



**Università di Trieste**  
**LAUREA MAGISTRALE IN GEOSCIENZE**  
**Curriculum Geofisico**  
**Curriculum Geologico Ambientale**

**Anno accademico 2016 – 2017**

**Geologia Marina**

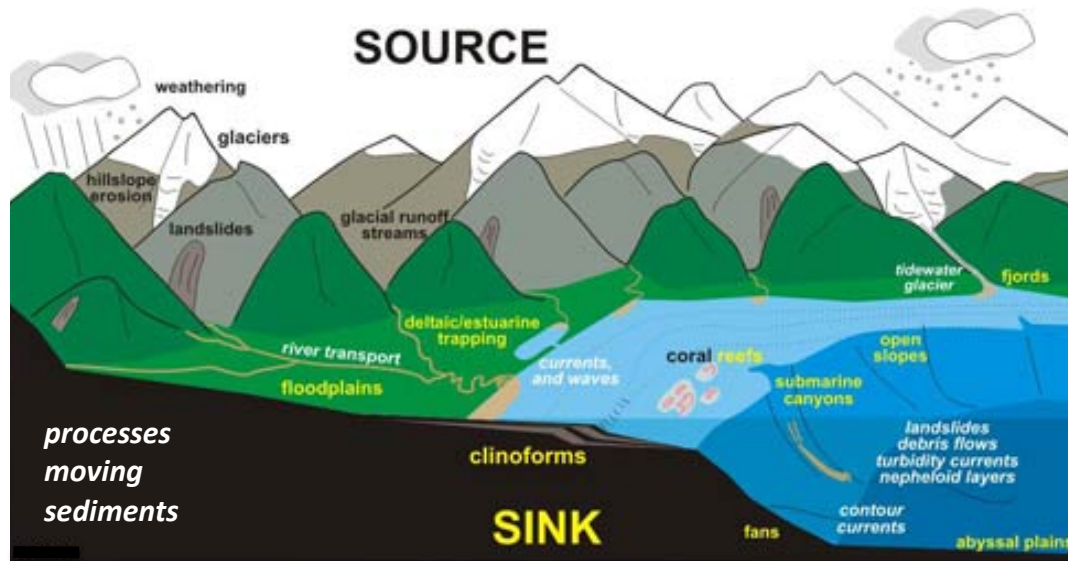
Parte III

**Modulo 3.1 Continental Margin Depositional Processes:  
down-slope processes**

Relatore

**Dr. Renata G. Lucchi**

[rglucchi@ogs.trieste.it](mailto:rglucchi@ogs.trieste.it)



# *the Source to Sink System*

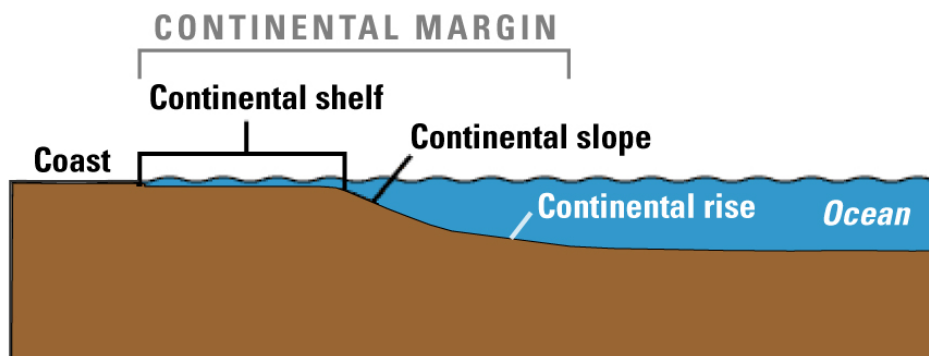


## Sedimentary Processes on Continental Margins

down-slope: driven by gravity forces

along-slope: driven by density forces

(thermo-haline or water mass accumulation)



### Continental shelf

Preferential area of sediment accumulation

High sediment accumulation

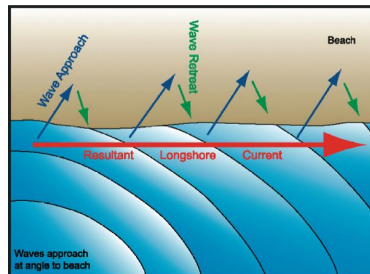
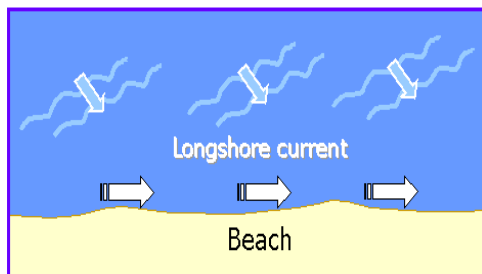
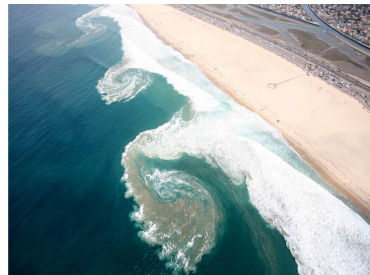
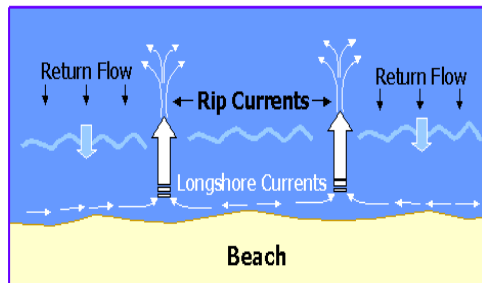
High isostatic subsidence

**Continental slope** sediment deposition and transfer toward deeper environments

**Continental rise**: sediment deposition (deep sea fans, sediment drifts)

# Siliciclastic continental shelves

**Wind/wave dominated shelves**  
e.g. Mediterranean margins (tides  $\leq 3$  m)

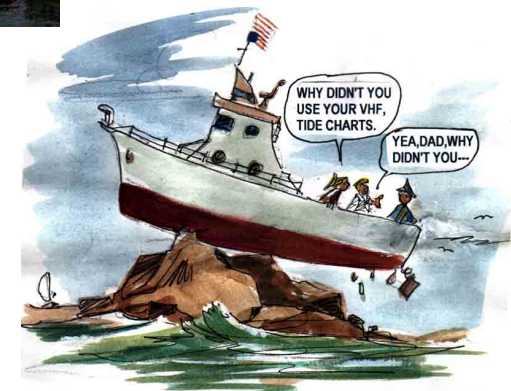


**Tide dominated shelves**  
e.g. North European margins (tides  $\gg 3$  m)

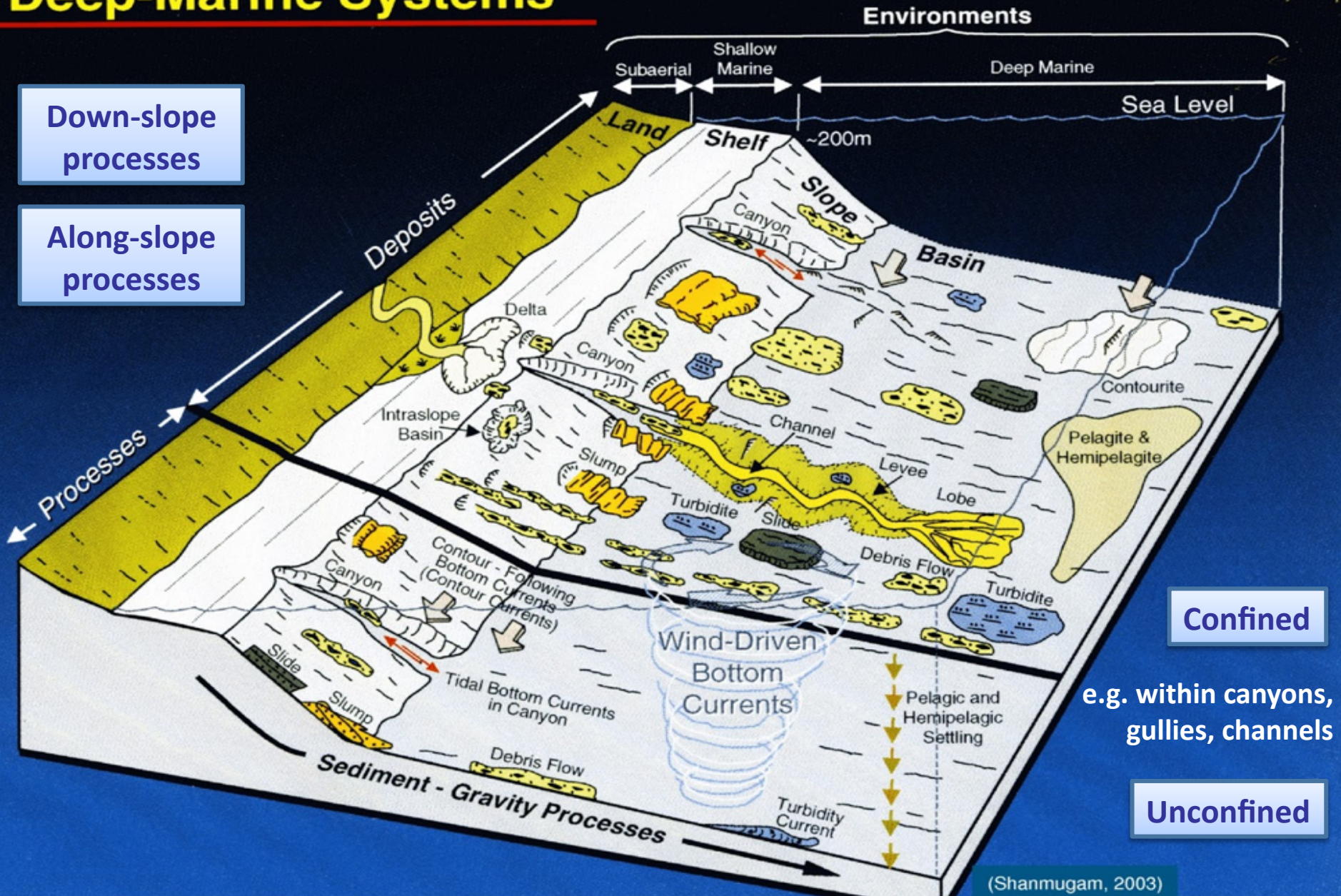


## Other sedimentary/biological processes

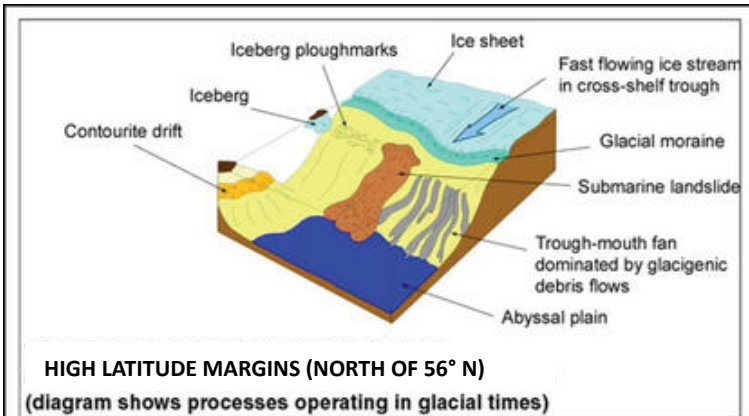
- Storms sediment resuspension
- sediment bioturbation
- Surface and bottom turbidity currents associated to river output (Hypopycnal and Hyperpycnal flows on deltas and prodeltas)
- Incursions of surface ocean currents on the outer shelf



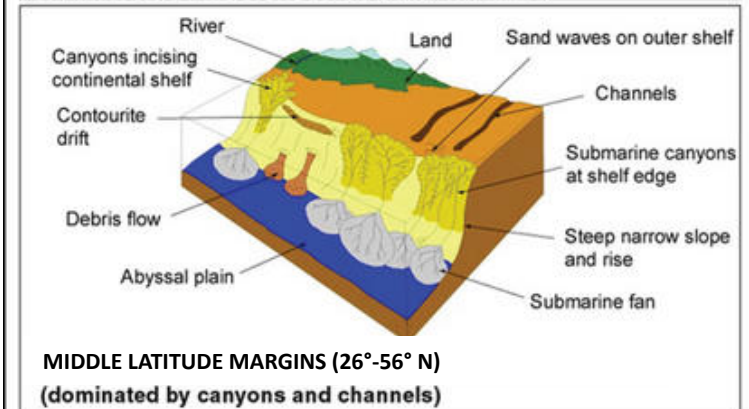
# Deep-Marine Systems



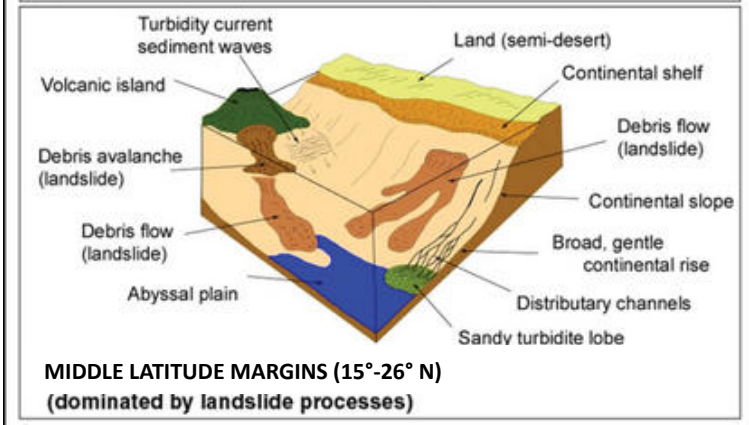
Glacial processes



River processes



Starving areas



# Sedimentary processes on Continental Margins

Depositional process → **Deposit**

down-slope processes:  
driven by gravity forces

- » Mass Transport Deposition → **MTDs**
- » Turbidity currents → **Turbidites**
- » Riverine outflows → **Hyper (Hypo)-picnites**
- » Turbid meltwaters → **Plumites**
- » Brine-related deposition

along-slope: driven by density forces (thermo-haline origin)

- » Contour currents → **Contourites**

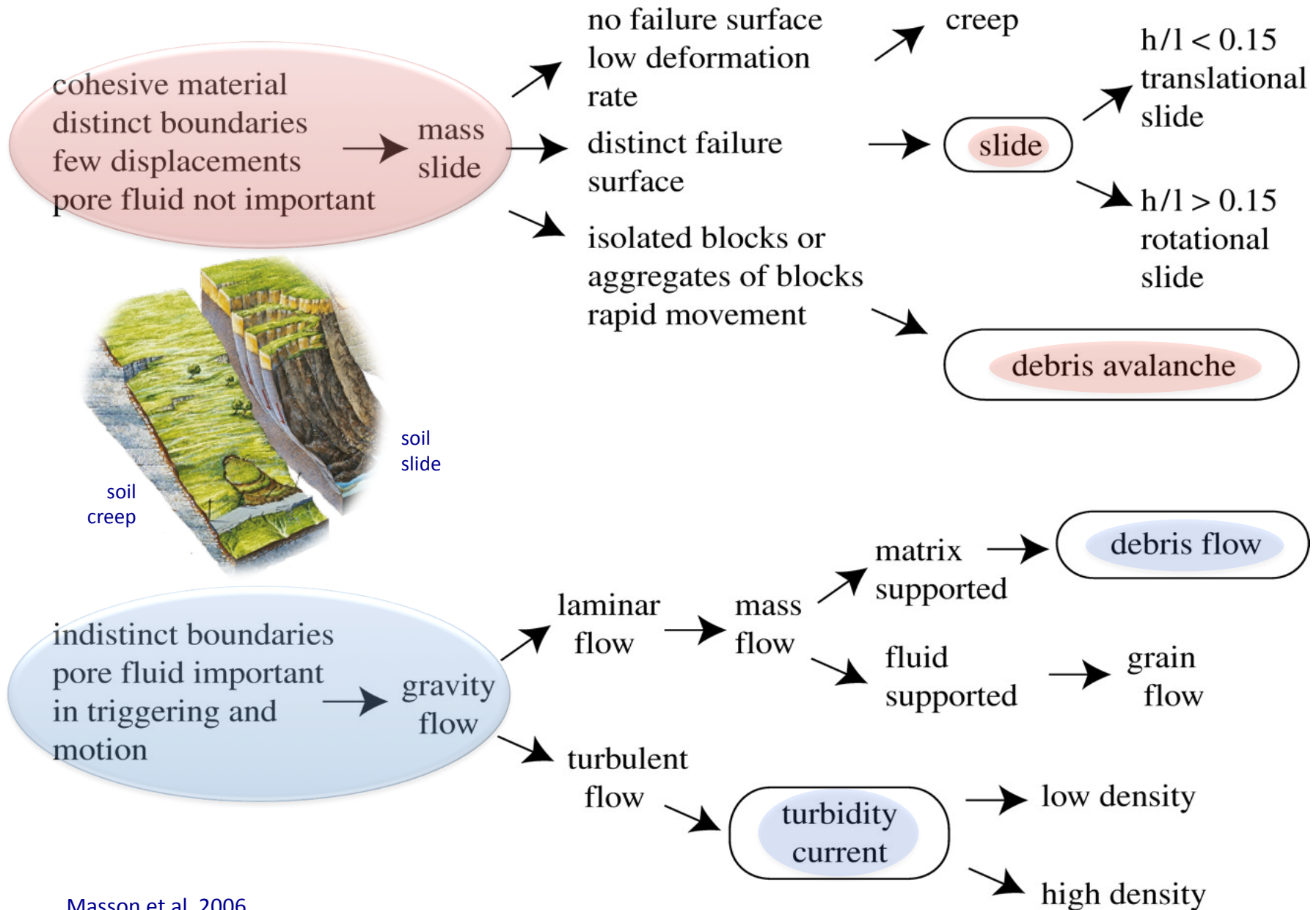


## Classification of MTDs (Mass Transport Deposits):

- Rheology (sediment deformation)
- Sediment mass mechanism of support (gravity, flow turbulence, grains interaction)
- Physical properties of the mass flow and deposit (sediment disturbance, shear strength, etc.)
- Morphological characteristics of the deposit

