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

Anno accademico 2017 – 2017

Geologia Marina

Parte III

Modulo 3.1 Continental Margin Depositional Processes: down-slope processes

Relatore
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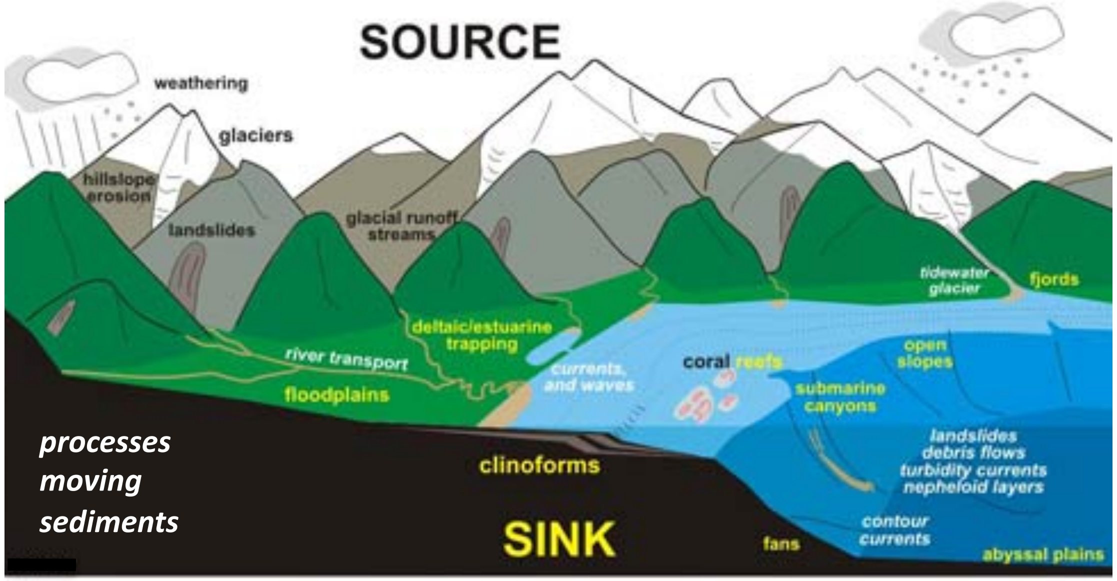
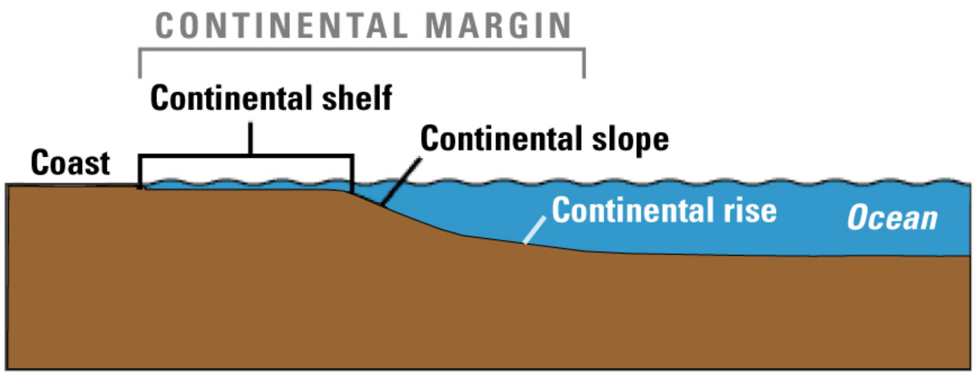
the Source to Sink System



Sedimentary Processes on Continental Margins

down-slope: driven by gravity forces
along-slope: driven by density forces (thermo-haline or water mass accumulation)

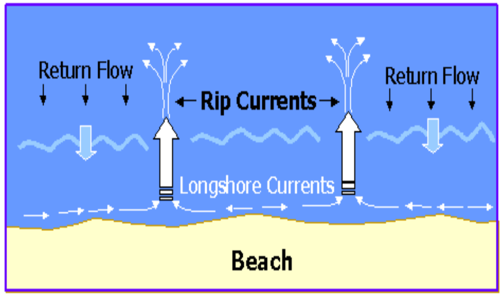


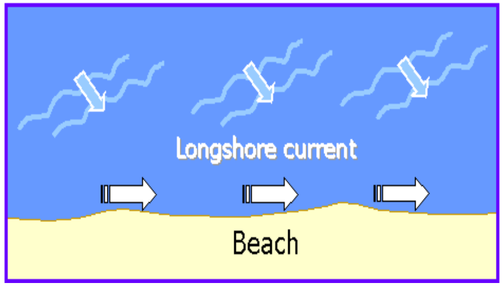
Continental shelf
Preferential area of sediment accumulation
High sediment accumulation
High isostatic subsidence
Continental slope sediment deposition and transfer toward deeper environments
Continental rise: sediment deposition (deep sea fans, sediment drifts)

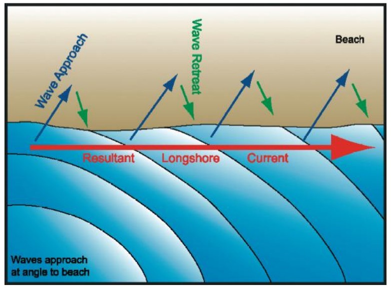
Siliciclastic continental shelves

Tide dominated shelves
e.g. North European margins (tides » 3 m)

Wind/wave dominated shelves
e.g. Mediterranean margins (tides ≤ 3 m)

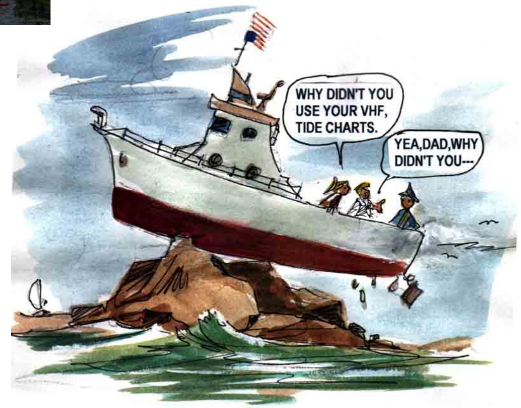


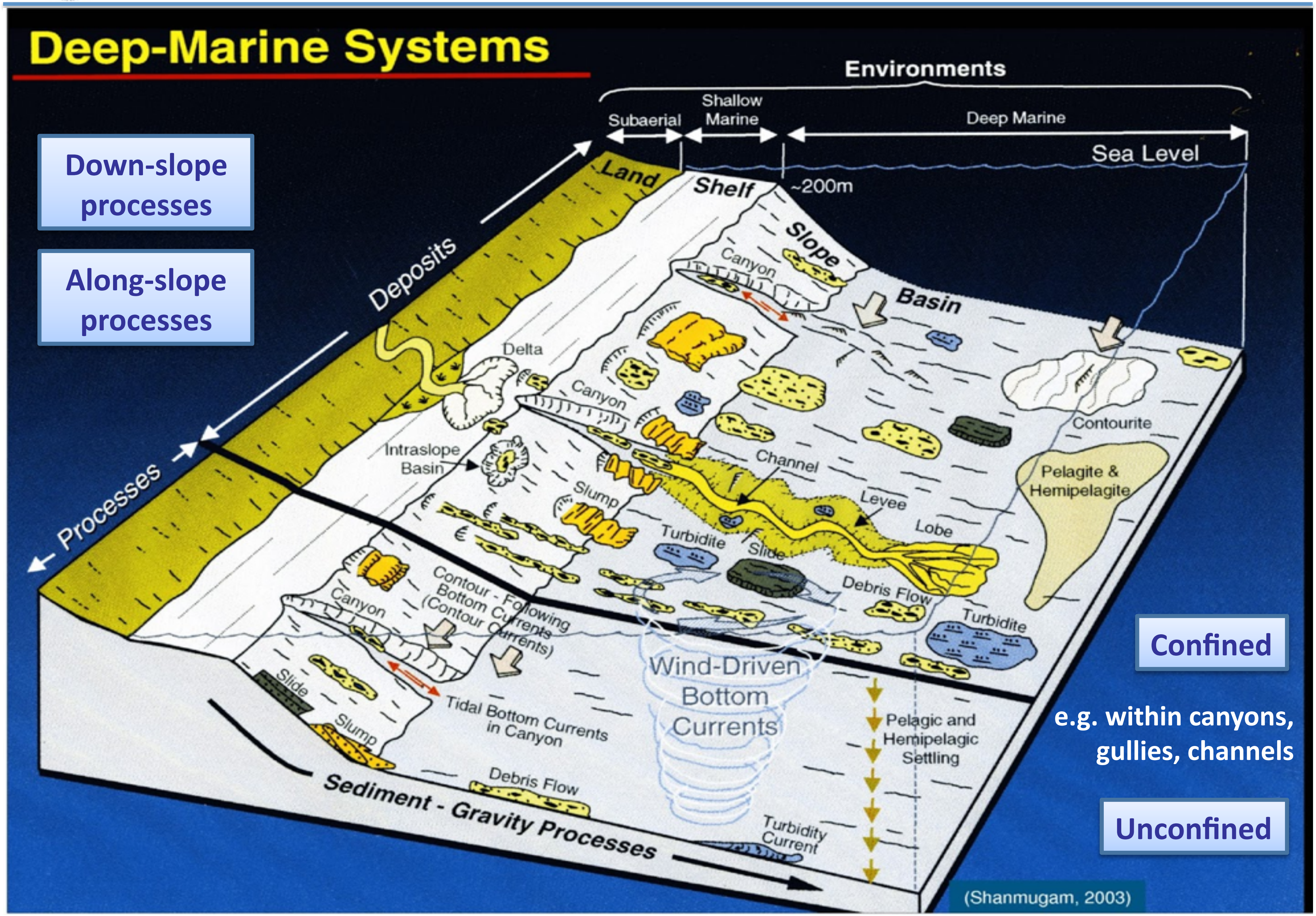




Other sedimentary/biological processes

- 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 outern shelf

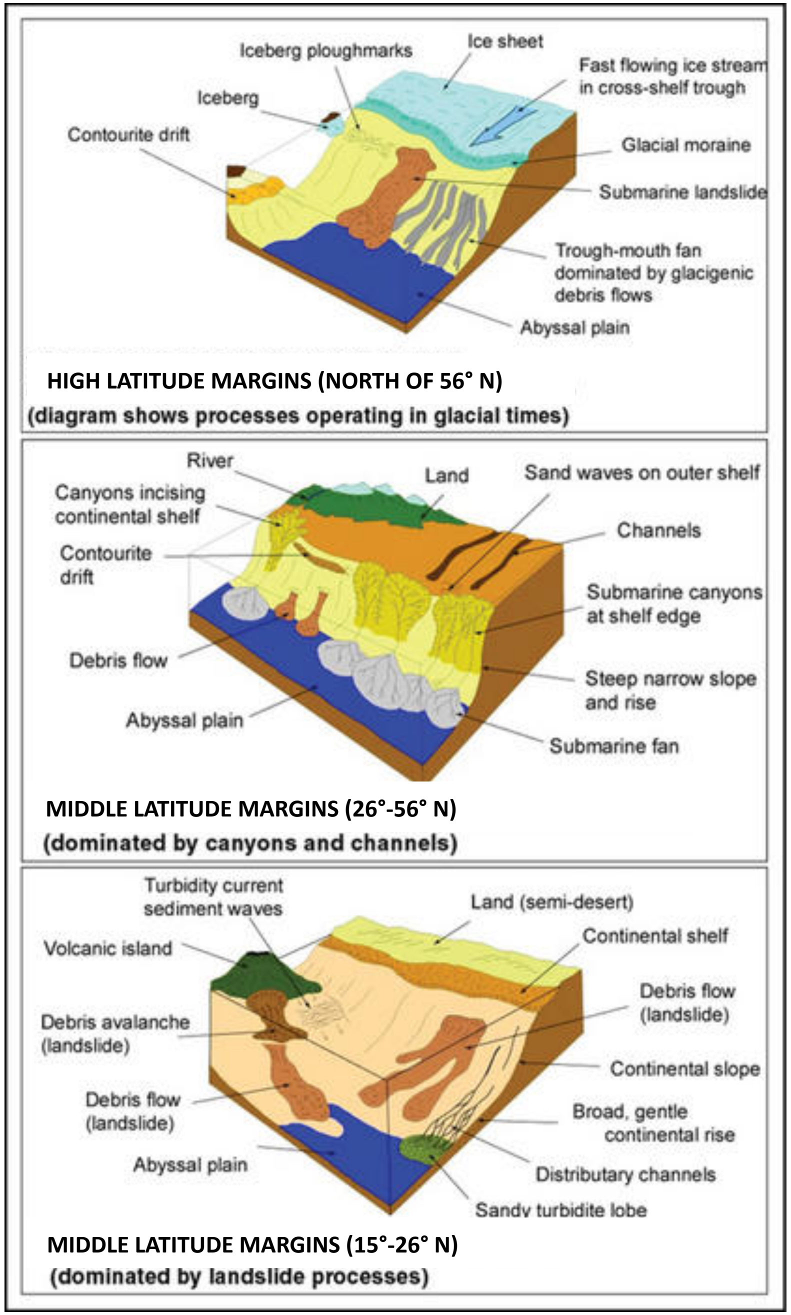



Deep-Marine Systems
Down-slope processes
Along-slope processes
Environments
Subaerial
Shallow Marine
Deep Marine
Sea Level
~200m
Land
Shelf
Slope
Basin
Deposits
Processes
Canyon
Delta
Intraslope Basin
Slump
Channel
Levee
Lobe
Turbidite
Slide
Debris Flow
Contourite
Pelagite & Hemipelagite
Contour - Following Bottom Currents (Contour Currents)
Tidal Bottom Currents in Canyon
Wind-Driven Bottom Currents
Pelagic and Hemipelagic Settling
Turbidity Current
Sediment - Gravity Processes
Confined
e.g. within canyons, gullies, channels
Unconfined
(Shanmugam, 2003)

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):

- Reology (sediment deformation)
- Sediment mass mechanism of support (gravity, flow turbolence, 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.

