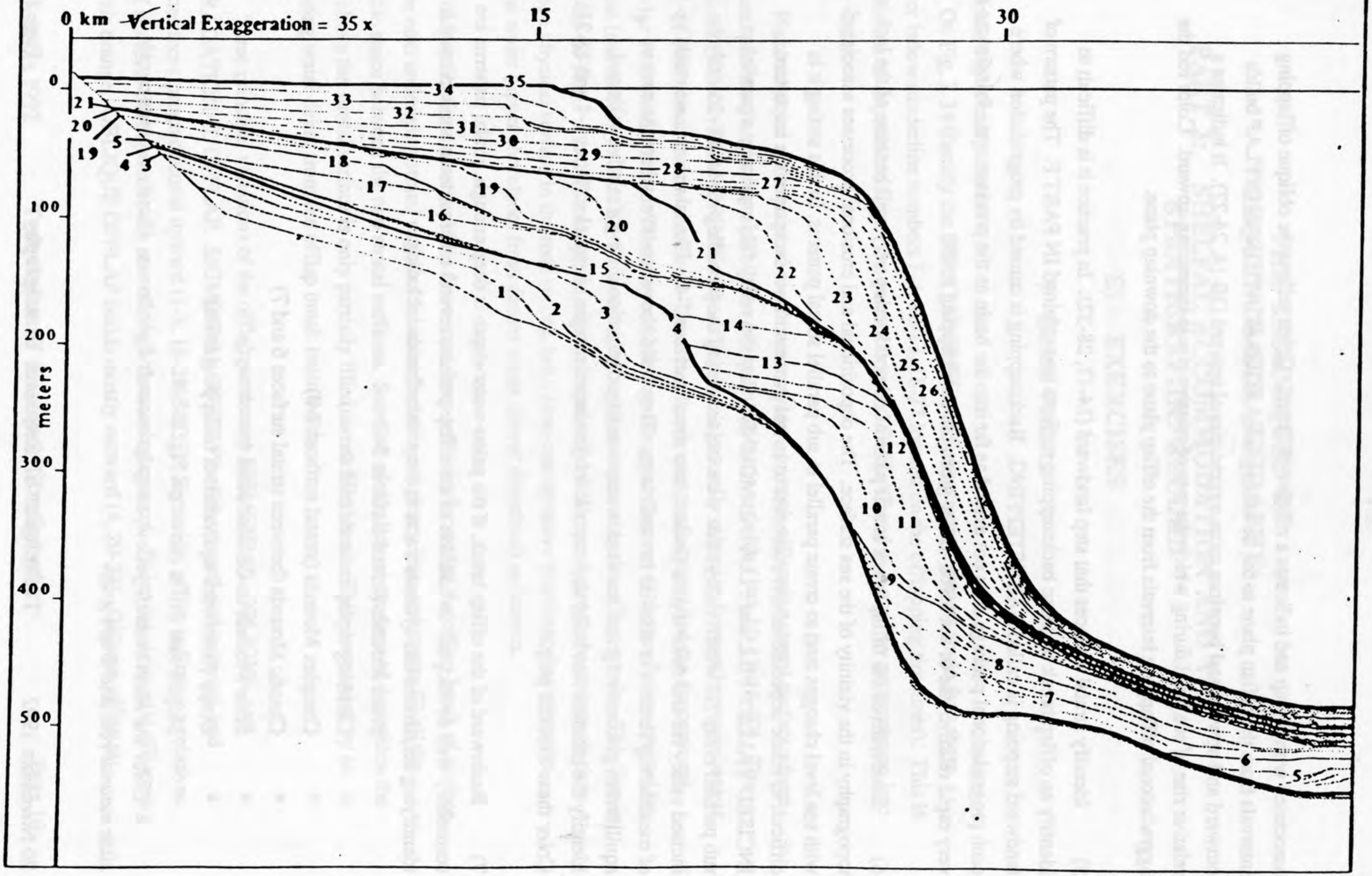
6) Landward of the offlap break stratal patterns do not develop very well because of the lack of topography in the vicinity of the sea surface. The depositional and erosional processes associated with sea level changes tend to create parallel to sub parallel stratal patterns. In this setting it is difficult to relate depositional environments to stratal patterns. Two exceptions are important, INCISED VALLEY FILL and FLUVIAL MOUNDS. Incised valley fill is typically a parallel to sub parallel onlap fill within valleys that were incised during the preceding lowstand. Identify the incised valley fill and color it pink (incised into stratal surfaces 1-4). Fluvial mounds are made up of meandering streams or alluvial fan sediments. They build above sea level where the stream equilibrium gradient migrates seaward in response to progradation during a relative stillstand. Identify the mounds that build above sea level (landward margin of stratal surfaces 1-4 and 18-21). Color these mounds purple.

7) Basinward of the offlap break, if the paleo-water-depth is deep enough, stratal patterns are commonly well developed. In addition to the offlap pattern, several other patterns are important in identifying sequences and systems tracts in deep water basins including:

- Sheet Mounds (stratal surfaces 5-6)
- Climbing toplap mounds (not shown)
- Complex Mounds (stratal surfaces 7-9)
- Chaotic Mounds (between stratal surfaces 6 and 7)
- Slide Mounds or Olistostromes (not shown)
- Drape (basinward equivalent of offlapping strata)
- Slope Front Fill is shown on Fig. B-3/4

Color the sheet mounds yellow, complex mounds light brown, chaotic mounds purple, slide mounds red, and drape gray.

WORKSHEET



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Stratal Termination Patterns

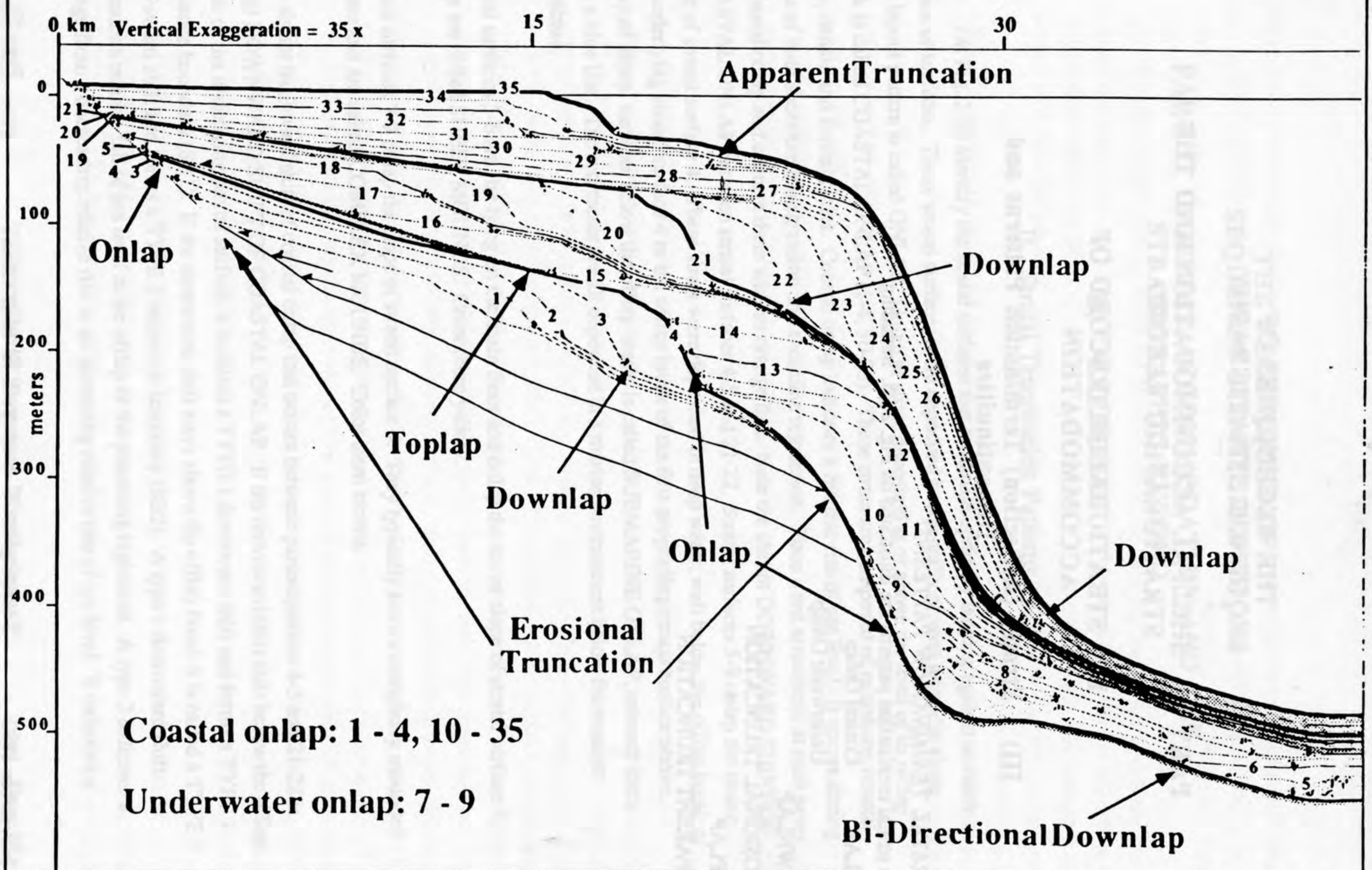

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Fig. 2-26

THE TECHNIQUES OF SEQUENCE STRATIGRAPHY

PART 2: SHELFAL ACCOMMODATION AND THE STRATIGRAPHIC RECORD

B) STRATIGRAPHIC RECORD OF ACCOMMODATION

III) Stratal (Reflection) Termination Patterns and Discontinuities

STRATAL TERMINATION PATTERNS:

The stratal termination patterns are illustrated on Fig. 2-26, including:

ONLAP Coastal Onlap
  Underwater Onlap

DOWNLAP

EROSIONAL TRUNCATION

TOPLAP

APPARENT TRUNCATION

THE TECHNIQUES OF SEQUENCE STRATIGRAPHY

PART 2: SHELFAL ACCOMMODATION AND THE STRATIGRAPHIC RECORD

E) EXERCISES

II Stratal Termination Patterns

1) On Fig. 2-35 identify the stratal surfaces that terminate updip by lapping against an older surface or surfaces. These stratal surfaces were deposited horizontally or with an updip slope. This lapout pattern is called ONLAP. Onlap of strata deposited at or above the level of its offlap break is called COASTAL ONLAP (1-4, 10-35). These strata are composed of nearshore, coastal plain, deltaic and fluvial facies. Coastal onlap indicates a relative rise of sea level. It occurs during times of both shoreline transgression and shoreline regression. Place a red arrowhead at each point of coastal onlap and connect them with an orange line. Note the abrupt DOWNWARD SHIFT OF COASTAL ONLAP between stratal surfaces 4-5 and 21-22. Stratal surfaces 5-9 onlap the lower slope of stratal surface 4. These strata were deposited in deep water, well below the offlap break of the underlying stratal surface 4 or the offlap break of the first prograding stratal surface above. Onlap of stratal surfaces below the offlap break is called SUBMARINE ONLAP, connect them with a blue line. The sediments are all deposited in a marine environment below fairweather wavebase.

Stratal surfaces 5-6 are flat lying on the basin floor and onlap the toe of slope of stratal surface 4. They are called SHEET MOUNDS. Color them yellow.

Stratal surfaces 7-9 onlap the slope of stratal surface 4. They typically have a complexly mounded pattern and are called COMPLEX MOUNDS. Color them brown.

The abrupt basinward shift of coastal onlap that occurs between parasequences 4-5 and 21-22 is called DOWNWARD SHIFT OF COASTAL ONLAP. If the downward shift falls below the offlap break of the underlying stratal surface, it is called a TYPE 1 downward shift and forms a TYPE 1 sequence boundary (SB1). If the downward shift stays above the offlap break it is called a TYPE 2 downward shift and forms a TYPE 2 sequence boundary (SB2). A type 1 downward shift indicates a relative fall of sea level at the offlap of the preceding highstand. A type 2 indicates a change from a decreasing relative rise to an increasing relative rise of sea level. It indicates a relative stillstand at the offlap break of the preceding highstand. A relative fall will occur landward of the offlap break where subsidence is less. Label the type 1 and type 2 downward shifts of coastal onlap with SB1 or SB2.

2) Mark with red arrows and label the terminations of the stratal surfaces that terminate down dip by lapping out against older surfaces (1-4, 10-12, and 18-27, 33-35). These stratal surfaces were deposited on a downdip slope. This lapout pattern is called DOWNLAP. It is caused by the basinward thinning of offlapping strata due to sediment starvation. Note that downlap also occurs within the sheet mound (surfaces 5 and 6). This is called BI-DIRECTIONAL DOWNLAP. Downlap is also prevalent within the complex mounds and marks the boundaries between channel / overbank lobes and the top of the sheet mound.

3) Mark with red arrows and label the terminations of the stratal surfaces that terminate down dip by pinching out against the overlying condensed section (13-17 and 27-32). This pattern is called APPARENT TRUNCATION. It is caused by basinward thinning of backstepping stratal units due to sediment starvation. Apparent truncation is commonly overlain by downlapping strata or drape.

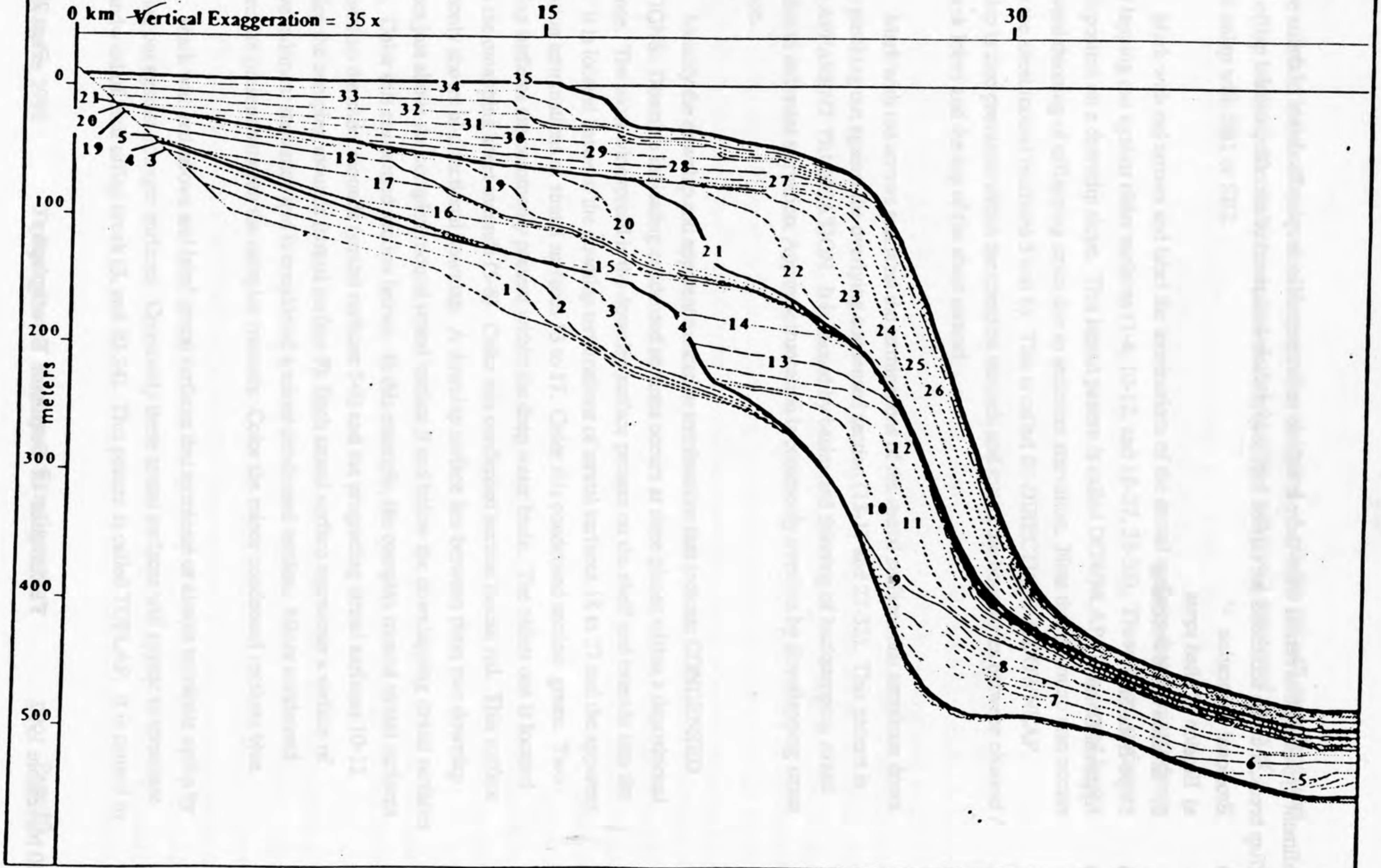
4) Identify the downlap and apparent truncation terminations that indicate CONDENSED SECTIONS. Downlap indicating condensed sections occurs at three places within a depositional sequence. The most widespread is the downlap surface present on the shelf and extends into the basin. It is located between the downlap terminations of stratal surfaces 18 to 27 and the apparent truncation terminations of stratal surfaces 13 to 17. Color this condensed section green. Two downlap surfaces are commonly present within the deep water basin. The oldest one is located above the onlapping sheet mounds (5-6). Color this condensed section tuscan red. This surface commonly shows bi-directional downlap. A downlap surface lies between these two downlap surfaces just above the complex mound stratal surface 9 and below the downlapping stratal surfaces 10-13. Color this condensed section brown. In this example, the complex mound stratal surfaces 7-9 downlap the sheet mounds (stratal surfaces 5-6) and the prograding stratal surfaces 10-12 downlap the complex mounds (stratal surface 9). Each stratal surface represents a surface of relative sediment starvation and is considered a minor condensed section. Minor condensed sections are present between the complex mounds. Color the minor condensed sections blue.

5) Mark with red arrows and label stratal surfaces that terminate or almost terminate updip by pinching out against younger surfaces. Commonly these stratal surfaces will appear to terminate just landward of their offlap break (3, and 20-24). This pattern is called TOPLAP. It is caused by

sediment bypassing that results when there is little to no accommodation space landward of the offlap break, thus the sediments are carried into deeper water basinward of the offlap break.

6) Erosional Truncation
   a) Erosion of tilted strata
   b) Erosion by downcutting
7) Slope-front-fill
8) Apparent Onlap

WORK SHEET



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SHELFAL ACCOMMODATION AND WELL LOG FACIES STACKING PATTERNS

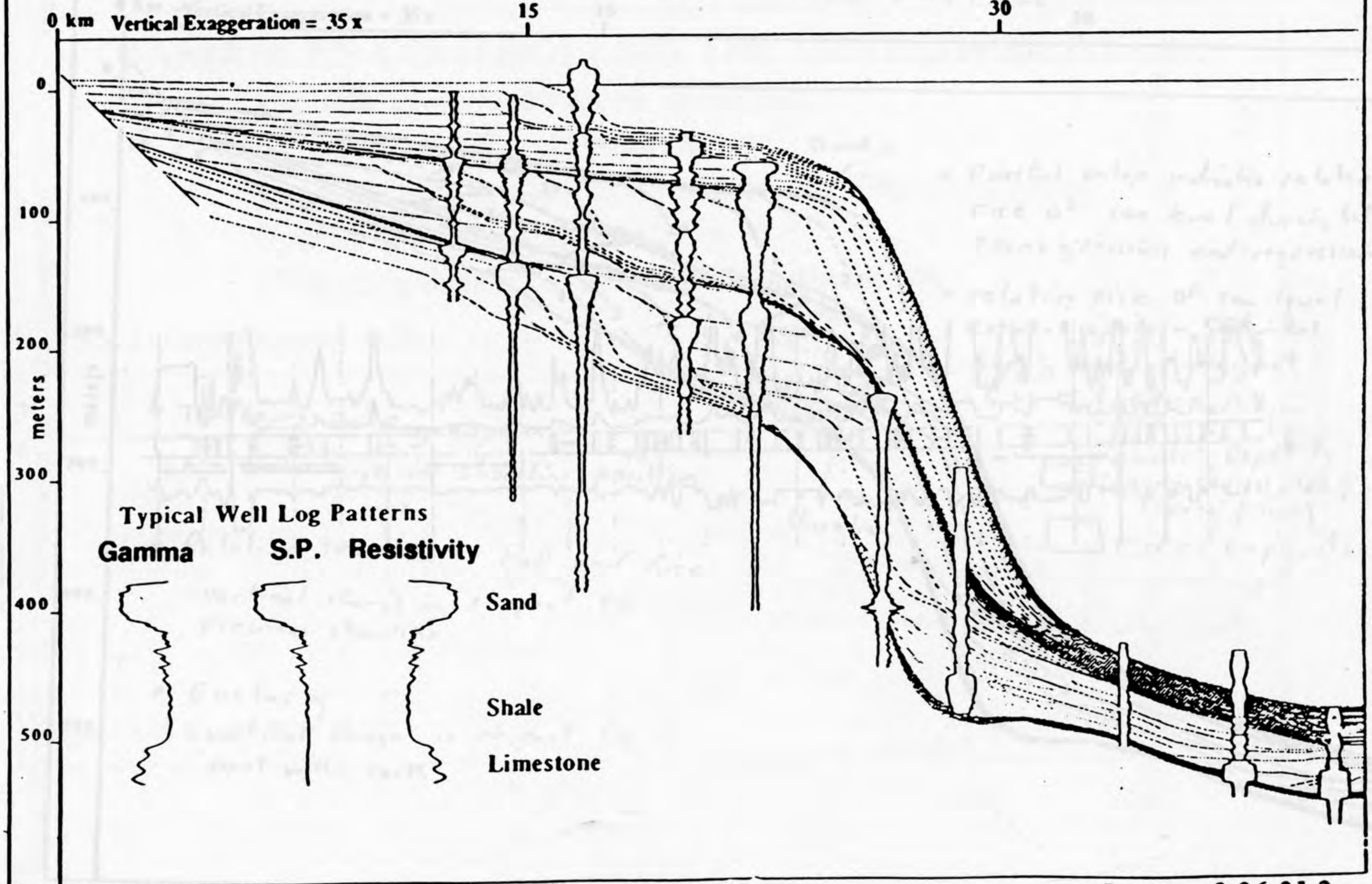

Fig. 2-29

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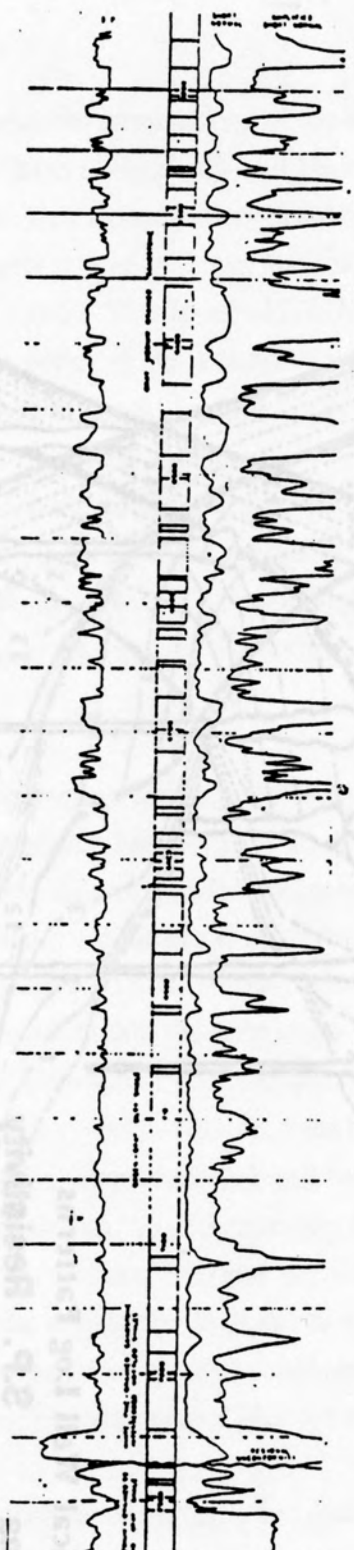
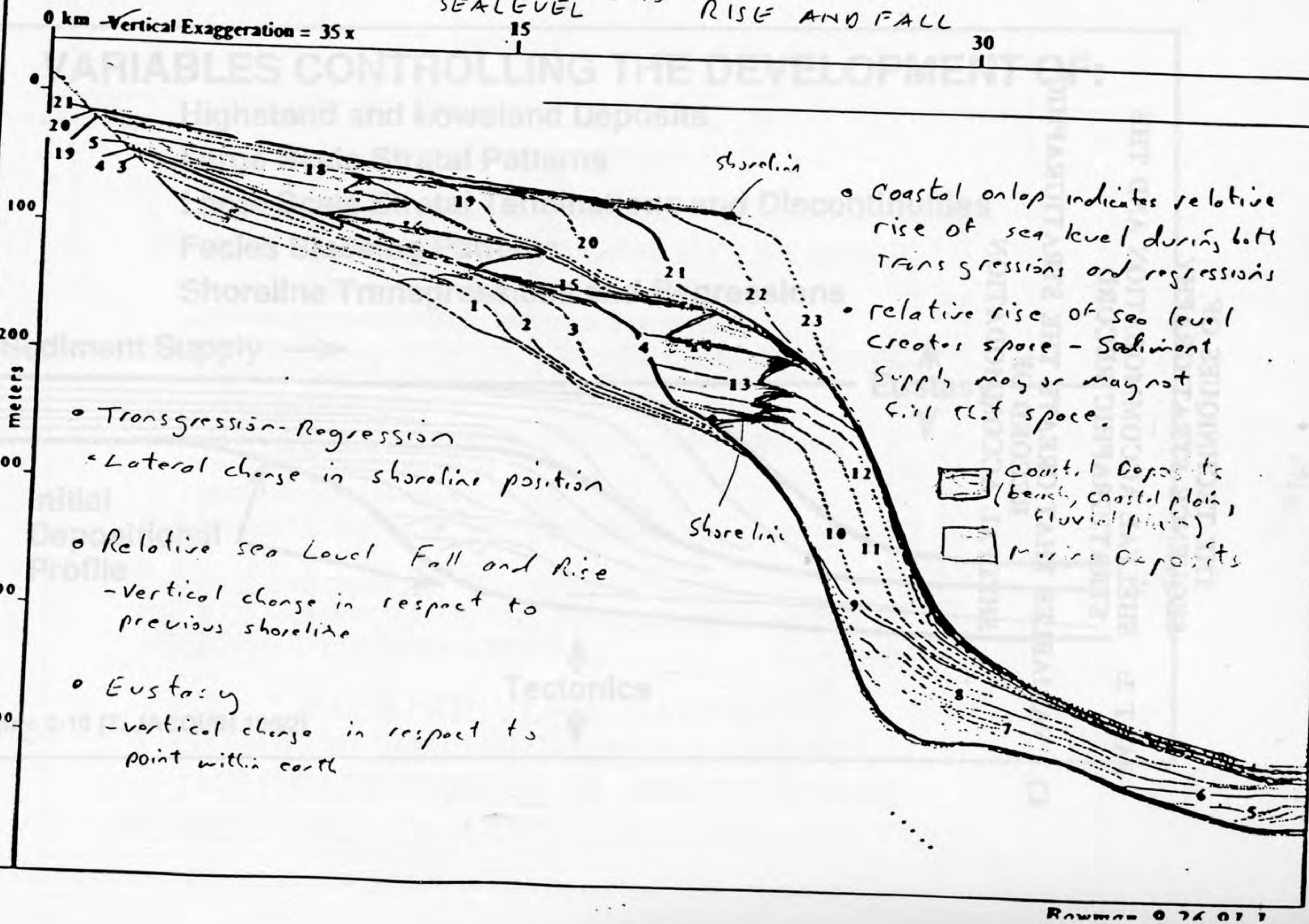
Well 3



TRANSGRESSION - REGRESSION AND SEALEVEL RISE AND FALL



- Transgression-Regression
  - Lateral change in shoreline position
- Relative sea Level Fall and Rise
  - Vertical change in respect to previous shoreline
- Eustasy
  - vertical change in respect to point within earth
- Coastal onlap indicates relative rise of sea level during both Transgressions and regressions
- relative rise of sea level creates space - Salimont Supply may or may not fill that space.

THE TECHNIQUES OF
SEQUENCE STRATIGRAPHY

PART 2: SHELFAL ACCOMMODATION AND THE STRATIGRAPHIC RECORD

C) VARIABLES THAT CREATE THE STRATIGRAPHIC RECORD OF SHELFAL ACCOMMODATION

VARIABLES CONTROLLING THE DEVELOPMENT OF:

- Highstand and Lowstand Deposits
- Large Scale Stratal Patterns
- Large Scale Stratal Terminations and Discontinuities
- Facies Stacking Patterns
- Shoreline Transgressions and Regressions

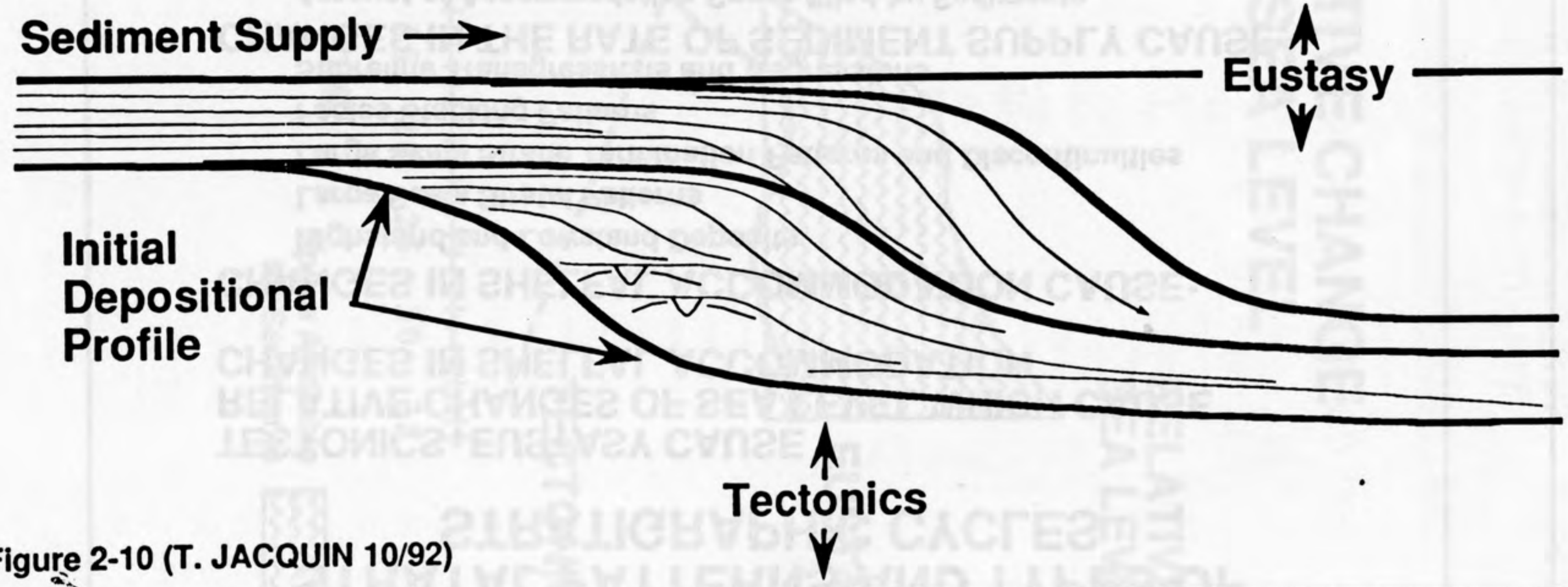


Figure 2-10 (T. JACQUIN 10/92)

SIGNIFICANCE OF VARIABLES CONTROLLING THE DEVELOPMENT OF LARGE SCALE STRATAL PATTERNS AND TYPES OF STRATIGRAPHIC CYCLES

TECTONICS+EUSTASY CAUSE
RELATIVE CHANGES OF SEA LEVEL WHICH CAUSE
CHANGES IN SHELFAL ACCOMMODATION

CHANGES IN SHELFAL ACCOMMODATION CAUSE:

- Highstand and Lowstand Deposits
- Large Scale Stratal Patterns
- Large Scale Stratal Termination Patterns and Discontinuities
- Facies Stacking Patterns
- Shoreline Transgressions and Regressions

CHANGES IN THE RATE OF SEDIMENT SUPPLY CAUSE:

- Amount of Accommodation Space filled by Sediments
- Minor Changes in the Timing of Discontinuities

CHANGES OF INITIAL DEPOSITIONAL PROFILE CAUSE:

- Variations in Stratal Patterns and Lithofacies, especially during Lowstands

Figure 2-11 (AV 11/92)

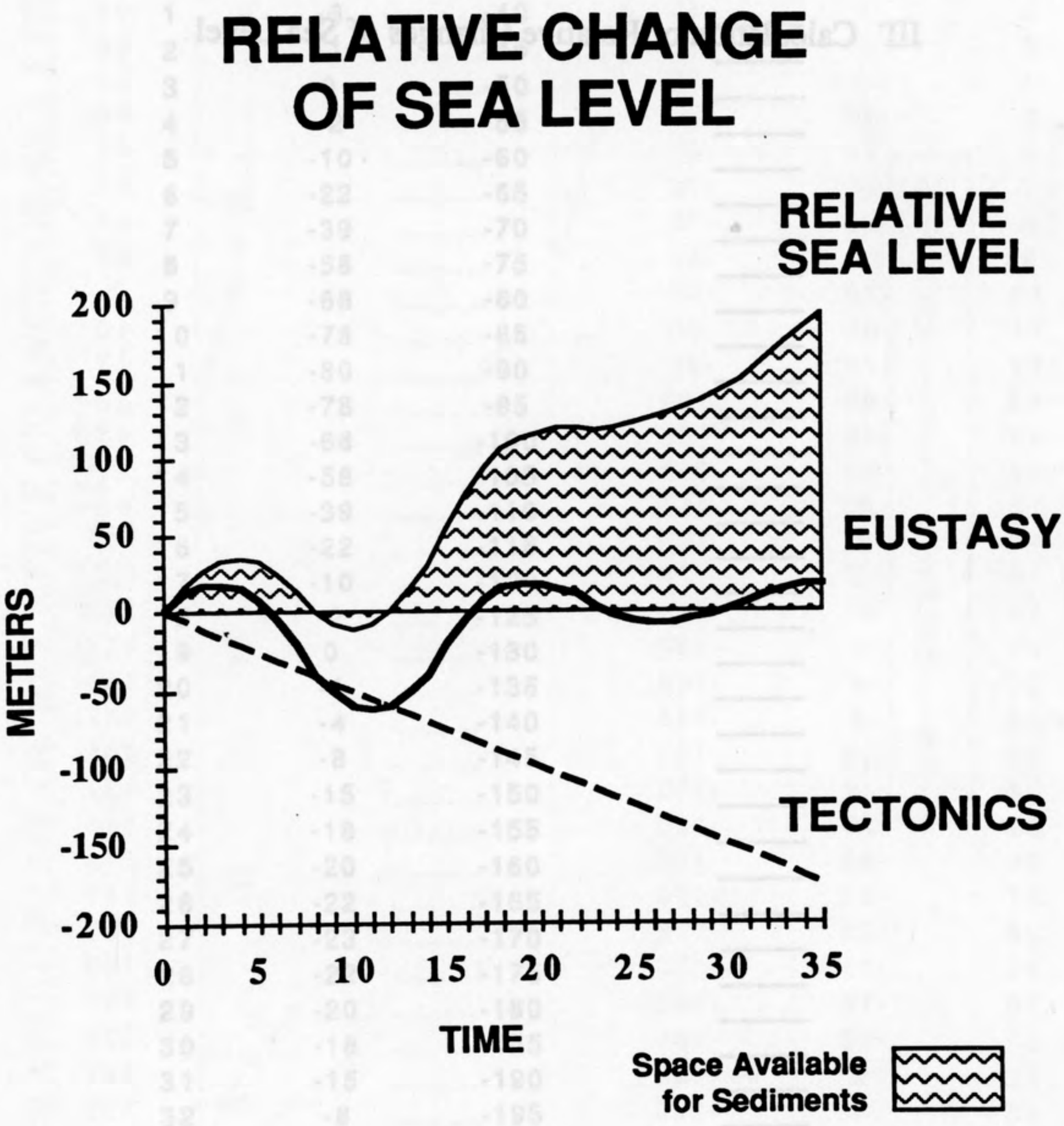


Figure 2-13 (T. JACQUIN 10/92)

THE TECHNIQUES OF SEQUENCE STRATIGRAPHY

PART 2: SHELFAL ACCOMMODATION AND THE STRATIGRAPHIC RECORD

E) EXERCISES

III Calculation of Relative Changes of Sea Level

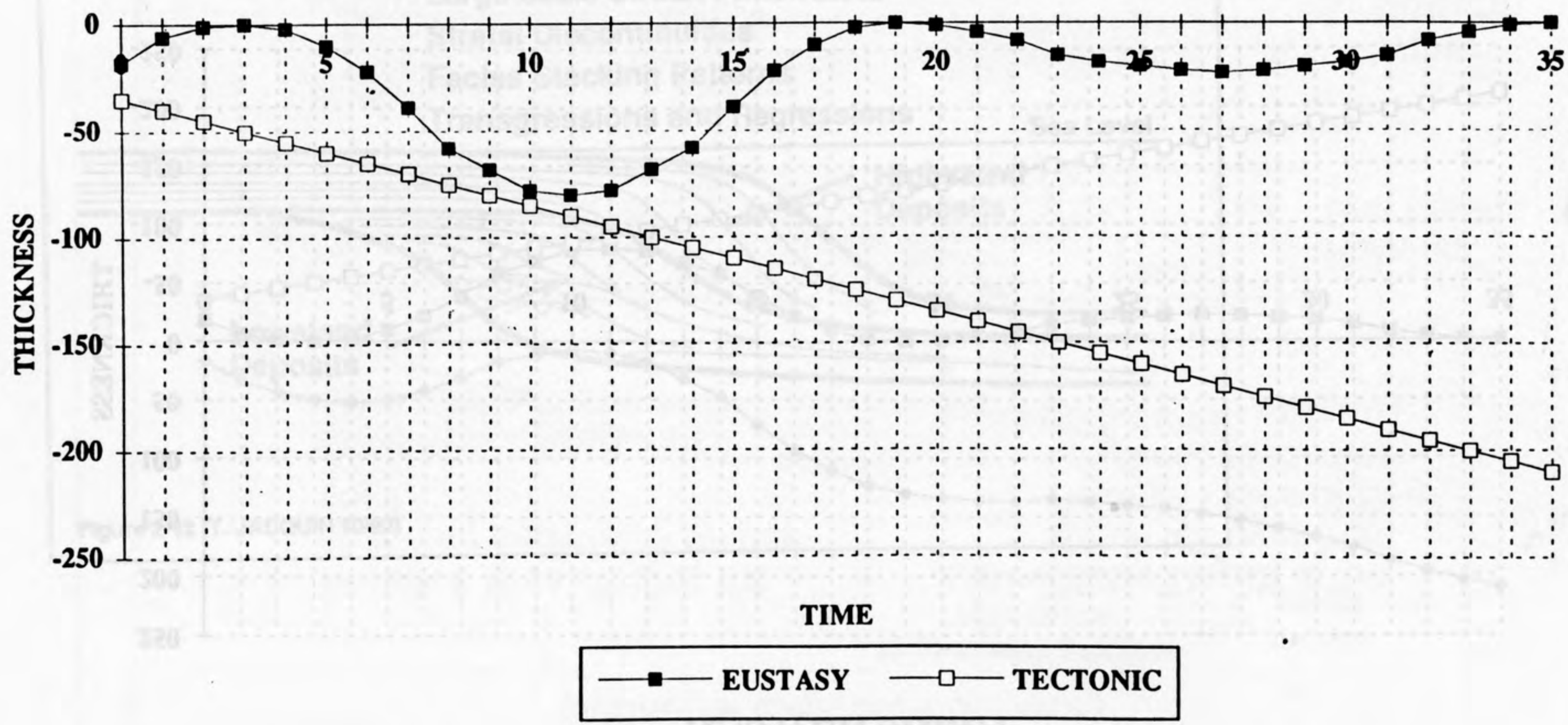
CALCULATION OF RELATIVE SEA LEVEL CHANGE WORKSHEET

TIME	EUSTASY	TECTONIC	RELATIVE SEA LEVEL
0	-18	-35	_____
1	-6	-40	_____
2	-1	-45	_____
3	0	-50	_____
4	-2	-55	_____
5	-10	-60	_____
6	-22	-65	_____
7	-39	-70	_____
8	-58	-75	_____
9	-68	-80	_____
10	-78	-85	_____
11	-80	-90	_____
12	-78	-95	_____
13	-68	-100	_____
14	-58	-105	_____
15	-39	-110	_____
16	-22	-115	_____
17	-10	-120	_____
18	-2	-125	_____
19	0	-130	_____
20	-1	-135	_____
21	-4	-140	_____
22	-8	-145	_____
23	-15	-150	_____
24	-18	-155	_____
25	-20	-160	_____
26	-22	-165	_____
27	-23	-170	_____
28	-22	-175	_____
29	-20	-180	_____
30	-18	-185	_____
31	-15	-190	_____
32	-8	-195	_____
33	-4	-200	_____
34	-1	-205	_____
35	0	-210	_____

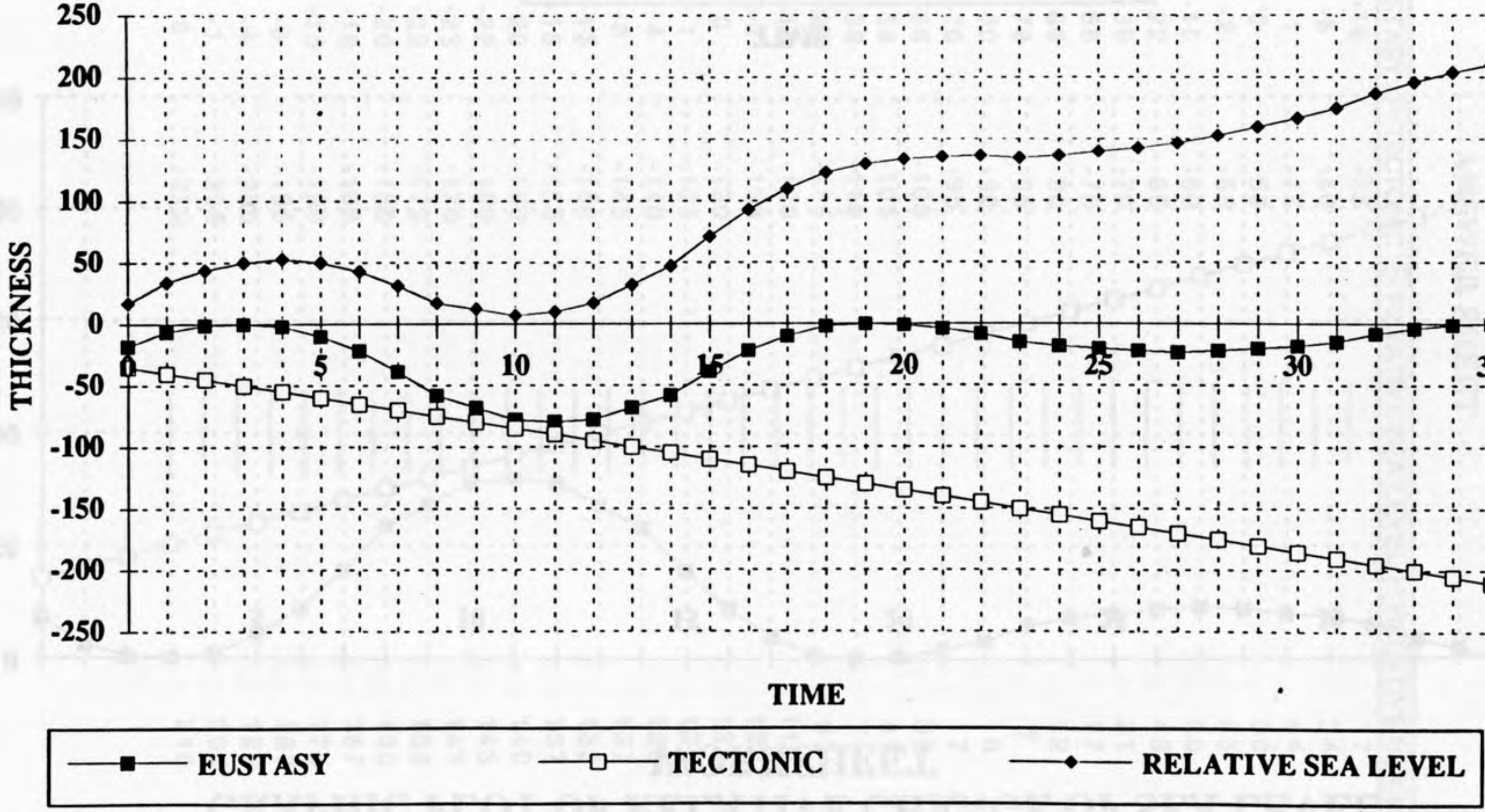
CALCULATION OF RELATIVE SEA LEVEL CHANGE
ANSWER SHEET

TIME	EUSTASY	TECTONIC	RELATIVE SEA LEVEL	RELATIVE SEA LEVEL
0	-18	-35		17
1	-6	-40		34
2	-1	-45		44
3	0	-50		50
4	-2	-55		53
5	-10	-60		50
6	-22	-65		43
7	-39	-70		31
8	-58	-75		17
9	-68	-80		12
10	-78	-85		7
11	-80	-90		10
12	-78	-95		17
13	-68	-100		32
14	-58	-105		47
15	-39	-110		71
16	-22	-115		93
17	-10	-120		110
18	-2	-125		123
19	0	-130		130
20	-1	-135		134
21	-4	-140		136
22	-8	-145		137
23	-15	-150		135
24	-18	-155		137
25	-20	-160		140
26	-22	-165		143
27	-23	-170		147
28	-22	-175		153
29	-20	-180		160
30	-18	-185		167
31	-15	-190		175
32	-8	-195		187
33	-4	-200		196
34	-1	-205		204
35	0	-210		210

GRAPHIC PLOT OF RELATIVE CHANGE OF SEA LEVEL WORKSHEET



GRAPHIC PLOT OF RELATIVE CHANGE OF SEA LEVEL
ANSWER SHEET



CHANGES IN SHELFAL ACCOMMODATION CAUSE:

- Highstand and Lowstand Deposits
- Large Scale Stratal Patterns
- Stratal Discontinuities
- Facies Stacking Patterns
- Transgressions and Regressions

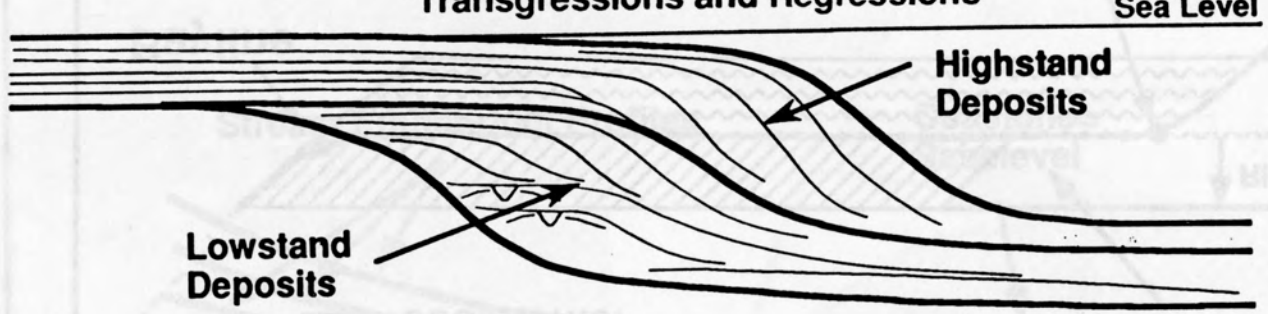


Figure 2-12 (T. JACQUIN 10/92)

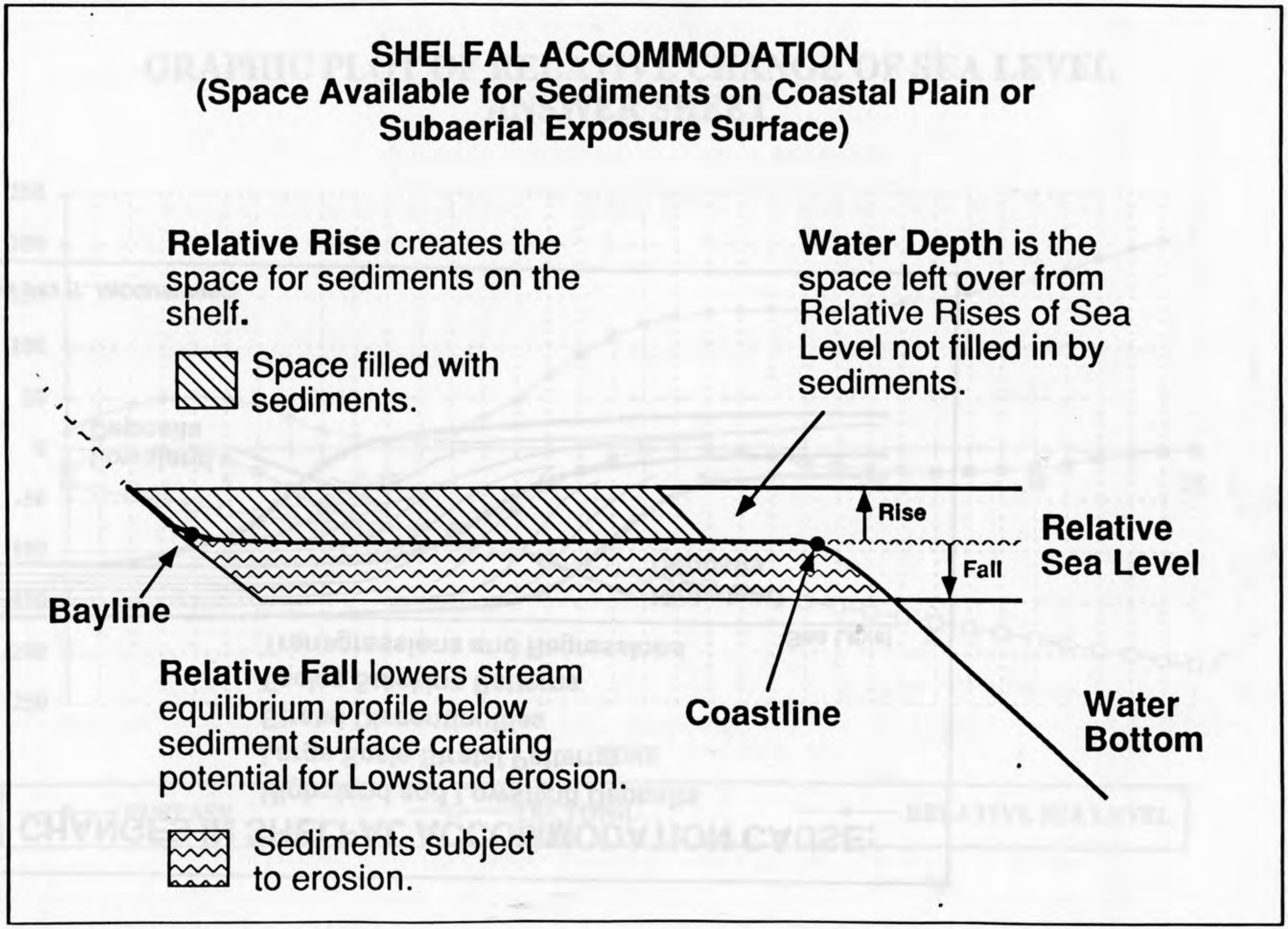


Figure 2-14 (AV 11/92)

BASELEVEL

DEFINITION: Baselevel is the intersection between Sea Level and the Stream Equilibrium Profile (Leopold et al., 1964).

