

Prática da Estratigrafia de Sequências: Interpretação Sísmica, Afloramentos e Testemunhos

Sismoestratigrafia: conceitos básicos

Definição - Sismoestratigrafia, ou estratigrafia sísmica, é o estudo de sucessões estratigráficas através dos métodos sísmicos de prospecção.

Compreende a interpretação de refletores sísmicos e conjuntos de refletores sísmicos em seções ou blocos tridimensionais.

Principais objetivos da Sismoestratigrafia - o estabelecimento de modelos de prospecção de petróleo em áreas pouco estudadas (sismoestratigrafia de exploração) e o estabelecimento de modelos detalhados, através da correlação de poços e integração de diversas fontes de dados, em áreas de produção (sismoestratigrafia de desenvolvimento).

Introdução aos métodos de prospecção sísmica

Métodos sísmicos de exploração – baseados criação de ondas sísmicas que se propagam em subsuperfície e na observação, em superfície, das ondas refletidas por feições geológicas ou refratadas ao longo de certas interfaces.

As ondas que propagam em subsuperfície são refletidas em limites entre camadas ou corpos de rocha com propriedades distintas e então retornam à superfície, onde são detectadas .

As ondas transmitidas podem também propagar horizontalmente em uma interface por uma certa distância e então retornar à superfície - este é o princípio da sísmica de refração.

Profundidade de alcance do método (reflexão) - até 10 km, e resolução melhor que a de outros métodos geofísicos. Custos são também maiores.

O método de reflexão

De forma análoga ao radar e o sonar, o método de reflexão mede o tempo decorrido entre a emissão de um pulso e seu retorno até o receptor após a reflexão.

As ondas sísmicas emitidas migram através de meios heterogêneos, sujeitos a reflexão a cada horizonte de contraste de características físicas das rochas.

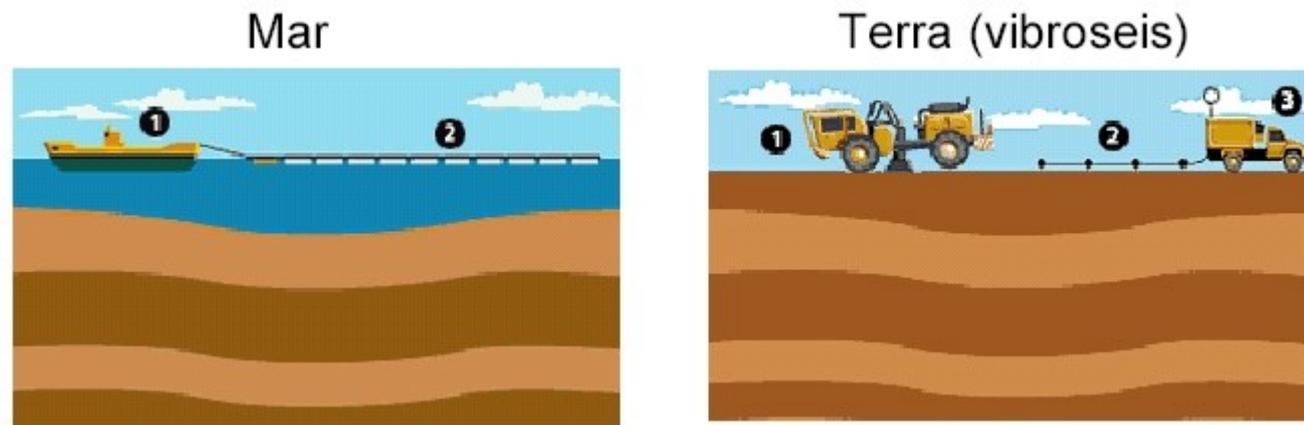
O objetivo do método é localizar e interpretar refletores, ou seja, estabelecer a posição de pontos de reflexão abaixo da superfície e delimitar, pelo deslocamento do conjunto de fonte e receptores, a extensão bidimensional ou tridimensional das feições geológicas responsáveis pela reflexão.

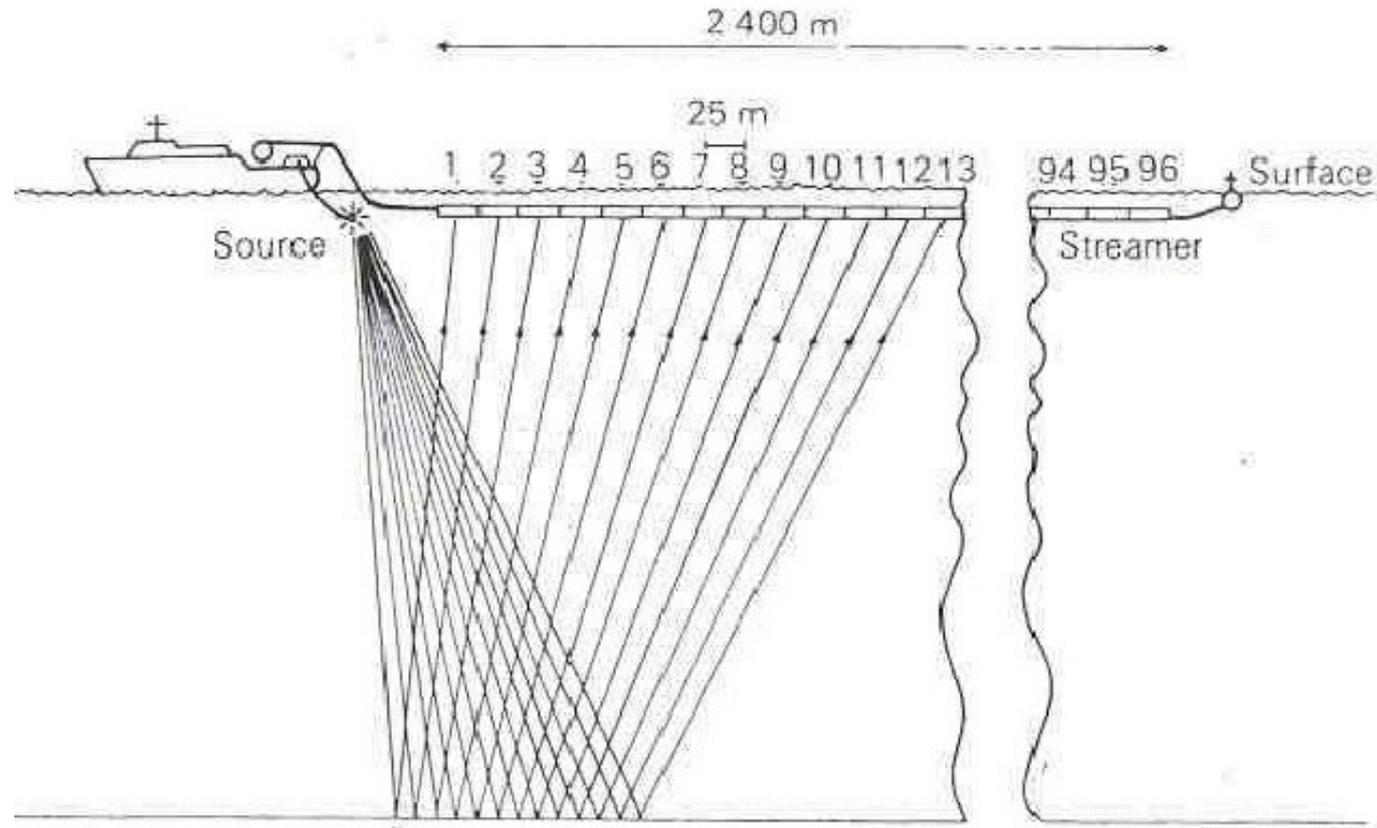
Sistemas de aquisição de dados: tipos de fontes e receptores

Um sistemas de aquisição de dados é composto por uma ou mais fontes, um arranjo de receptores e um sistema de armazenamento e pré-processamento.

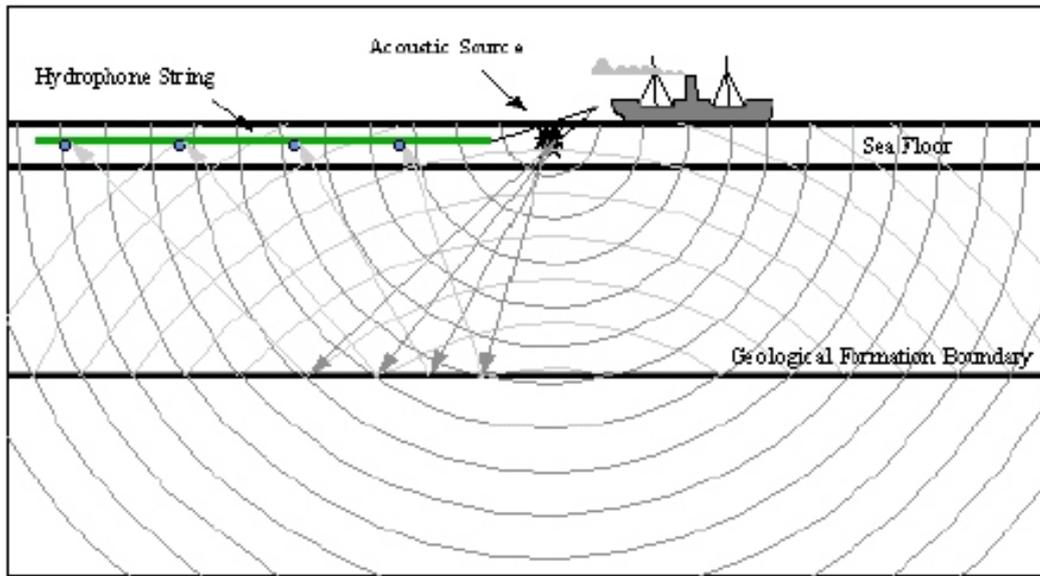
Fontes são caracterizadas como sistemas de geração de ondas sísmicas pela aplicação repentina de energia na água do mar ou diretamente na rocha.

Devido às particularidades de cada um dos meios, existem grandes diferenças entre os sistemas de aquisição de dados sísmicos em terra e no mar.





Modelo esquemático do sistema de aquisição de dados sísmicos em regiões submersas. A cada pulso emitido pela fonte (source), diferentes hidrofones captam sinal relativo a um ponto diferente do refletor, equidistante da fonte e do hidrofone. (Fonte: Waters, 1987)



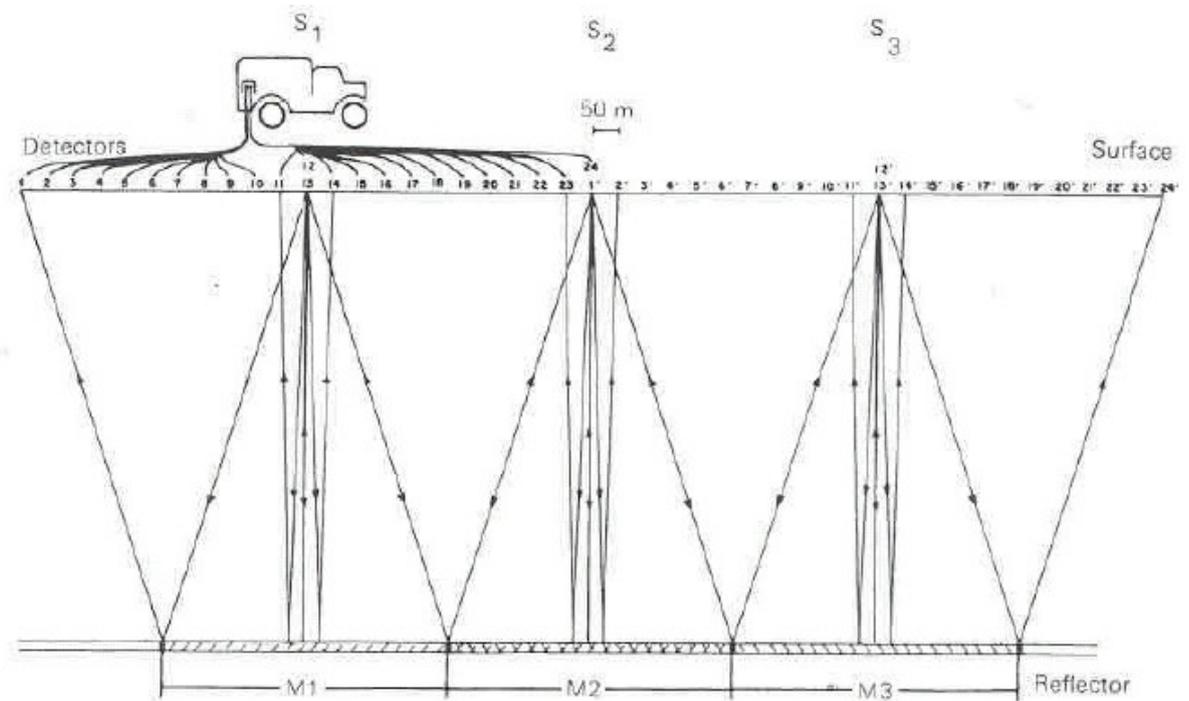
Modelo esquemático de aquisição marinha.

Sistema de aquisição marinha 3D.





Modelo esquemático do sistema de aquisição de dados sísmicos em regiões emersas. (Fonte: Waters, 1987)

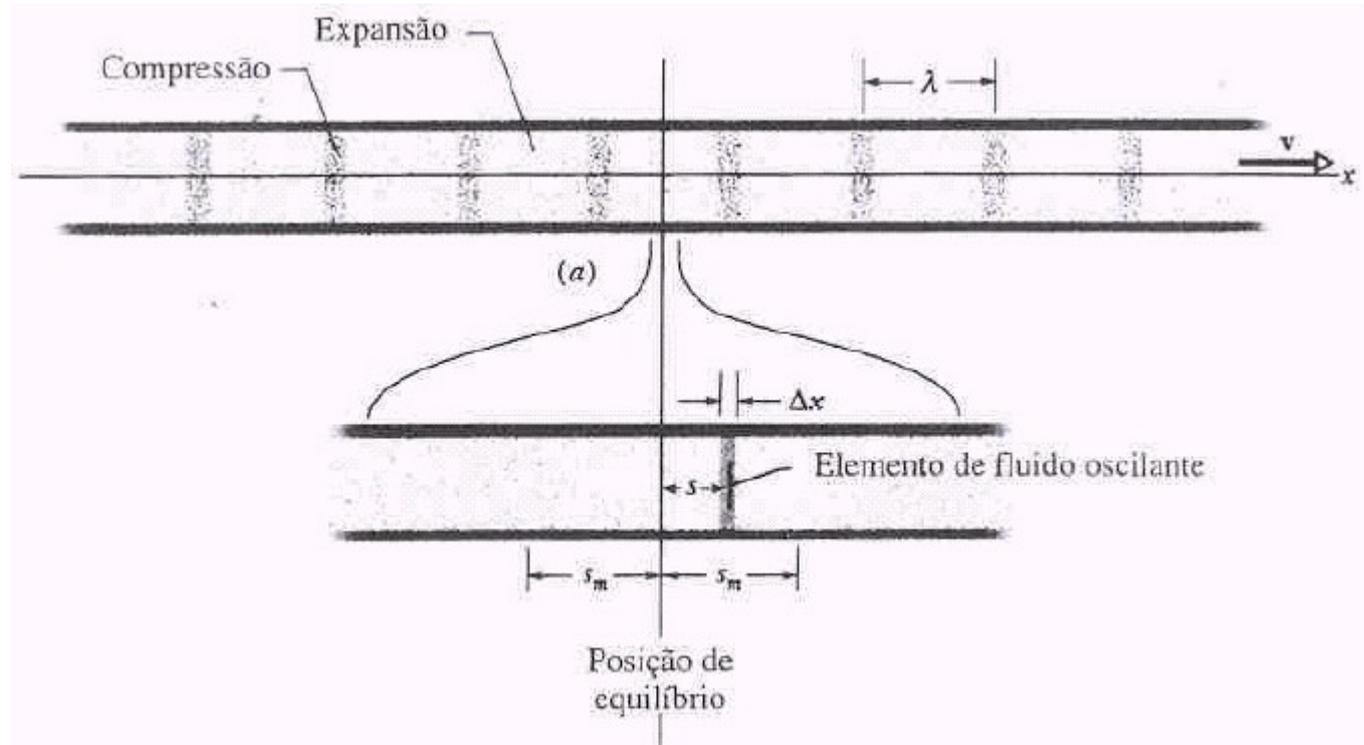


Fundamentos físicos da Sismoestratigrafia

Ondas em meios sólidos elásticos

Uma onda é uma perturbação da matéria que se propaga em uma direção, ou seja, as partículas em um determinado ponto de um meio sólido movimentam-se em um momento e logo voltam ao repouso, porém o movimento passa para partículas em um ponto adjacente, e assim por diante.

Podemos classificar as ondas de corpo (que propagam em volumes e não em superfícies) em dois tipos: ondas P e ondas S.



Representação gráfica da propagação de uma onda longitudinal em um tubo (Fonte: Halliday *et al.* 1993).

Reflexão e refração

Quando uma onda de corpo atinge um limite entre dois meios com velocidades diferentes, ocorrem dois fenômenos principais:

- Parte da onda incidente é refletida de volta para o meio 1. O ângulo de reflexão é igual ao de incidência, ou seja, o ângulo entre o raio da onda incidente e uma normal ao plano de reflexão é igual ao ângulo entre o raio da onda refletida e essa normal.

- Parte é transmitida pelo meio 2. Para que se mantenha a coerência da frente de onda com o Princípio de Huygens, o raio muda de direção de acordo com a mudança de velocidade.

Essa mudança de direção segue a **Lei de Snell**, que relaciona o ângulo de incidência (θ_1), o ângulo de refração (θ_2), ambos medidos em relação a uma normal ao plano, e as velocidades dos meios 1 e 2 (V_1 e V_2) da seguinte forma:

$$\text{sen } \theta_1 / V_1 = \text{sen } \theta_2 / V_2$$

Reflexão de ondas sísmicas em prospecção

Essa breve introdução mostra que cada superfície de contraste de velocidade em uma sucessão de rochas poderia refletir parte da energia e transmitir outra parte na forma de uma onda refratada, mas há algumas questões que são fundamentais para se entender o que acontece de fato na propagação de ondas sísmicas:

1- o que controla a “intensidade” de uma reflexão? Ou seja quanta energia é refletida e quanta é refratada?