### References:

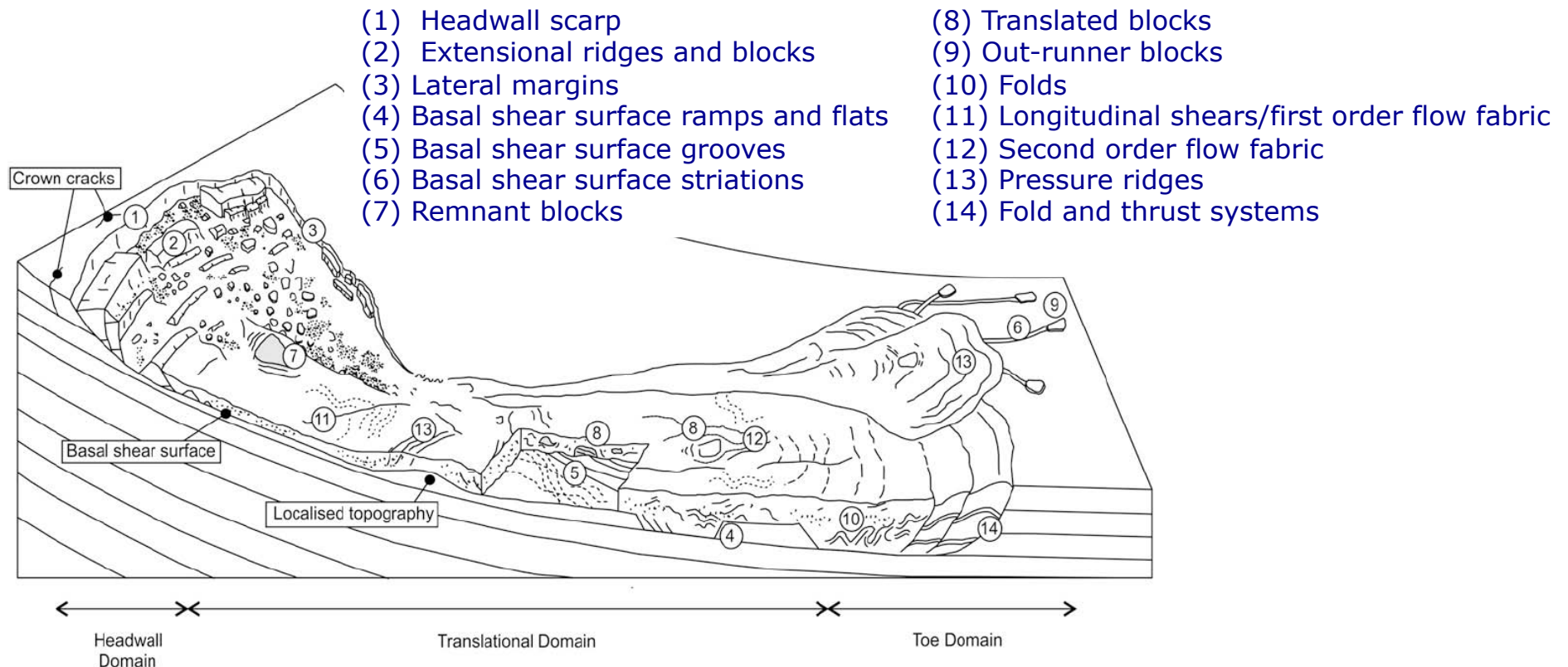
- Dott R. H., 1963. Dynamics of subaqueous gravity depositional processes. AAPG Bulletin, 47, 1, pp. 104-128.
- Lowe, D.R., 1982, Sediment gravity flows II. Depositional models with special reference to the deposits of high-density turbidity currents: Journal Sed. Petrology, 52, pp. 279-297.
- Prior, D.B. (1984). Submarine landslides. Proceedings of the IV International Symposium on Landslides, Toronto, Vol. 2, pp. 179-196.
- Norem, H., Locat, J. and Schieldrop, B. (1990). An approach to the physics and the modelling of submarine landslides. Mar. Geotech., 9, 93-111.
- Martinsen, O. (1994). Mass movements. in: The geological deformation of sediments, (A. Maltman Ed.), Chapman and Hall, London, pp. 127-165.
- Mulder, T. and Cochonat, P. (1996). Classification of offshore mass movements. J. Sediment. Res., 66, 43-57.
- Masson, D.G., Harbitz, C.B., Wynn, R.B, Pedersen, G., Lovholt, F. (2006). Submarine Landslides: processes, triggers and hazard prediction. Phil. Trans. R. Soc. A, 364, pp 2009-2039.



## Complexity:

Once failure initiates, the event may **progress by means of a number of mass movement processes**. Although various subdivisions and classification schemes for these processes exist, each process represents part of a continuum, whereby one type may evolve into or trigger another.

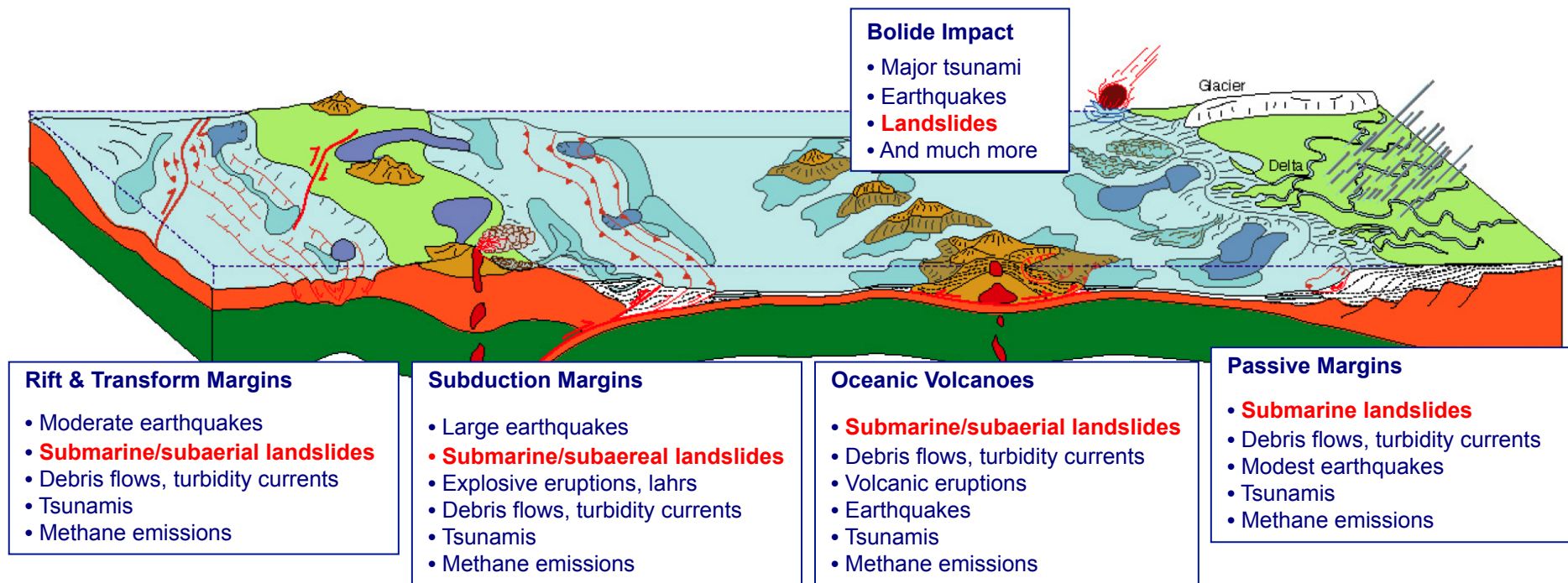
Many submarine slope failures are likely to have involved a number of processes, possibly active at different stages of failure. Therefore, it is common that the depositional units resulting from submarine mass movements are defined as '**Mass-Transport Complexes (MTC)**'.





## Submarine slides/slumps

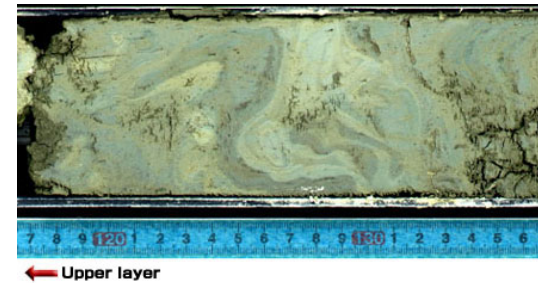
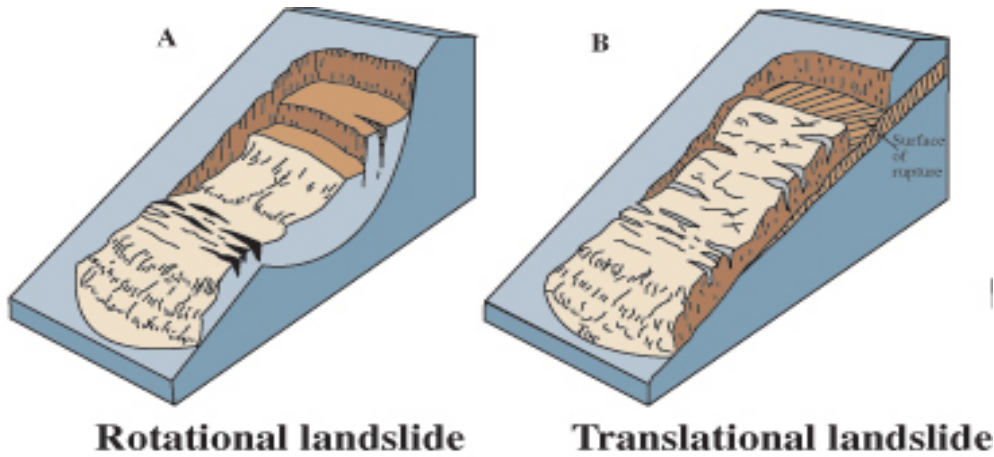
They are **ubiquitous** features of submarine slopes in all geological settings and at all water depths, particularly in areas where fine grained sediments predominate.



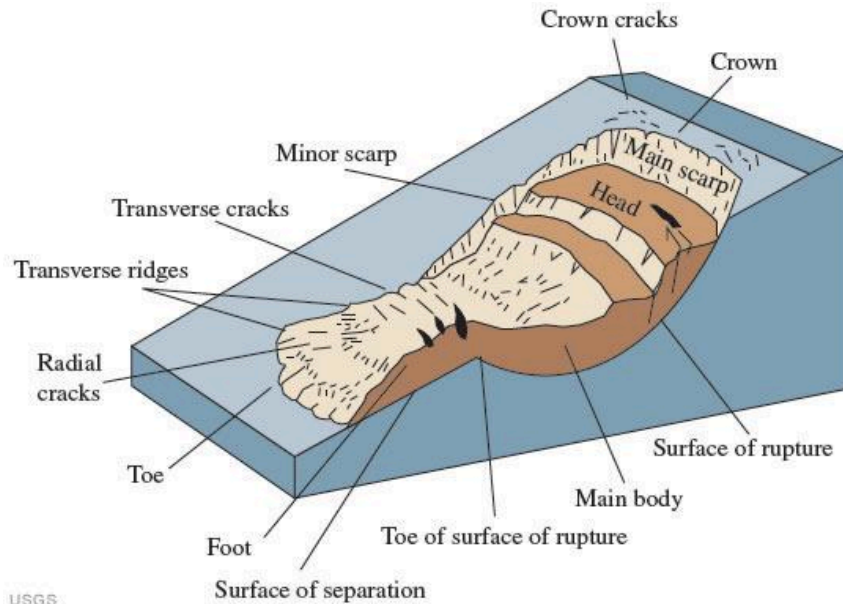
Adapted from Morgan et al., 2009. *Scientific Drilling*, available at: <http://www.iodp.org/geohazards/>

# Submarine slides/slumps

Number of Skempton  
height of slide/length of slide  $\begin{cases} < 0.15 \text{ SLIDE} \\ > 0.15 \text{ SLUMP} \end{cases}$



Small slump  
In sediment  
core

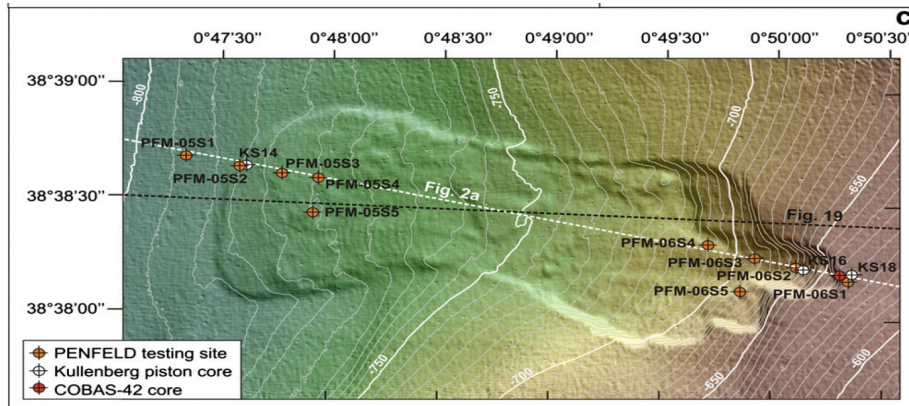
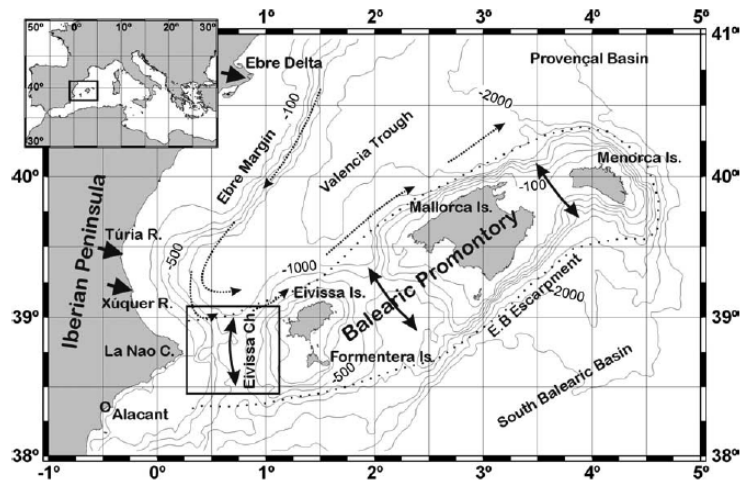


USGS

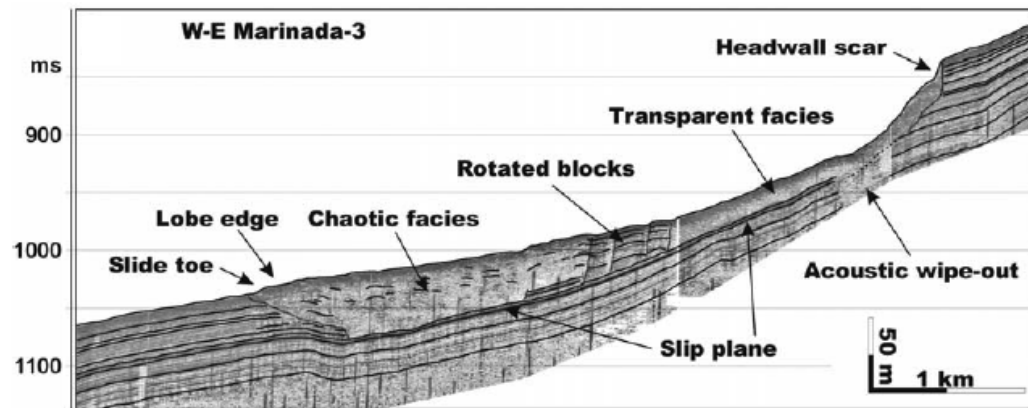


Pleistocene Submarine Landslides in the Boso Peninsula, Japan

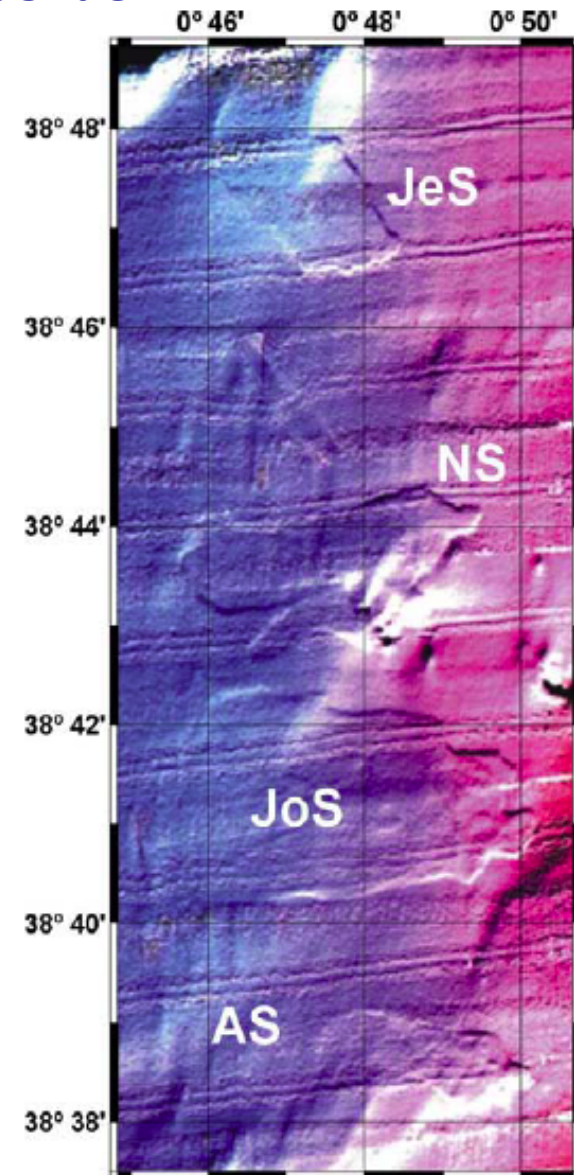
# Ana submarine landslide Ibiza Channel Western Mediterranean