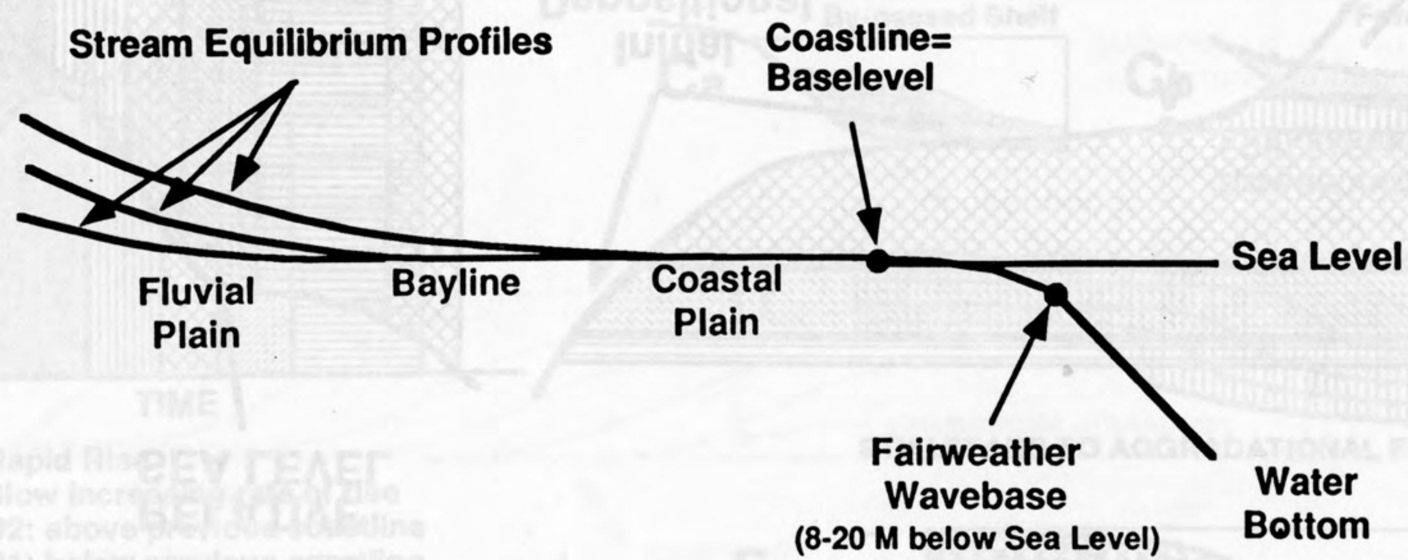


Figure 2-17 (AV 10/92)

HOW SHELFAL ACCOMMODATION VARIES WITH RELATIVE CHANGES OF SEA LEVEL

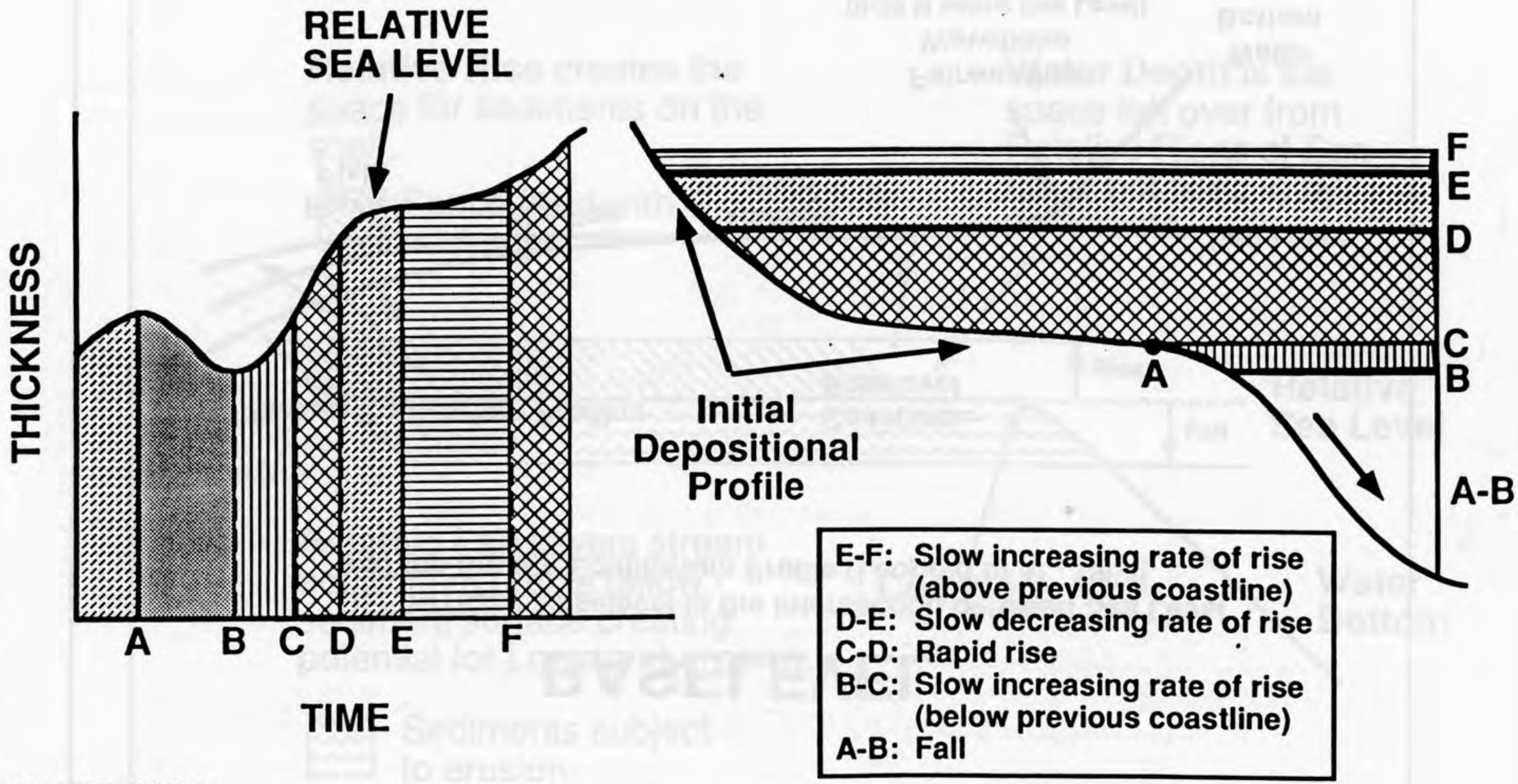


Figure 2-15 (AV 10/92)

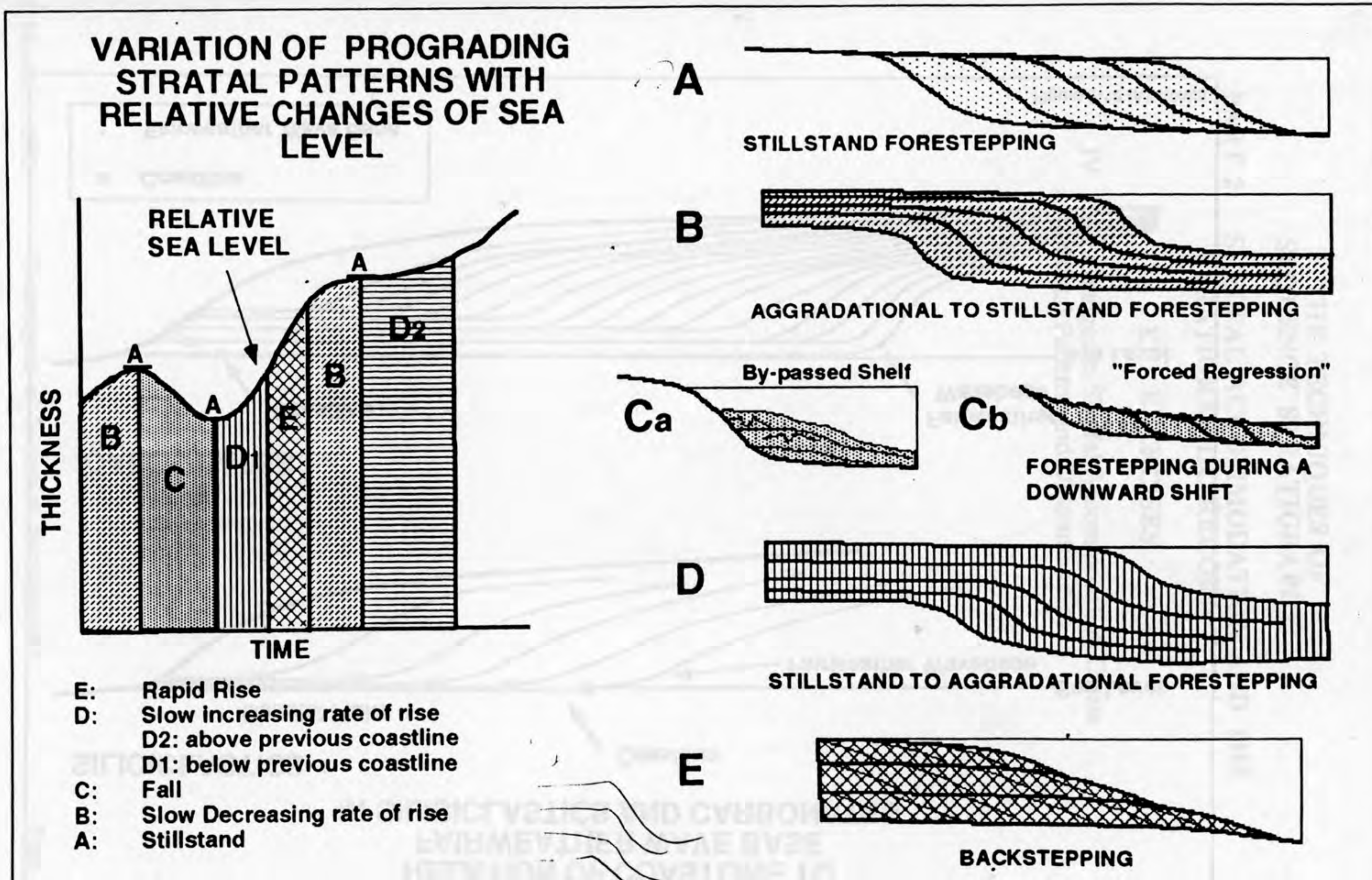


Figure 2-16 (AV 11/92)

RELATION OF COASTLINE TO FAIRWEATHER WAVE BASE IN SILICICLASTICS AND CARBONATES

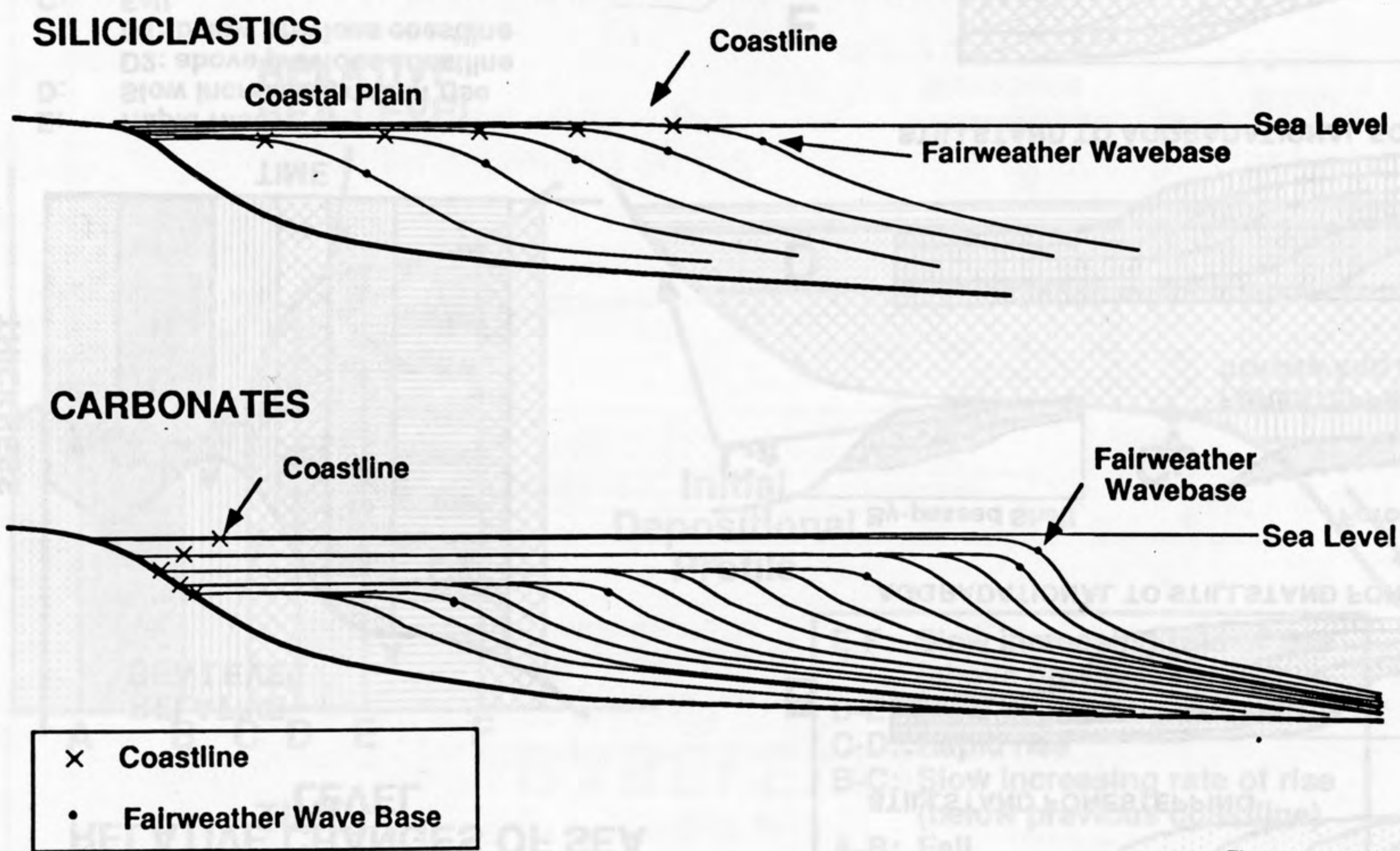


Figure 2-18 (AV-10/92)

THE TECHNIQUES OF SEQUENCE STRATIGRAPHY

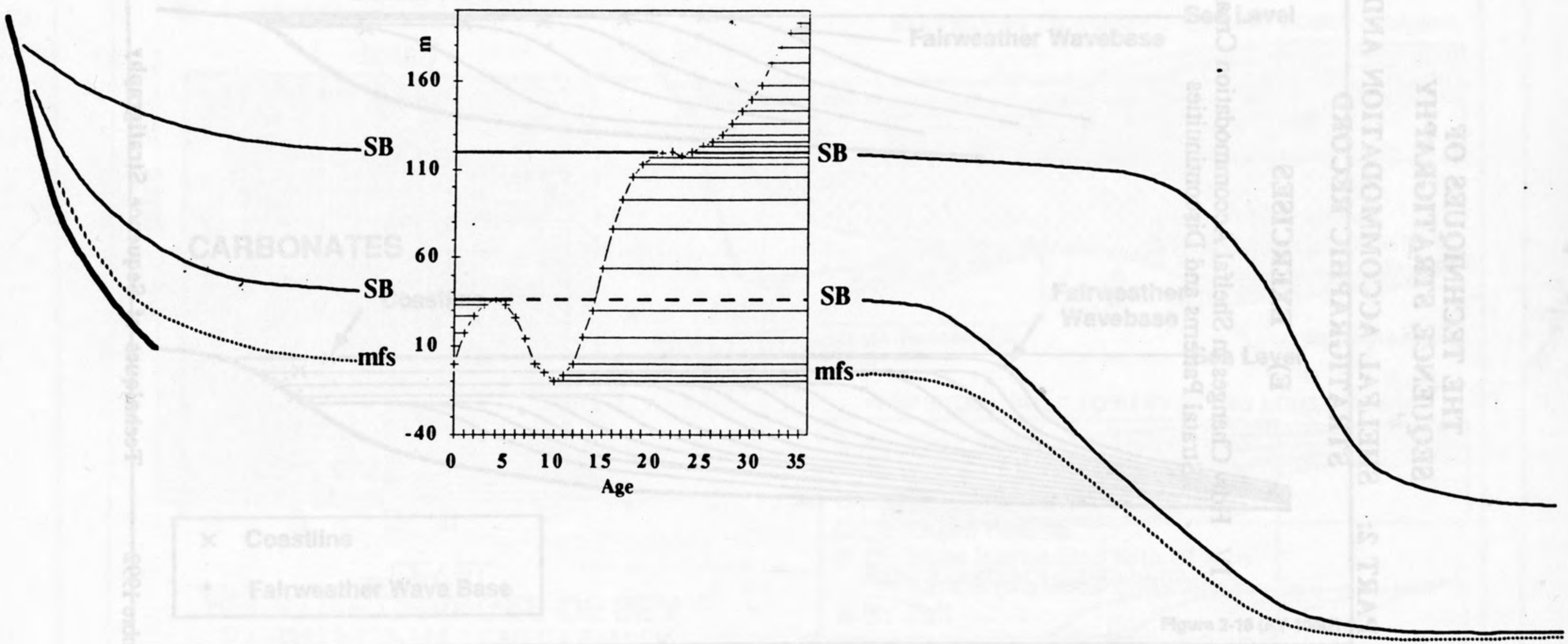
PART 2: SHELFAL ACCOMMODATION AND THE STRATIGRAPHIC RECORD

E) EXERCISES

IV How Changes in Shelfal Accommodation Create Stratal Patterns and Discontinuities

HOW RELATIVE CHANGES OF SEA LEVEL CREATE STRATAL PATTERNS

worksheet



Changes in Shelfal Accommotion and their Relation to the Depositional Profile

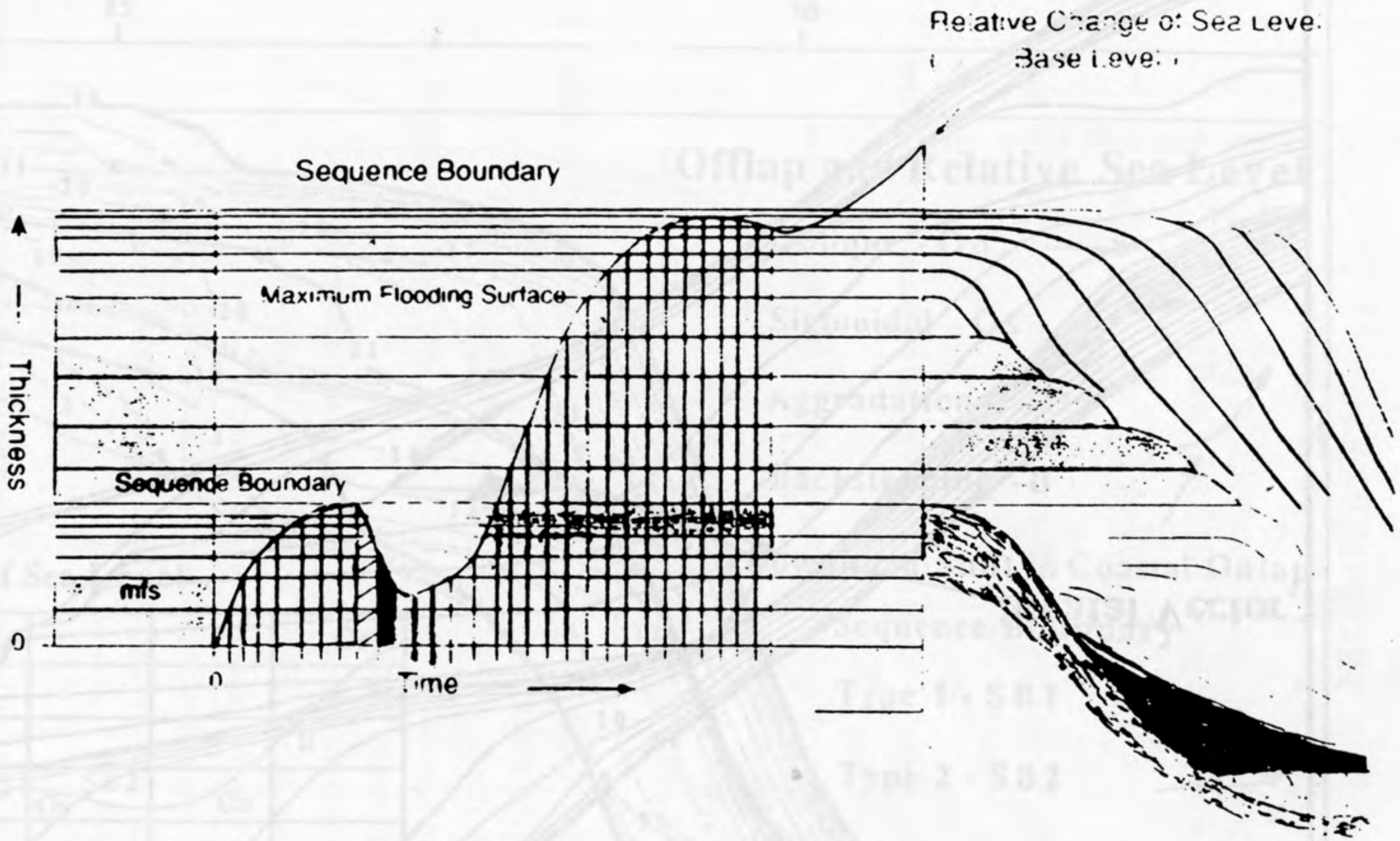


Fig. 2-14

Stratal Signature of the Relative Change of Sea Level

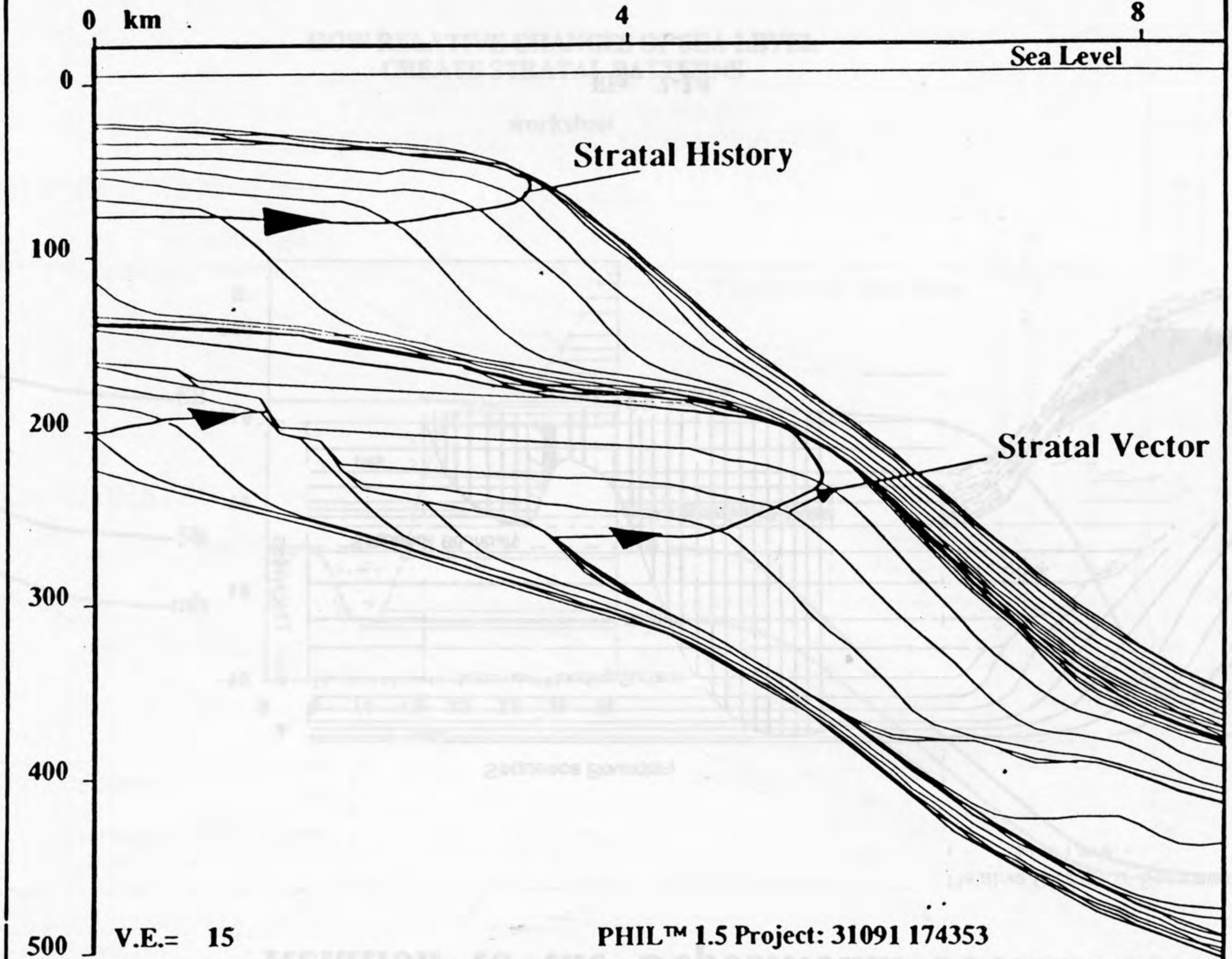


Fig. 2-27

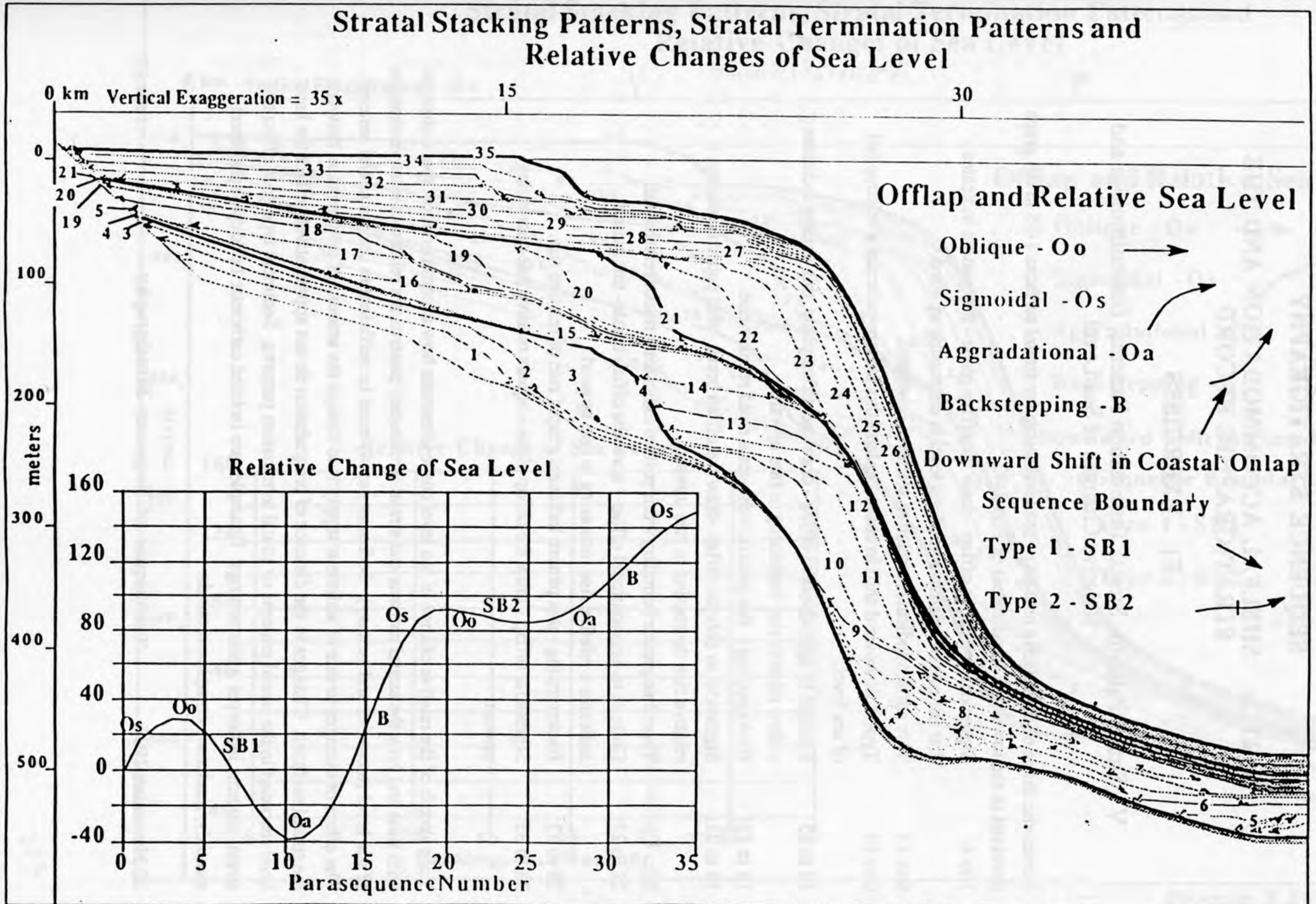


Fig 2-28

Bowman 9.26.91.1

THE TECHNIQUES OF SEQUENCE STRATIGRAPHY

PART 2: SHELFAL ACCOMMODATION AND THE STRATIGRAPHIC RECORD

E) EXERCISES

V Stratal Patterns, Stratal Termination Patterns, Discontinuities and Relative Changes of Sea Level

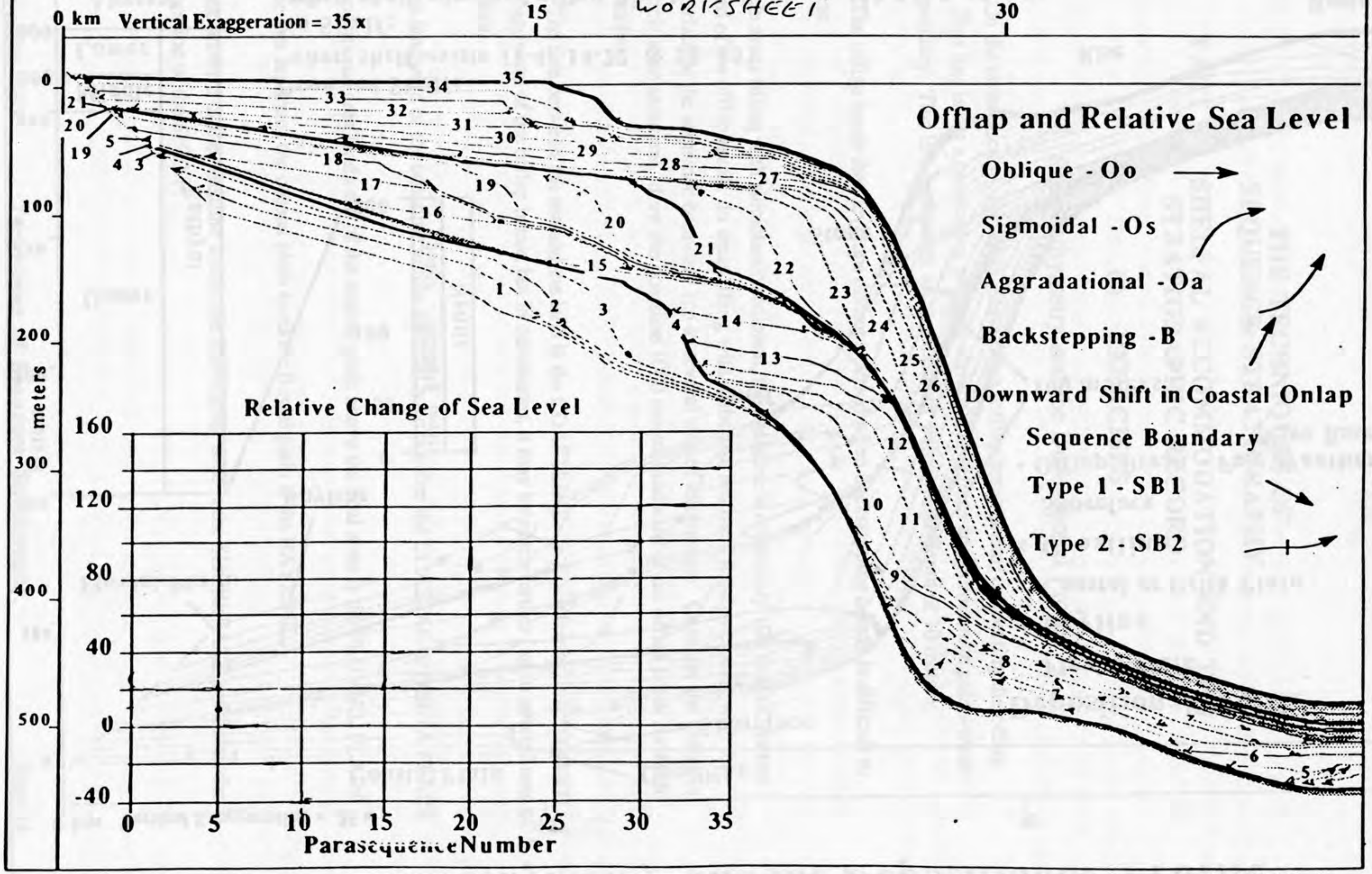
Sketch the shape of the relative change of sea level curve for stratal surfaces 1-35 in the graph provided in the lower left-hand corner of Fig. 2-42.

1 to 4:	Sigmoidal to oblique offlap - draw the offlap plane - this pattern indicates that the rate of relative rise of sea level is decreasing upward.
6 to 13:	This pattern indicates a relative sea level Lowstand.
6 to 14:	Type 1 downward shift in coastal onlap - this pattern indicates a relative fall of sea level.
10 to 13:	Oblique to aggradational offlap - draw the offlap plane, this pattern indicates a slow relative rise increasing in rate upward.
14 to 18:	Backstepping - this pattern indicates a rapid relative rise.
18 to 21:	Sigmoidal to oblique offlap -draw the offlap break - this pattern indicates a relative rise decreasing in rate upward.
21:	Type 2 sequence boundary - this pattern indicates a minor relative fall.
22 to 27:	Oblique to aggradational offlap - draw the offlap break - this pattern indicates a relative rise increasing in rate upward.
28 to 33:	Backstepping - this pattern indicates a rapid rate of relative rise.
33 to 35:	Sigmoidal offlap - draw the offlap plane - equals relative rise decreasing upward

Your sketch of the relative change of sea level curve illustrates how accommodation space changes with time and how the stratal patterns and stratal termination patterns are related to relative changes of sea level (tectonics and eustasy). Sediment supply must be sufficient to see the stratal patterns. The effect of changes in rate of sediment supply is to change the amount of progradation between the stratal surfaces. Changes in the distance of progradation do not appreciatively effect the base level recorded in the stratal patterns or stratal termination patterns. Sediment type does effect the stratal patterns in deeper water settings. Examples are isolated carbonate buildups, sand sheet mounds, mudstone complex mounds.

Stratal Stacking Patterns, Stratal Termination Patterns and Relative Changes of Sea Level

WORKSHEET



Bowman 9.26.91.1

B-31(

205

Paleobathymetry and the Depositional Profile

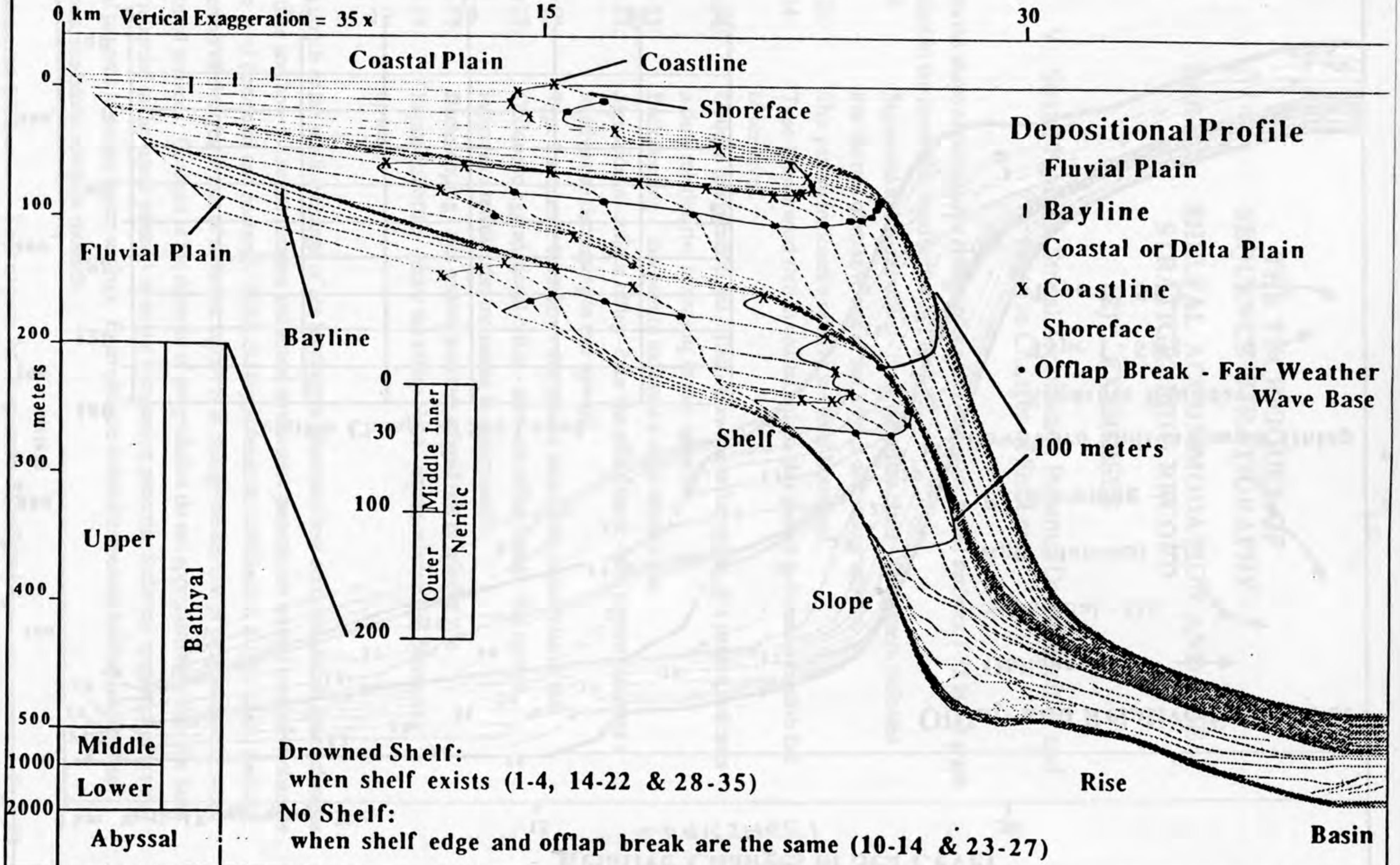


Fig. 2-15

THE TECHNIQUES OF SEQUENCE STRATIGRAPHY

PART 2: SHELFAL ACCOMMODATION AND THE STRATIGRAPHIC RECORD

E) EXERCISES

VI Paleobathymetry and the Depositional Profile

1) On the cross-section, Fig. 2-43, draw a line (offlap break plane) connecting the offlap breaks. This line is not a continuous physical surface, but defines an approximate paleo-water-depth boundary. This line represents an approximate paleo-water-depth of 10 meters.

2) The offlap break that develops during a period when backstepping occurs is difficult to recognize.

3) In areas filling with siliciclastic sediment, the coastline is commonly 100 to 1000 meters landward of the offlap break. In areas filling with carbonate sediment it may coincide with the onlap surface at the sequence boundary (up to several tens of kilometers). Consider the example with siliciclastic sediment, draw the coastline 1000 meters landward of the offlap break for each stratal surface.

4) The line between the sea and the land is the COASTLINE. In siliciclastics, it is 100-1000 meters landward of the offlap break, but in carbonates, it may be much farther (up to several tens of kilometers).

The area landward of the coastline within the tidal zone is either the COASTAL or DELTA PLAIN.

The depositional area landward of the coastal plain above the tidal zone is the FLUVIAL PLAIN.

The line that separates the coastal plain from the fluvial plain is the BAYLINE.

The area seaward of the coastline within the fairweather zone is the SHOREFACE and forms the inner portion of the SHELF.

5) For each stratal surface, measure downward 30 meters below the coastline at right angles to the dip of the coastal plain. Move seaward parallel to the dip of the coastal plain until the stratal surface is intersected.

Place a black dot at this point and connect the dots of all the stratal surfaces with a line. Consider this the approximate AVERAGE STORM WAVEBASE PLANE. It is also the base of the INNER NERETIC PALEOBATHYMETRIC ZONE. Color yellow the interval from 0-30 meter paleo-water-depth.

6) Repeat the procedure, but measure downward 50 meters, place a black dot for each stratal surface and then connect them with a line. This is approximately the 50 meter paleo-water-depth. It approximates the MAJOR STORM WAVEBASE.

7) From the 50 meter paleo-water-depth measure downward another 50 meters following the same procedure. This new line is approximately the 100 meter paleo-water-depth. It is the base of the MIDDLE NERETIC PALEOBATHYMETRIC ZONE. Color light blue the interval from 30-100 meter paleo-water-depth.

8) Repeat the procedure, measuring another 100 meters downward from the base of the middle neritic zone. This line corresponds approximately to the 200 meter paleo-water-depth. It is the base of the OUTER NERITIC PALEOBATHYMETRIC ZONE. Color dark blue the interval between the 100 and 200 meter paleo-water-depth.

9) From the 200 meter paleo-water-depth line, repeat the procedure measuring downward 300 meters. This marks the 500 meter paleo-water-depth is the base of the UPPER BATHYAL PALEOBATHYMETRIC ZONE. Color red the interval between the 200 and 500 meter paleo-water-depth.

10) Repeat again the procedure, measuring another 500 meters downward from the base of the upper bathyal zone. This approximately 1000 meter paleo-water-depth is the base of the MIDDLE BATHYAL PALEOBATHYMETRIC ZONE. Color purple the interval between the 500 and 1000 meter paleo-water-depth.

11) If the paleo-water-depth is deeper, measure downward another 1000 meters and draw the approximately 2000 meter paleo-water-depth line. This would correspond to the base of the LOWER BATHYAL and top of the ABYSSAL PALEOBATHYMETRIC ZONES.

Discussion About Shelf, Slope And Basin:

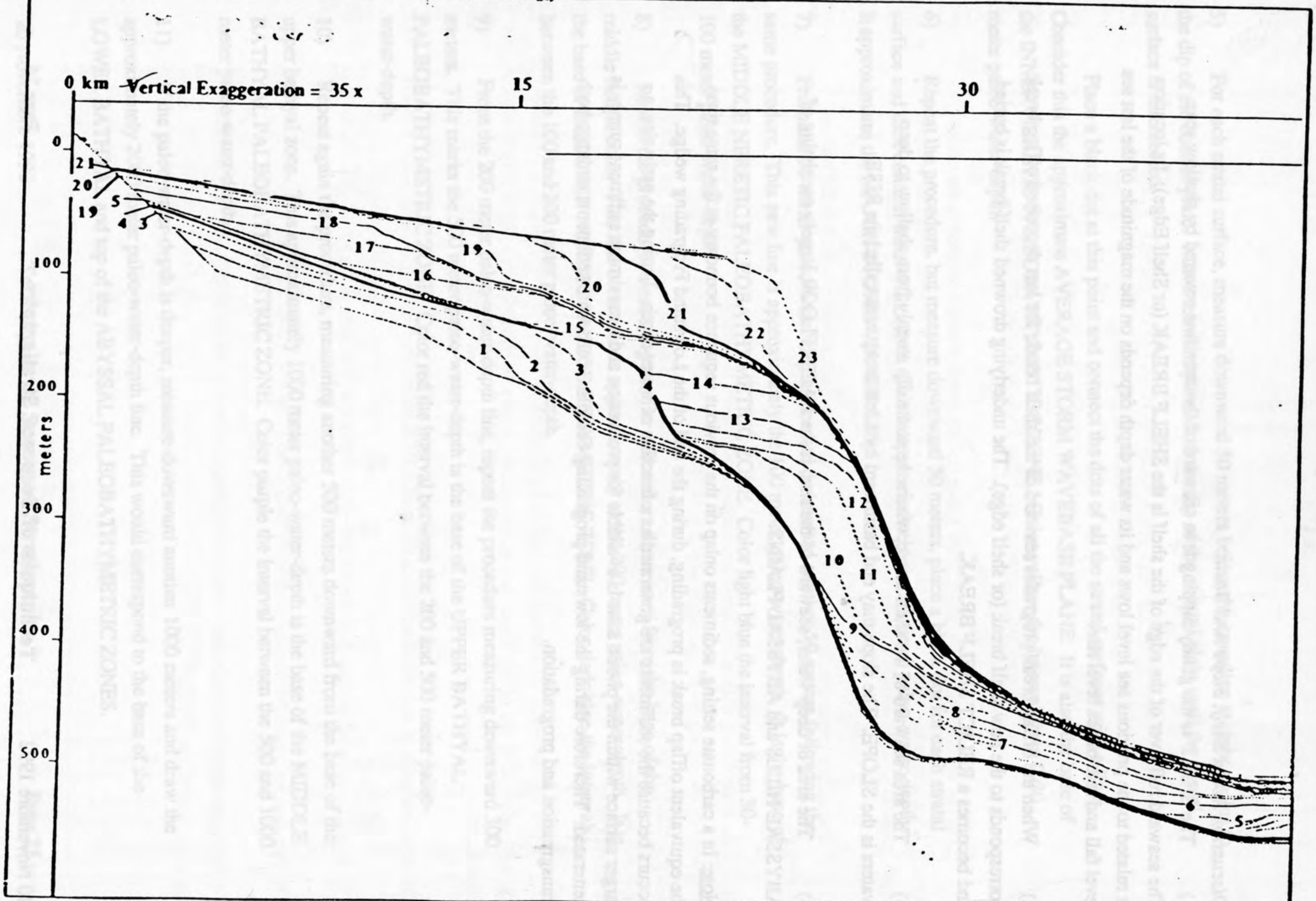
1) The SHELF is the gently dipping area seaward of the coastline covered by shallow seas. The seaward roll-over of the edge of the shelf is the SHELF BREAK (or Shelf Edge). Its location is related to the previous sea level lows and its water depth depends on the magnitude of the last sea level fall and rate of sea level rise.