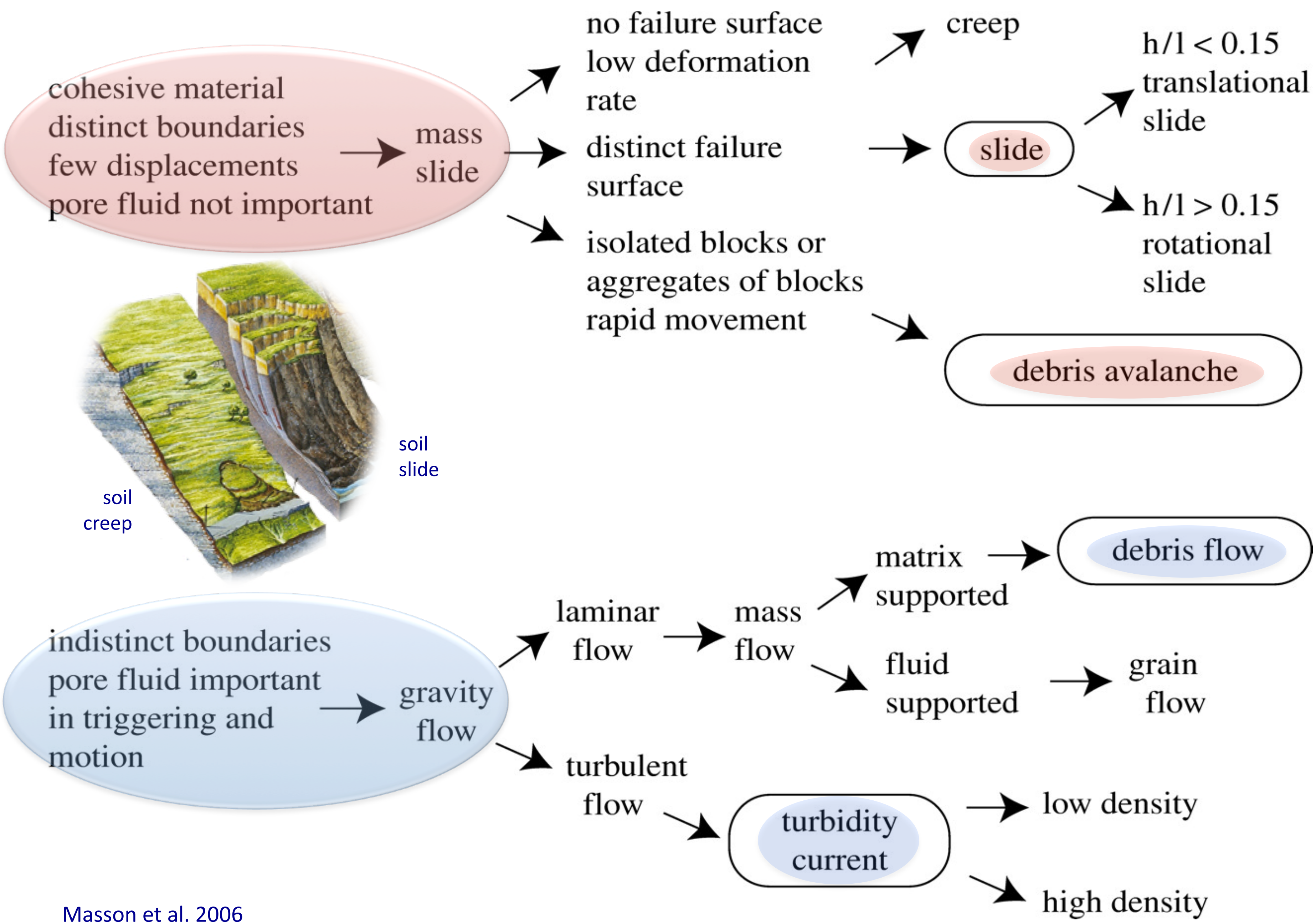
• Prior, D.B. (1984). Submarine landslides. Proceedings of the IV International Symposium on Landslides, Toronto, Vol. 2, pp. 179–196.

• 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.

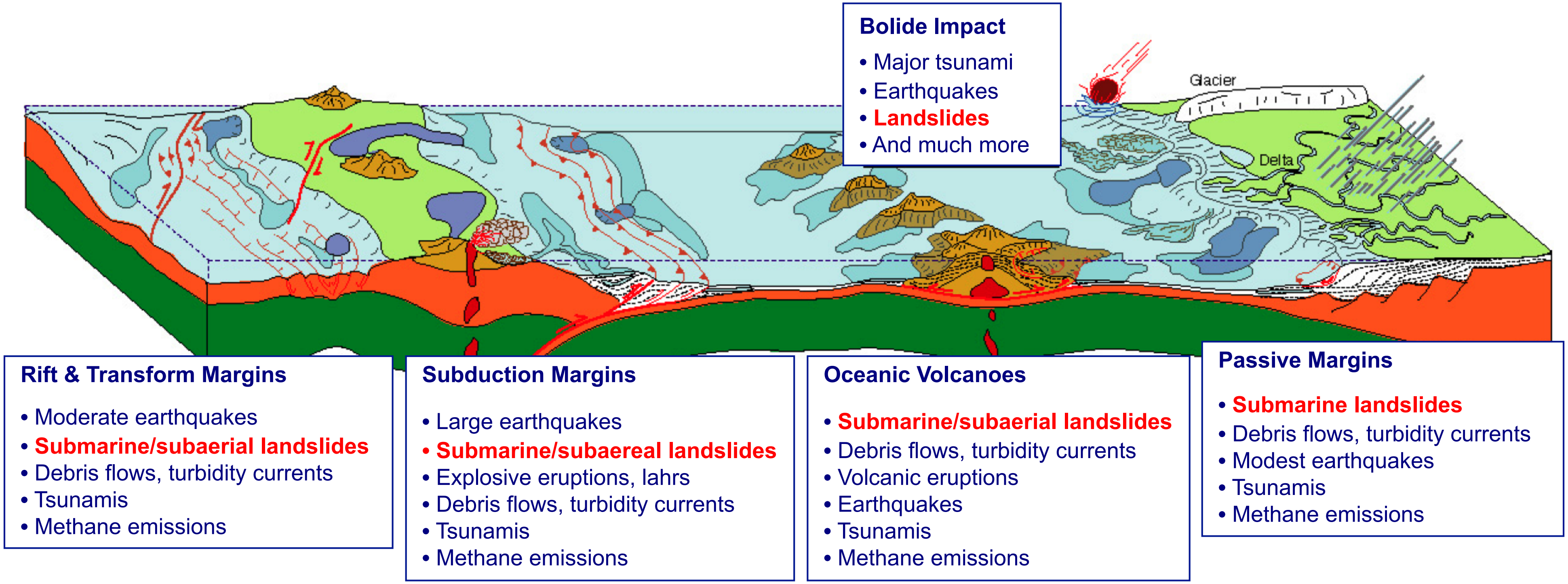
• Masson, D.G., Harbitz, C.B., Wynn, R.B, Pedersen, G., Lovholt, F. (2006). Submarine Landslides: processes, triggers and hazard prediction. Phil. Trans. R. Soc. A, 364, pp 2009-2039.



Masson et al. 2006

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.



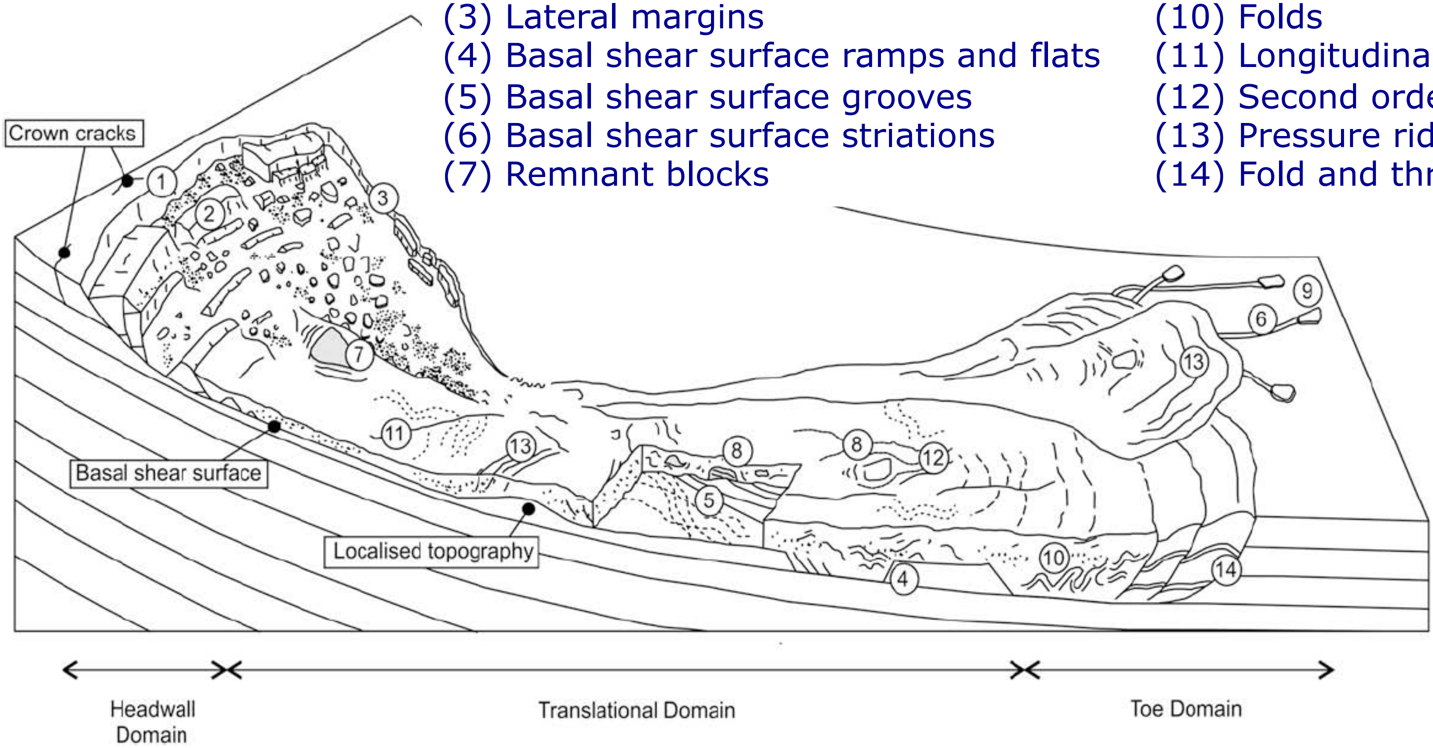
Adapted from Morgan et al., 2009. *Scientific Drilling*, available at: http://www.iodp.org/geohazards/

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)'**.

(1) Headwall scarp
(2) Extensional ridges and blocks
(3) Lateral margins
(4) Basal shear surface ramps and flats
(5) Basal shear surface grooves
(6) Basal shear surface striations
(7) Remnant blocks
(8) Translated blocks
(9) Out-runner blocks
(10) Folds
(11) Longitudinal shears/first order flow fabric
(12) Second order flow fabric
(13) Pressure ridges
(14) Fold and thrust systems

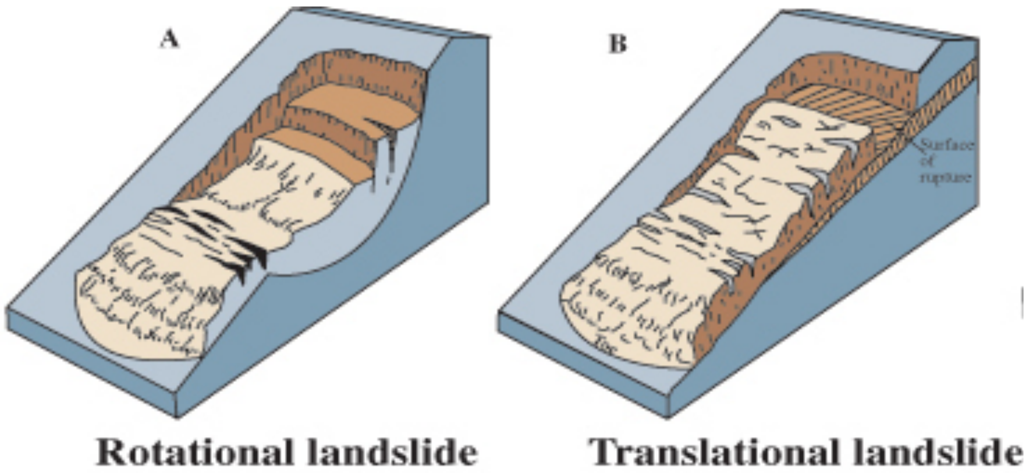


Modified after Prior et al. (1984)   Bull et al., 2009. Marine and Petroleum Geology