2- uma sucessão sedimentar tem muitas camadas de litologias diferentes e de diferentes espessuras, o que a sísmica “enxerga”, ou qual a sua resolução?

Impedância acústica e coeficiente de reflexão.

Uma onda P (transversal), plana com uma determinada amplitude é refletida em uma superfície.

É gerada uma onda refletida e outra transmitida para o segundo meio, cuja soma de intensidades é igual à intensidade da onda incidente.

A intensidade da onda é definida como a taxa média de transmissão de energia por unidade de área, e tem que ser constante no sistema.

$$I_{\text{incidente}} = I_{\text{refletida}} + I_{\text{transmitida}}$$

A questão de como a energia se distribuí quando chega à superfície equivale a perguntar quanto da amplitude da onda incidente será refletida e quanto será transmitida.

Essa proporção entre a amplitude incidente e a refletida é denominada **coeficiente de reflexão**.

$$R = A_r / A_i$$

$$R = (\rho_2 v_2) - (\rho_1 v_1) / (\rho_2 v_2) + (\rho_1 v_1)$$

Ou seja, a razão entre as amplitudes da onda incidente e a da onda refletida é função do contraste entre o produto da densidade pela velocidade de propagação em cada um dos meios. Esse produto é denominado **impedância acústica**.

Impedância acústica = densidade do meio X velocidade de propagação da onda = ρv

Quando a impedância acústica do meio 2 é maior que a do meio 1, o coeficiente de reflexão é positivo, e está entre 0 e 1 - Parte da amplitude é refletida sem inversão de fase.

Quando é negativo, ou seja a IA do meio 2 é menor que a do meio 1, o coeficiente de reflexão é negativo – A onda refletida terá fase invertida, ou seja, se o pulso inicial a chegar à superfície foi uma compressão, o pulso inicial refletido será uma distensão.

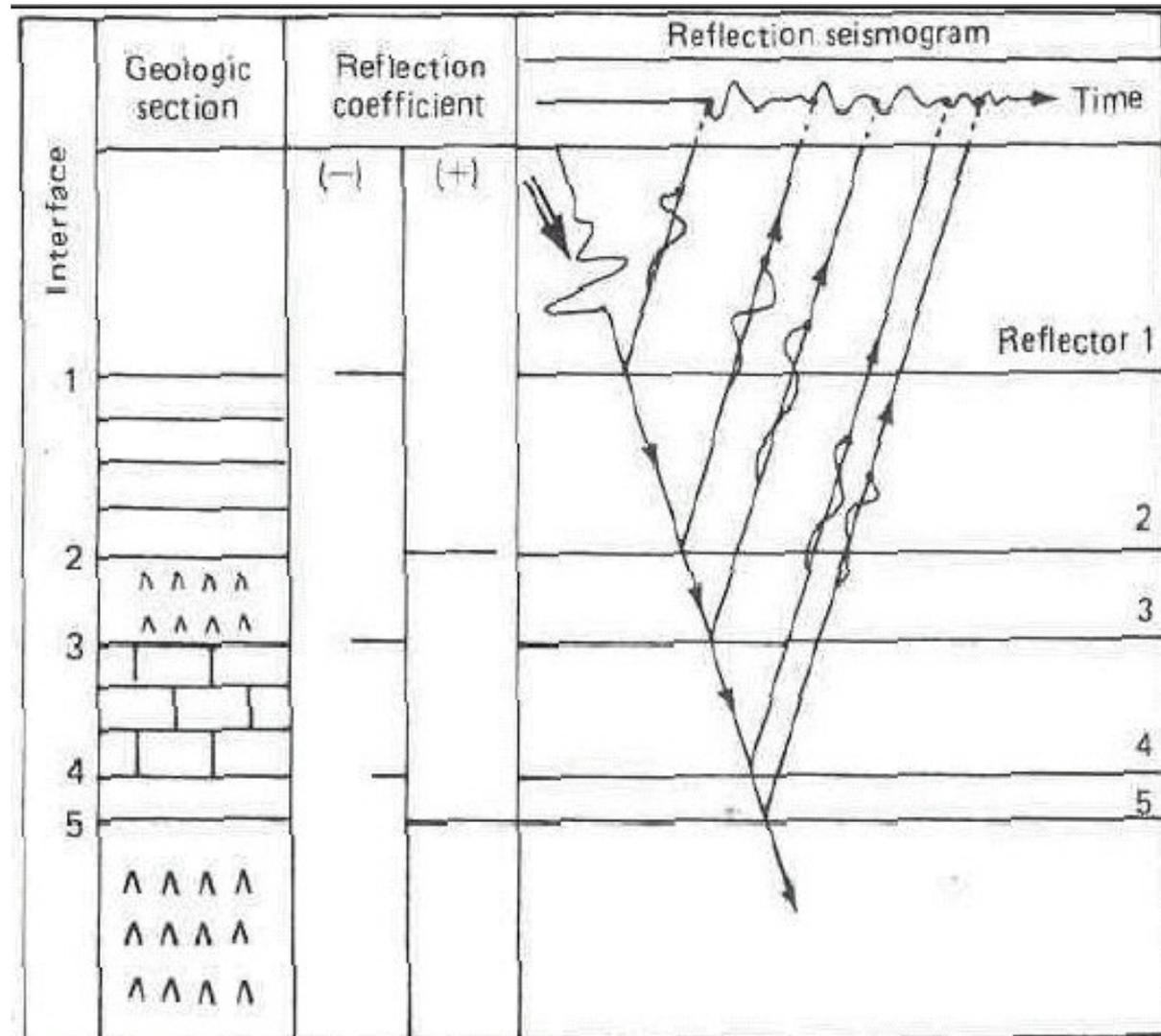
Em uma situação geológica real, o que controla a impedância acústica é um conjunto de fatores, principalmente litologia, conteúdo e tipo de fluido intersticial, quantidade e tipo de cimento e profundidade de soterramento.

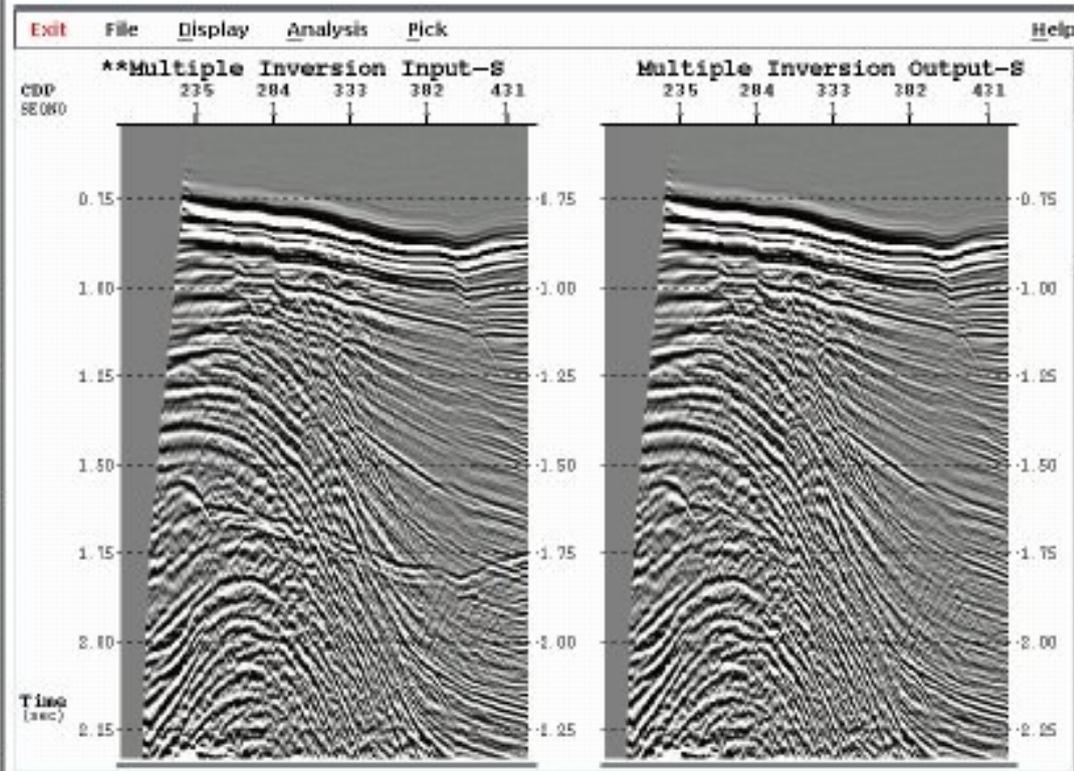
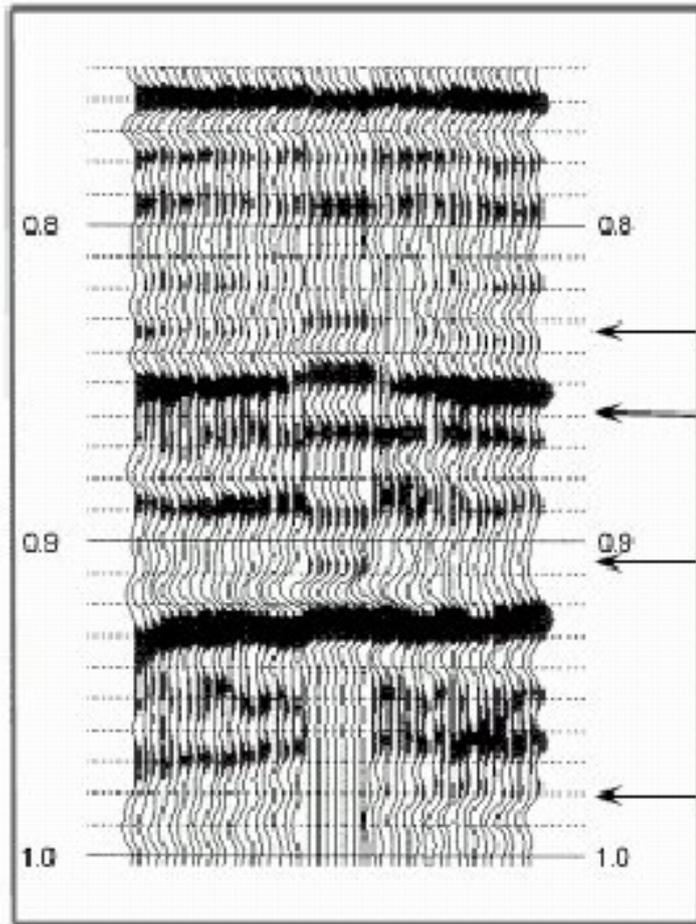
Type of formation	<i>P</i> -wave velocity (m/s)	<i>S</i> -wave velocity (m/s)	Density
Weathered rocks	300- 700	100- 300	1.7-2.4
Dry sands	400-1200	100- 500	1.5-1.7
Wet sands	1500-4000	400-1200	1.9-2.1
Clays	1100-2500	200- 800	2.0-2.4
Marls	2000-3000	750-1500	2.1-2.6
Sandstones	3000-4500	1200-2800	2.1-2.4
Limestones	3500-6000	2000-3300	2.4-2.7
Chalk	2300-2600	1100-1300	1.8-2.3
Salt	4500-5500	2500-3100	2.1-2.3
Anhydrite	4000-5500	2200-3100	2.9-3
Dolomite	3500-6500	1900-3600	2.5-2.9
Granite	4500-6000	2500-3300	2.5-2.7
Basalt	5000-6000	2800-3400	2.7-3.1
Coal	2200-2700	1000-1400	1.3-1.8
Water	1450-1500	—	1
Ice	3400-3800	1700-1900	0.9
Oil	1200-1250	—	0.6-0.9

Então a cada superfície com contraste de impedância acústica parte da energia é refletida e parte é transmitida.

Desta forma a energia, indicada pela amplitude, do pulso inicial é dividida ao longo do percurso e chega como um sinal complexo nos receptores.

A resposta de cada superfície chega a um determinado tempo, que é função da profundidade do refletor.

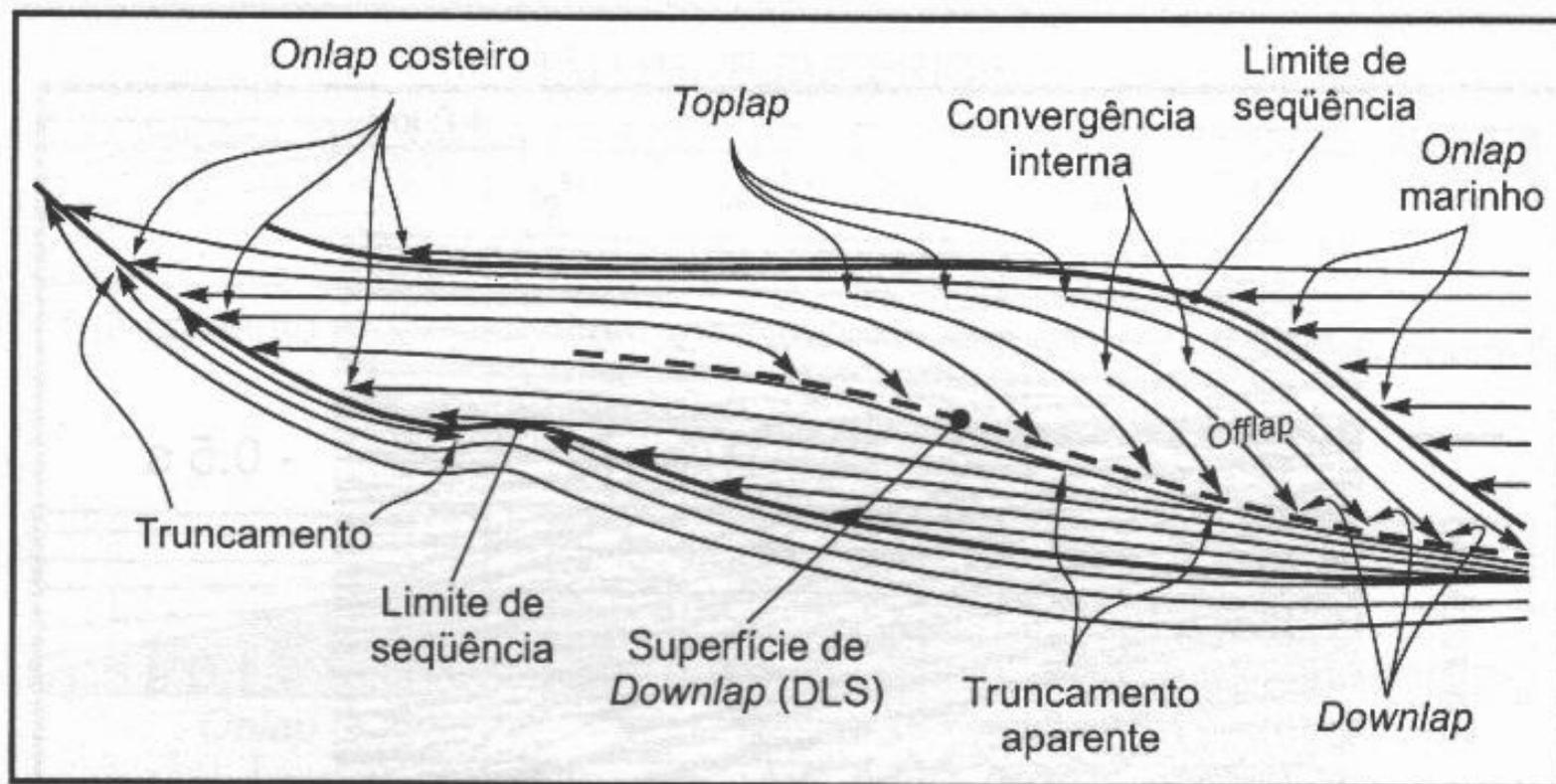




Cada linha vertical representa a amplitude de cada evento de reflexão (deslocamento horizontal) pelo tempo de ida e volta (eixo vertical).

A justaposição dessas linhas de diferentes posições na bacia gera a linha sísmica bruta.

Padrões de terminação de refletores



Severiano Ribeiro (2001)

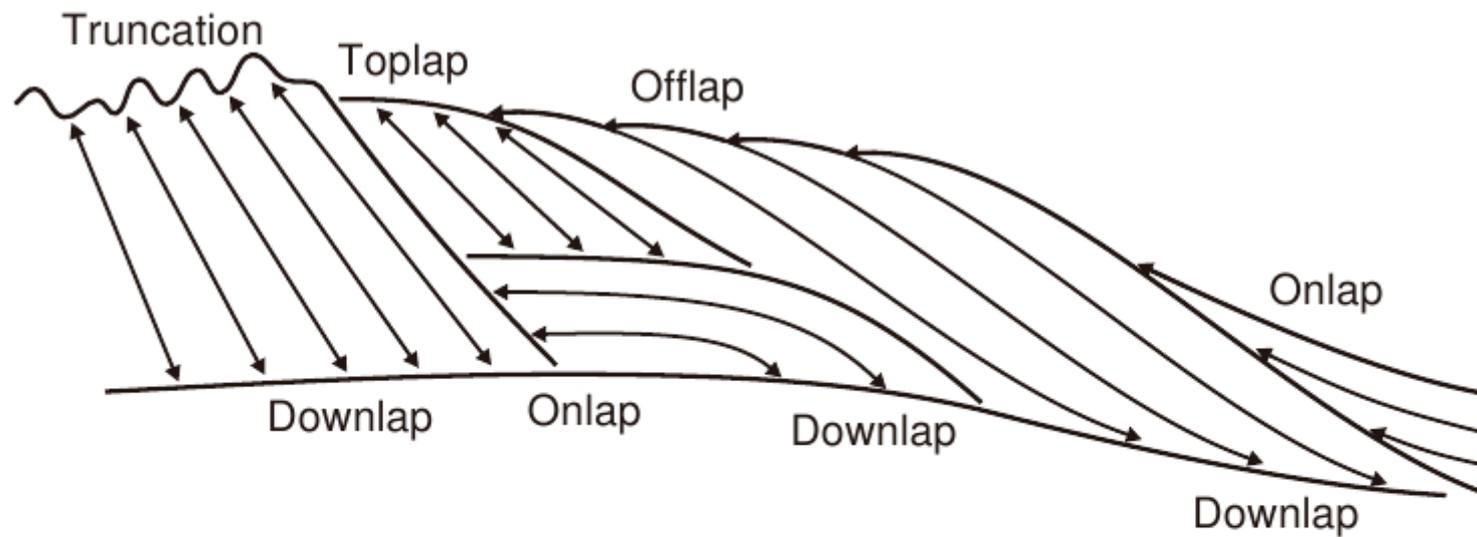


FIGURE 4.1 Types of stratal terminations (modified from Emery and Myers, 1996). Note that tectonic tilt may cause confusion between onlap and downlap, due to the change in ratio between the dip of the strata and the dip of the stratigraphic surface against which they terminate.