2) When the offlap break progrades seaward of the shelf break, the last deposited offlap break corresponds to the new shelf break (or shelf edge). The underlying drowned shelf break is buried and becomes a RELICT SHELF BREAK.

3) The area seaward of the shelf break, where the strata dip steeply from shallow to deep waters is the SLOPE. The slope may end basinward by a less steep area called the RISE.

4) The area of deep water, seaward of the rise, is the BASIN FLOOR largely consisting of ABYSSAL HILLS and ABYSSAL PLAINS.

Note: In a carbonate setting, sediments onlap on the previous sequence boundary at the same time the equivalent offlap break is prograding, during the end of the Lowstand Prograding wedge. This occurs because the sediments are generated as a function of water depth. During the early rise, a larger surface within the photic zone is available for production and a maximum sediment supply is generated. Therefore during the lowstand prograding complex, carbonate sediments undergo both transgression and progradation.



Bowman 9.26.91.1

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CHANGES OF SEDIMENT SUPPLY:

- Determine the amount of Accommodation Space filled with Sediments.
- Cause minor changes in the timing of Discontinuities.
- Cause some Transgressions and Regressions.

Figure 2-22 (AV-11/92)

SEDIMENT SUPPLY

Constant Input approaching a Steady State Condition

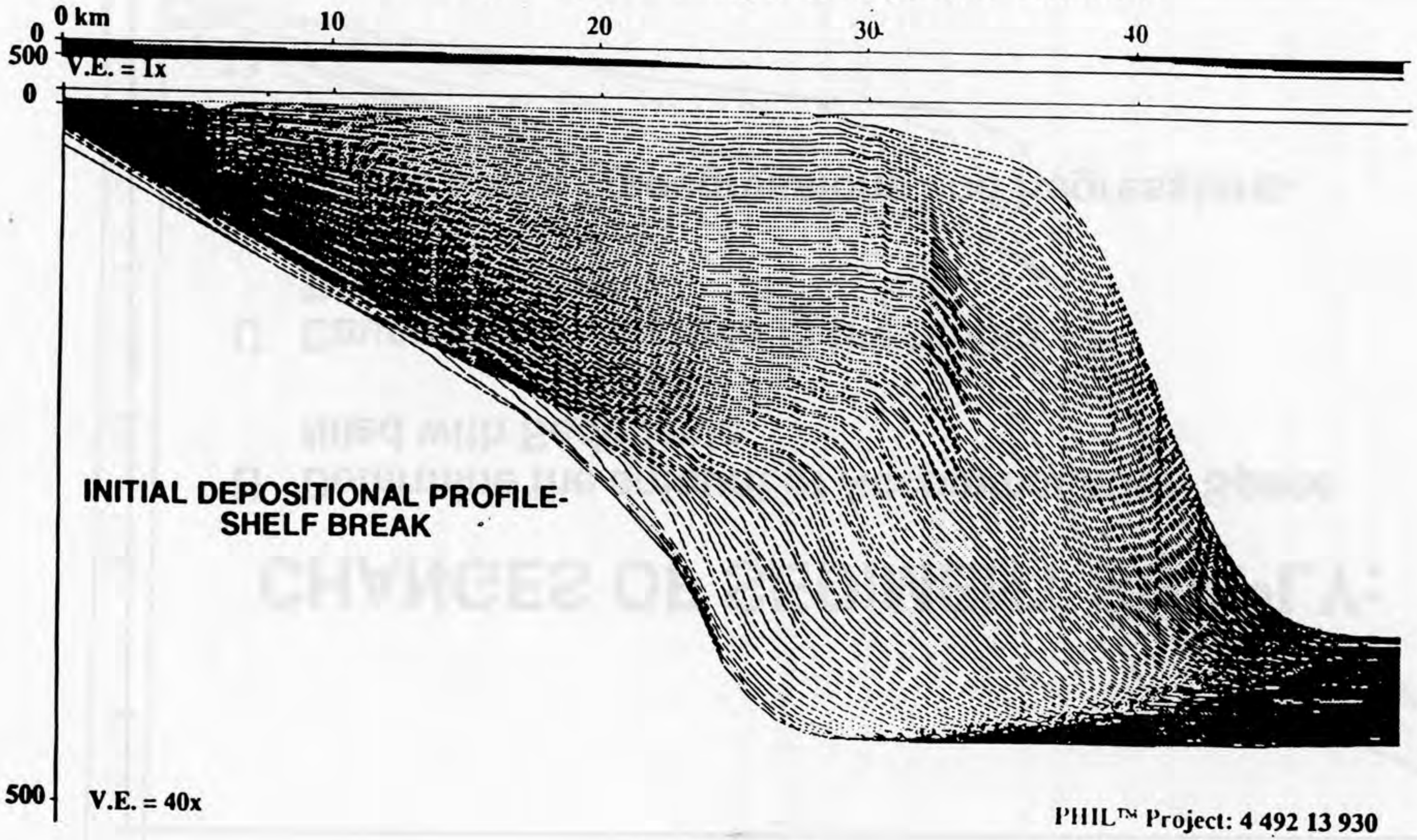


Fig. 2-9

SEDIMENT SUPPLY AND CHANGES IN SHELFAL ACCOMMODATION

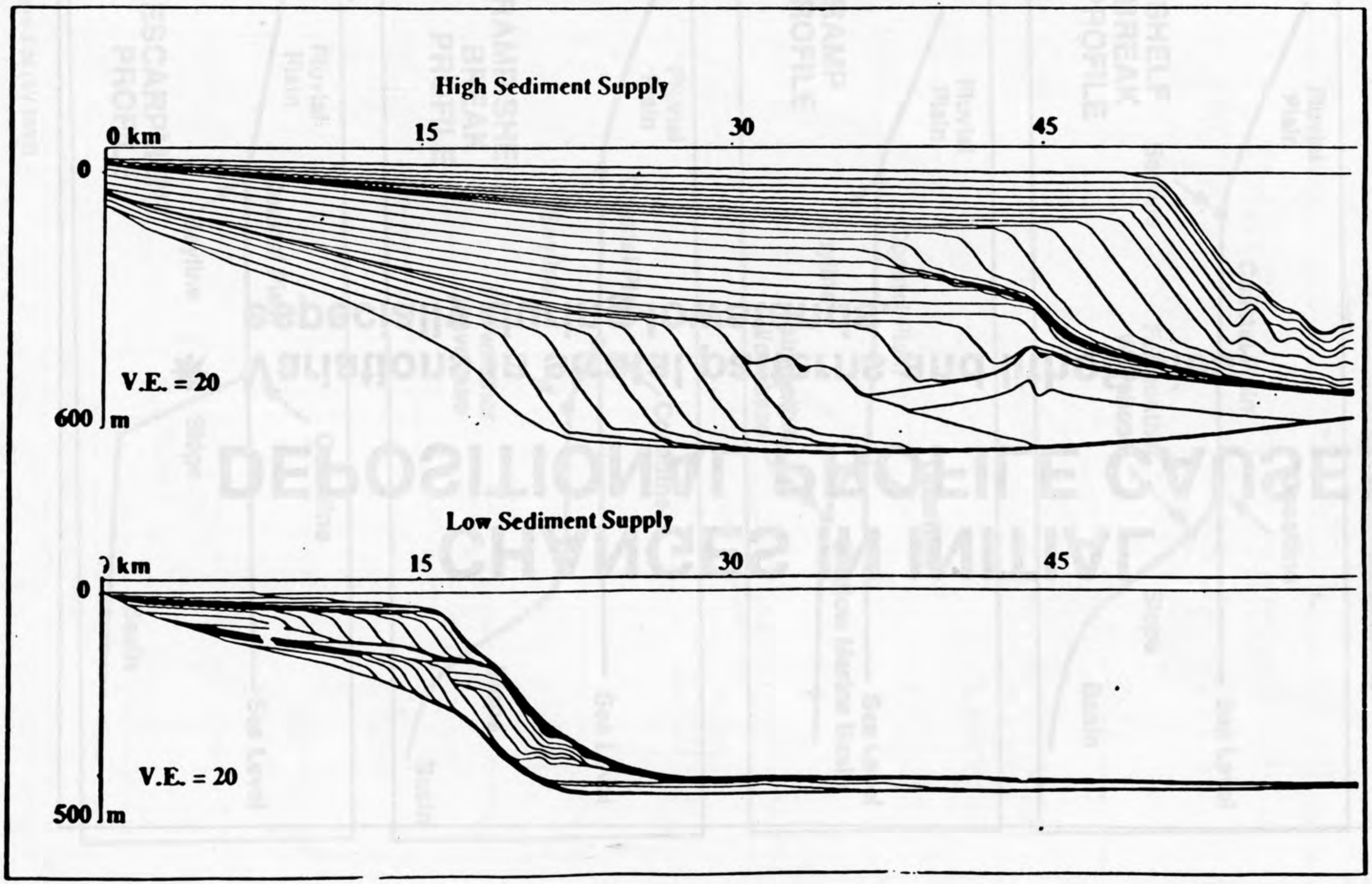


Fig. 2-10

CHANGES IN INITIAL DEPOSITIONAL PROFILE CAUSE:

* Variations in stratal patterns and lithofacies, especially during lowstands.

Figure 2-28 (AV-11/92)

INITIAL DEPOSITIONAL PROFILES

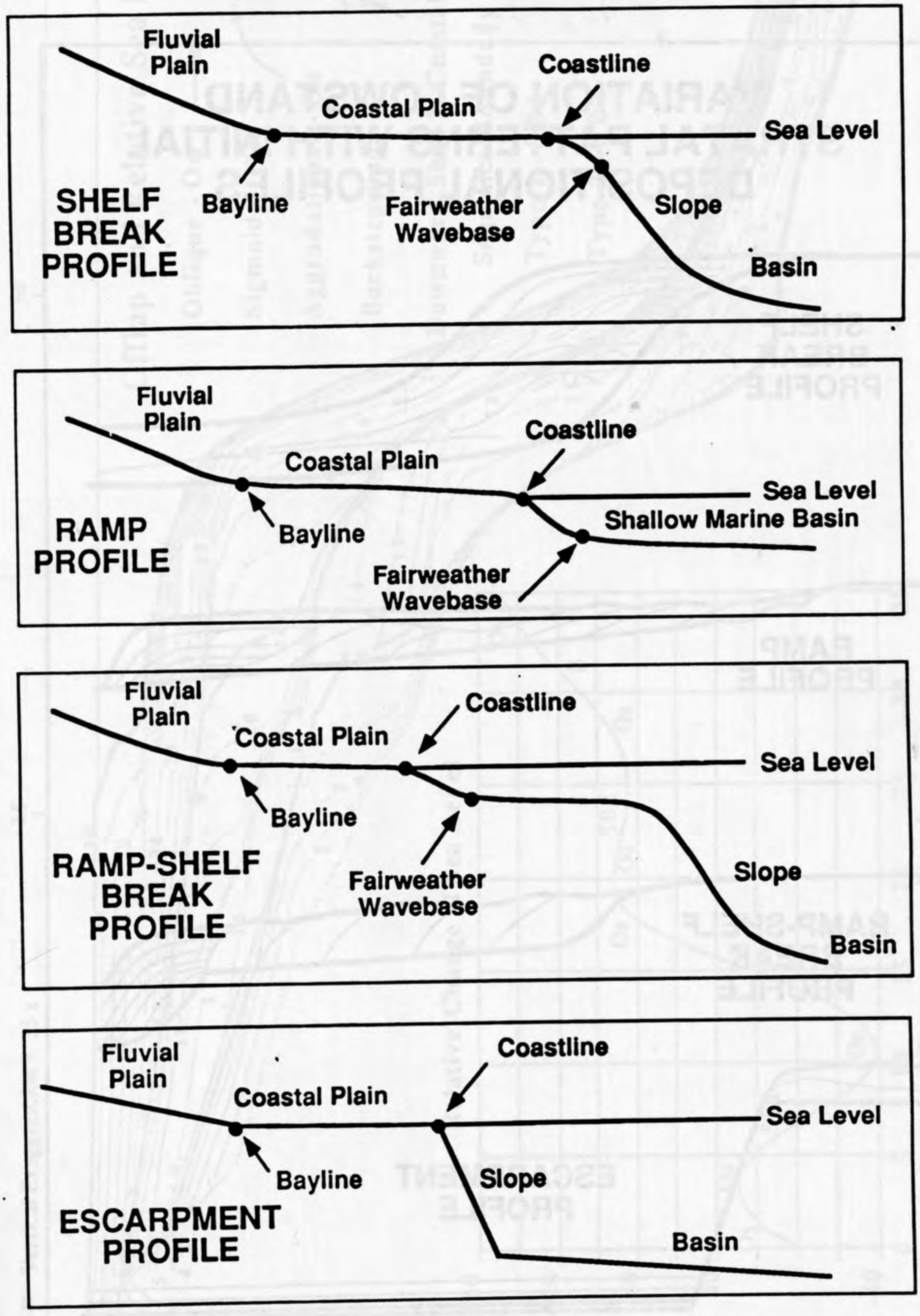


Figure 2-26 (AV 10/92)

VARIATION OF LOWSTAND STRATAL PATTERNS WITH INITIAL DEPOSITIONAL PROFILES

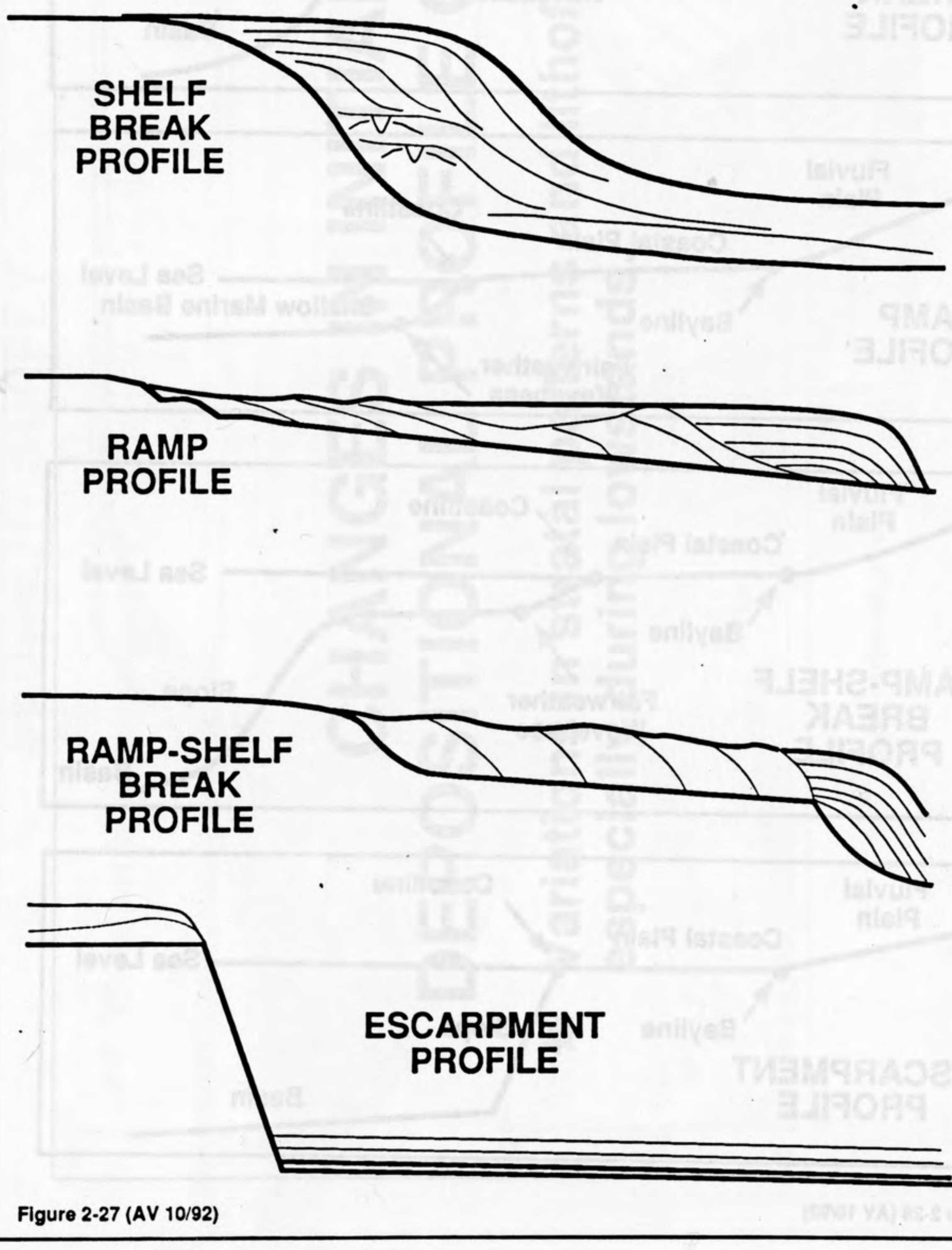
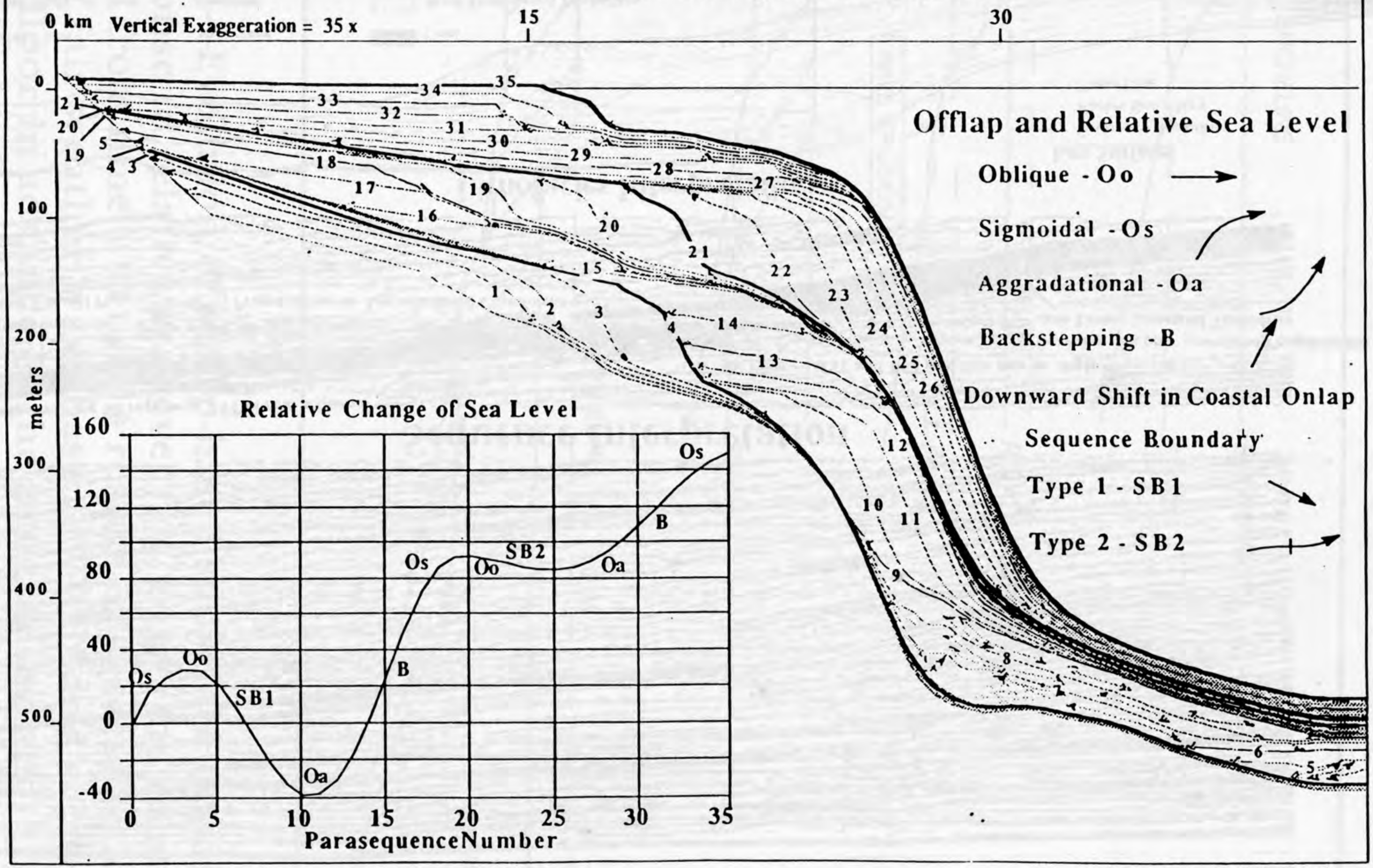


Figure 2-27 (AV 10/92)

Stratal Stacking Patterns, Stratal Termination Patterns and Relative Changes of Sea Level



Bowman 9.26.91.1

Shelf Break Lowstand Progradation

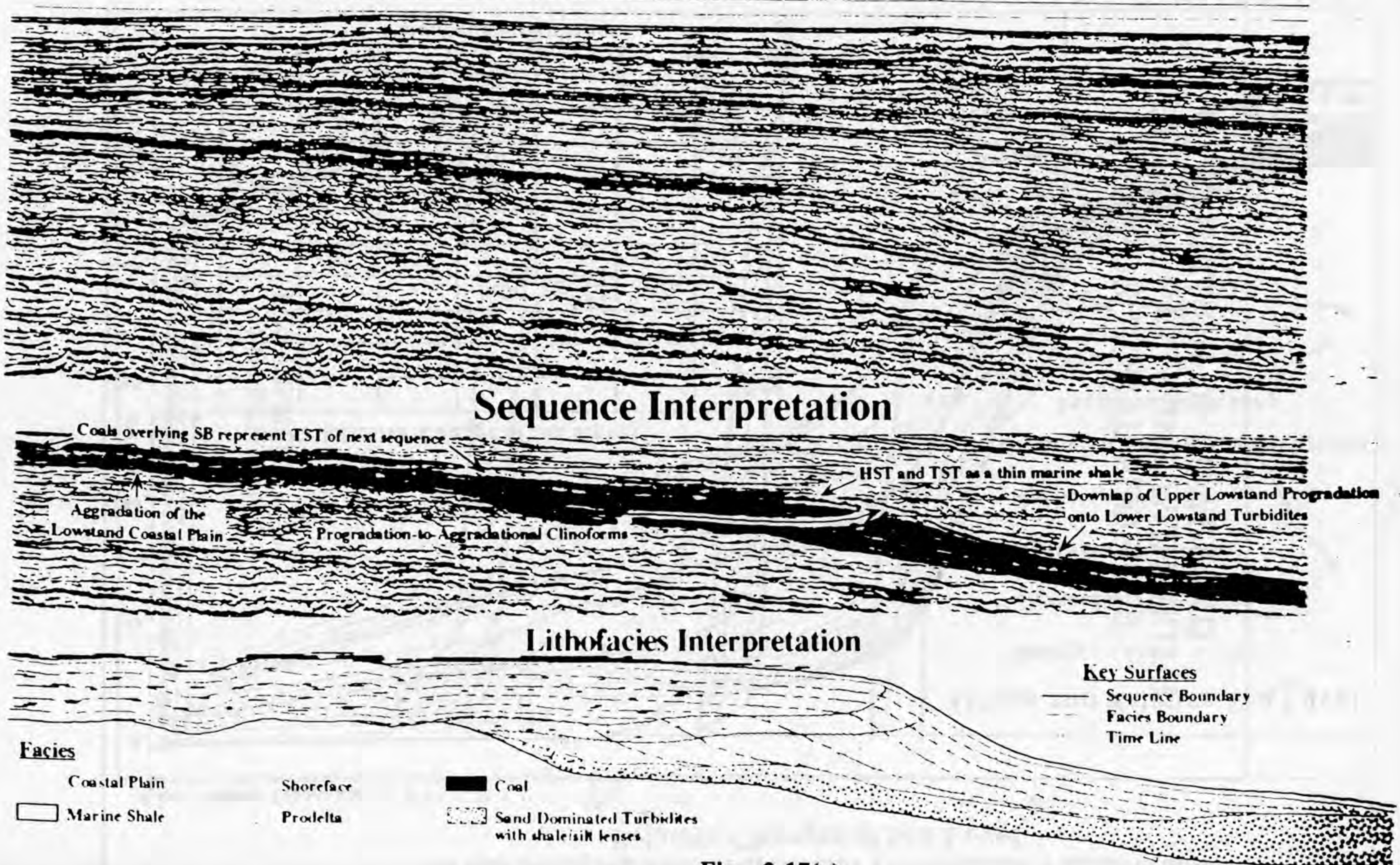
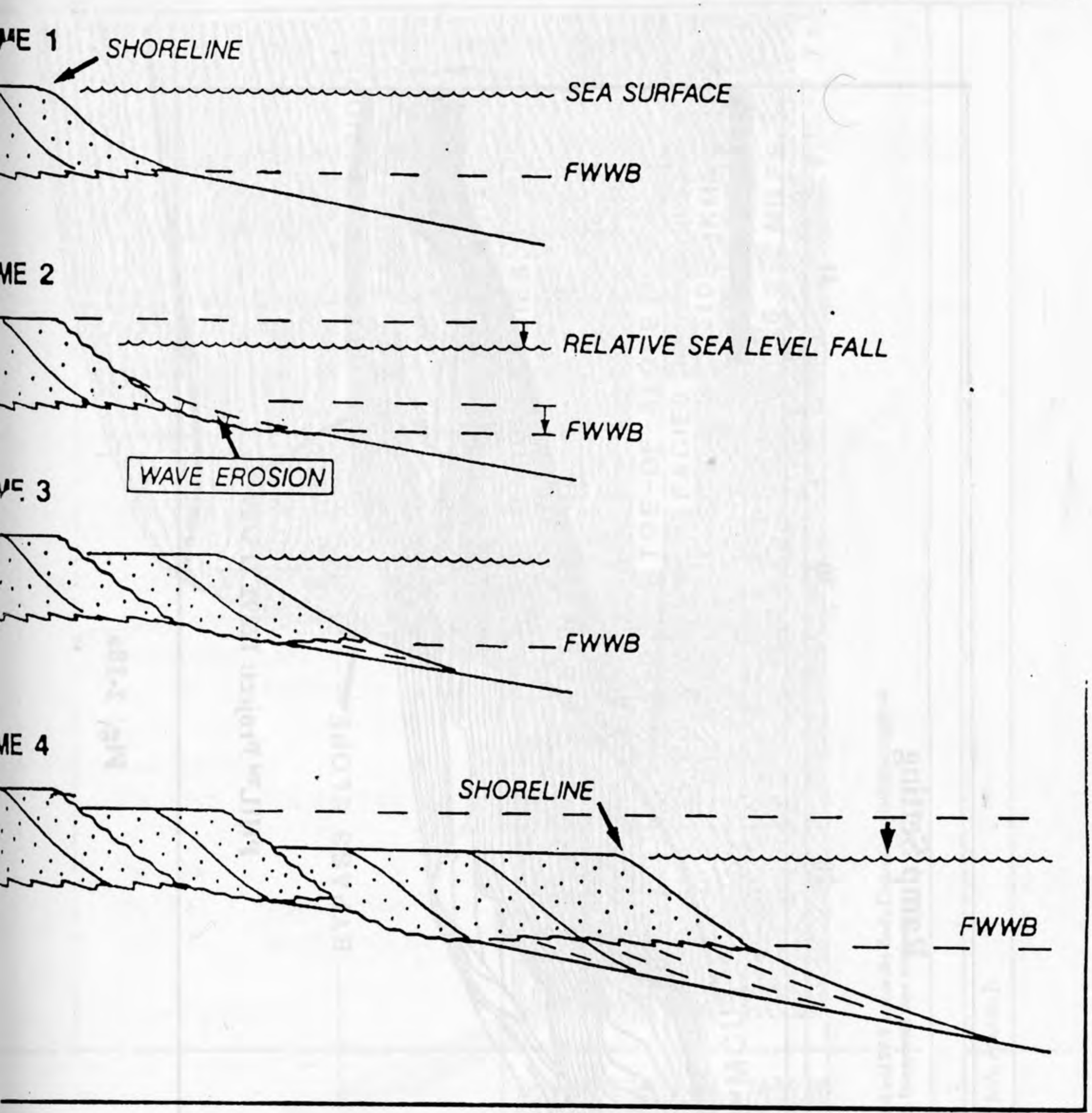


Fig. 2-17(r)



ure 6—Evolution of sharp-based shoreface deposits response to relative sea level fall. Lowering relative level from time 1 to time 4 results in successive lowing of fair-weather wave base (FWWB) and scour of sea floor in advance of the prograding shoreface ter Swift, 1976, and Plint, 1988).

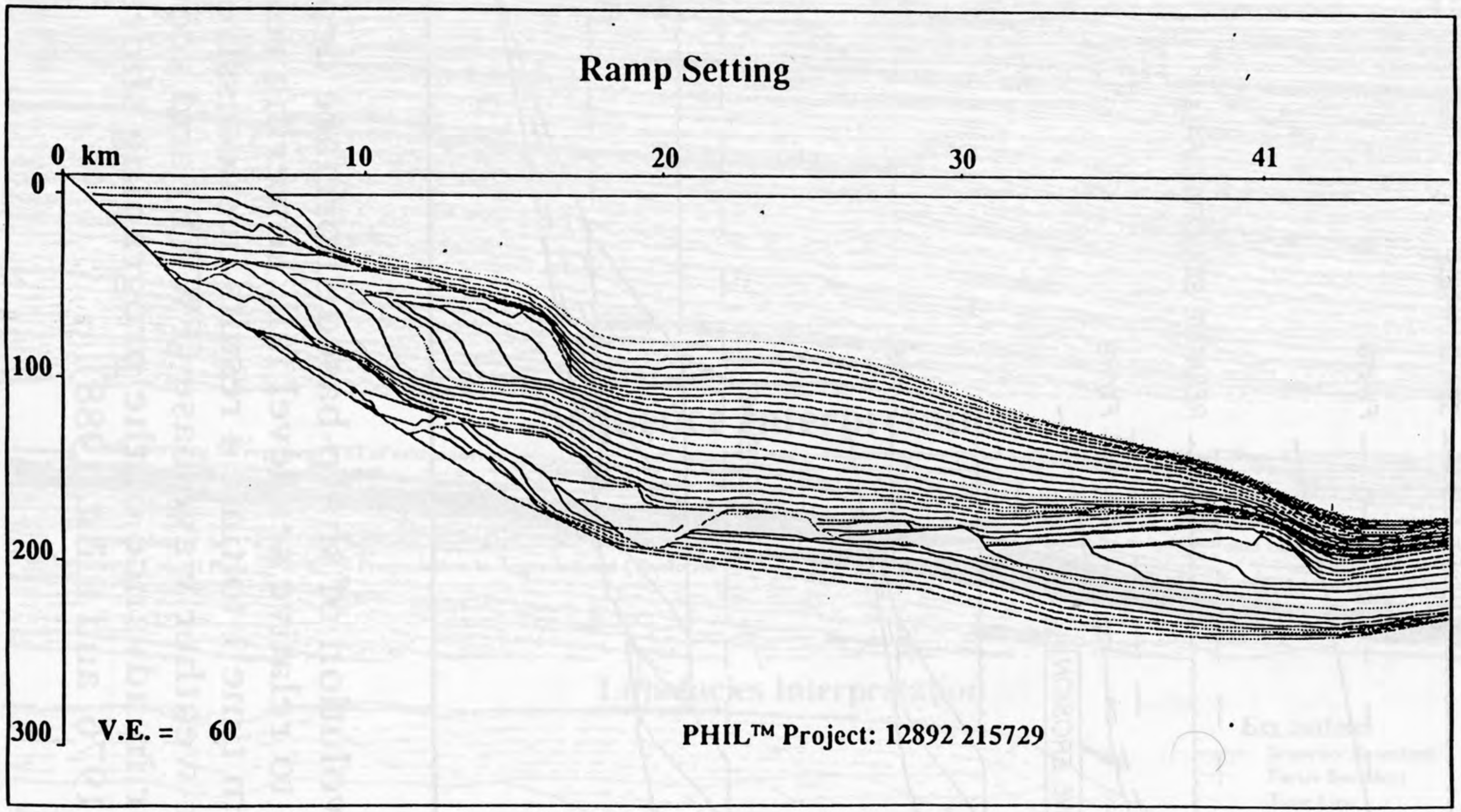

Ramp Setting
0 km
10
20
30
41
0
100
200
300
V.E. = 60
PHIL™ Project: 12892 215729

Fig. 2-18a

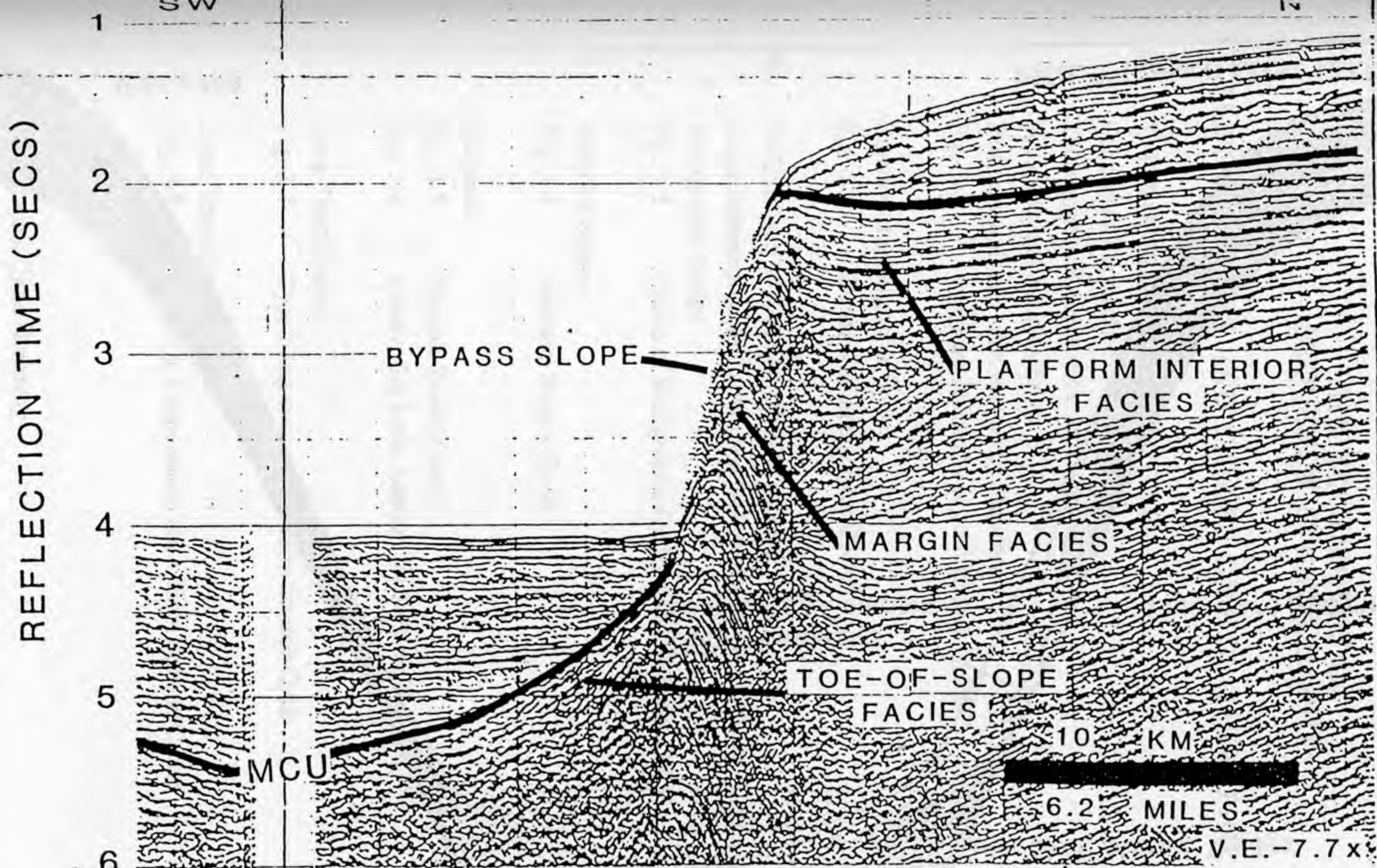
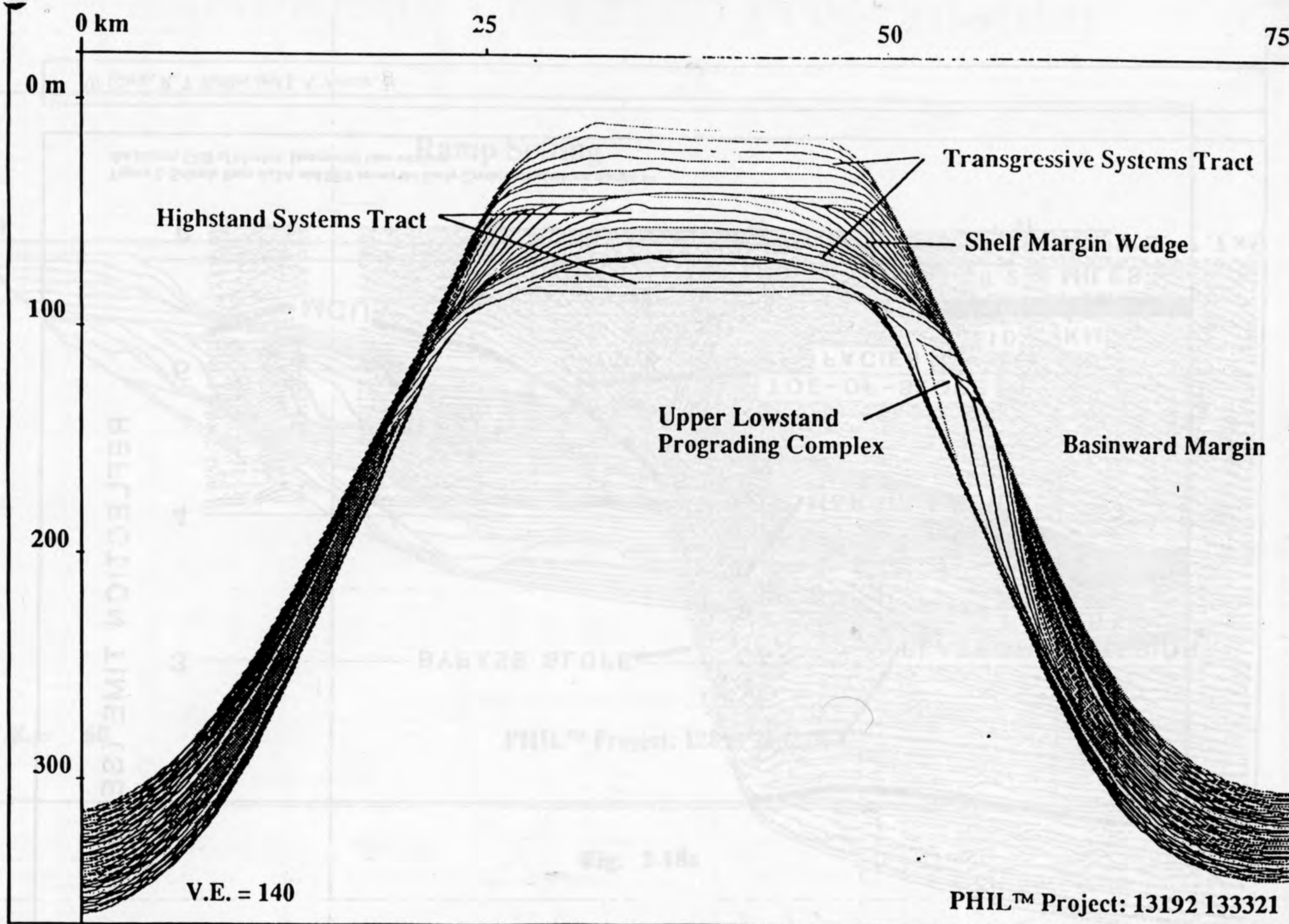


Figure 2. Seismic lines AG-4 and SF-9 across the Early Cretaceous platform margin in the eastern Gulf of Mexico. Interpreted time sections.

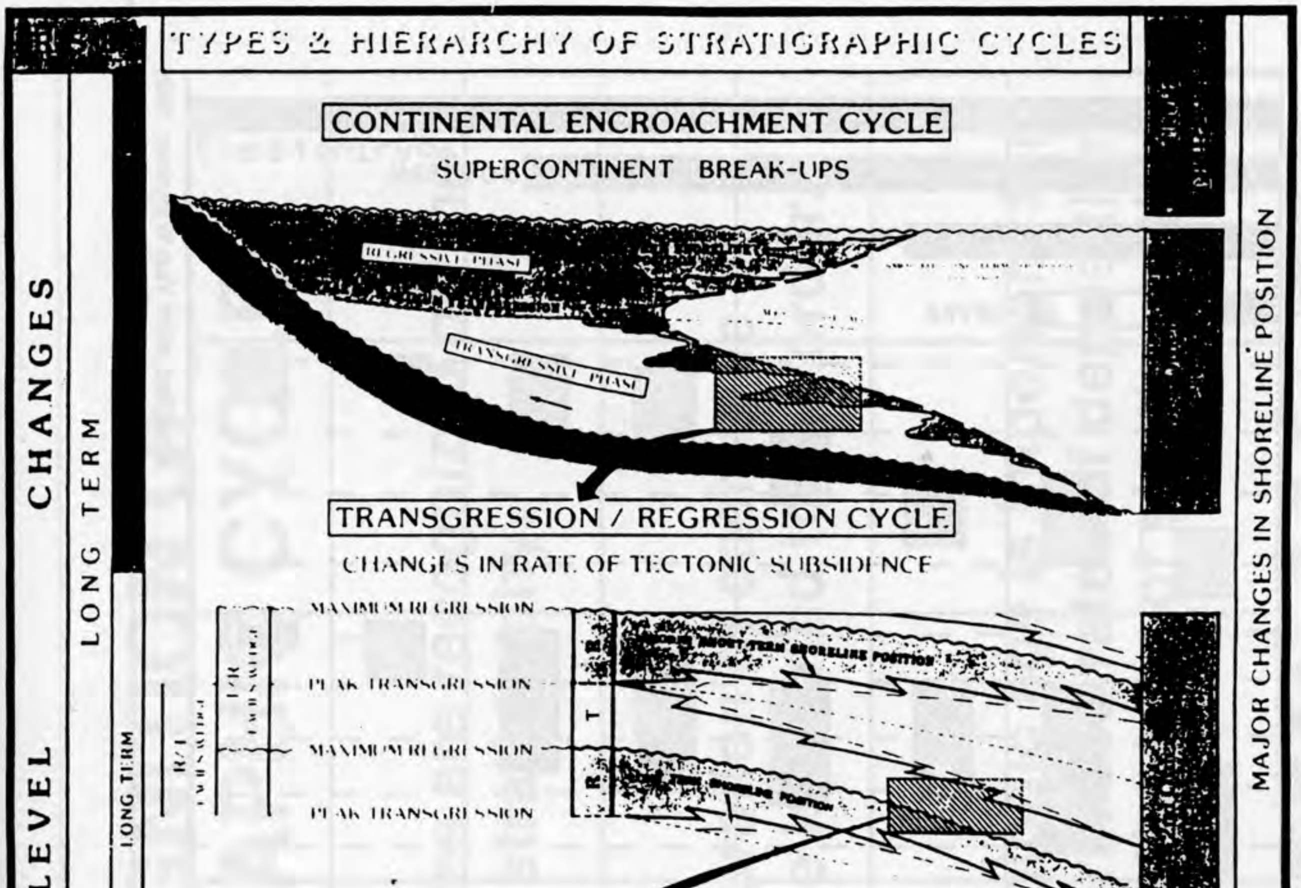

0 km
25
50
75
0 m
100
200
300
Transgressive Systems Tract
Highstand Systems Tract
Shelf Margin Wedge
Upper Lowstand Prograding Complex
Basinward Margin
V.E. = 140
PHIL™ Project: 13192 133321

THE TECHNIQUES OF SEQUENCE STRATIGRAPHY

PART 3: TYPES AND CAUSES OF STRATIGRAPHIC CYCLES

Stratigraphic Cycle Hierarchy

Types of Stratigraphic Cycles and their Causes

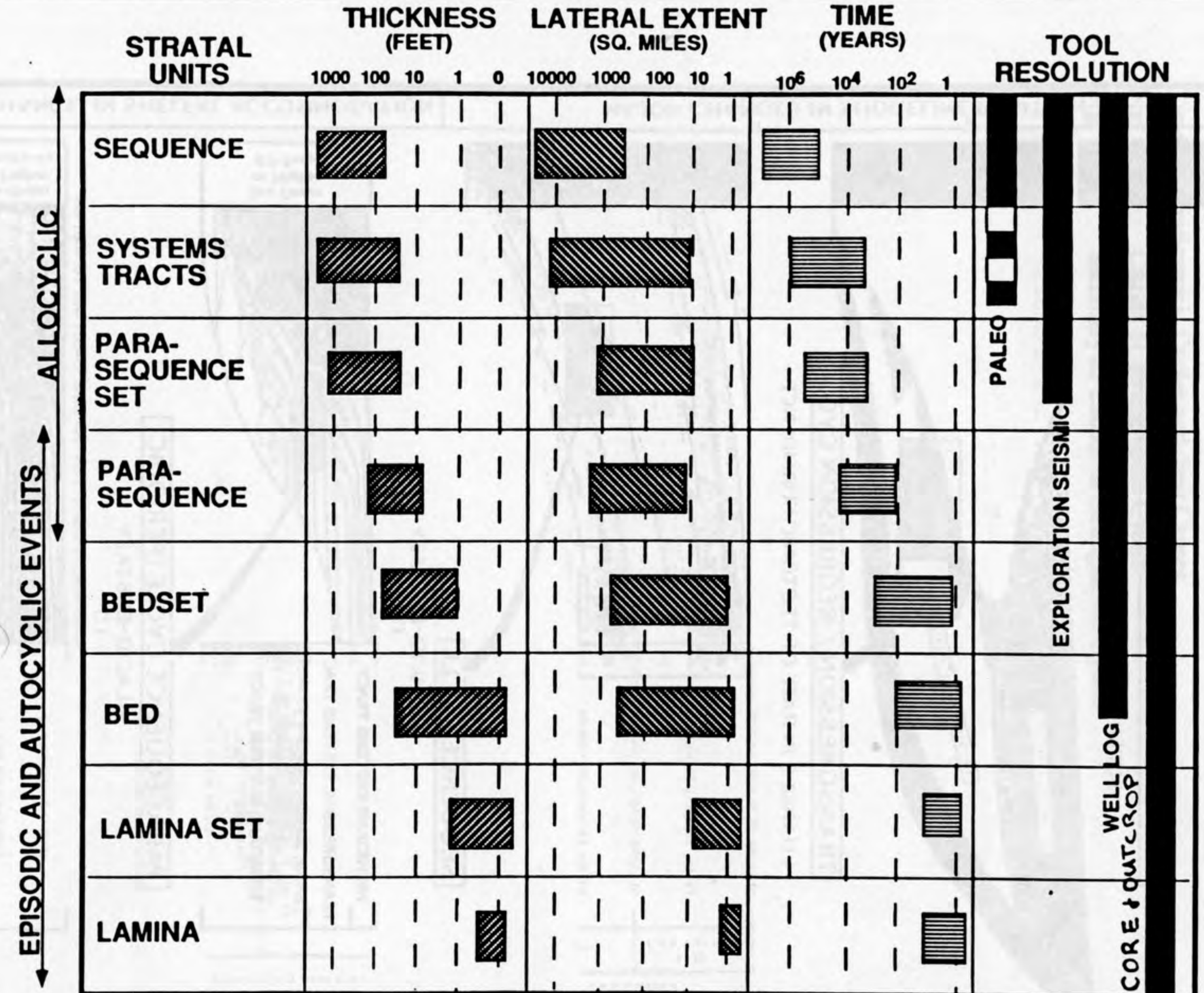


Types & Hierarchy of Stratigraphic Cycles

Fig. 3-1

C.Cramez, 06/92

STRATAL UNITS IN HIERARCHY



Modified after Van Wagoner, 1988

AV 11/92

RECOGNITION OF STRATIGRAPHIC CYCLES

Stratigraphic cycles are recognized on the basis of physical stratigraphy.

