Introdução

Elementos Morfológicos

Tipos

Modelos de Fácies

Sistemas de leques submarinos

Processos de transporte e deposição em águas profundas:

- Decantação de partículas finas

- Fluxos gravitacionais

- Correntes de contorno

Depósitos de decantação:

- Sedimentos hemipelágicos – pelitos terrígenos e detritos biogênicos finos

- Sedimentos pelágicos – fora da área de influência dos sedimentos continentais – concentração de detritos biogênicos, poeira soprada pelo vento e cinza vulcânica

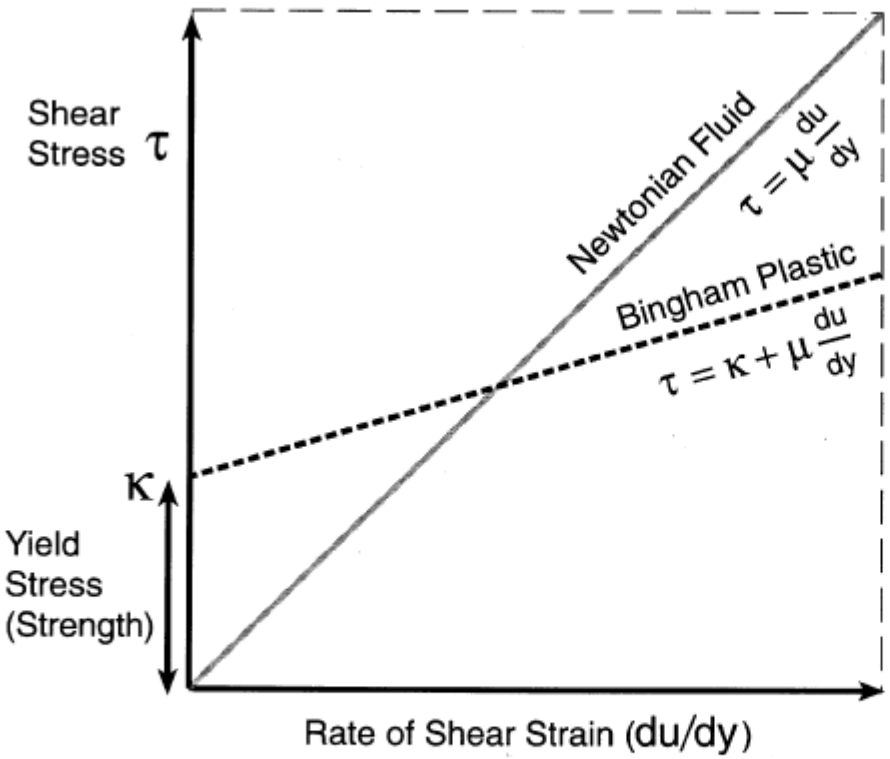
Fluxos gravitacionais em águas profundas:

- Origem: aporte fluvial - desestabilização do talude

- Principais tipos de fluxos gravitacionais de sedimento em águas profundas:

    - Fluxos de detritos

    - Correntes de turbidez



Reynolds Number:

$$R = \frac{\rho u D}{\mu}$$

R > 2000 = Turbulent
R < 500 = Laminar

Bingham Number:

$$B = \frac{\kappa D}{\mu u}$$

R ≈ 1000B = Turbulent
$R/B = \rho u^2/\kappa \approx 1000$ = Turbulent

κ = Strength
μ = Viscosity
ρ = Density
u = Velocity
du/dy = Rate of Change of Velocity
D = Flow Thickness

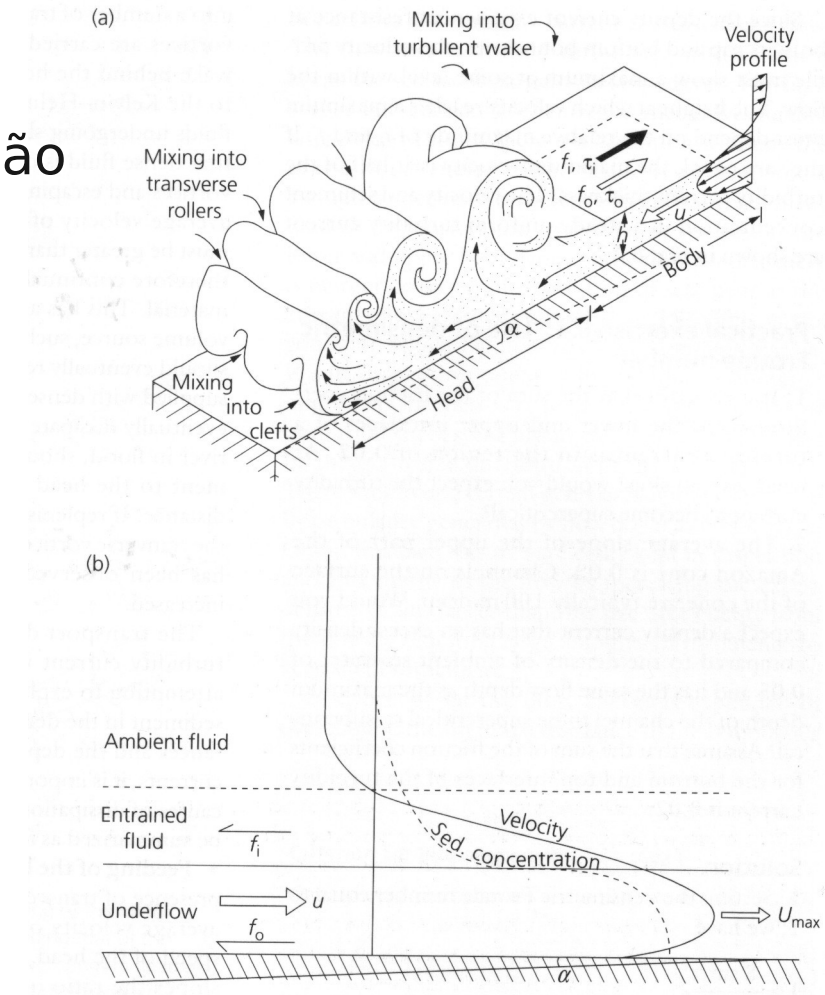
Fig. 3. Rheology (stress-strain relationships) of Newtonian fluids (e.g., turbidity currents) and Bingham plastics (e.g., debris flows), compiled from several sources (Dott, 1963; Enos, 1977; Pierson and Costa, 1987; Phillips and Davies, 1991; Middleton and Wilcock, 1994). This graph shows that a fundamental rheological difference between debris flows (Bingham plastics) and turbidity currents (Newtonian fluids) is that debris flows exhibit strength, whereas turbidity current do not. In general, turbidity currents are turbulent, and debris flows are laminar in state. From Shanmugam (1997a).

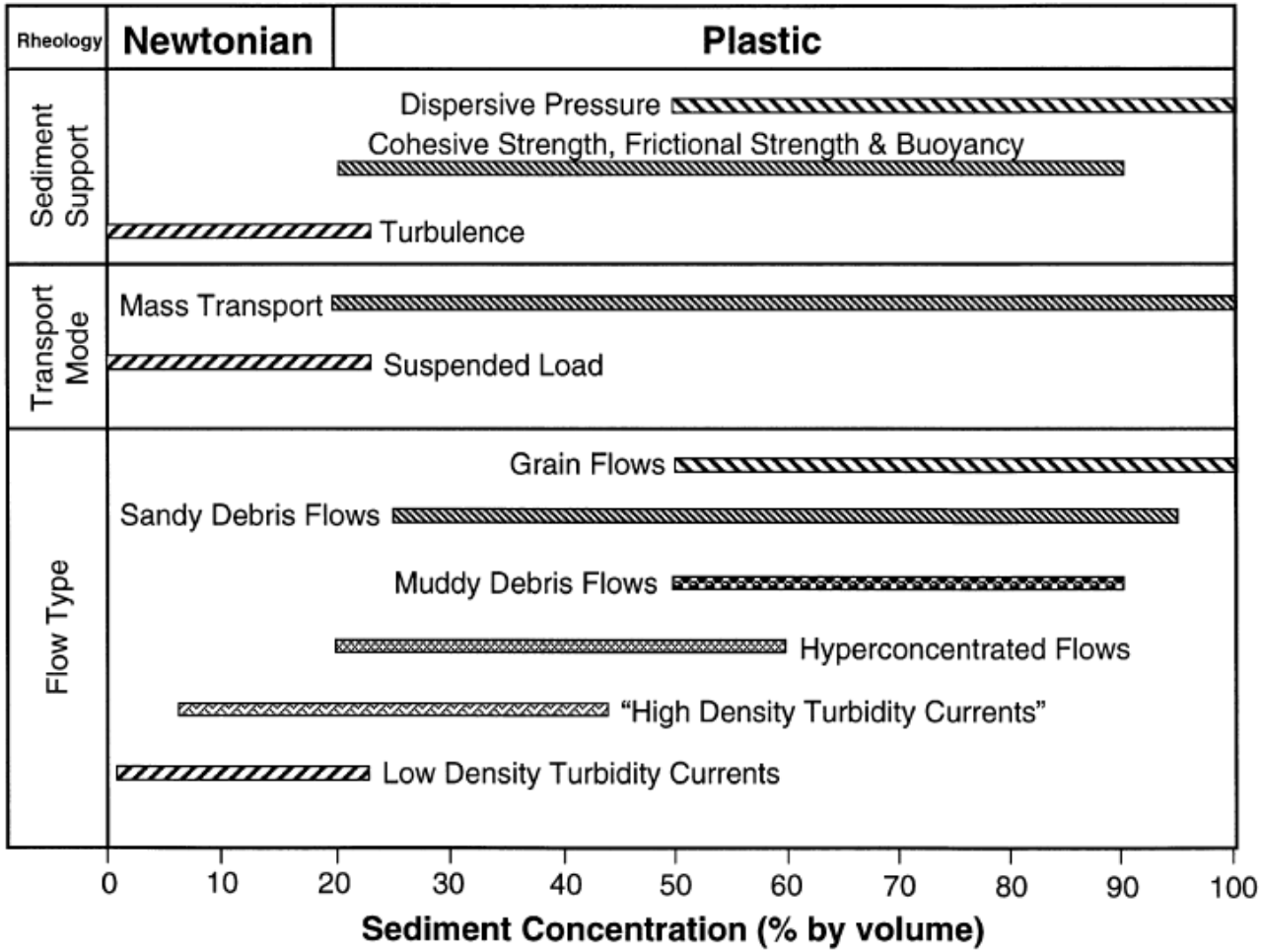
Shanmugam (2000)

Correntes de turbidez:

- Aceleração

- Desaceleração e deposição





Shanmugam (2000)

Fig. 4. A classification of subaqueous gravity flows, based on fluid rheology, showing two general types, *Newtonian* and *Plastic*. This classification is analogous to a classification originally advocated by Dott (1963). Turbidity currents are *Newtonian* flows, whereas all mass flows (muddy debris flows, sandy debris flows, and grain flows) are *Plastic flows*. Turbidity currents occur only as subaqueous flows, whereas debris flows and grain flows can occur both as subaerial and as subaqueous flows. For purposes of comparison, subaerial flows (river currents and hyperconcentrated flows) are included. Sediment concentration is the most important property in controlling fluid rheolgy. High-density turbidity currents are not meaningful in this rheologic classification because their sediment concentration values represent both Newtonian and plastic flows; however, I have included them here for discussion purposes. Published values of sediment concentration by volume % are: (1) river currents (1–5%; e.g., Galay, 1987), (2) low-density turbidity currents (1–23%; e.g., Middleton, 1967, 1993), (3) high-density turbidity currents (6–44%; Kuenen, 1966; Middleton, 1967), (4) hyperconcentrated flows (20–60%; Pierson and Costa, 1967), (5) muddy debris flows (50–90%; Coussot and Muenier, 1996), (6) sandy debris flows (25–95%; Shanmugam, 1997a; partly based on my reinterpretations of various processes that exhibit plastic rheology in papers by Middleton, 1966, 1967; Wallis, 1969; Lowe, 1982; Shultz, 1984;), and (7) grain flows (50–100%; partly based on Rodine and Johnson, 1976; Shultz, 1984; Pierson and Costa, 1987). Concentration values of more than 95 vol.% can be without significant particle interlocking (Rodine and Johnson, 1976), and therefore flow (i.e., deformation of material in response to applied stress) is possible at high concentration values. Two general modes of transport represent different subaqueous flow types: (1) suspended mode in turbidity currents, and (2) mass transport mode in plastic flows. Bed-load transport is meaningful only in river currents, but not in turbidity currents because sediment is held in suspension by flow turbulence during transport. Two general sediment support mechanisms represent different subaqueous flow types: (1) turbulence in turbidity currents, and (2) cohesive strength, frictional strength, and buoyancy in plastic flows. Dispersive pressure (frictional strength) can become an important sediment support mechanism at sediment concentration values of 50–100% (Rodine and Johnson, 1976).

Correntes de turbidez subaquáticas frequentemente desenvolvem-se a partir de fluxos granulares, e fluxos de detritos, quando estes aceleram e misturam-se à água, ficando diluídos.

Isso pode ocorrer quando um grande volume de sedimentos é posto em suspensão por um terremoto ou quando ocorre colapso de um talude muito inclinado.

As correntes de turbidez têm duração curta (horas).

Durante o terremoto de Grand Banks em Newfoundland, em 1929, o rompimento sequencial de cabos telegráficos submarinos revelou um fluxo de sedimentos com velocidade de 7 m/s.

Ciclo de Bouma – primeiros modelos

Ta – Arenitos Maciços

Tb – Arenitos Laminados

Tc – Arenitos com laminação cruzada

Td – Siltitos laminados

Te – Siltitos e argilitos laminados

Qual a sucessão de processos?