Multibeam



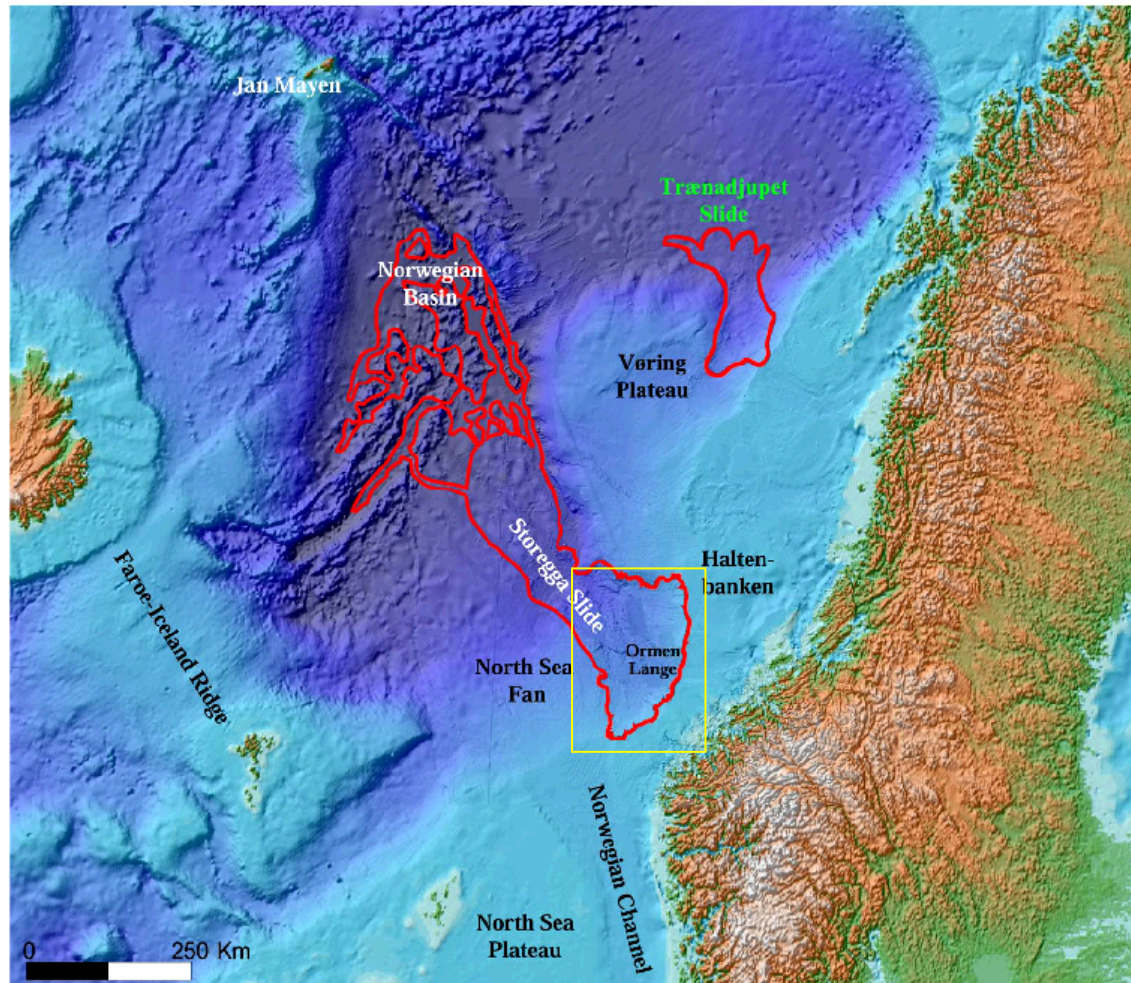
Sub-bottom



Lastras et al., 2004 Sedimentology

# STOREGGA SUBMARINE LANDSLIDE, NORWAY

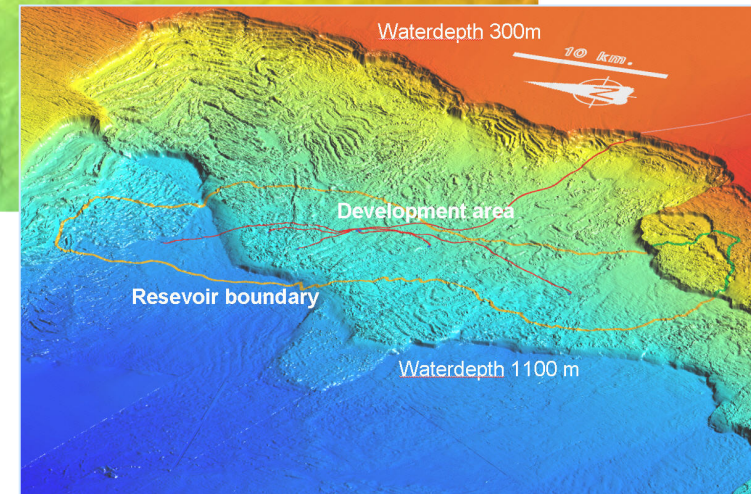
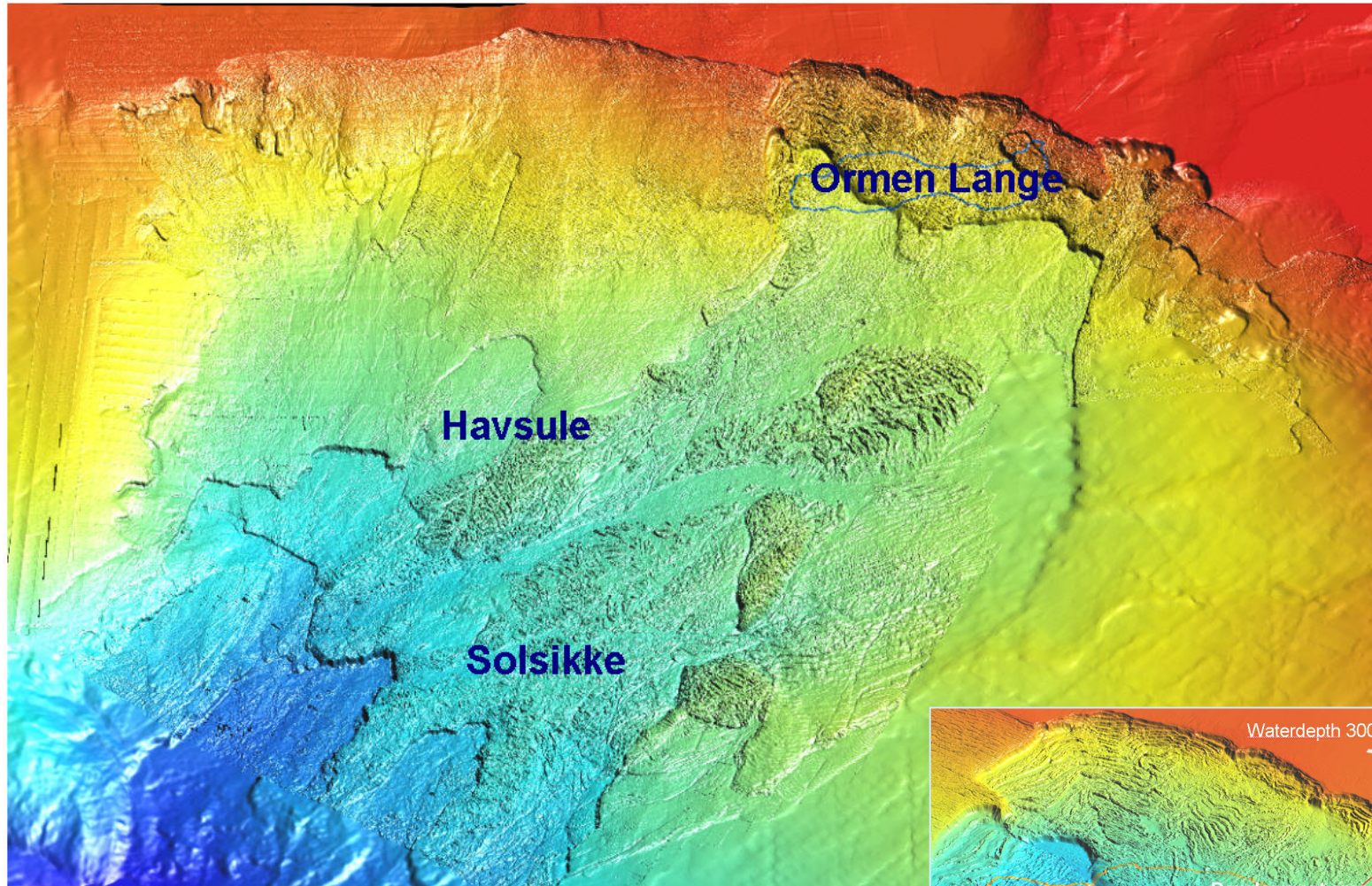
8000 y BP  
3500 km<sup>3</sup> of debris