The most likely duration of each type of stratigraphic cycle is related to the order.

Knowledge of geologic age is important for determining generalized rates of deposition before identifying the type of stratigraphic cycle.

AV 11/92

STRATIGRAPHIC CYCLE DURATION

Order	Duration
1	50+ My
2	3 to 50 My
3	0.5 to 3 My
4	0.08 to 0.5 My
5	0.03 to 0.08 My
6	0.01 to 0.03 My

Figure 3-2 (AV 10/92)

CAUSES OF STRATIGRAPHIC CYCLES: SIMILARITIES AND DIFFERENCES

Feature	Sediment Supply	Tectonic	Type 2 Eustatic	Type 1 Eustatic
Marine condensed section with Maximum flooding surface	Yes	Yes	Yes	Yes
Maximum flooding surface correlates with maximum rate of accommodation	No	Yes	Yes	Yes
Aggradation during transgression	Minimum	Maximum	Maximum	Maximum
Divergence stratal patterns	Dominant	Major		
Parallel stratal patterns			Dominant	Dominant
Uplift and angular unconformities		Major		
Onlap	Condensed	Major	Major	Major
Base-level fall with erosion	No	Yes	Minor	Yes
Contains a lowstand systems tract	No	No	No	Yes
Contains a shelf margin wedge systems tract		Yes	Yes	No
Globally correlative magitude and timing	No	No	Yes	Yes
Gravity-flow of coarse-grained sediment	No	Minor	No	Yes

Fig. 3-3

Sediment Supply Cycle

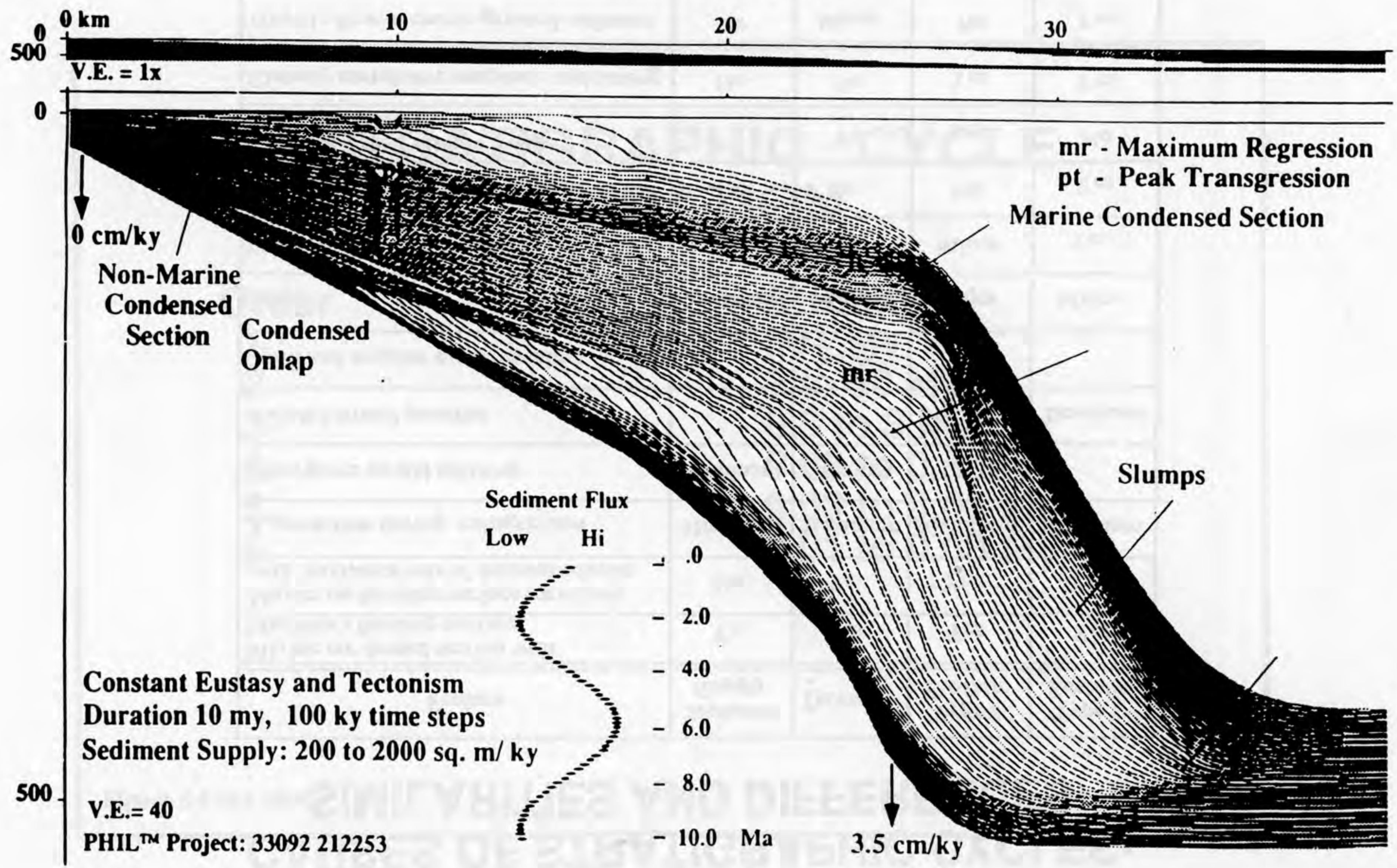


Fig. 3-4

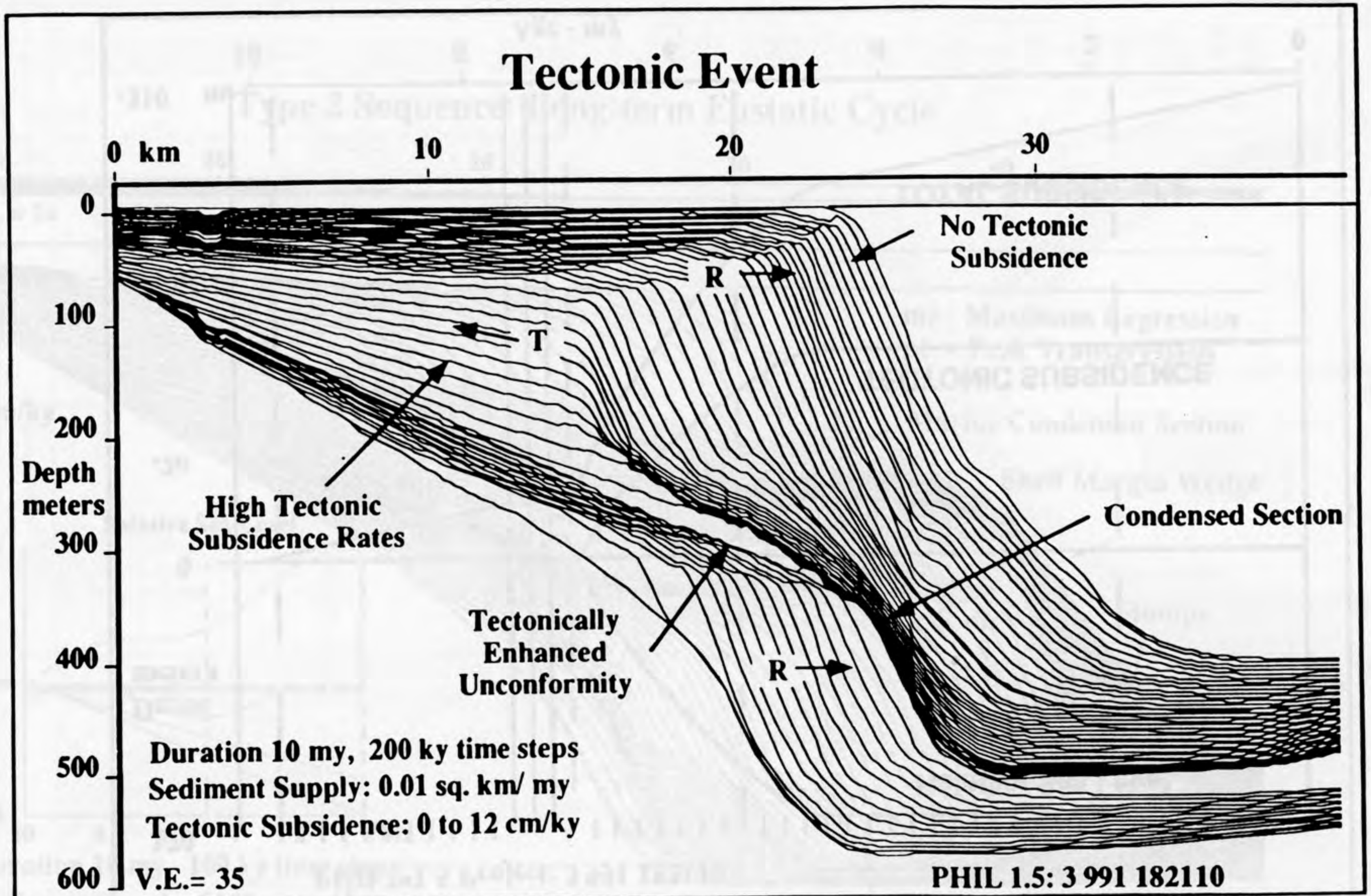

Tectonic Event
0 km
10
20
30
0
100
200
Depth
meters
300
400
500
600
No Tectonic
Subsidence
R
T
High Tectonic
Subsidence Rates
Condensed Section
Tectonically
Enhanced
Unconformity
R
Duration 10 my, 200 ky time steps
Sediment Supply: 0.01 sq. km/ my
Tectonic Subsidence: 0 to 12 cm/ky
V.E.= 35
PHIL 1.5: 3 991 182110

Fig. 3-5

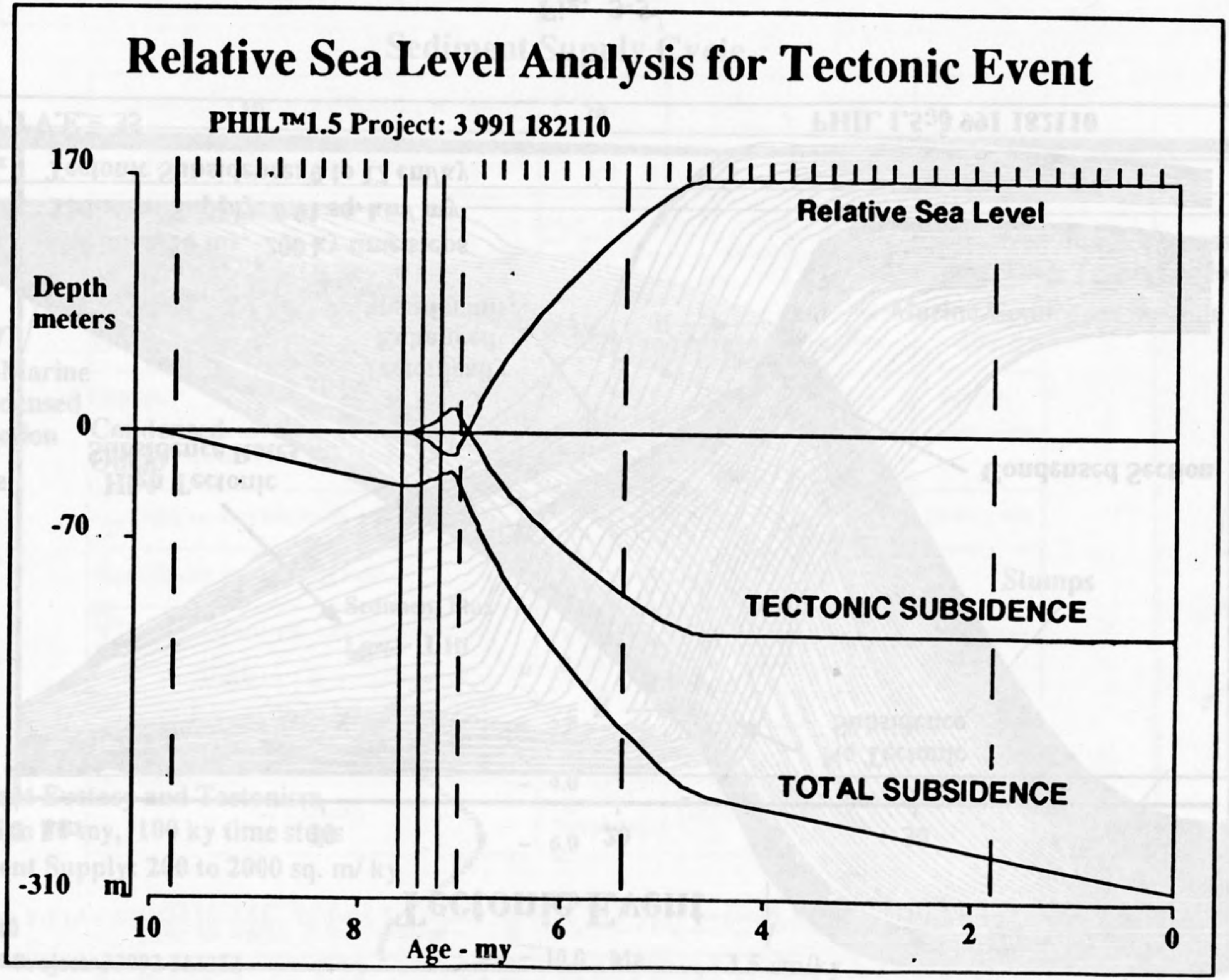

Relative Sea Level Analysis for Tectonic Event
PHIL™1.5 Project: 3 991 182110
170
Depth
meters
0
-70
-310
m
Relative Sea Level
TECTONIC SUBSIDENCE
TOTAL SUBSIDENCE
10
8
6
4
2
0
Age - my

Fig. 3-6

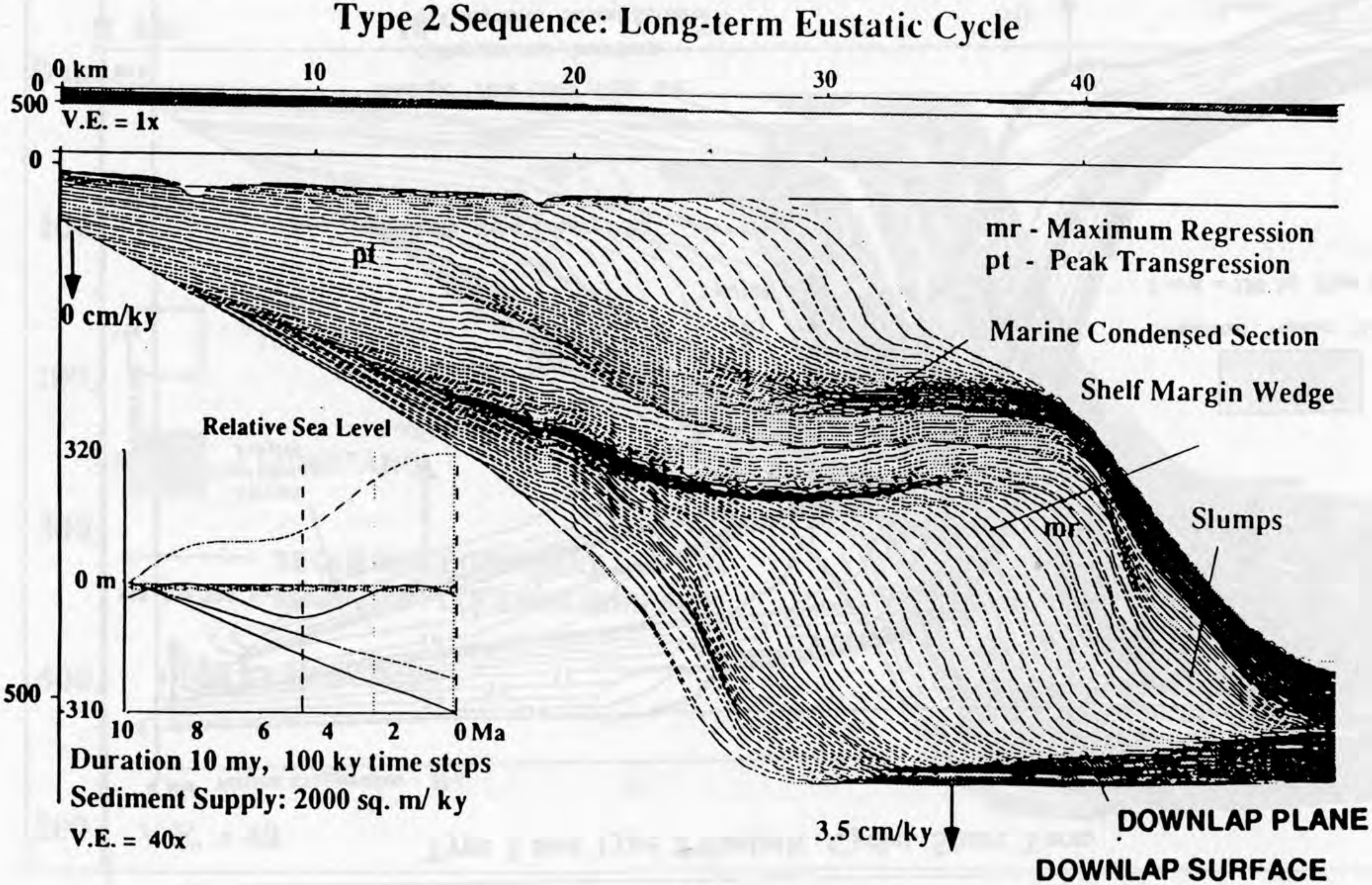
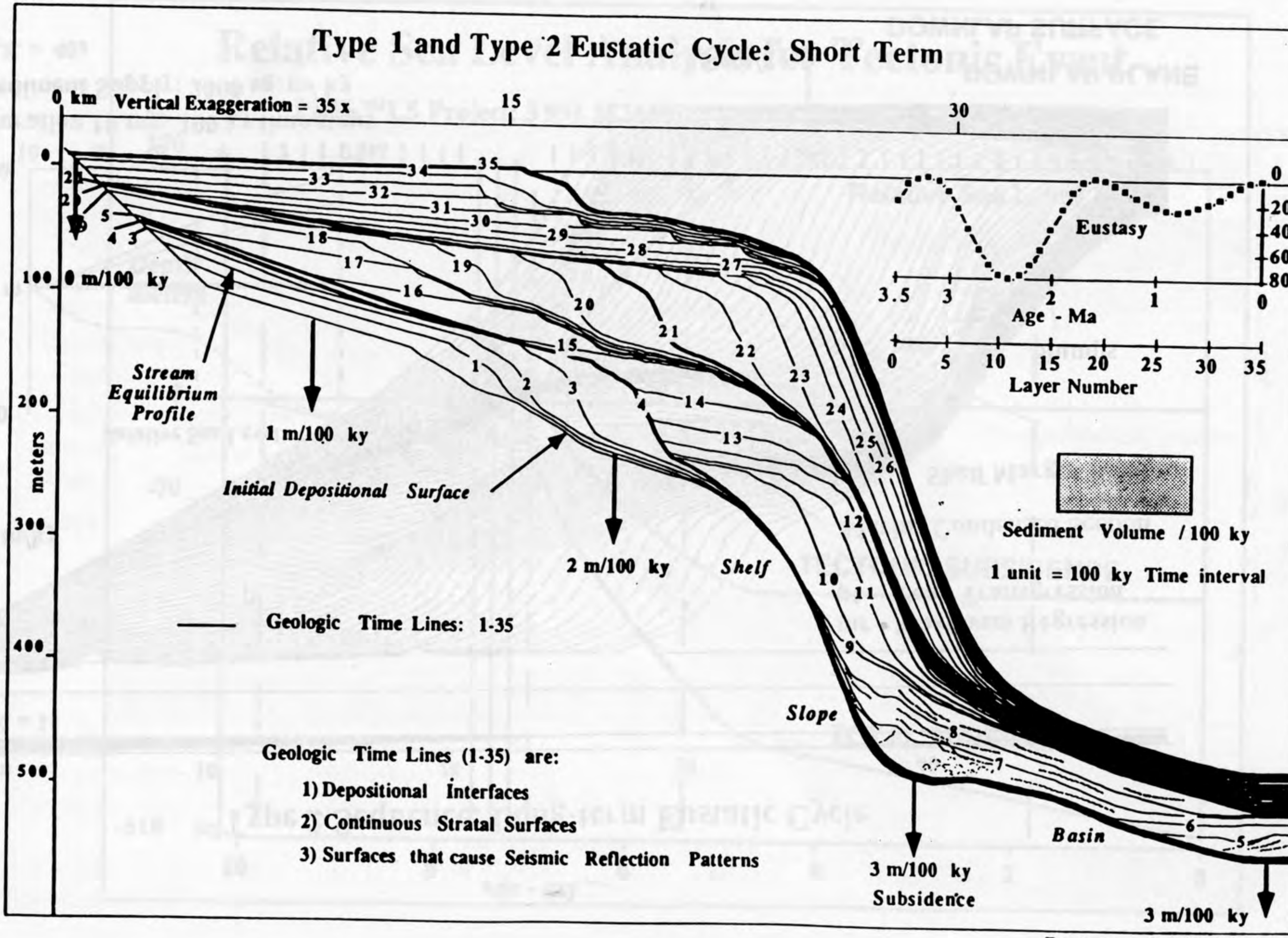

Type 2 Sequence: Long-term Eustatic Cycle
0 km
10
20
30
40
0
500
V.E. = 1x
0
0 cm/ky
pt
mr - Maximum Regression
pt - Peak Transgression
Marine Condensed Section
Shelf Margin Wedge
mr
Slumps
Relative Sea Level
320
0 m
500
-310
10
8
6
4
2
0 Ma
Duration 10 my, 100 ky time steps
Sediment Supply: 2000 sq. m/ ky
V.E. = 40x
3.5 cm/ky
DOWNLAP PLANE
DOWNLAP SURFACE

Fig. 3-7



Bowman 9.26.91.3

Fig. 3-8

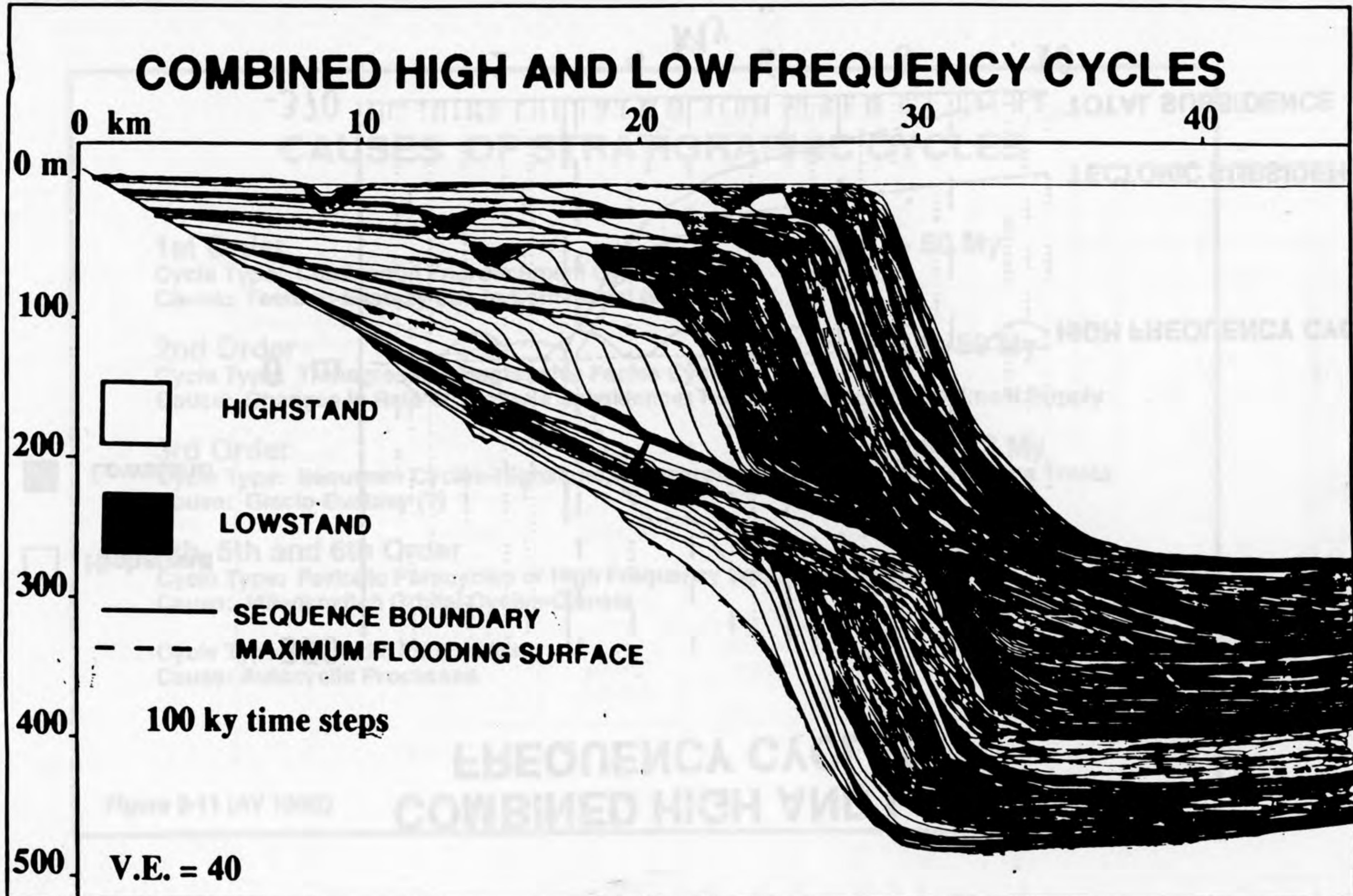

COMBINED HIGH AND LOW FREQUENCY CYCLES
0 km
10
20
30
40
0 m
100
200
300
400
500
HIGHSTAND
LOWSTAND
SEQUENCE BOUNDARY
MAXIMUM FLOODING SURFACE
100 ky time steps
V.E. = 40

Fig. 3-9

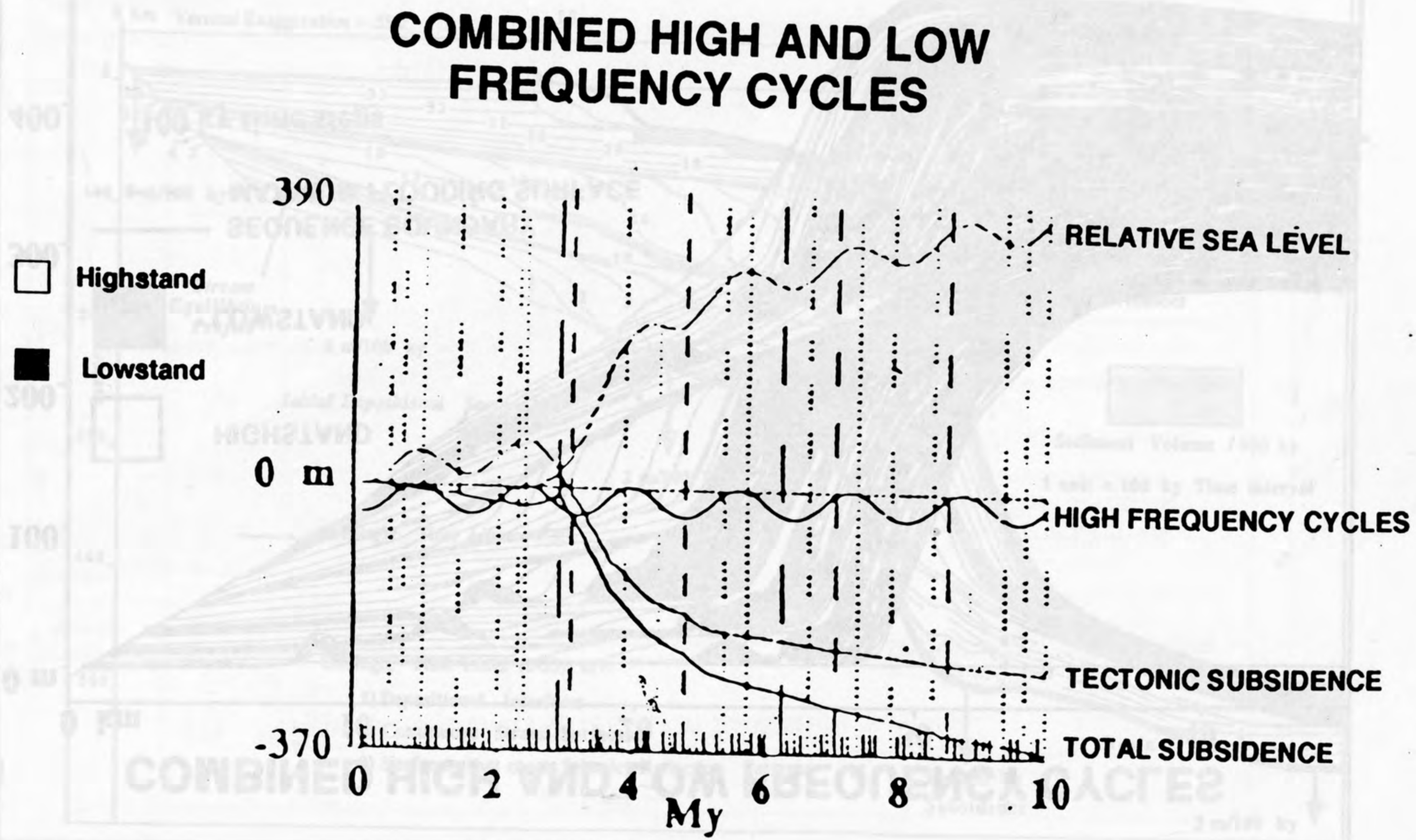

COMBINED HIGH AND LOW FREQUENCY CYCLES
Highstand
Lowstand
390
0 m
-370
0
2
4
6
8
10
My
RELATIVE SEA LEVEL
HIGH FREQUENCY CYCLES
TECTONIC SUBSIDENCE
TOTAL SUBSIDENCE

Fig. 3-10

CAUSES OF STRATIGRAPHIC CYCLES

1st Order — **> 50 My**
Cycle Type: Continental Encroachment Cycles
Cause: Tectono-Eustasy due to Continental Breakup

2nd Order — **3 to 50 My**
Cycle Type: Transgressive/Regressive Facies Cycles
Cause: Changes in Rate of Tectonic Subsidence, Tectono-Eustasy or Sediment Supply

3rd Order — **0.5 to 3 My**
Cycle Type: Sequence Cycles-Highstand, Transgressive and Lowstand Systems Tracts
Cause: Glacio-Eustasy (?)

4th, 5th and 6th Order — **< 0.5 My**
Cycle Type: Periodic Paracycles or High Frequency Sequence Cycles
Cause: Milankovitch Orbital Cycles-Climate

Cycle Type: Episodic Paracycles
Cause: Autocyclic Processes

Figure 3-11 (AV 10/92)

SUMMARY OF CAUSES OF STRATIGRAPHIC CYCLES

	Tectonics			Eustasy			Sedimentation
Signatures	Sedimentary basin	Major Transgressive/ Regressive facies cycle	Folding Faulting Magmatism and Diapirism	Major continental flooding cycle	Major Transgressive/ Regressive facies cycle	Sequence cycle Systems tracts Periodic parasequence	Depositional system Lithofacies tracts Episodic parasequence Marker beds Beds Laminae
Distribution in space	Regional	Regional	Local + Regional	Global	Global	Global	Local
Distribution in time	1st Order Episodic Event	2nd Order Non-periodic	3rd Order + Episodic Event	1st Order Cycle	2nd Order Cycle	3th-6th Order Cycles	Episodic Event
Causes	Crustal extension Thermal cooling Flexure loading	Changes in rate of 1) Tectonic subsidence 2) Sediment supply	Local and regional stress release	Changes in ocean basin volume	Changes in ocean basin volume	Changes in climate, water volume	Local sedimentary processes

Signatures in the stratigraphic record. This diagram presents the distribution in time and space of the six stratigraphic signatures in the rock record

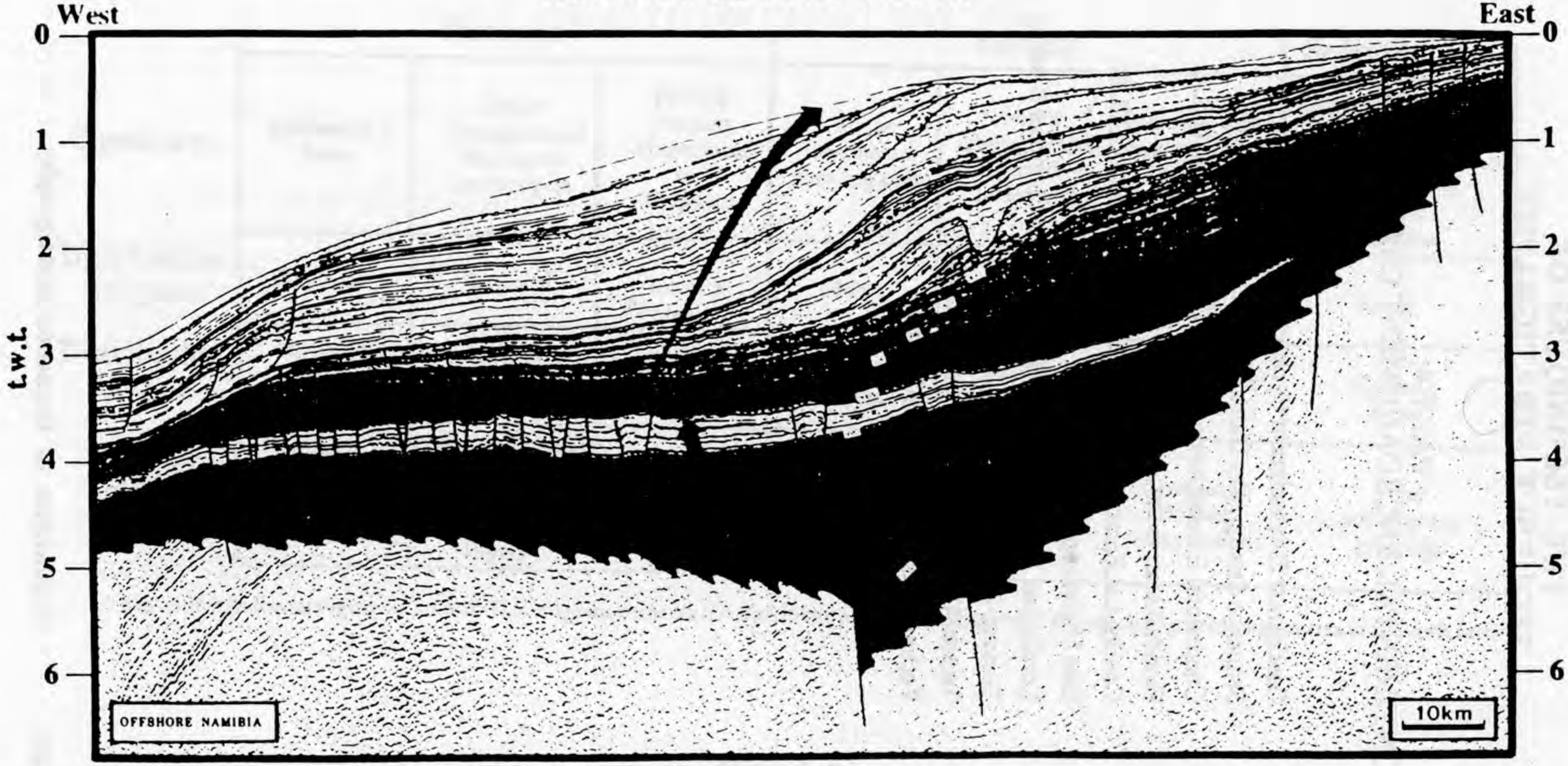
Fig. 3-12

THE TECHNIQUES OF SEQUENCE STRATIGRAPHY

PART 4: CONTINENTAL ENCROACHMENT CYCLE WEDGES

Post-Pangea Continental Encroachment Cycle

Marine source rocks



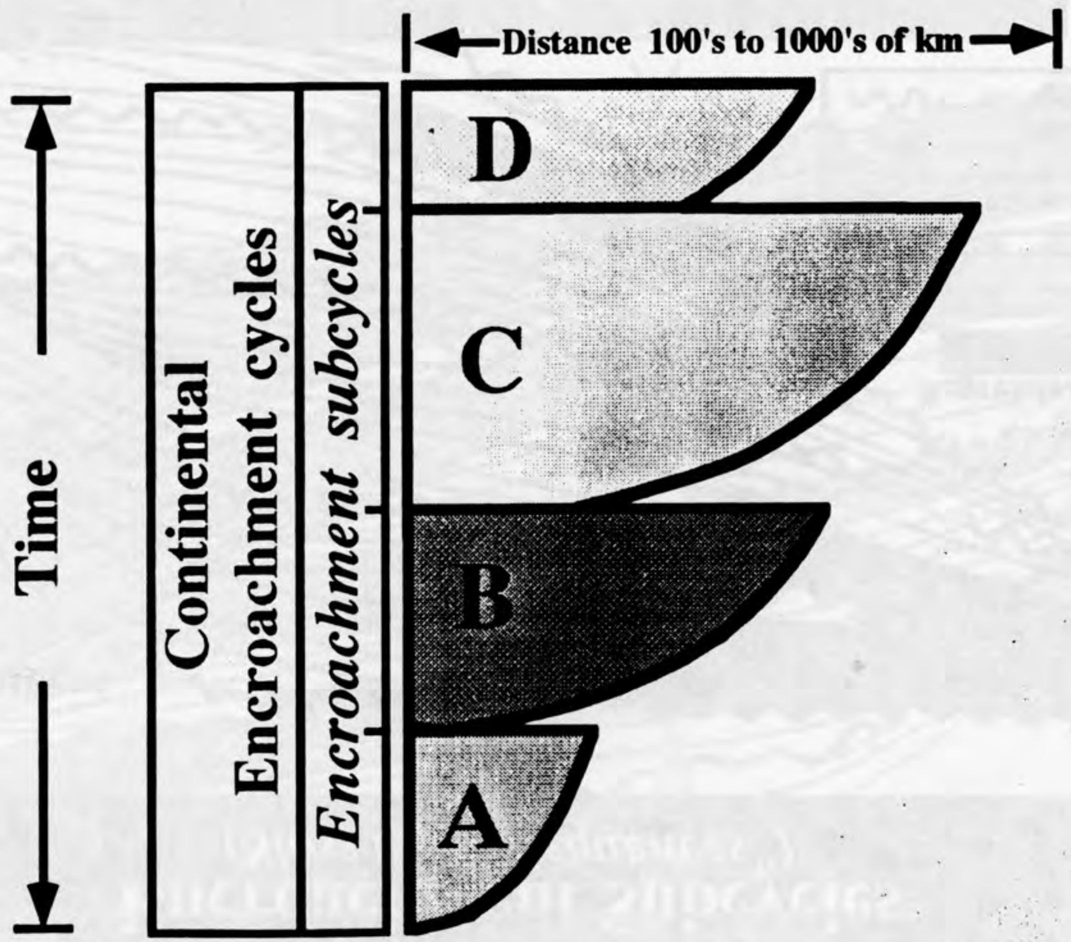
Offshore Namibia

Courtesy of ECL

The picking of the limit between the transgressive and regressive phase of this offshore of the post-Pangea Continental Stratigraphic Continental Cycle emphasizes the more likely marine source rocks of this offshore. Unfortunately, as we can see in this seismic line the condensed stratigraphic section associated to these potential source rocks has not buried enough; the organic matter of these source rocks is immature and consequently he hydrocarbon potential of this offshore is very poor.

Fig. 4-1

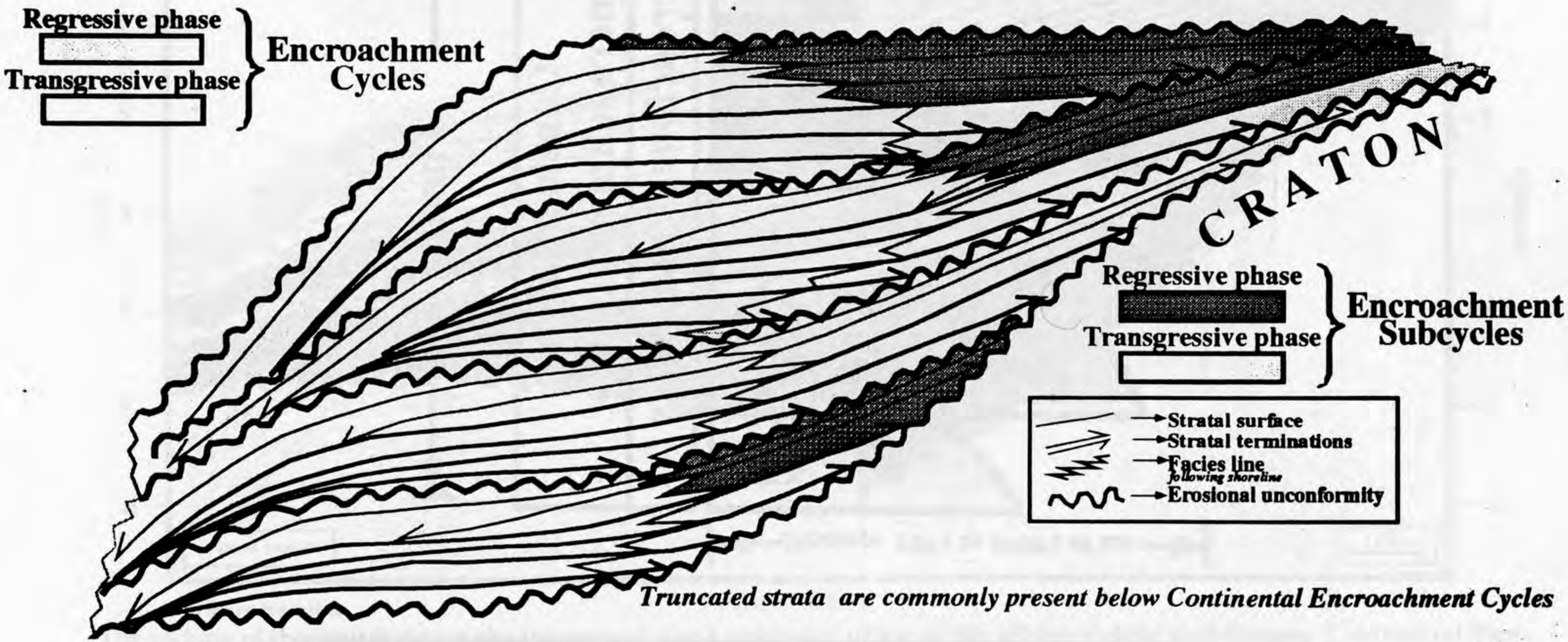
Continental Encroachment Cycles & Subcycles



P. Vail

C.Cramez
B. Duval, 1993

Continental Encroachment Cycles and Encroachment Subcycles
(Sloss type "Sequences")



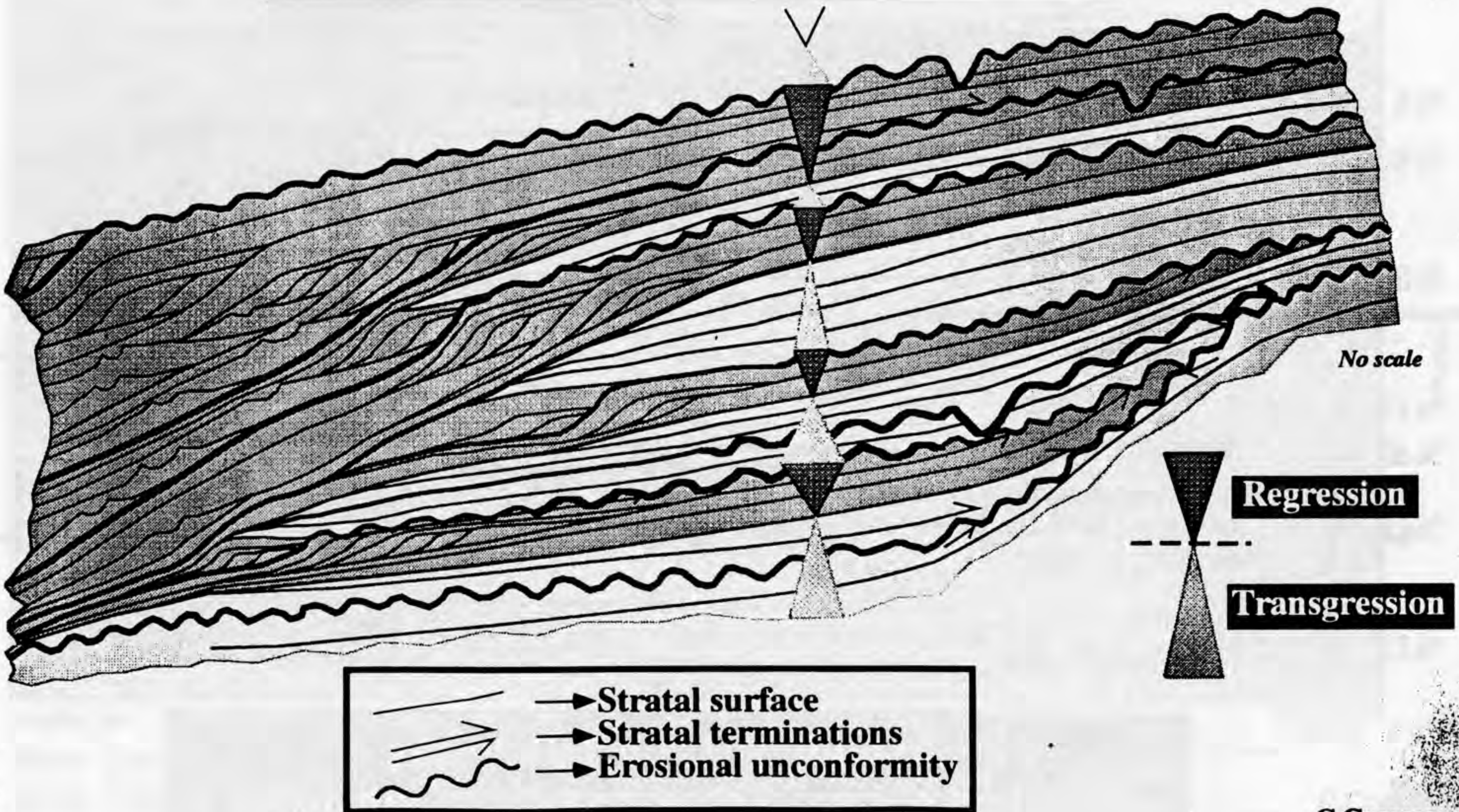
Truncated strata are commonly present below Continental Encroachment Cycles

Encroachment Subcycles are characterized by Major Downward Shifts in Continental Encroachment.