Truncation: termination of strata against an overlying erosional surface. *Toplap* may develop into truncation, but truncation is more extreme than toplap and implies either the development of erosional relief or the development of an angular unconformity.

Toplap: termination of inclined strata (clinoforms) against an overlying lower angle surface, mainly as a result of nondeposition (sediment bypass), \pm minor erosion. Strata lap out in a landward direction at the top of the unit, but the successive terminations lie progressively seaward. The toplap surface represents the proximal depositional limit of the sedimentary unit. In seismic stratigraphy, the *topset* of a deltaic system (delta plain deposits) may be too thin to be “seen” on the seismic profiles as a separate unit (thickness below the seismic resolution). In this case, the topset may be confused with toplap (i.e., *apparent toplap*).

Onlap: termination of low-angle strata against a steeper stratigraphic surface. Onlap may also be referred to as *lapout*, and marks the lateral termination of a sedimentary unit at its depositional limit. Onlap type of stratal terminations may develop in marine, coastal, and nonmarine settings:

- marine onlap: develops on continental slopes during transgressions (*slope aprons*, Galloway, 1989; *healing-phase deposits*, Posamentier and Allen, 1993), when deep-water transgressive strata onlap onto the maximum regressive surface.
- coastal onlap: refers to transgressive coastal to shallow-water strata onlapping onto the transgressive (tidal, wave) ravinement surfaces.
- fluvial onlap: refers to the landward shift of the upstream end of the aggradation area within a fluvial system during base-level rise (normal regressions and transgression), when fluvial strata onlap onto the subaerial unconformity.

Downlap: termination of inclined strata against a lower-angle surface. Downlap may also be referred to as *baselap*, and marks the base of a sedimentary unit at its depositional limit. Downlap is commonly seen at the base of prograding clinoforms, either in shallow-marine or deep-marine environments. It is uncommon to generate downlap in nonmarine settings, excepting for lacustrine environments. Downlap therefore represents a change from marine (or lacustrine) slope deposition to marine (or lacustrine) condensation or nondeposition.

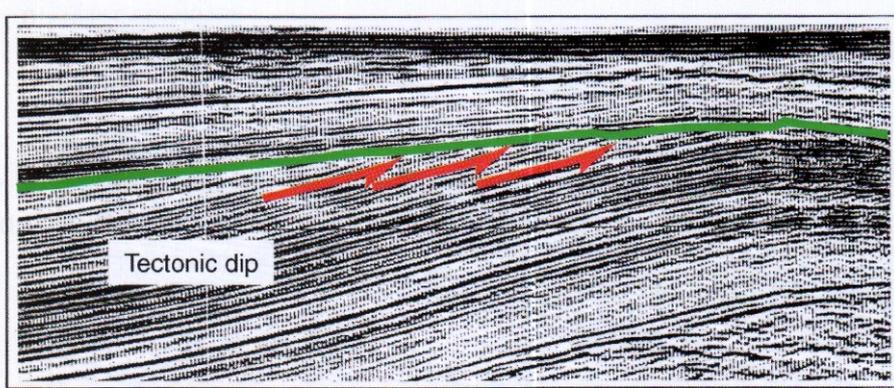
Offlap: the progressive offshore shift of the updip terminations of the sedimentary units within a conformable sequence of rocks in which each successively younger unit leaves exposed a portion of the older unit on which it lies. Offlap is the product of base-level fall, so it is diagnostic for forced regressions.

2.2.1 – Padrões de Terminação de Refletores

- Principais: discordâncias, concordâncias e truncamentos
- Discordâncias são superfícies de erosão e/ou não-deposição que constituem hiatus no registro sedimentar, sendo geralmente diacrônicas.
- As discordâncias geram refletores pois eles separam camadas com diferentes propriedades físicas e litologias, apresentando assim diferentes características de impedância acústica.
- Geralmente o truncamento coincide com a mudança no structural dip entre as unidades sotopostas e sobrepostas – contato angular (basculamento da unidade mais antiga)
- Erosão gera truncamento da unidade sotoposta. Caso haja concordância entre estratos de tempos diferentes, o estabelecimento deste hiato deposicional é feito por análises bioestratigráficas, isotópicas, etc

Tipos de discordâncias displayed pelas geometrias de reflexões em seções sísmicas

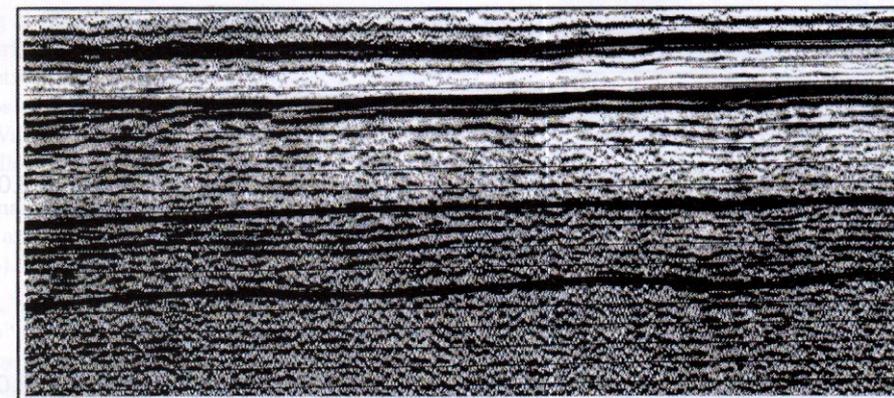
Limite Superior



Top lap



Erosional truncation



Concordance with subtle indications for sediment bypass

0
TWT in seconds
1.0
1.0
TWT in seconds
1.5

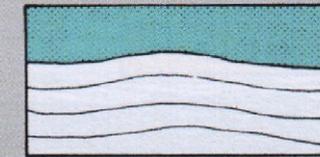
UPPER BOUNDARY



EROSIONAL TRUNCATION



TOPLAP

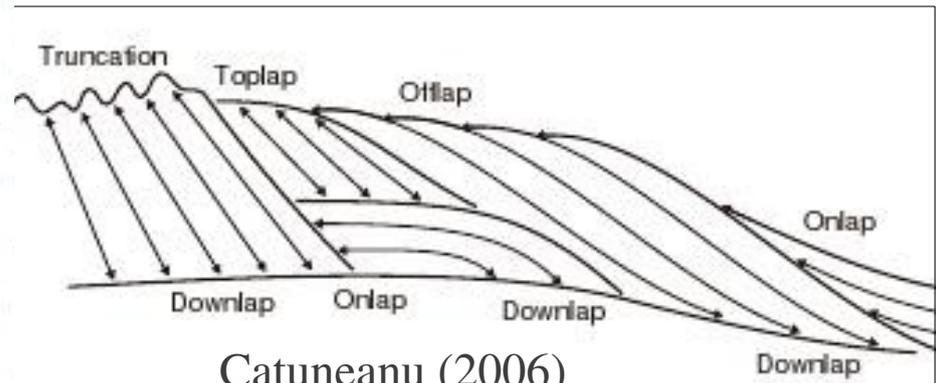


CONCORDANCE

GEOMETRICAL RELATIONSHIPS DISPLAYED BY SEISMIC REFLECTIONS

Veeken (2007)

2.0
TWT in seconds
3.0

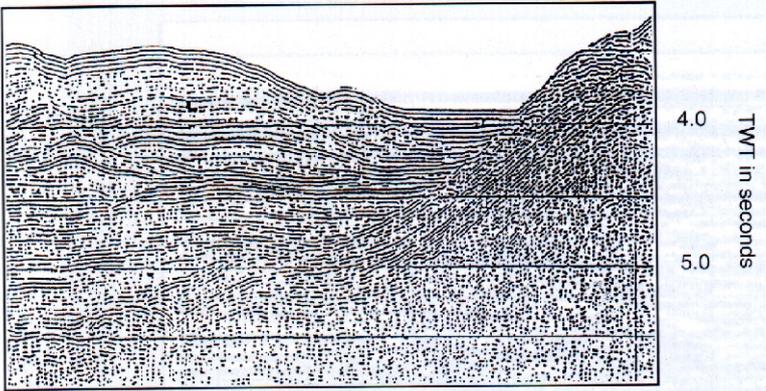


Catuneanu (2006)

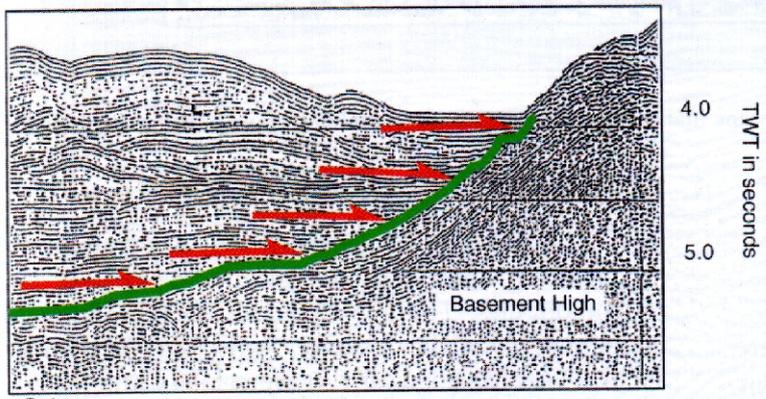
Tipos de discordâncias displayed pelas geometrias de reflexões em seções sísmicas

Limite Inferior

Onlap



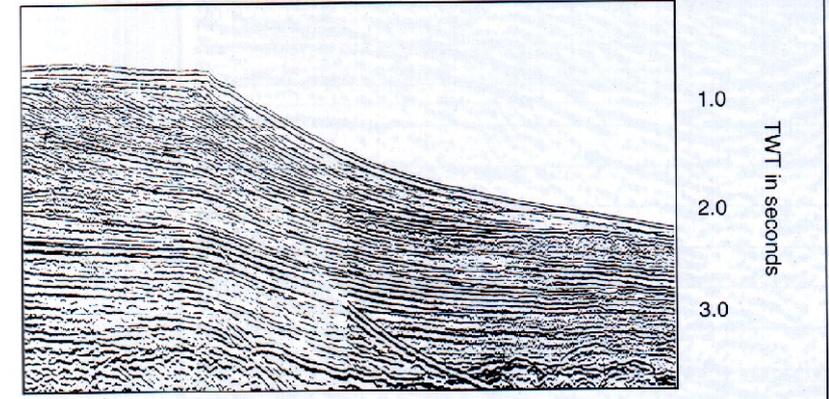
Onlap



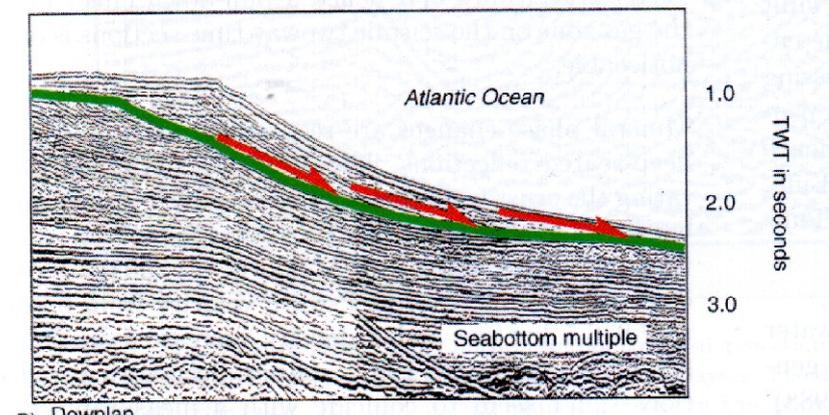
Onlap

Veeken (2007)

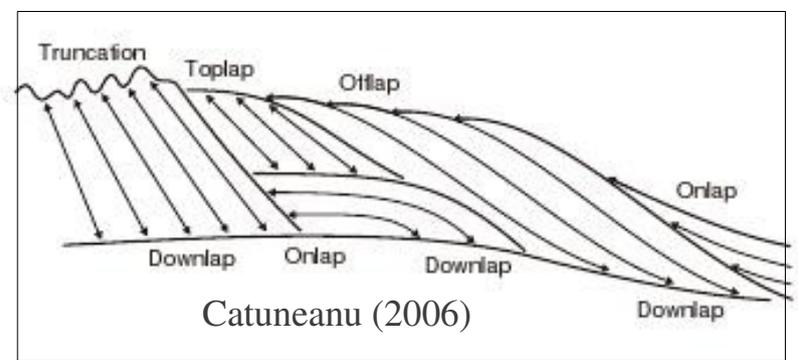
Downlap



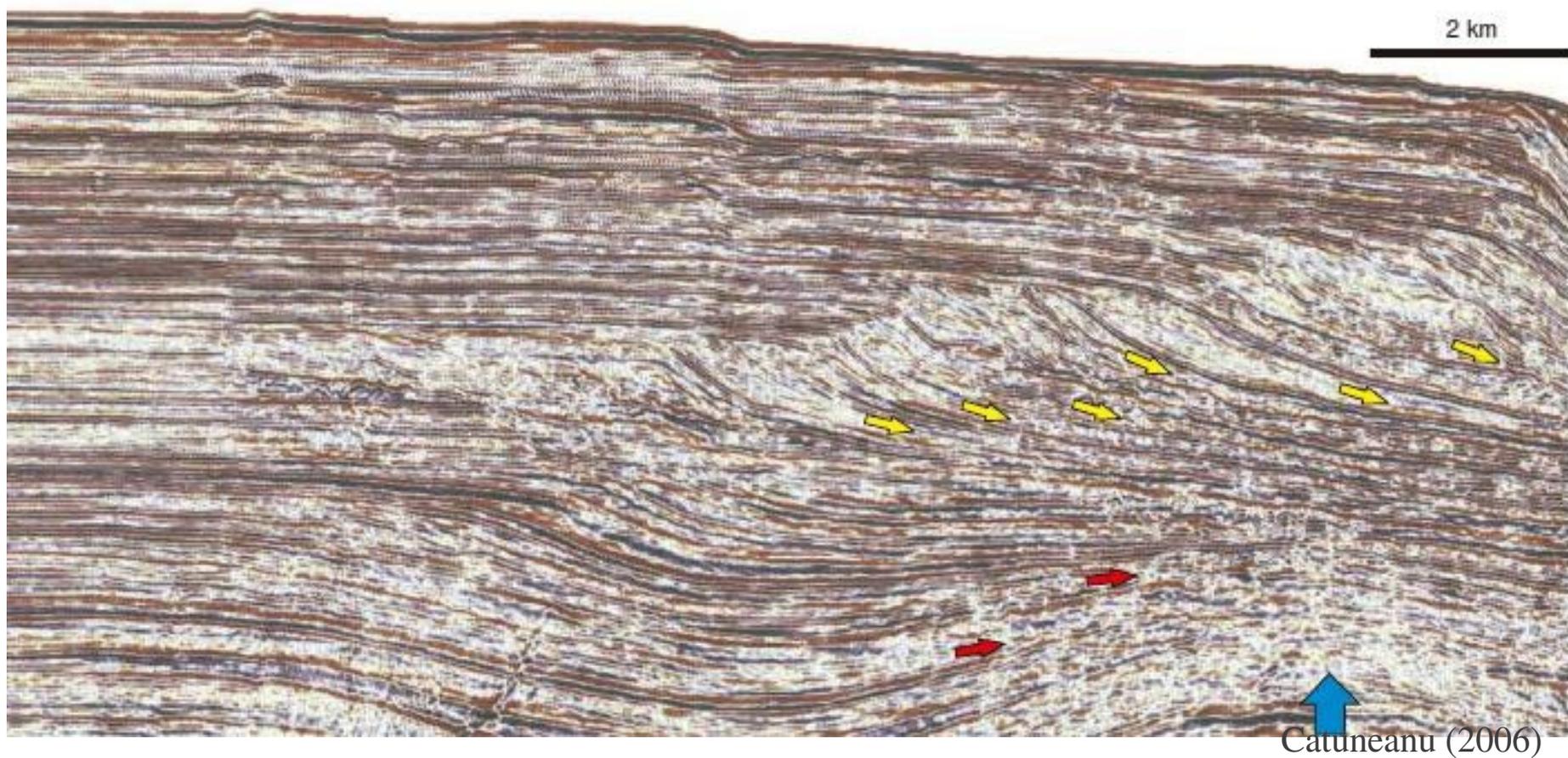
A) Downlap



B) Downlap



Catuneanu (2006)