Elementos morfológicos:

1- Canions

2- Canais

3 - Lobos

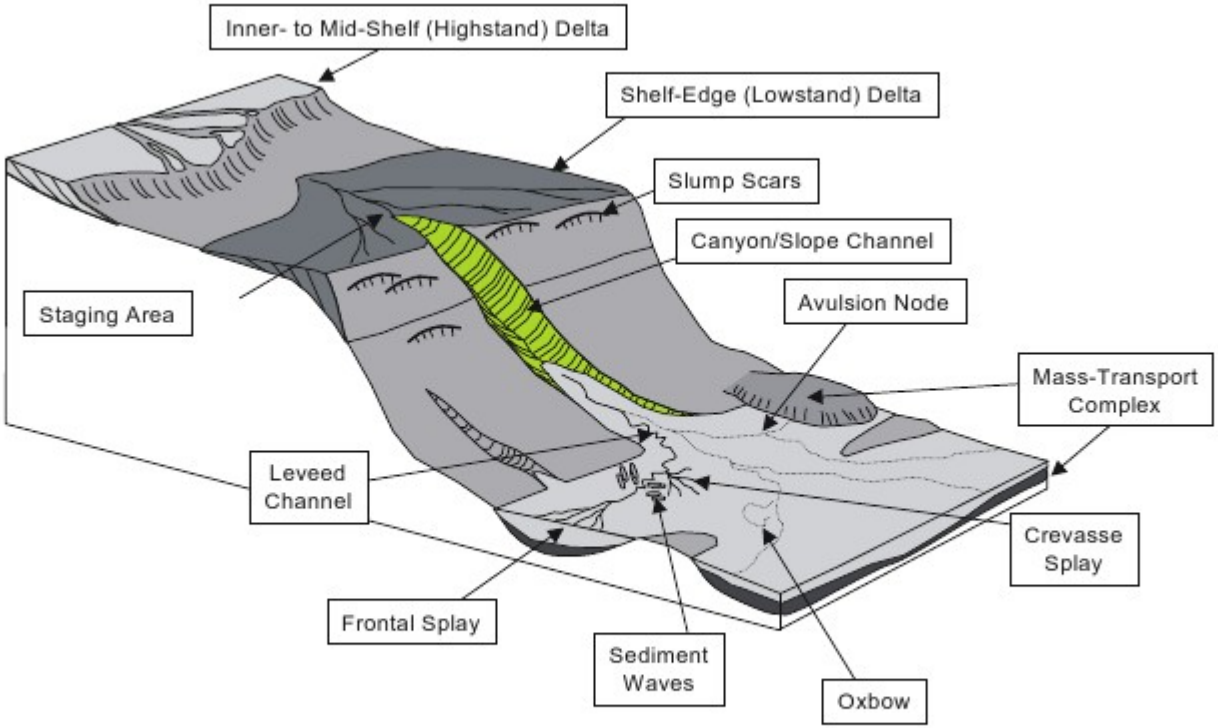
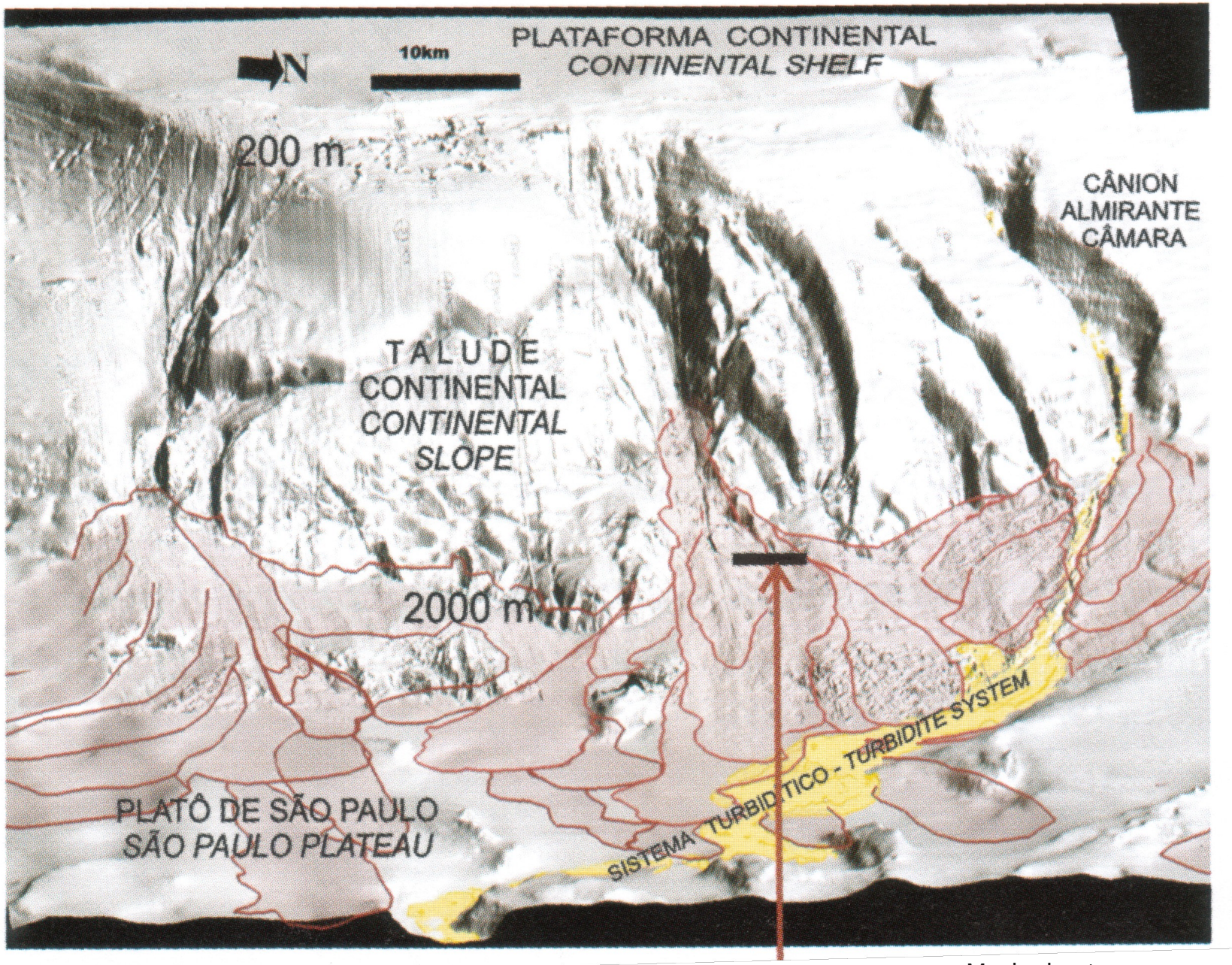


FIG. 1.—Schematic representation of shelf to deep-water physiography. The shelf staging area is connected to the deep-water environment through slope channels and / or canyons. Depositional elements in the deep water include leveed channels, crevasse splays, sediment waves, and frontal splays or lobes. (modified after Posamentier and Kolla, 2003a).

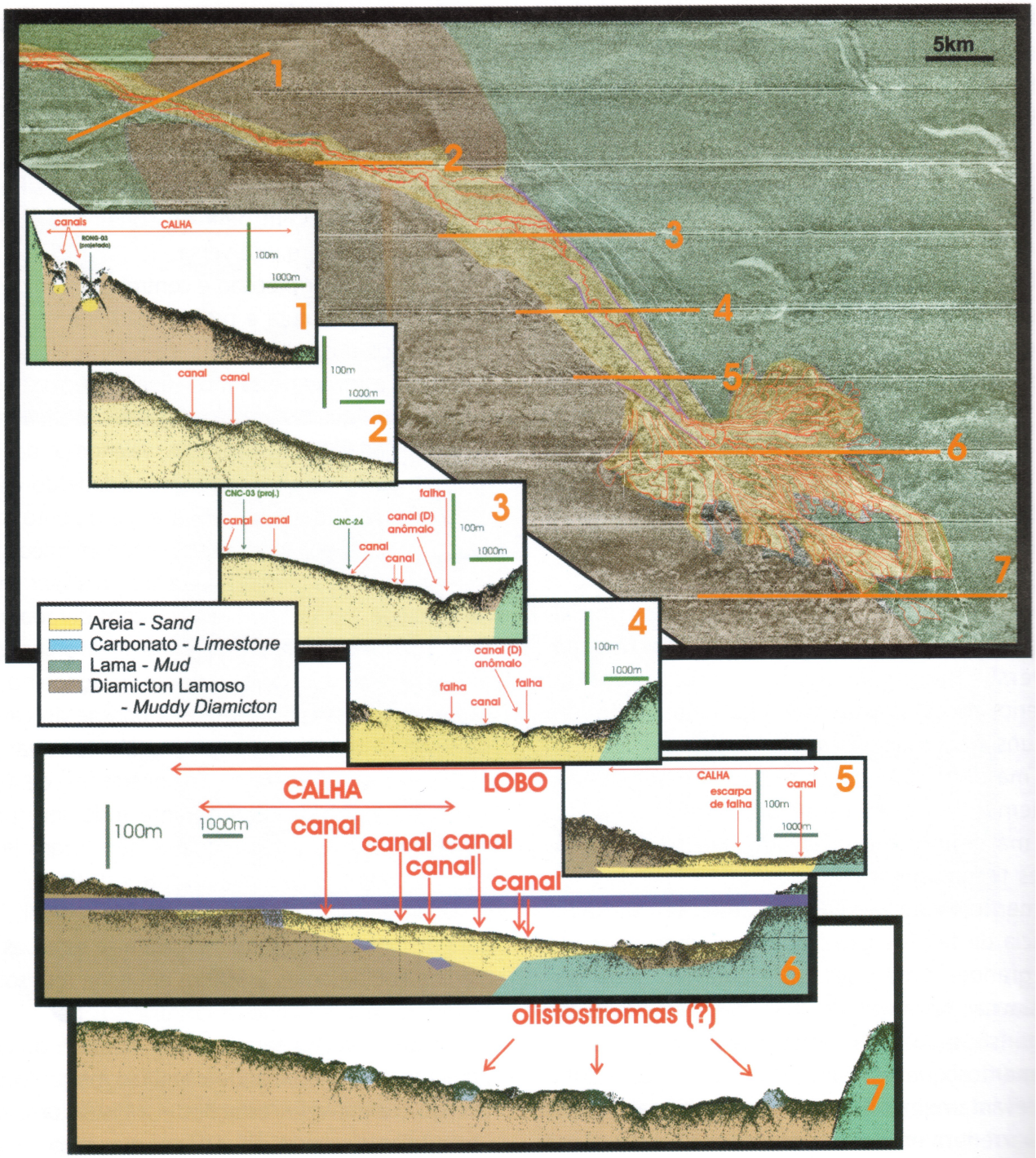
Posamentier & Walker (2006)

Modelo do sistema atual da Bacia de Campos, baseado em sonar de varredura lateral

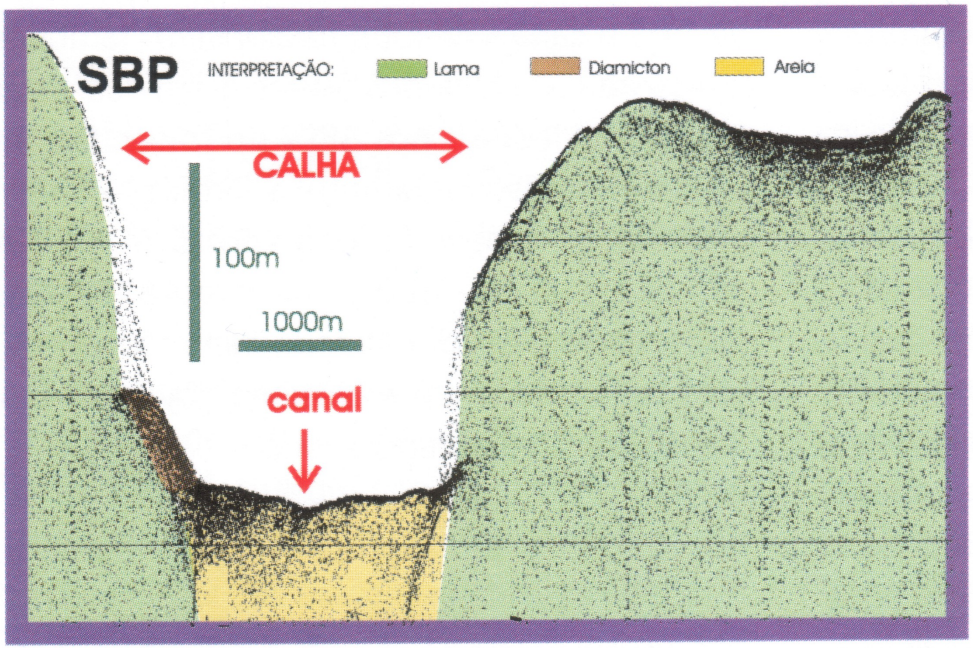


Machado *et al.* (2004)

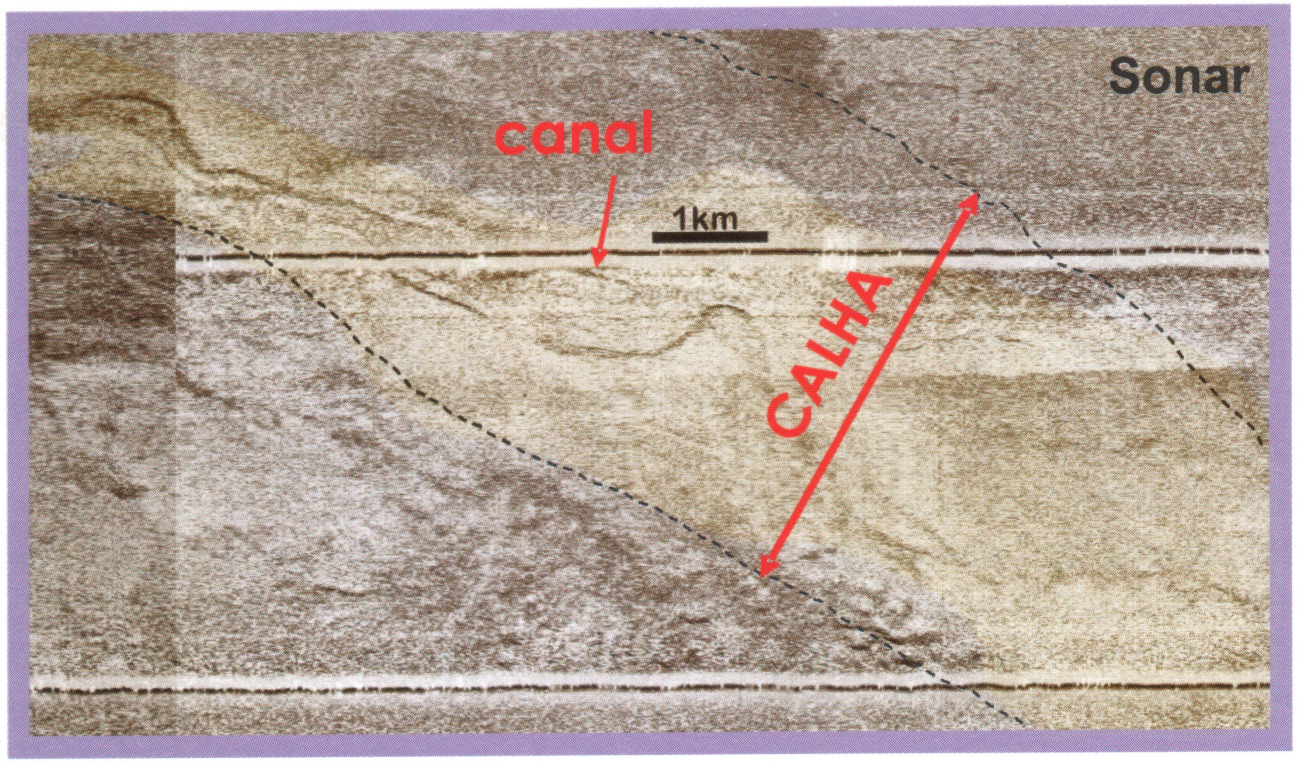
Imagem interpretada de sonar e seções sísmicas de alta freqüência mostrando canal e lobo turbidítico