P. Vail

C.Cramez
B. Duval, 1993

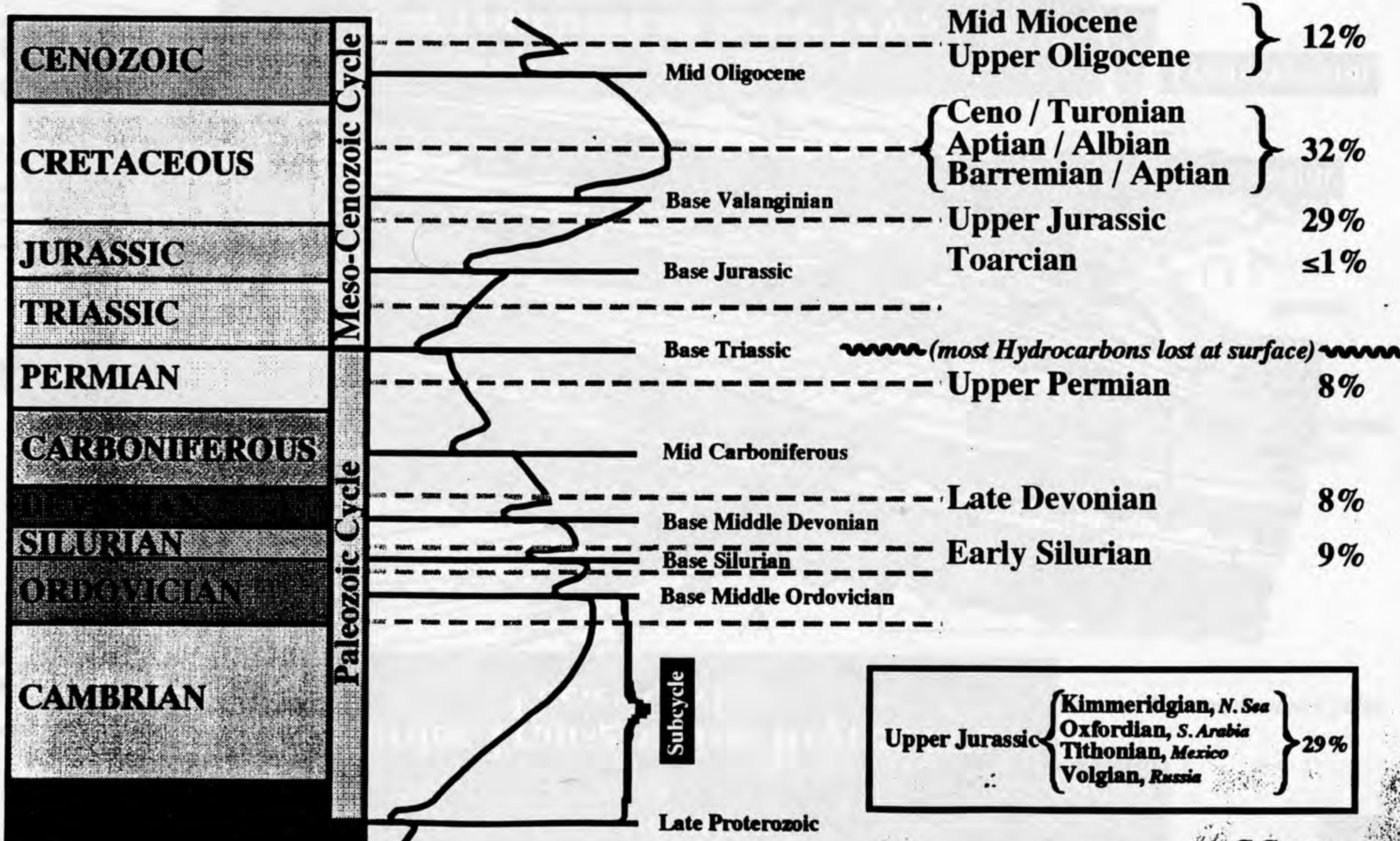
1st order Encroachment Cycle and 2nd order Transgressive/ Regressives Facies Cycles



P. Vail

C.Cramez
B. Duval, 1993

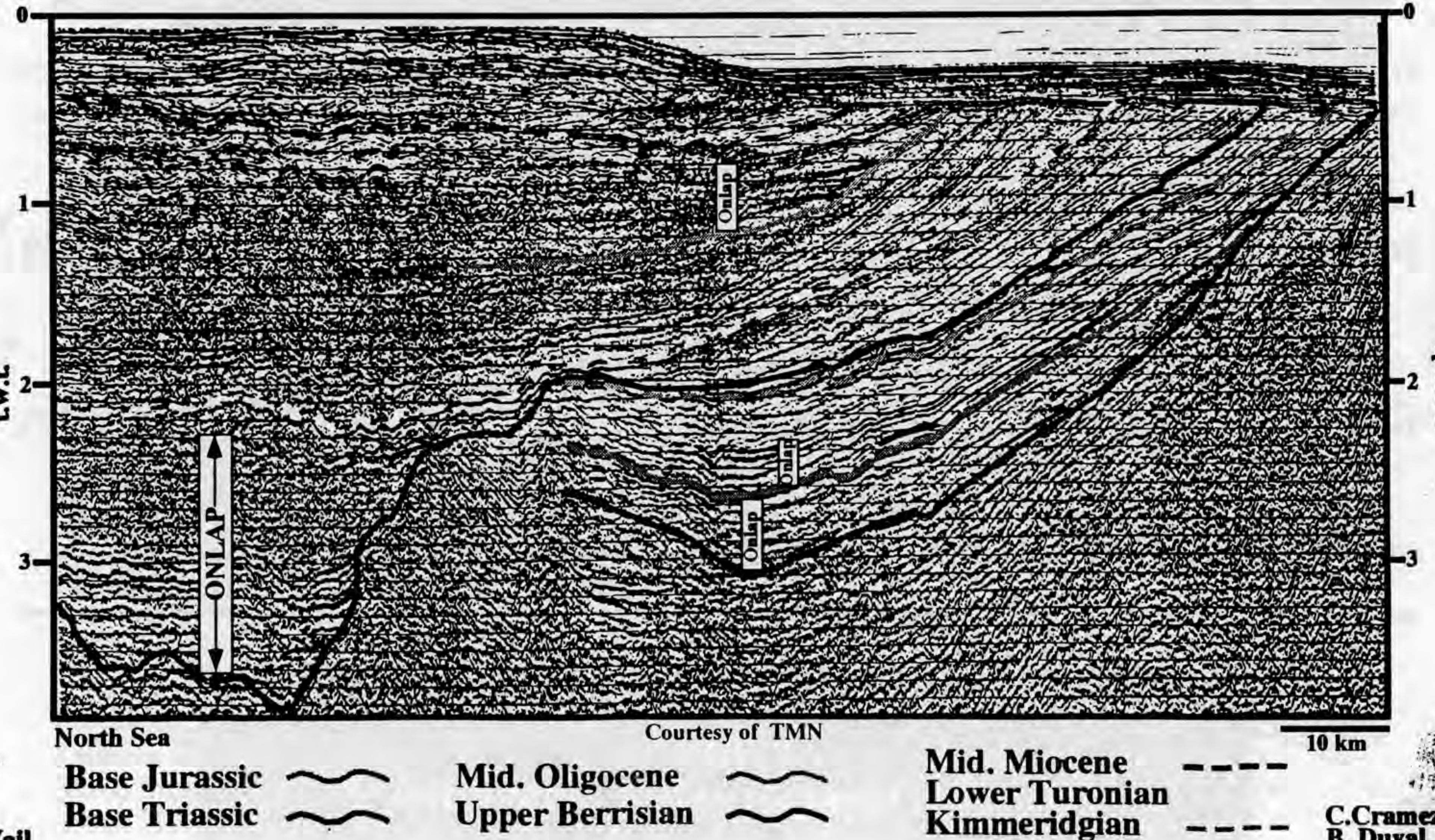
Continental Encroachment Cycles & Subcycles
Major Organic rich intervals



P. Vail

C. Cramez
B. Duval, 1993

Continental Encroachment Subcycles within Meso-Cenozoic Continental Encroachment Cycle



P. Vail

C.Cramez
B. Duval, 1993

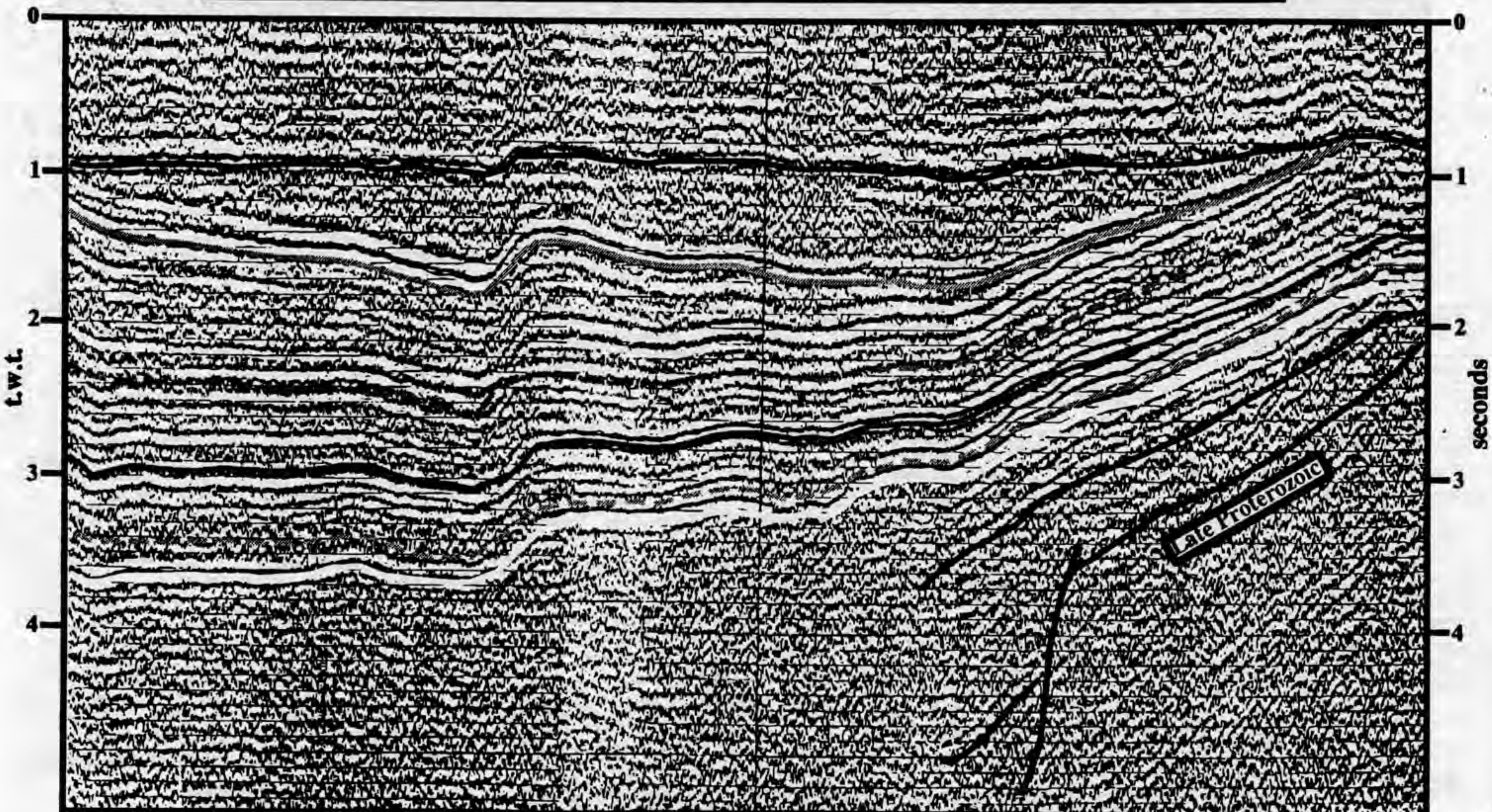
Continental Encroachment Subcycles within Meso-Cenozoic Continental Encroachment Cycle

Courtesy of TMN

P. Vail

C.Cramez
B. Duval, 1993

Continental Encroachment Subcycles within Paleozoic Continental Encroachment Cycle



Onshore Algeria

Courtesy of Sonatrach

Base Silurian

Base Mid. Ordovician

Base Mid. Carboniferous

Base Mid. Devonian

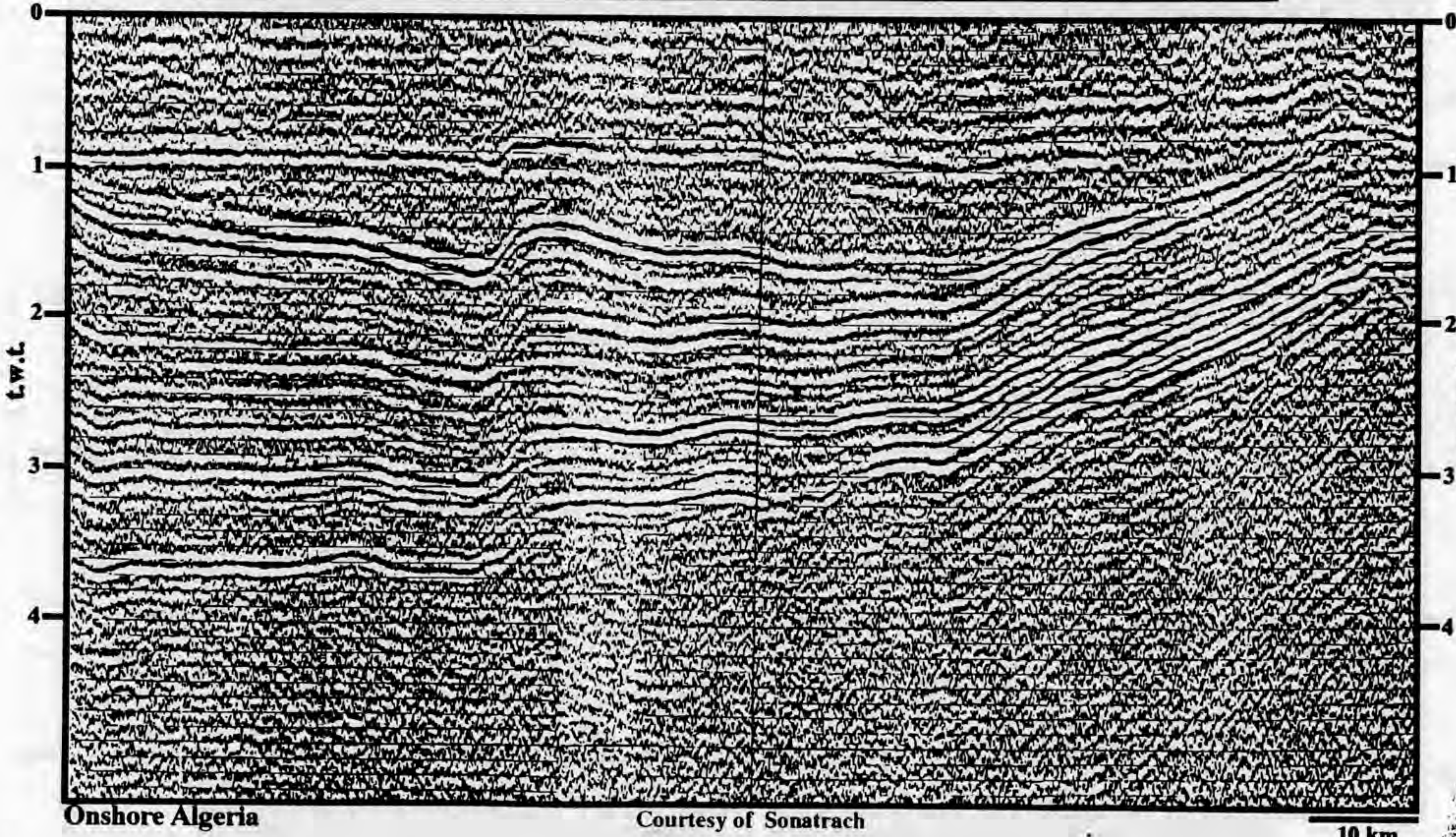
Late Devonian

Early Silurian

P. Vail

C.Cramez
B. Duval, 1993

Continental Encroachment Subcycles within Paleozoic Continental Encroachment Cycle

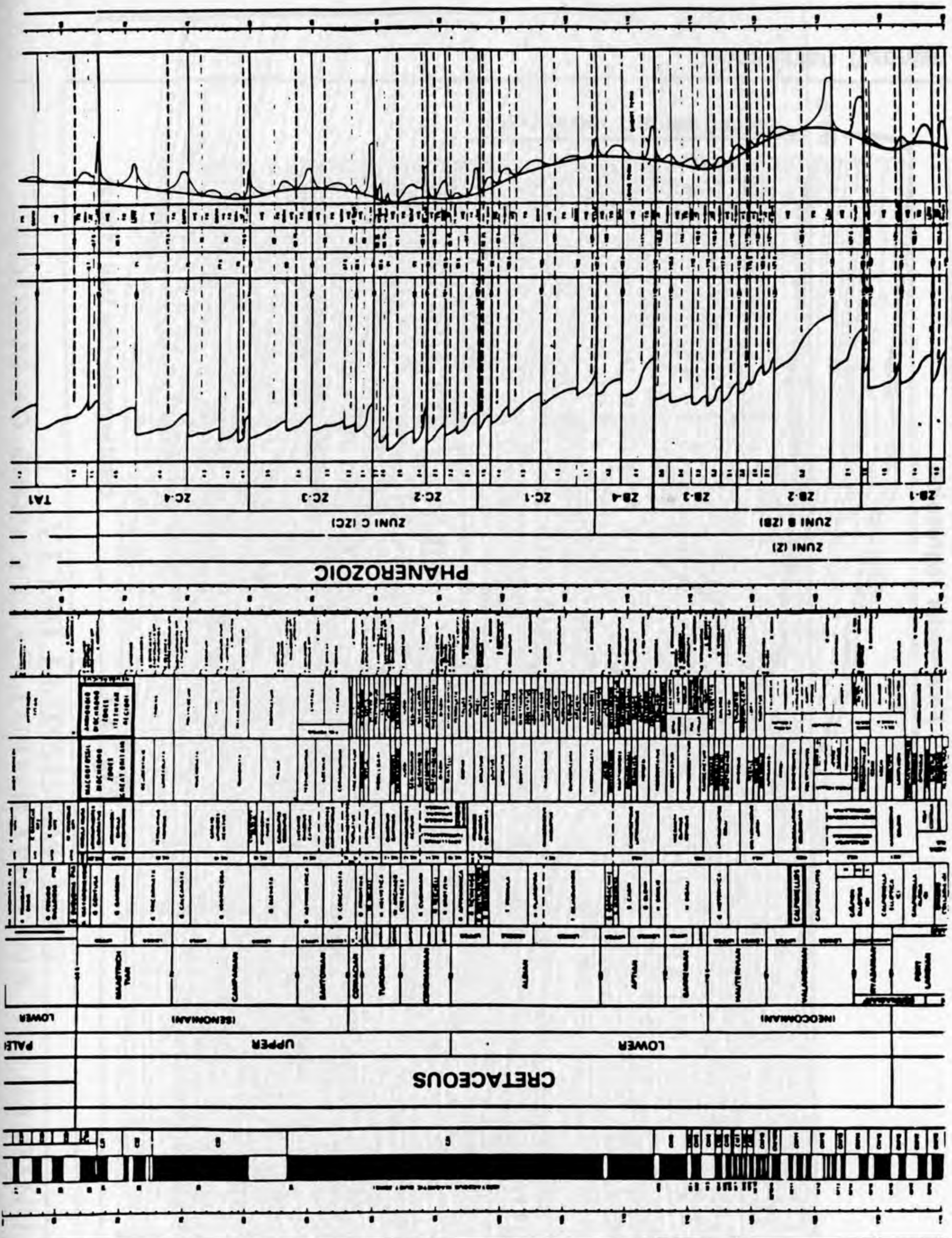


Onshore Algeria

Courtesy of Sonatrach

P. Vail

C.Cramez
B. Duval, 1993



Cretaceous chronostratigraphy and cycles of sea level change. Linear time scale is in millions of years beforepresent. Collaborators for the Cretaceous cycle chart are B.U. Haq, J. Harenbol, P.R. Vail, L.E. Stover, ?. Wright and R. Jan du Chene. For Sources and references in Haq and others ..987b). Slightly modified after Haq and others (1987a).

Fig. 4-2

CONTINENTAL ENCROACHMENT CYCLE-GULF OF MEXICO FLORIDA ESCARPMENT

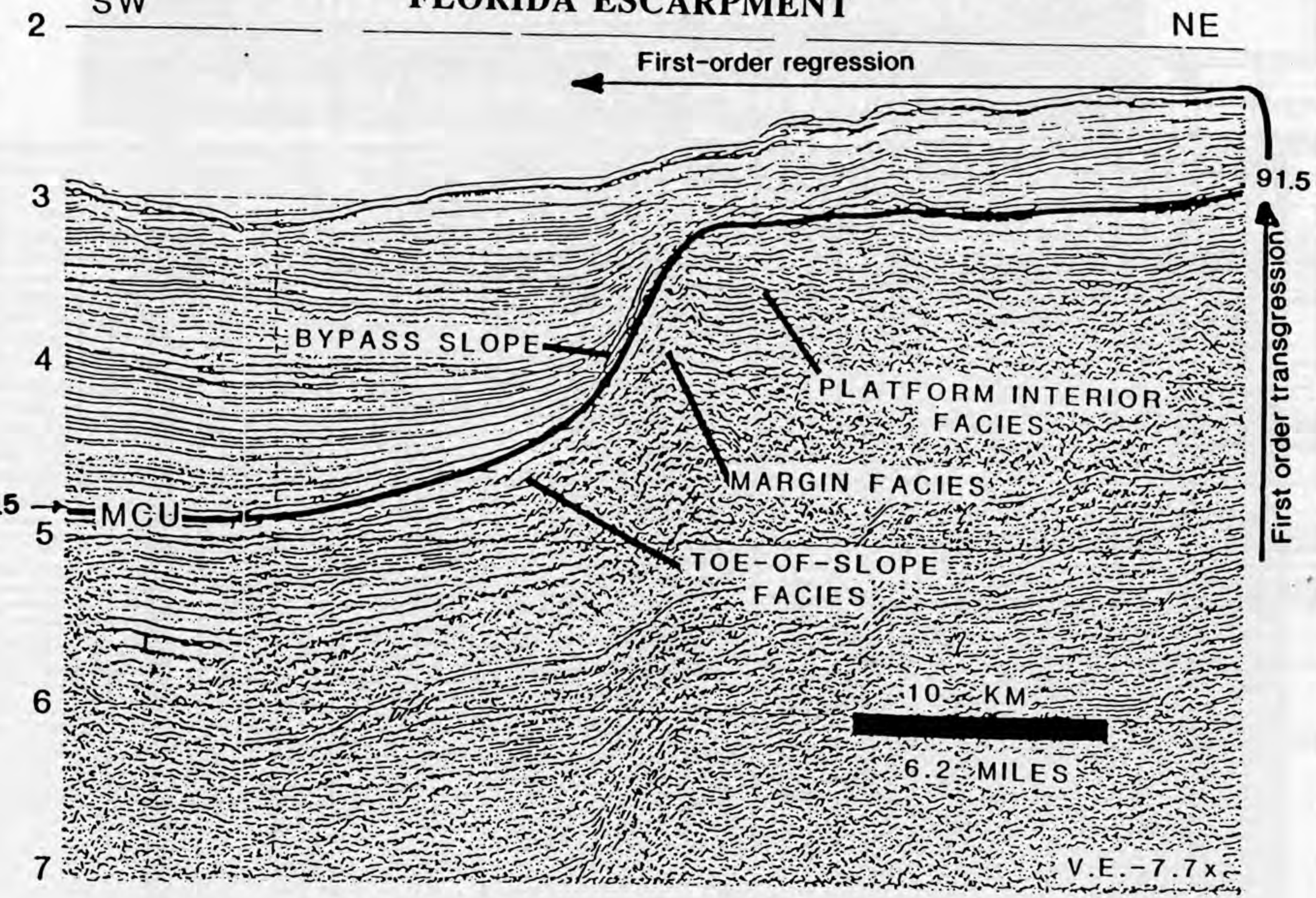


Fig. 4-3 reinterpreted by Vail (1991)

Erosion of the southern Florida escarpment

CONTINENTAL ENCROACHMENT CYCLE-GULF OF MEXICO
EAST MISSISSIPPI DELTA

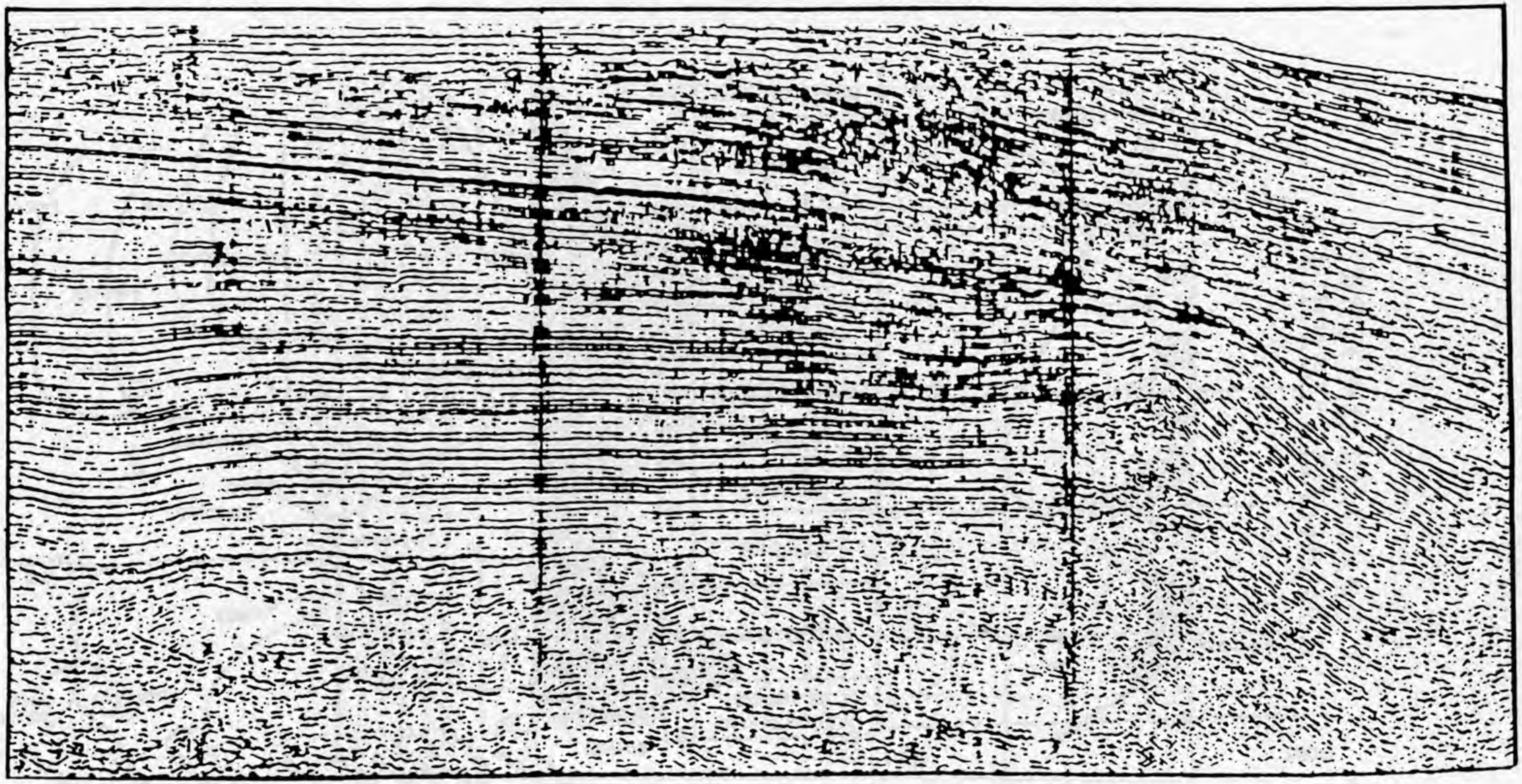


Fig. 4-4

CONTINENTAL ENCROACHMENT CYCLES AND SUPER-CONTINENT BREAKUP

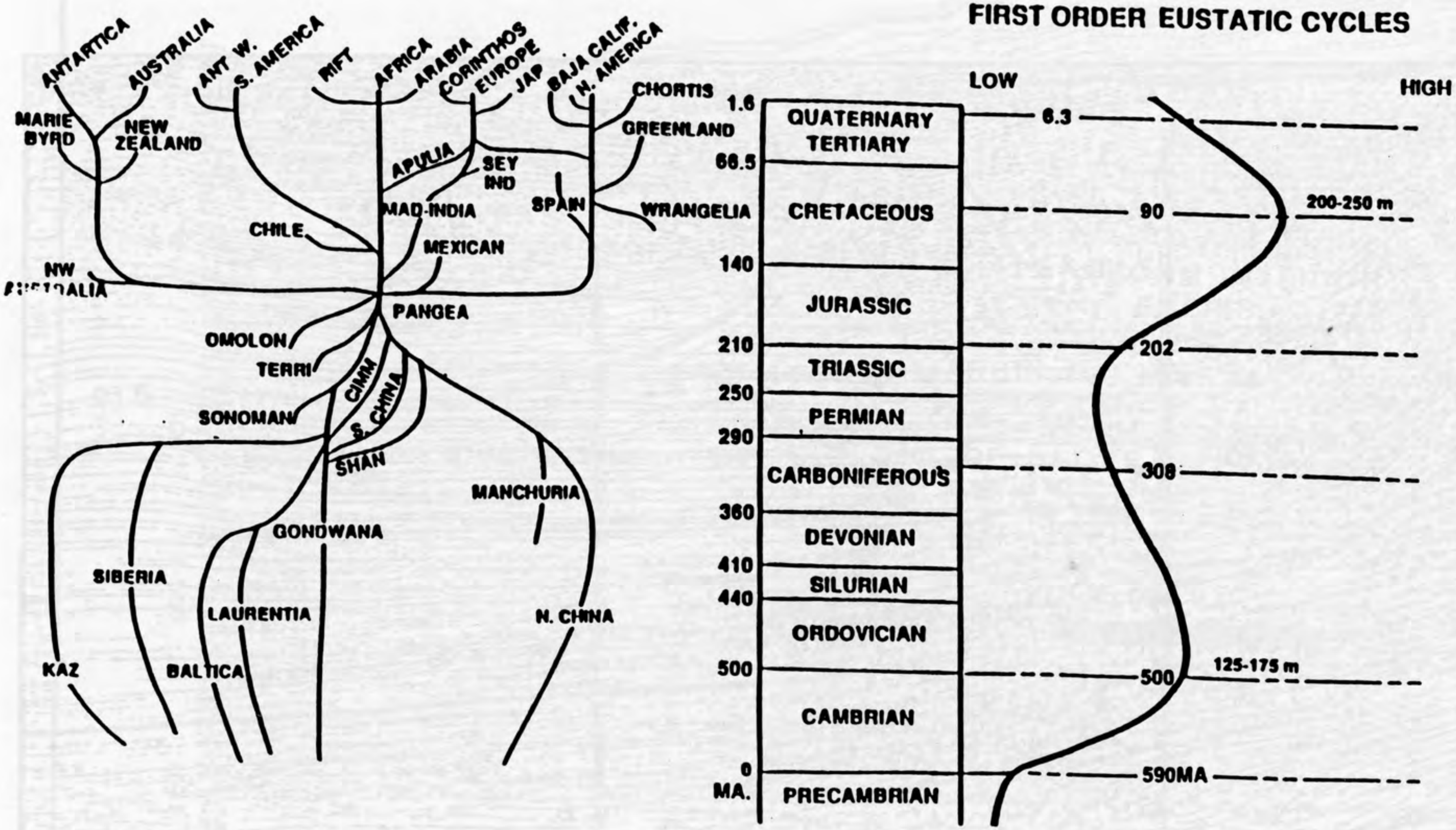


Fig. 4-5

TECTONO-EUSTASY
ICEHOUSE / GASHOUSE

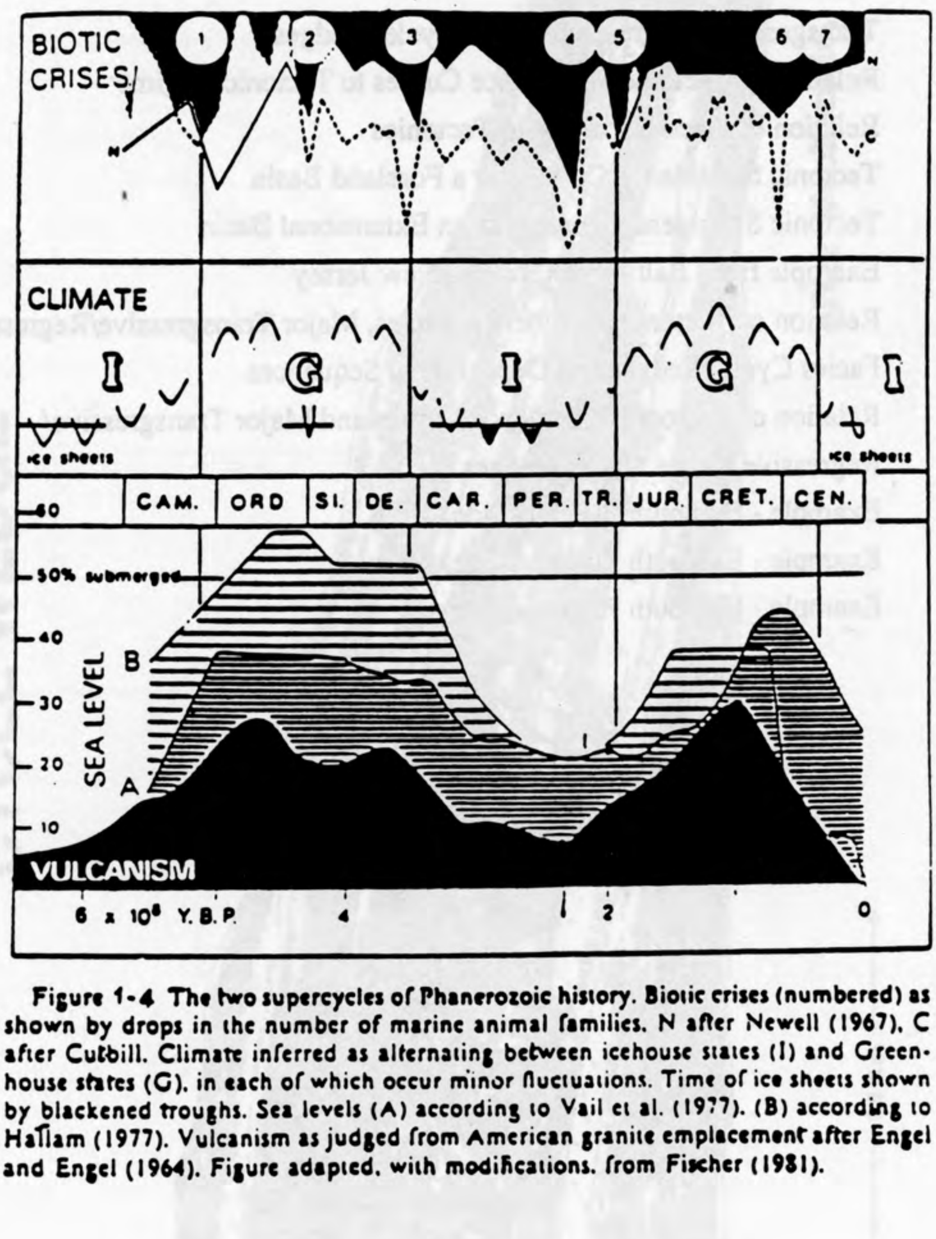


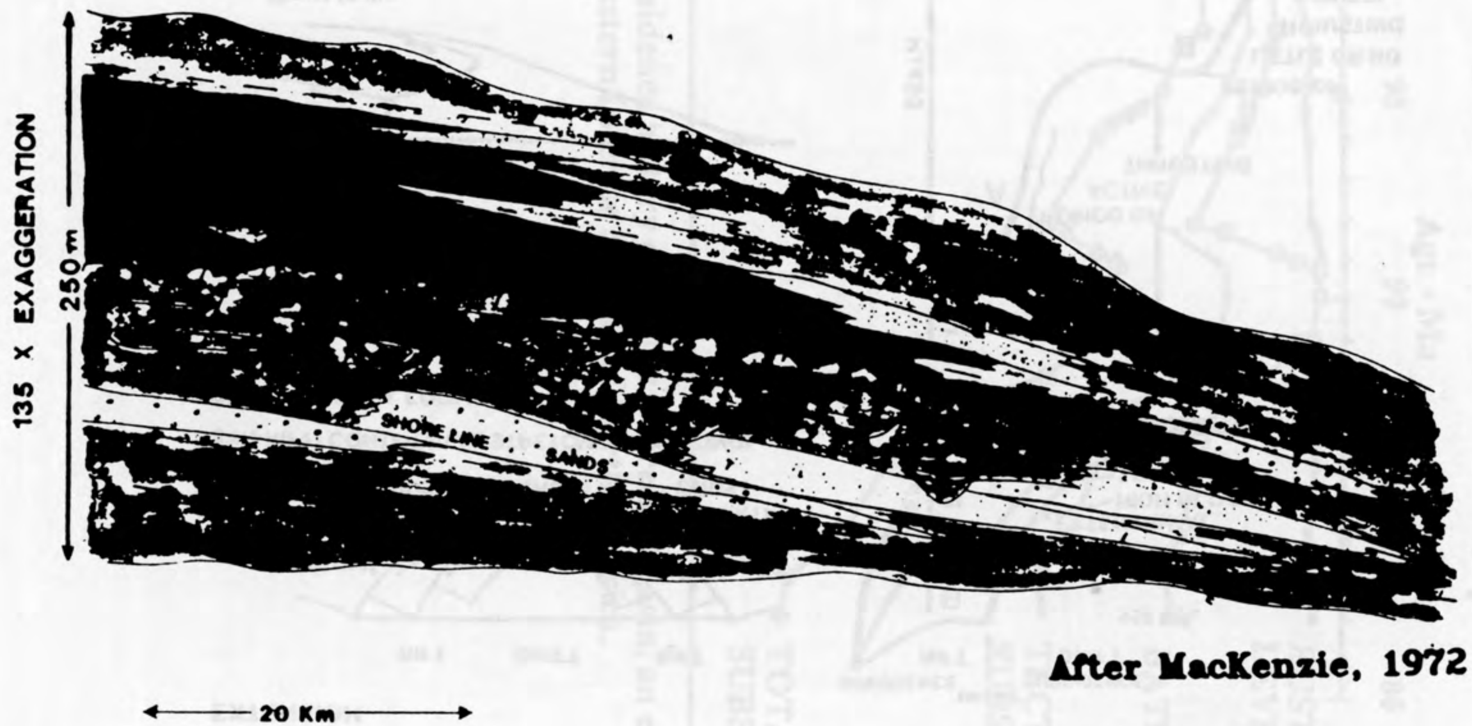
Figure 1-4 The two supercycles of Phanerozoic history. Biotic crises (numbered) as shown by drops in the number of marine animal families. N after Newell (1967). C after Cutbill. Climate inferred as alternating between icehouse states (I) and Greenhouse states (G). in each of which occur minor fluctuations. Time of ice sheets shown by blackened troughs. Sea levels (A) according to Vail et al. (1977). (B) according to Hallam (1977). Vulcanism as judged from American granite emplacement after Engel and Engel (1964). Figure adapted, with modifications, from Fischer (1981).

Fig. 4-8

THE TECHNIQUES OF SEQUENCE STRATIGRAPHY

PART 5: TRANSGRESSIVE/REGRESSIVE FACIES CYCLE WEDGES

TRANSGRESSIVE-REGRESSIVE FACIES CYCLE WEDGE



After MacKenzie, 1972

Fig. 5-1

RELATION OF TECTONIC SUBSIDENCE CURVES TO TECTONIC REGIME

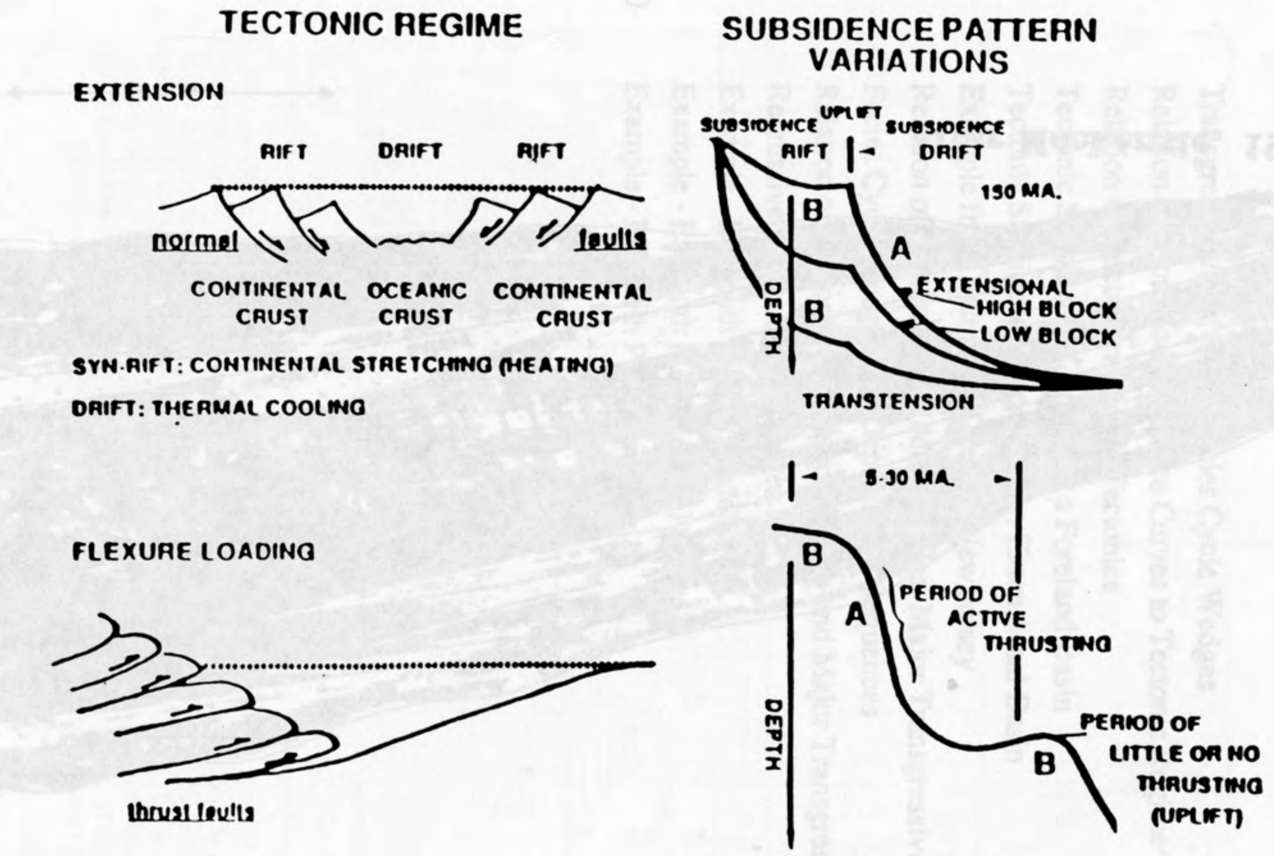
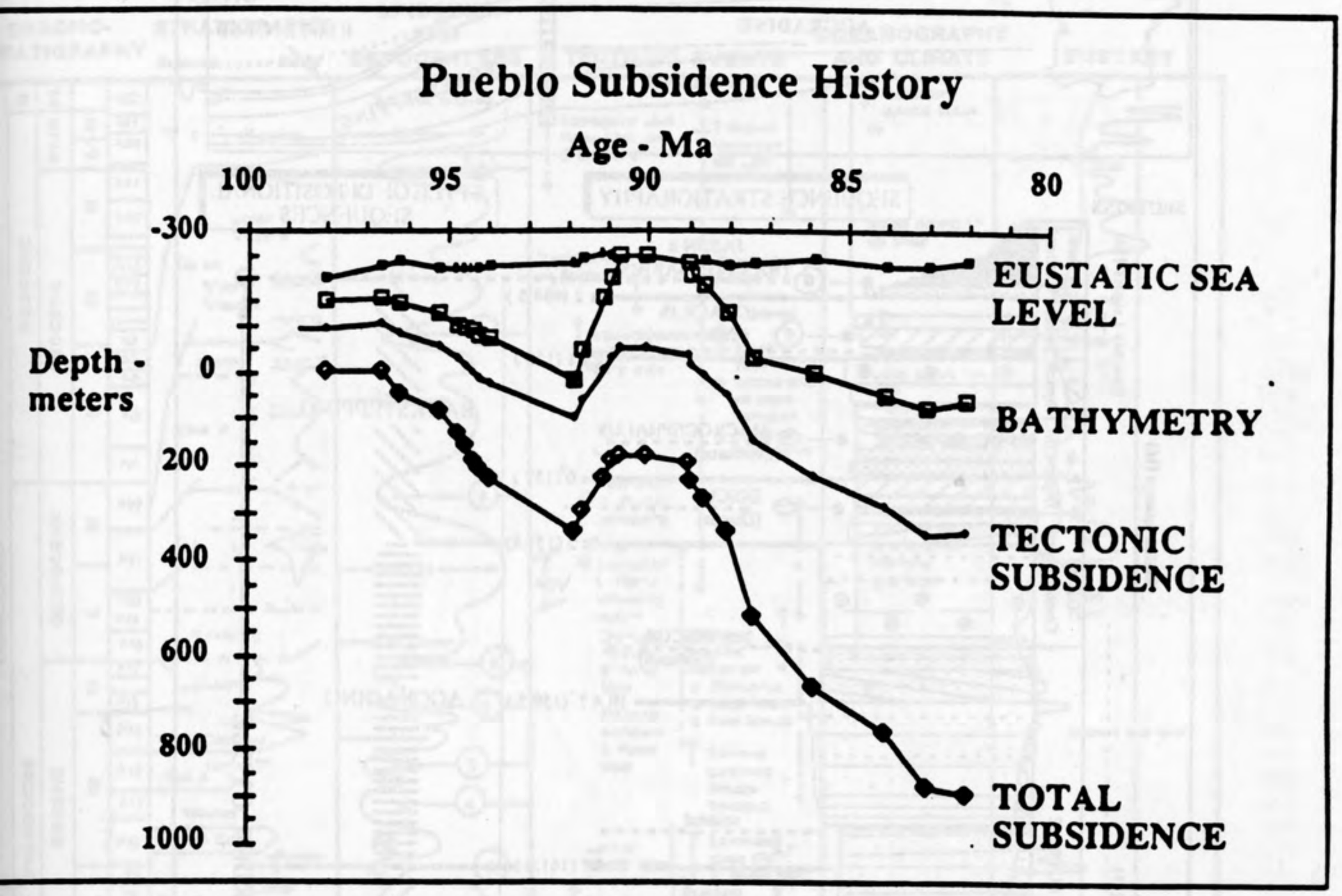


Fig. 5-2

TECTONIC SUBSIDENCE CURVES FOR A FORELAND BASIN



Tectonic Subsidence history curve for a foreland basin, an example from the Western Interior Seaway of North America.