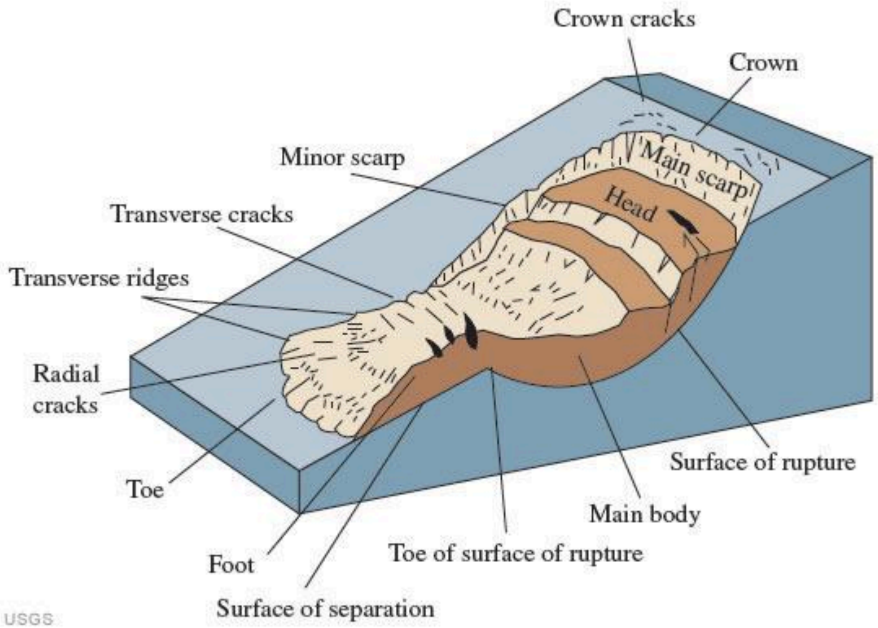
Submarine slides/slumps

Number of Skempton

hight of slide/lenght of slide → <0.15 **SLIDE** ; >0.15 **SLUMP**

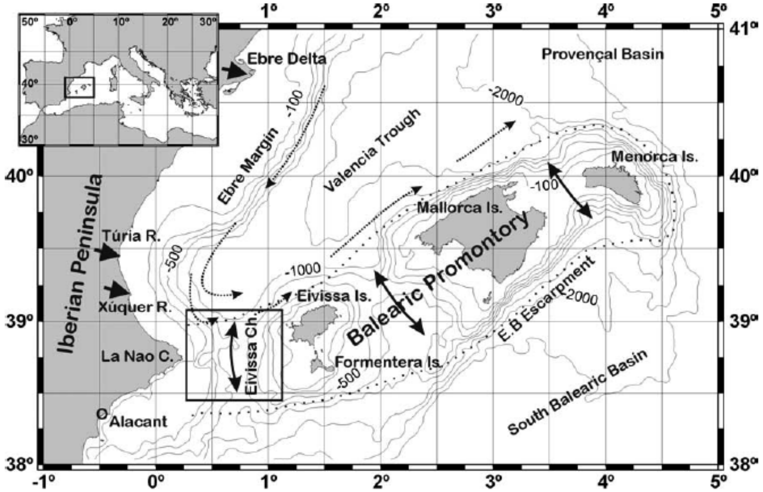


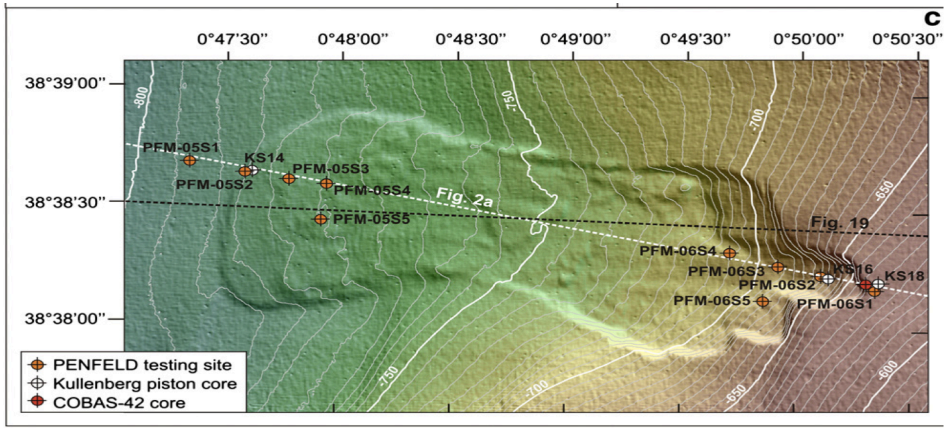
Small slump
In sediment
core



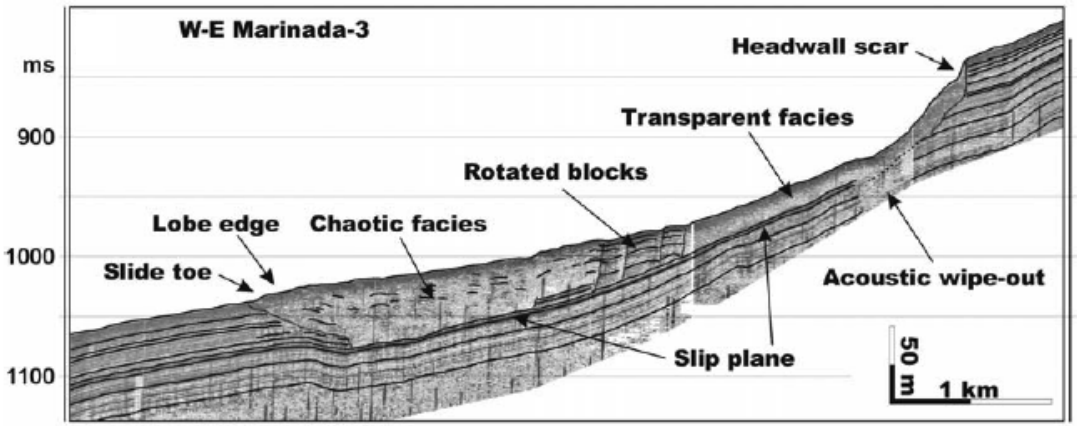
Pleistocene Submarine Landslides in the Boso Peninsula, Japan