Courtesy Petter Bryn

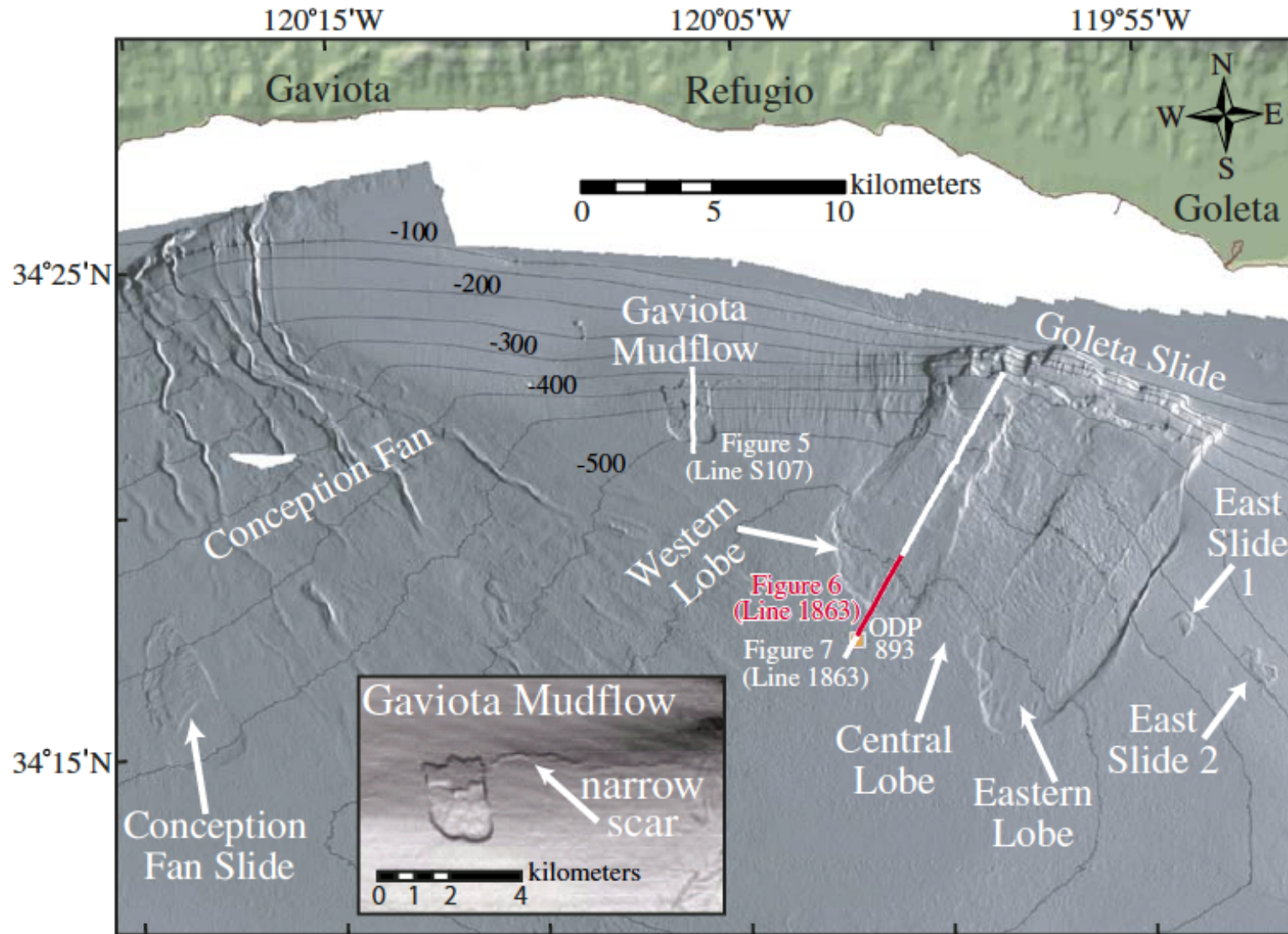


Norsk Hydro  
E&D Norway  
Geophysical Operations

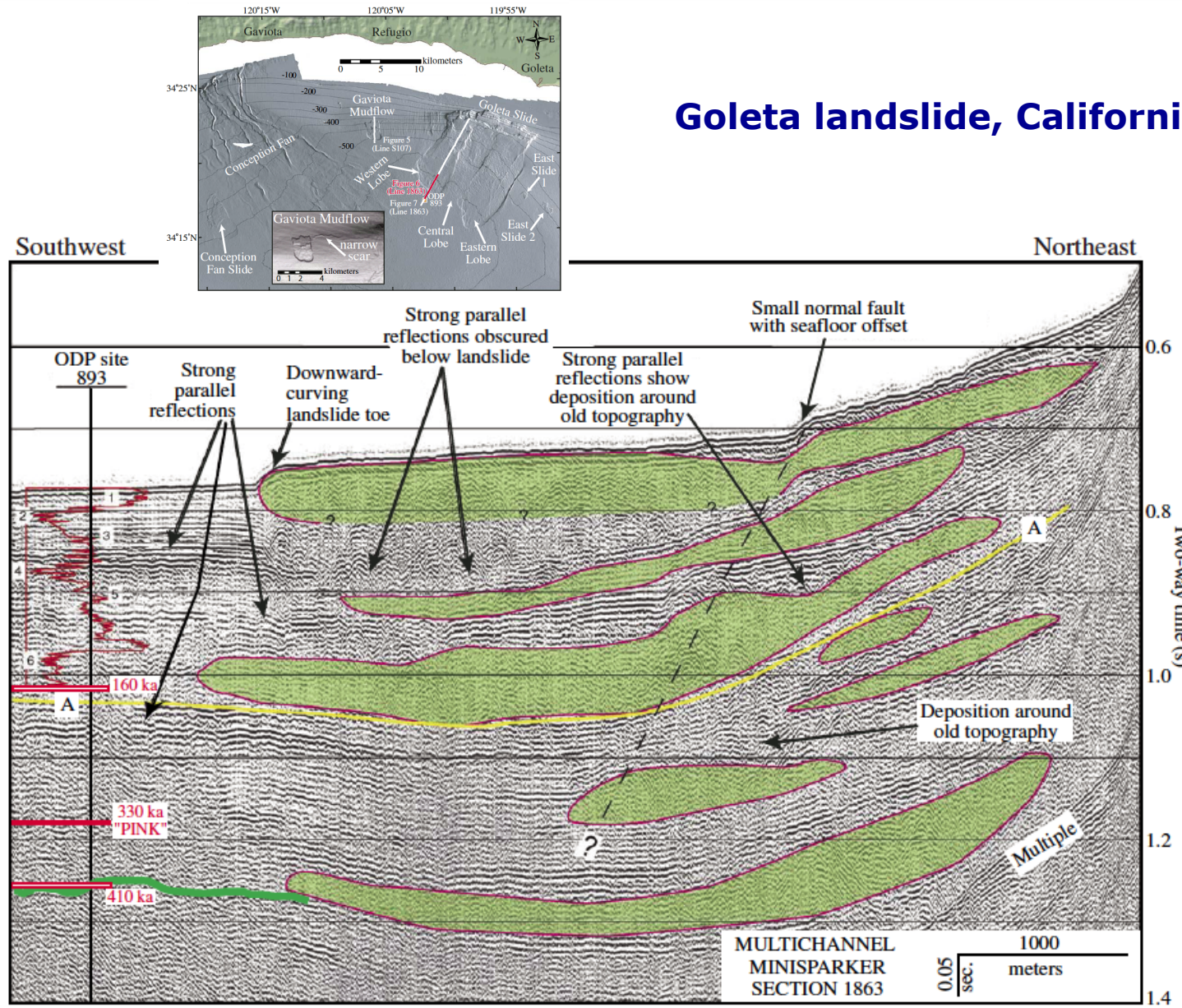


## STOREGGA SUBMARINE LANDSLIDE

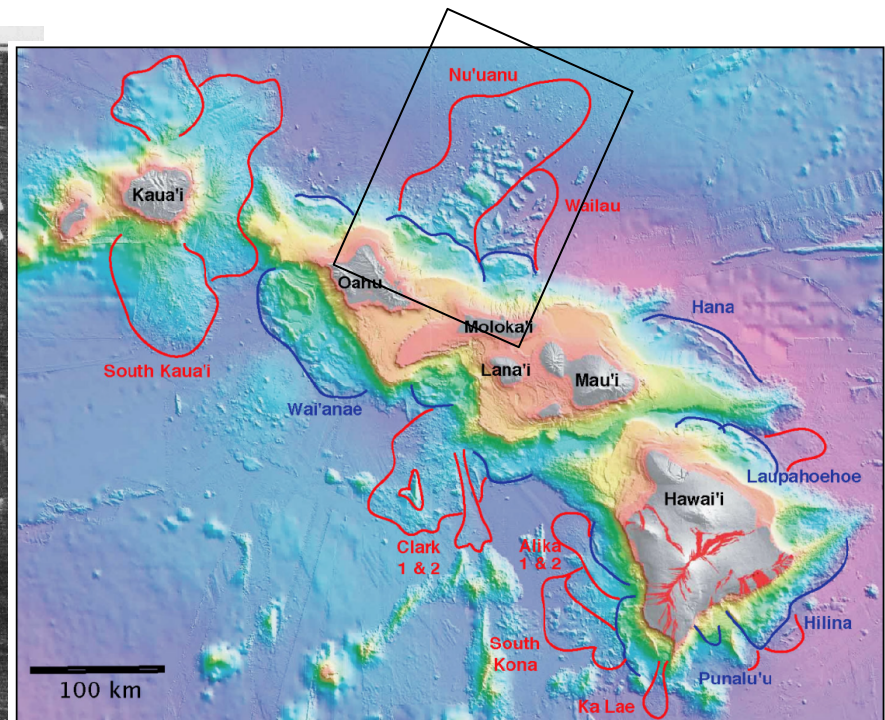
## Goleta landslide, California



# Goleta landslide, California



Deep penetration seismics  
2D Sparker



Morgan et al., 2009. Scientific Drilling

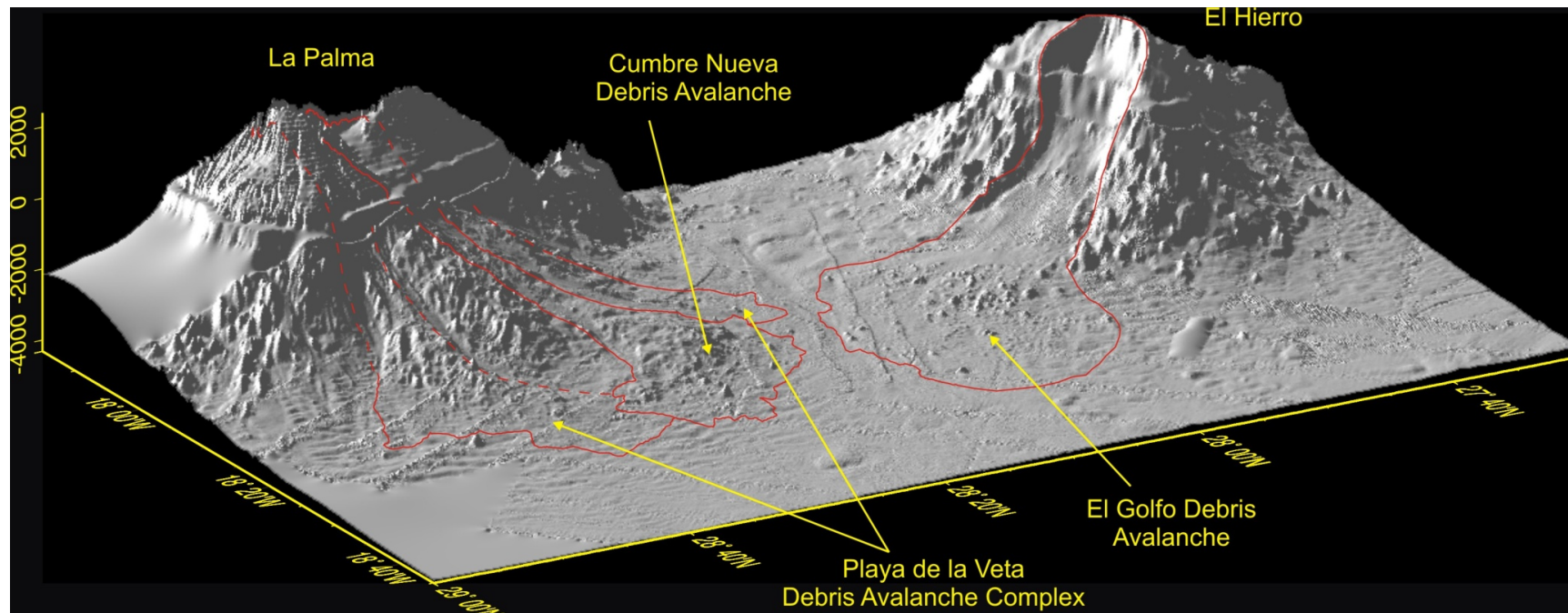
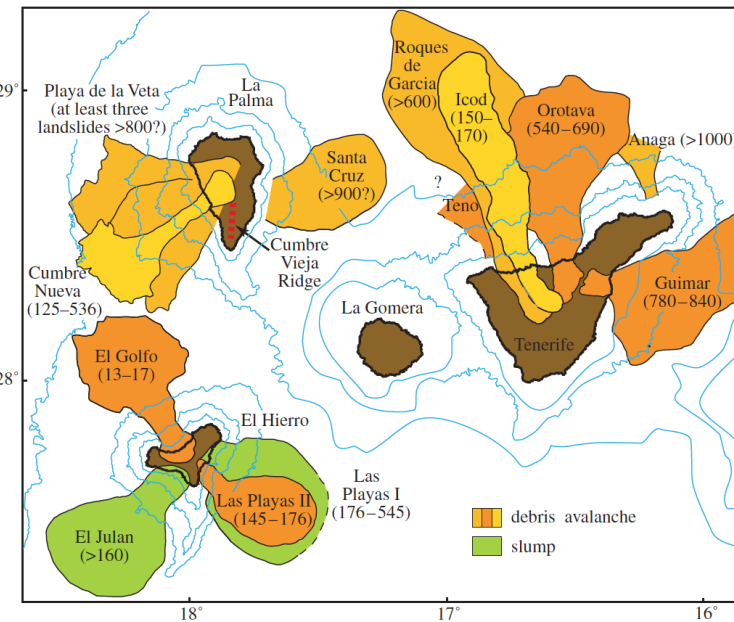
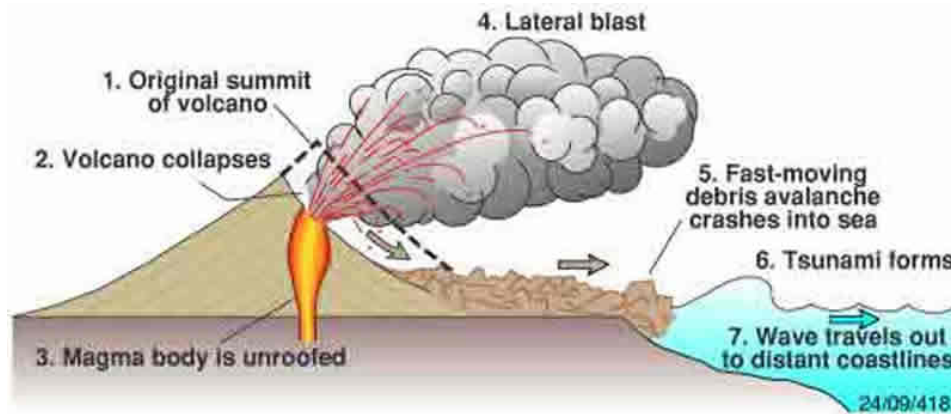
**Submarine  
debris avalanches**

**Volcanic Island Margins  
Hawaii**

Moore et al., 1994. JGR

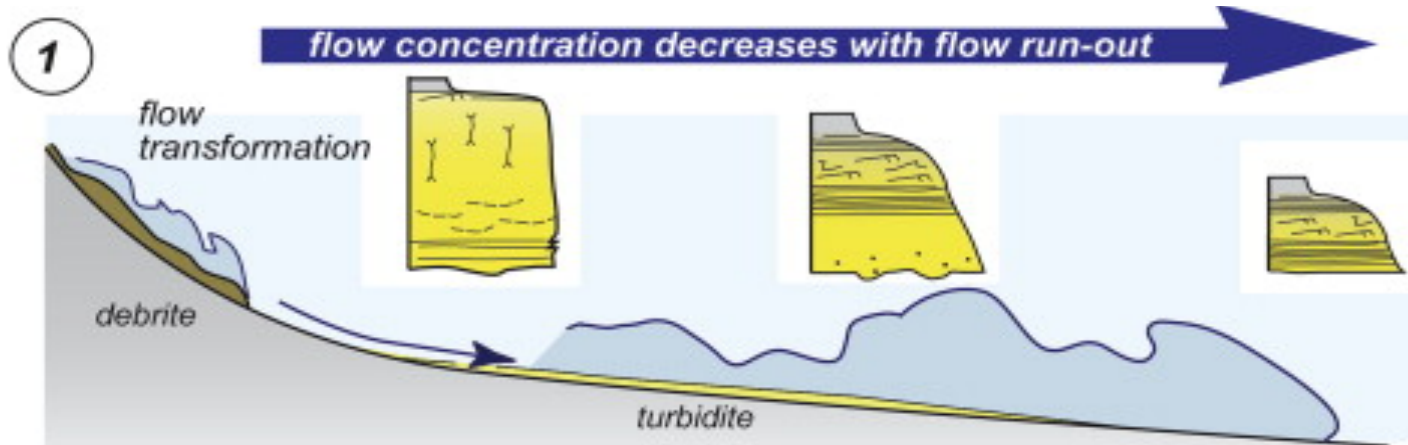
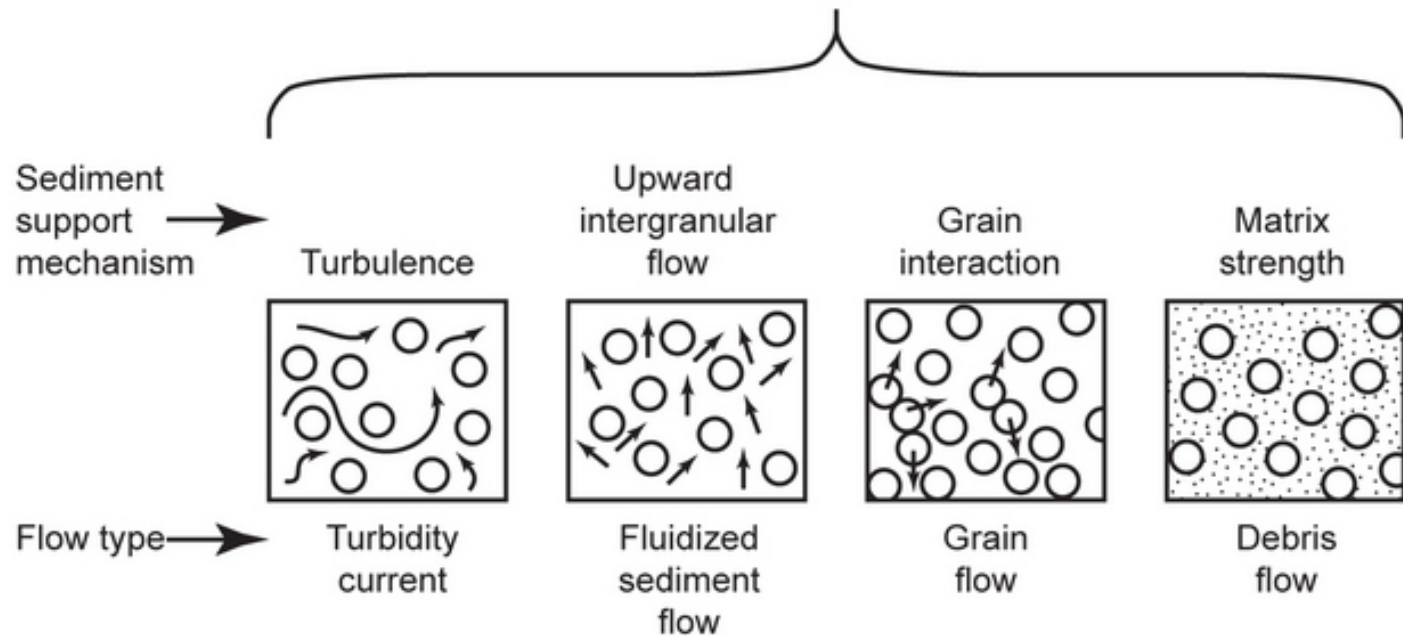


# Volcanic Island Margins Canarie





# Gravity flows

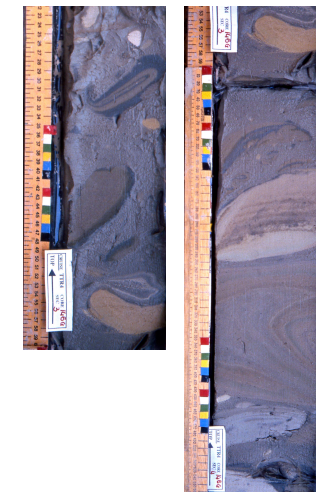
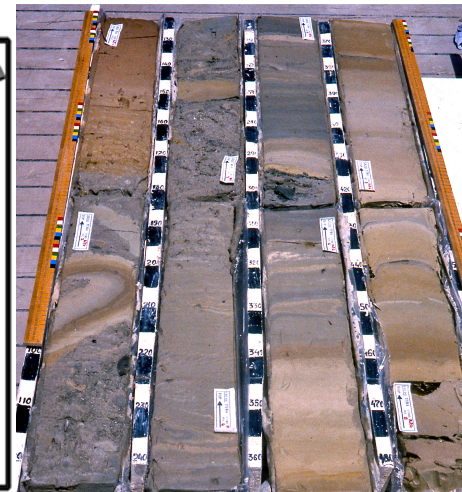
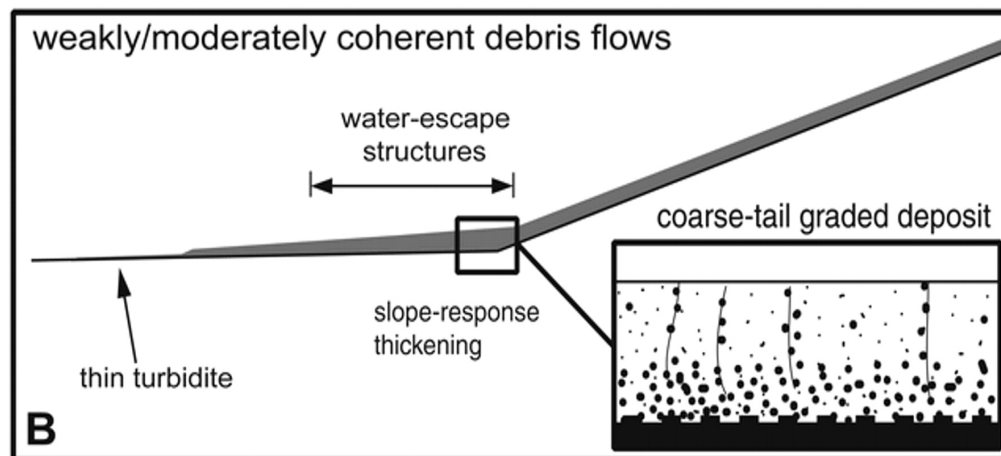
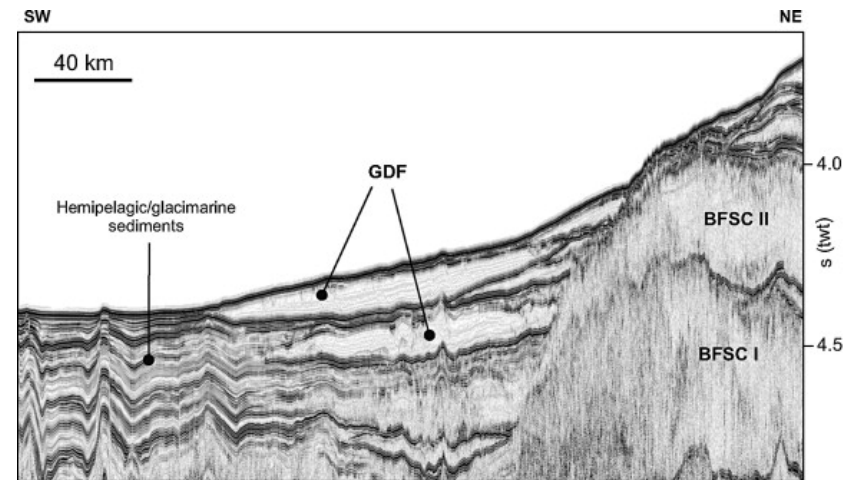
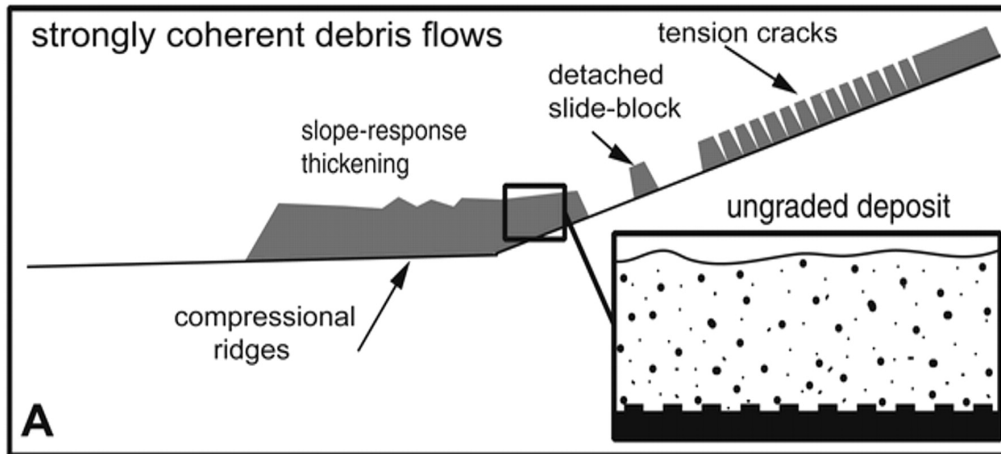


# Debris flows

Laminar flux supported by the water-rich muddy matrix

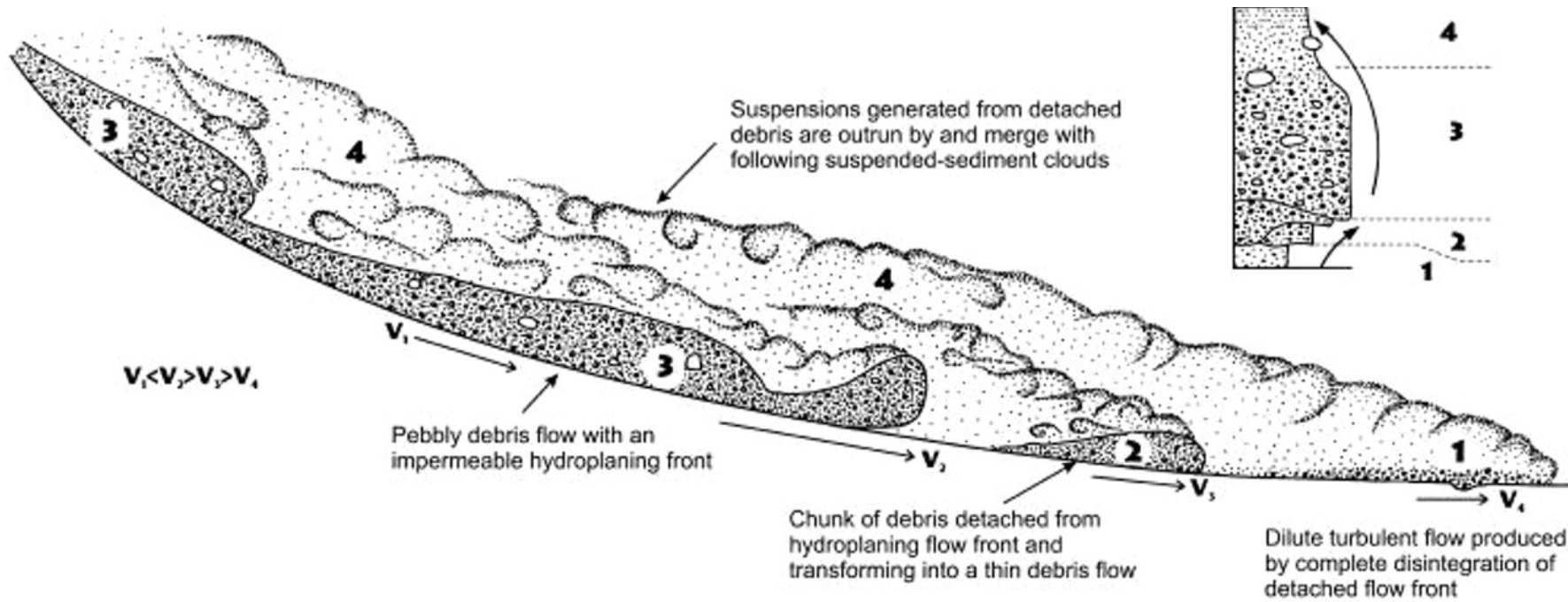
**Debris flow:** mud/sand >1; pebbles >5%