Fig. 5-4

PLANCHE II/*PLATE II*

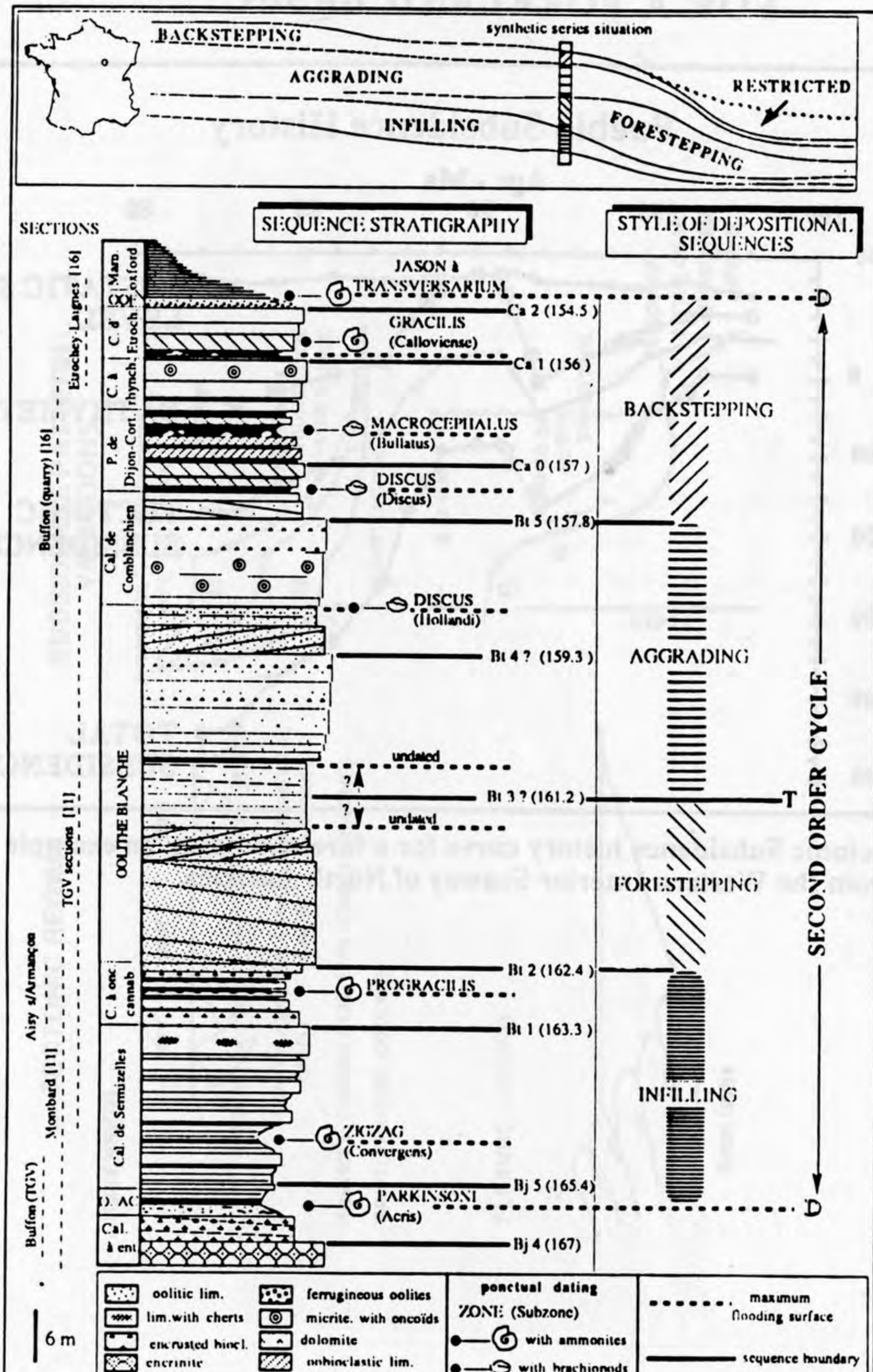
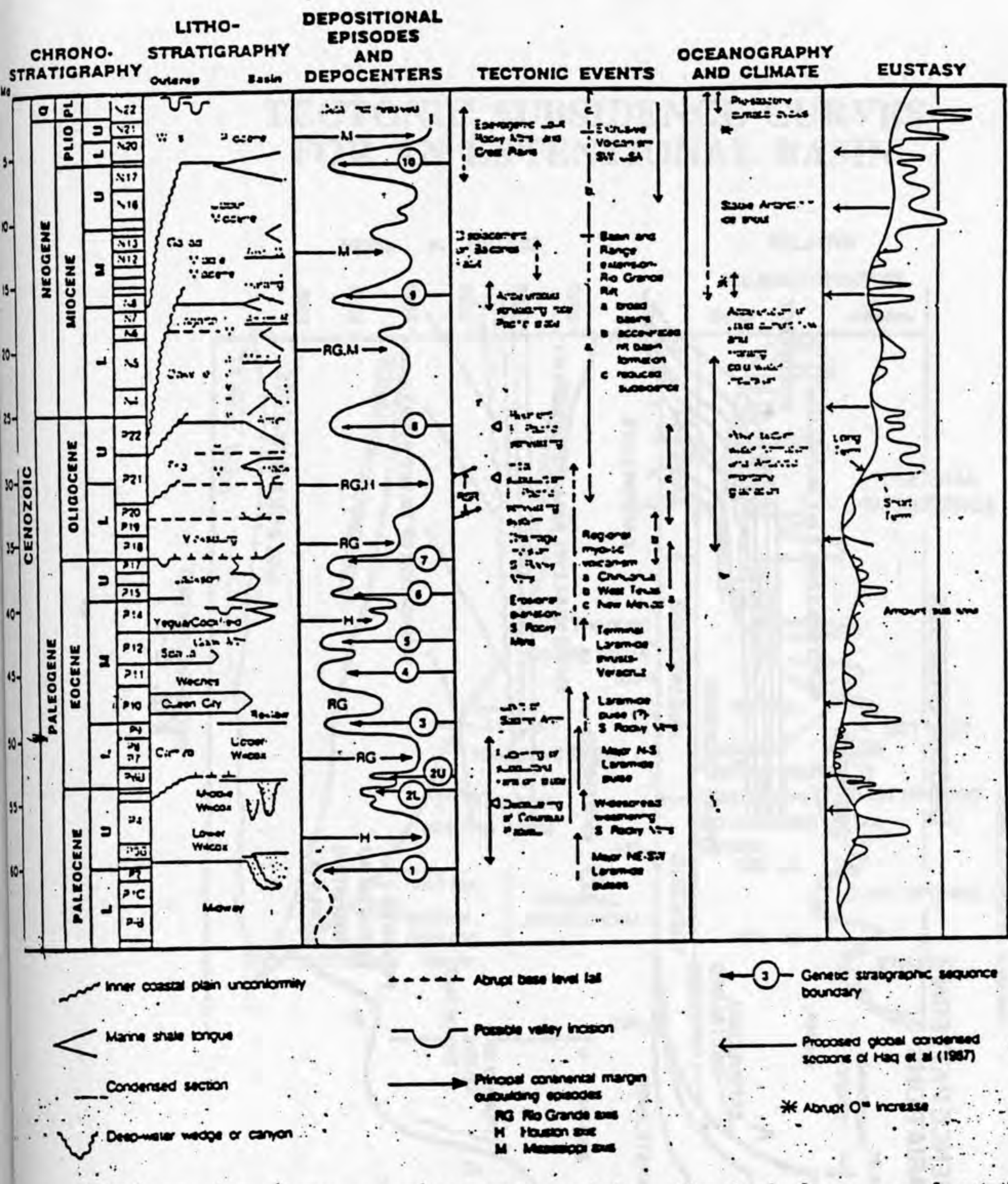


Fig. 2



igure 1. Comparative geologic history of Gulf Coast Cenozoic depositional episodes, proposed eustatic sea-level changes, oceanographic evolution in response to Cenozoic climatic cooling, and tectonic events of the western North American plate. Major continental-margin outbuilding episodes and their depocenters are shown by excursions to the right on the episode curve. The principal lithostratigraphic elements (including basin-margin unconformities and submarine erosion features) are tabulated according to published and unpublished planktonic dates. Genetic stratigraphic sequence boundaries are labelled in number circles. Modified from Galloway (1989b).

RELATION OF UNCONFORMITIES TO TECTONICS

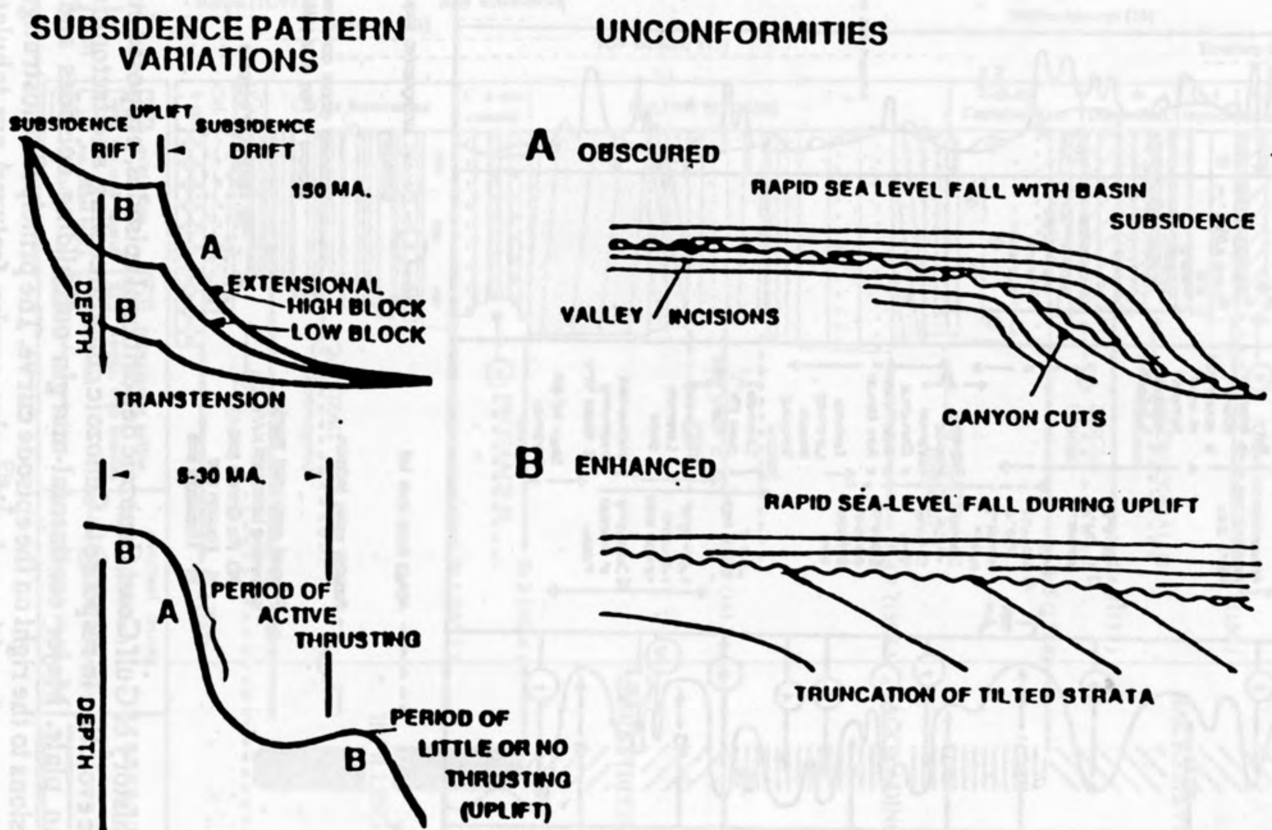


Fig. 5-3

TECTONIC SUBSIDENCE CURVES FOR AN EXTENTIONAL BASIN

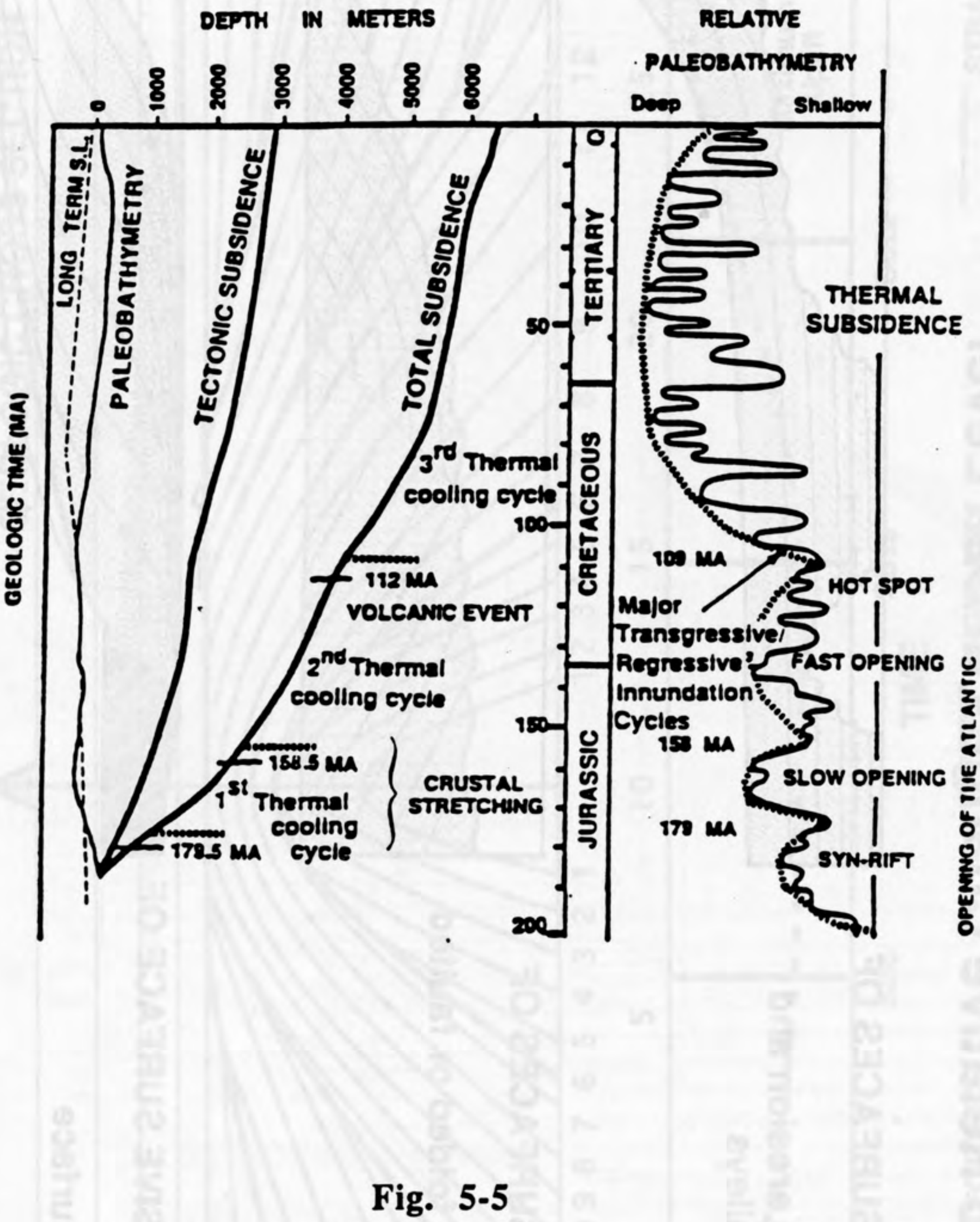
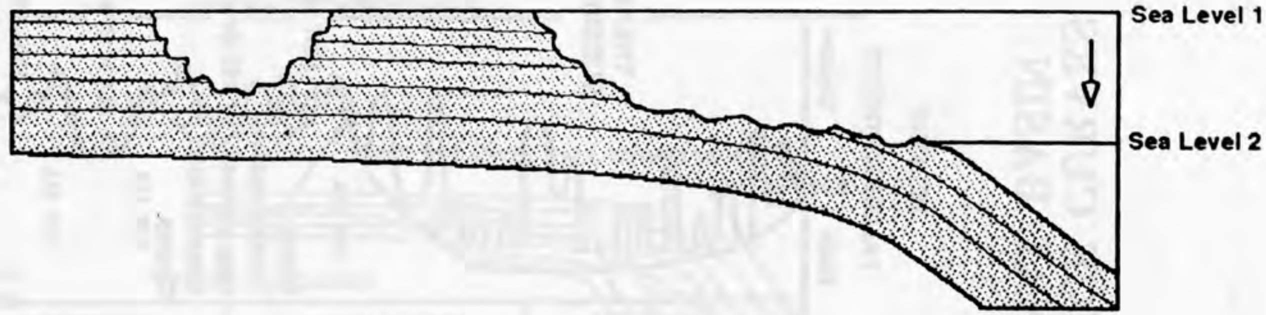


Fig. 5-5

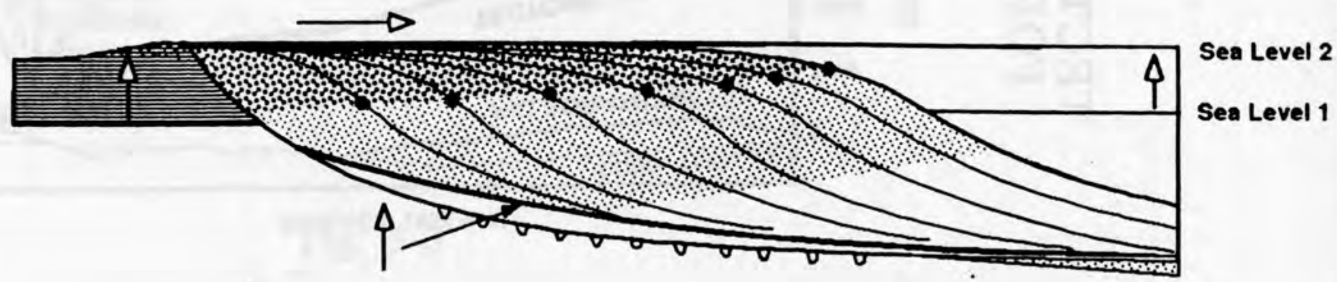
MAJOR TYPES OF EROSION
Related to Relative Changes of Sea Level

LOWSTAND SURFACES OF EROSION
a) Headward erosion and incised valleys



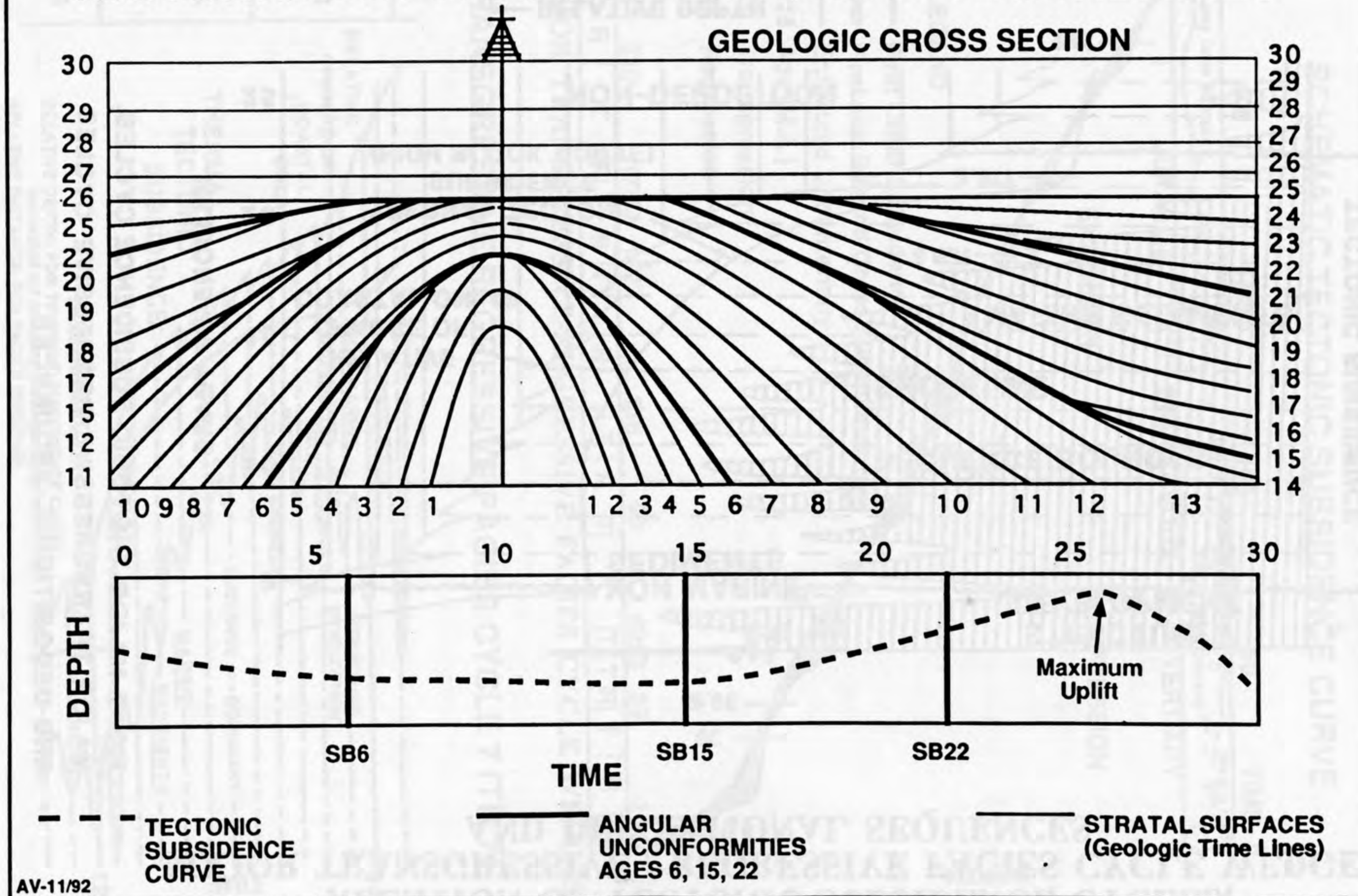
LOWSTAND SURFACES OF EROSION
b) Erosion of folded or faulted beds

TRANSGRESSIVE SURFACE OF EROSION
Ravinement surface



AV-11/92

TECTONICALLY ENHANCED SEQUENCE BOUNDARIES



RELATION OF TECTONIC SUBSIDENCE CYCLES, MAJOR TRANSGRESSIVE / REGRESSIVE FACIES CYCLE WEDGES, AND DEPOSITIONAL SEQUENCES

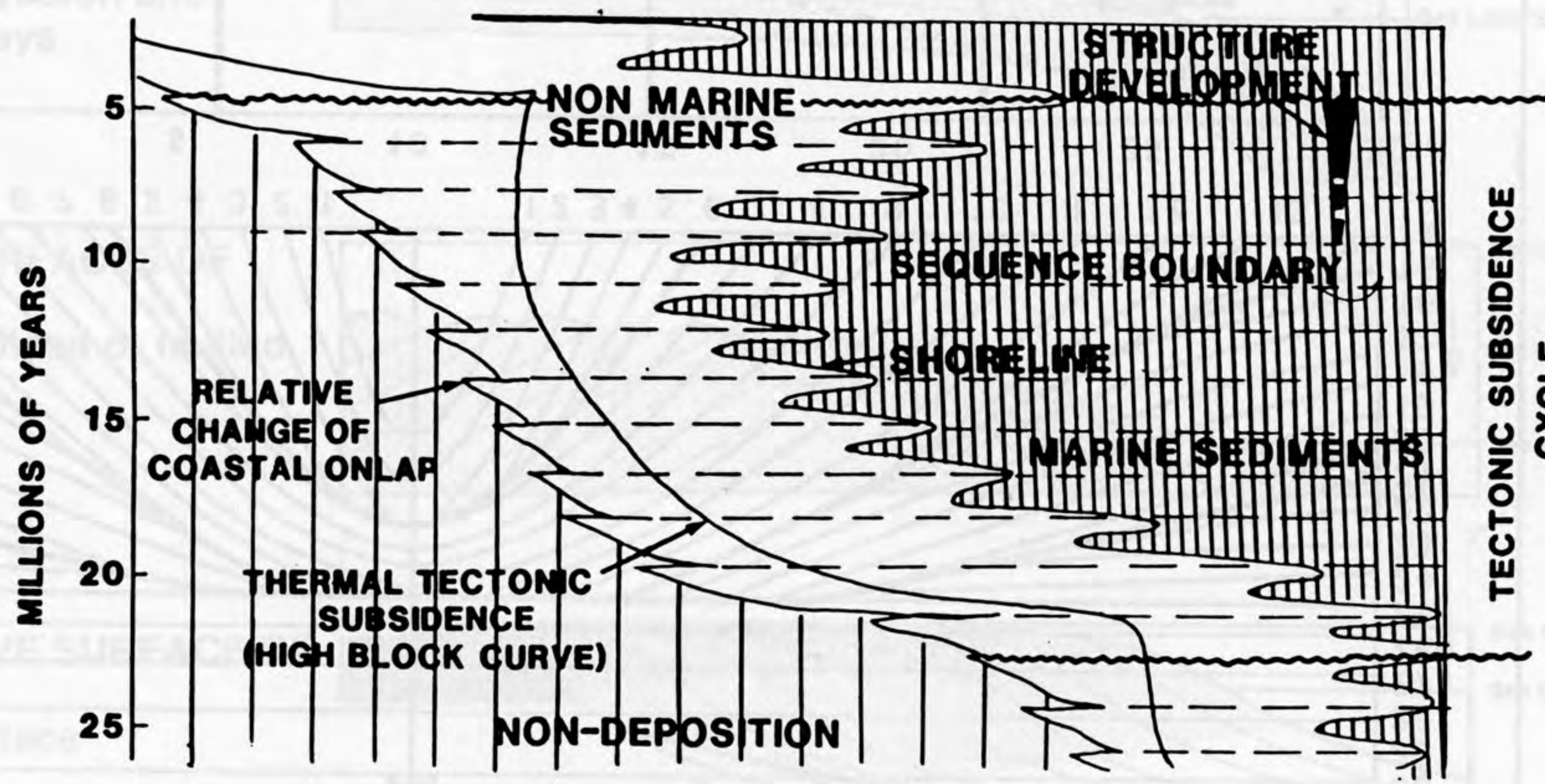


FIG. 2 MAJOR TECTONIC SUBSIDENCE CYCLES, MAJOR TRANSGRESSIVE/REGRESSIVE CYCLES AND DEPOSITIONAL SEQUENCES.

JBS882646

Fig. 5-6

After Vail, 1987

RELATION OF TECTONIC SUBSIDENCE CURVES AND MAJOR TRANSGRESSIVE-REGRESSIVE FACIES CYCLE WEDGES

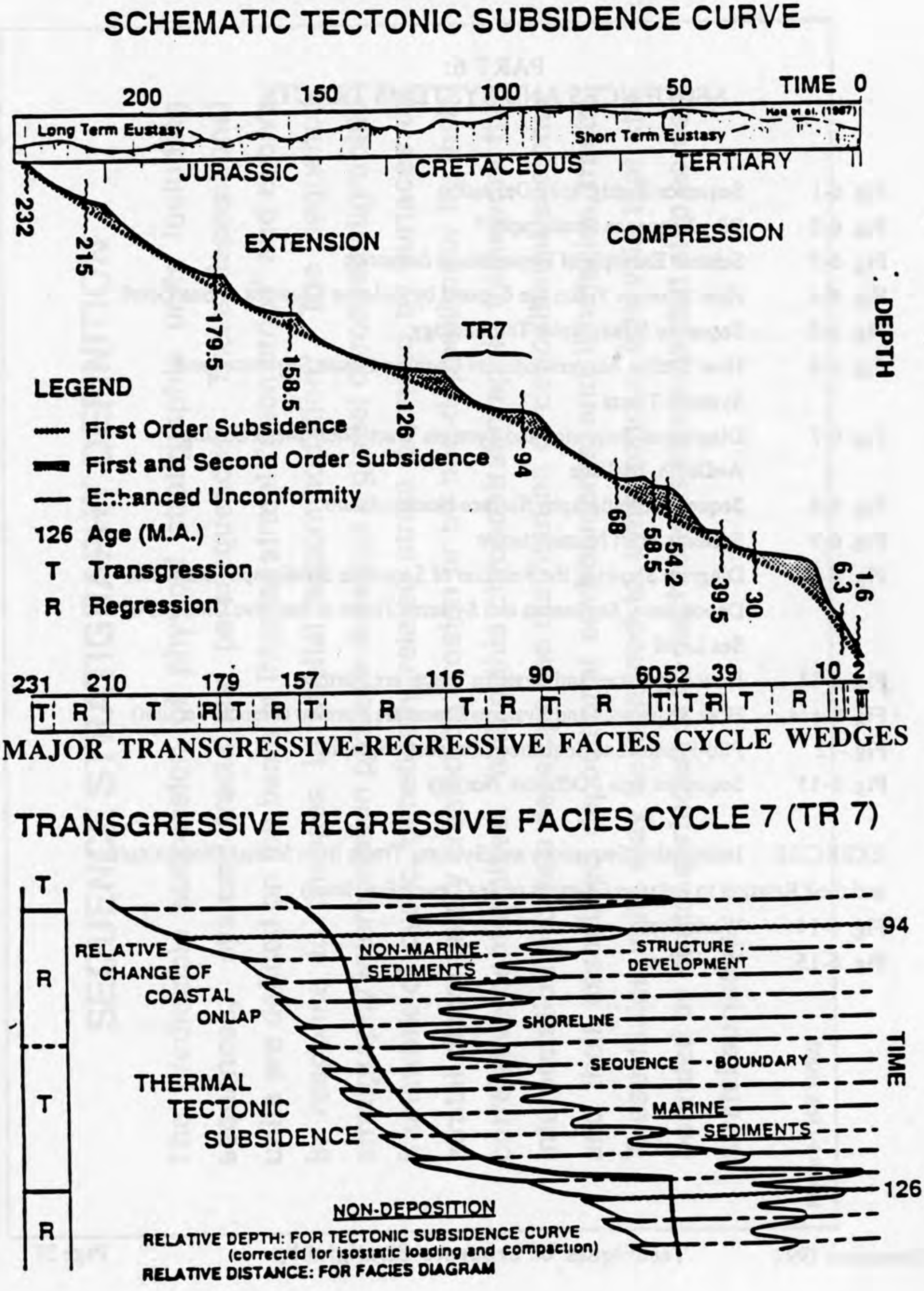


Fig. 5-7

THE TECHNIQUES OF SEQUENCE STRATIGRAPHY

PART 6: SEQUENCES AND SYSTEMS TRACTS

SEQUENCE STRATIGRAPHY DEFINITION

The predictable succession of physical stratigraphic units including sequences, systems tracts and parasequences. These depositional units are defined on the basis of internal stratal "geometrics" and evolve in response to changes in shelfal accommodation. The sequence stratigraphy interpretation process develops a global chronostratigraphic framework of cyclic, genetically related strata bounded by surfaces of stratal discontinuity created by erosion or by non-deposition or by their correlative conformities. Within this chronostratigraphic framework the interpretation process develops the distribution of depositional systems and their associated depositional environments and lithofacies tracts. These facies units may be confined to synchronous intervals that are bounded by stratal surfaces, or to diachronous intervals that step across stratal surfaces.

Figure 6-1 (AV 10/92)

WHY SEQUENCE STRATIGRAPHY?

INTERVAL SELECTION

Intervals are genetic, chronostratigraphic intervals defined from physical stratigraphy and age dated with biostratigraphy. Therefore, they can be defined on outcrop sections, on well logs and on seismic reflection profiles and correlated with physical characteristics and biostratigraphy.

Boundaries are genetic not arbitrary. Therefore, the same boundaries can be defined independently by different workers on outcrop sections, on well logs and, if the resolution is good enough, on seismic reflection profiles. Thus, there is a right and wrong location for sequence stratigraphic "tops".

CORRELATION

More accurate and precise method to correlate well logs, outcrops and seismic reflection profiles.

Sequence and systems tract boundaries are global. Therefore, the same physical boundaries can be identified in any basin with a sea level baselevel.

MAPPING

Intervals are chronostratigraphic, therefore, they are ideal for mapping lithofacies distribution and paleogeography.

A series of paleogeographic maps show geologic history.

RESOURCE EVALUATION

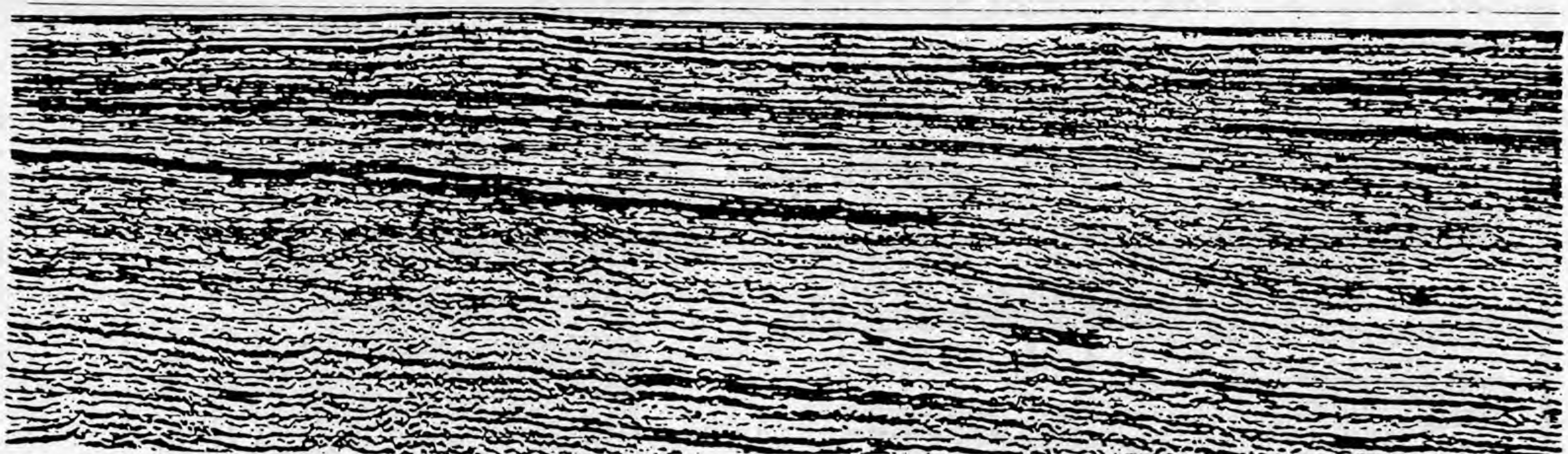
Each system tract has predictable relationship to lithofacies.

Each type of systems tract has different types of reservoirs, source rocks and seal rocks. Therefore, there is a different exploration philosophy for each type of systems tract.

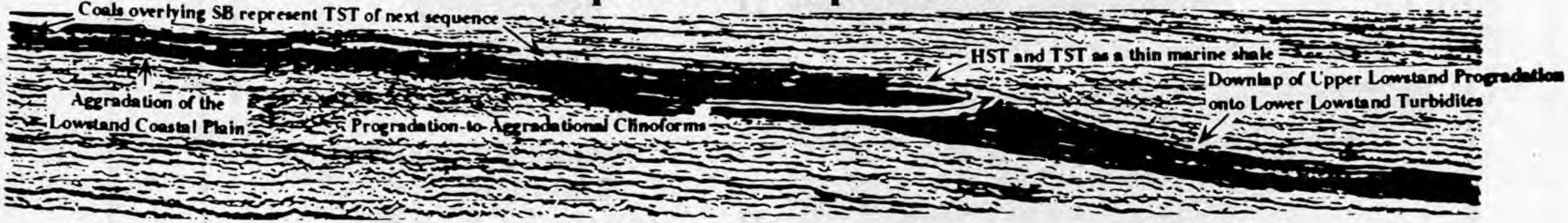
Parasequences control primary porosity distribution. Therefore, parasequences are the basic intervals for reservoir description.

Figure 6-2 (AV 10/92)

SEISMIC EXAMPLE OF DEPOSITIONAL SEQUENCE:
Shelf Break Lowstand Progradation



Sequence Interpretation



Lithofacies Interpretation

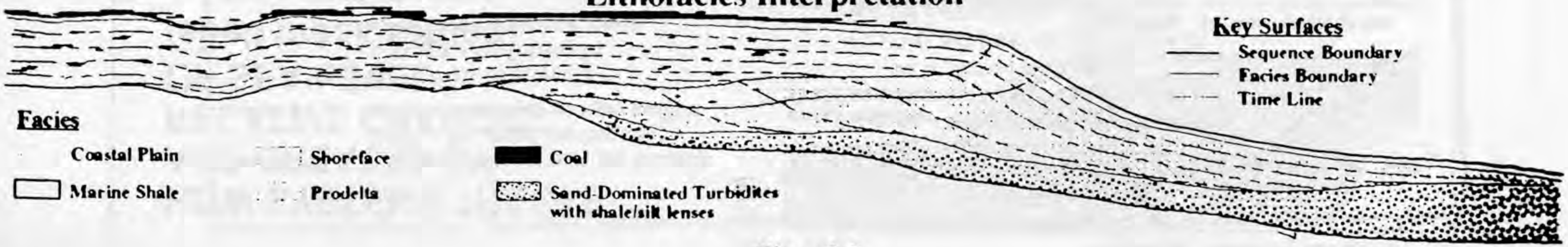


Fig. 6-3

HOW SYSTEMS TRACTS ARE CREATED BY RELATIVE CHANGES OF SEA LEVEL (shelf break setting)

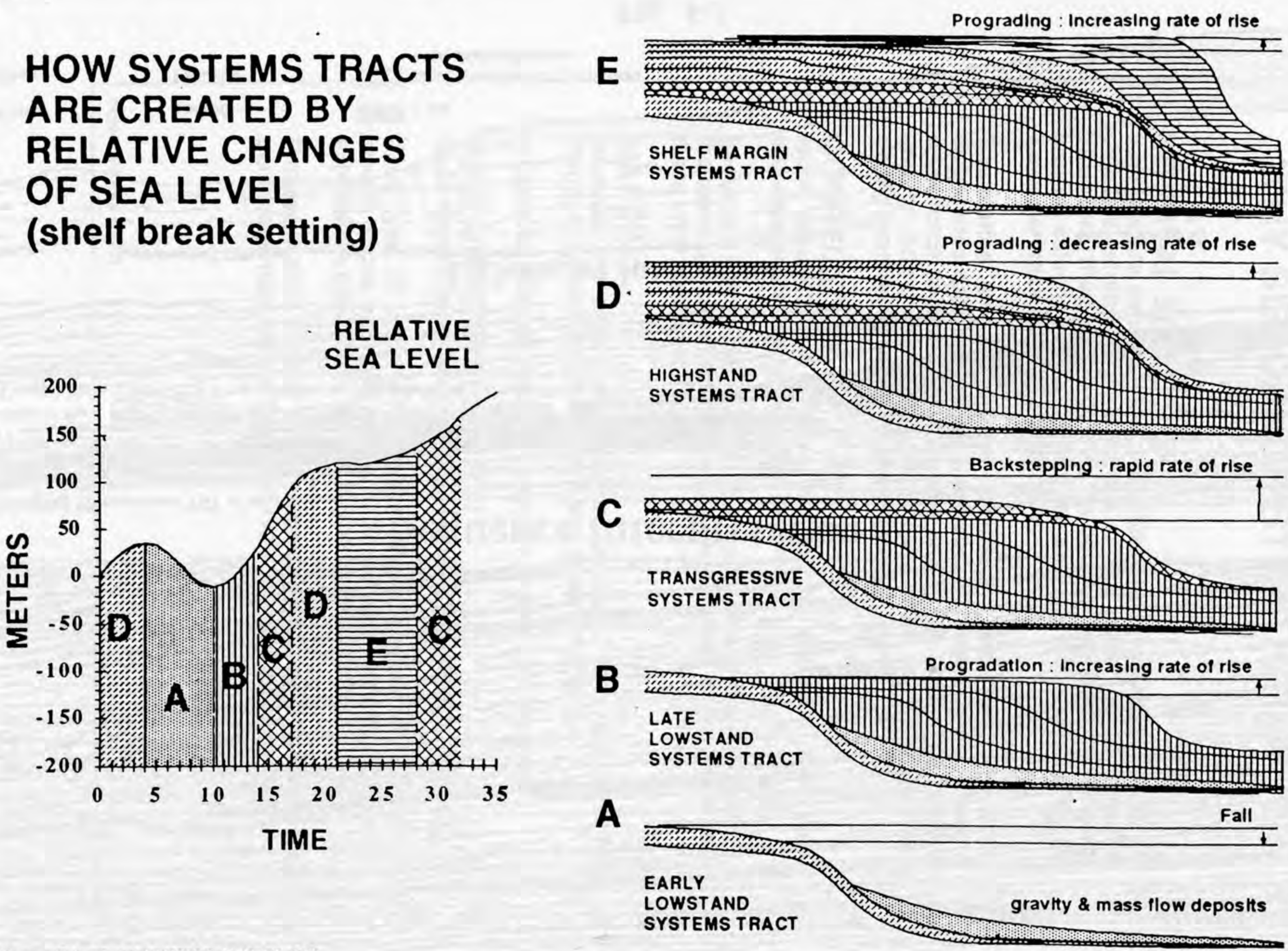
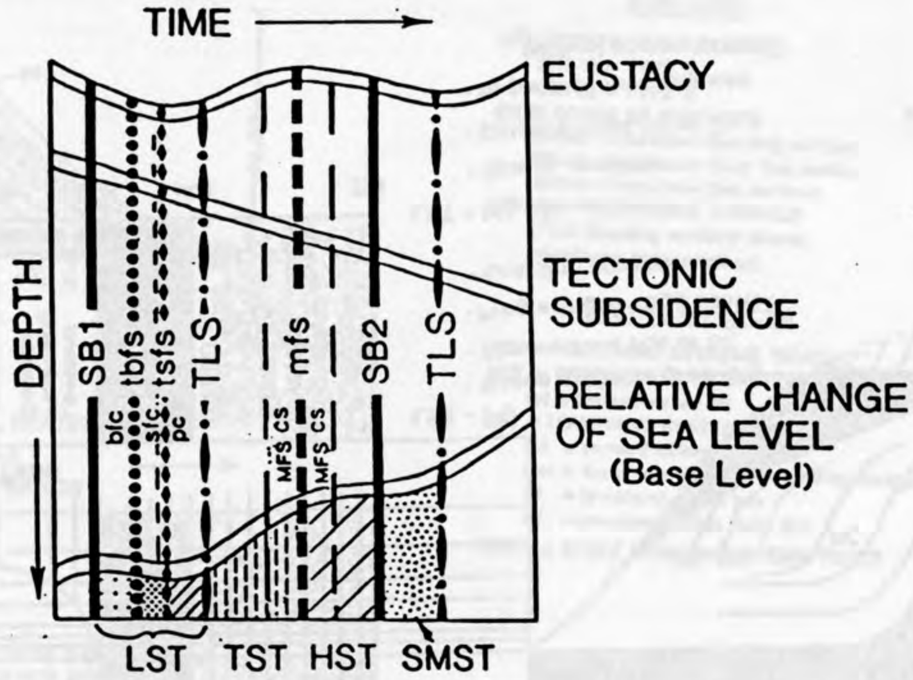


Figure 6-4 (T. JACQUIN & P. VAIL 92)

SEQUENCE STRATIGRAPHIC TERMINOLOGY

- Shelf Margin Systems Tract (SMST)
- Highstand Systems Tract (HST)
- Transgressive Systems Tract (TST)
- LST Lowstand Systems Tract (LST)
  - Prograding Complex (pc)
  - Slope Fan Complex (sfc)
  - Basin Floor Complex (bfc)



SURFACES

(SB) SEQUENCE BOUNDARIES
(SB 1) = TYPE 1
(SB 2) = TYPE 2
(TLS) TOP LOW STAND SURFACE
(first flooding surface above maximum progradation)
(DLS) DOWNLAP SURFACES
(mfs) = maximum flooding surface
(tsfs) = top slope fan surface
(tbfs) = top basin floor fan surface

SYSTEMS TRACTS

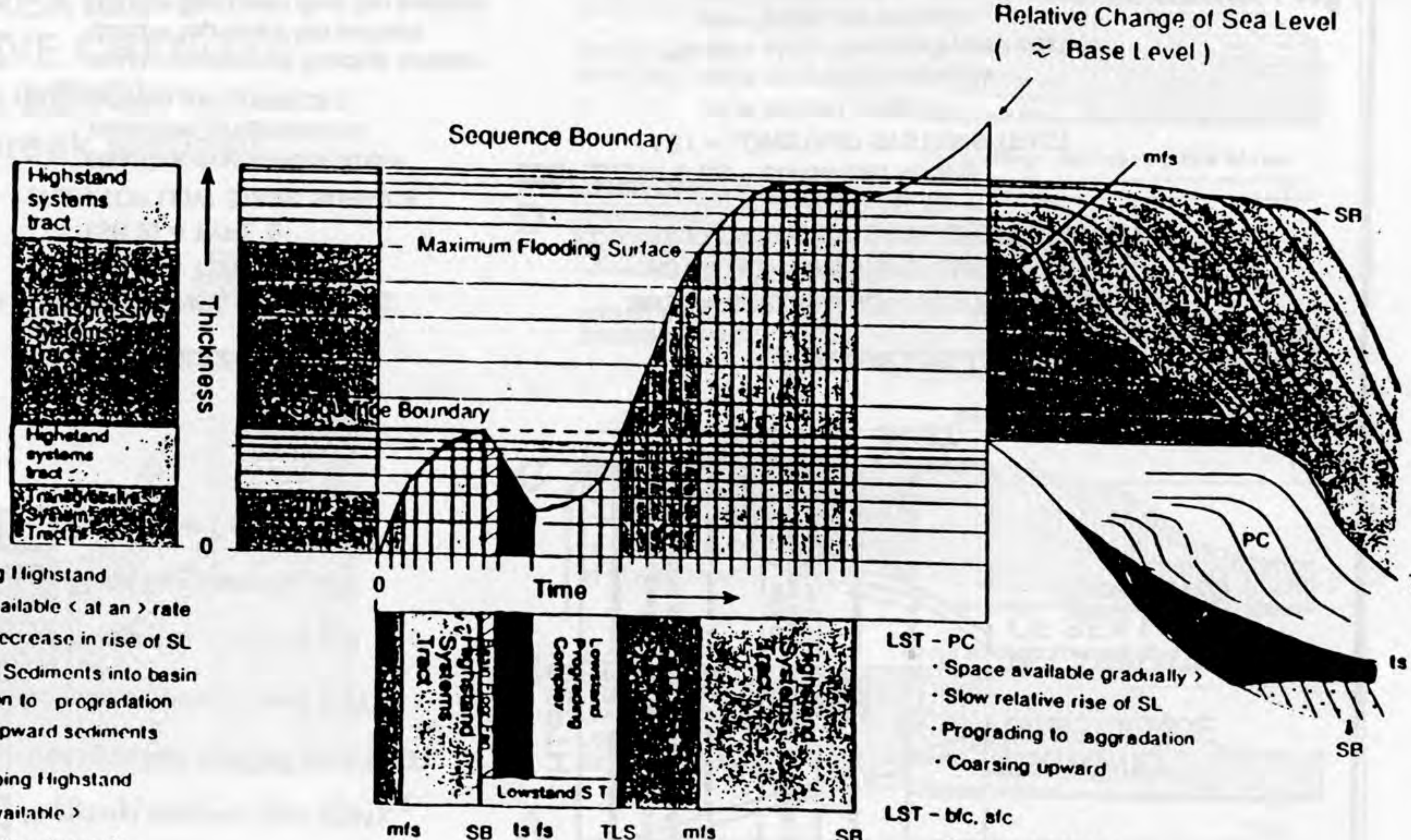
SMST = SHELF MARGIN SYSTEMS TRACT
HST = HIGHSTAND SYSTEMS TRACT
TST = TRANSGRESSIVE SYSTEMS TRACT
ivf = incised valley fill
MFS CS = condensed section
LST = LOWSTAND SYSTEMS TRACT
ivf = incised valley fill
pc = prograding complex
sf cs = slope fan condensed section
sfc = slope fan complex
cs = condensed section
bfc = basin floor fan complex

MICRO-STRAT INC. 1-90 ©
JBS, PRV & WWW

Fig. 6-5

How Shelfal Accommodation Changes
Create Sequences and Systems Tracts

MICRO-STRAT INC. 1-90
PRV & WWW



HST - Prograding Highstand
- Space available < at an > rate
- Relative Decrease in rise of SL
- by pass of Sediments into basin
- aggradation to progradation
- coarsing upward sediments

TST - Backstepping Highstand
- Space available >
- Rapid relative rise of SL
- Sediment starvation
- Backstepping of parasequence
- Fining upward sediments

LST - PC
- Space available gradually >
- Slow relative rise of SL
- Prograding to aggradation
- Coarsing upward

LST - bfc, sfc
- Space available >
- Relative rapid fall of SL
- by pass of sediment into bathyal portion of basin