Ana submarine landslide
Ibiza Channel
Western Mediterranean

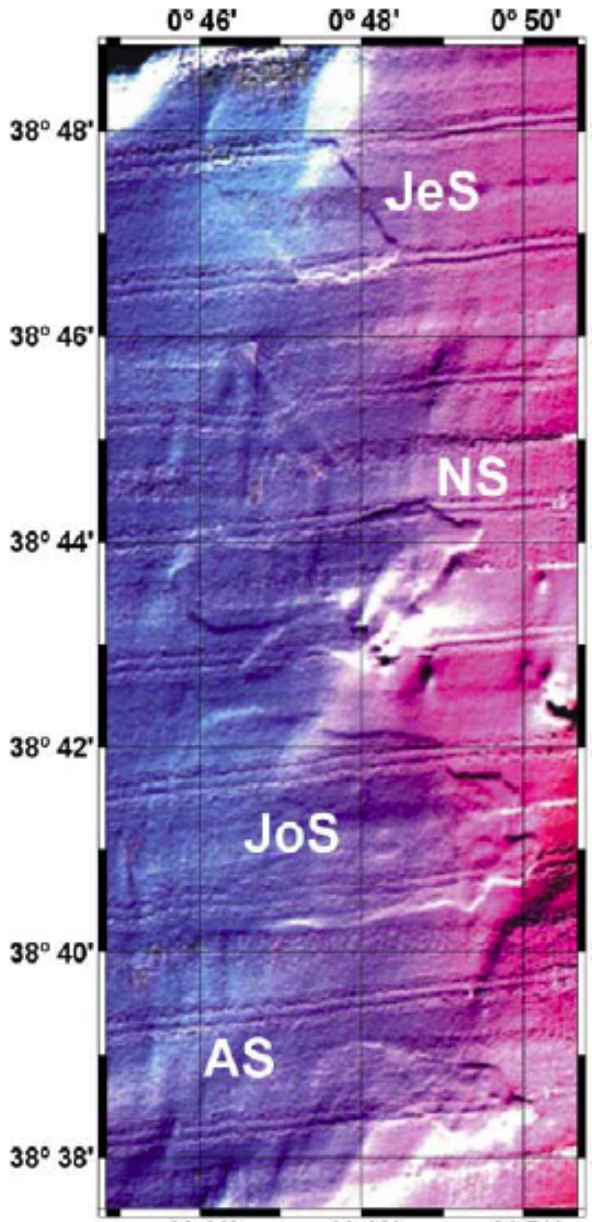




Multibeam



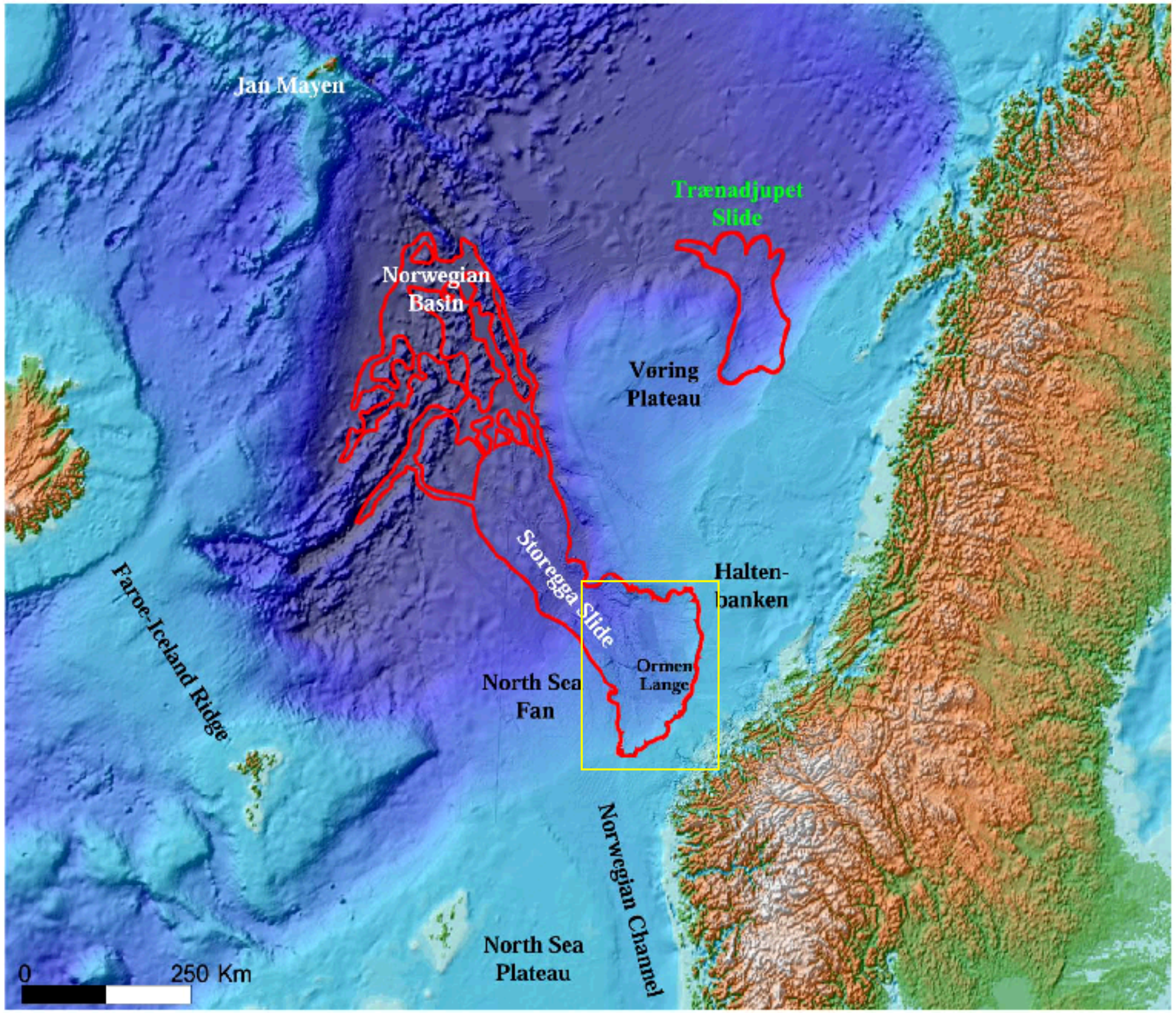
Sub-bottom



Lastras et al., 2004 Sedimentology

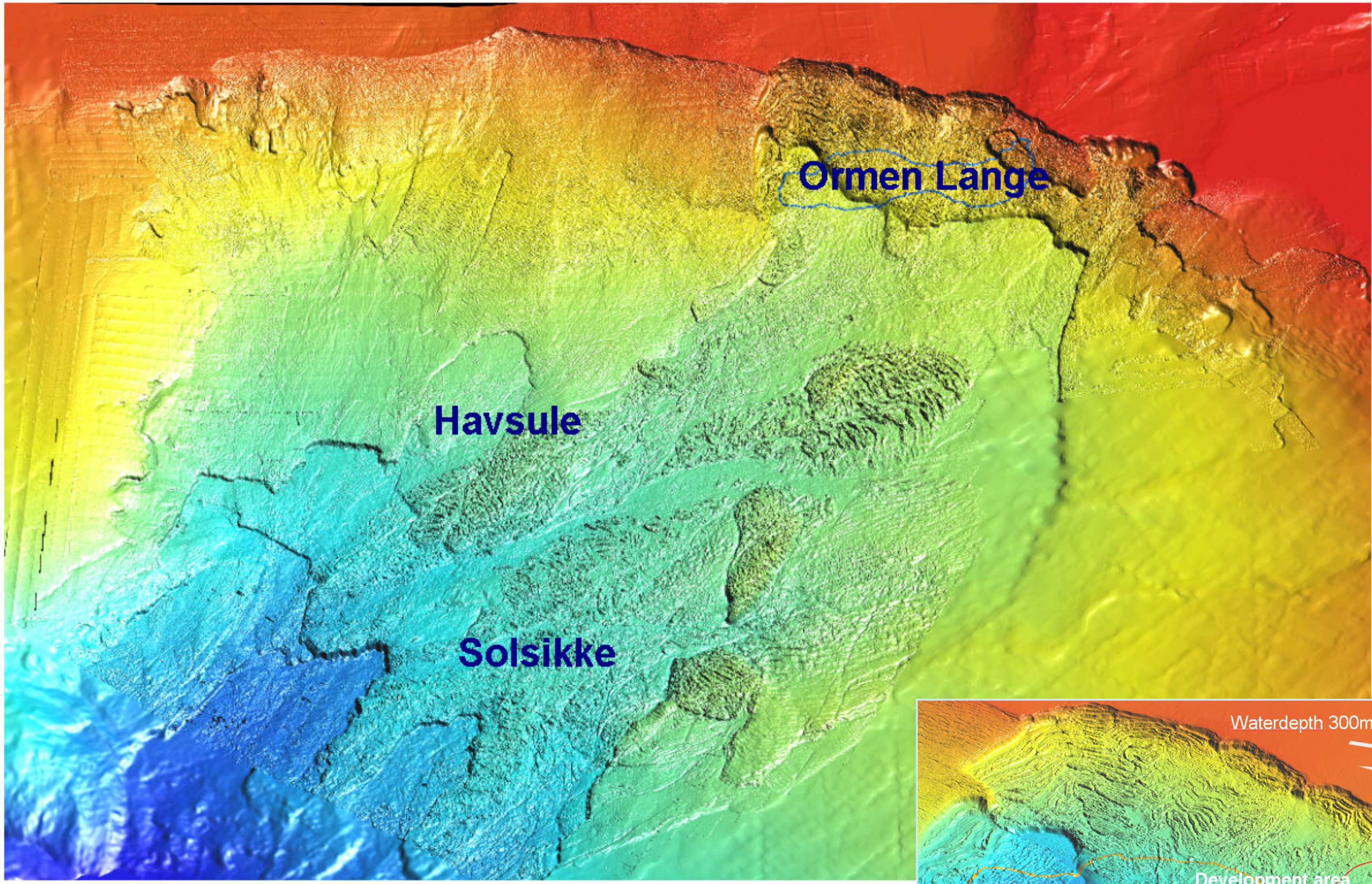
STOREGGA SUBMARINE LANDSLIDE, NORWAY

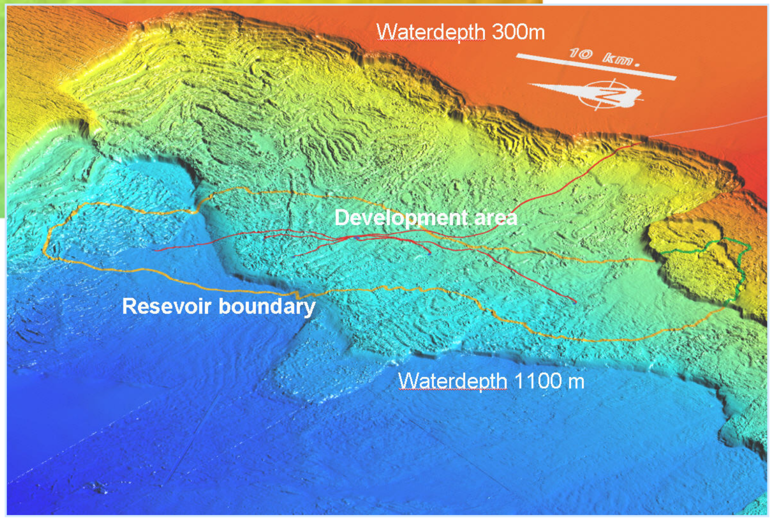
8000 y BP
3500 km^3 of debris



Courtesy Petter Bryn

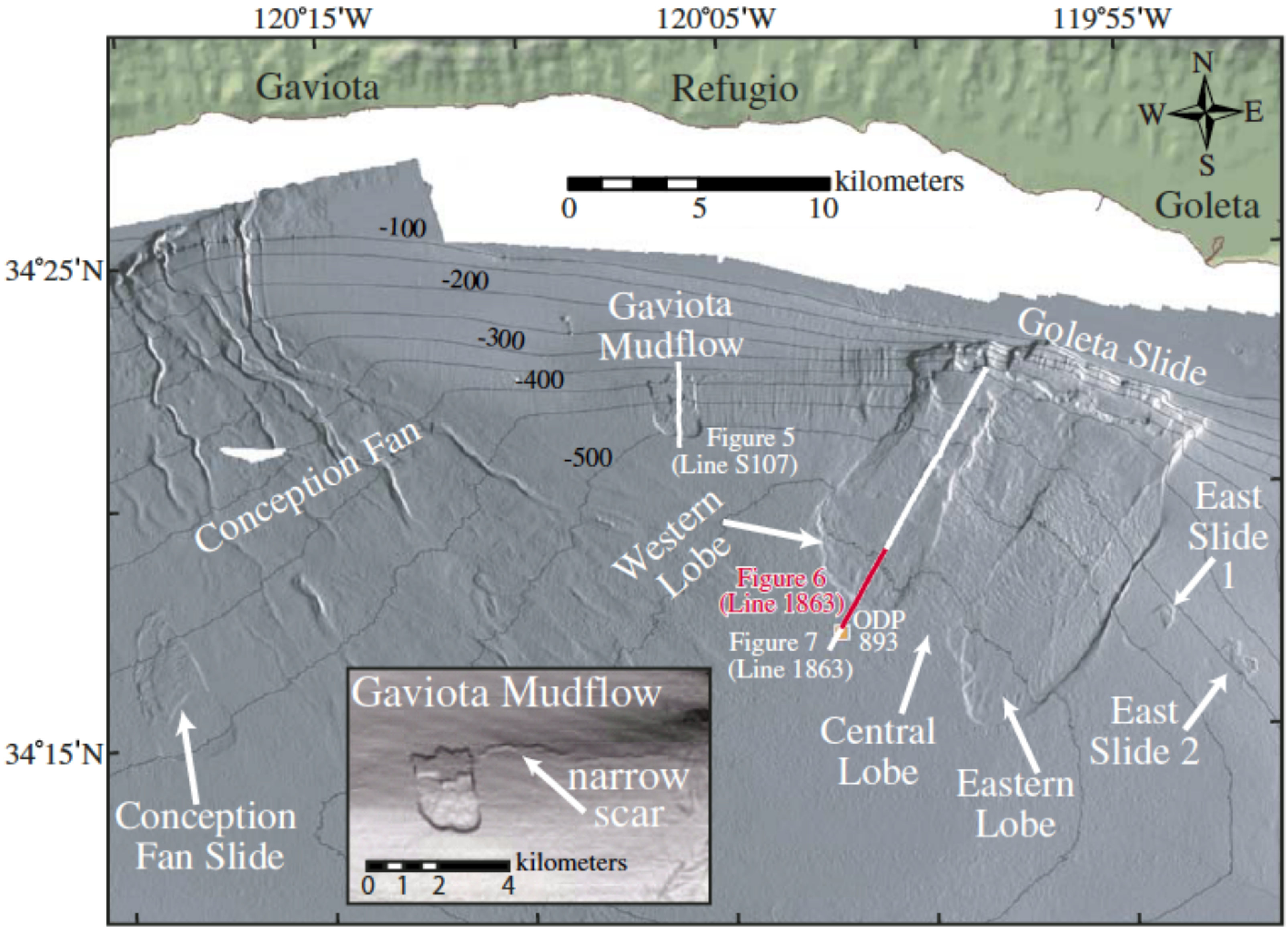
Norsk Hydro
E&D Norway
Geophysical Operations





STOREGGA SUBMARINE LANDSLIDE

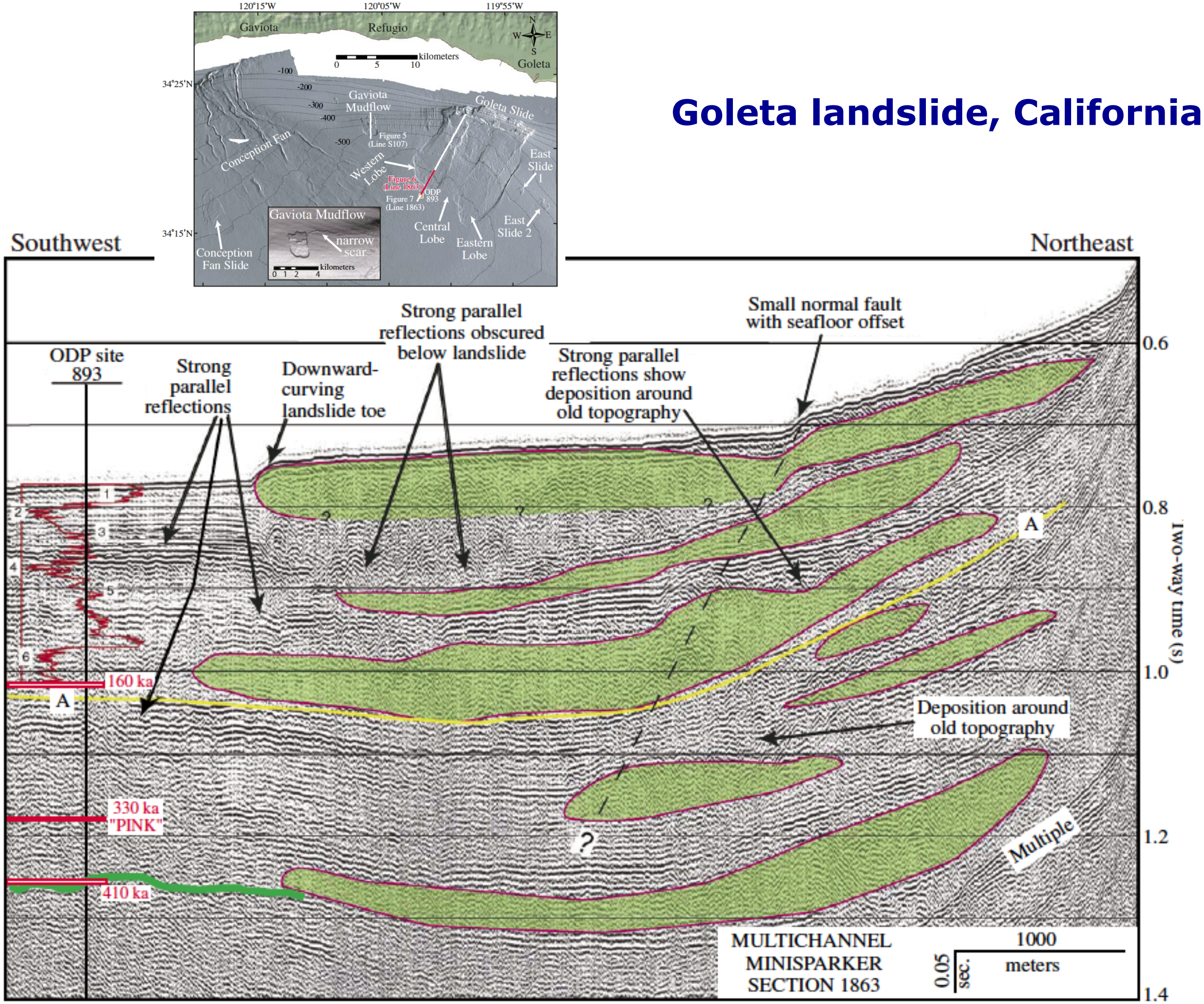
Goleta landslide, California



Multibeam echosounder

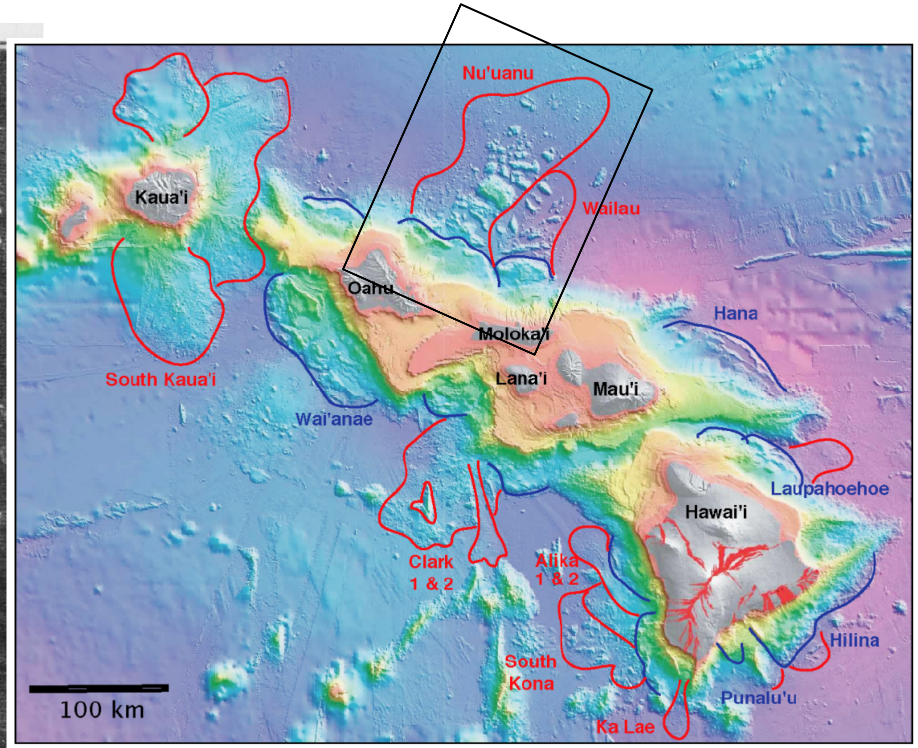
Lee et al., 2009. GSA Special Paper

Goleta landslide, California



Deep penetration seismics
2D Sparker

Lee et al., 2009. GSA Special Paper



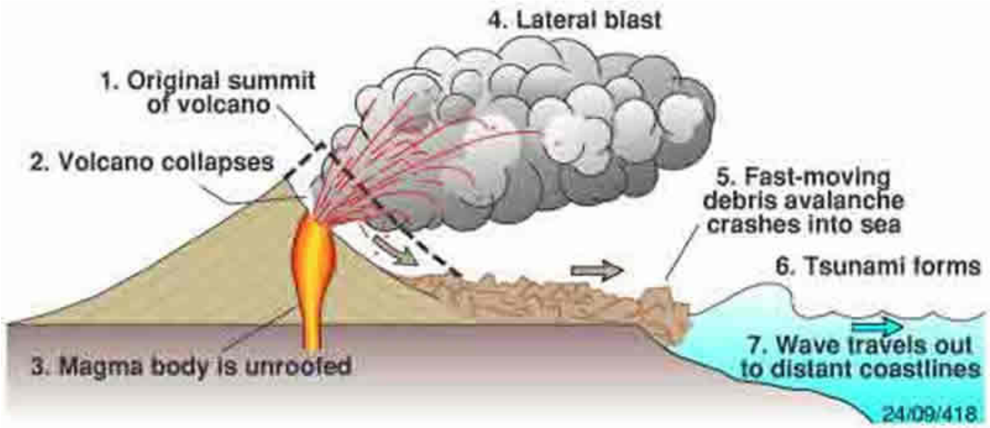
Morgan et al., 2009. Scientific Drilling