Seção sísmica mostrando progradação em margem continental

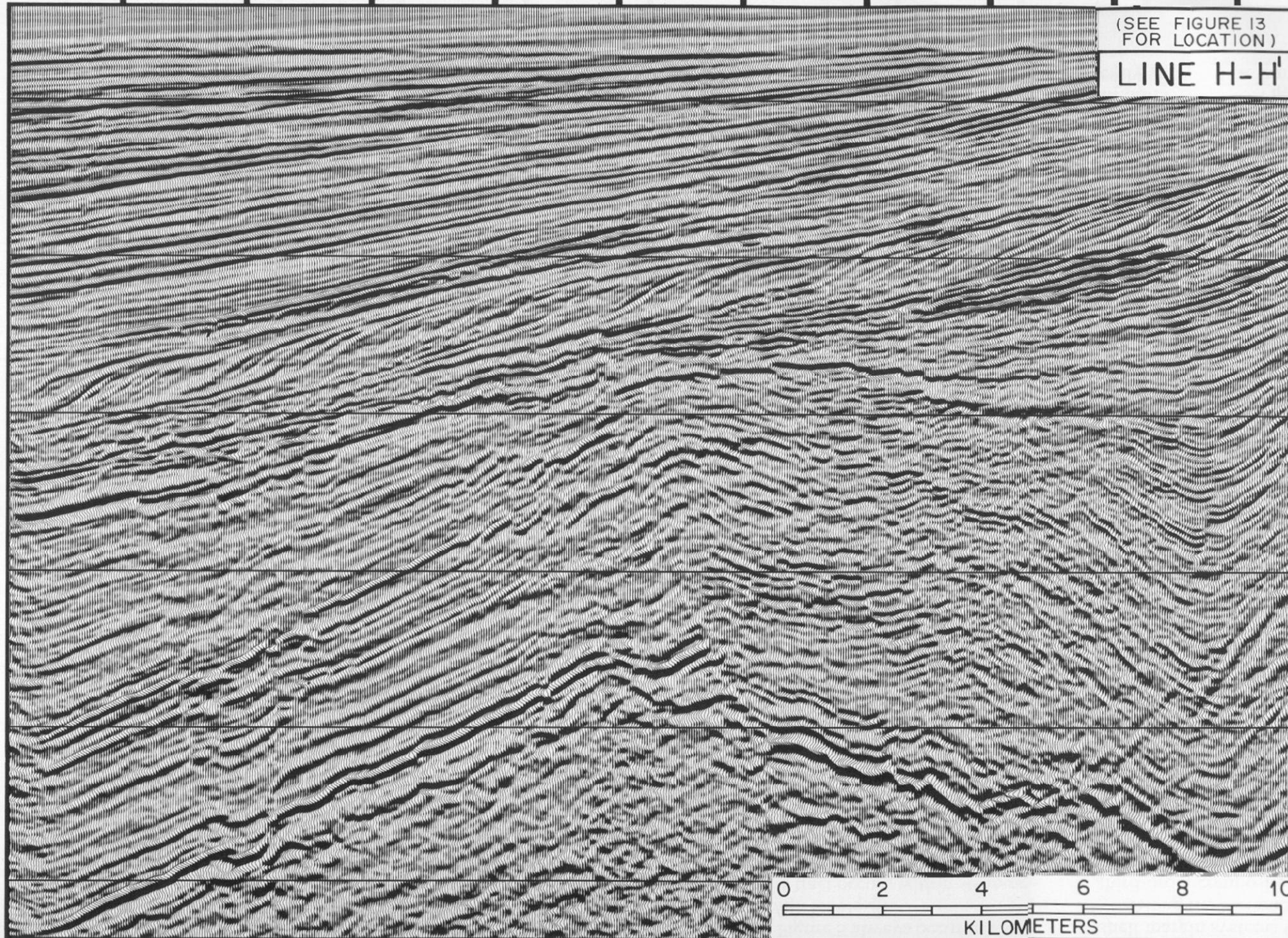
- setas mostram downlap. No entanto, devido à intrusão e deformação de domo de sal, setas em vermelho parecem (equivocadamente) mostrar onlap

SSW

NNE

(SEE FIGURE 13
FOR LOCATION)

LINE H-H'



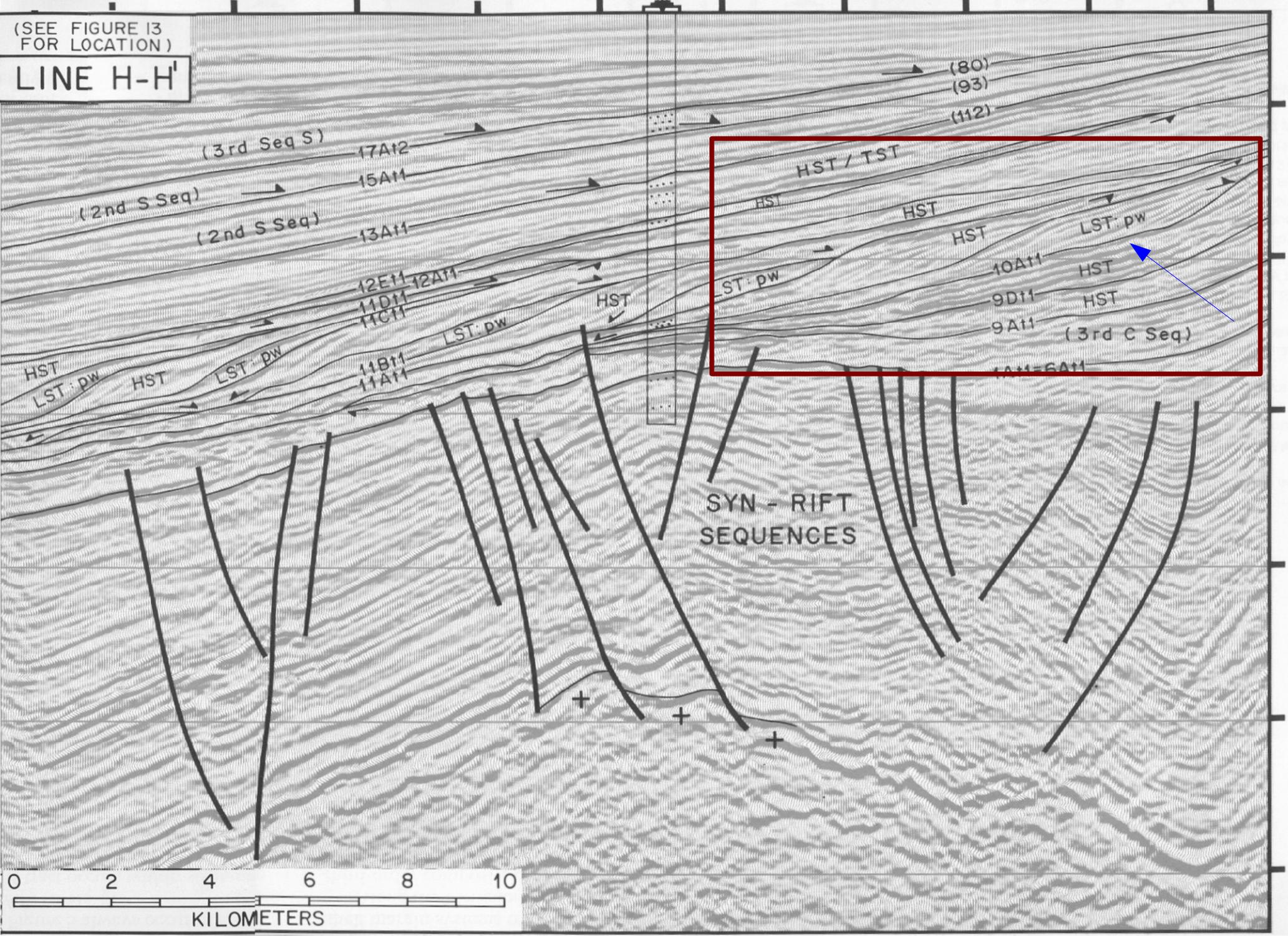
SSW

NNE

G-G' 7

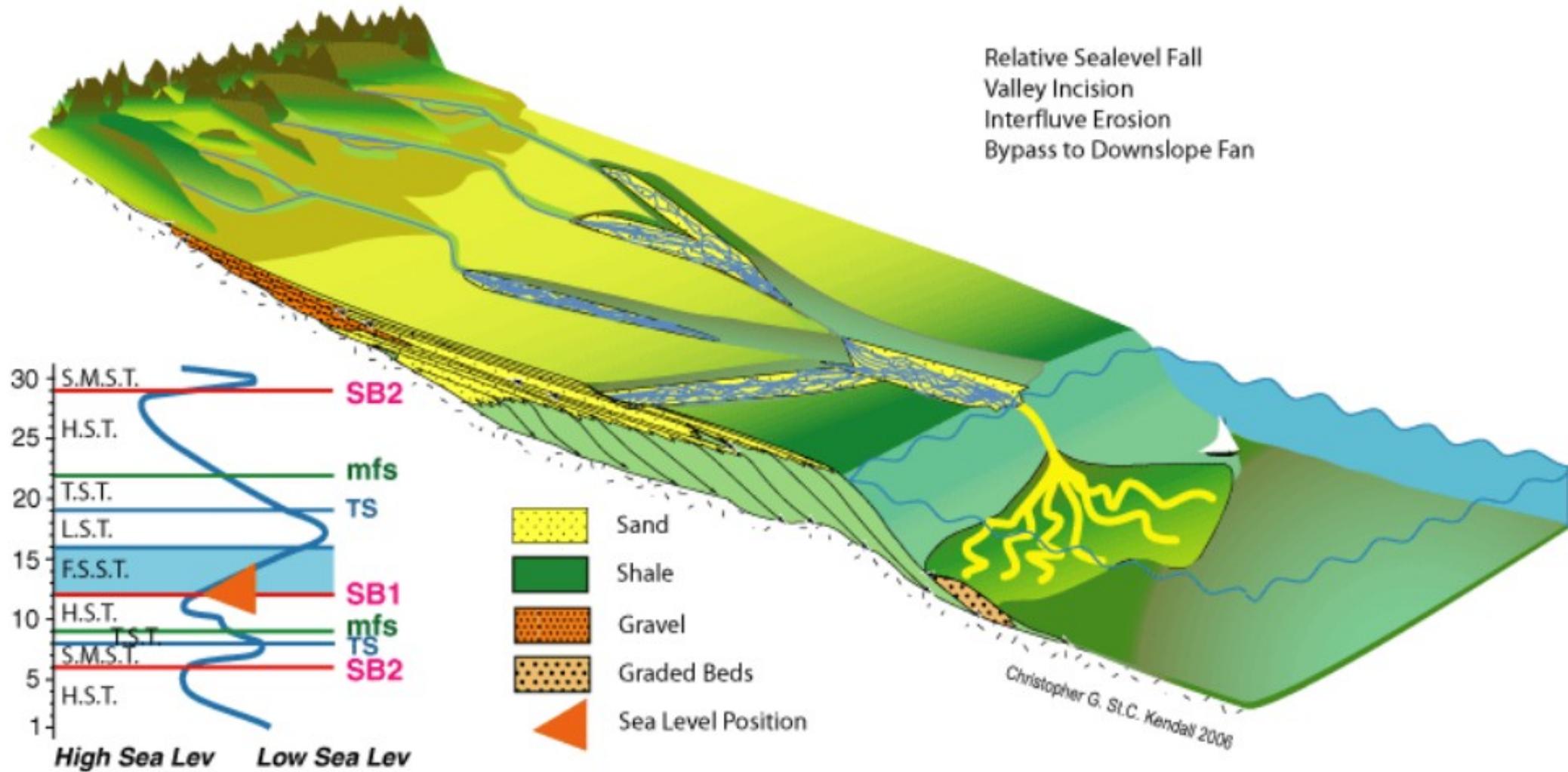
(SEE FIGURE 13 FOR LOCATION)

LINE H-H'



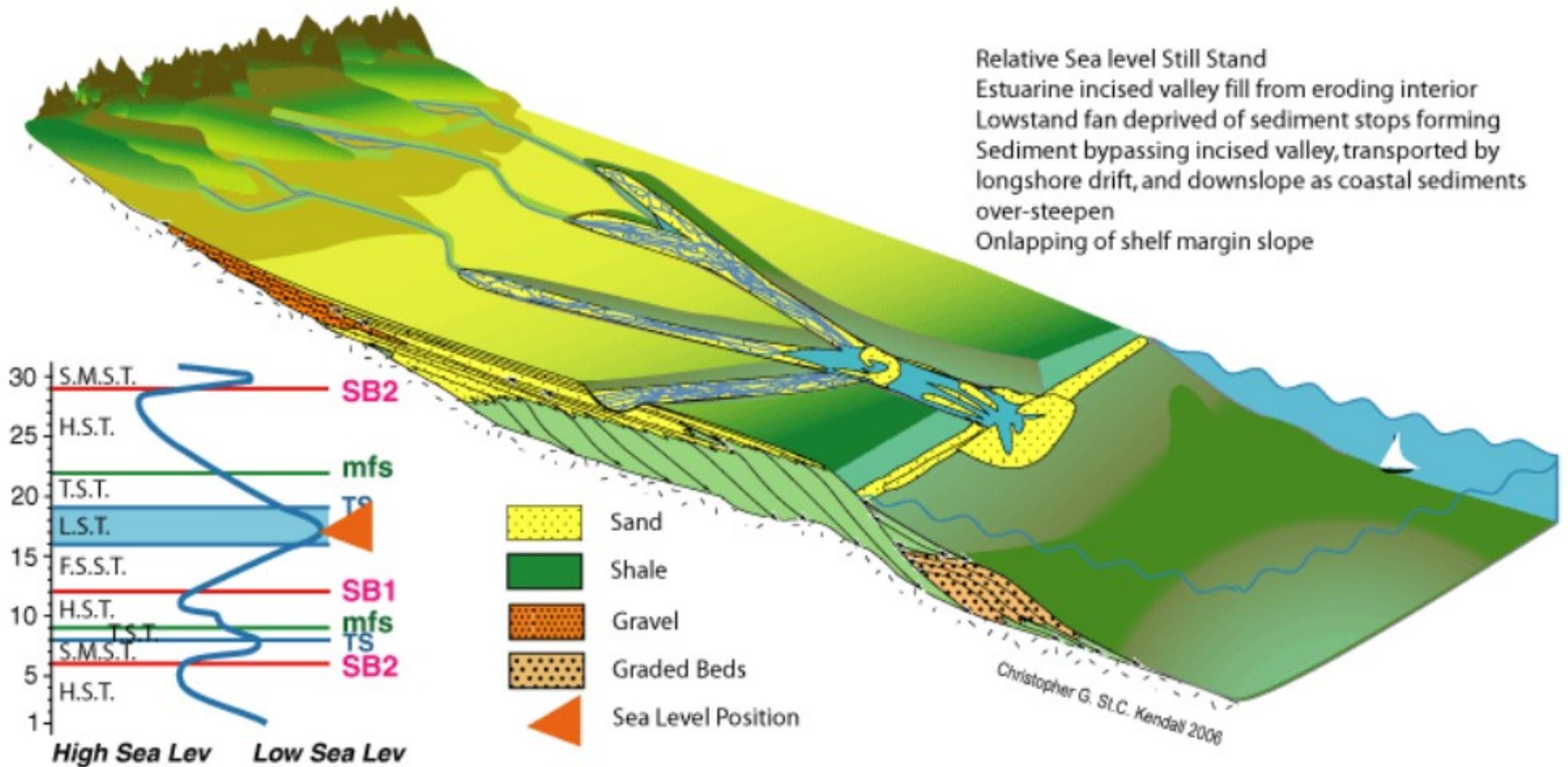
Padrões de preenchimento – tratos de sistemas deposicionais

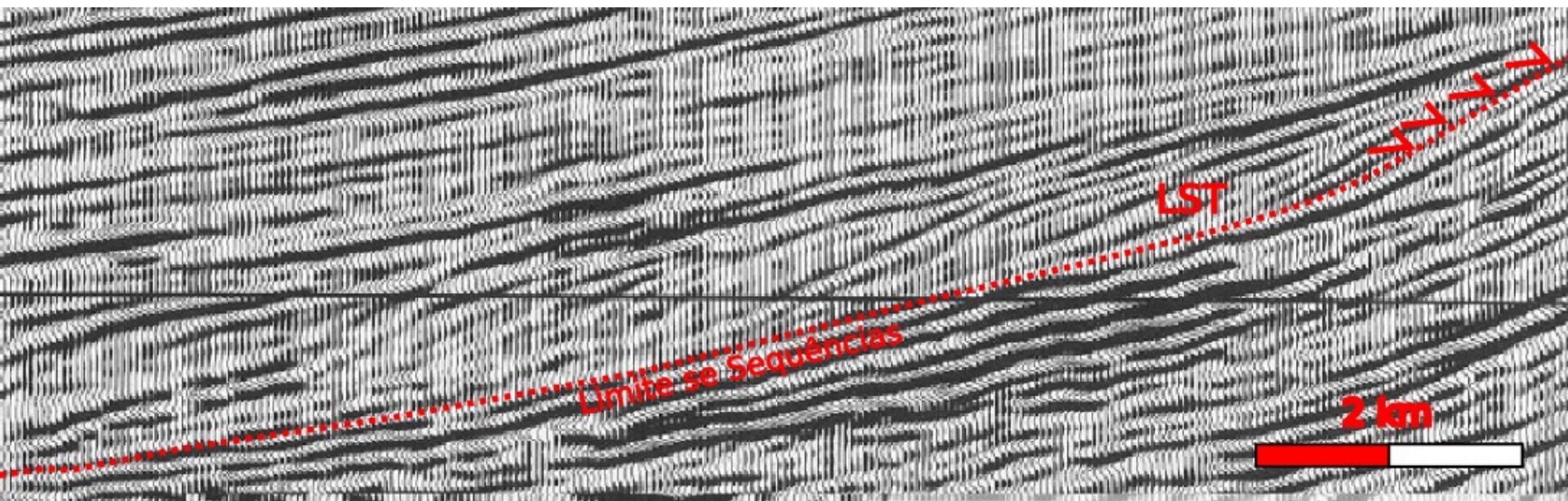
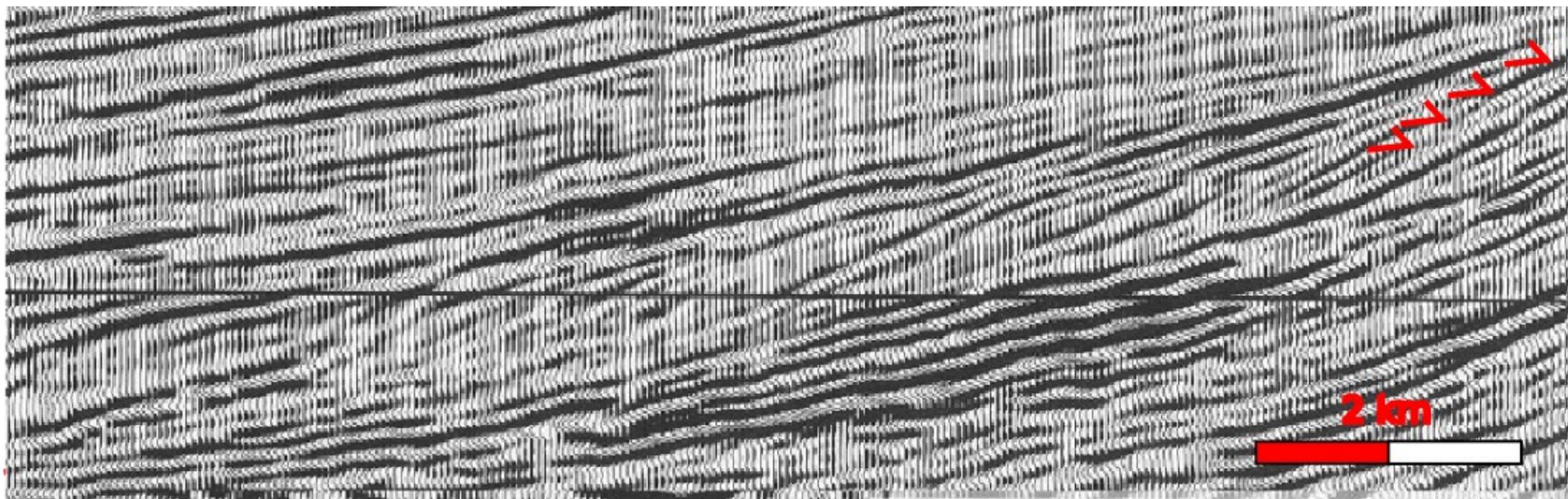
Trato de Mar Baixo