Machado et al. (2004)



Detalhe de calha e canal turbidítico



Machado et al. (2004)

Imagem interpretada deseções sísmicas de alta freqüência mostrando perfil de canal turbidítico do leque do Amazonas

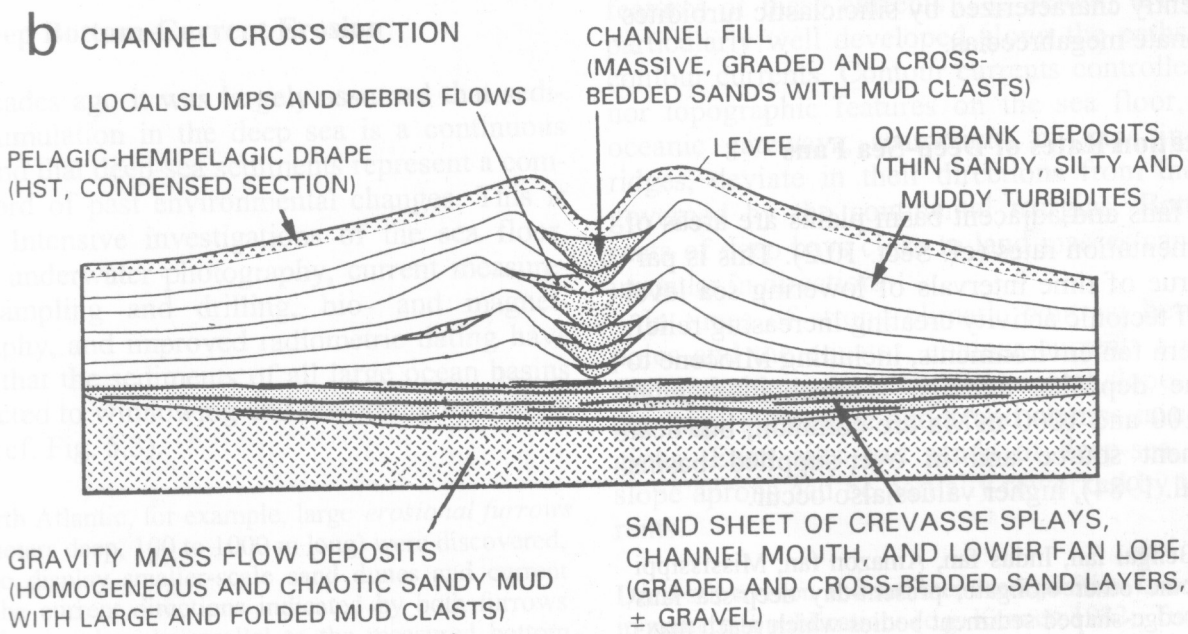
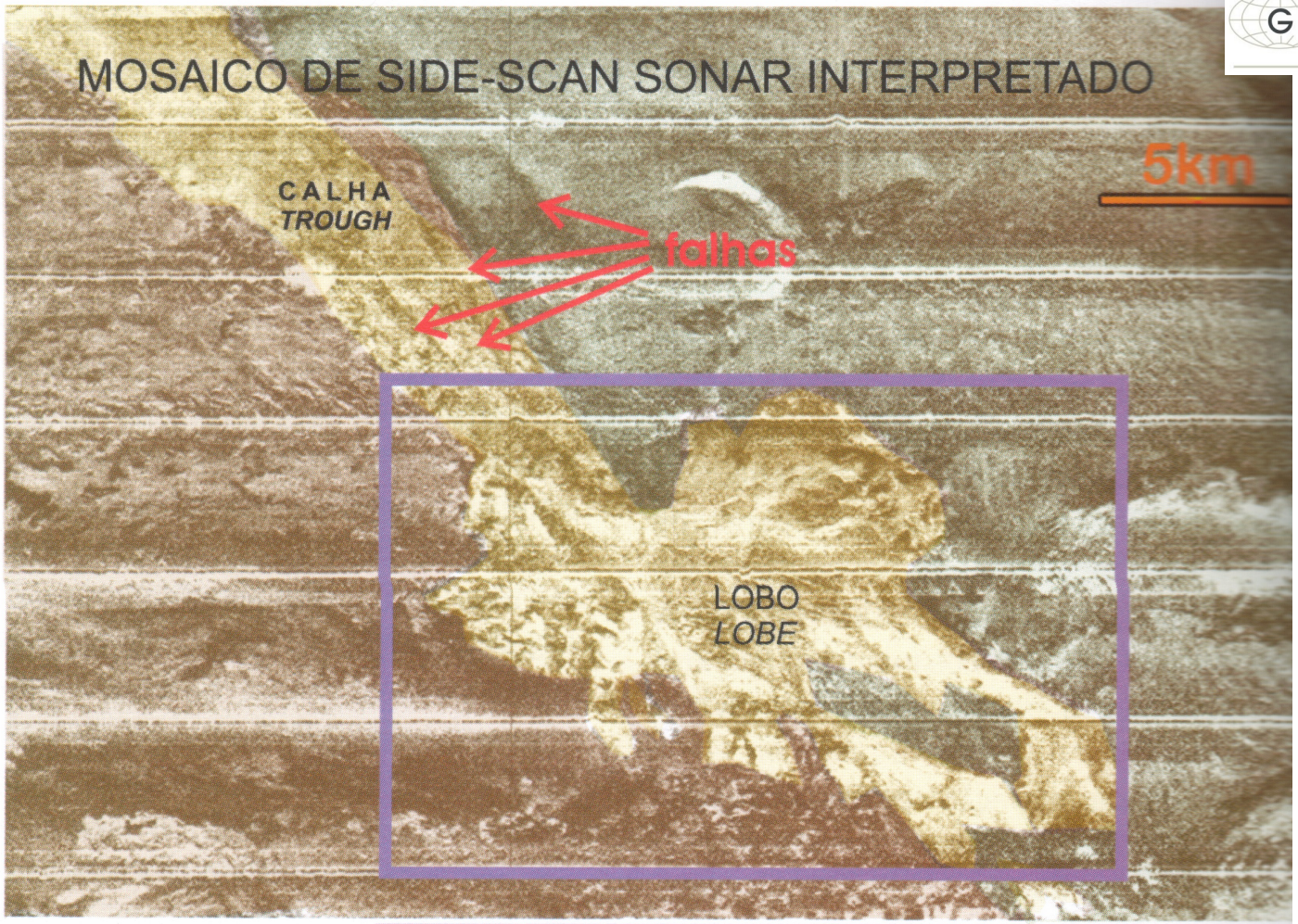
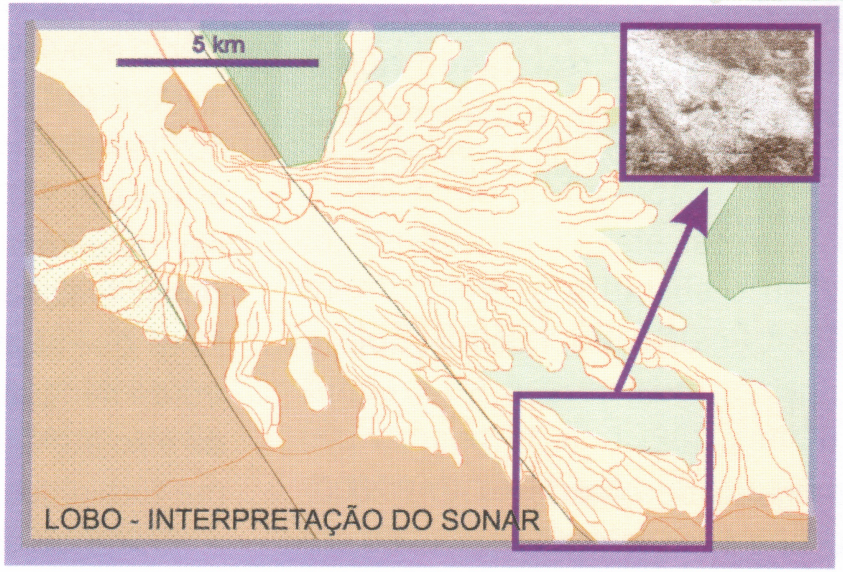


Fig. 5.22. a Cross section of Amazon Fan in mid-fan region as revealed by seismic investigations and drill holes (Site numbers of ODP Leg 155). Note contrast between thick levee complexes (formed during sea-level lowstands) and thin hemipelagic drape (highstand). **b** Close-up of individual channel-levee system, schematized. (After Flood and Piper 1997; Pirmez et al. 1997, modified)



Detalhe de lobo turbidítico

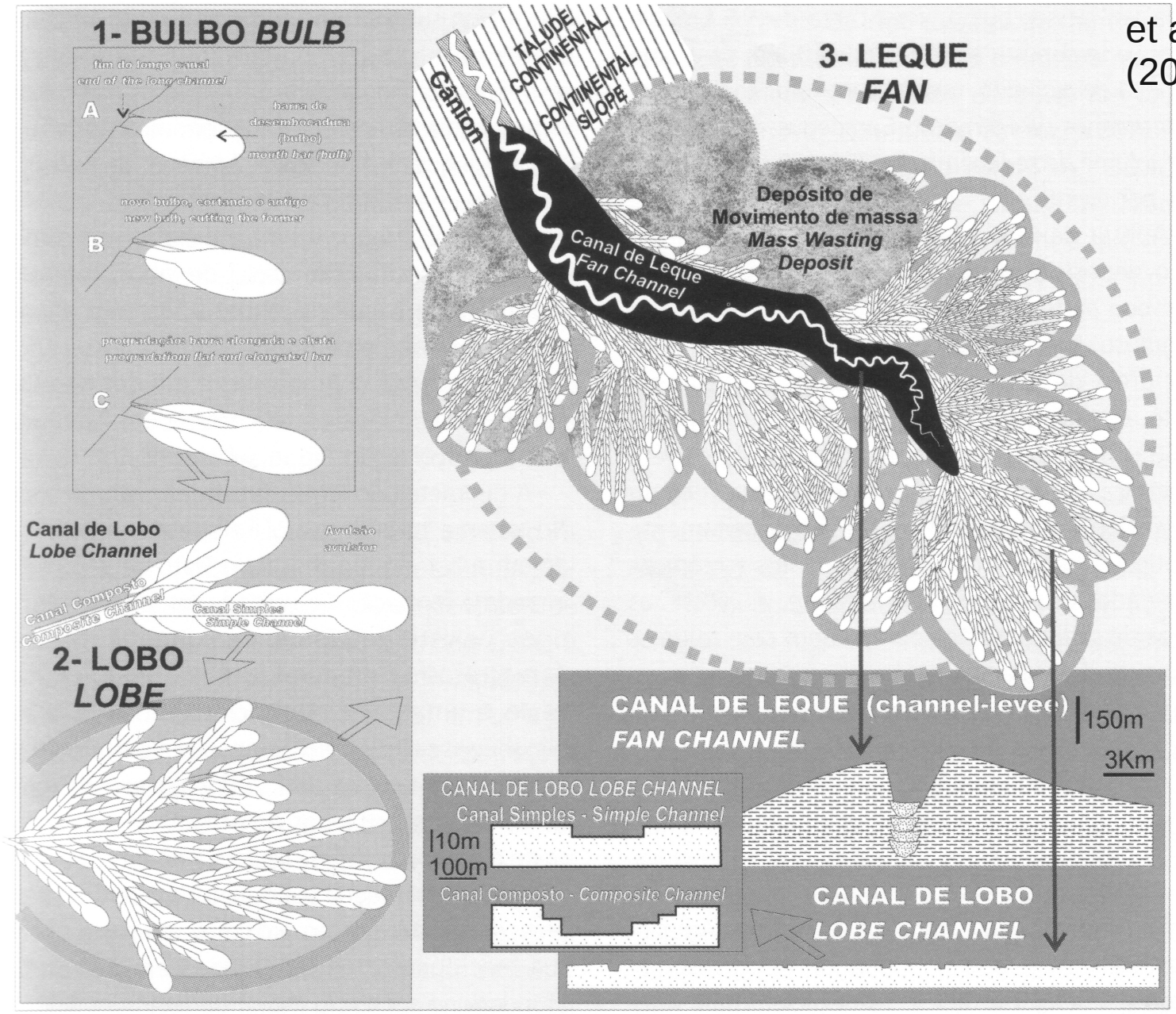


- Areia - *Sand*
- Carbonato - *Limestone*
- Lama - *Mud*
- Diamicton Lamoso - *Muddy Diamicton*

Machado et al. (2004)

Arquitetura de um sistema de canal e lobos

Machado et al. (2004)



Tipos de leques submarinos:

- Leques ricos em pelitos
- Leques areno-pelíticos
- Leques ricos em areia
- Leques conglomeráticos
- Rampas