**Mud flow:** mud/sand <1; pebbles <5%

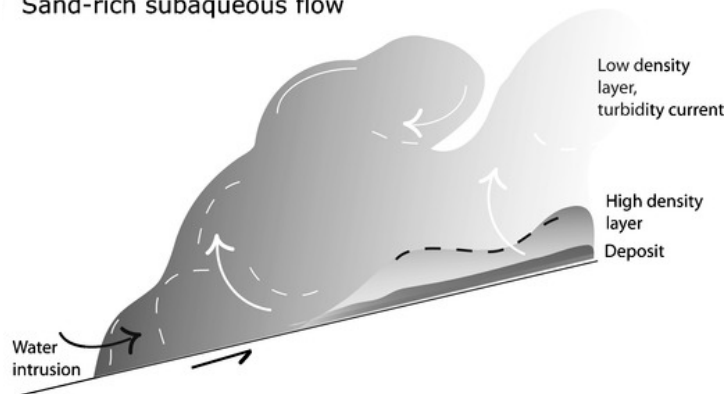


# Hydroplaning

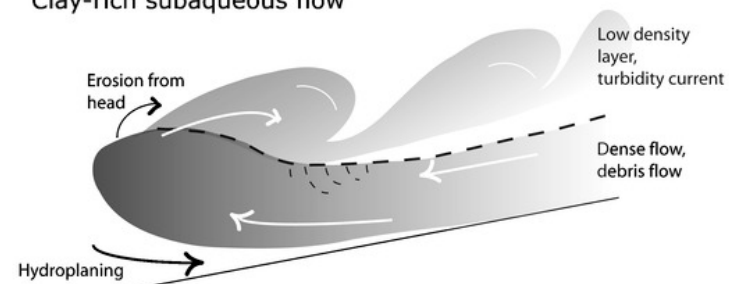
Debrisites were found some hundreds km away from the continental margin



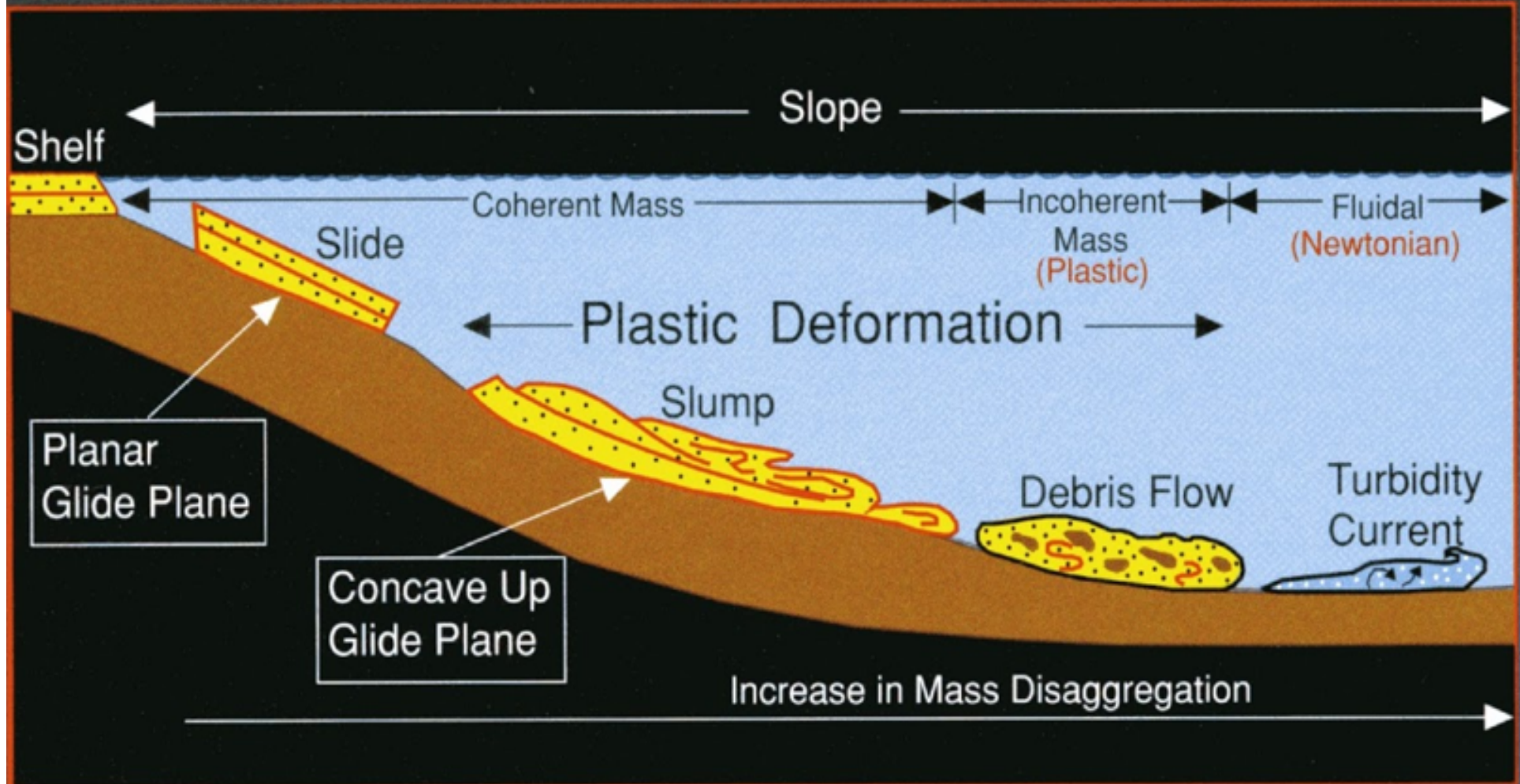
Sand-rich subaqueous flow



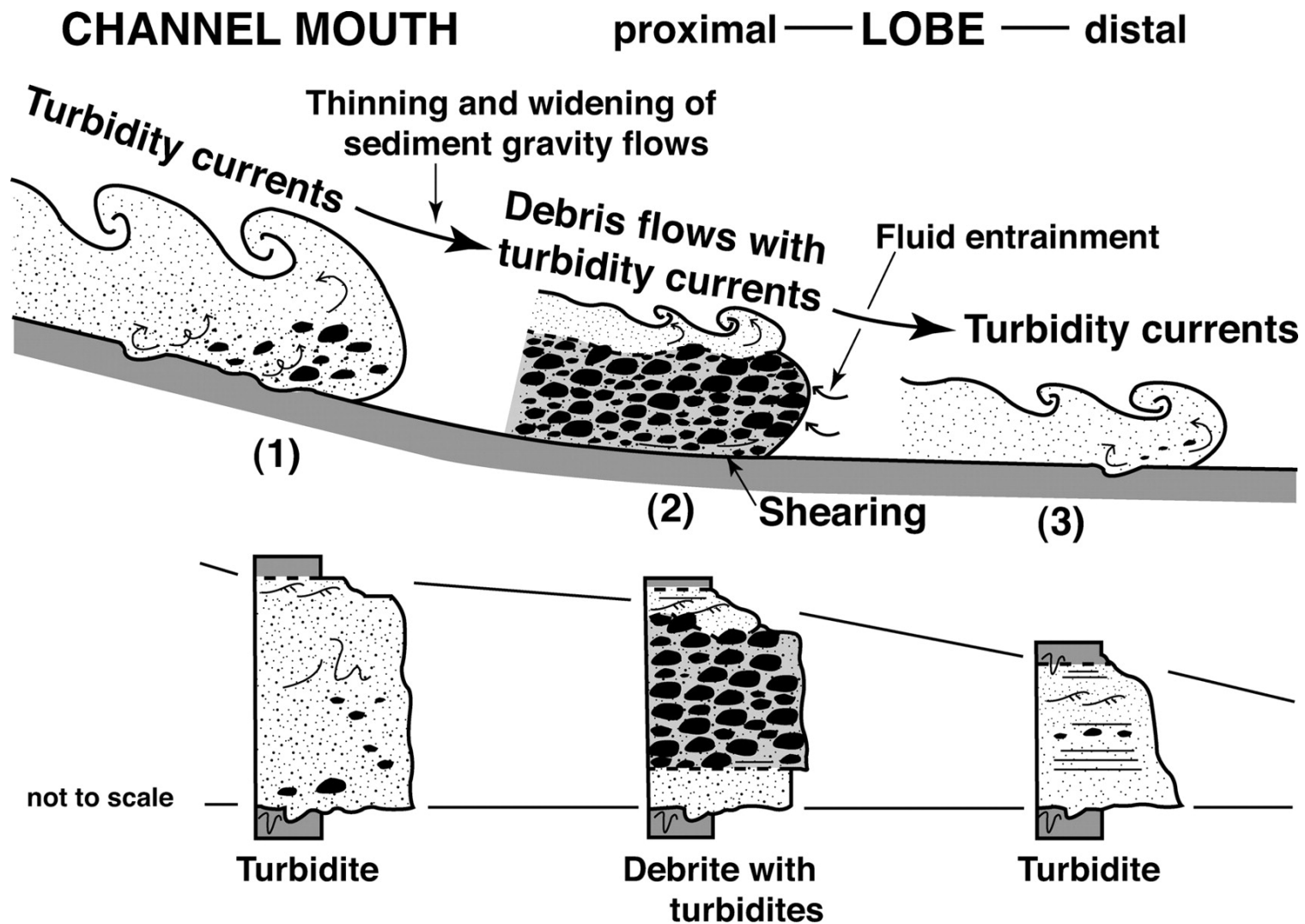
Clay-rich subaqueous flow

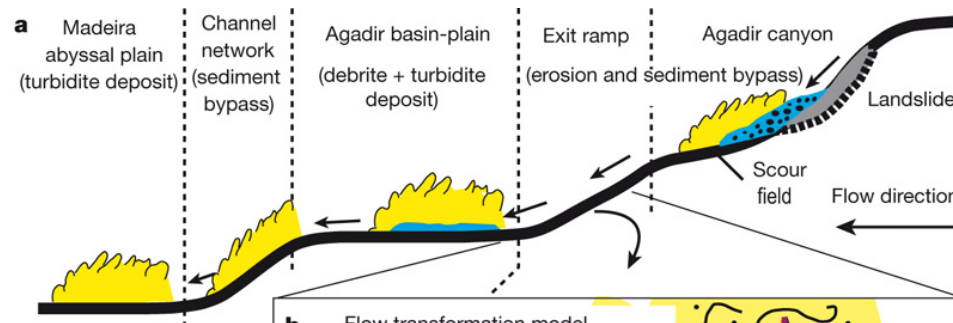
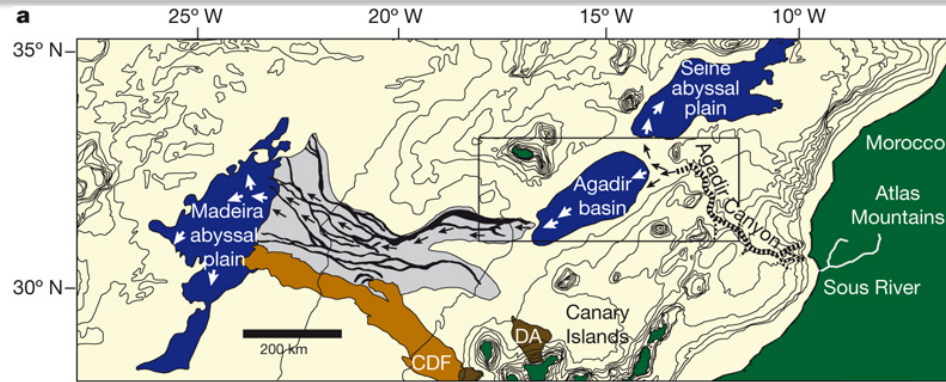


# Gravity-Driven Downslope Processes in Deep Water

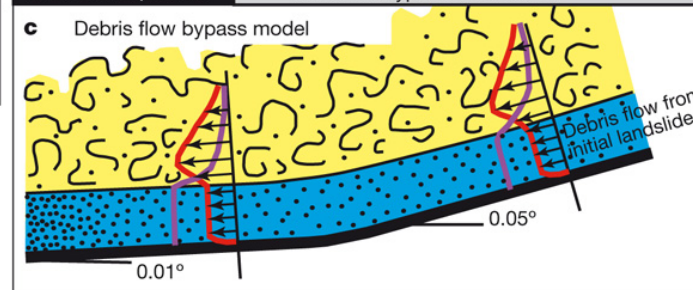
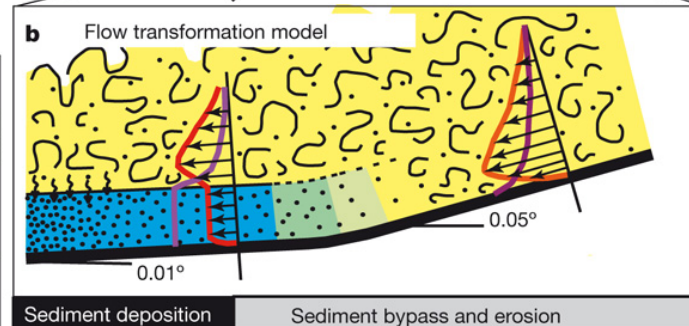


# Linked debrite Debrites incorporated in turbidites



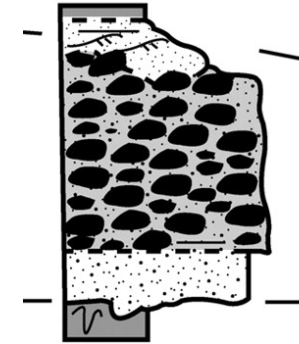
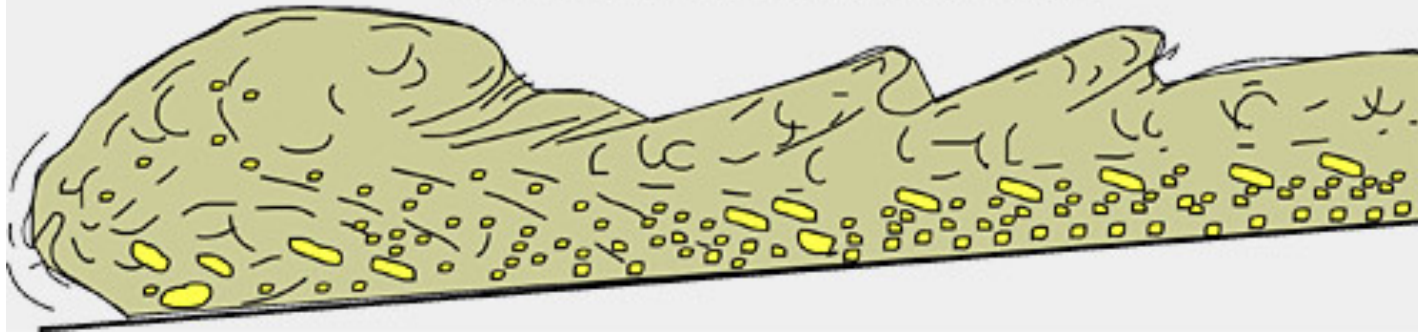


- Turbidity current (sediment supported mainly by turbulence)
- Debris flow (sediment supported mainly by mechanisms other than turbulence, although flow can be weakly turbulent)
- Density profile
- Velocity profile



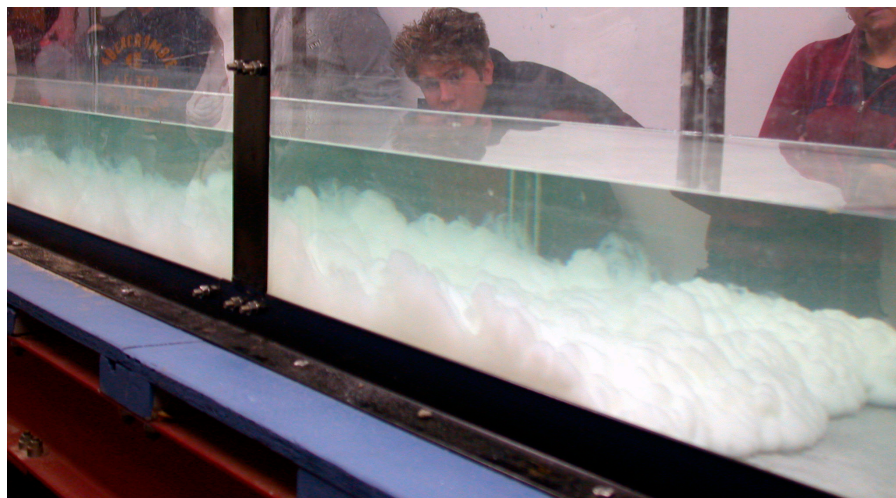
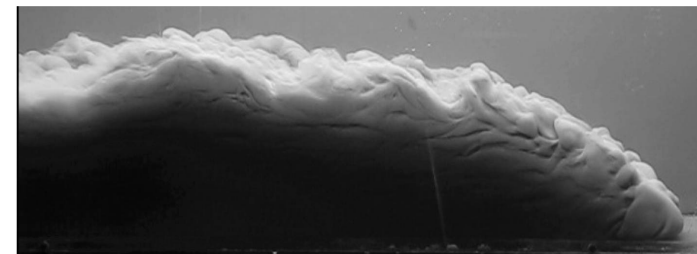
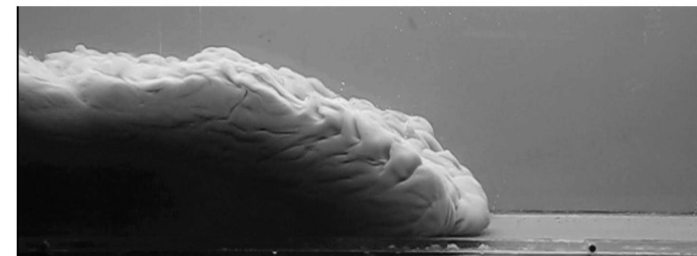
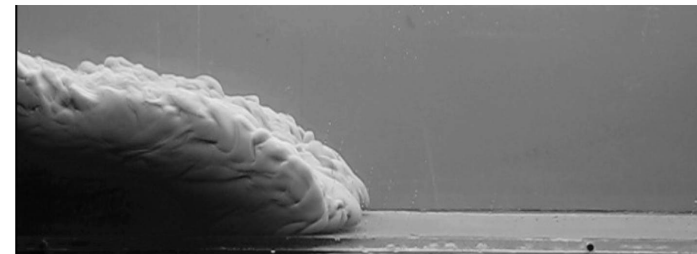
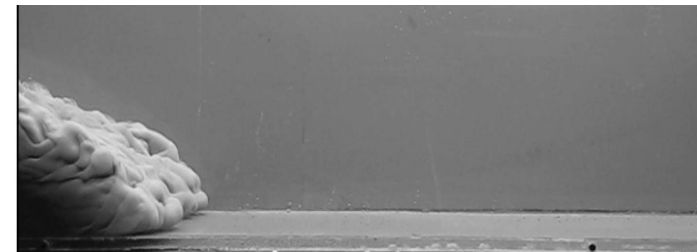
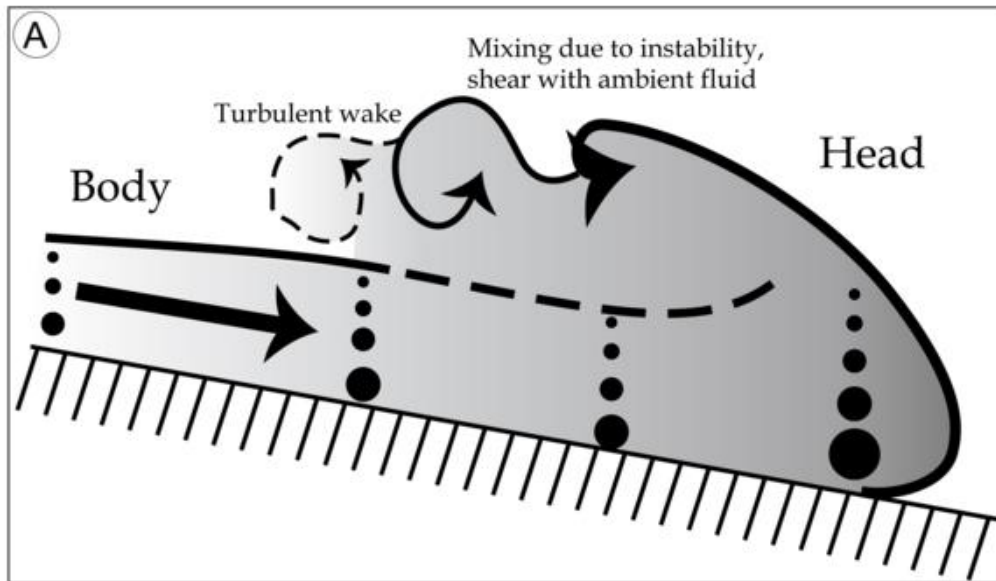