Fig. 6-6

Shelf Break Setting

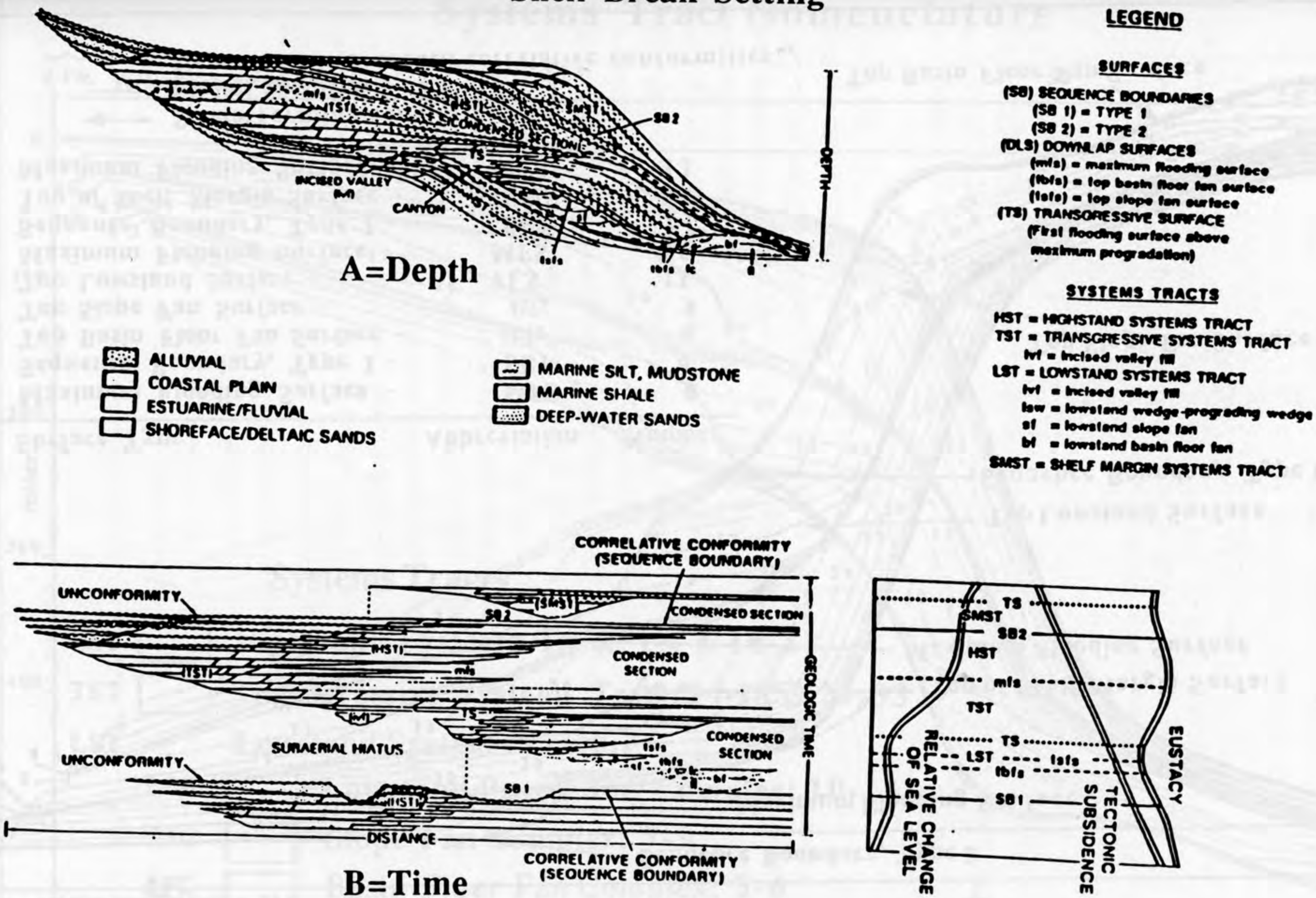
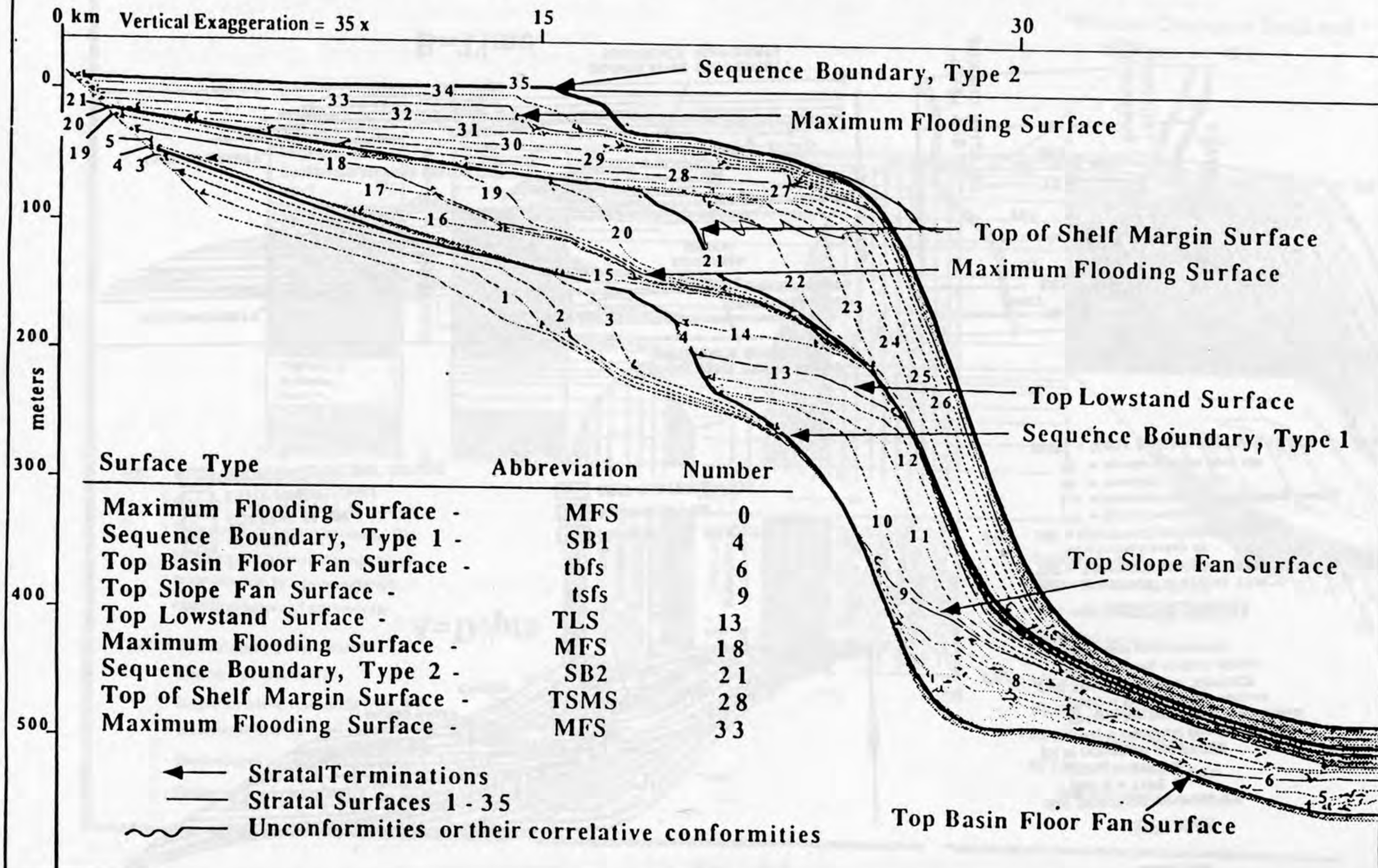


Fig. 6-7

Sequence Stratigraphic Surface Nomenclature



Surface Type	Abbreviation	Number
Maximum Flooding Surface -	MFS	0
Sequence Boundary, Type 1 -	SB1	4
Top Basin Floor Fan Surface -	tbfs	6
Top Slope Fan Surface -	tsfs	9
Top Lowstand Surface -	TLS	13
Maximum Flooding Surface -	MFS	18
Sequence Boundary, Type 2 -	SB2	21
Top of Shelf Margin Surface -	TSMS	28
Maximum Flooding Surface -	MFS	33

Fig. 6-8

Bowman 9.26.91.1

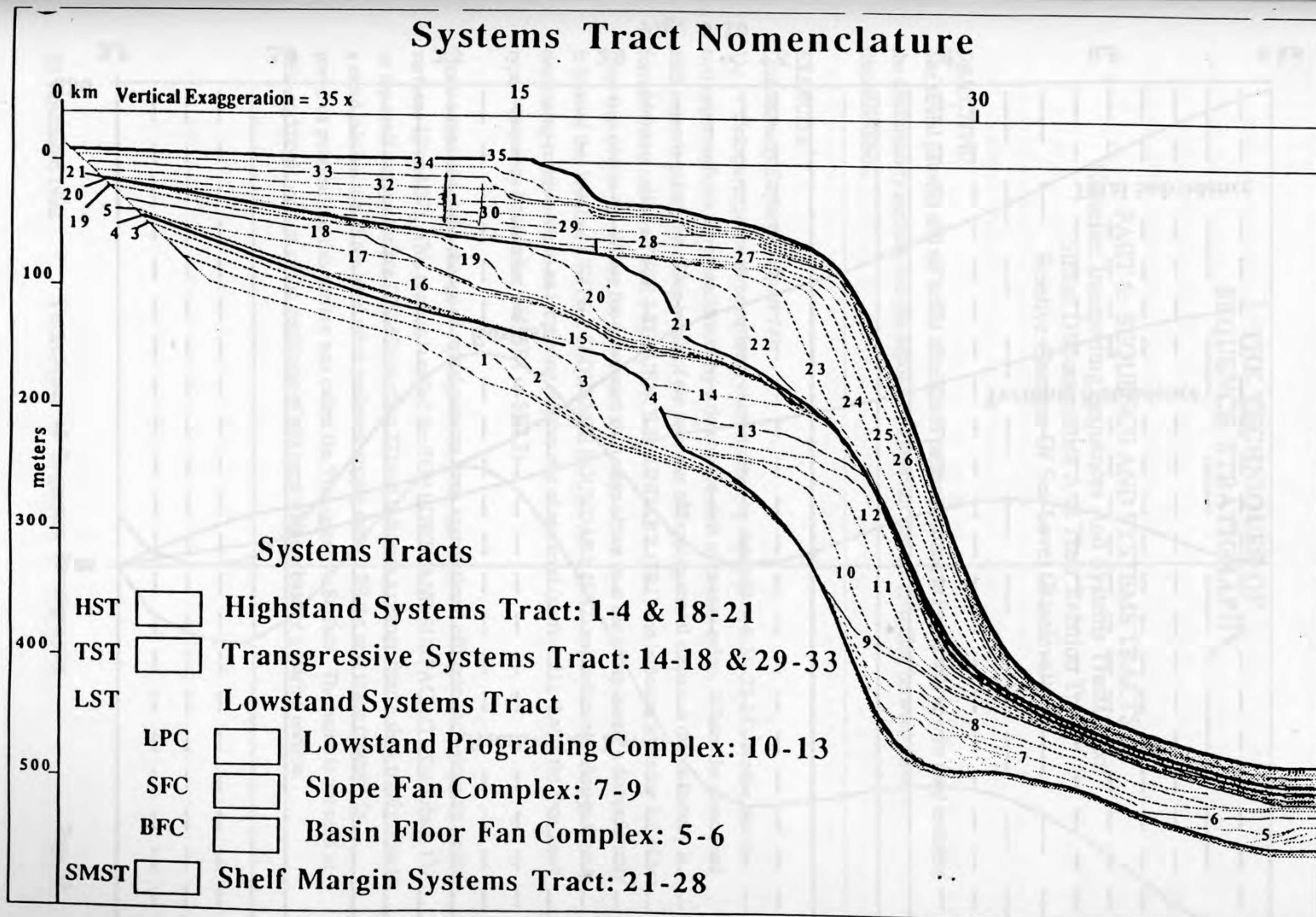


Fig. 6-9

Bowman 9.26.91.1

DEPOS IONAL SEQUENCES AND SYS EMS TRACTS TO RELATIVE CHANGES OF SEA LEVEL

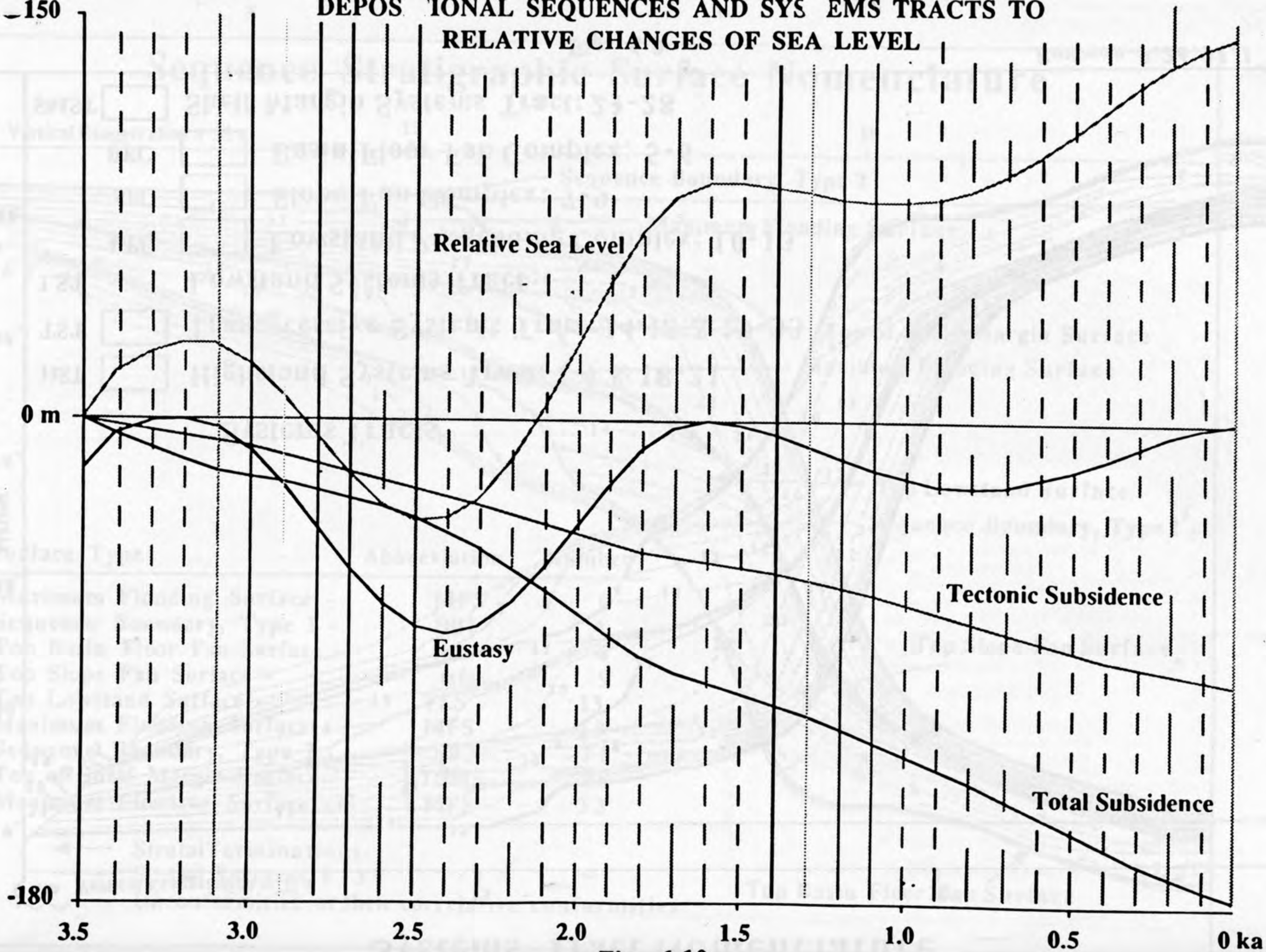


Fig. 6-10

THE TECHNIQUES OF SEQUENCE STRATIGRAPHY

PART 6: SEQUENCE AND SYSTEMS TRACTS

Exercise: Interpreting Sequences And Systems Tracts From Stratal Discontinuities And Their Relation To Relative Changes Of Sea Level (Baselevel)

OBJECTIVE:

The stratal patterns and the stratal termination patterns defined in Part B will now be used to define the discontinuity surfaces and the depositional intervals that are identified between these discontinuities.

EXERCISE:

Discontinuity Surfaces (Fig. 6-14):

1) Color orange the three surfaces characterized by onlap (0-4, 5-21, 22-35). Notice that the two upper surfaces are characterized by a downward shift of coastal onlap. Where the downward shift extends below the offlap break of the previous offlapping stratal surface, a disconformity is formed that is called a TYPE 1 SEQUENCE BOUNDARY (SB1) and indicates a relative fall of sea level (top of line 4). Where,the downward shift stays above or at the offlap break, a disconformity is formed that is called a TYPE 2 SEQUENCE BOUNDARY (SB2) and indicates a change from a decreasing relative rise to an increasing relative rise of sea level (surface 21). Label the type 1 and type 2 sequence boundaries with SB1 or SB2.2)

Draw a rose line at the change of stratal patterns from aggradational offlap to back-stepping.(stratal surfaces 13 and 27). This surface is called the TOP LOWSTAND SURFACE (TLS) (surface 13) or top shelf margin surface (TSMS) (surface 27) and indicates a change from a slow relative rise to a rapid relative rise of sea level when sediment supply cannot fill the new space created. In previous publications this surface was called the Transgressive Surface. The name is not used in this workbook because of the confusion of this term with the base of a marine section.

3) Draw a green line at the change from backstepping to sigmoidal offlap stratal patterns (line 17). This line corresponds to a condensed section between downlapping strata above (stratal surfaces 18-27) and apparent truncation below (stratal surfaces 13-17). These stratal terminations indicate a condensed section that extends across the shelf into the basin. This surface is called the MAXIMUM FLOODING SURFACE (MFS) and indicates the end of a rapid relative rise of sea level when the sediment supply can fill all the new space created.

4) Draw a tuscan red line on the downlap surface on top of the sheet mounds. This surface is called TOP BASIN FLOOR FAN SURFACE (TBFS). It indicates the change from a sand-rich to a mud-rich sediment supply during the relative fall of sea level (stratal surface 6).

5) Draw a brown line on the downlap surface on top of the complex mounds. This surface is called the TOP SLOPE FAN SURFACE (TSFS). It indicates a change to stable prograding deposition during the relative low of sea level (stratal surface 9).

Depositional Sequence Nomenclature (Fig. 6-15):

The interval of deposition between two sequences boundaries is called a DEPOSITIONAL SEQUENCE. If the basal sequence boundary is a type 1 sequence boundary, the sequence will be a TYPE 1 DEPOSITIONAL SEQUENCE and will be subdivided into three SYSTEMS TRACTS: Lowstand systems tract, Transgressive systems tract and Highstand systems tract. If the basal sequence boundary is a type 2 sequence boundary, the sequence will be a TYPE 2 DEPOSITIONAL SEQUENCE and will be subdivided into three systems tracts: Shelf margin systems tract, Transgressive systems tract and Highstand systems tract.

Systems Tract Nomenclature (Fig. 6-15):

1) Color yellow the sheet mound between stratal surfaces 4 and 6. It corresponds to a BASIN FLOOR FAN and is bounded by a SB1 below and by a TBFS above. The basin floor fan is the lowermost unit of the LOWSTAND SYSTEMS TRACT. It is commonly present in deep water settings and does not develop in ramp settings.

2) Color brown the complex mounds between stratal surfaces 6 and 9. It corresponds to a SLOPE FAN and is bounded by a TBFS or a SB1 below and by a TSFS above. The slope fan is the middle unit of the LOWSTAND SYSTEMS TRACT. It is commonly present in deep water settings associated with submarine canyons, slump scars, collapse features and debris flows, but does not develop in ramp settings. Show medium slope and ramp setting.

3) Color rose the oblique to aggradational offlapping interval that pinches out by onlap near the offlap break of the previous highstand between stratal surfaces 10 and 12. These intervals form the LOWSTAND PROGRADING COMPLEX and is bounded by a TSFS or a SB1 below and by a TLS above. The lowstand prograding complex is the upper unit of the LOWSTAND SYSTEMS TRACT.

4) Color green the backstepping intervals that shift landward between stratal surfaces 12 and 17 and stratal surfaces 27 and 32. These intervals form the TRANSGRESSIVE SYSTEMS TRACTS (backstepping highstand) and are bounded by a SB1, SB2, TLS, or TSMS below and by a MFS above.

5) Color orange the sigmoidal to oblique offlapping intervals between stratal surfaces 1 and 4 and stratal surfaces 17 and 21. These intervals form the HIGHSTAND SYSTEMS TRACTS (forestepping highstand) and are bounded by a MFS below and by a SB1 or a SB2 above.

6) Color lavender the oblique to aggradational offlapping interval between stratal surfaces 21 and 27. These intervals form the SHELF MARGIN SYSTEMS TRACT and are bounded by a SB2 below and a TSMS above. It laps out landward of the offlap break of the previous highstand of the underlying depositional sequence.

Relation Of Sequences And Systems Tracts To Relative Changes Of Sea Level (Fig. 6-10):
Fig. 6-10 shows the relation between relative sea level, tectonic subsidence, and eustasy to sequences and systems tracts.

WORKSHEET

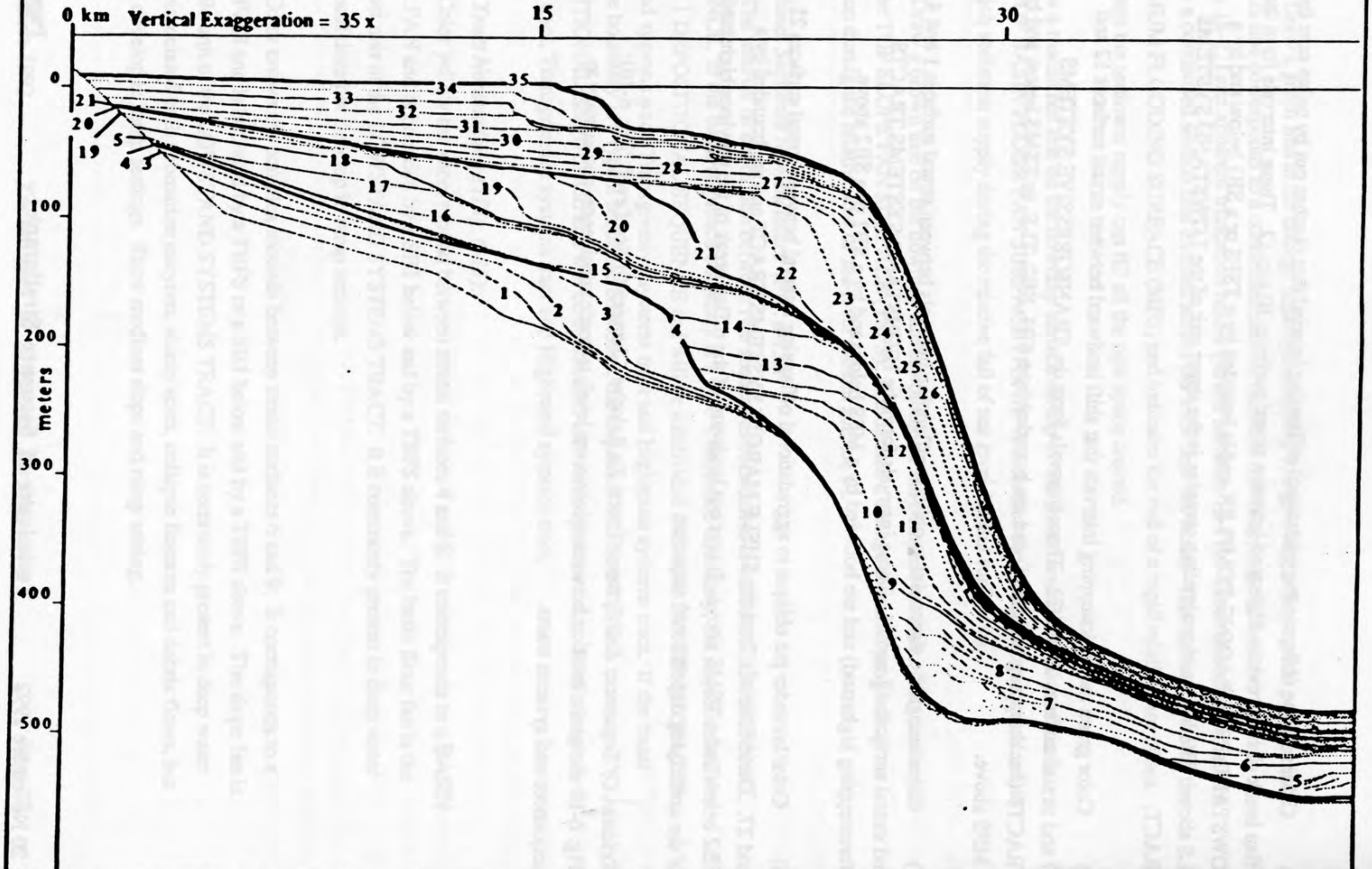


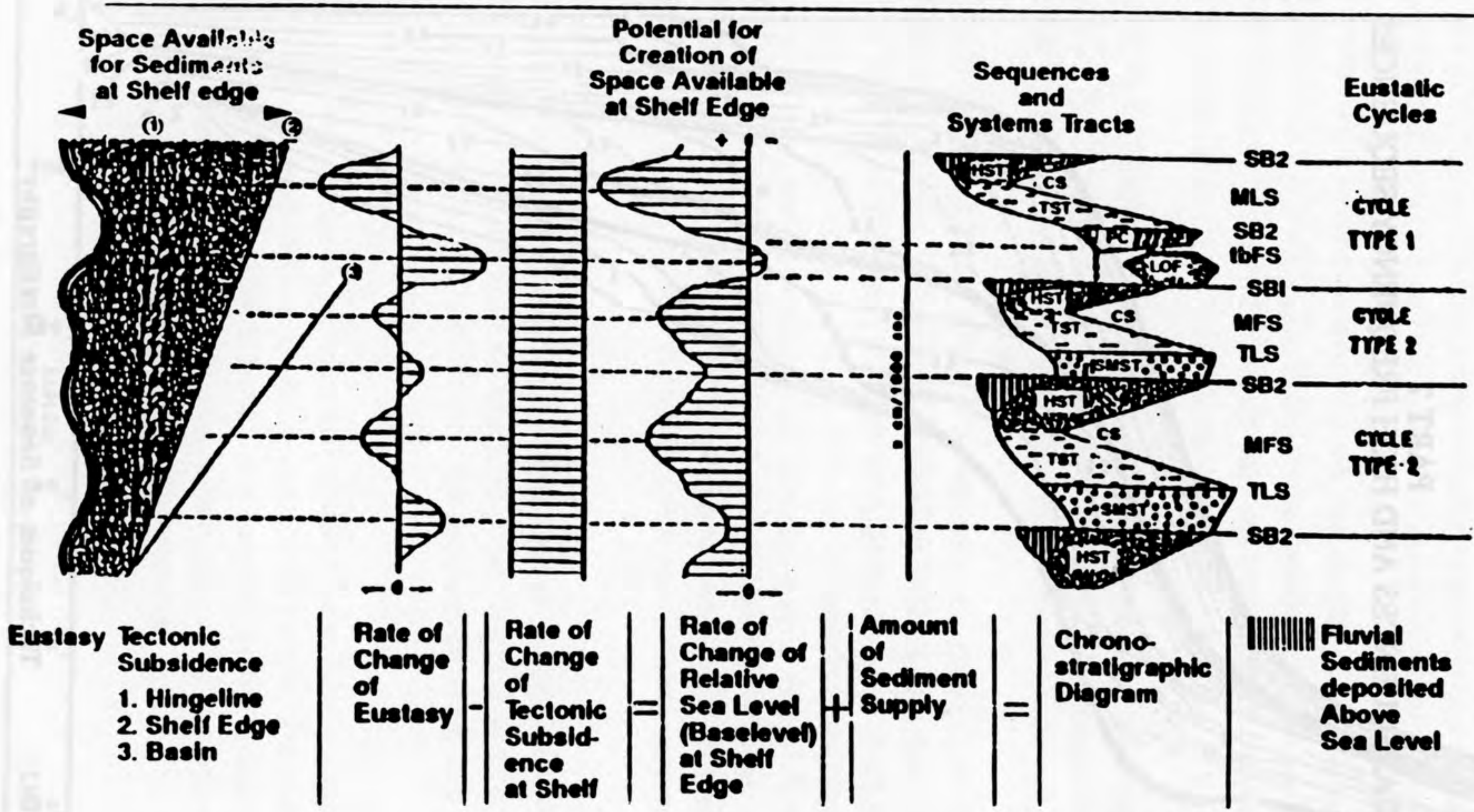
Fig. 6-14

Bowman 9.26.91.1

THE TECHNIQUES OF SEQUENCE STRATIGRAPHY

PART 7
PARASEQUENCES AND HIGH FREQUENCY SEQUENCES

How Sequences and Systems Tracts are Formed



Translated from Vail et al 1987

Fig. 6-11

PLIO-PLEISTOCENE SEQUENCE CHRONOSTRATIGRAPHY

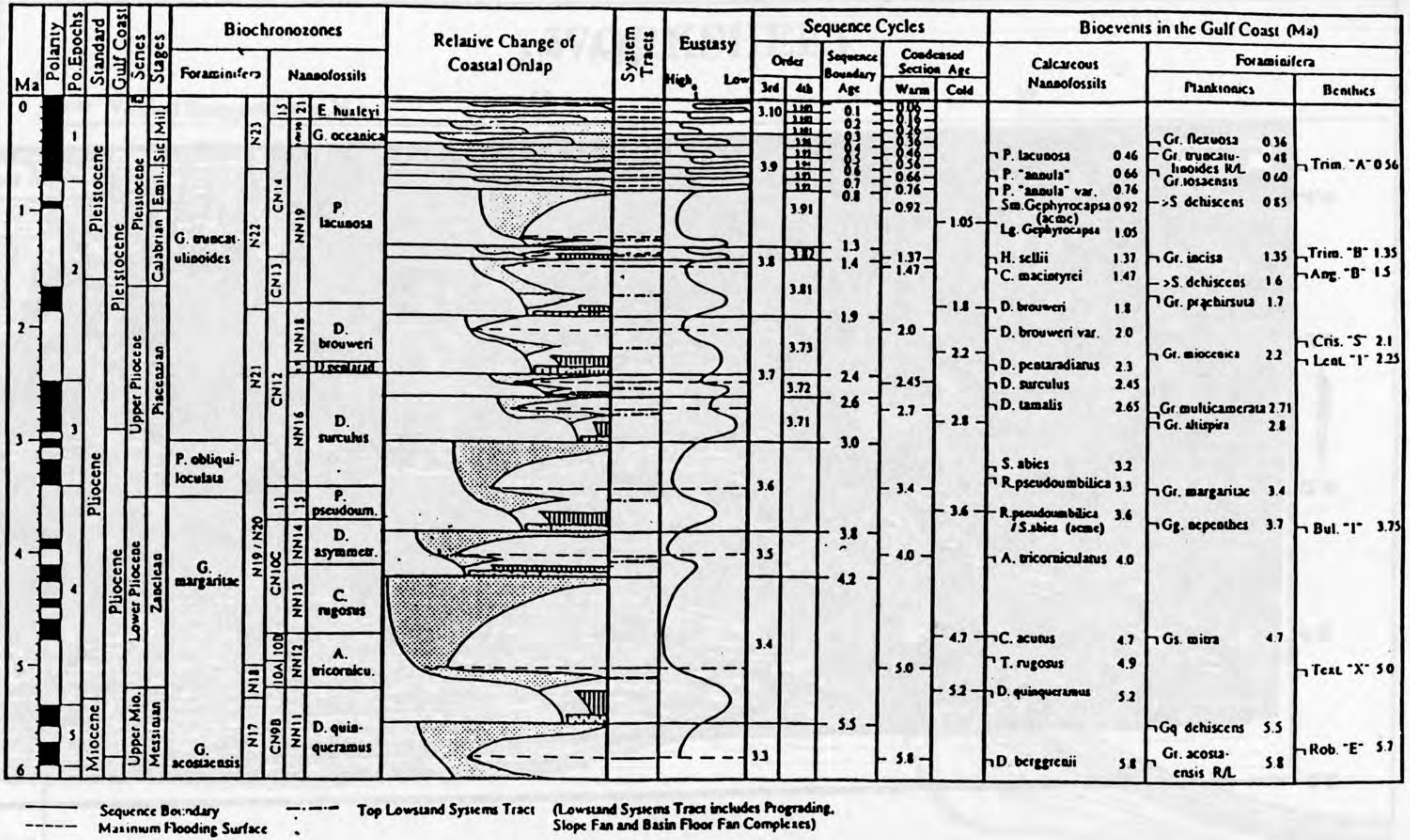


Fig. 6-12

SEQUENCE SETS - OFFSHORE NORWAY

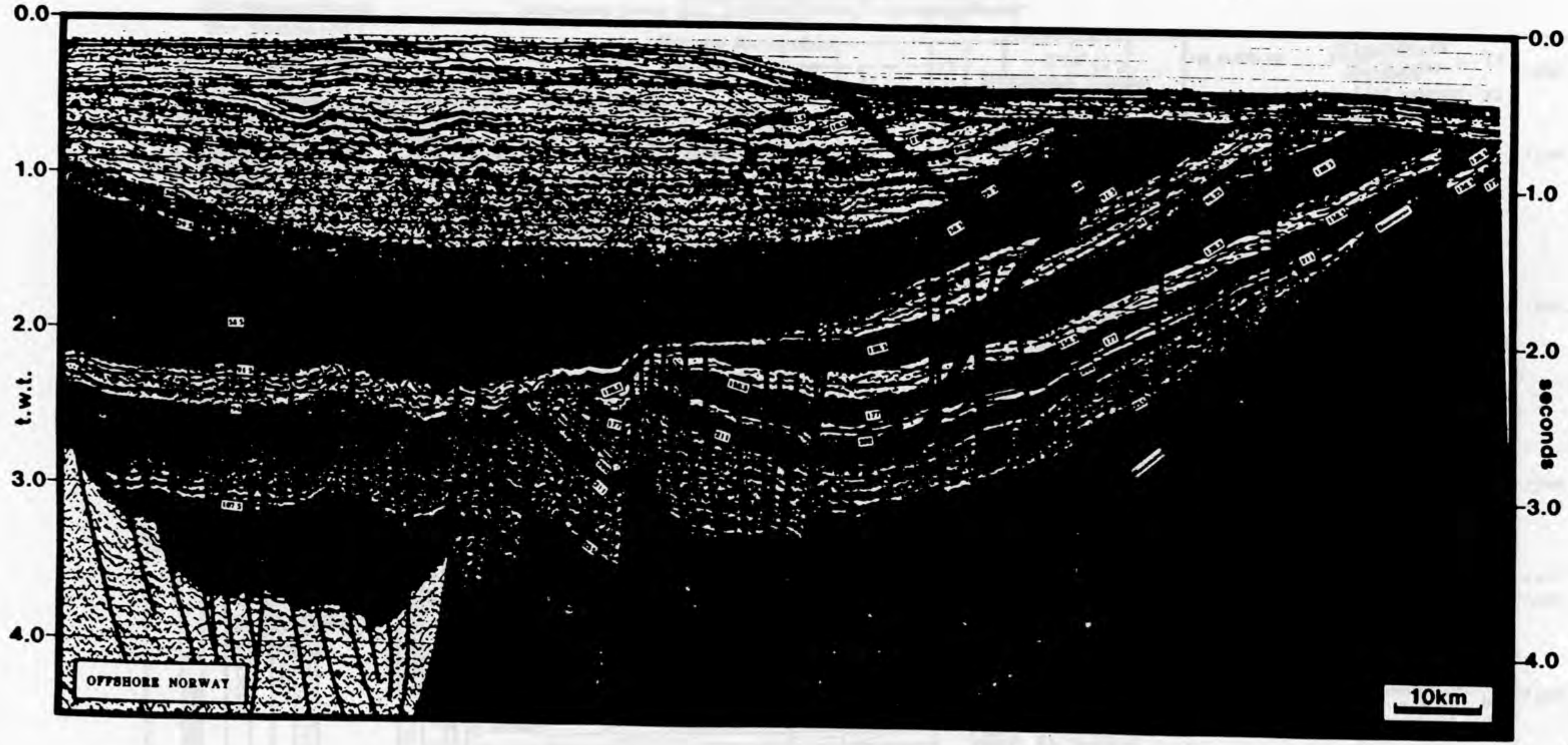


Fig. 6-13

WORKSHEET

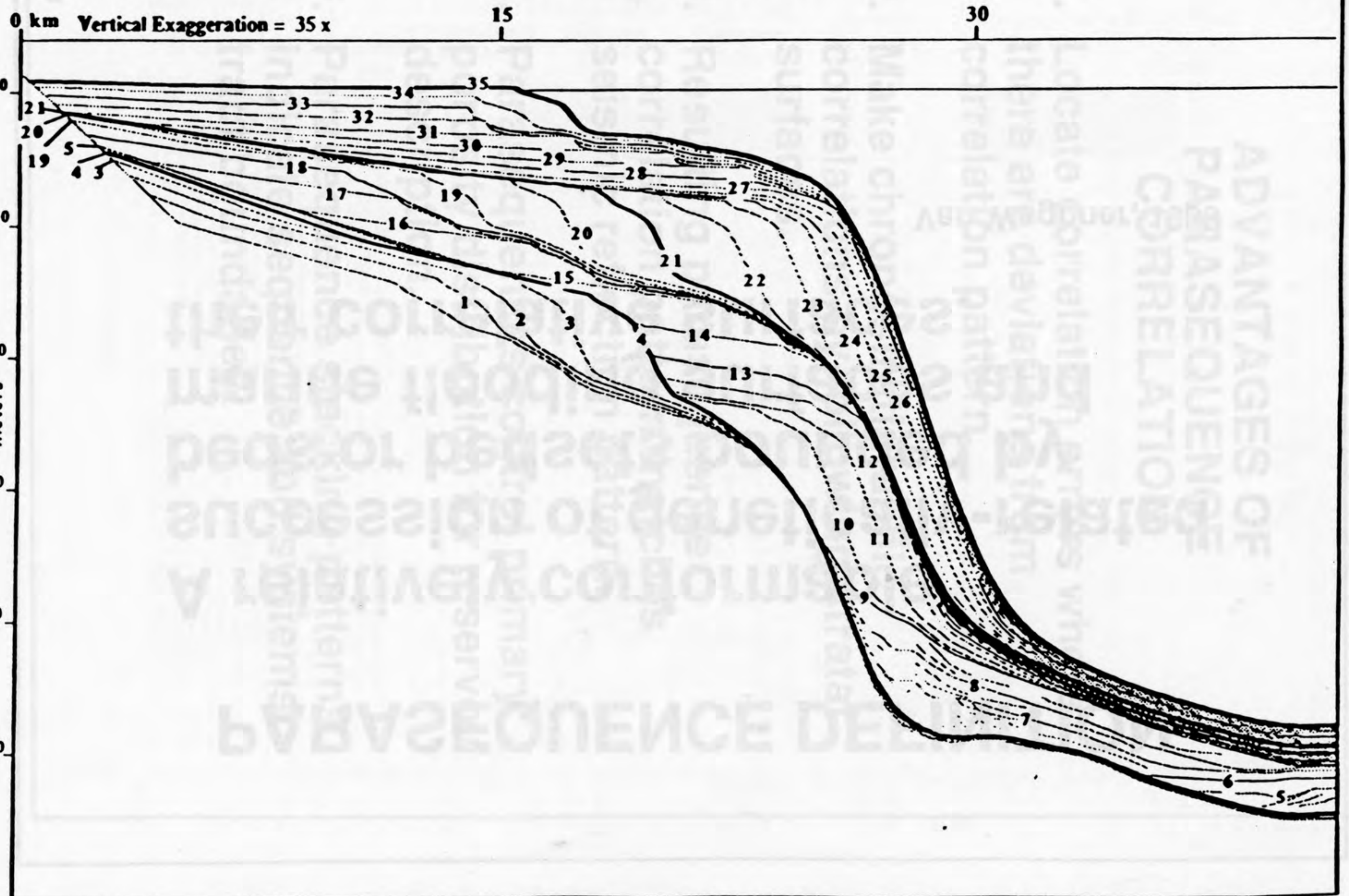


Fig. 6-15

Bowman 9.26.91.1

PARASEQUENCE DEFINITION

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

Van Wagoner, 1988

AV 11/92

ADVANTAGES OF PARASEQUENCE CORRELATION

1. Locate correlation errors where there are deviations from correlation pattern.

2. Make chronostratigraphic correlations by following stratal surfaces.

3. Resulting parasequence correlation pattern matches seismic reflection pattern.

4. Parasequences control primary porosity distribution for reservoir description.

5. Parasequence stacking patterns indicate sequence and systems tract boundaries.

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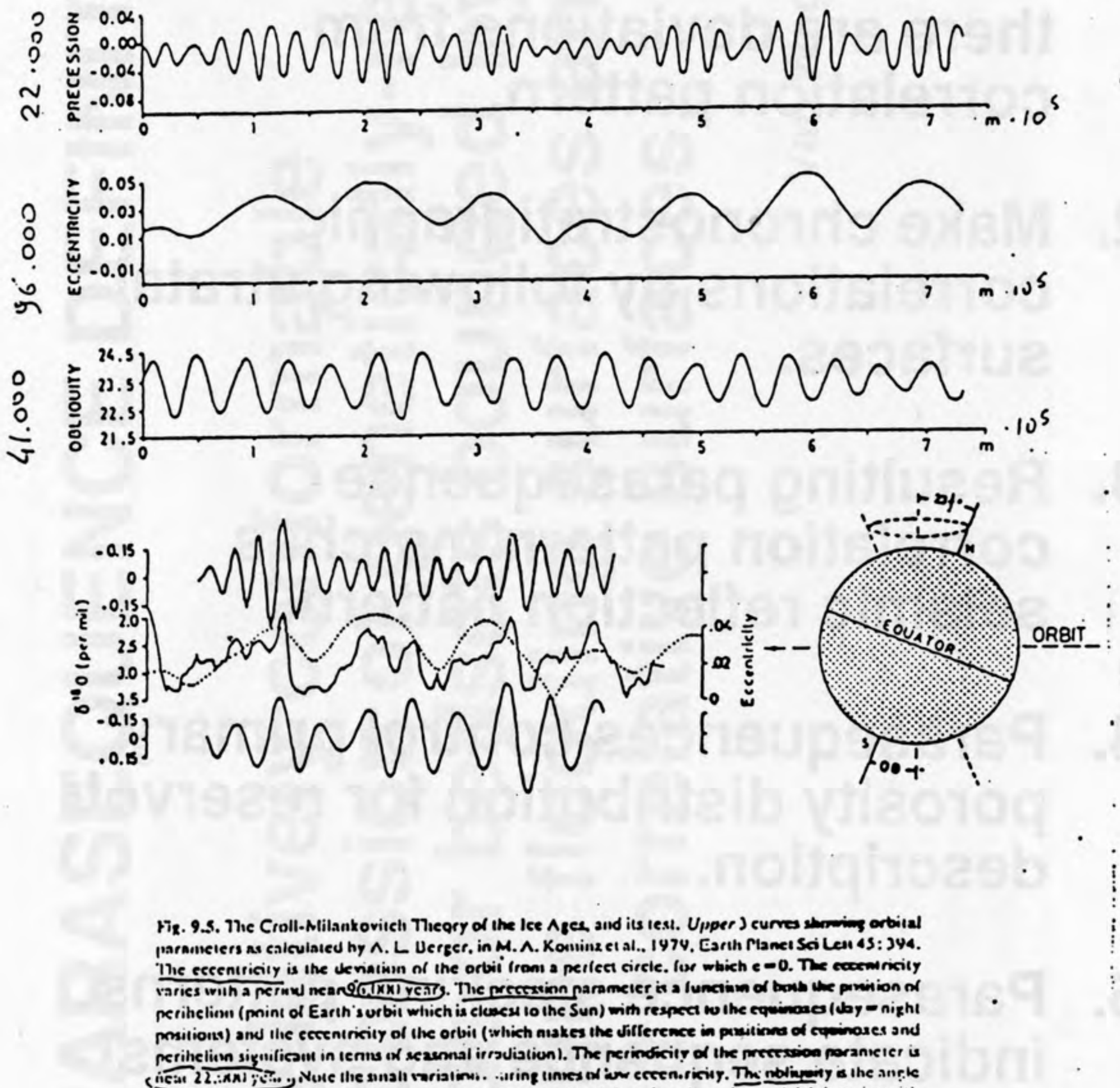
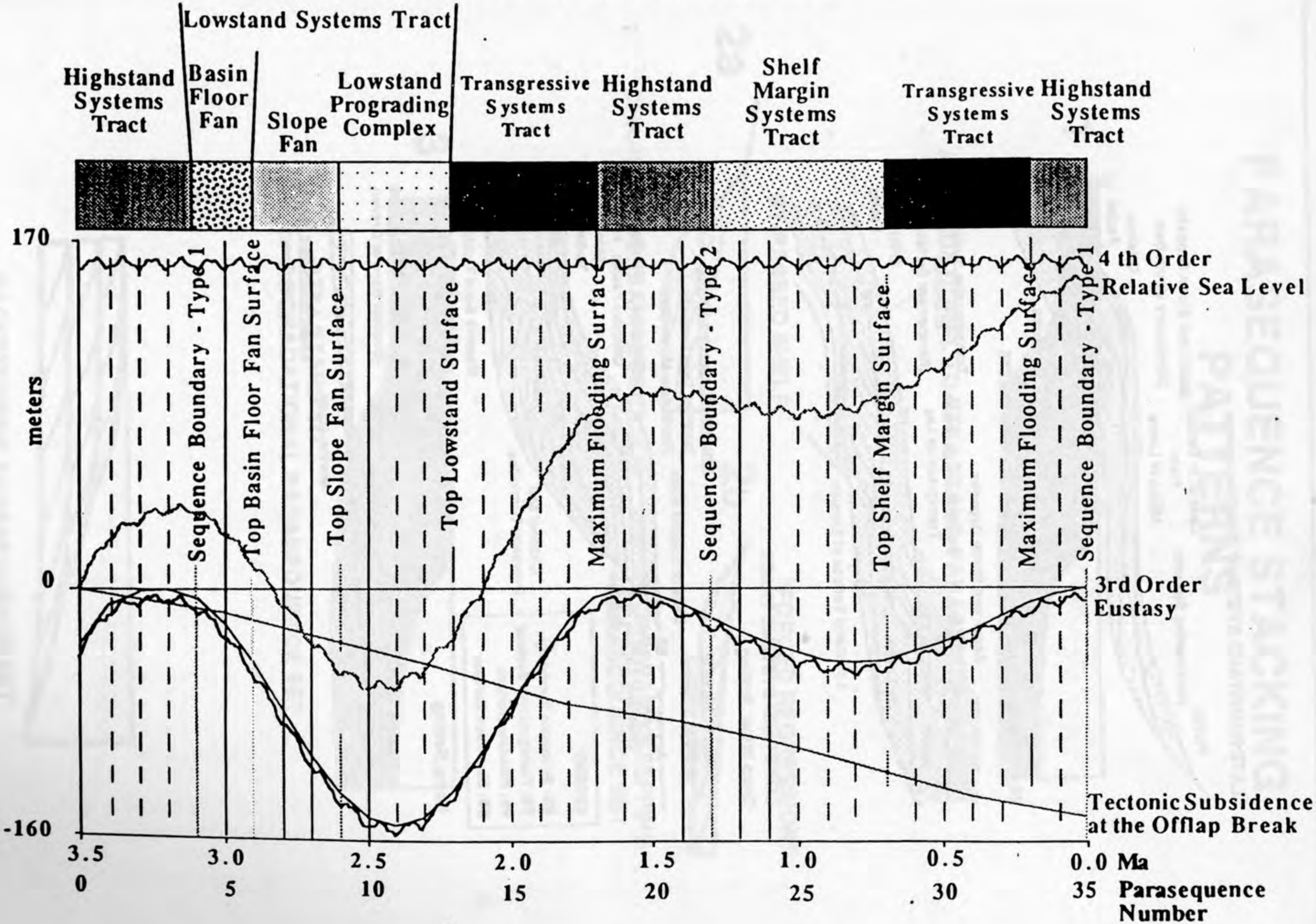
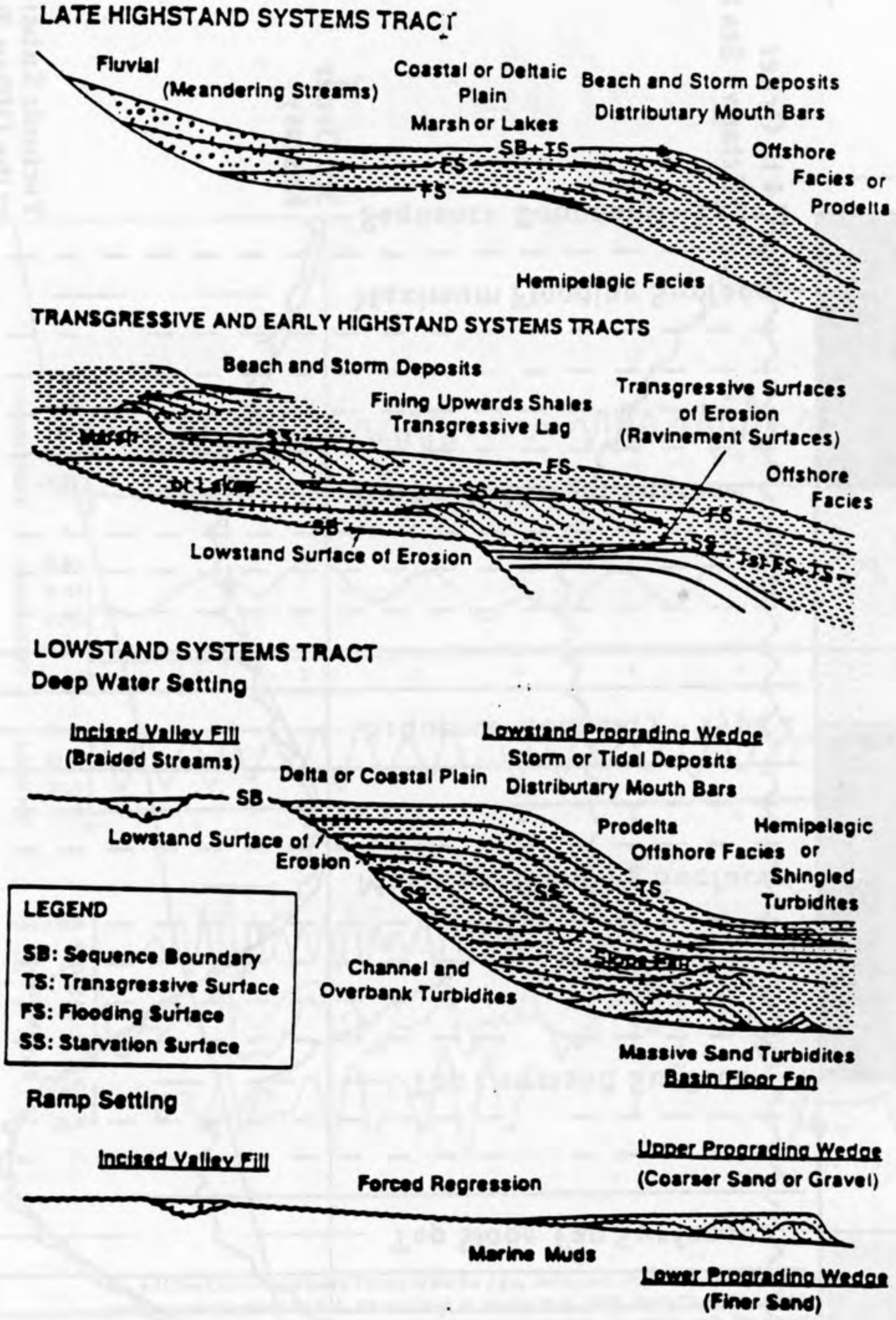