Leque submarino rico em pelitos

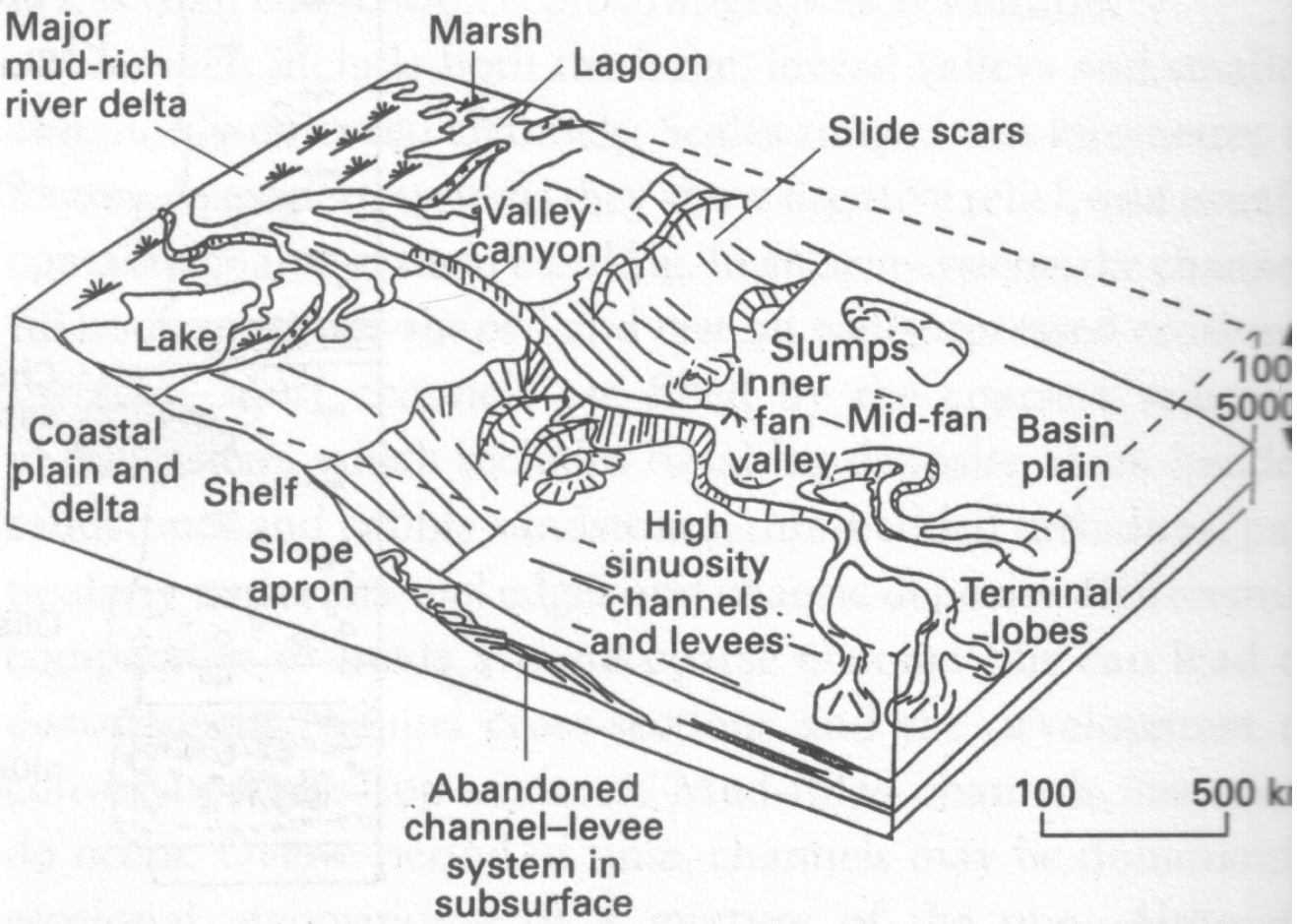


Figure 10.37 Depositional model for mud-rich submarine fan (from Reading & Richards, 1994).

Leque submarino areno-pelítico

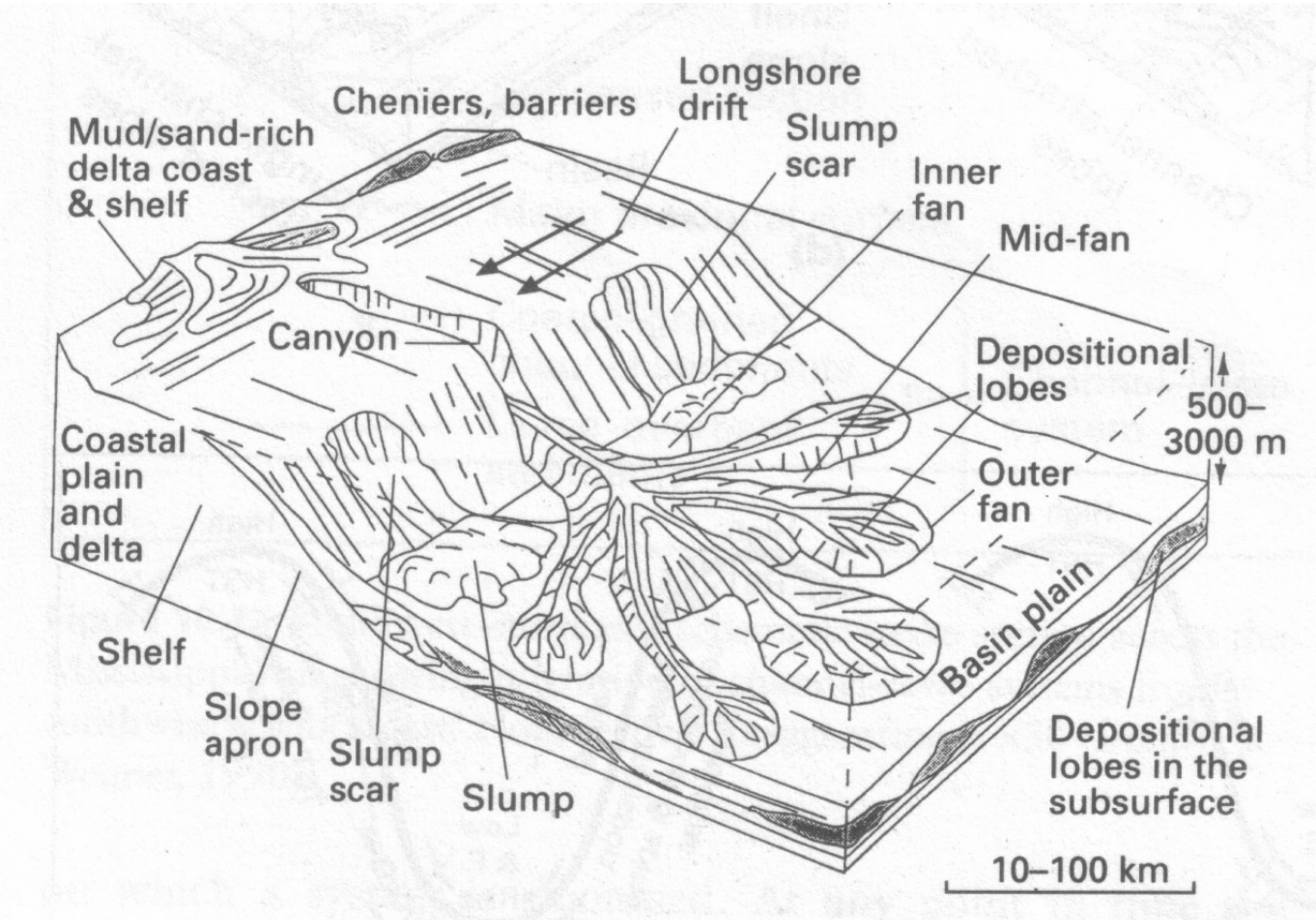


Figure 10.46 Depositional model for mud/sand-rich submarine fan (from Reading & Richards, 1994).

Leque submarino rico em areia

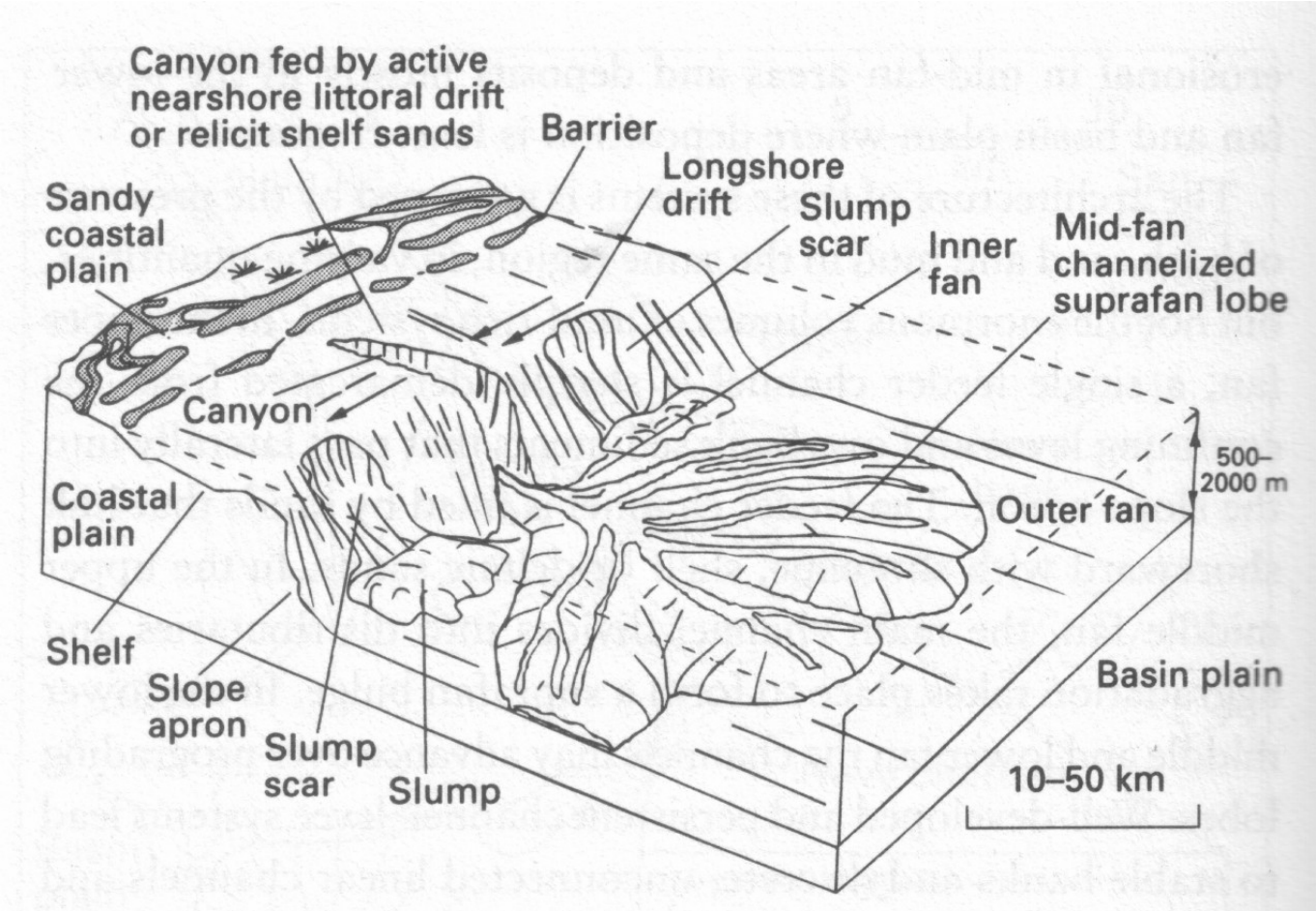
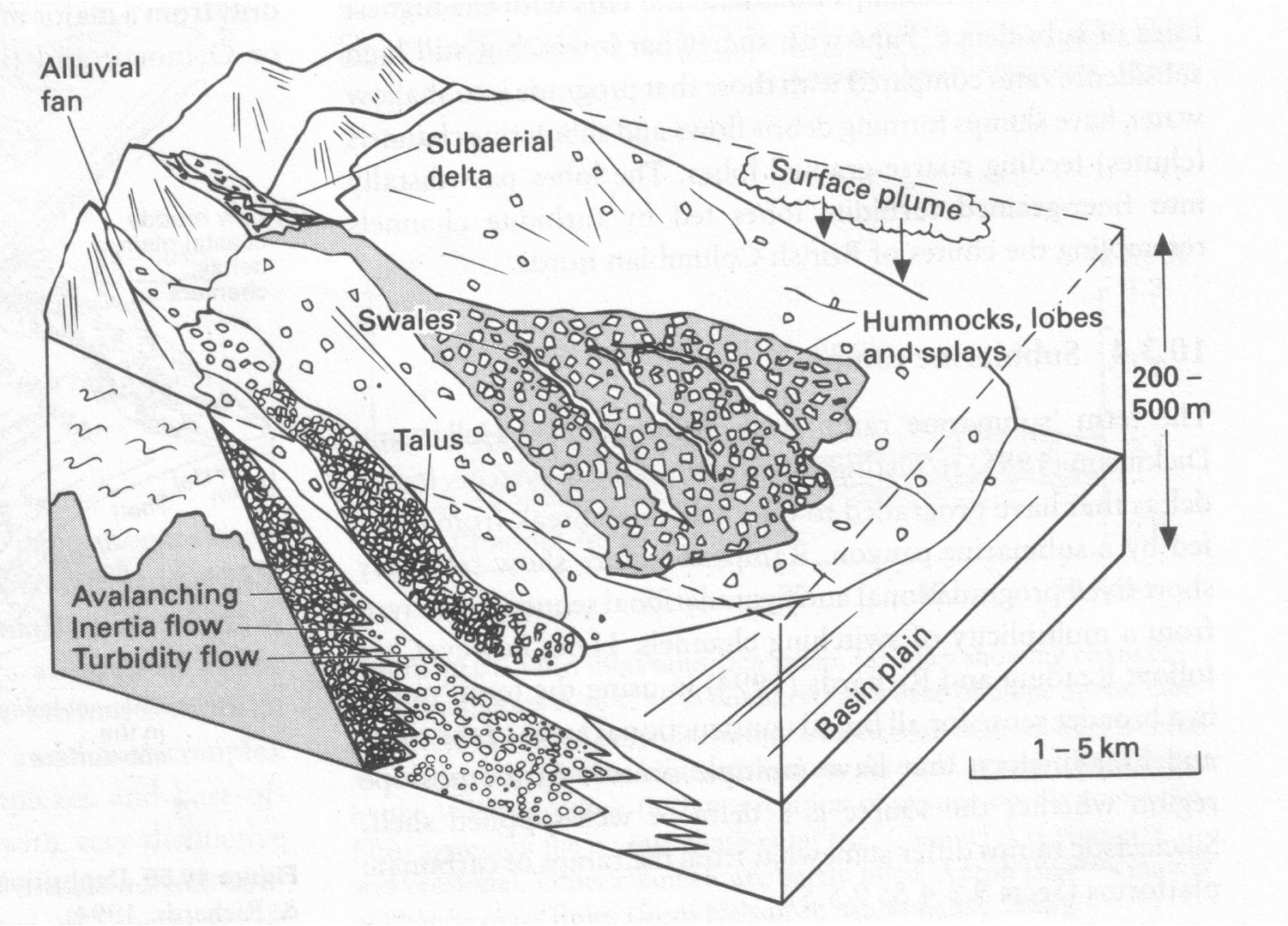


Figure 10.51 Depositional model for sand-rich submarine fan (from Reading & Richards, 1994).