## High-Density Turbidite Flow



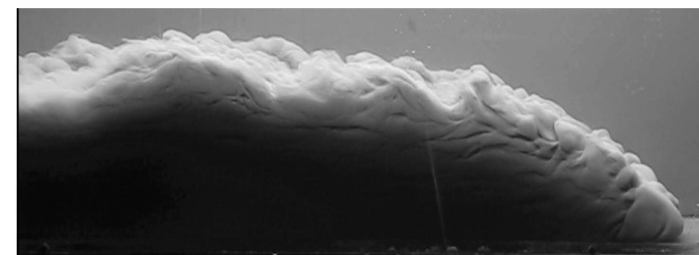
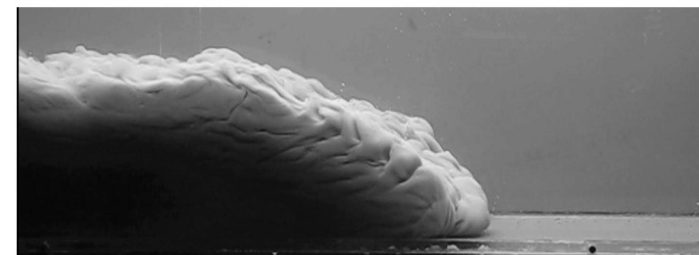
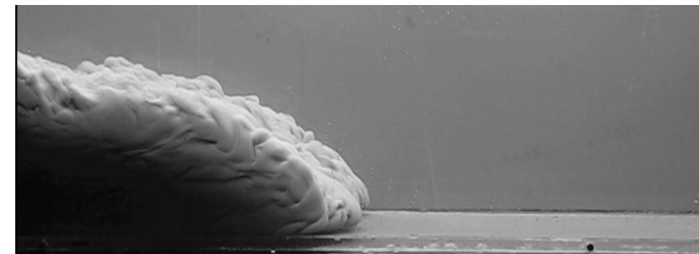
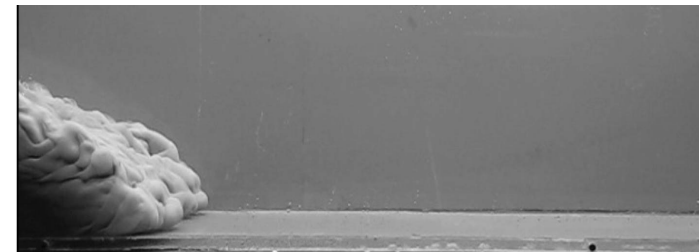
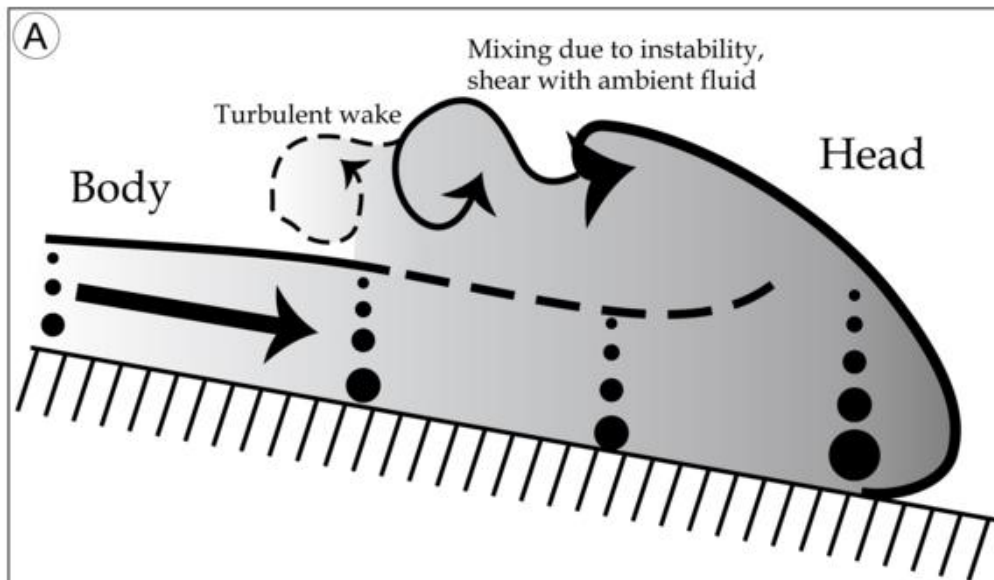
# Turbidity flows

Density currents in which the granular support is maintained by the vertical component of the turbulent flux



## Turbidity flows

Density currents in which the granular support is maintained by the vertical component of the turbulent flux



### TYPE OF EVENT

Long steady flow (e.g. river fed)  
Short surge-type (e.g. river floods, slope instability)

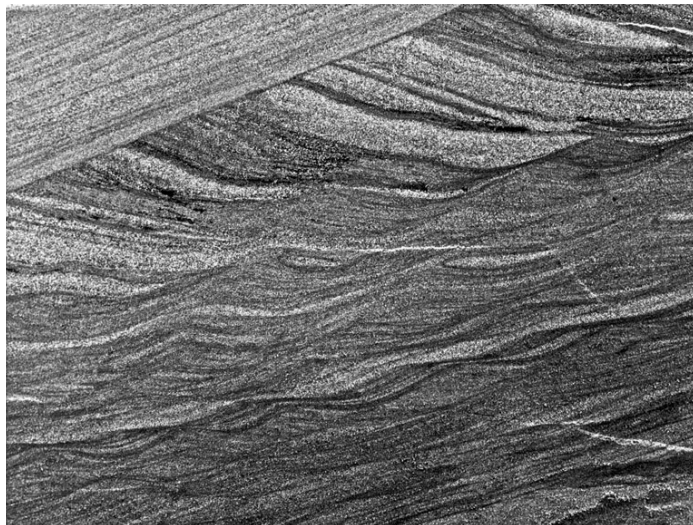
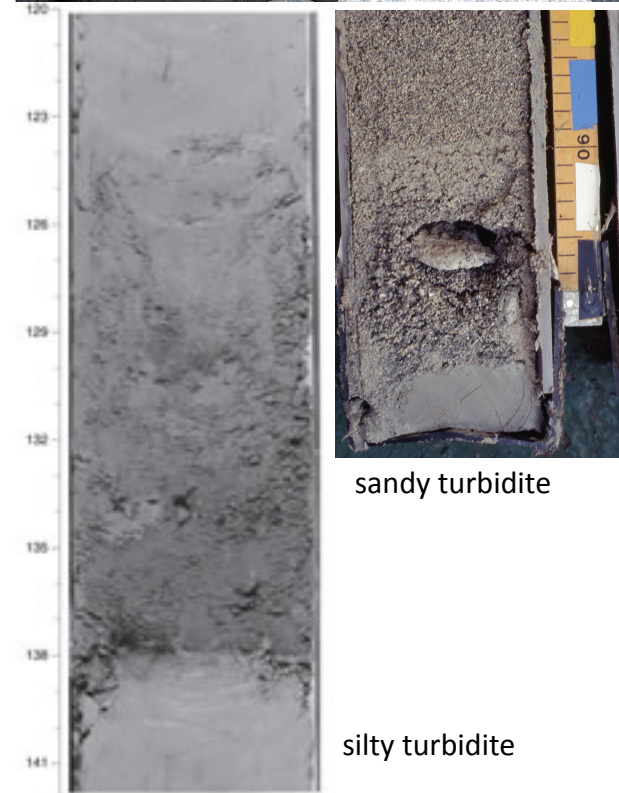
### FLOW DENSITY

High density (higher velocity)  $>1.1 \text{ g/cm}^3$   
Low density (lower velocity)  $<1.1 \text{ g/cm}^3$

### FLOW TRANSFER

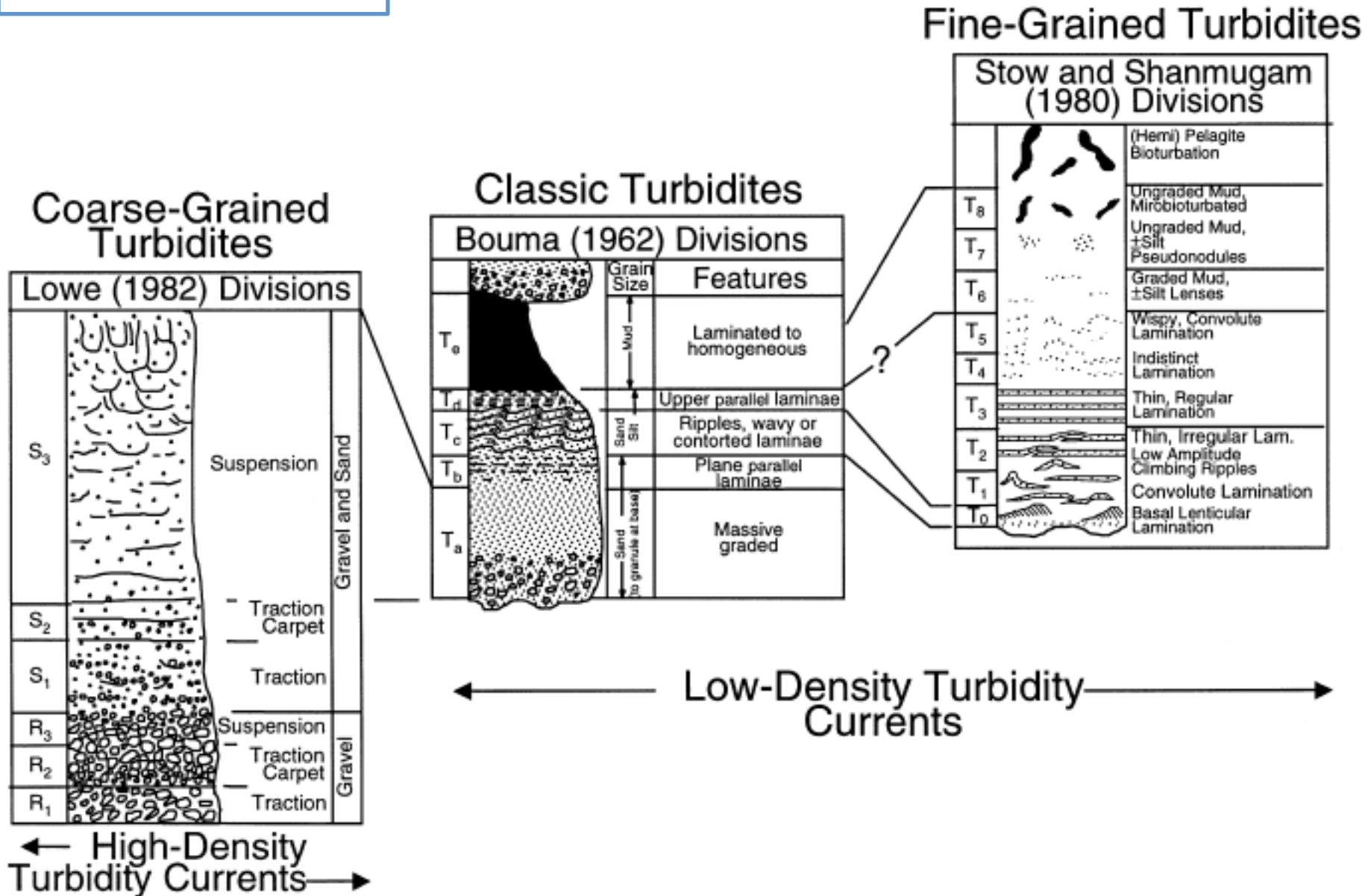
Confined (canyon, channel, levee, deep-sea fan)  
Unconfined

GRAIN SIZE	BOUMA (1962) DIVISION	INTERPRETATION
Silt	D - Upper mud/silt laminae	Shear sorting of grains and flocs
Sand	C - ripples, climbing ripples wavy or convolute laminae	Lower part of lower flow regime of Simons et al. (1965)
	B - plane laminae	Upper flow regime plane beds
Coarse sand	A - structureless or graded sand to granule	Rapid deposition with no traction transport possible quick (liquefied) beds

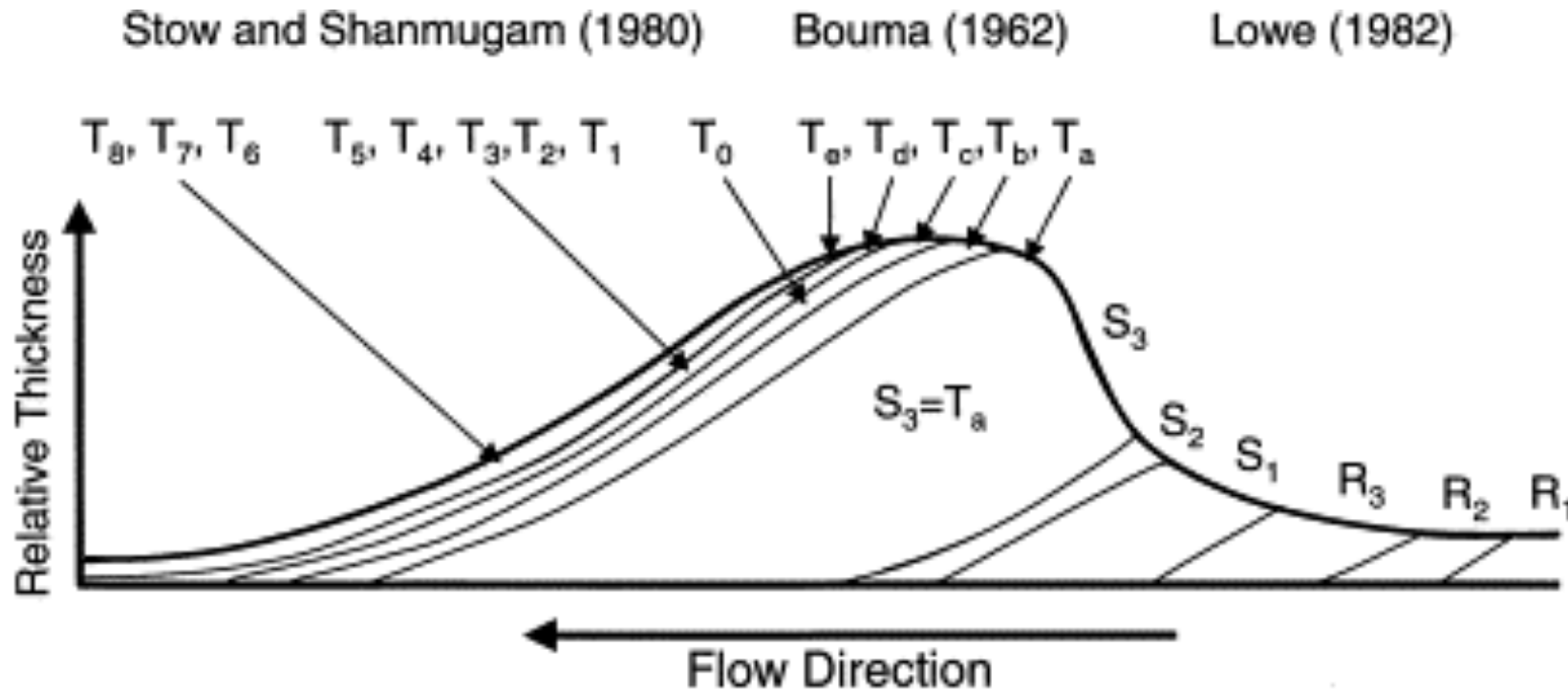


(after Pickering et al., 1989)

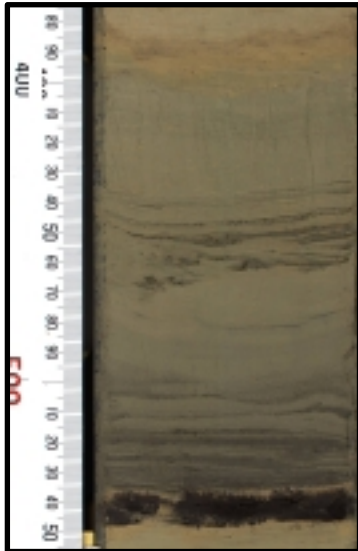
# Turbidite facies



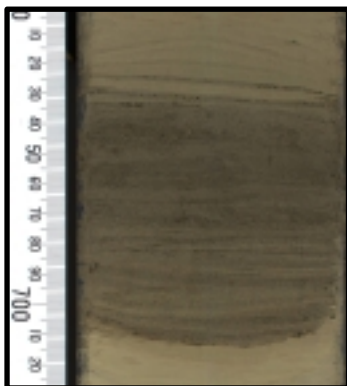
## LOW DENSITY turbidity flows



- Shanmugam, G., 2000. 50 years of the turbidite paradigm (1950s-1990s): deep-water processes and facies models – a critical perspective. *Marine and Petroleum Geology* 17, 285-342.
- Kevin Pickering, Richard Hiscott, 2014. *Deep Marine Systems: Processes, Deposits, Environments, Tectonic and Sedimentation*. Wiley-Blackwell, ISBN: 978-1-4051-2578-9, 776p.