Padrões de preenchimento – tratos de sistemas deposicionais

Trato de Mar Baixo II

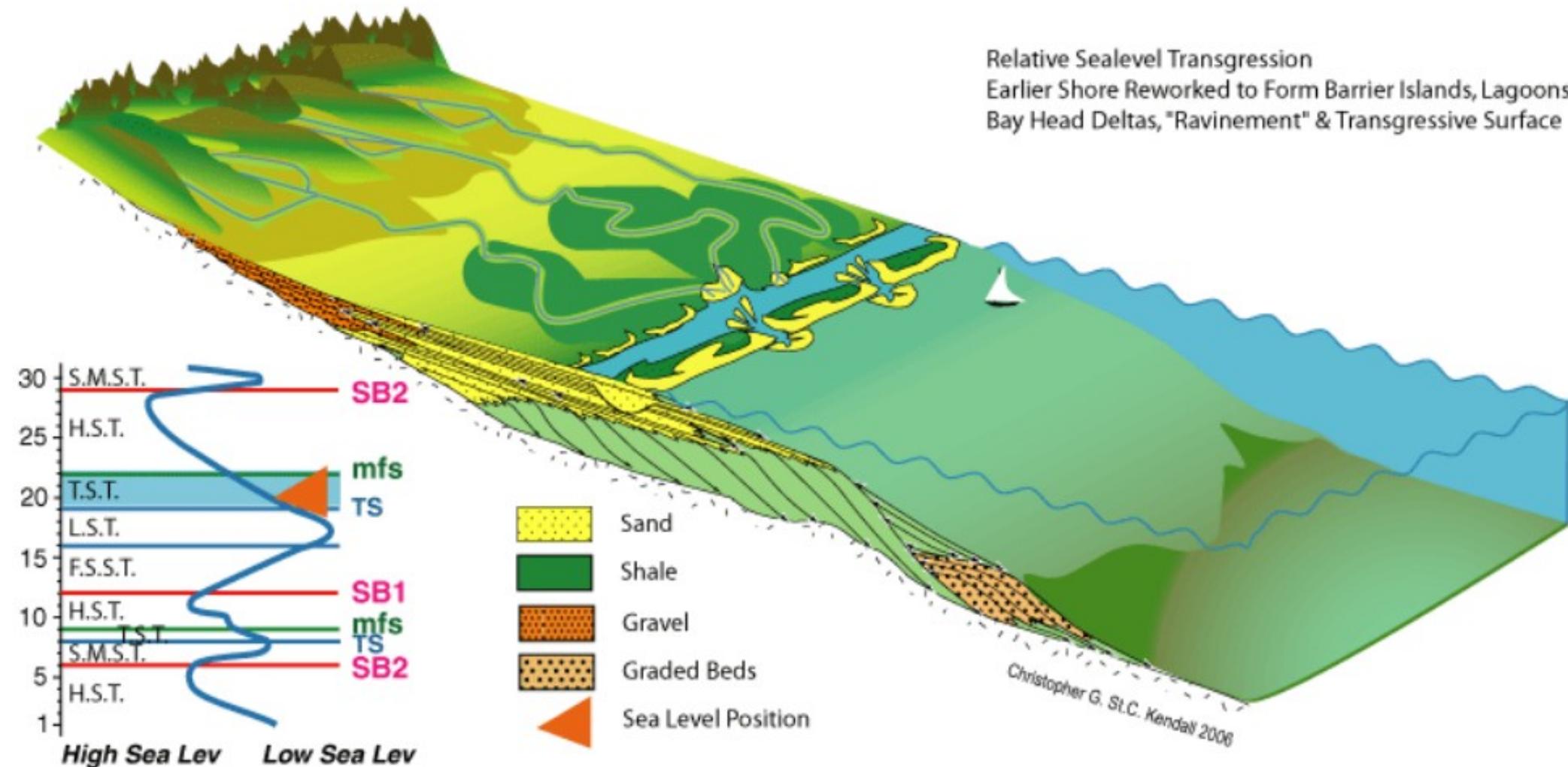


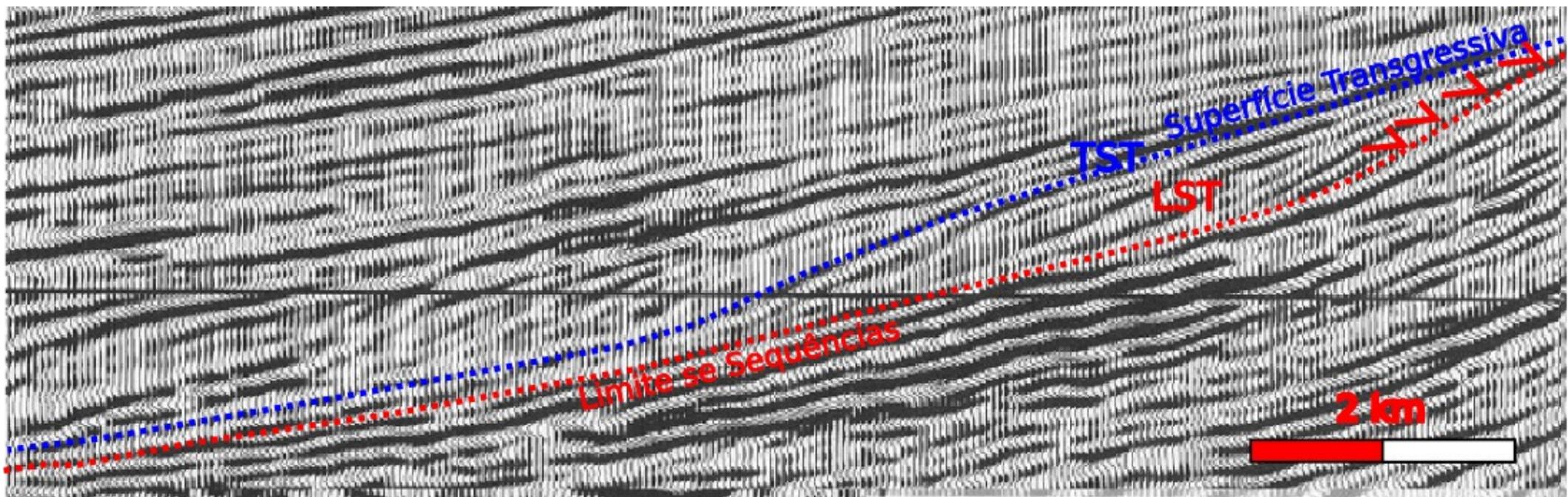


Padrões de preenchimento – tratos de sistemas deposicionais

Trato Transgressivo

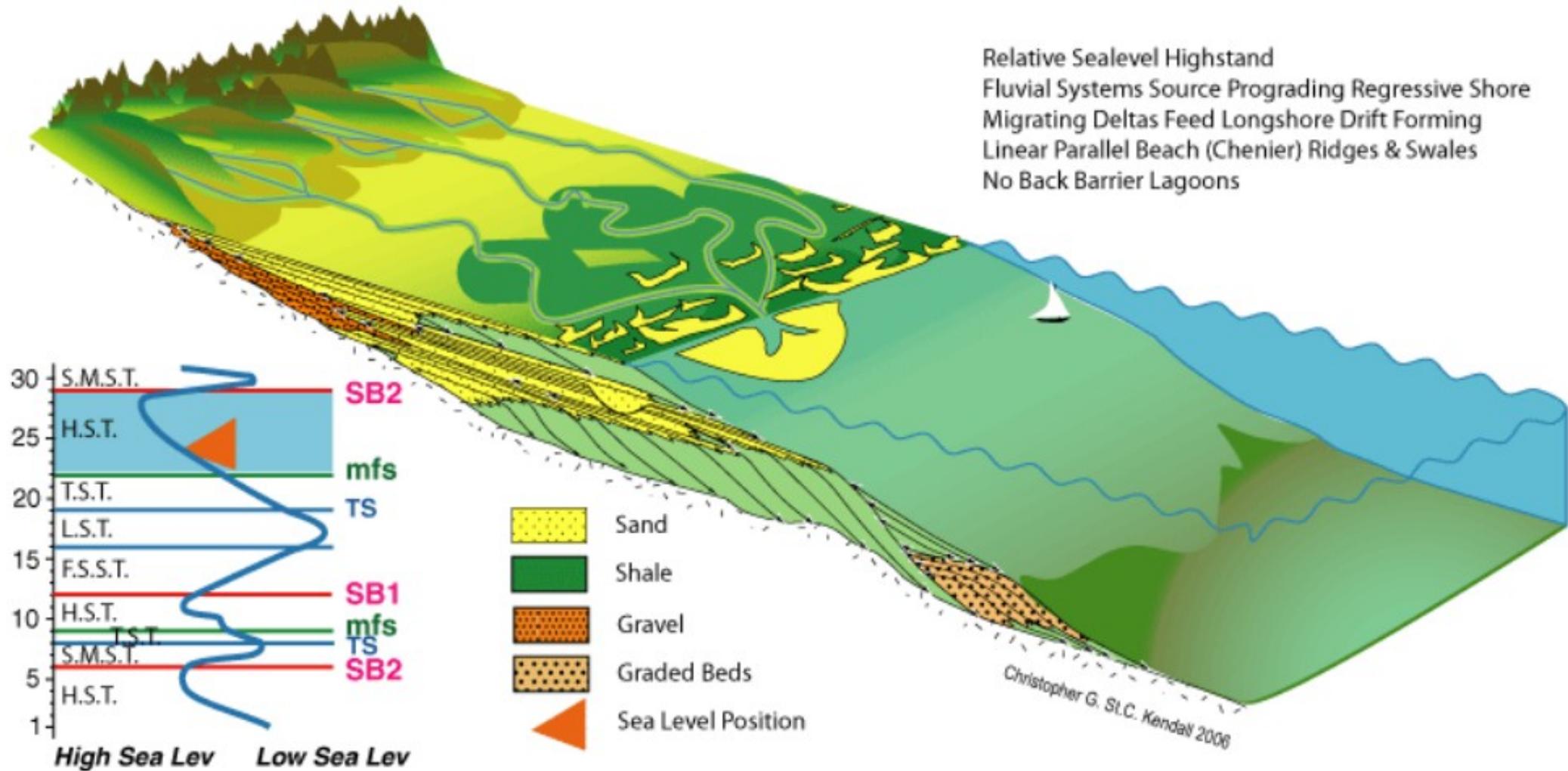
Relative Sealevel Transgression
Earlier Shore Reworked to Form Barrier Islands, Lagoons
Bay Head Deltas, "Ravinement" & Transgressive Surface





Padrões de preenchimento – tratos de sistemas deposicionais

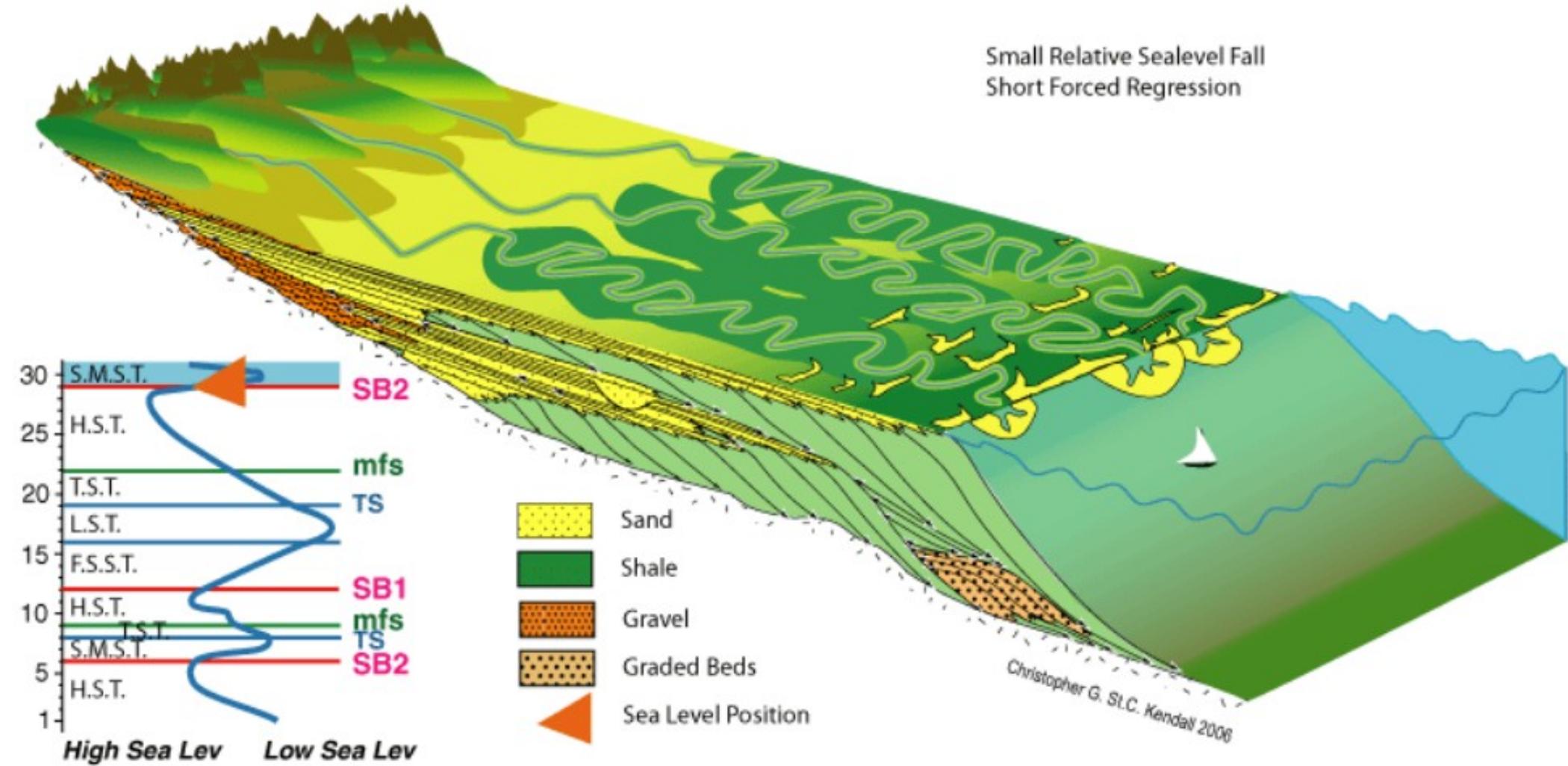
Trato de Mar Alto

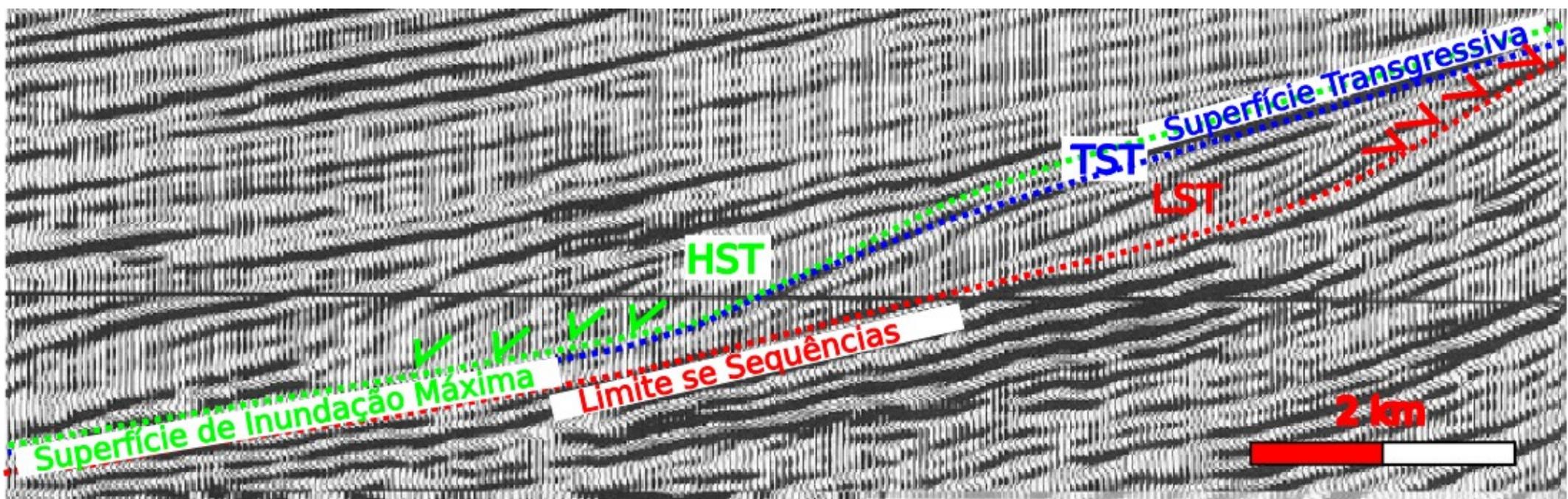
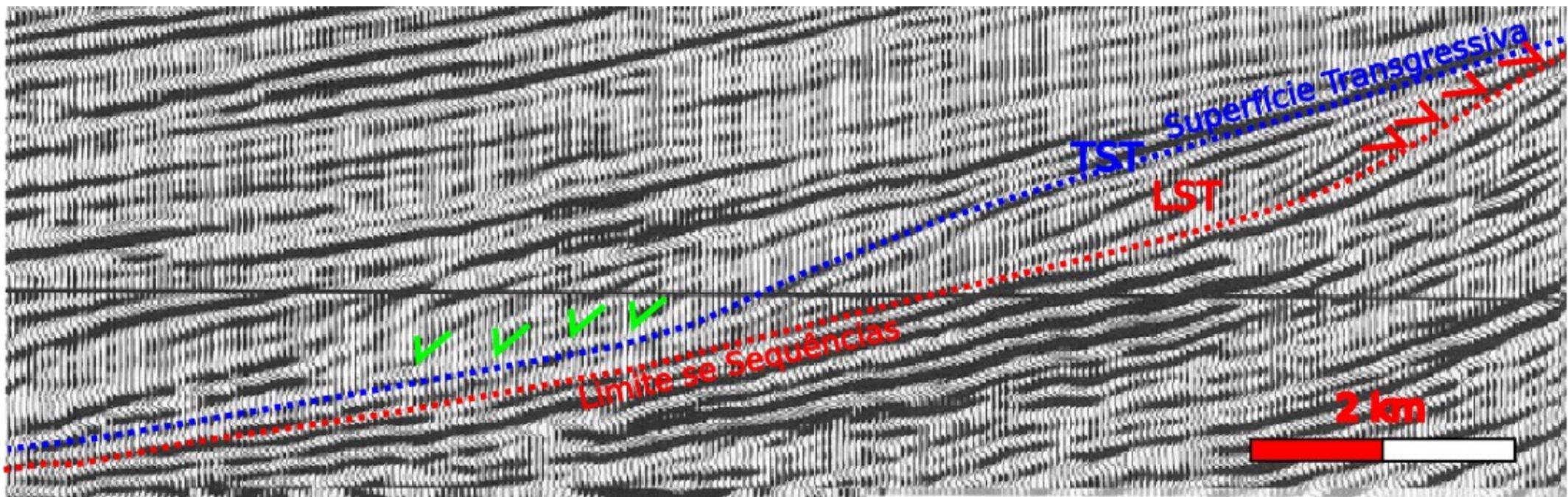