Leque submarino rico em areia



Modelos de fácies:

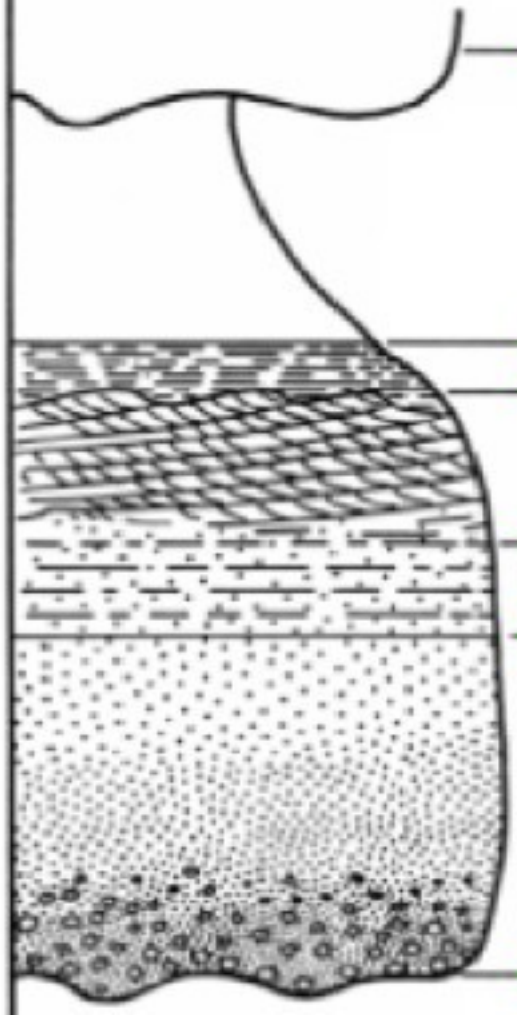
- Primeiros modelos: empilhamento vertical

- Modelo de Mutti: distribuição horizontal

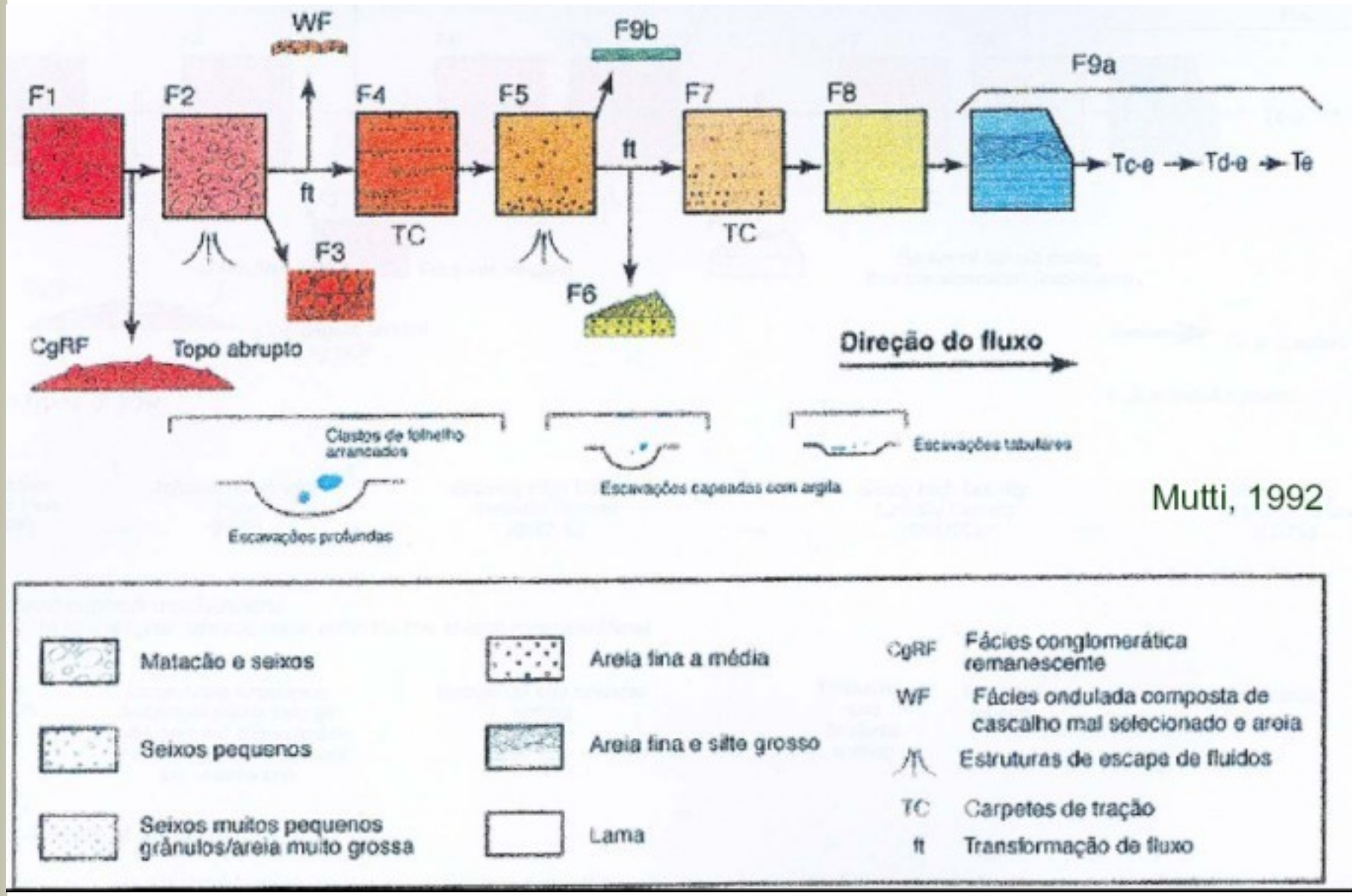
- Modelos de variação tridimensional de fácies

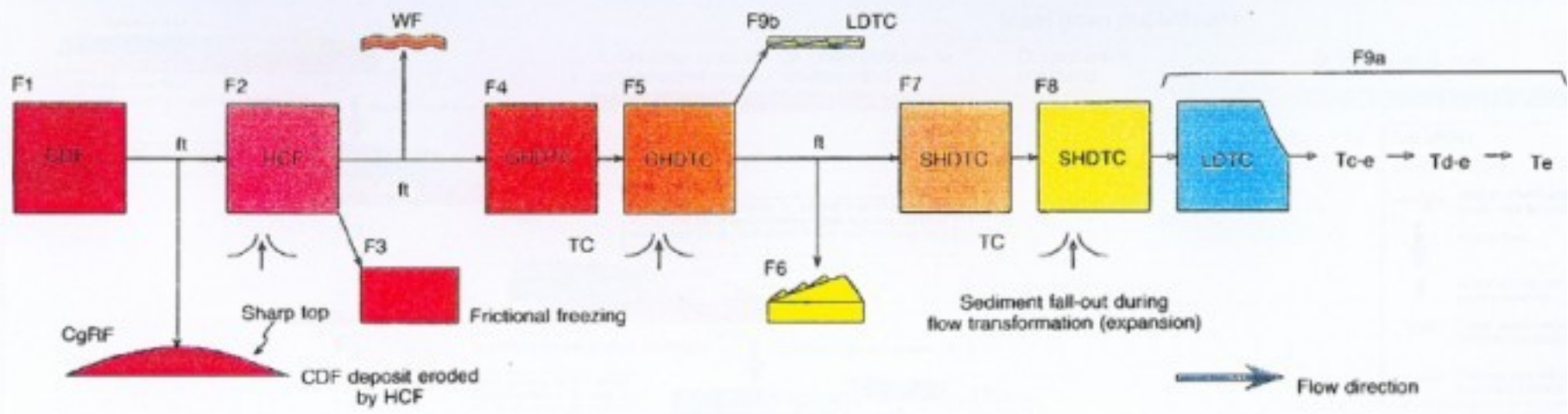
"Turbiditos Clássicos"

A Seqüência de Bouma



ϕ		Divisões de Bouma (1962)	Interpretação hidrodinâmica
Lama	Te	Pelitos laminados (Td/Te)	Sedimentação pelágica, decantação em águas calmas ou a partir de suspensão por correntes lentas e diluídas
	Td	Silte e argila laminados	A partir de suspensão Leito Plano
Silte Areia	Tc	Laminações cavalgantes ou laminações convolutas	Regime de Fluxo Inferior *"climbing ripples"*
	Tb	Laminações plano-paralelas	Regime de Fluxo Superior Leito plano
Areia a grânulos na base	Ta	Intervalo maciço ou com gradação normal	Alta velocidade de fluxo e deposição rápida a partir de transporte por suspensão


WF
F9b
F9a
F1
F2
F4
F5
F7
F8
ft
ft
TC
TC
F3
F6
Tc-e
Td-e
Te
CgRF
Topo abrupto
Direção do fluxo
Clastos de folhelho arrancados
Escavações profundas
Escavações capeadas com argila
Escavações tabulares
Mutti, 1992
Matacão e seixos
Seixos pequenos
Seixos muitos pequenos grânulos/areia muito grossa
Areia fina a média
Areia fina e silte grosso
Lama
CgRF Fácies conglomerática remanescente
WF Fácies ondulada composta de cascalho mal selecionado e areia
Estruturas de escape de fluidos
TC Carpetes de tração
ft Transformação de fluxo



Main types of flow:

Cohesive Debris Flow (CDF)	ft →	Hyperconcentrated Flow (HCF)	ft →	Gravelly High Density Turbidity Current (GHDTC)	ft →	Sandy High Density Turbidity Current (SHDTC)	→	Low Density Turbidity Current (LDTC)

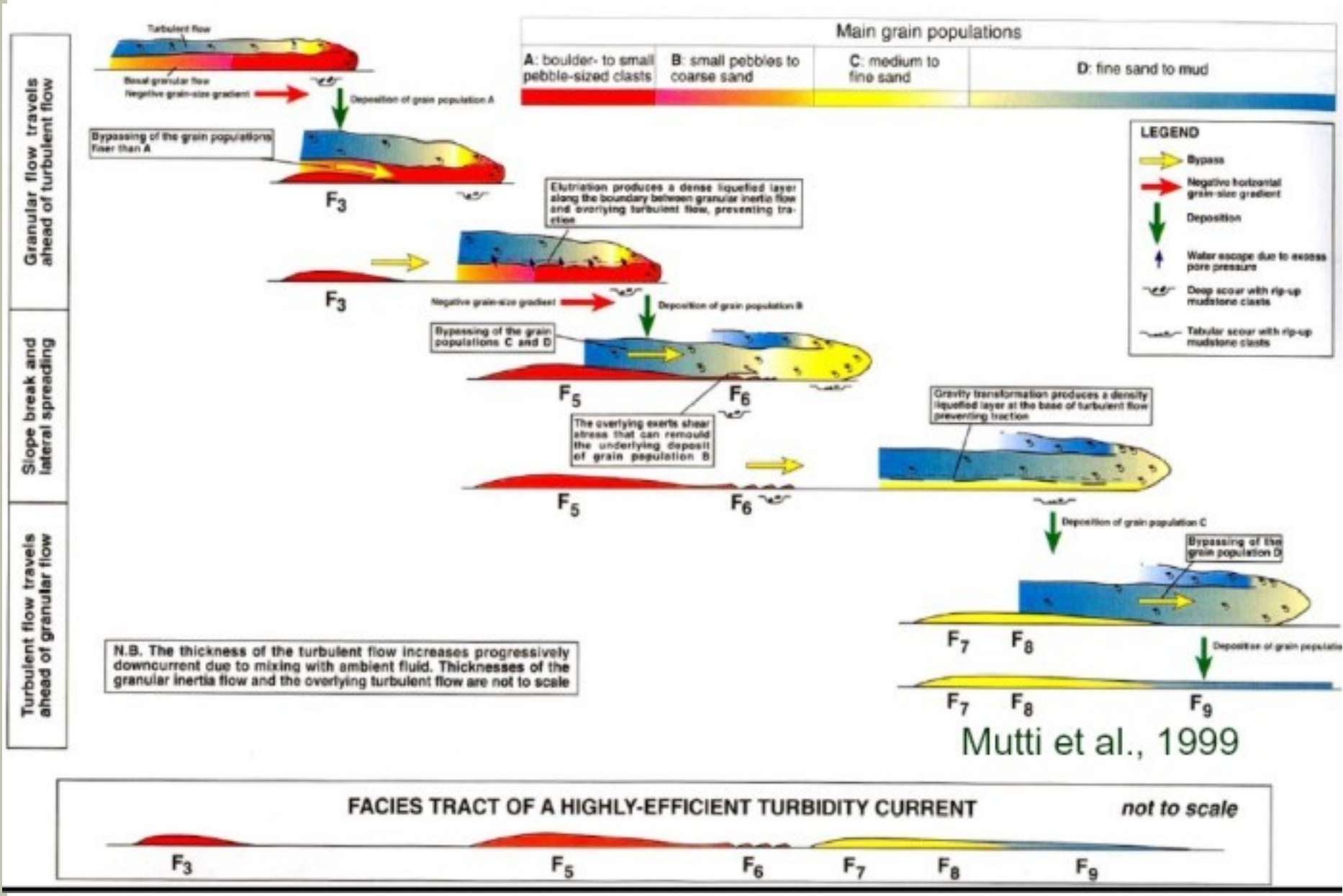
Sediment support mechanisms
(refer to the coarser grain size population within the flow at each considered time)

Matrix strength	Large-scale turbulence, decreased matrix strength and increased concentration of coarse-grained sediment per volume unit	Turbulence and hindered settling	Turbulence and hindered settling	Hindered settling	Turbulence

Mutti, 1992

Mechanisms of deposition:

Cohesive freezing (F1)	Frictional freezing (F3) followed by cohesive freezing (F2)	Traction carpets (F4) followed by en-masse deposition (F5)	Thin traction carpets (F7) followed by en-masse deposition (F8)	Traction-plus-fallout process (*b* through *d* divisions) followed by deposition of homogeneous mud (*e* division)


Granular flow travels ahead of turbulent flow
Slope break and lateral spreading
Turbulent flow travels ahead of granular flow
Turbulent flow
Basal granular flow
Negative grain-size gradient
Deposition of grain population A
Bypassing of the grain populations finer than A
F3
Elutriation produces a dense liquefied layer along the boundary between granular inertia flow and overlying turbulent flow, preventing traction
F3
Negative grain-size gradient
Deposition of grain population B
Bypassing of the grain populations C and D
F5
F6
The overlying exerts shear stress that can remould the underlying deposit of grain population B
F5
F6
Gravity transformation produces a density liquefied layer at the base of turbulent flow preventing traction
Deposition of grain population C
Bypassing of the grain population D
F7
F8
F7
F8
F9
N.B. The thickness of the turbulent flow increases progressively downcurrent due to mixing with ambient fluid. Thicknesses of the granular inertia flow and the overlying turbulent flow are not to scale
Main grain populations
A: boulder- to small pebble-sized clasts
B: small pebbles to coarse sand
C: medium to fine sand
D: fine sand to mud
LEGEND
Bypass
Negative horizontal grain-size gradient
Deposition
Water escape due to excess pore pressure
Deep scour with rip-up mudstone clasts
Tabular scour with rip-up mudstone clasts
Mutti et al., 1999
FACIES TRACT OF A HIGHLY-EFFICIENT TURBIDITY CURRENT
not to scale
F3
F5
F6
F7
F8
F9