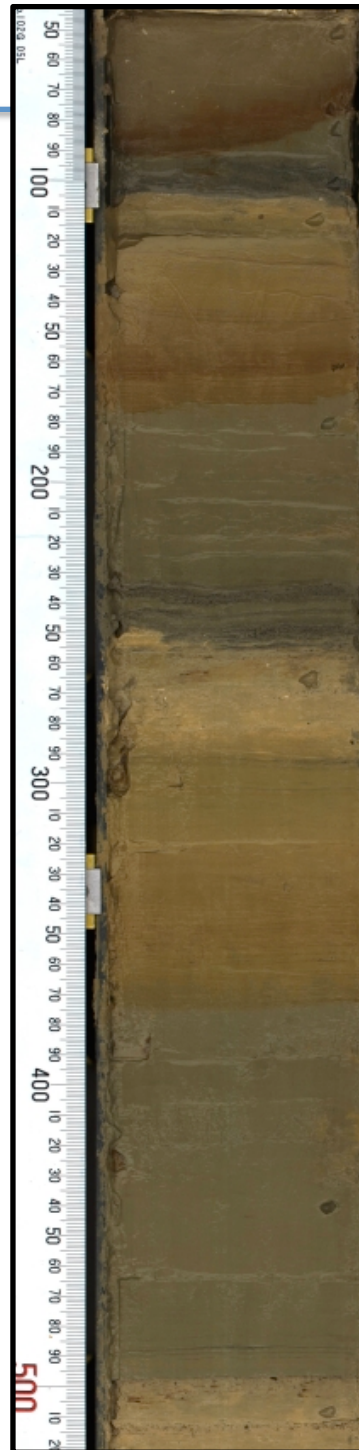


silty turbidites



sandy turbidite

muddy turbidites



silty turbidite







## **MOST COMMON FEATURES**

- « Sharp base characterized by sharp grain size change often with sharp color change (careful with sediment oxidation)
- « Planar laminations
- « Bioturbated top

## **INDICATION OF SHEAR SORTING**

Grain size and compositional sorting through the deposit. Sorting occurs according to size and specific weight e.g. large forams with medium-size quartz with small-size pyroxene)

## **COMPOSITION**

Presence of alloctonous particle e.g. shelf derived particle in deep-sea environments (typically bryozoa, autigenic glauconite)



## **MOST COMMON FEATURES**

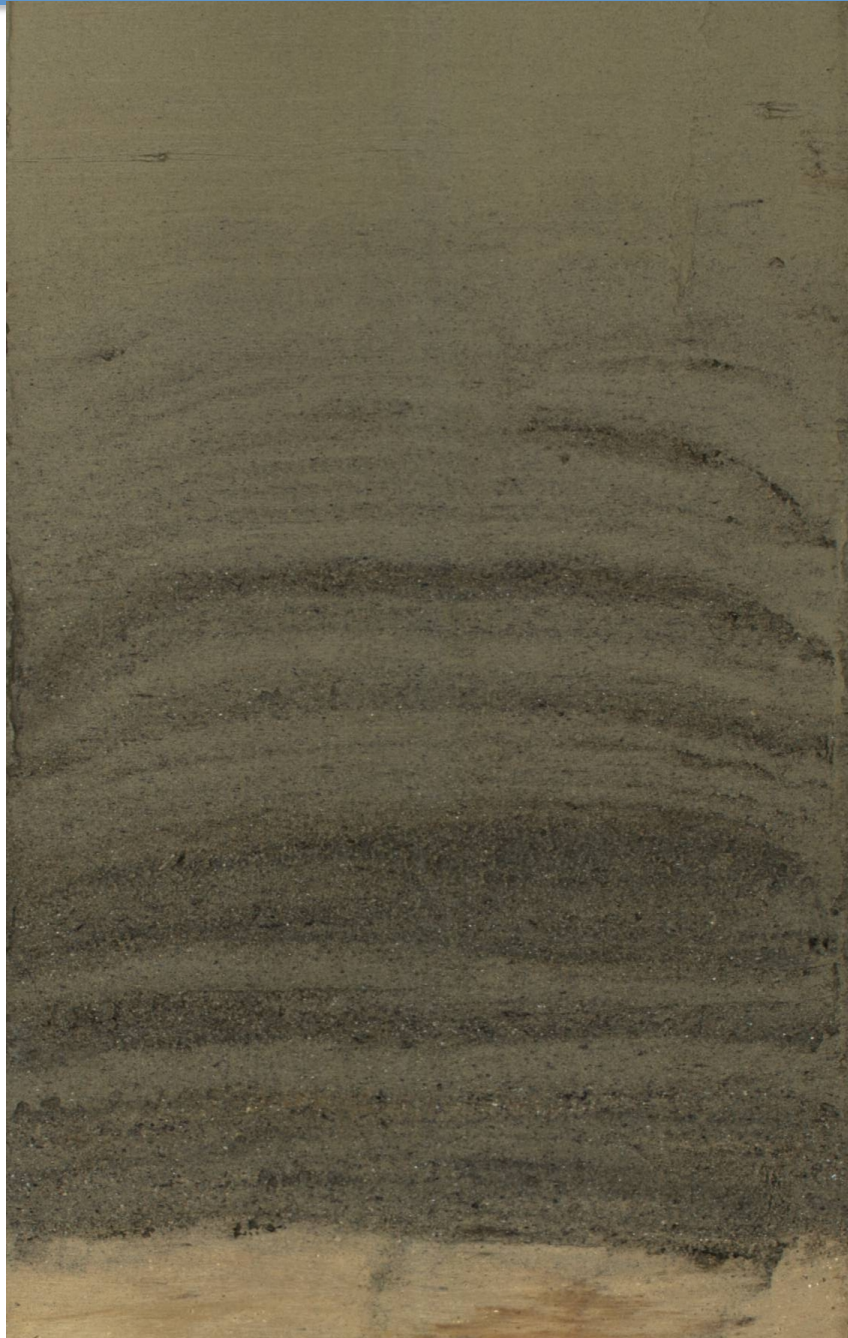
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Presence of alloctonous particle e.g. shelf derived particle in deep-sea environments (typically bryozoa, autigenic glauconite)



## **MOST COMMON FEATURES**

- « Sharp base characterized by sharp grain size change often with sharp color change (careful with sediment oxidation)
- « Planar laminations
- « Bioturbated top

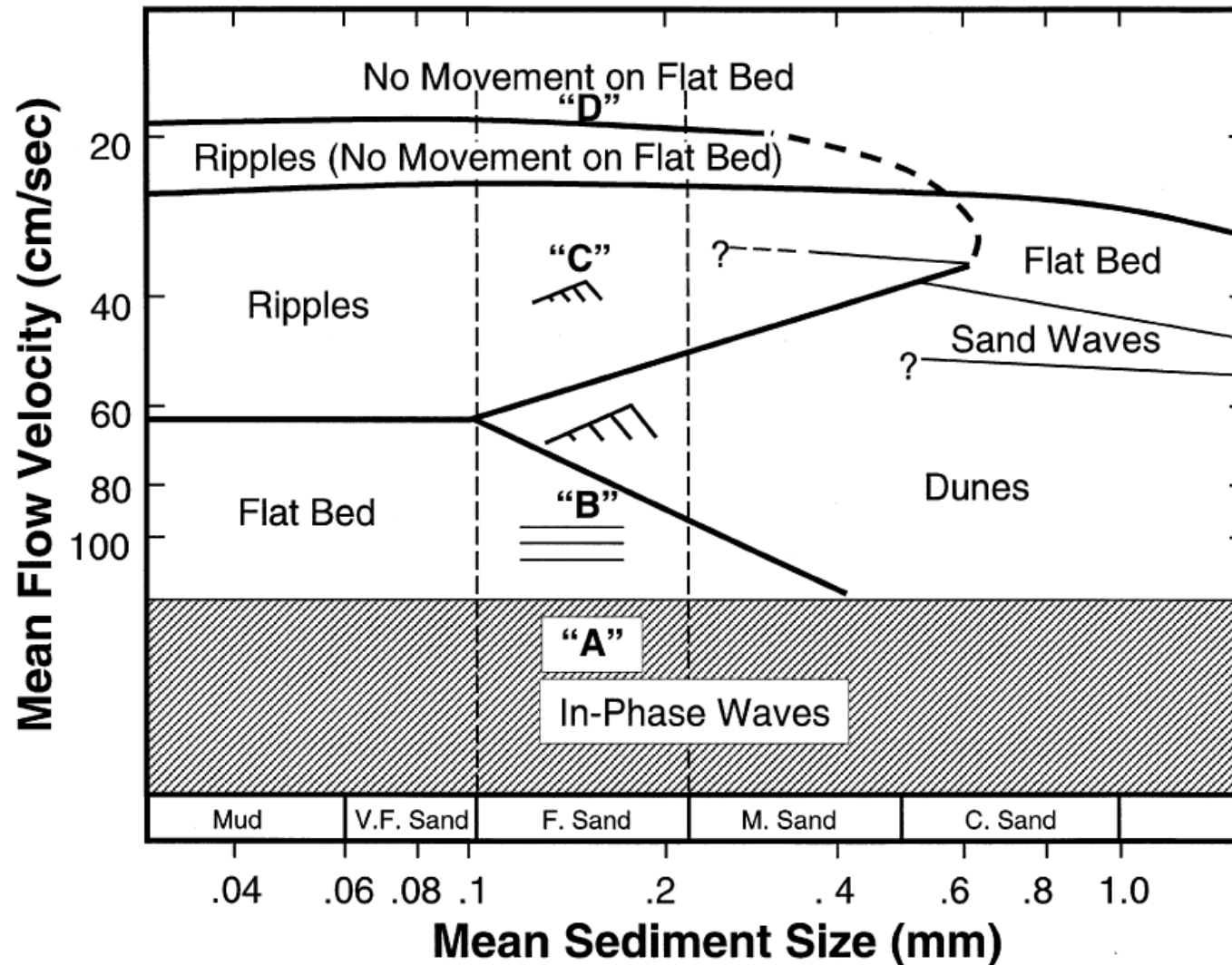
## **INDICATION OF SHEAR SORTING**

Grain size and compositional sorting through the deposit. Sorting occurs according to size and specific weight e.g. large forams with medium-size quartz with small-size pyroxene)

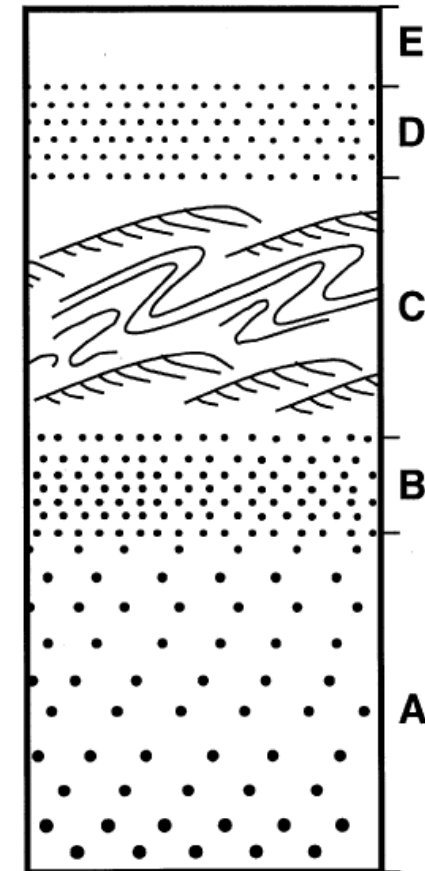
## **COMPOSITION**

Presence of allocthonous particle e.g. shelf derived particle in deep-sea environments (typically bryozoa, autigenic glauconite)

# Size - Velocity Diagram



# Bouma Sequence



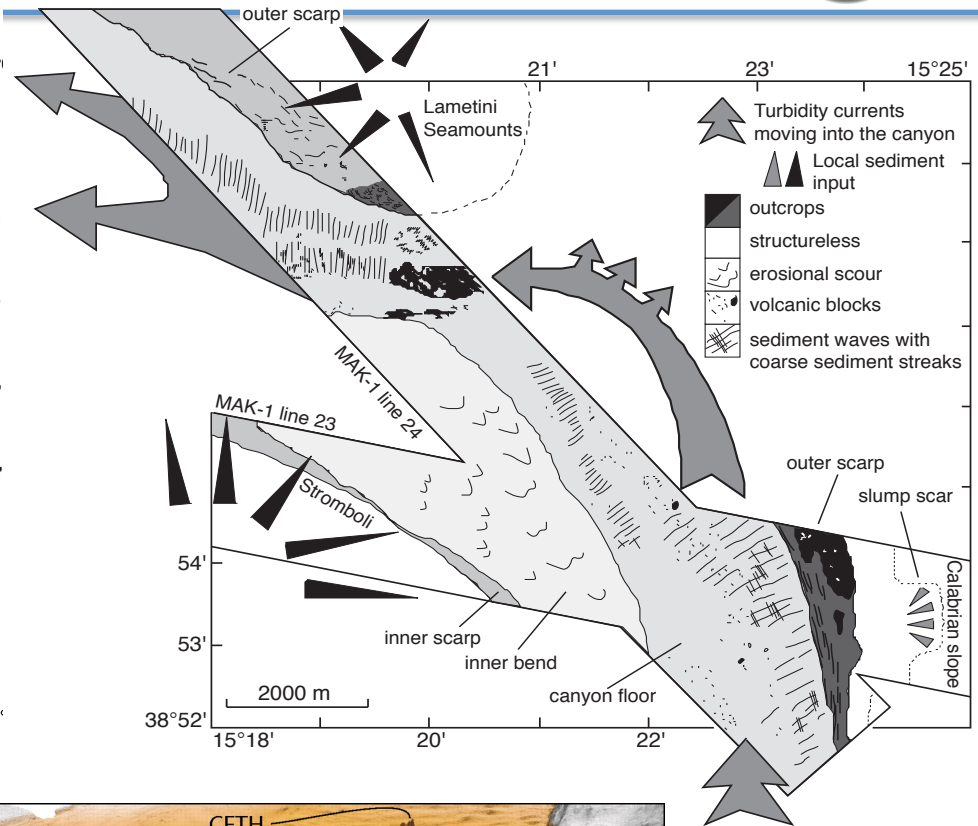
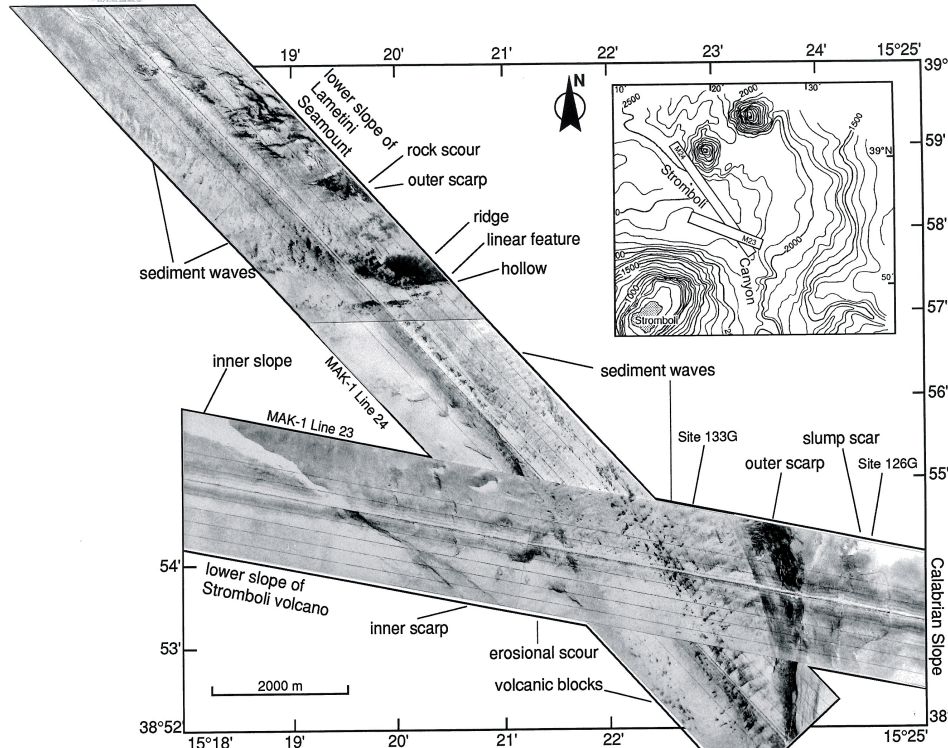
	$< 40 \text{ cm/s}$ + $- 0-4 \text{ cm/s}$	$< 40 \text{ cm/s}$ + $- 5-10 \text{ cm/s}$	$< 40 \text{ cm/s}$ + $> 10 \text{ cm/s}$	$0 \text{ cm/s}$ + $> - 10 \text{ cm/s}$
<b>SMALL-SCALE BED FORMS:</b> $\lambda < 20 \text{ cm}$				
Bed form	<b>Symmetric small ripples (SSR)</b> regular, 2D, symmetrical, sharp crests, straight flanks, broad troughs	<b>SSR + asymmetric small ripples (ASR)</b> more irregular, 2-2.5D, still symmetrical, rounder crests, some straight and some biconvex flanks	<b>ASR + asymmetric large ripples</b> irregular, 3D, asymmetrical, larger $\lambda$ and height, round biconvex profiles, pronounced scour on lower end of stoss	<b>Current ripples</b> very irregular, 3D, sharp crests, steep and straight lee, convex-up stoss
Symmetry index	-1.2		-1.5	
Dip of lee side		11-18°	24-27° dip of lee side increases with increasing $U_b$	- angle of repose (30-35°)
Roundness index	0.44	- 0.50	> 0.50	0.5-0.6 (Yokokawa 1995)
Ripple index	generally between 8-12 for all bed forms			
Orbital diameter/wavelength	8-15	- 8-15	8-15	N/A
	$40-100 \text{ cm/s}$ + $- 0-4 \text{ cm/s}$	$40-100 \text{ cm/s}$ + $- 5-10 \text{ cm/s}$	$40-100 \text{ cm/s}$ + $> 10 \text{ cm/s}$	$0 \text{ cm/s}$ + $> - 40 \text{ cm/s}$
<b>LARGE-SCALE BED FORMS:</b> $\lambda > 100 \text{ cm}$				
Bed form	<b>Symmetric large ripples (SLR)</b> SLR: 2.5D, symmetrical, sharp discontinuous crests = to brink, straight flanks	<b>Hammocky (HM) + SLR + ALR</b> HM: 3D, symmetrical, no brink point, broad round crests, domal, convex-up flanks	<b>Asymmetric large ripples (ALR)</b> ALR: 2D-3D, asymmetrical, brink not always = to crest, round stoss with break in slope, can have scour pits on lower end of stoss	<b>Dunes</b> regular (2D) to irregular (3D), sharp crests, steep and straight lee, straight to convex-up stoss
Symmetry index	-1.0 (< 1.5)	< 2	> 2	-
Dip of lee side	14-24° (SLR), 15-25° reverse large ripples (RLR)			- angle of repose (30-35°)
Roundness index	- 0.40-0.50 highest for HM bed forms	- 0.45-0.60	- 0.55-0.75 (up to 0.95)	-
Ripple index	generally between 8-12 for all bed forms			
Orbital diameter/wavelength	1-2	1-2	1-2	N/A