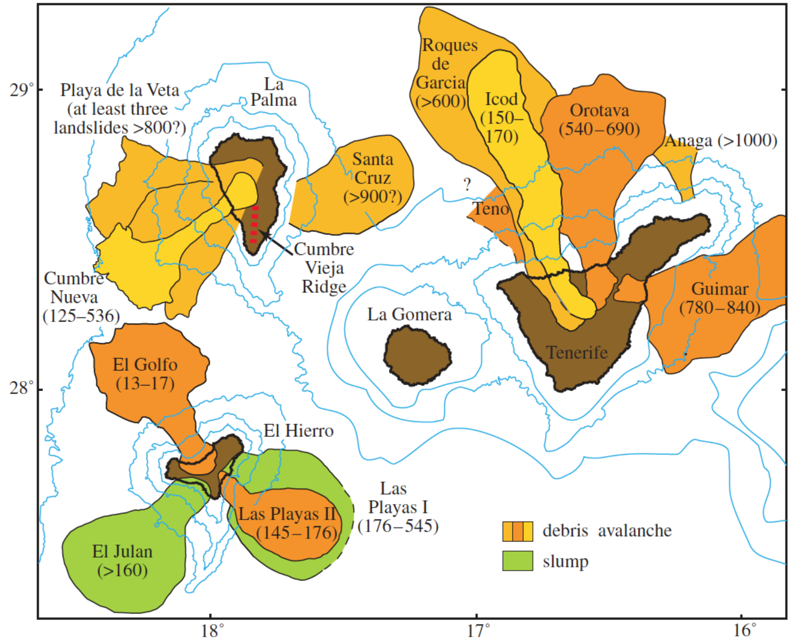
Submarine debris avalanches

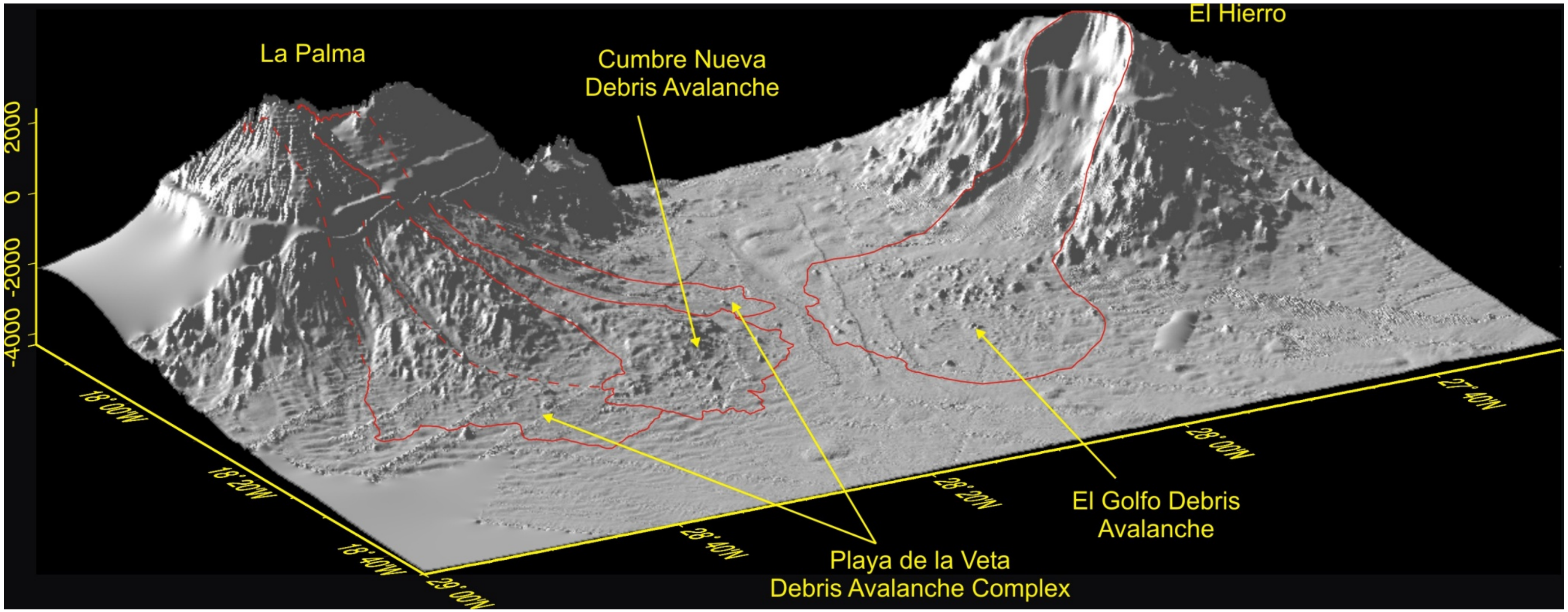
Volcanic Island Margins Hawaii

Moore et al., 1994. JGR

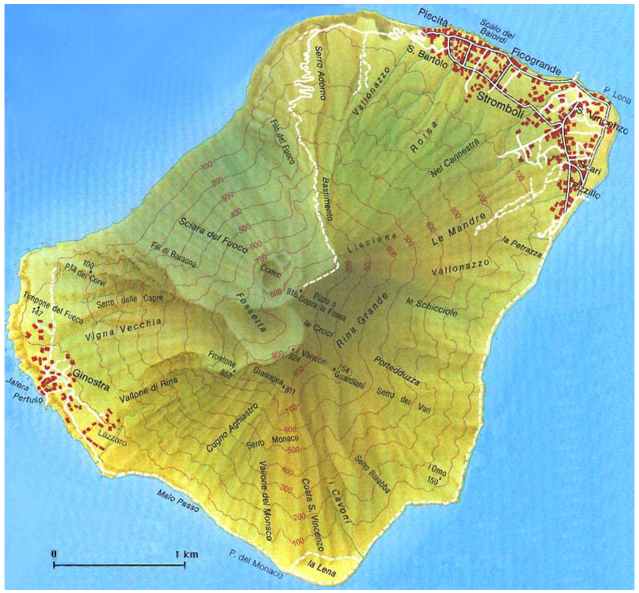
Volcanic Island Margins
Canarie

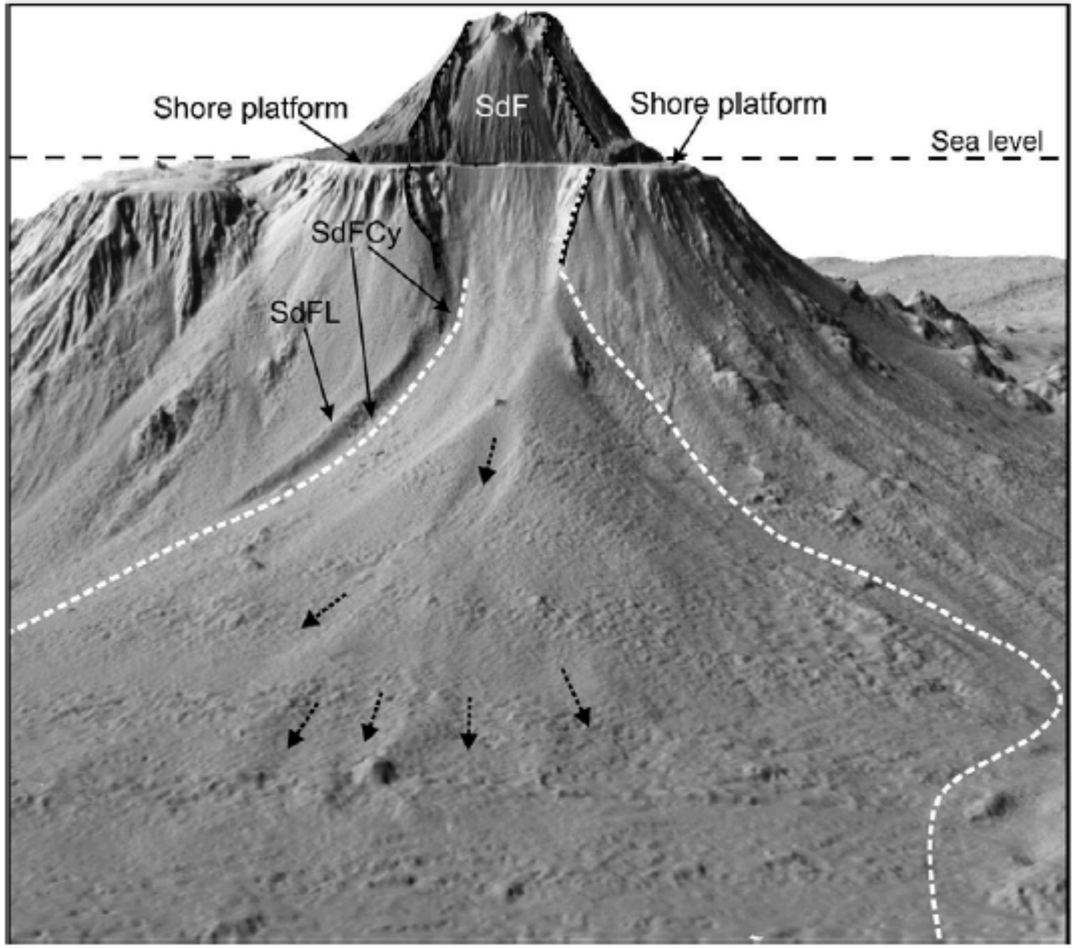






Volcanic Island Margins
Stromboli, Lipari Islands, Italy





Romagnoli et al., 2009. Marine Geology

Stromboli Sciara di Fuoco
100.000 y

cohesive material
distinct boundaries
few displacements
pore fluid not important
→ mass slide

no failure surface
low deformation rate → creep

distinct failure surface → slide
→ h/l < 0.15 translational slide
→ h/l > 0.15 rotational slide

isolated blocks or aggregates of blocks
rapid movement → debris avalanche

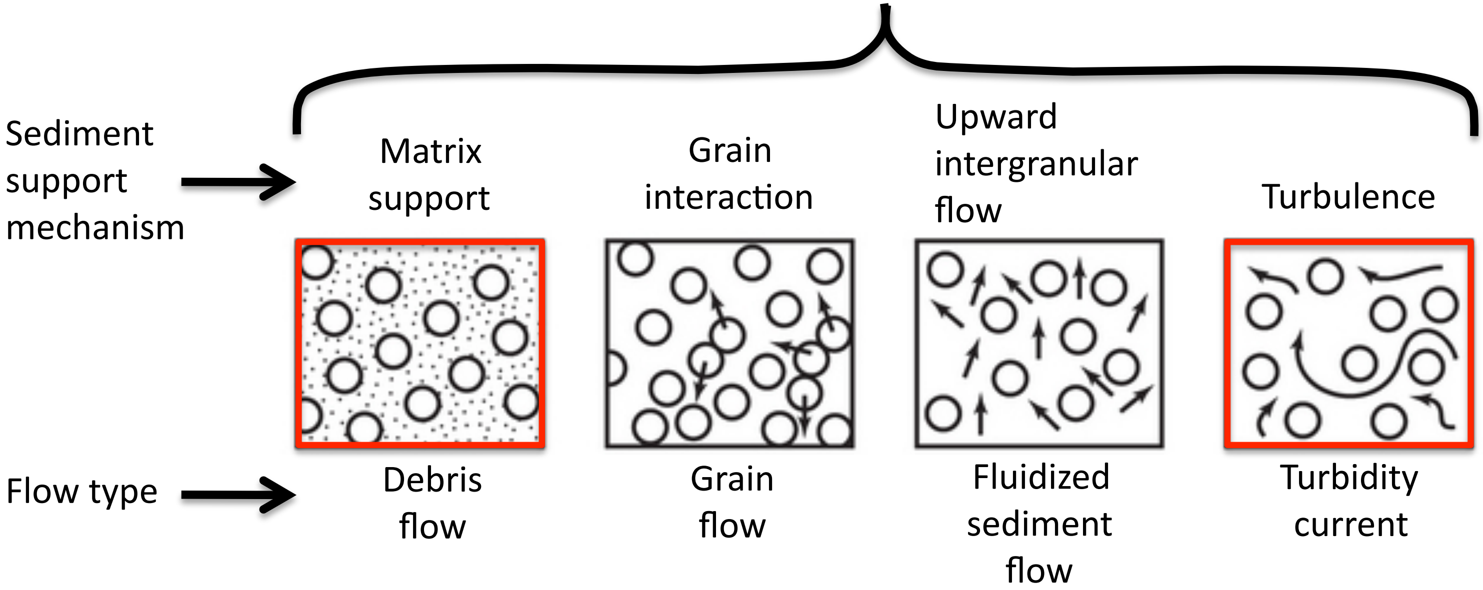
indistinct boundaries
pore fluid important in triggering and motion
→ gravity flow

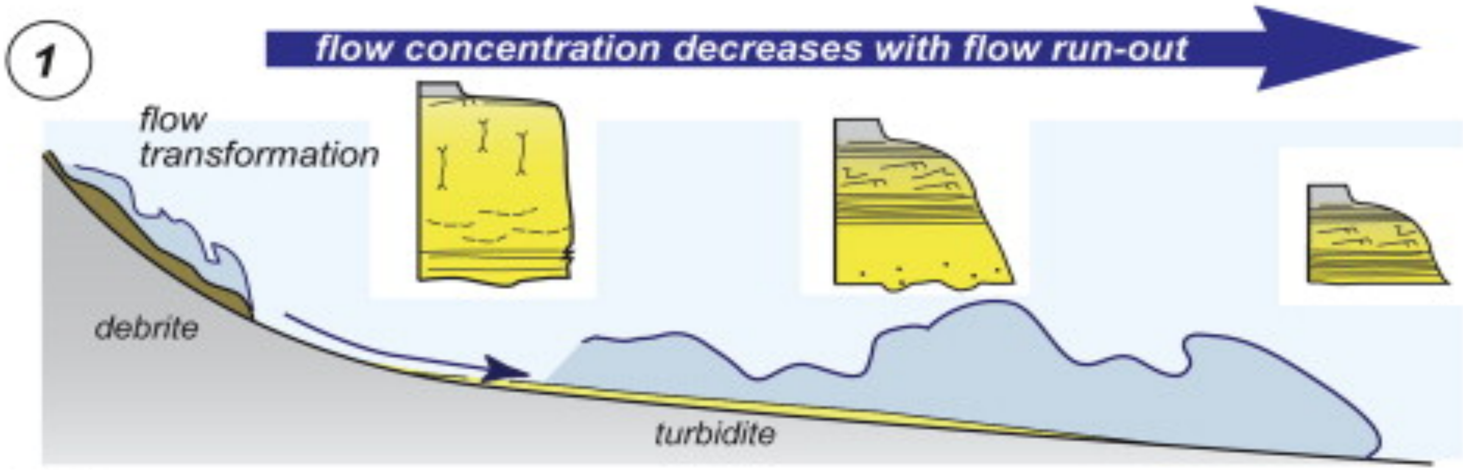
laminar flow → mass flow
→ matrix supported → debris flow
→ fluid supported → grain flow

turbulent flow → turbidity current
→ low density
→ high density

Masson et al. 2006

Gravity flows



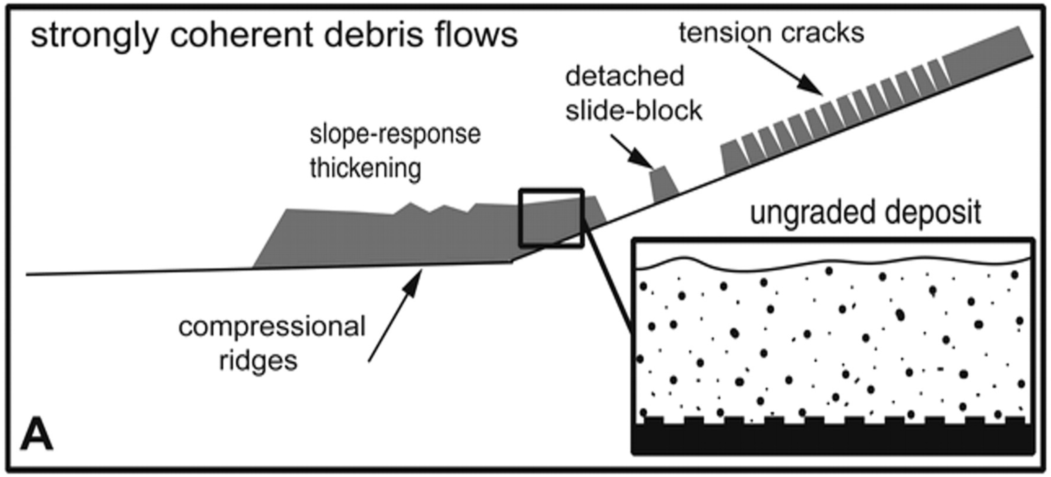


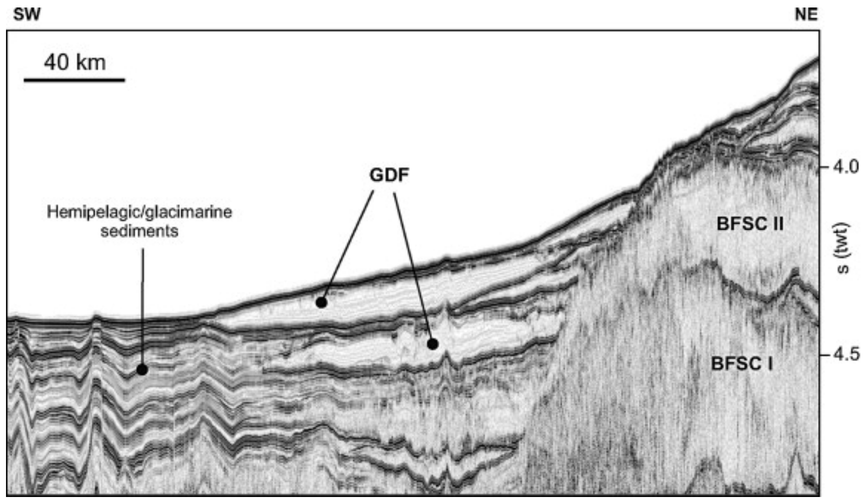
Debris flows

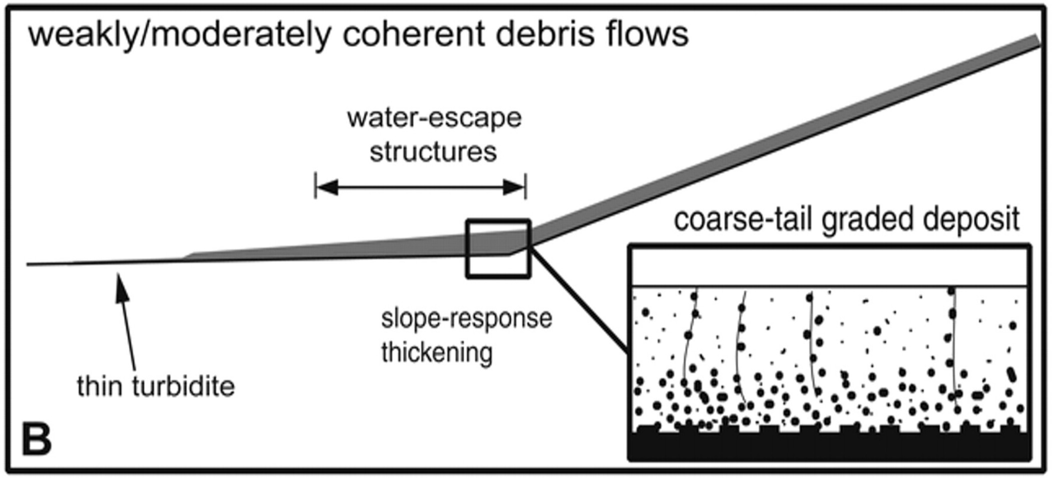
Laminar flux supported by the water-rich muddy matrix