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0 1 2 3 4 5
METRIC

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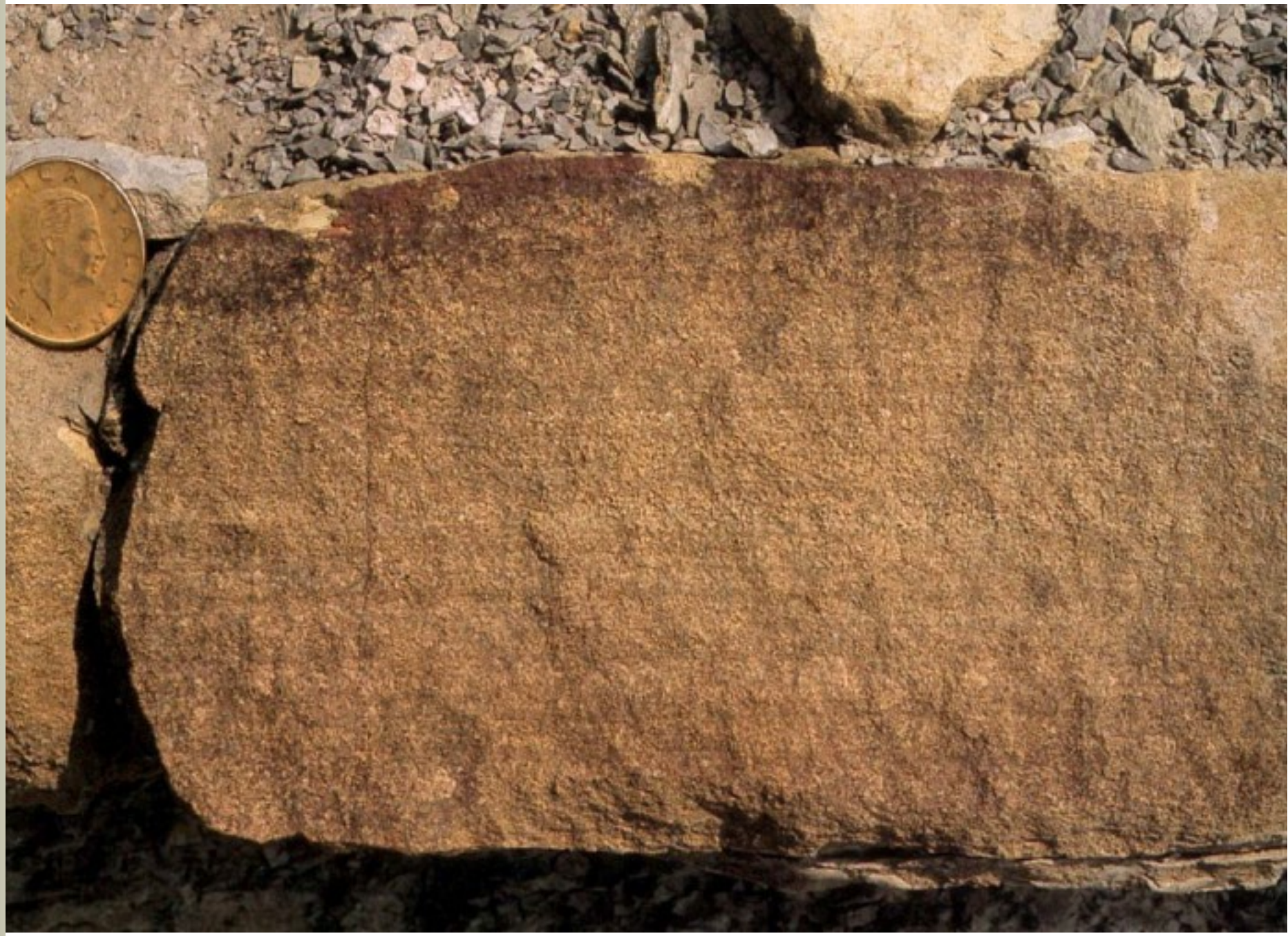

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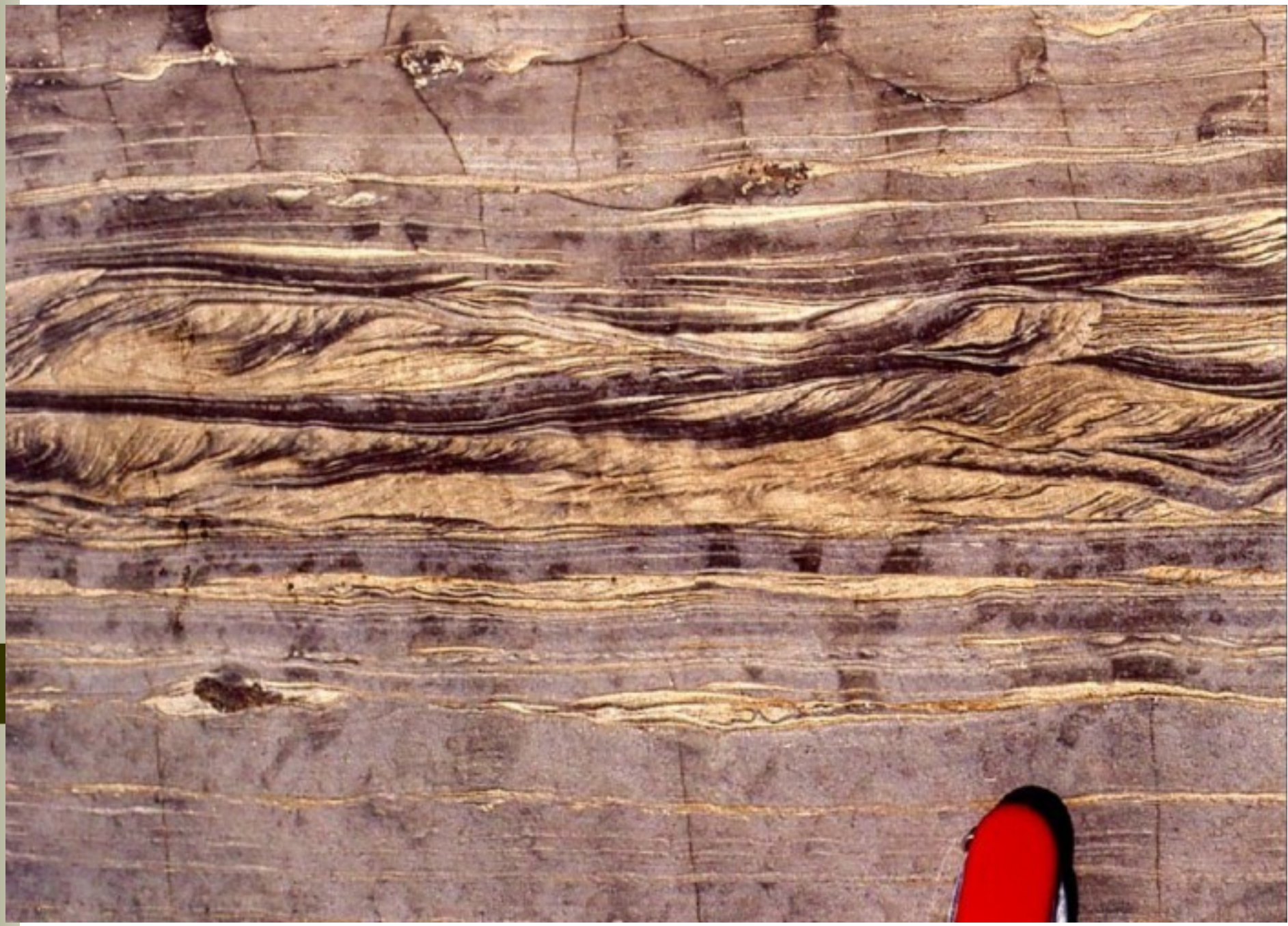


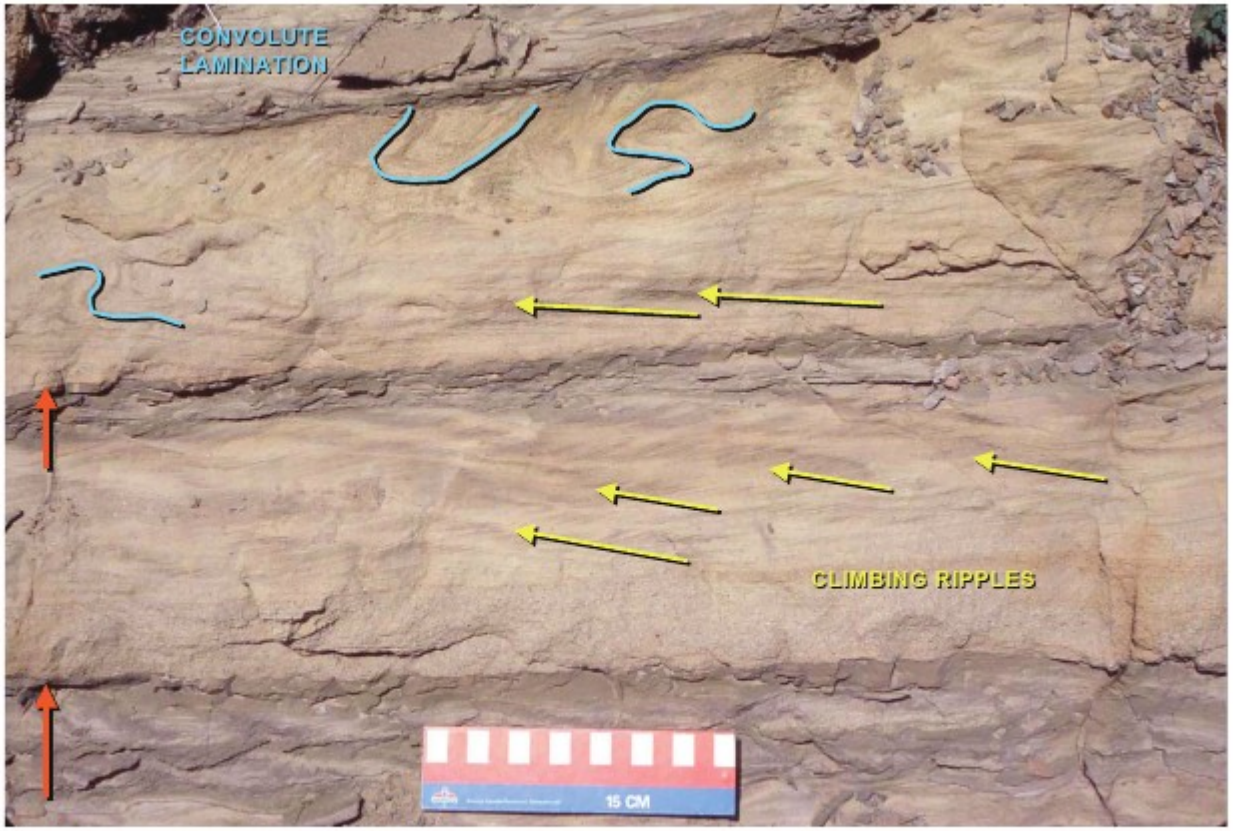


FIG. 7.—Thin-bedded turbidites in the Chatsworth Sandstone (Cretaceous), Chatsworth (Simi Hills), California. Bases shown by red arrows, and climbing ripples shown by yellow arrows. Convolute lamination is outlined in blue. Compare with Figure 6 (where there is no climbing and no convolution).