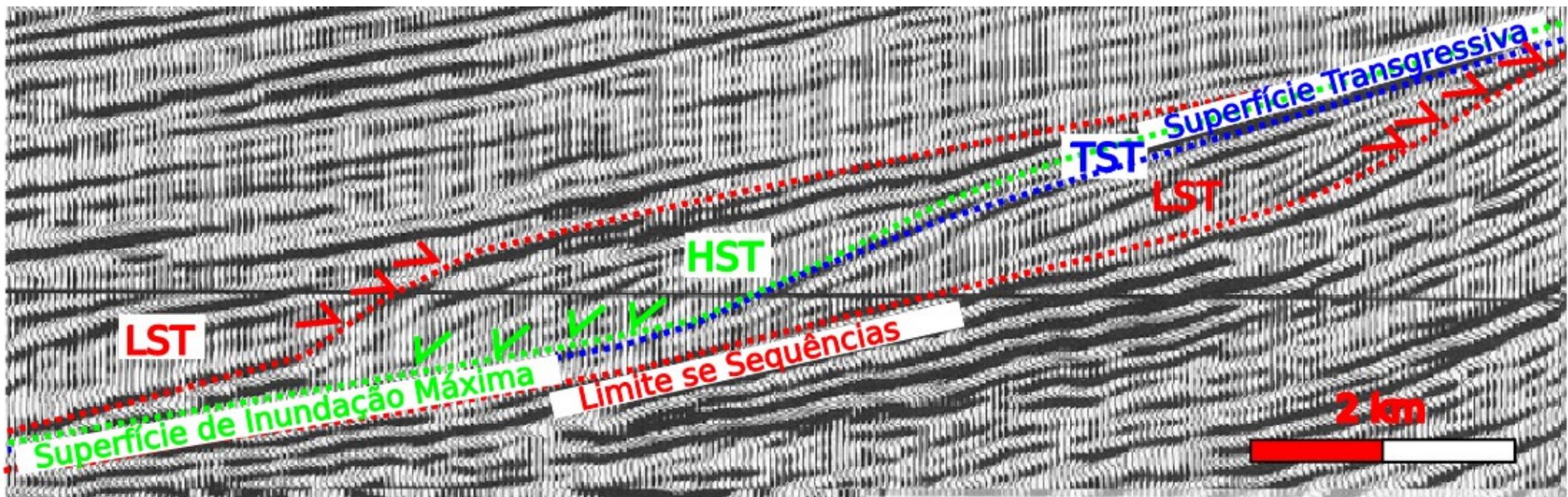
Padrões de preenchimento – tratos de sistemas deposicionais

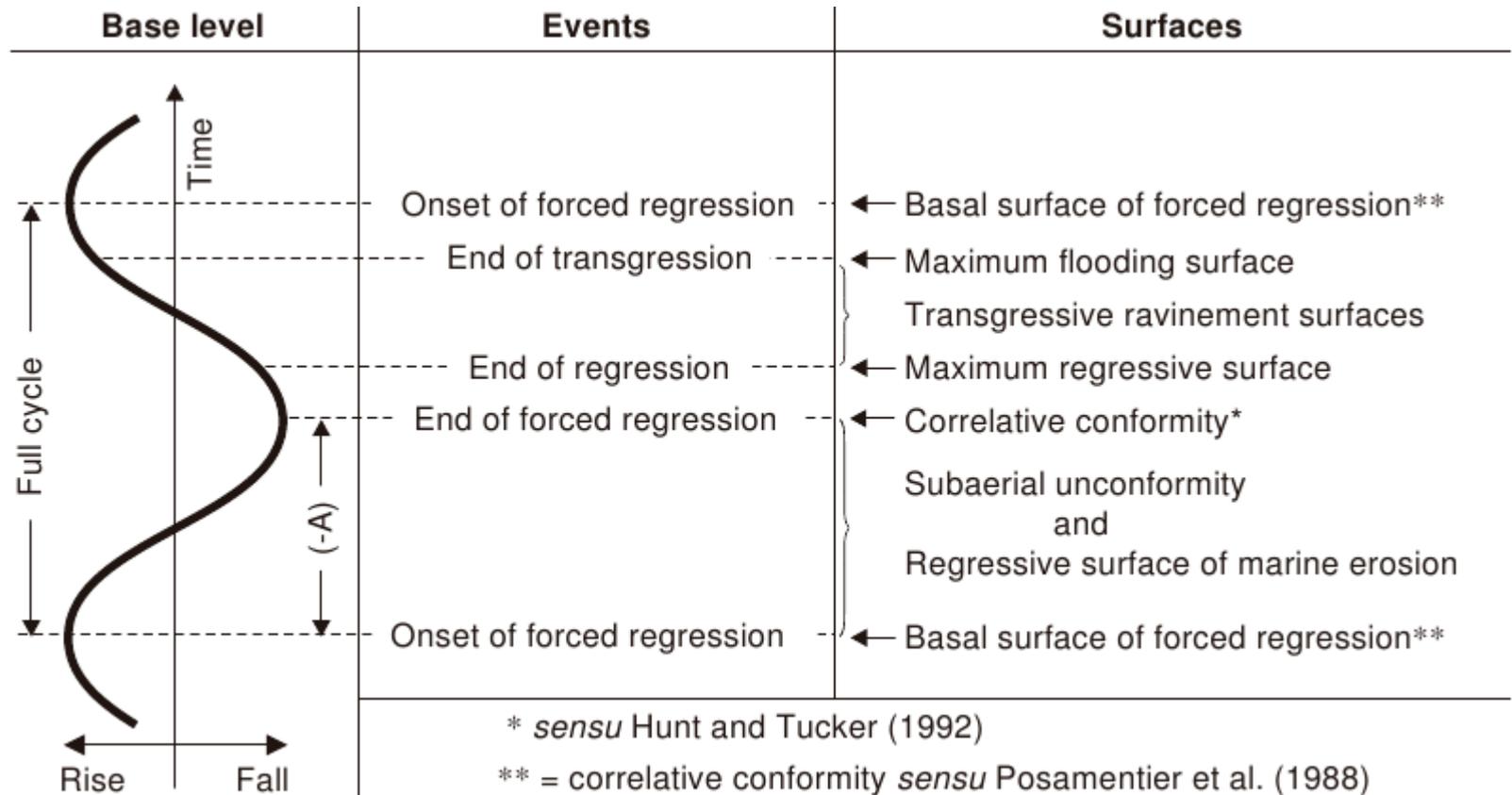
Trato de Mar Alto

Small Relative Sealevel Fall
Short Forced Regression









Surfaces of Sequence Stratigraphy

Base-level fall

- 1, 2. Subaerial unconformity, and its correlative conformity*
3. Basal surface of forced regression**
4. Regressive surface of marine erosion

Base-level rise

5. Maximum regressive surface
6. Maximum flooding surface
7. Ravinement surfaces (transgressive)

Within-trend facies contacts

Regression

1. Within-trend NR surface
2. Within-trend FR surface

Transgression

3. Flooding surface (other than MRS, MFS, or RS)

Sequence stratigraphic surfaces may be used, at least in part, as systems tract boundaries or sequence boundaries. This is their fundamental attribute that separates them from any other type of mappable surface.

Within-trend facies contacts are lithological discontinuities within systems tracts. Such surfaces may have a strong physical expression in outcrop or subsurface, but are more suitable for lithostratigraphic or allostratigraphic analyses.

Superfície de ravinamento

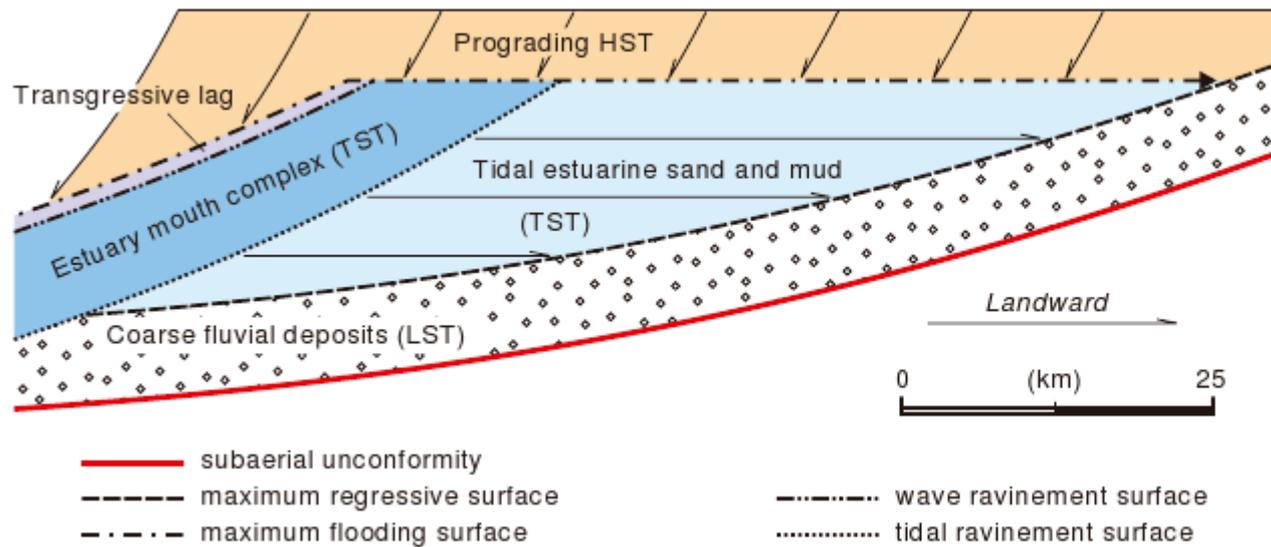
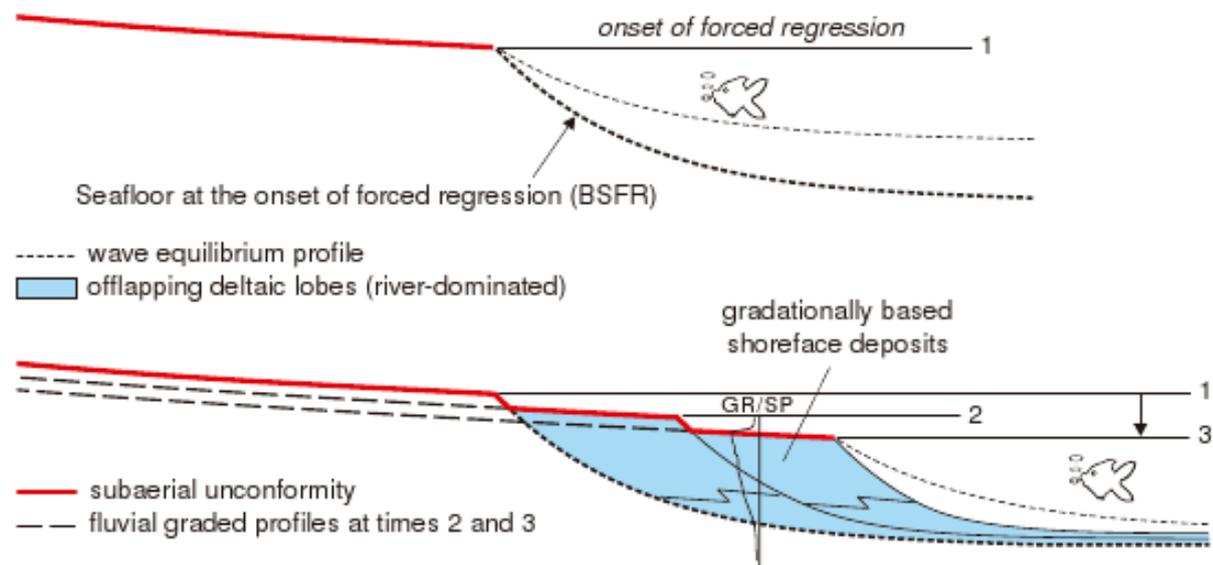
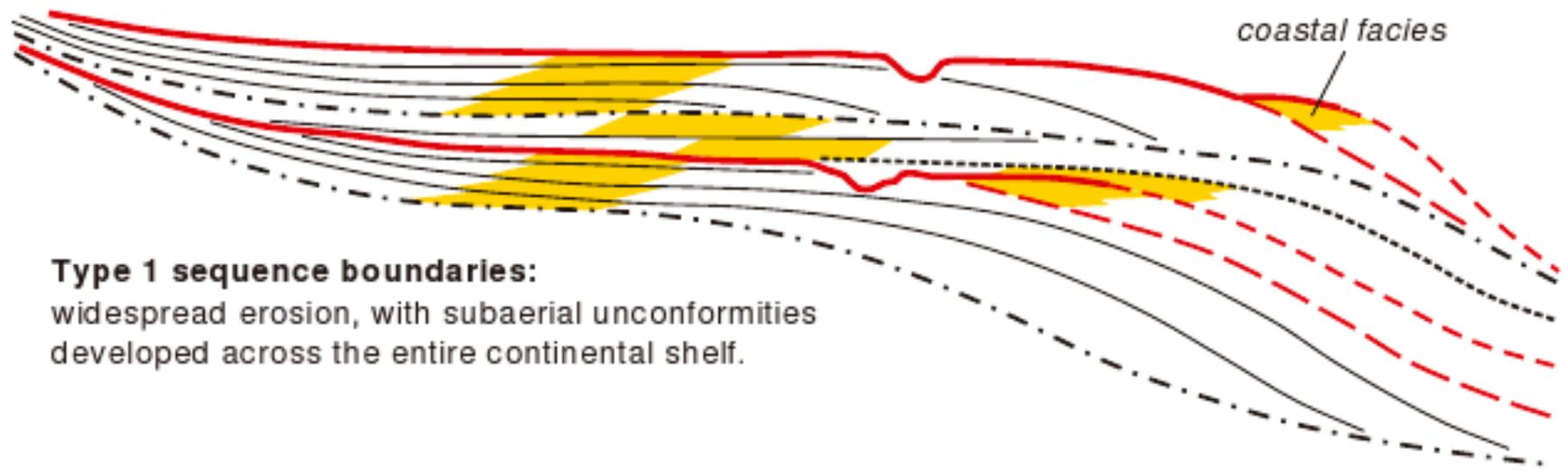


FIGURE 4.52 Stratigraphic model of an incised-valley fill, based on the Gironde estuary (modified from Allen and Posamentier, 1993). Note the spatial relationship between sequence stratigraphic surfaces, as well as their relation with the various facies of the incised-valley fill. This case study provides a most complete scenario, where all systems tracts that form during base-level rise are represented in the rock record of the valley fill.