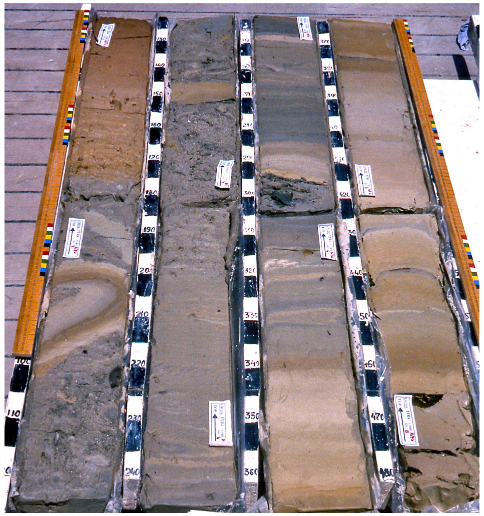
Debris flow: mud/sand >1; pebbles >5%

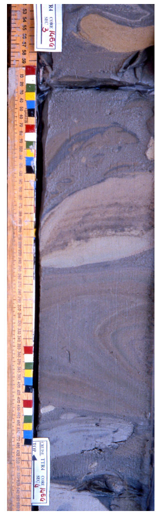
Mud flow: mud/sand <1; pebbles <5%

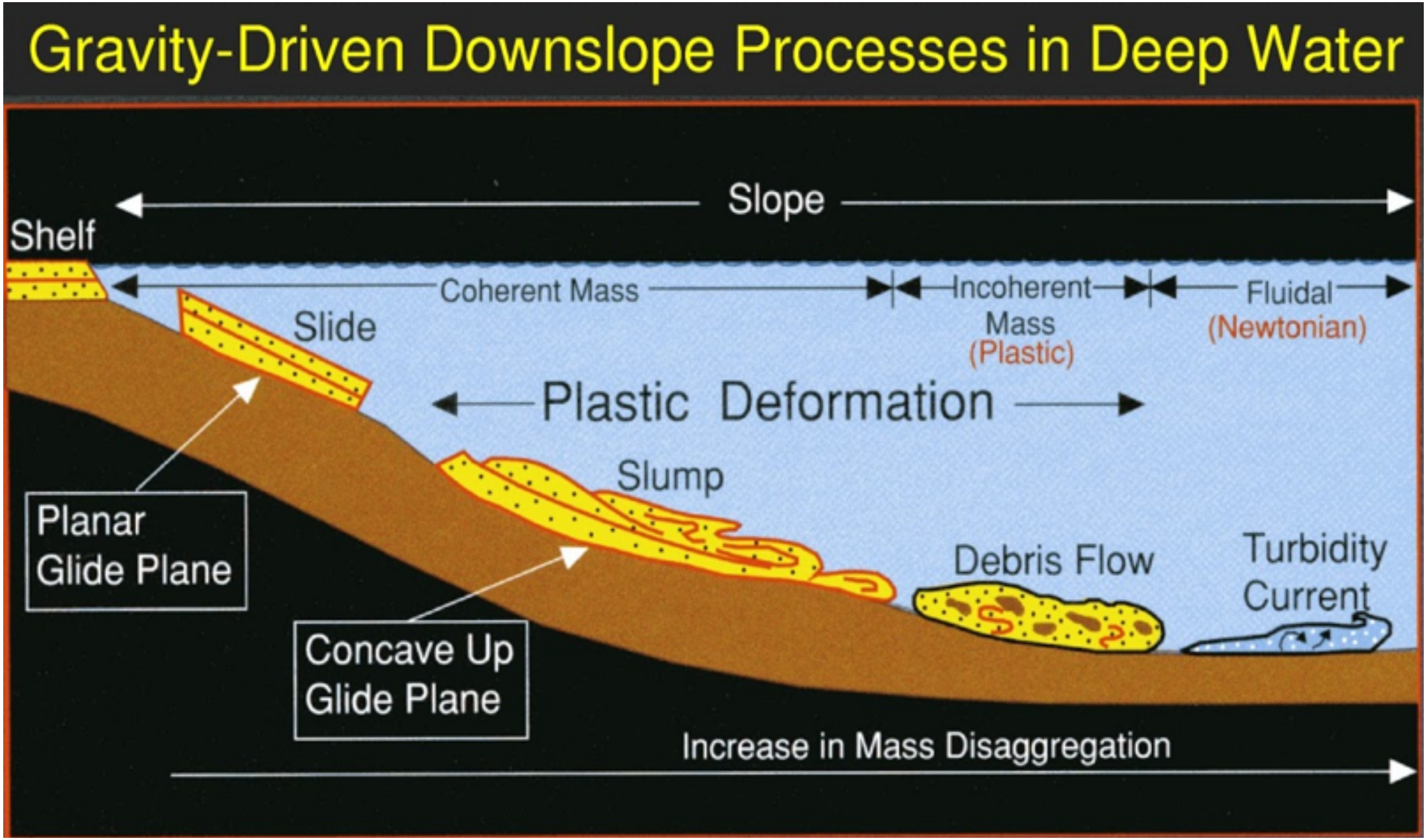






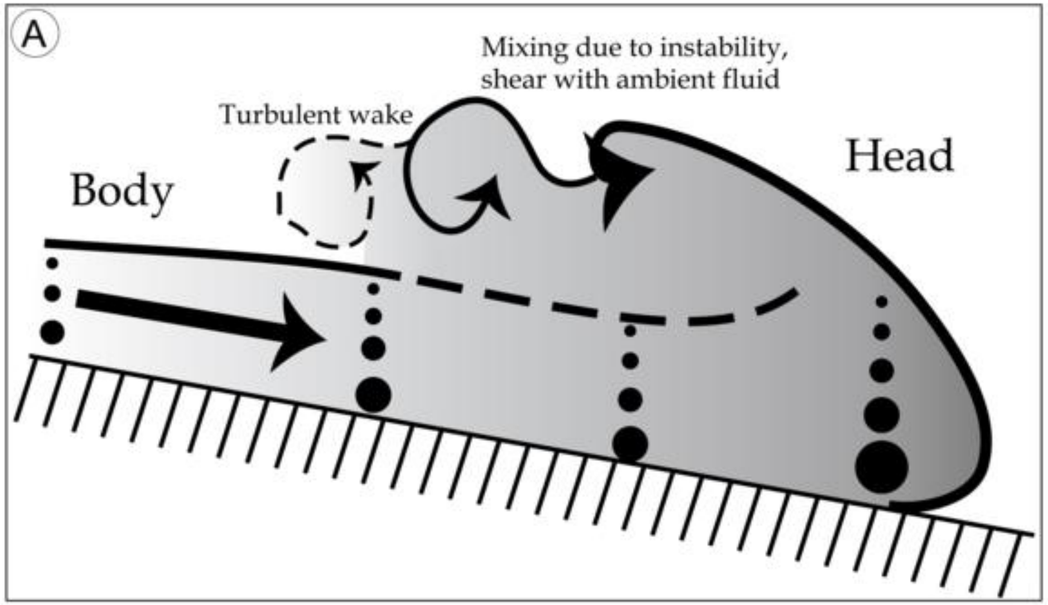


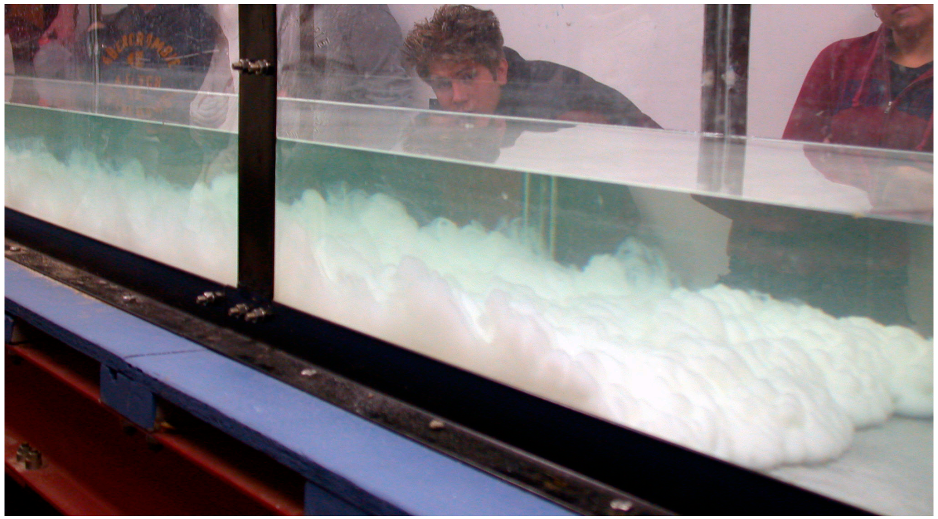


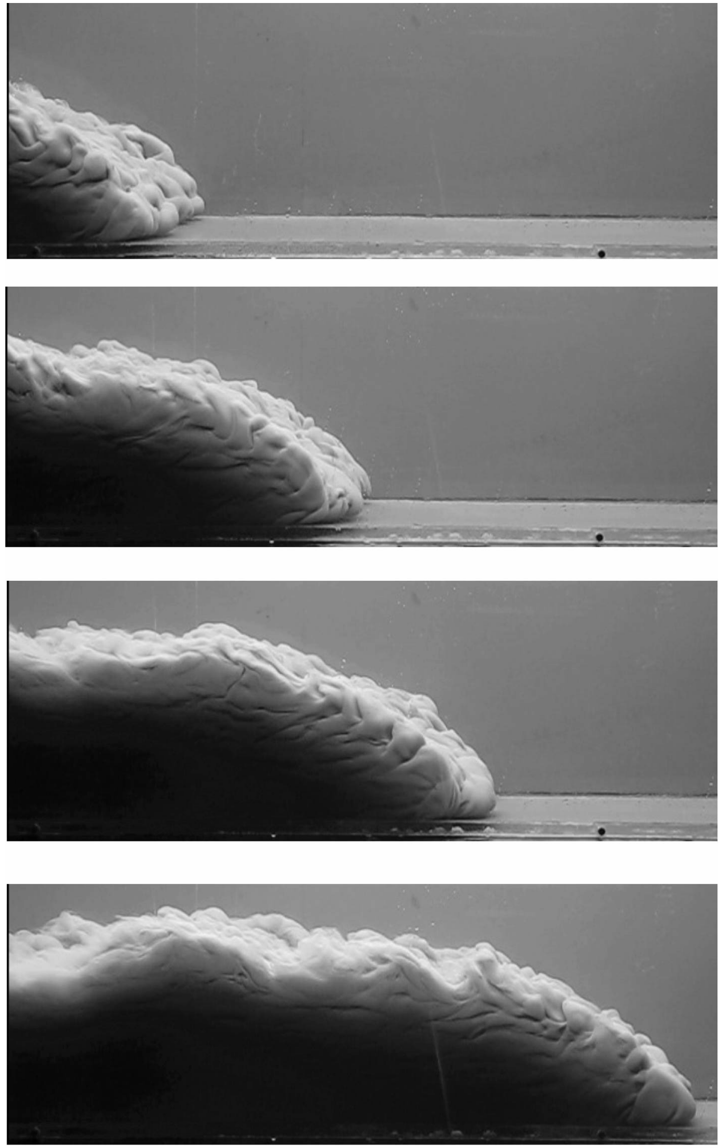

Gravity-Driven Downslope Processes in Deep Water
Slope
Shelf
Coherent Mass
Incoherent Mass (Plastic)
Fluidal (Newtonian)
Slide
Plastic Deformation
Slump
Planar Glide Plane
Concave Up Glide Plane
Debris Flow
Turbidity Current
Increase in Mass Disaggregation

Turbidity flows

Density currents in which the granular support is mantained by the vertical component of the turbolent flux

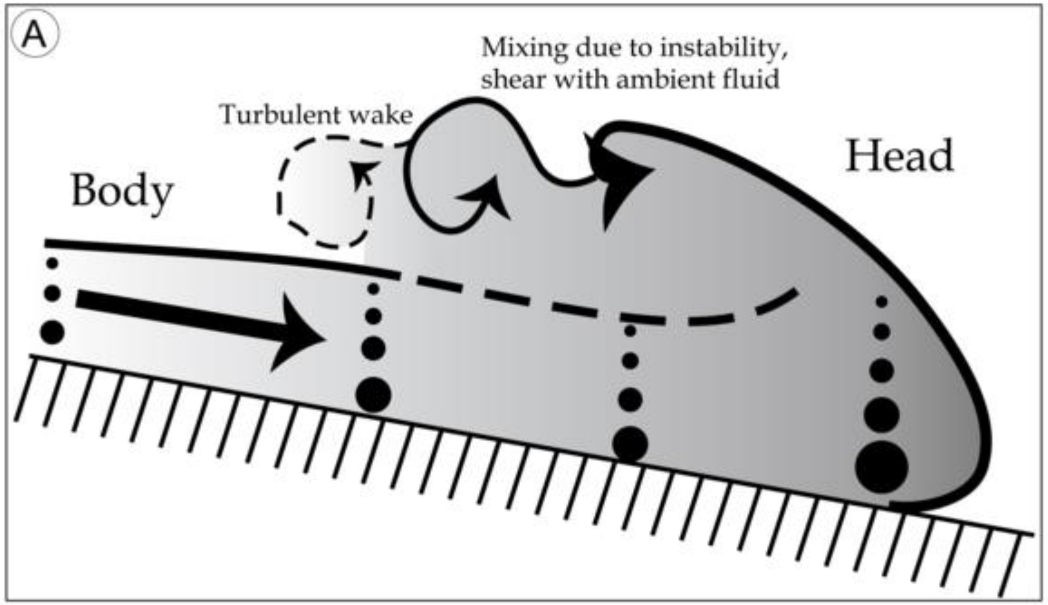


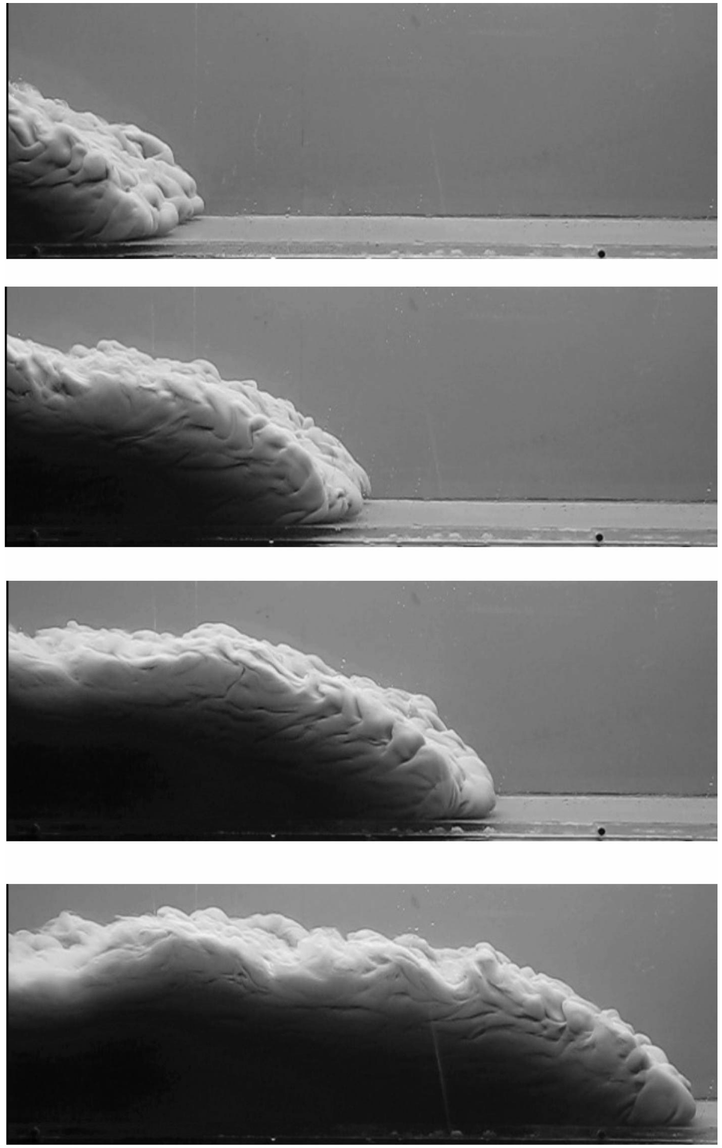




Turbidity flows

Density currents in which the granular support is mantained by the vertical component of the turbolent flux