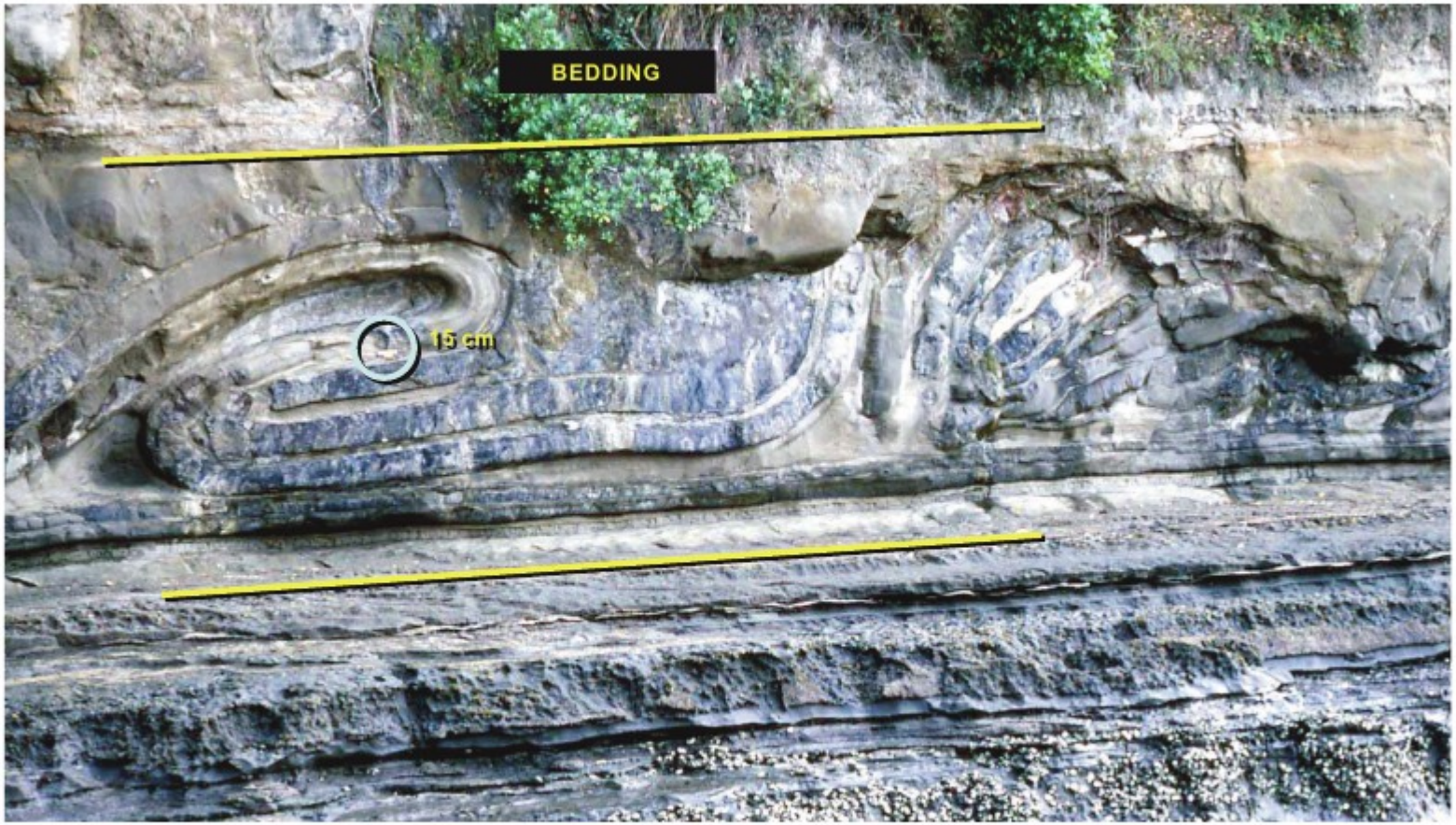
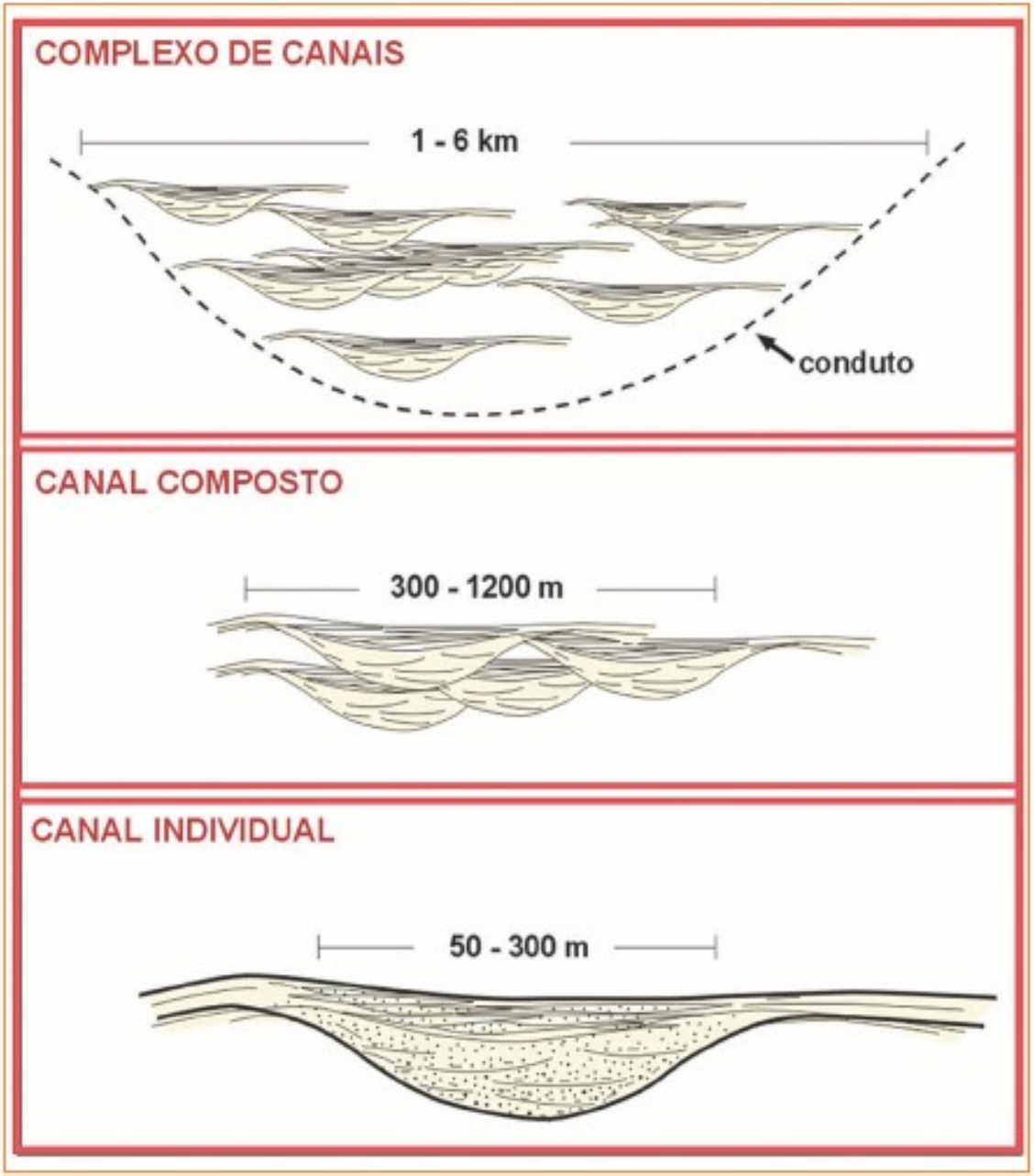


FIG. 25.—Small-scale slump involving only two beds within otherwise flat-bedded succession, Eocene, Waitemata Group, New Zealand.



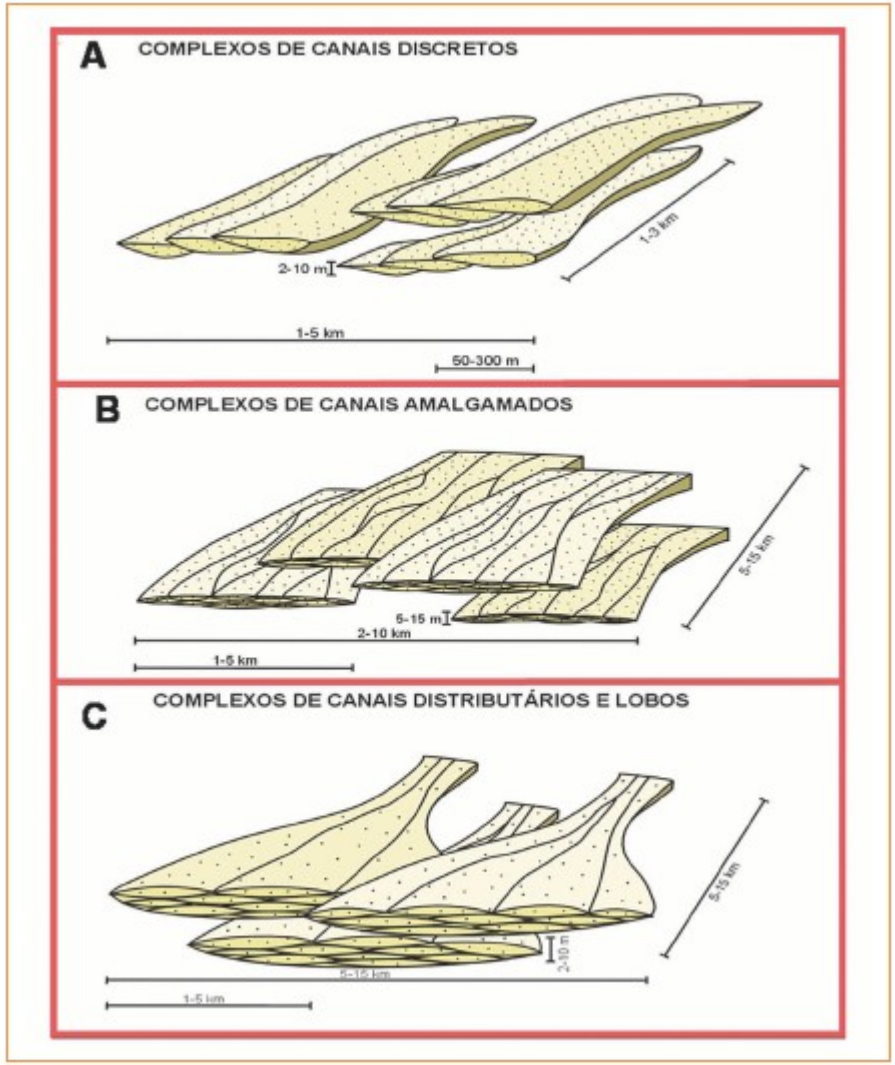


Figura 6 – Hierarquia de elementos de arquitetura observada em reservatórios de águas profundas, com exemplos dos complexos de canais discretos. Note que cada nível de hierarquia apresenta um intervalo de dimensões específico.

Figure 6 – Hierarchy of architectural elements observed in deep-water reservoirs, using the examples of discrete-channel complex. Note that each hierarchical level refers to a specific set of dimensions.

Moraes et al. (2006)

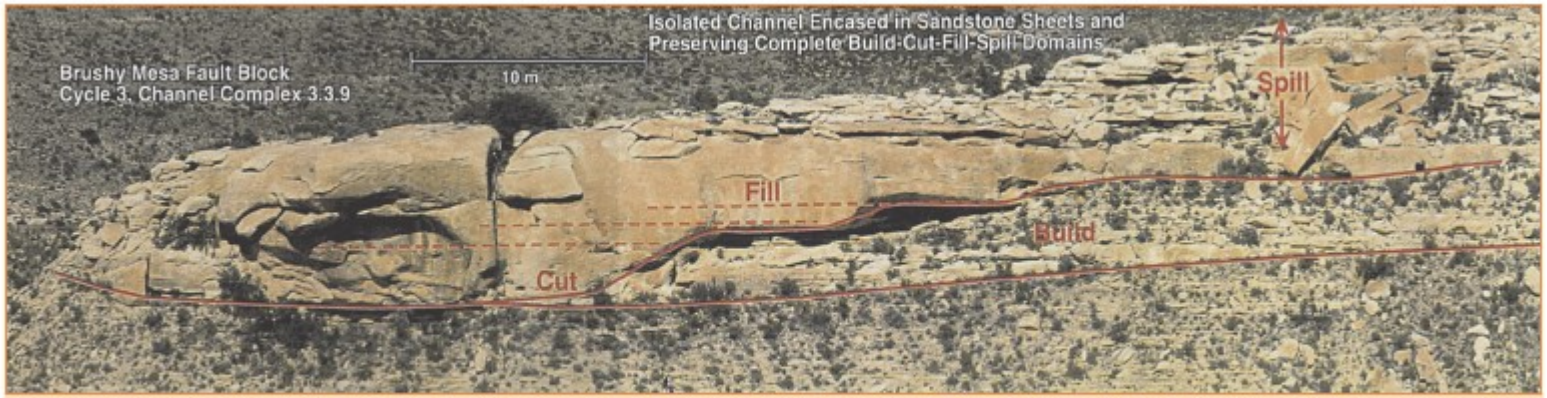


Figura 7 – Fotografia de canal individual da Formação Brushy Canyon (localidade de Brushy Mesa). Extraída de Gardner *et al.* (2000).

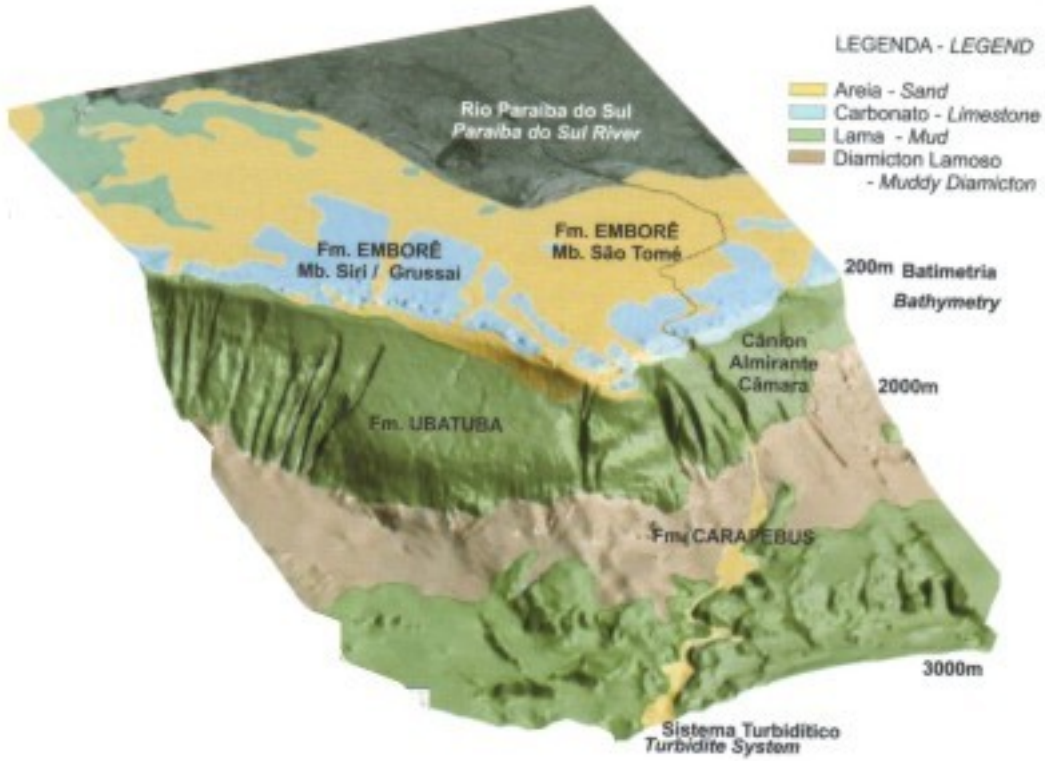
Figure 7 – Individual channel of the Brushy Canyon Formation. Extracted from Gardner et al. (2000).

Moraes et al. (2006)

Figura 8

Outra imagem dos canais discretos da Formação Brushy Canyon apresentados na figura 2. Note que a principal feição de canal se trata de um canal composto com cerca de 600 m de largura. Em seu interior são identificados canais individuais menores (como o marcado em amarelo) com largura em torno de 200 m. As paleocorrentes são ligeiramente oblíquas, para a esquerda, no sentido do afloramento.

Distribuição espacial das fácies – variação em área e não só longitudinal



Machado et al. (2004)

Distribuição espacial das fácies – variação em área e não só longitudinal

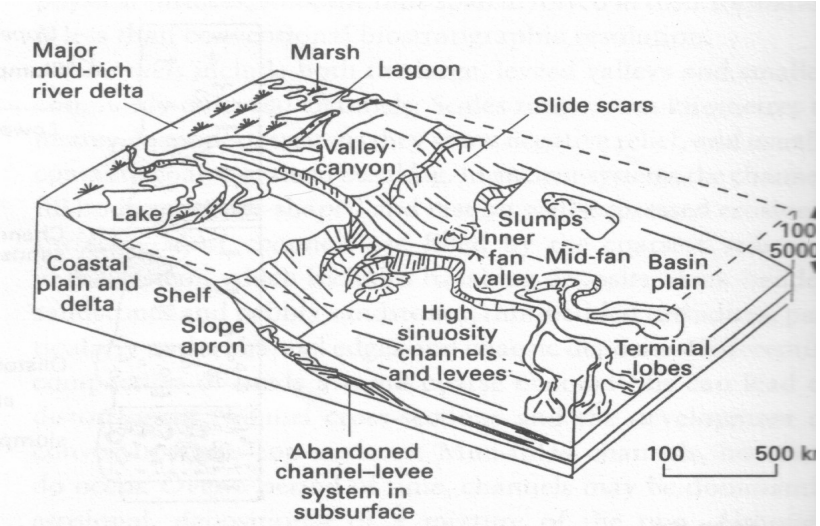


Figure 10.37 Depositional model for mud-rich submarine fan (from Reading & Richards, 1994).