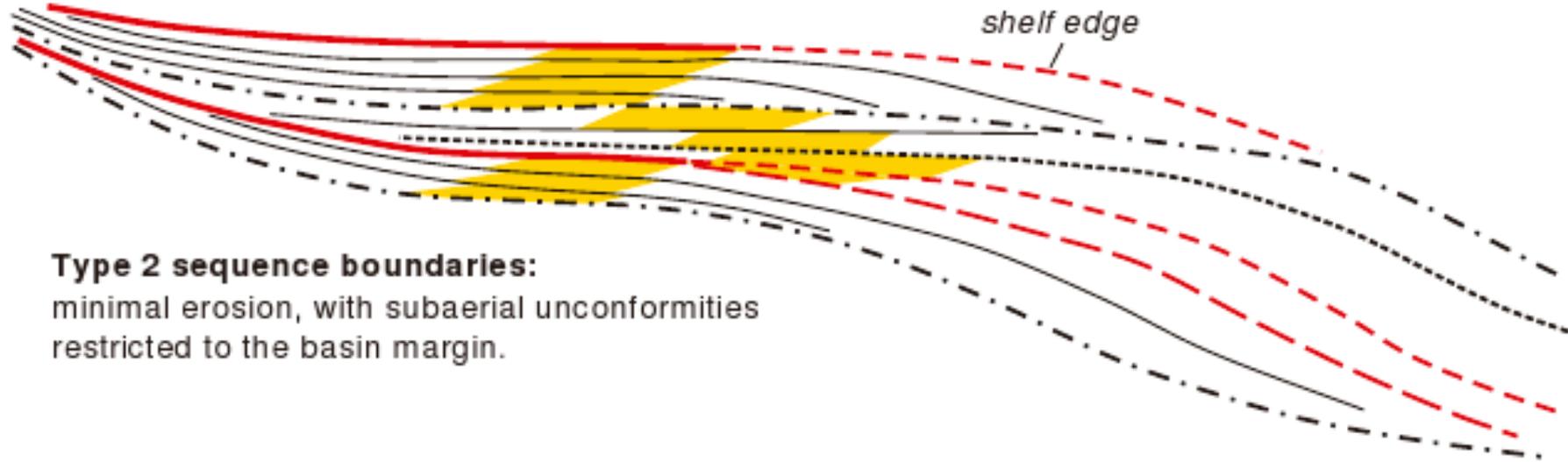
Regressão forçada

FIGURE 4.26 Shallow-marine deposits of the falling stage, in a *river-dominated* deltaic setting. Since the angle of repose of the prograding clinoforms is steeper than the wave equilibrium profile, no wave scouring affects the seafloor during forced regression. As a result, the basal surface of forced regression (BSFR) is preserved along the entire shallow-marine profile, and the forced regressive shoreface deposits are gradationally based—for a field example, see Fig. 3.30. GR/SP—synthetic gamma ray/spontaneous potential log.





Type 1 sequence boundaries:
widespread erosion, with subaerial unconformities developed across the entire continental shelf.

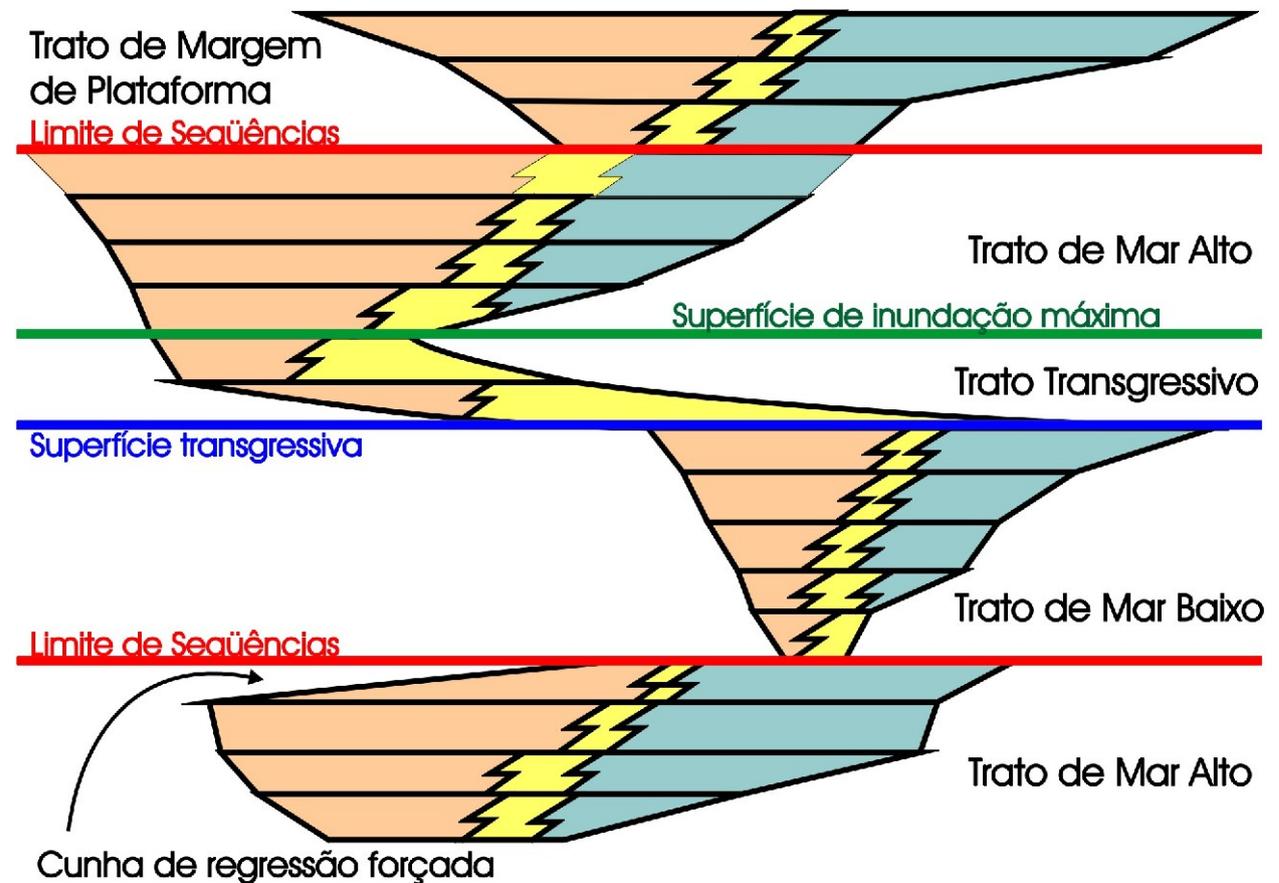
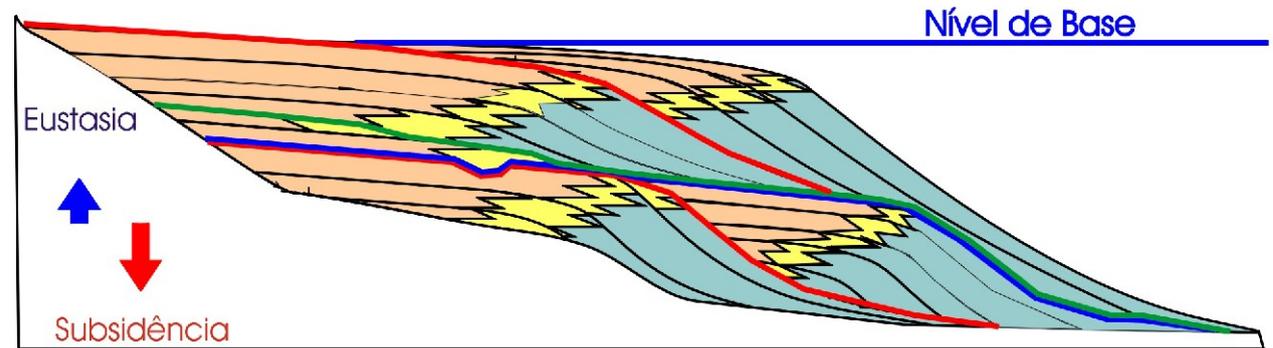


Type 2 sequence boundaries:
minimal erosion, with subaerial unconformities restricted to the basin margin.

- subaerial unconformity
- - - - - correlative conformity
- - - - - basal surface of forced regression
- . . . - maximum flooding surface
- - - - - maximum regressive surface
- within-trend facies contacts

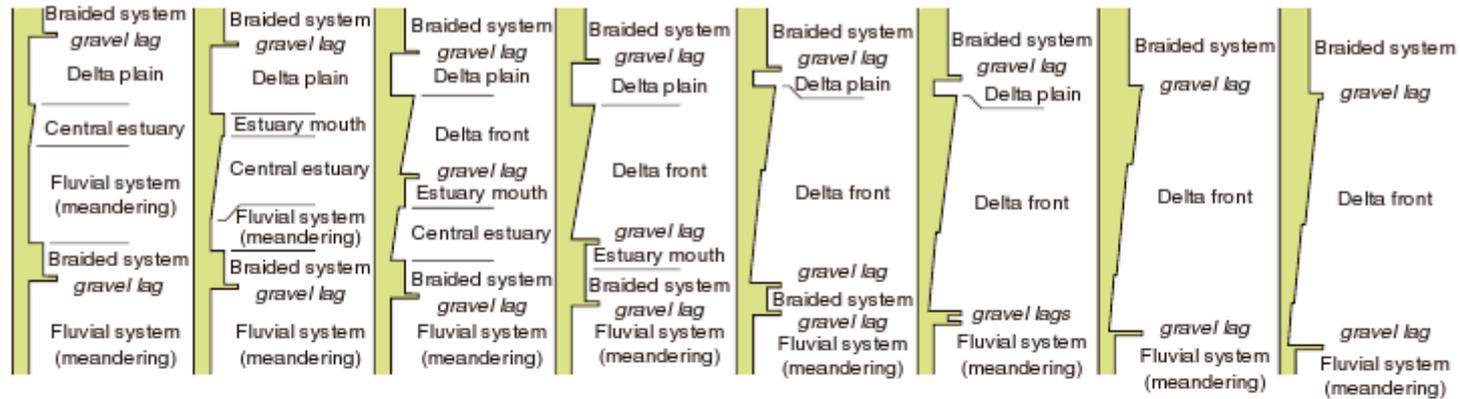
Cartas crono-estratigráficas

Seqüência 3 - Trato de Margem de Plataforma

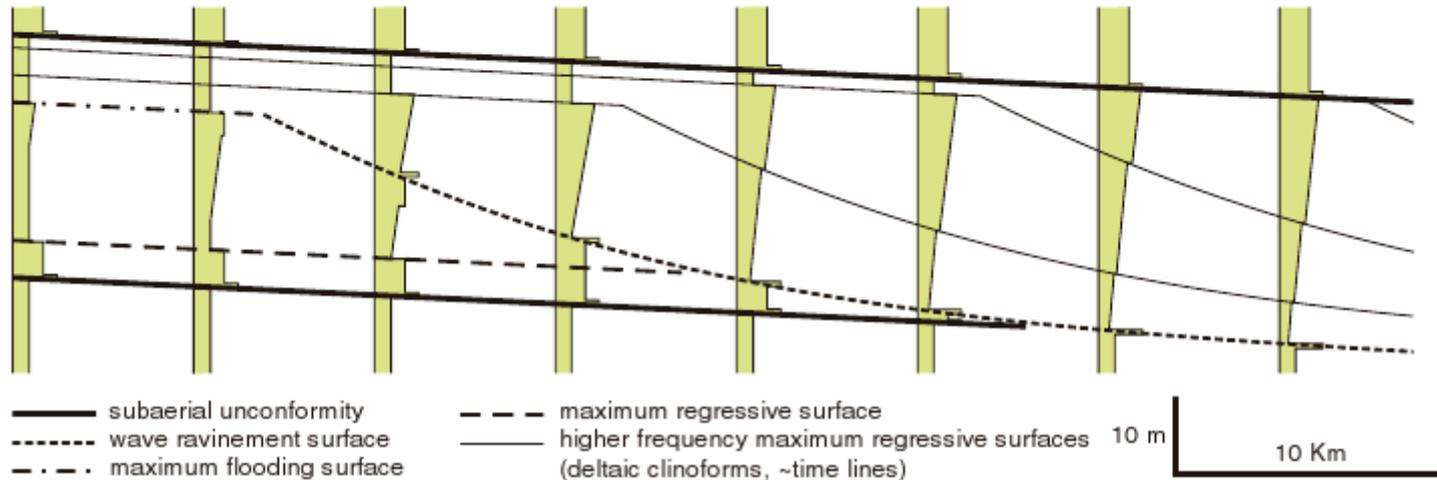


Rochas e afloramentos

1. Data: vertical profiles and paleo-environments

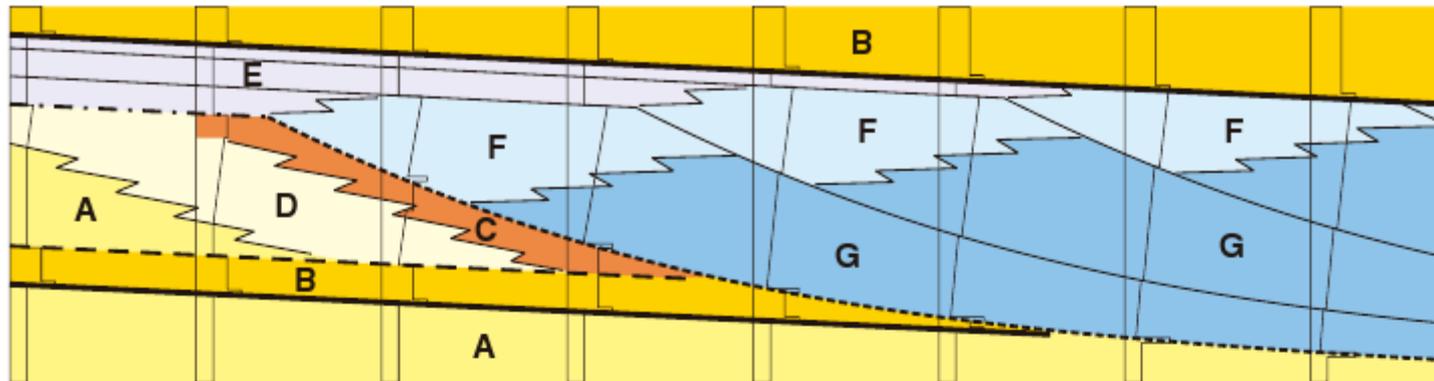


2. Sequence stratigraphic framework



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3. Sequence stratigraphic framework, facies contacts, and paleo-depositional environments



4. Cross-section emphasizing lithostratigraphic units

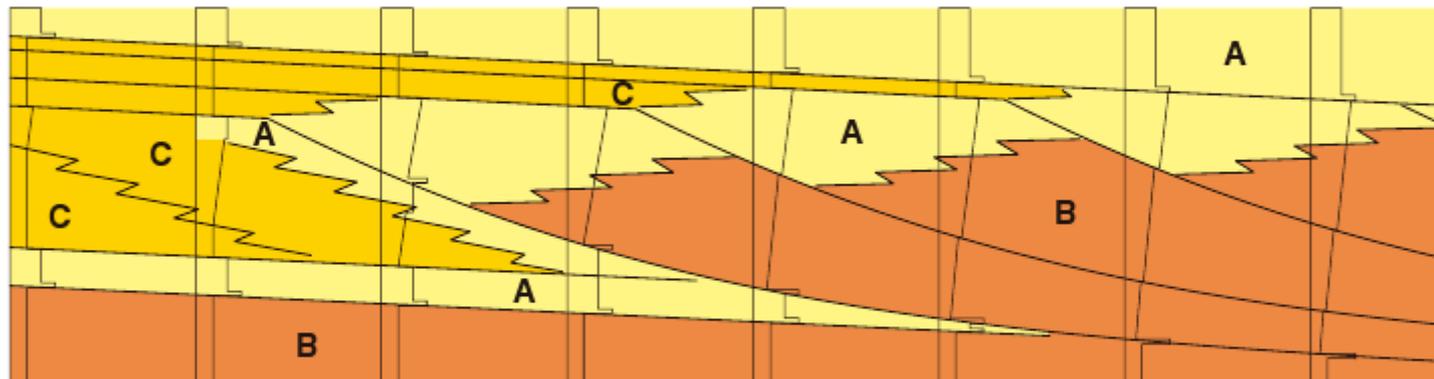


FIGURE 1.15 Sequence stratigraphic *vs.* lithostratigraphic frameworks, starting from the same set of facies data. 1. The reconstruction of paleodepositional environments *via* facies analysis is an important pre-requisite for sequence stratigraphic interpretations. The nature of stratigraphic contacts (scoured, conformable) also needs to be assessed *via* sedimentological analysis. 2. The sequence stratigraphic framework is constructed by correlating the key sequence stratigraphic surfaces. All sequence stratigraphic surfaces shown on the cross section are good chronostratigraphic markers (low diachroneity), with the exception of the transgressive wave-ravinement surface which is highly diachronous. 3. Sequence stratigraphic cross section, showing key surfaces, within-trend facies contacts, and paleodepositional environments. Within-trend facies contacts, marking lateral changes of facies, are placed on the cross-section *after* the sequence stratigraphic framework is constructed. Facies codes: A—meandering system; B—braided system; C—estuary-mouth complex; D—central estuary; E—delta plain; F—upper delta front; G—lower delta front—prodelta. 4. Lithostratigraphic cross-section. Three main lithostratigraphic units (e.g., formations) may be defined: A—a sandstone-dominated unit; B and C—mudstone-dominated units, with silty and sandy interbeds. Formations B and C are separated by Formation A. Additional lithostratigraphic units (e.g., members—subdivisions of units A, B, C) may be defined as a function of variations in lithology and color.

Progradação e downlap

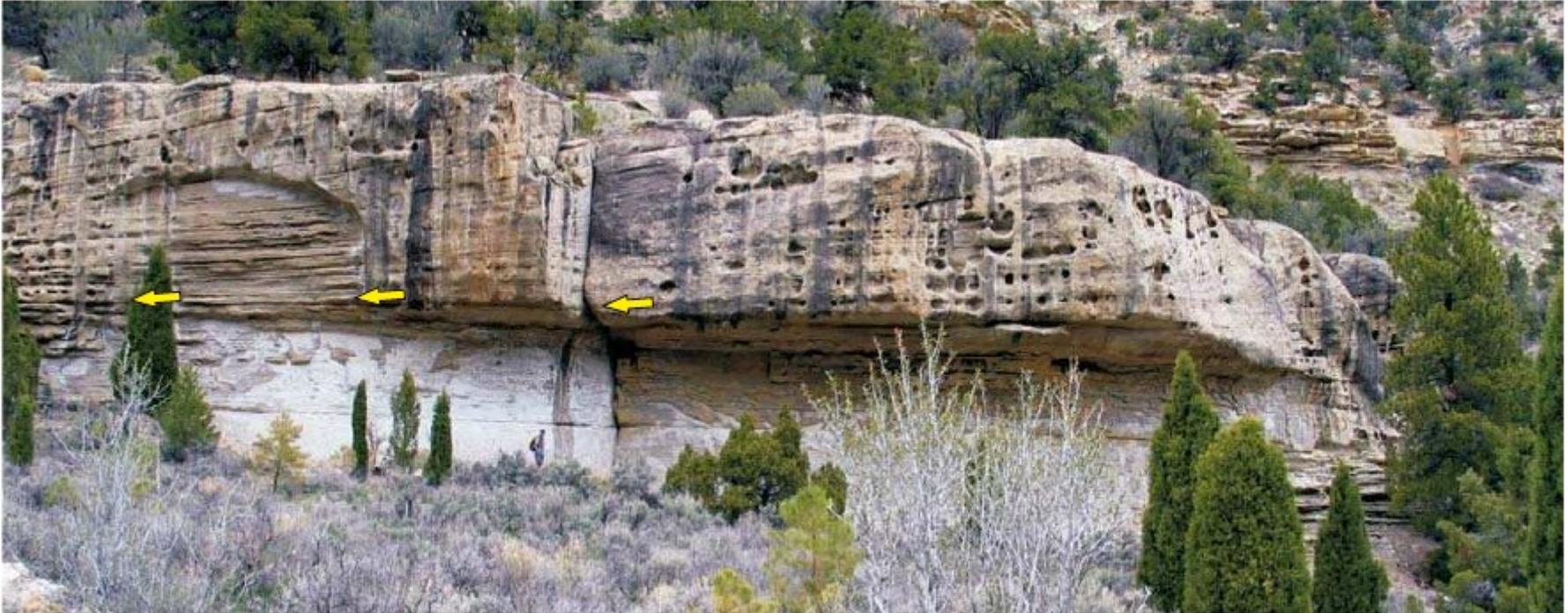


FIGURE 2.68 Gilbert-type delta front, prograding to the left (Panther Tongue, Utah). The delta front clinoforms downlap the paleo-seafloor (arrows). Note person for scale.