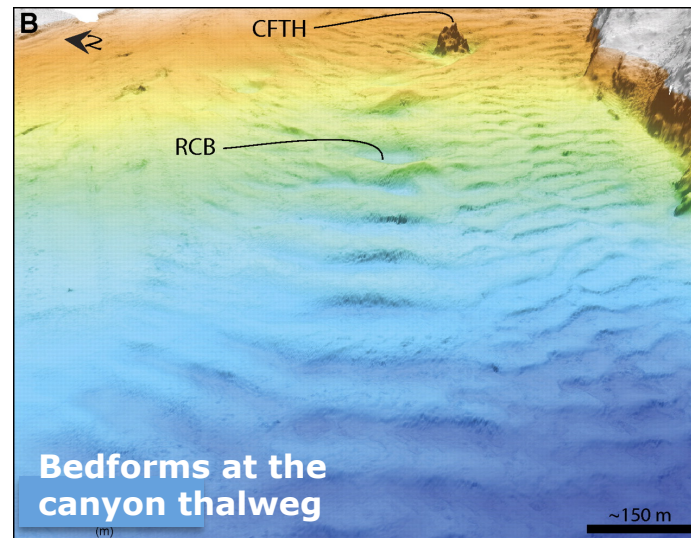
antidune formation



bedforms



Lucchi, 1997. PhD Thesis, University of Cardiff



# Confined systems: Canyons and associated deep sea fans

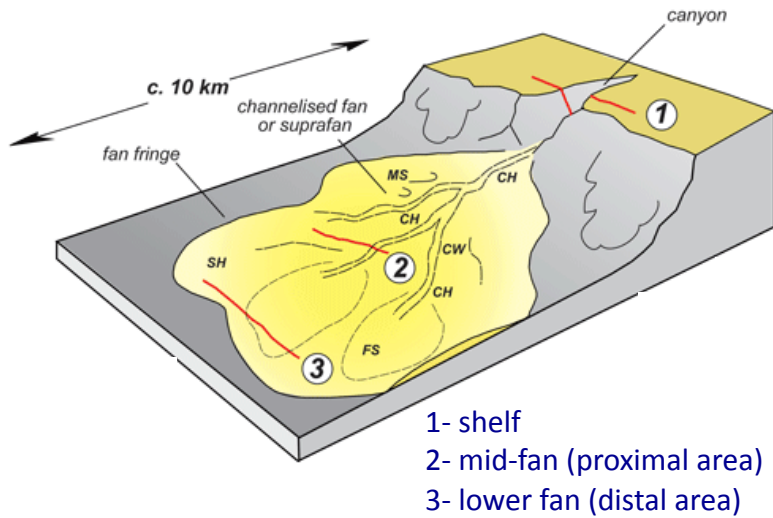
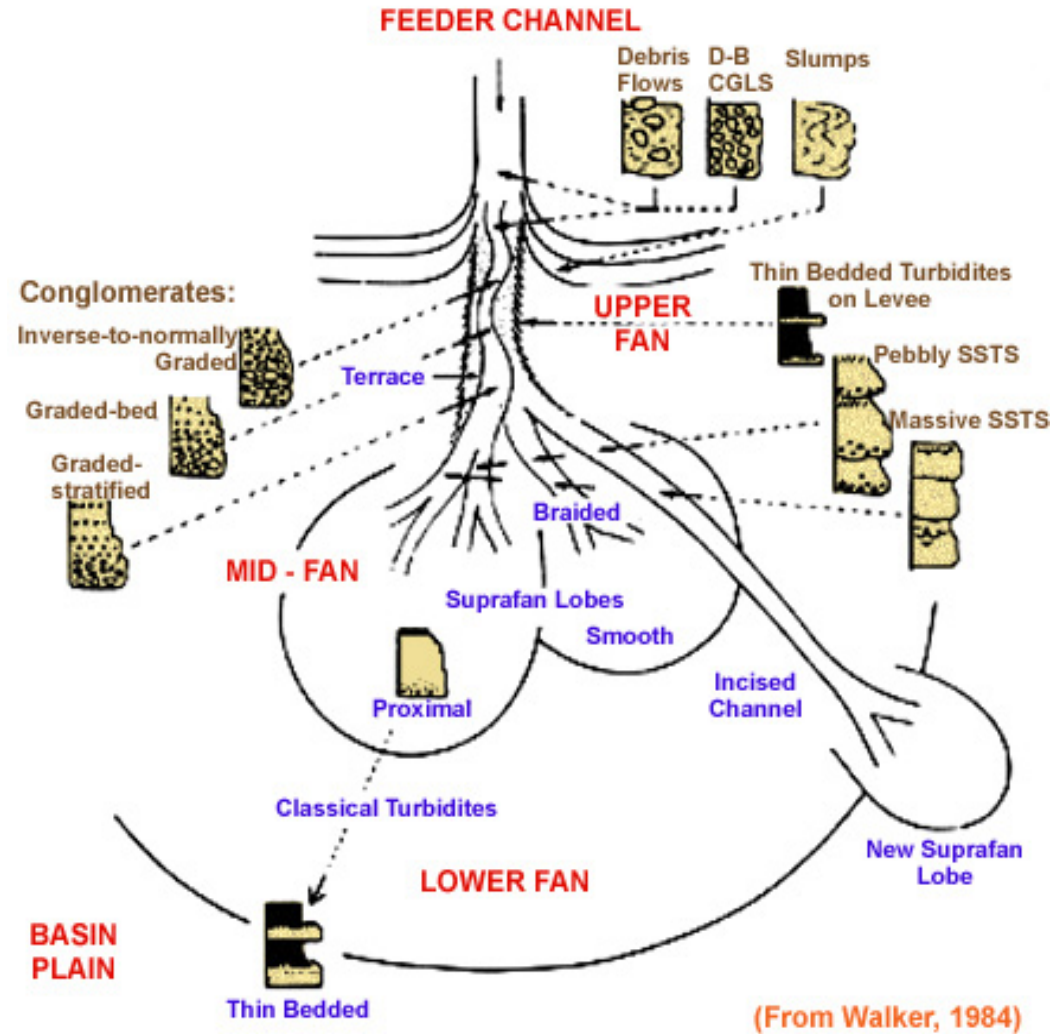
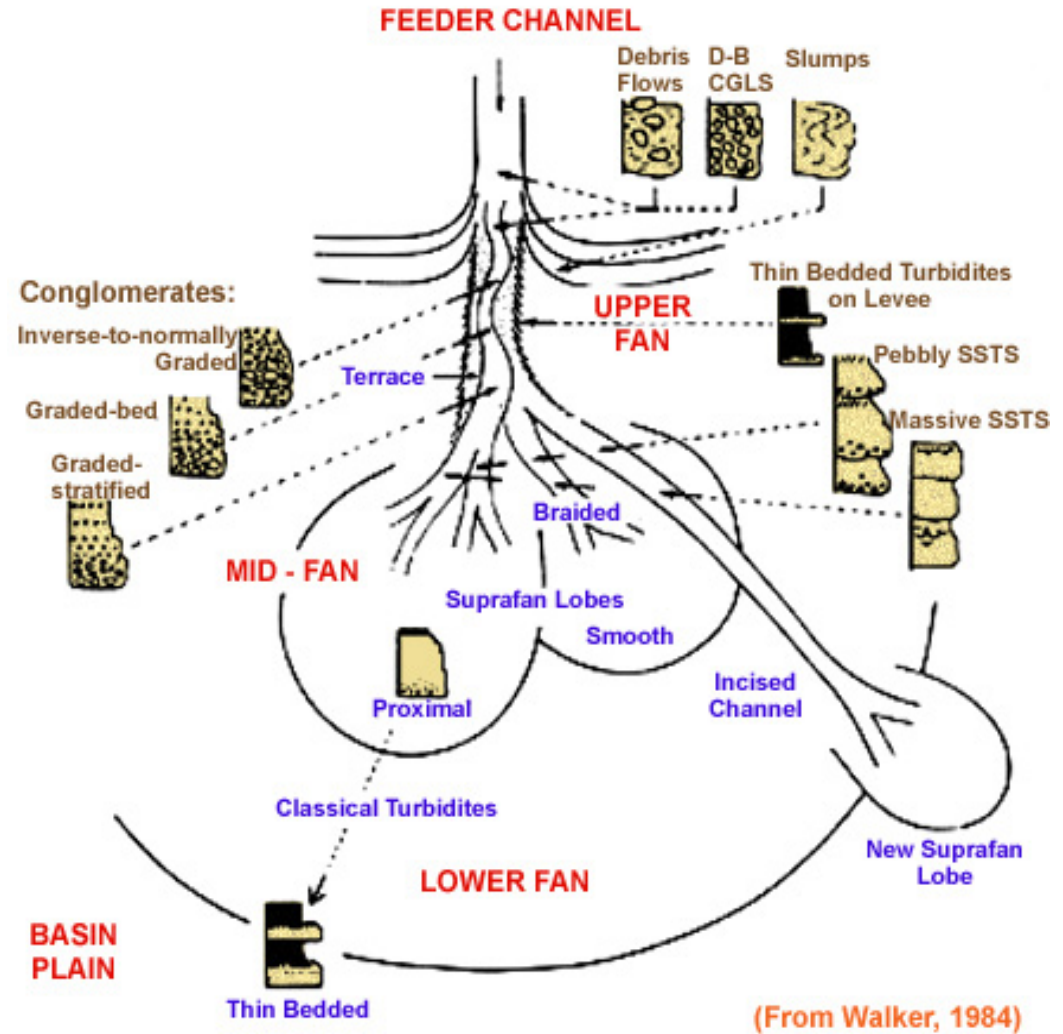
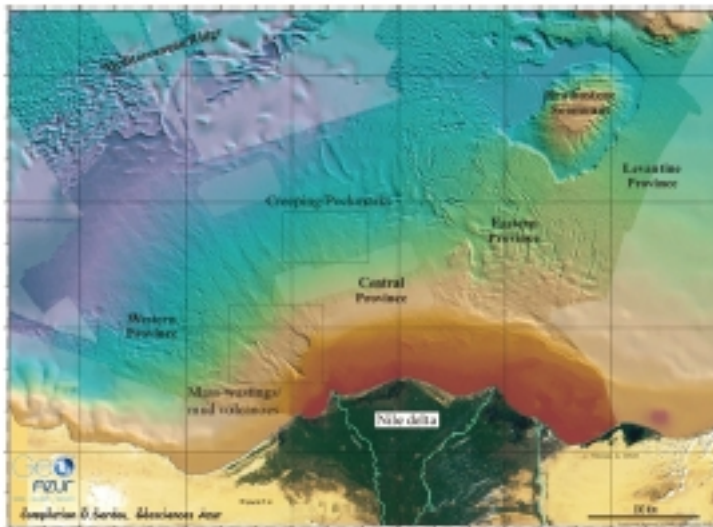
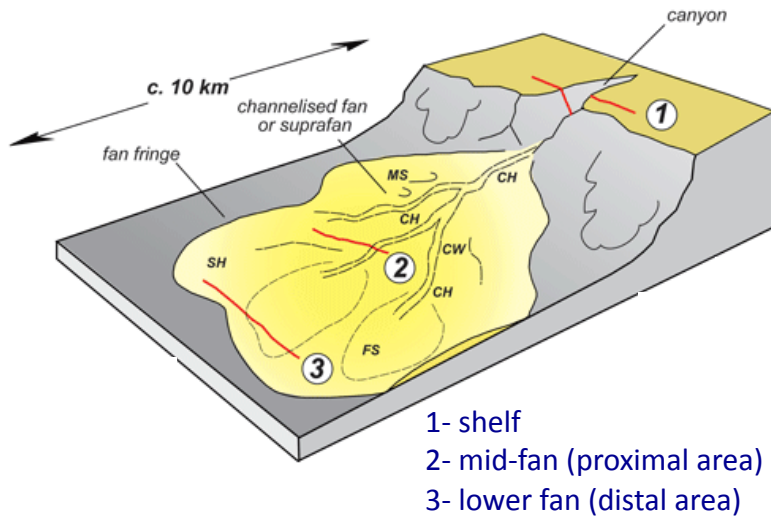


Image courtesy of the Open University

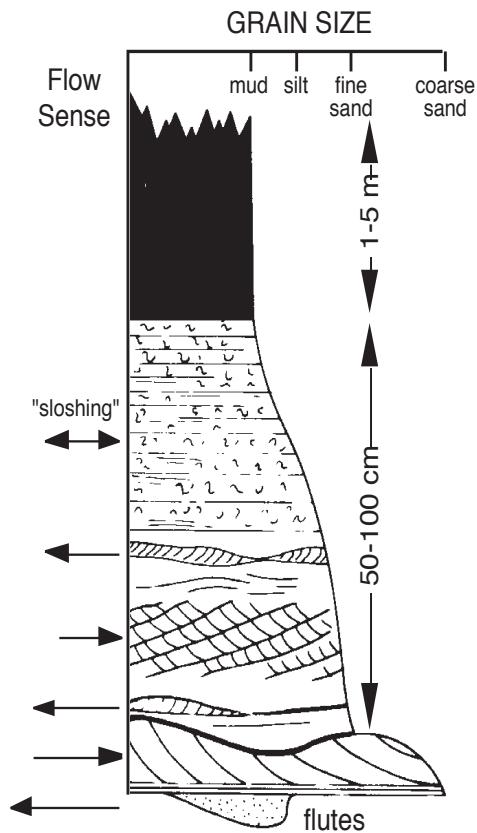


# Confined systems: Canyons and associated deep sea fans

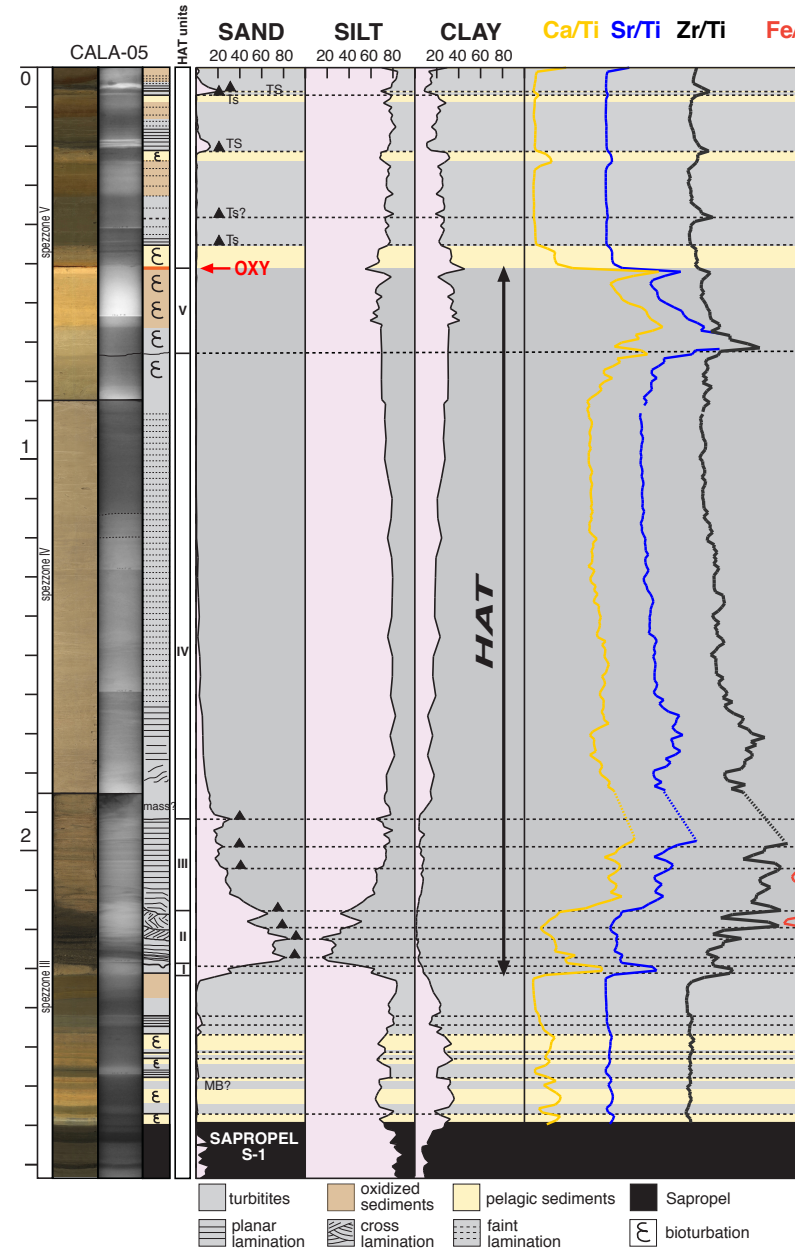




# Reflected turbidites and Multi-sources turbidites



DIVISIONS	INTERPRETATION
Homogeneous silty mudstone cap, with scattered load balls near the base	Rapid deposition of mud floccs under ponded suspension
Alternating laminated and pseudonoduled very fine sand and silt in couplets that thin upward	Gradual decay of reversing flow in an enclosed basin, leading to ponding
Wavy and ripple laminated divisions with reverse flow directions and spaced mud partings	multiple reflections and deflections of a single large flow from basin margins. Flow strength and bedform scale decrease exponentially. Mud drapes form between passes of the current
Parallel and/or cross-stratified coarse sand	



# Contourites

or

# Fine-grained turbidites