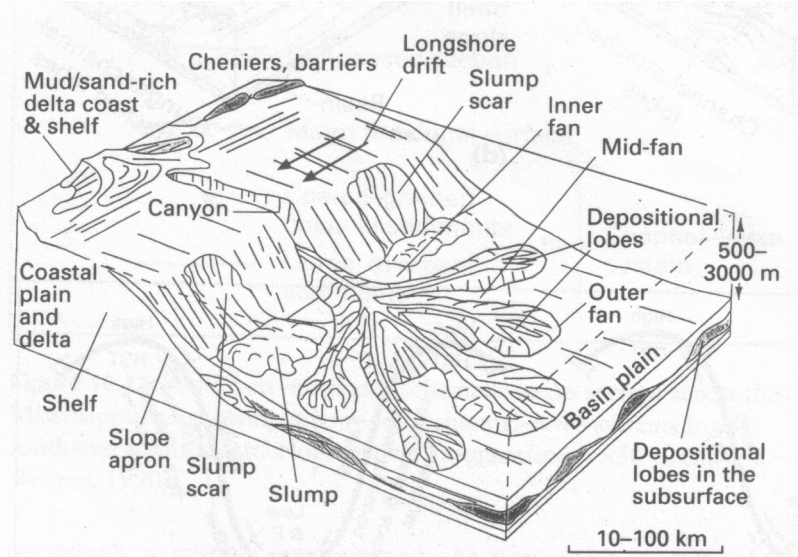


Figure 10.46 Depositional model for mud/sand-rich submarine fan (from Reading & Richards, 1994).

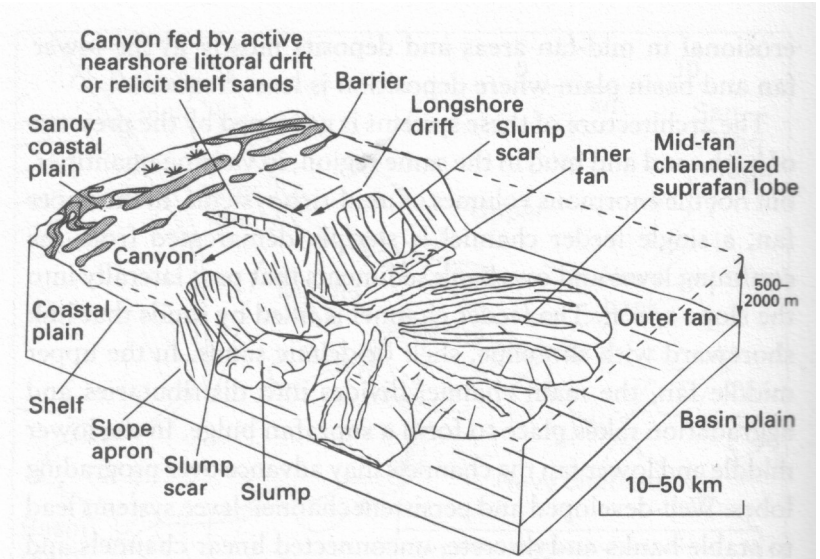
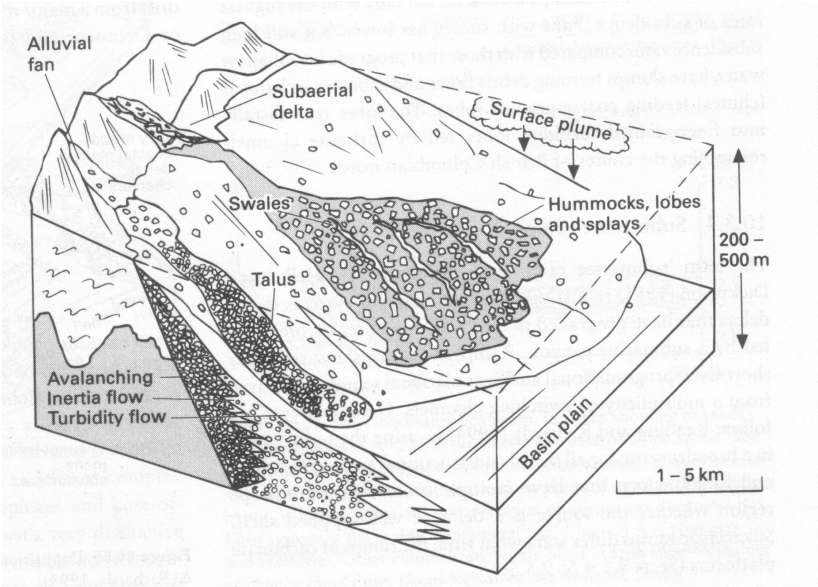


Figure 10.51 Depositional model for sand-rich submarine fan (from Reading & Richards, 1994).



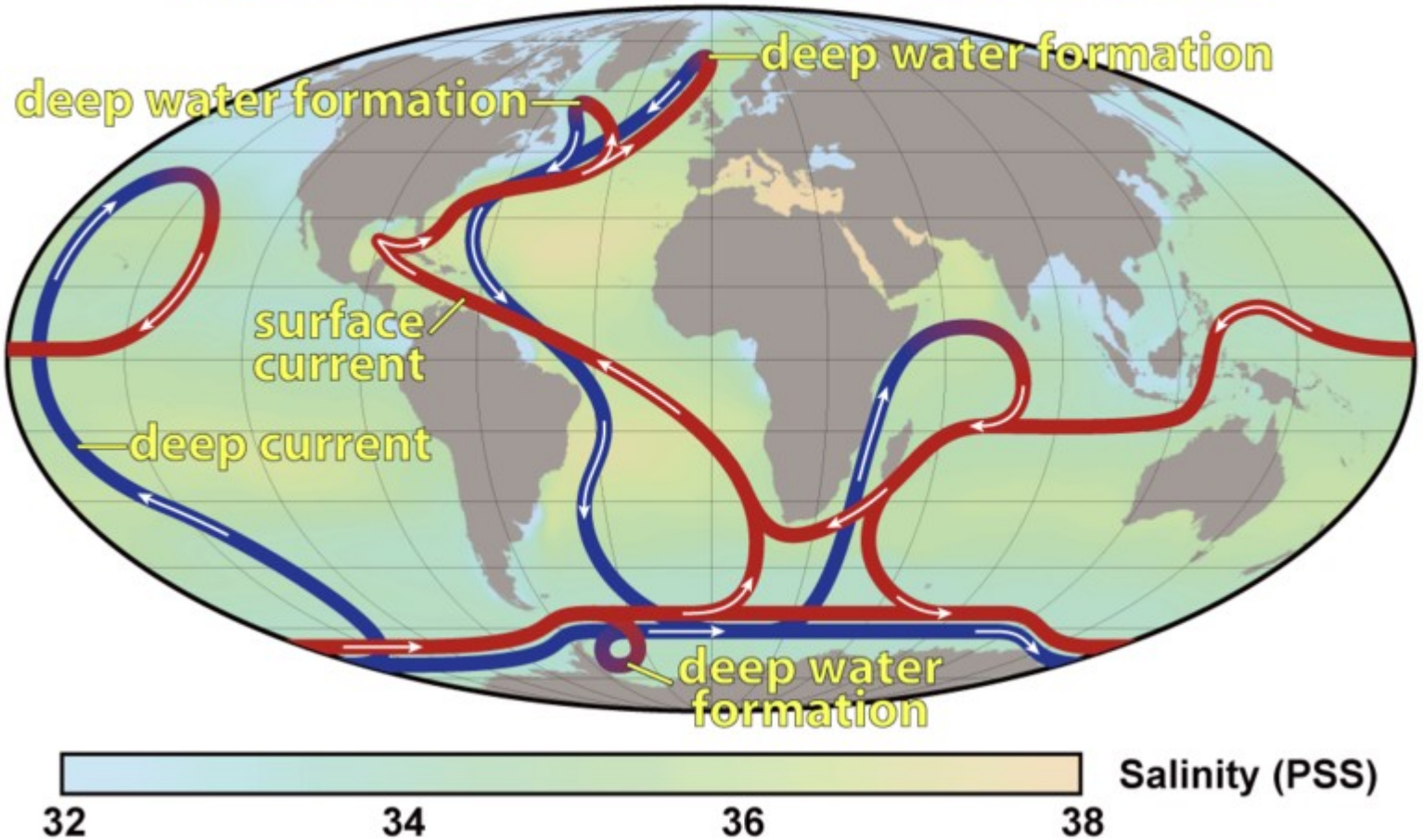
Bypass

Correntes de turbidez descendo o talude podem mover-se a muitos metros por segundo, a velocidades nas quais areia e partículas mais finas mantêm-se em suspensão. Esses fluxos gradualmente desaceleram para velocidades de 1-2 m por segundo, quando as frações maiores da areia começam a a depositar. Durante esse período de desaceleração, as correntes podem atravessar o talude sem depositar sedimento (bypass), movendo-se por grandes distâncias pelo assoalho oceânico.

Contornitos

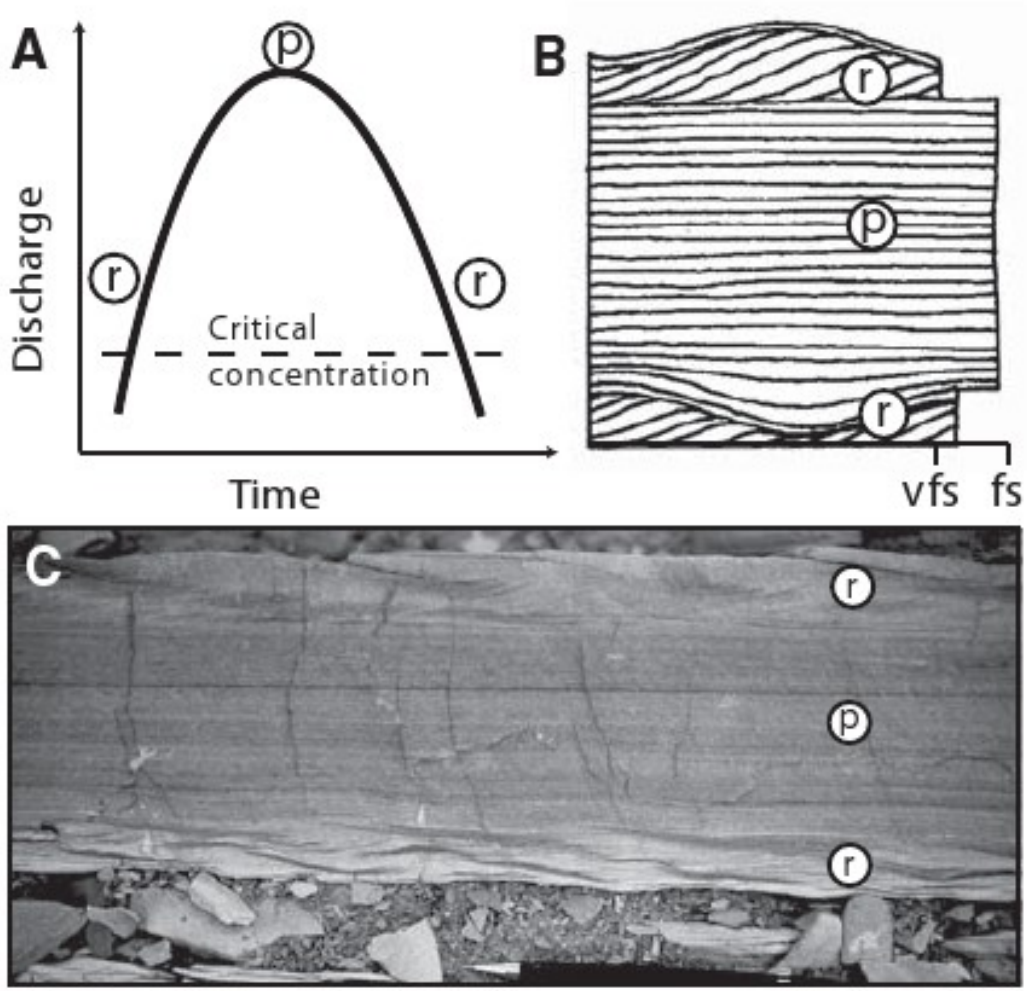
Correntes termohalinas e algumas correntes profundas induzidas pelo vento tranportam sedimentos lateralmente em águas profundas, afetando a distribuição de sedimentos pelágicos, hemi-pelágicos e transportados por correntes de turbidez. Correntes de contorno (que fluem paralelamente aos contornos do talude) transportam sedimentos de fundo pelas margens dos principais oceanos, particularmente nas áreas de sopé continental. Velocidades de correntes de contorno são tipicamente da ordem de 0,01 m por segundo, mas podem atingir 0,1 m por segundo em áreas em que o fluxo é forçado a convergir pela ação da força de Coriolis e da topografia do fundo oceânico. A velocidade e a direção dessas correntes podem variar no tempo em diversas escalas, com por exemplo sazonalmente. Correntes de contorno com velocidades de dezenas de centímetros por segundo podem transportar podem transportar até areia fina, mas correntes ocasionais transportam até partículas mais grossas.Formas de leito incluem ondulações e dunas, mas bioturbação tende a destruir as estruturas resultantes.

Thermohaline Circulation



Hiperpicnitos

Correntes de turbidez relativamente contínuas (com duração de dias ou semanas) podem ocorrer quando águas de rios densas, ricas em sedimentos,adentram um corpo d'água estagnada (mar ou lago), formando uma corrente mais densa que o meio e que flui pelo fundo (fluxo hiperpicnal = mais denso).



Lamb & Mohig (2010)

Figure 1. A: Hypothetical flood hydrograph that generates a hyperpycnal river plume; after Mulder et al. (2003). Once critical concentration is exceeded, turbidity current is expected to mirror rising and falling river discharge, producing an inverse to normally graded bed with sedimentary structures indicating waxing to waning flow. B: Schematic drawing of an event bed. C: Photograph of an event bed from the Pennsylvanian Minturn Formation, Colorado, interpreted to be from a hyperpycnal plume (Lamb et al., 2008; Myrow et al., 2008), showing initial deposition of ripples (r) in very fine sand (vfs), then higher-energy plane bed (p) in fine sand (fs), and finally ripples (r) in very fine sand. Pencil for scale is 14 cm long.

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