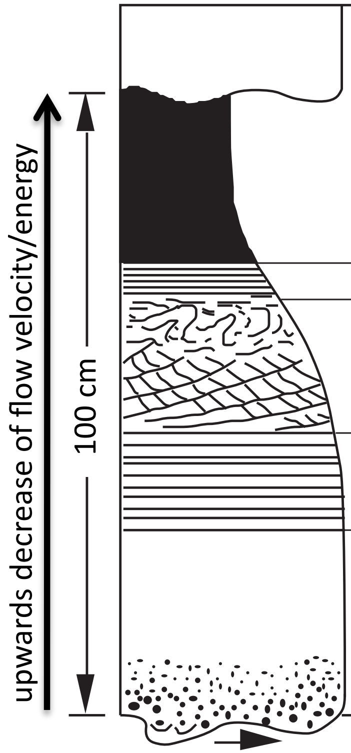




TYPE OF EVENT
Long steady flow (e.g. river fed)
Short surge-type (e.g. river floods, slope instability)

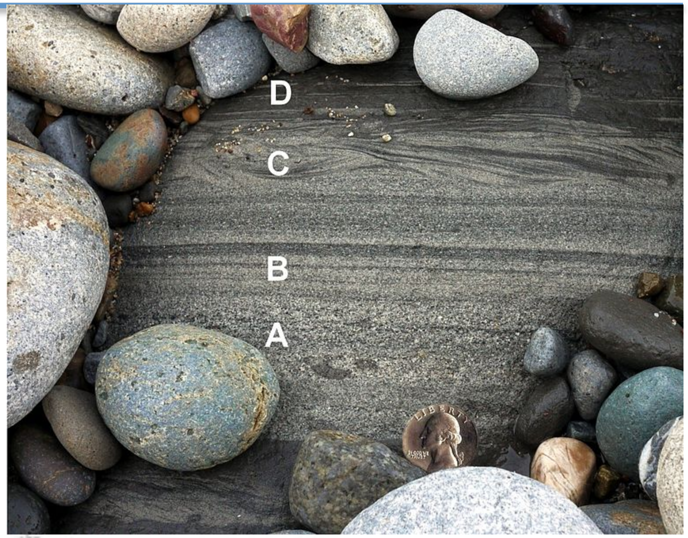
FLOW DENSITY
High density (higher velocity) >1.1 g/cm^3
Low density (lower velocity) <1.1 g/cm^3

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

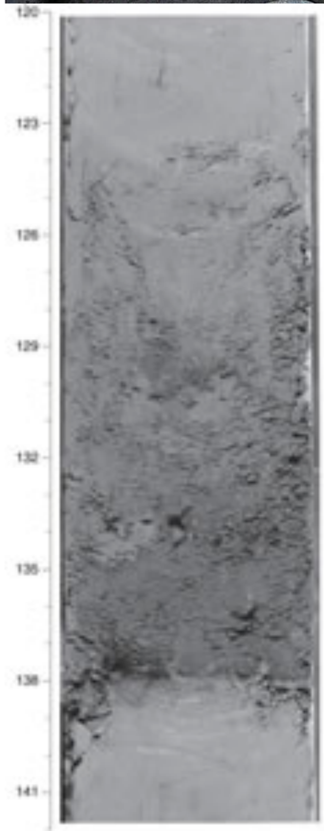


GRAIN SIZE	BOUMA (1962) DIVISION	INTERPRETATION
Mud	E - Laminated to homogeneus mud	Deposition from low-density tail or turbiditi current settling of pelagic or hemipelagic particels
Silt	D - Upper mud/silt laminae	Shear sorting of grains and flocs
Sand	C - ripples, climbing ripples wavy or convolute laminae	Lower part of lower flow regime of Simons et al. (1965)
	B - plane laminae	Upper flow regime plane beds
Coarse sand	A - structurless or graded sand to granule	Rapid deposition with no traction transport possible quick (liquefied) beds

(after Pickering et al., 1989)

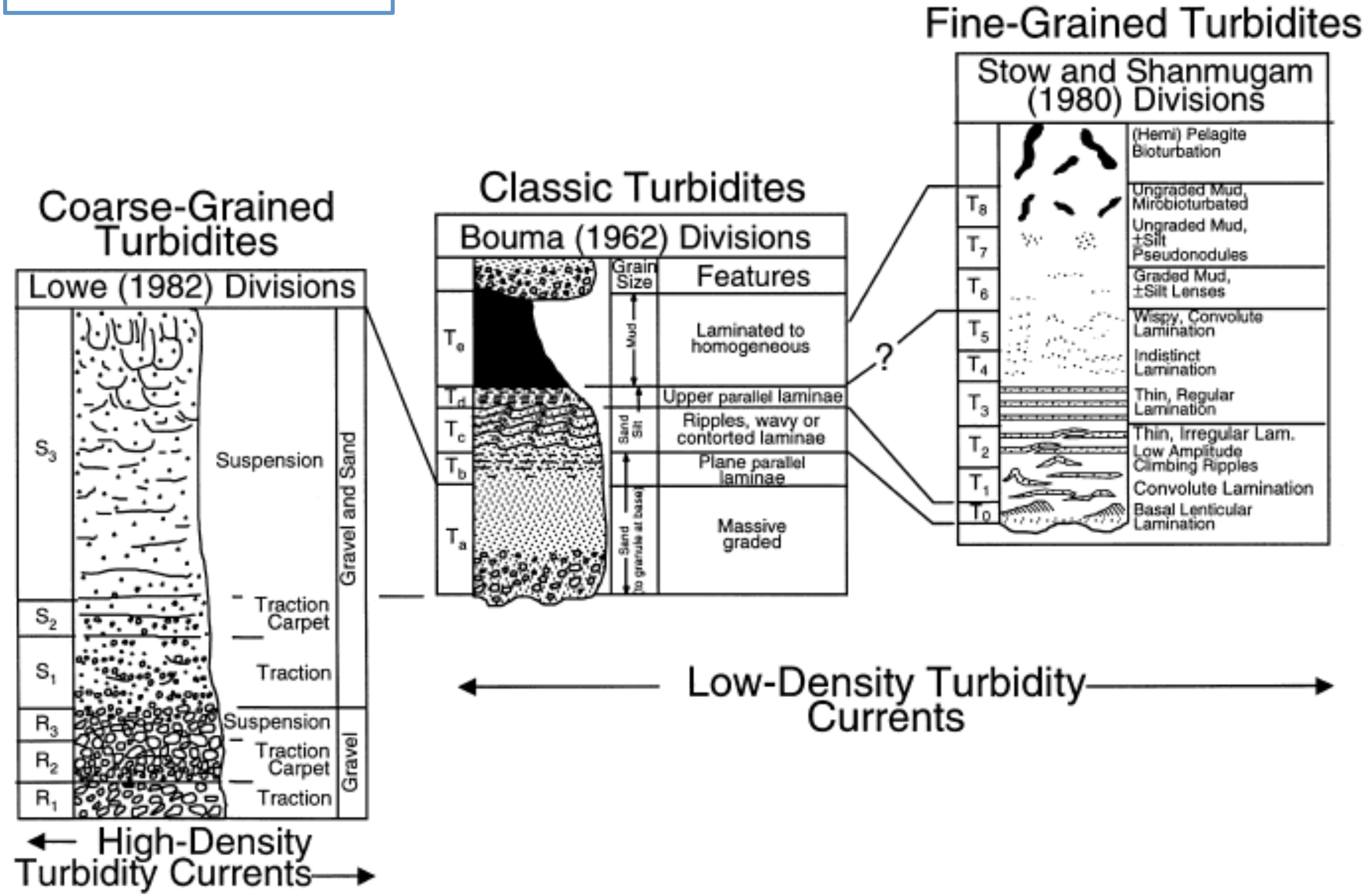


sandy turbidite

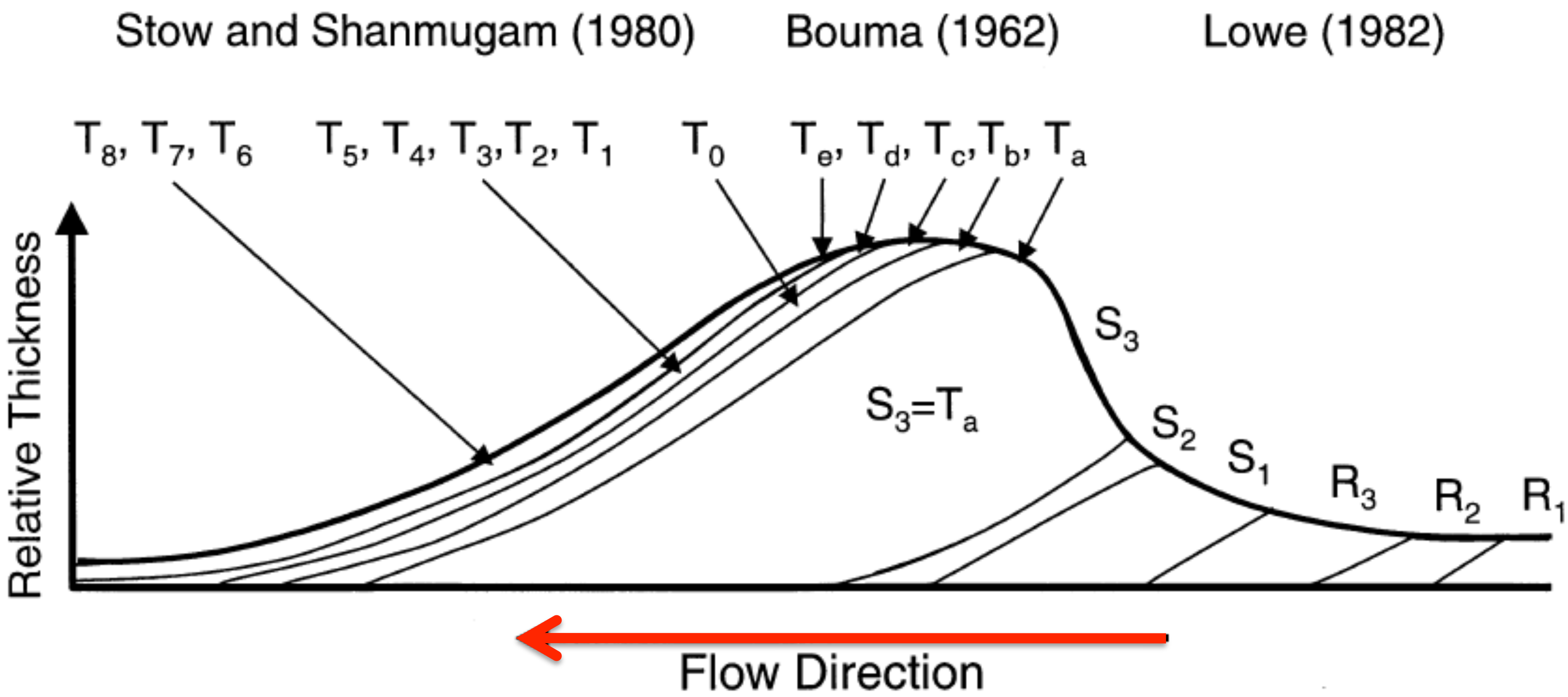


silty turbidite

Turbidite facies

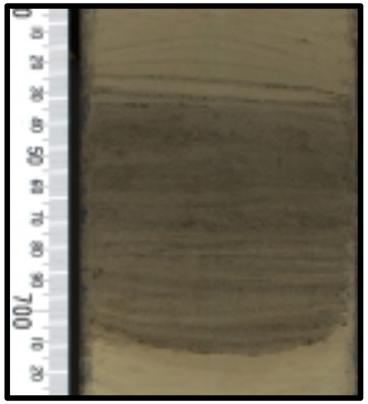


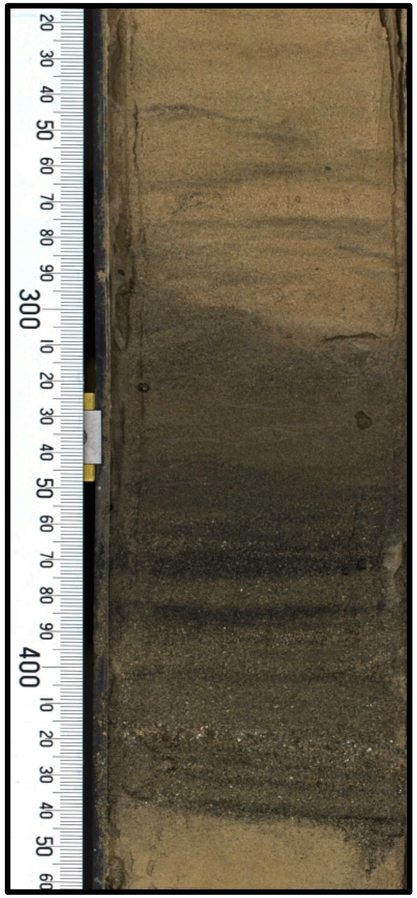
LOW DENSITY turbidity flows



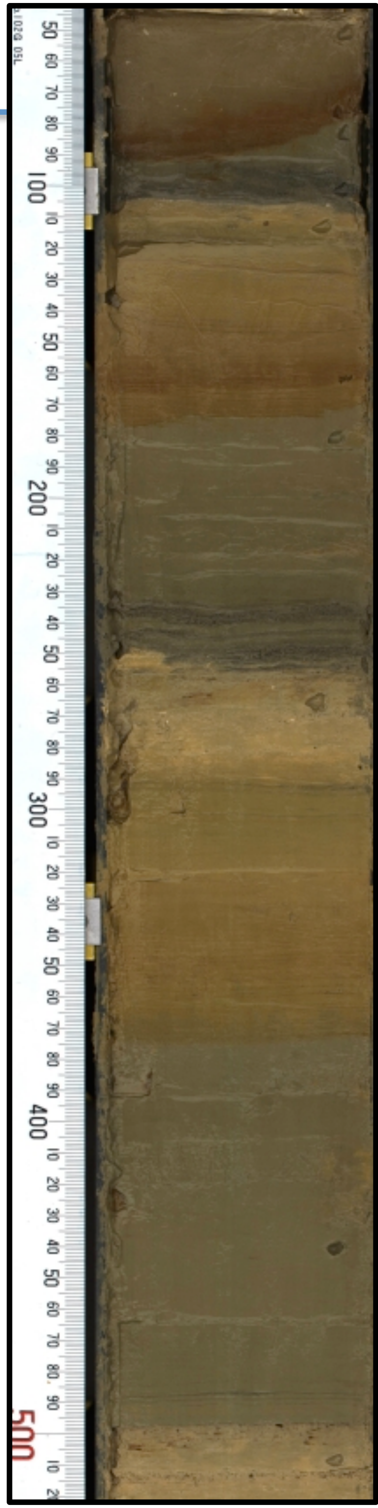
- Shanmugam, G., 2000. 50 years of the turbidite paradigm (1950s-1990s): deep-water processes and facies models – a critical perspective. Marine and Petroleum Geology 17, 285-342.
- Kevin Pickering, Richard Hiscott, 2014. Deep Marine Systems: Processes, Deposits, Environments, Tectonic and Sedimentation.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