Fig. 9.5. The Croll-Milankovitch Theory of the Ice Ages, and its test. *Upper* 3 curves showing orbital parameters as calculated by A. L. Berger, in M. A. Kominz et al., 1979, Earth Planet Sci Lett 45: 394. The eccentricity is the deviation of the orbit from a perfect circle, for which e = 0. The eccentricity varies with a period near 96,000 years. The precession parameter is a function of both the position of perihelion (point of Earth's orbit which is closest to the Sun) with respect to the equinoxes (day = night positions) and the eccentricity of the orbit (which makes the difference in positions of equinoxes and perihelion significant in terms of seasonal irradiation). The periodicity of the precession parameter is near 22,000 years. Note the small variations during times of low eccentricity. The obliquity is the angle of the Earth's axis with respect to the vertical on the orbital plane (see *inset, lower right*). It varies with a period near 41,000 years.
Lower 3 curves showing the orbital periodicities extracted from the oxygen isotope record in a sub-antarctic deep sea core. (From J. D. Hays et al., 1976, Science 194: 1121). *Middle* Isotope record (solid) with superimposed eccentricity variation. *Top* 23,000 year component extracted from the isotope record by band pass filter (a statistical method). *Bottom* 40,000 year component extracted in a similar fashion. *Inset in right* illustrates obliquity

Relative Changes of Sea Level

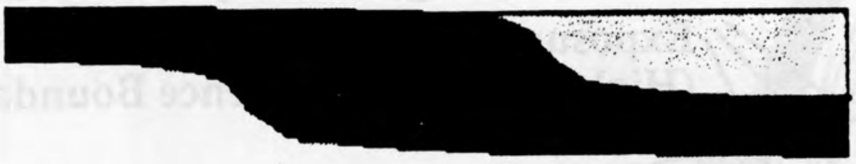


Slide


LATE HIGHSTAND SYSTEMS TRACT
Fluvial
(Meandering Streams)
Coastal or Deltaic Plain
Marsh or Lakes
Beach and Storm Deposits
Distributary Mouth Bars
SB+TS
FS
TS
Offshore Facies or Prodelta
Hemipelagic Facies
TRANSGRESSIVE AND EARLY HIGHSTAND SYSTEMS TRACTS
Beach and Storm Deposits
Fining Upwards Shales
Transgressive Lag
Transgressive Surfaces of Erosion
(Ravinement Surfaces)
Marsh
SS
FS
Offshore Facies
SB
Lowstand Surface of Erosion
LOWSTAND SYSTEMS TRACT
Deep Water Setting
Incised Valley Fill
(Braided Streams)
Lowstand Prograding Wedge
Storm or Tidal Deposits
Distributary Mouth Bars
Delta or Coastal Plain
SB
Lowstand Surface of Erosion
Prodelta
Offshore Facies
Hemipelagic or Shingled Turbidites
TS
SS
LEGEND
SB: Sequence Boundary
TS: Transgressive Surface
FS: Flooding Surface
SS: Starvation Surface
Channel and Overbank Turbidites
Slope Fan
Massive Sand Turbidites
Basin Floor Fan
Ramp Setting
Incised Valley Fill
Forced Regression
Upper Prograding Wedge
(Coarser Sand or Gravel)
Marine Muds
Lower Prograding Wedge
(Finer Sand)

PARASEQUENCE STACKING PATTERNS

1



AGGRADATIONAL TO STILLSTAND PARASEQUENCE SET

BY-PASSED SHELF

2a

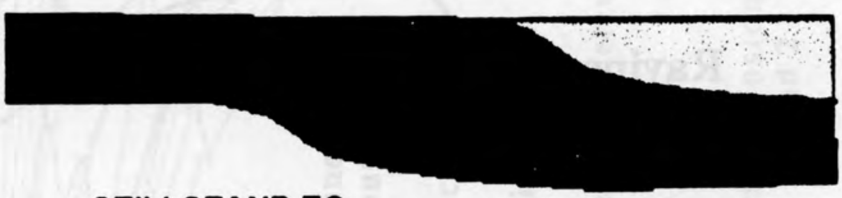
CHANNEL OVERBANK LOBES

"FORCED REGRESSION"

2b

DOWNWARD-STEPPING PARASEQUENCE SET

3



STILLSTAND TO AGGRADATIONAL PARASEQUENCE SET

4

BACKSTEPPING PARASEQUENCE SET

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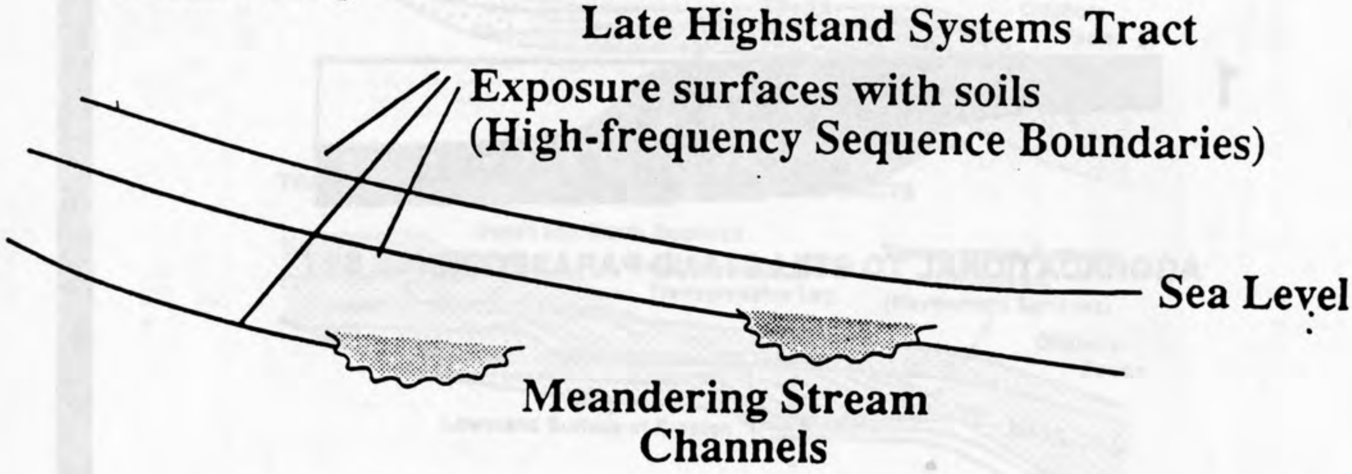
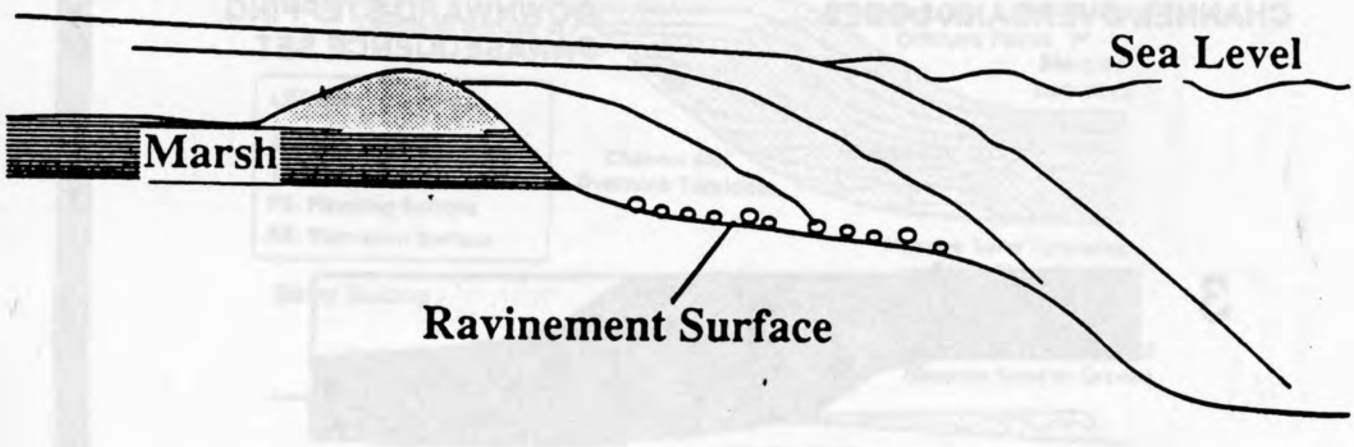
Erosional Surfaces that can be Erroneously Interpreted as Sequence Boundaries

- Meandering Stream Channels

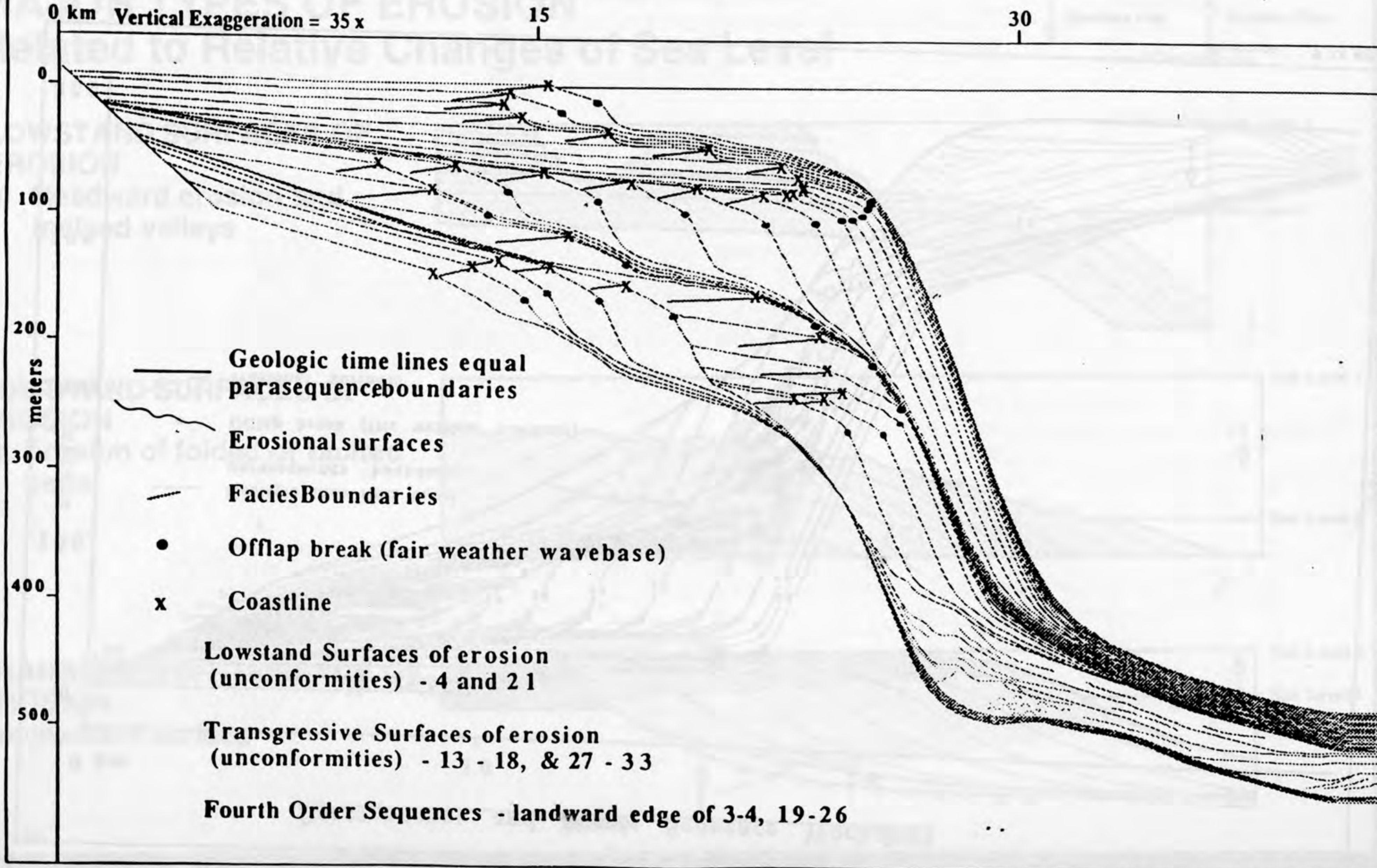


- Transgressive Surface of Erosion (Ravinement Surface)



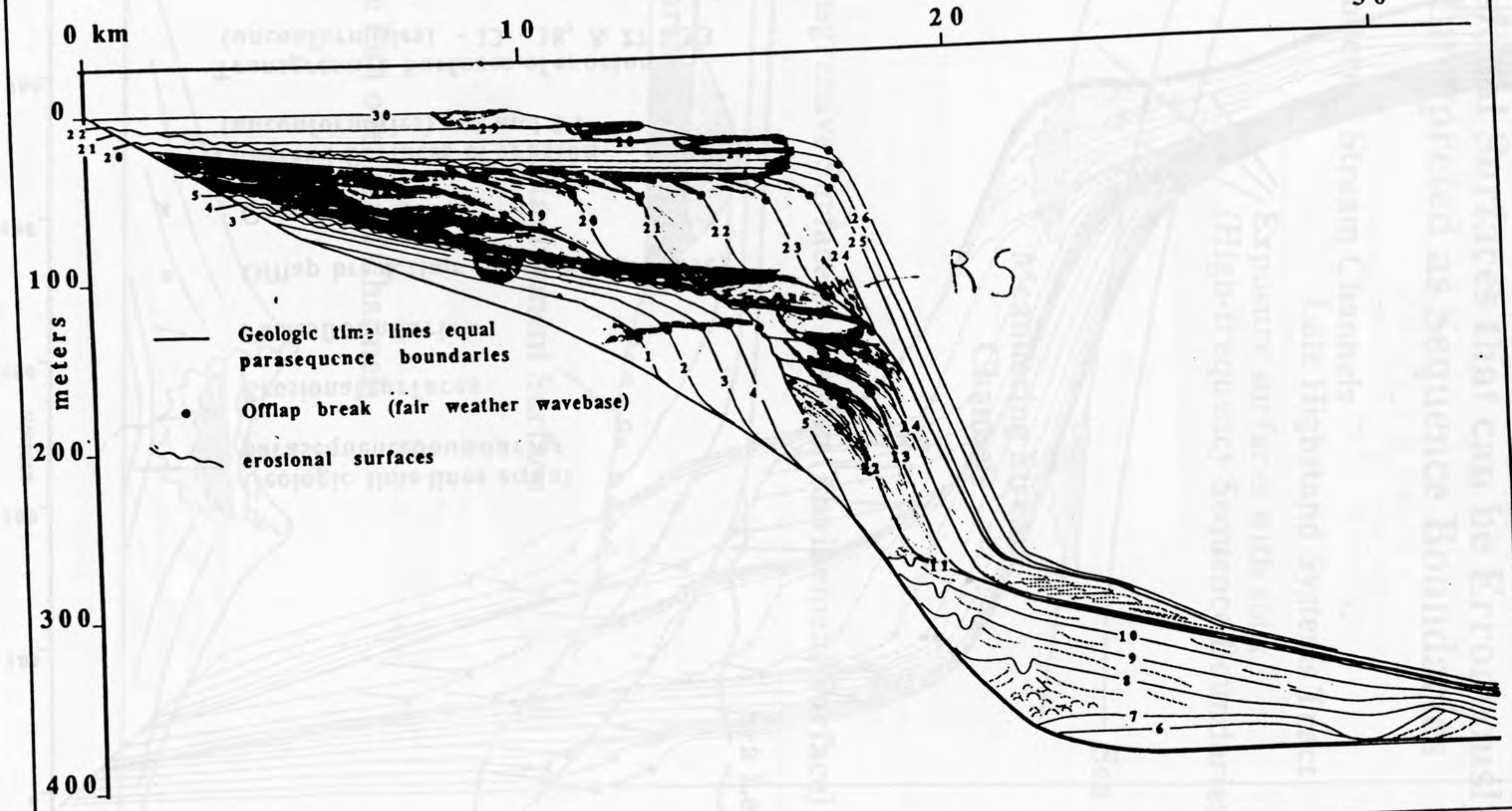
- Slope Fan overbank Channels

Parasequence and Simple Sequences and Relative Sea Level



Bowman 9.26.91.2

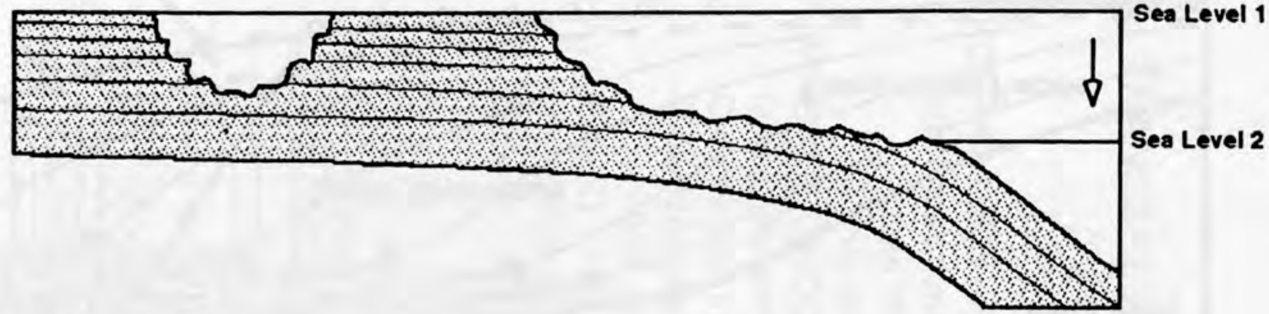
Parasequence and ~~Simple~~ Sequence Worksheet



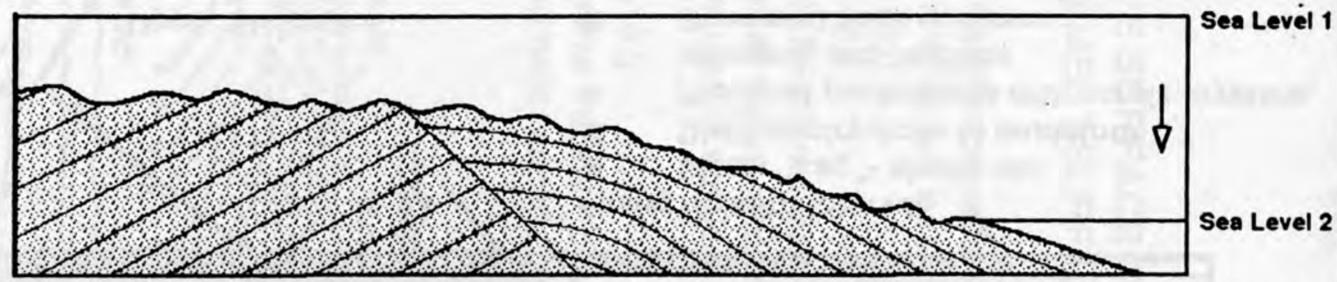
Bowman 9.18.90

MAJOR TYPES OF EROSION
Related to Relative Changes of Sea Level

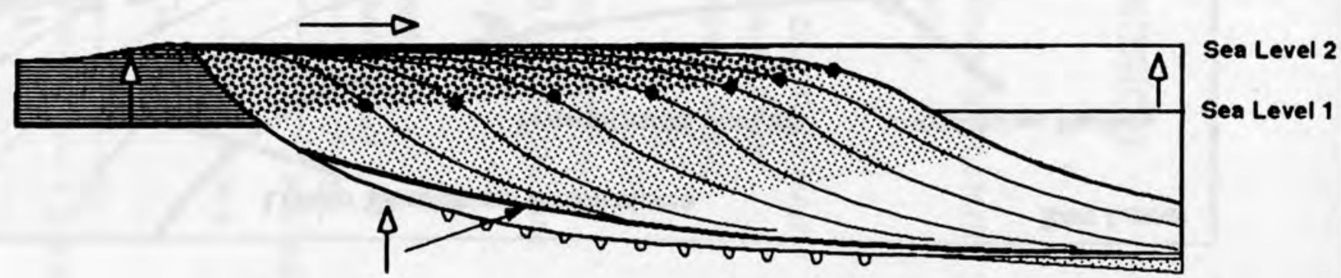
LOWSTAND SURFACES OF EROSION
a) Headward erosion and incised valleys



LOWSTAND SURFACES OF EROSION
b) Erosion of folded or faulted beds



TRANSGRESSIVE SURFACE OF EROSION
Ravinement surface



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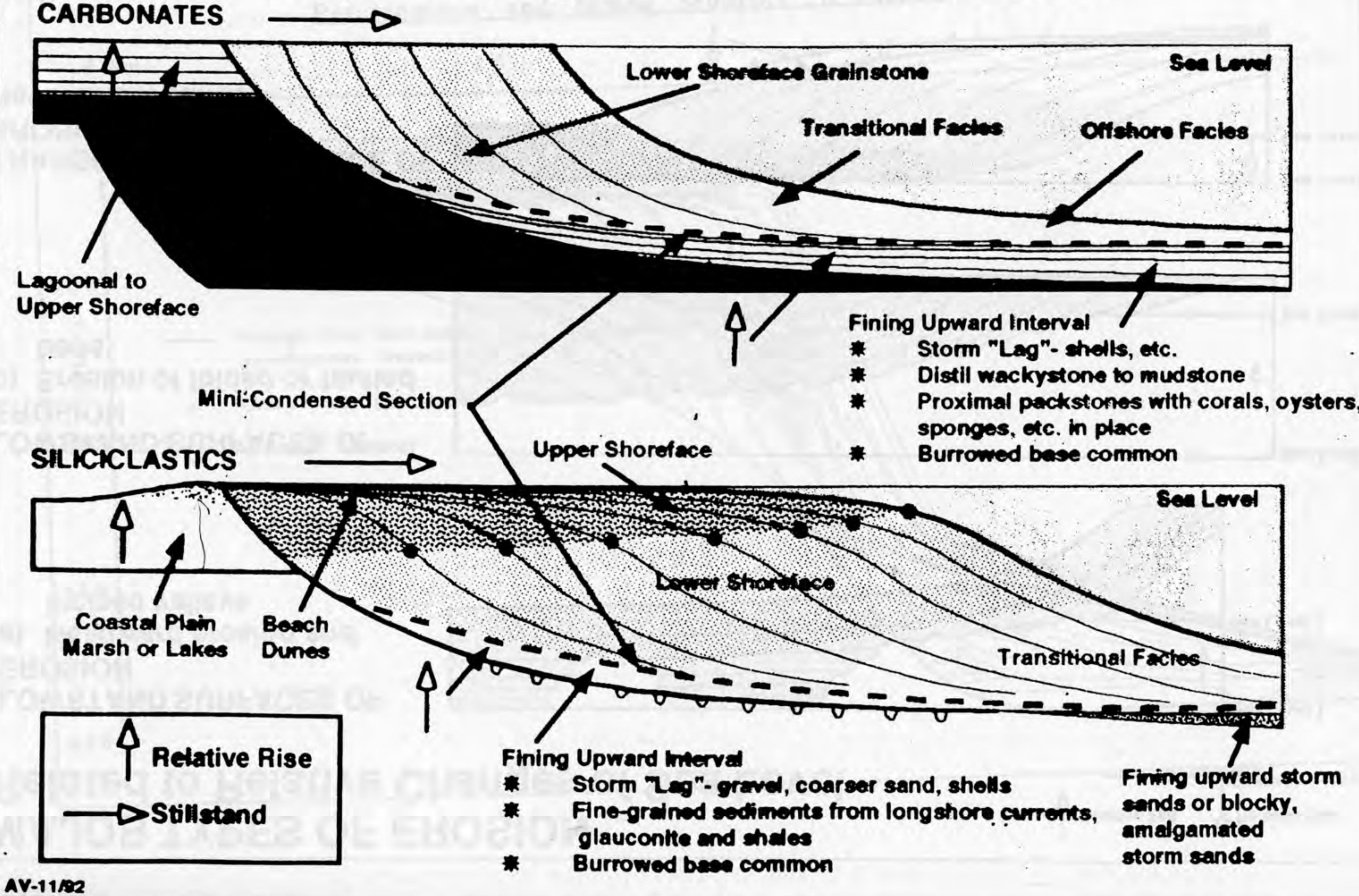
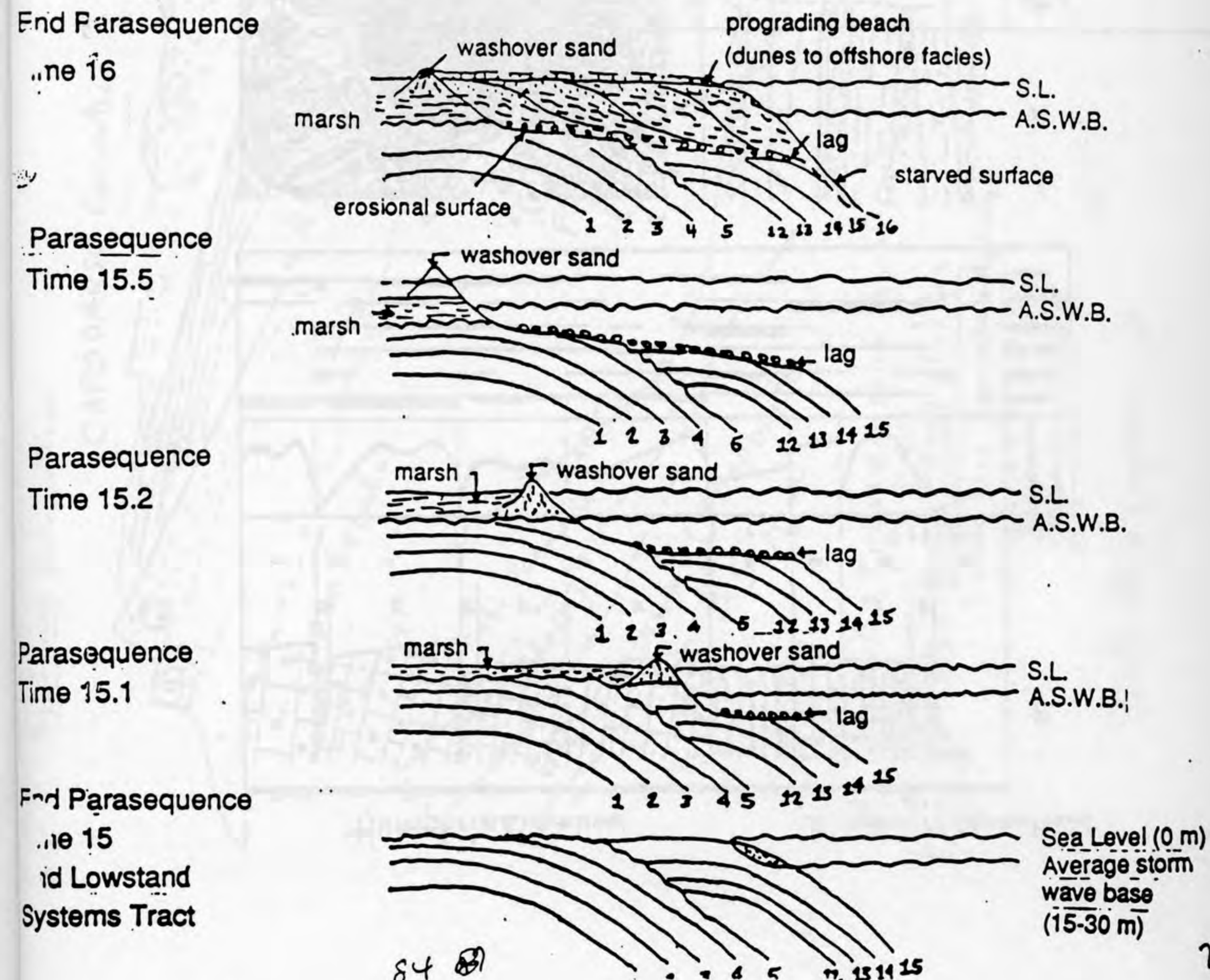
IDEALIZED PARASEQUENCES:
Typical of High Accommodation Rates

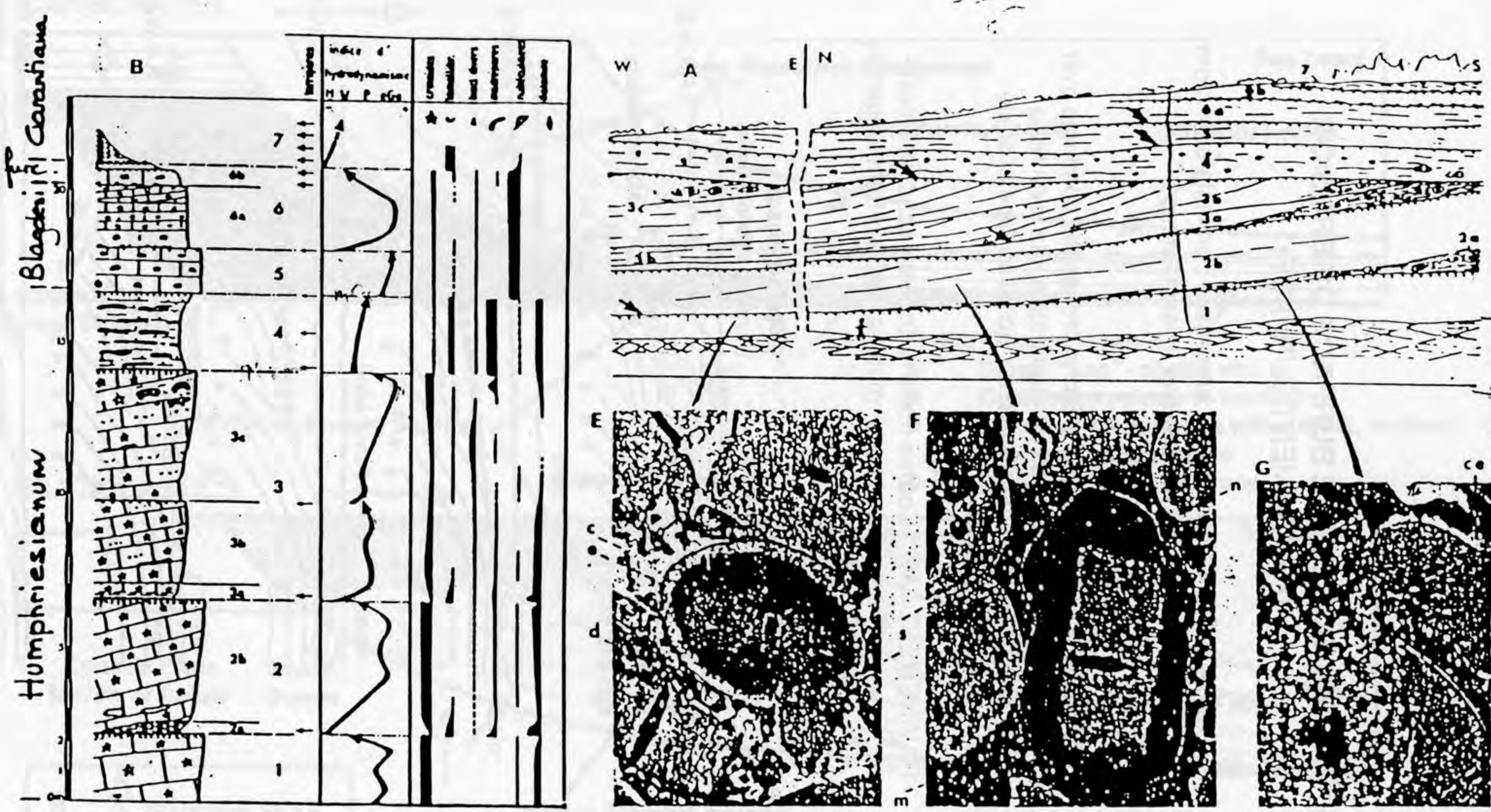


TRANSGRESSIVE SURFACE OF EROSION
(RAVINEMENT SURFACE)

- PROGRADATION - Fairweather processes dominate over storm processes during relative sea level stillstands.
  - time 15.5-16.0
  - time 14.0-15.0
- RAVINEMENT PROCESSES - Storm processes dominate over fairweather processes during relative sea level rises. Creates time transgressive erosional surface at scale of parasequence.
  - time 15.0-15.5
- RAVINEMENT LAG - Coarse material (coarse sand, pebbles, shells) from eroded beds; material derived from longshore currents



84


B
Blagdeni
Garantiana
Humphriesianum
indice d'
hydrodynamisme
H V P eGa
7
6
5
4
3
2
1
6a
4a
3c
3b
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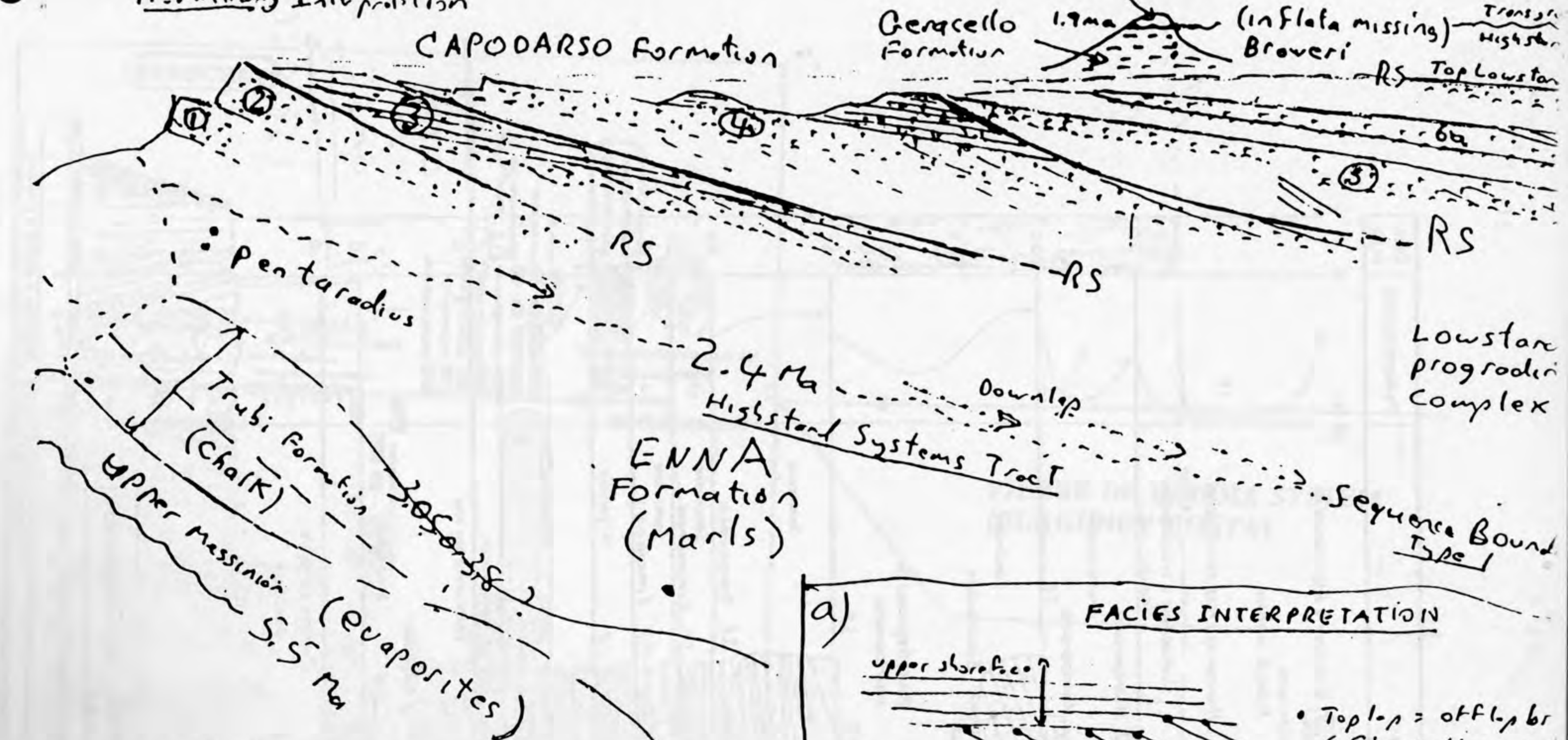
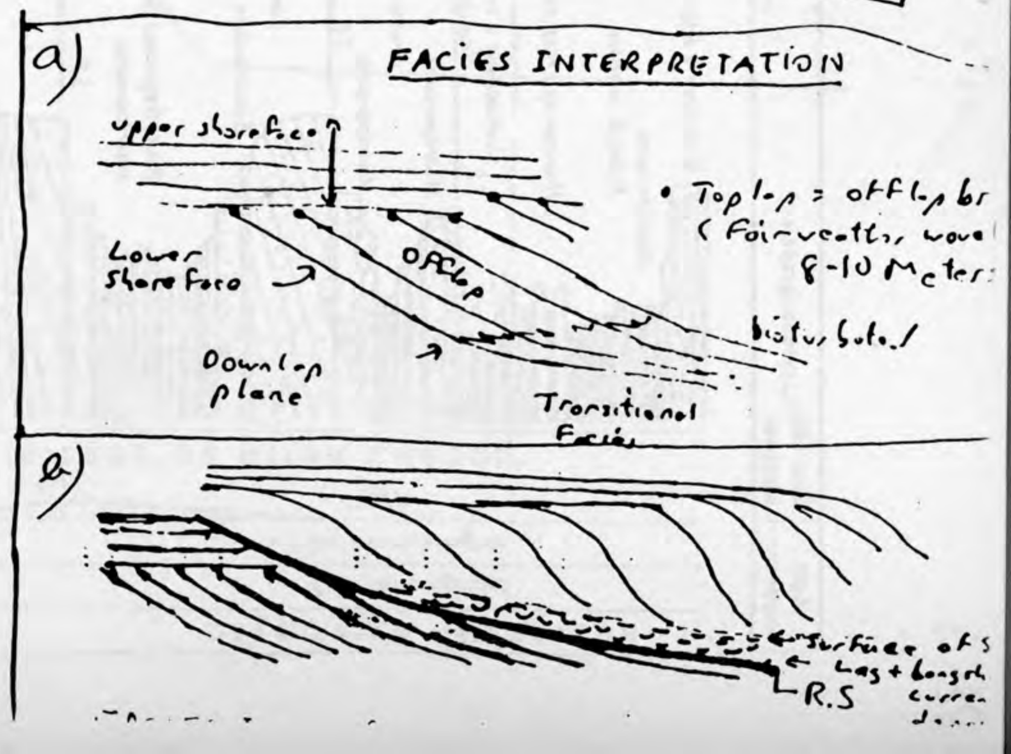
J.P. Garcia

Preliminary Interpretation

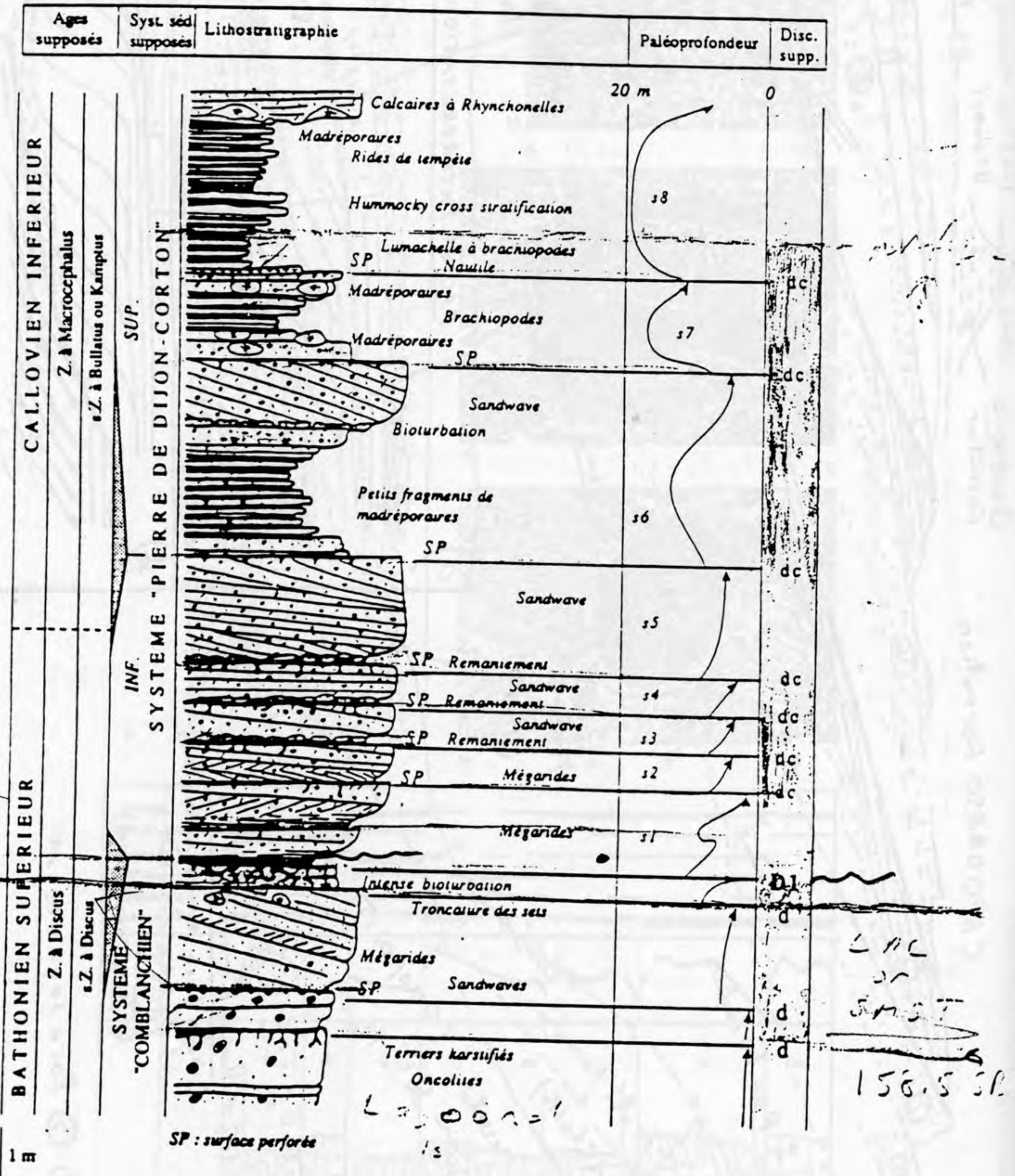




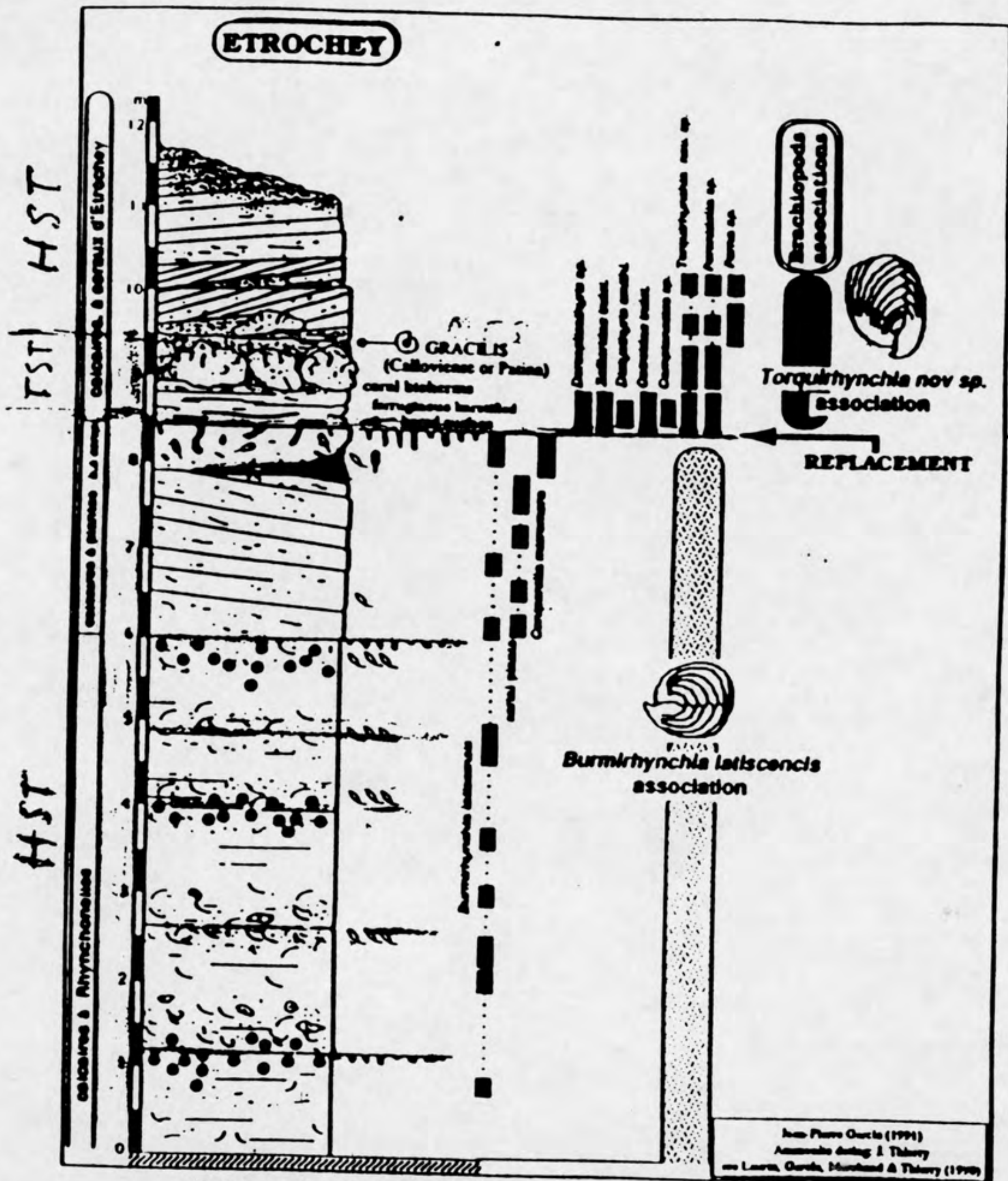
TSE = Transgressive Surface of Erosion

RS = Ravinement Surface
(wave base erosion during shoreline retreat)
(storm wave base)

①-⑨ Para sequence #



BUFFON : En Charibeau



Stratigraphical section of Roche Quarry at Etrochey.

PIERRE DE LADOIX SYSTEM
(BURGUNDY COSTA)