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Progradação e downlap



FIGURE 2.69 River-dominated delta showing prodelta fine-grained facies at the base, delta front sands prograding to the left, and coal-bearing delta plain facies at the top (the Ferron Sandstone, Utah). The prograding delta front clinofolds dip at an angle of 5–7°, and downlap the underlying prodelta deposits (arrows). The outcrop is about 30 m high.

Superfície erosiva

FIGURE 2.7 Subaerial unconformity (arrows) at the contact between the Burgersdorp Formation and the overlying Molteno Formation (Middle Triassic, Dordrecht–Queenstown region, Karoo Basin). The succession is fluvial, with an abrupt increase in energy levels across the contact. Note the change in fluvial styles from meandering (with lateral accretion) to amalgamated braided systems. The unconformity is associated with an approximately 7 Ma stratigraphic hiatus (Catuneanu *et al.*, 1998a), and hence separates fluvial sequences that are genetically unrelated.



Catuneanu (2006)



A



B



C



D



E



F

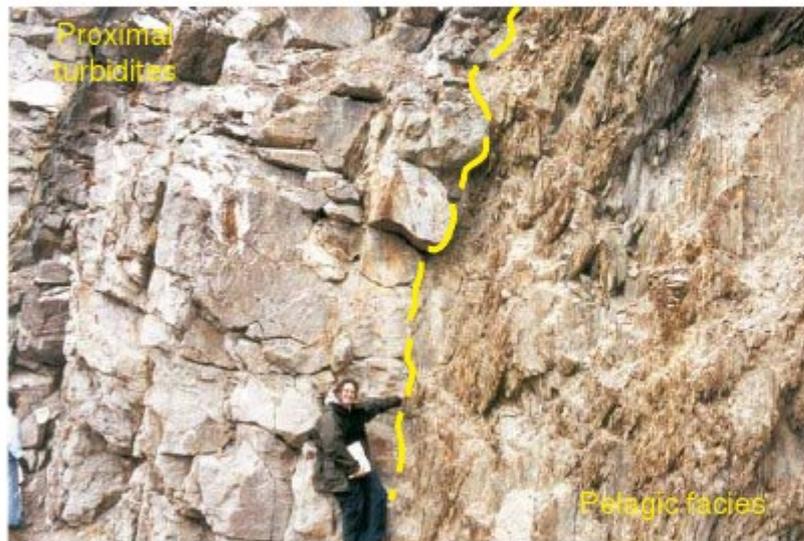
Paleossolos

FIGURE 2.12 Calcareous paleossols and associated facies, formed during base-level fall and subaerial exposure (photographs courtesy of M.R. Gibling; Pennsylvanian Sydney Mines Formation, Sydney Basin, Nova Scotia; for more details, see Gibling and Bird, 1994; Gibling and Wightman, 1994; Tandon and Gibling, 1994, 1997). A—calcrete, marking a 'subaerial unconformity' (depositional sequence boundary) within coastal plain deposits. The carbonate soil implies a semi-arid climatic period, suggesting that lowstands in base level were relatively more arid than the peat-forming periods that represent the overlying transgressive and highstand systems tracts; B—close up of calcrete in image A, showing well-developed vertic and nodular fabric; C—calcrete in image A, with strong nodular texture. Note the non-disrupted nature of the siltstone below; D—calcrete exposed on wave-cut platform, with strong vertic fabric (scale 50 cm); E—upright tree cast, partially replaced by carbonate beneath a 'lowstand' calcareous paleosol layer. This occurrence suggests that carbonate-rich groundwaters caused local cementation through conduits below the main soil level; F—close up of carbonate-cemented tree in image E.

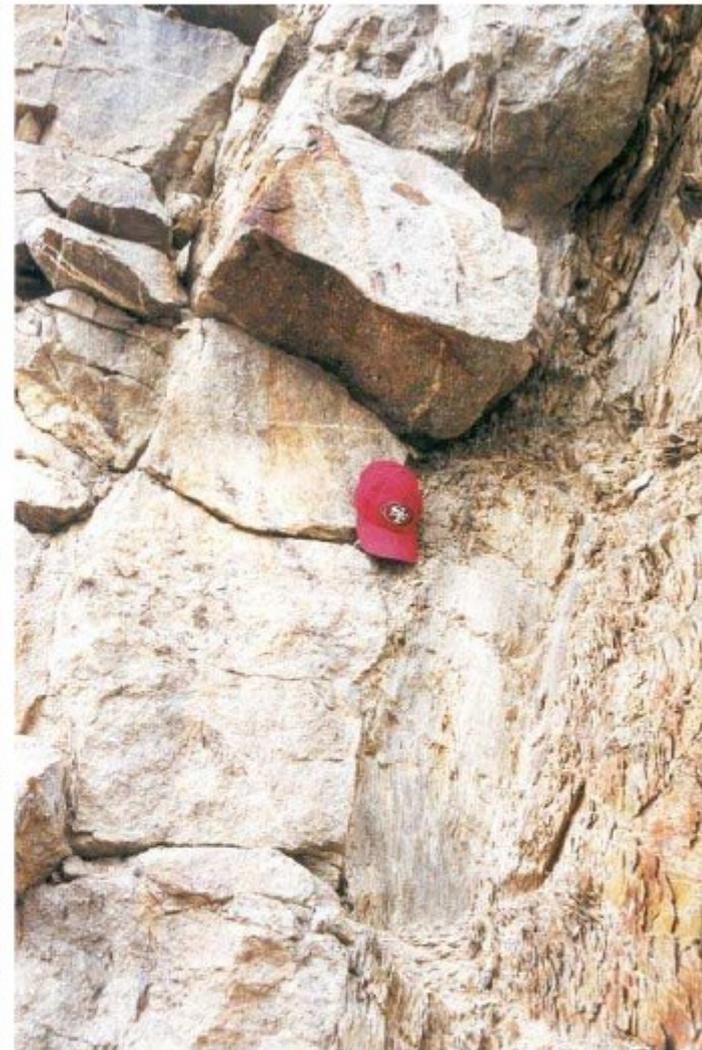
Catuneanu (2006)



A



B



C

FIGURE 4.27 Outcrop examples of the 'basal surface of forced regression,' showing the base of the submarine fan complex in discrete locations within the deep-water setting. A—contact between pelagic sediments and the overlying gravity-flow facies: the base of the submarine fan complex (contact between the Whitehill and Collingham formations, Early Permian, Eccu Pass, Karoo Basin); B—contact between pelagic sediments and the overlying gravity-flow facies: the base of the submarine fan complex (Miette Group, Precambrian, Jasper National Park, Alberta). The turbidites comprise the divisions A to C of the Bouma sequence, and belong to a proximal frontal splay; C—contact between pelagic sediments and the overlying gravity-flow facies: the base of the submarine fan complex (detail from B). A potential pitfall of this method of mapping the basal surface of forced regression is that, due to autocyclic shifts in the *locus* of deposition of the different lobes of the submarine fan complex, the base of a particular lobe may not correspond to the *earliest* manifestation of gravity flows associated with the forced regression of the shoreline. Hence, some of these surfaces are just facies contacts, *younger* than the basal surface of forced regression (see Chapters 5 and 6 for more details).

Superfície
basal de
regressão
forçada

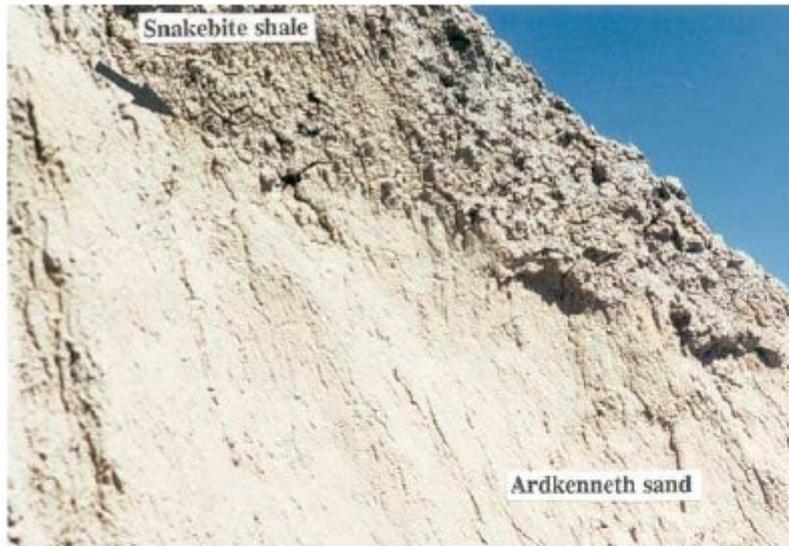


FIGURE 4.28 Regressive surface of marine erosion at the contact between forced regressive shoreface (above) and outer shelf (below) facies (Late Cretaceous Marshybank Formation, Alberta; photo courtesy of A.G. Plint). The sharp-based shoreface deposits have large, shore-normal gutter casts at their base (arrows).

Superfície de regressão máxima = transgressiva



FIGURE 4.33 Outcrop photograph of a maximum regressive surface (yellow arrow) at the contact between fluvial normal regressive strata (facies A) and the overlying backstepping beach deposits (facies B) (Bahariya Formation, Lower Cenomanian, Bahariya Oasis, Western Desert, Egypt). The maximum regressive surface is scoured by high-energy swash currents during the earliest stage of shoreline transgression. Underlying the maximum regressive surface, the fluvial strata correlate with a prograding and aggrading delta, and are part of the lowstand systems tract. The backstepping beach is the only preserved portion of the transgressive systems tract. The beach deposits are truncated at the top by a subaerial unconformity (red arrow, base of incised valley), and are overlain by coarse fluvial channel fills (facies C, part of a younger lowstand systems tract; Catuneanu *et al.*, in press). Note the landward shift of facies recorded across the maximum regressive surface, in contrast with the basinward shift of facies associated with the subaerial unconformity.



C



E



D

FIGURE 4.36 Outcrop examples of maximum regressive surfaces in distal shallow-water settings (arrows). A—maximum regressive surface in a conformable lower shoreface to shelf succession (top of the Magrath Member, Bearpaw Formation, Late Campanian, St. Mary River, Alberta, Western Canada Sedimentary Basin); B—maximum regressive surface in a conformable shelf succession (Beechy Member, Bearpaw Formation, Late Campanian, Saskatchewan, Western Canada Sedimentary Basin). In both cases, the slope breaks indicate textural changes across the maximum regressive surfaces, from coarsening-upward (below) to fining-upward (above).

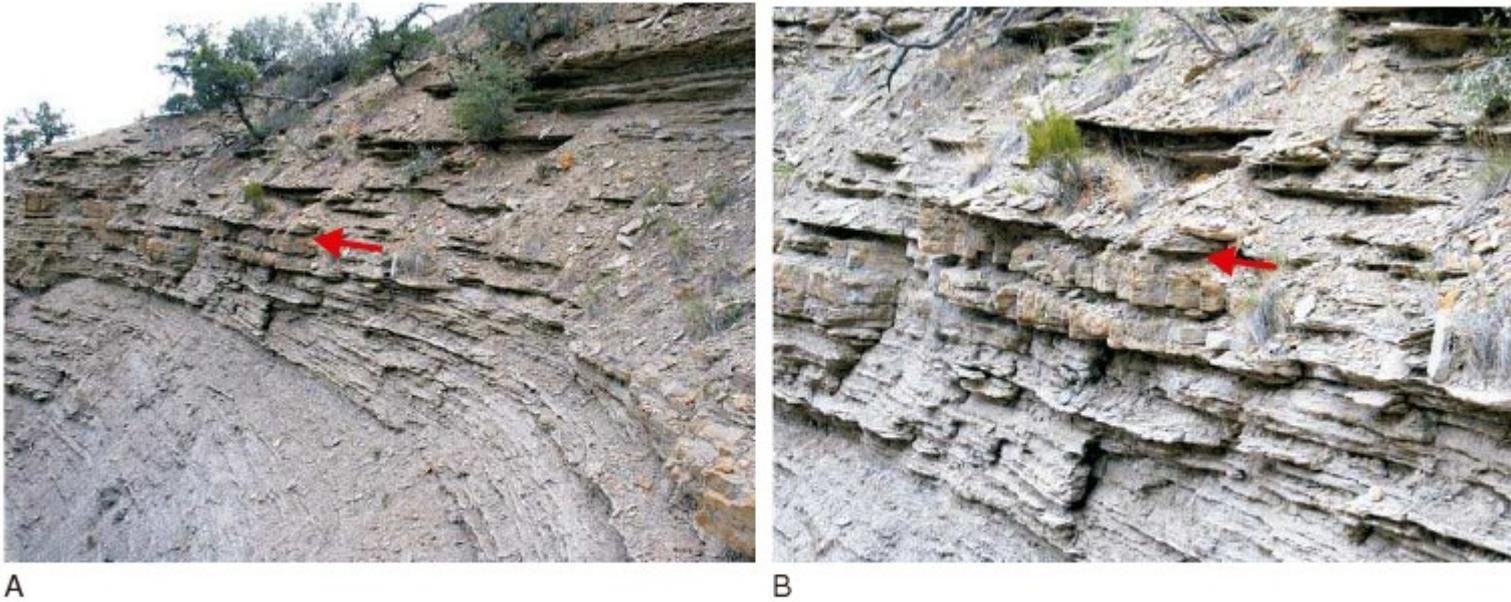


FIGURE 4.37 Maximum regressive surface (arrows) in a conformable succession of prodelta facies (Campanian Panther Tongue Formation, Utah). The break in slope gradients indicates textural changes across the surface, from coarsening-upward (below) to fining-upward (above). Photograph B: detail from A.

Inundação máxima sobre regressão máxima (amalgamadas)

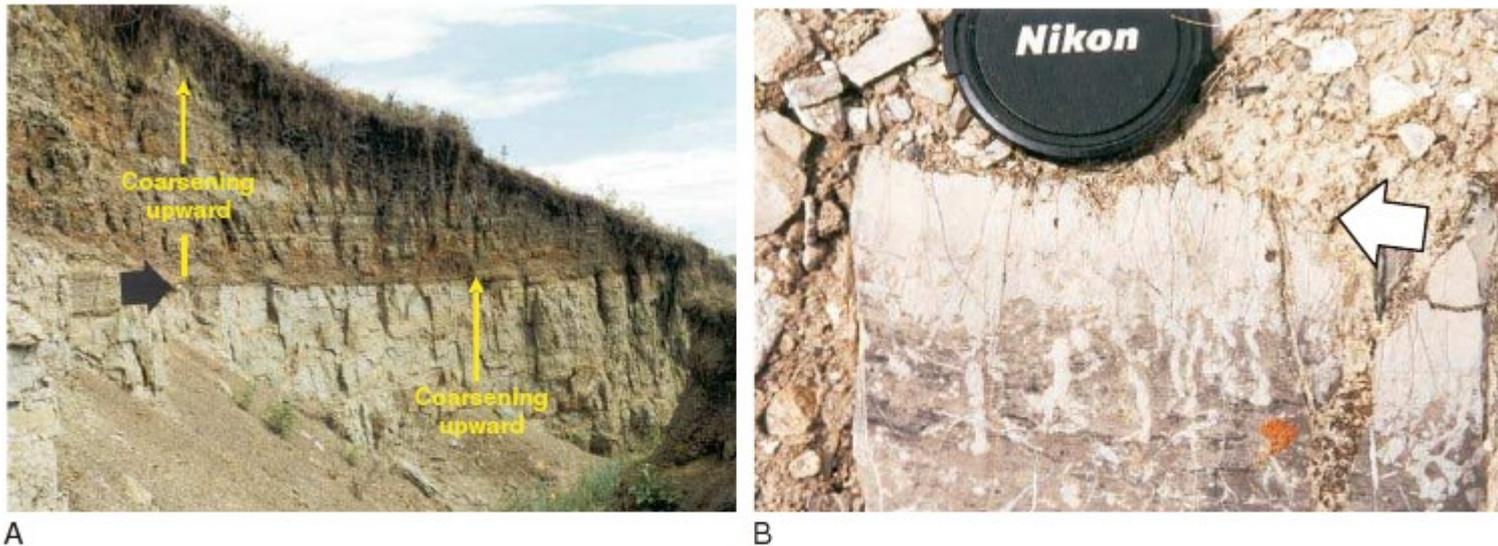


FIGURE 4.44 Outcrop examples of maximum flooding surfaces (scoured) that rework the underlying maximum regressive surfaces. The transgressive facies are missing. A—Young Creek Member (Bearpaw Formation, Early Maastrichtian), Castor area, Alberta, Western Canada Sedimentary Basin; B—firmground associated with the *Glossifungites* ichnofacies, formed as a result of prolonged sediment starvation (Mississippian Shunda Formation, Talbot Lake area, Jasper National Park).