silty turbidites



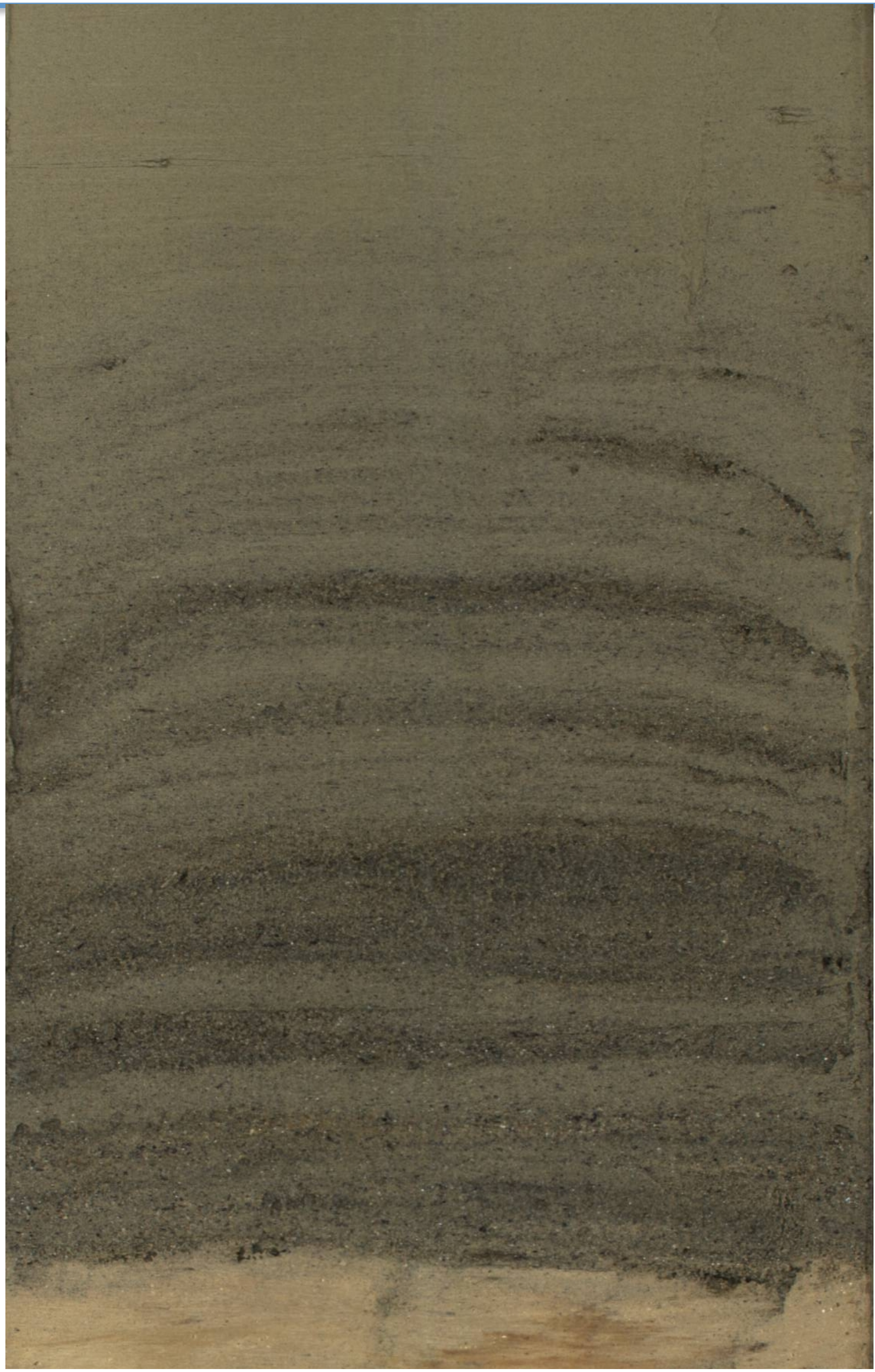


sandy turbidite



muddy turbidites

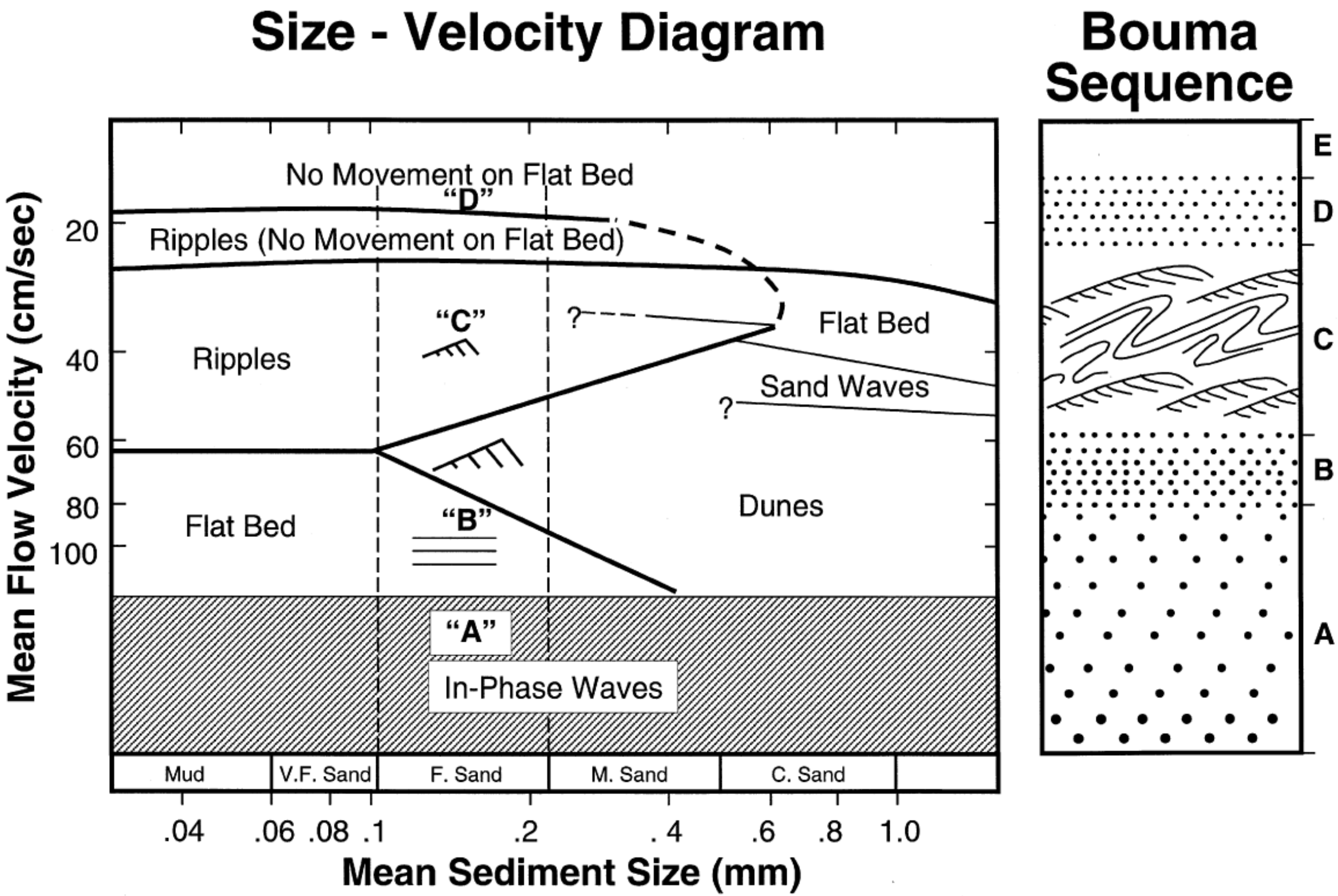
silty turbidite

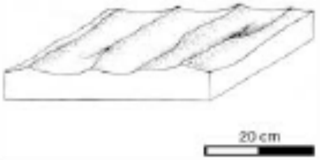
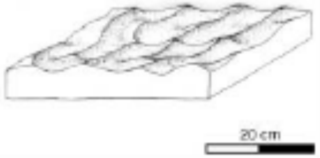
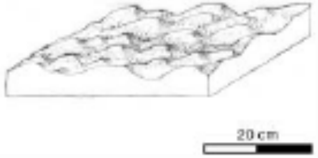
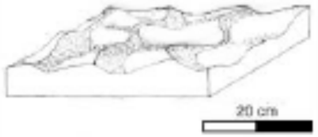


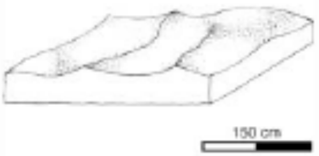
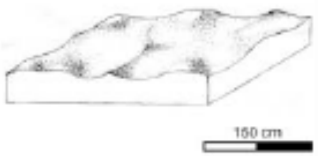
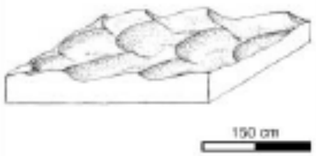
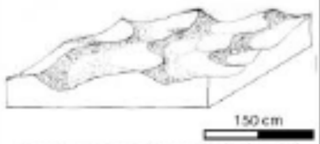
MOST COMMON FEATURES
« Sharp base characterized by sharp grain size change often with sharp color change (careful with sediment oxidation)
« Planar laminations
« Bioturbated top

INDICATION OF SHEAR SORTING
Grain size and compositional sorting trough the deposit. Sorting occur according to size and specific weight (e.g. large forams with medium-size quartz with small-size pyroxene)

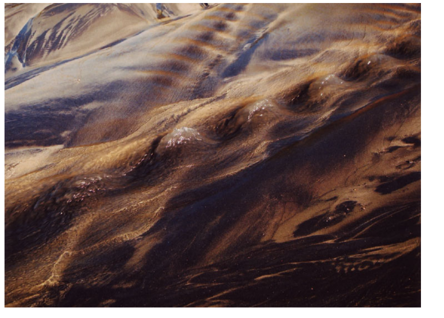
COMPOSITION
Presence of alloctonous particle e.g. shelf derived particle in deep-sea environments (tipically bryozoa, autigenic glauconite)


Size - Velocity Diagram
Bouma Sequence
No Movement on Flat Bed
"D"
Ripples (No Movement on Flat Bed)
"C"
Ripples
Flat Bed
Sand Waves
Flat Bed
"B"
Dunes
"A"
In-Phase Waves
Mud
V.F. Sand
F. Sand
M. Sand
C. Sand
20
40
60
80
100
.04
.06
.08
.1
.2
.4
.6
.8
1.0
Mean Flow Velocity (cm/sec)
Mean Sediment Size (mm)
E
D
C
B
A

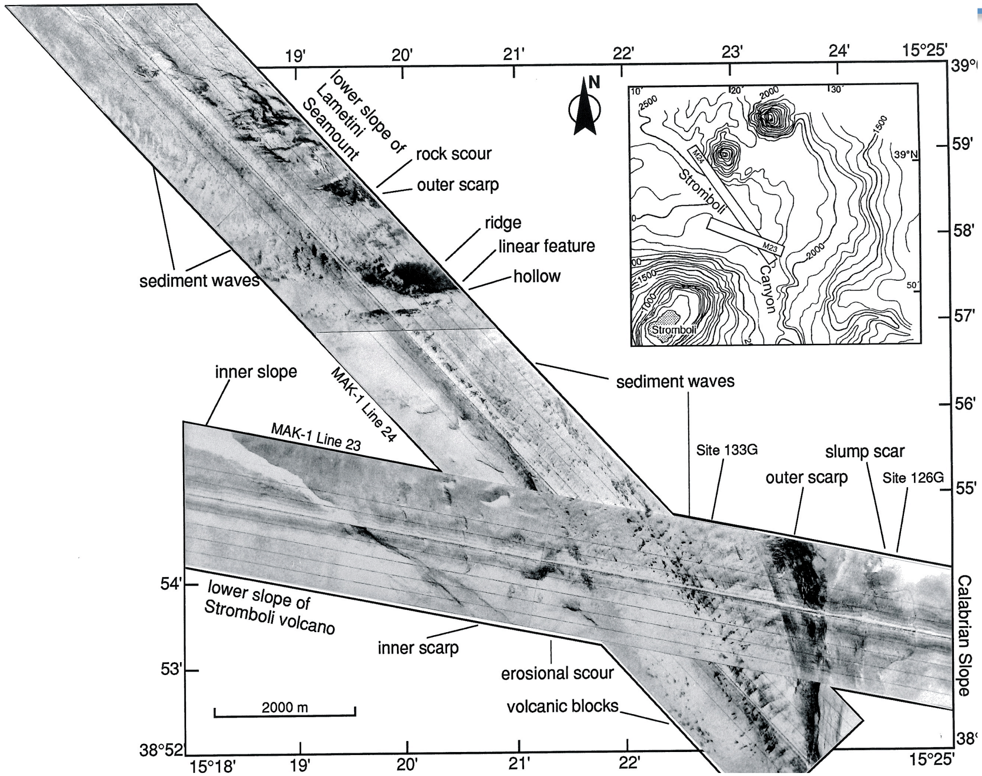
SMALL-SCALE BED FORMS: λ < 20 cm	< 40 cm/s + ~ 0-4 cm/s	< 40 cm/s + ~ 5-10 cm/s	< 40 cm/s + > 10 cm/s	0 cm/s + > ~ 10 cm/s
				 (adapted from Harms et al. 1982, fig.3.7a)
Bed form	**Symmetric small ripples (SSR)** regular, 2D, symmetrical, sharp crests, straight flanks, broad troughs	**SSR + asymmetric small ripples (ASR)** more irregular, 2-2.5D, still symmetrical rounder crests, some straight and some biconvex flanks	**ASR + asymmetric large ripples** irregular, 3D, asymmetrical, larger λ and height, round biconvex profiles, pronounced scour on lower end of stoss	**Current ripples** very irregular, 3D, sharp crests, steep and straight lee, convex-up stoss
Symmetry index	~1.2	~ 1.5		5-10 (Yokokawa 1995)
Dip of lee side	11-18°		"24-27° dip of lee side increases with increasing Uu	~ 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			12-22 (Harms 1969) 7-20 (Allen 1985a) 8-11, fsa (Yokokawa 1995) ~ 20, fsa (Boggs 2001)
Orbital diameter/ wavelength	8-15	~ 8-15	8-15	N/A

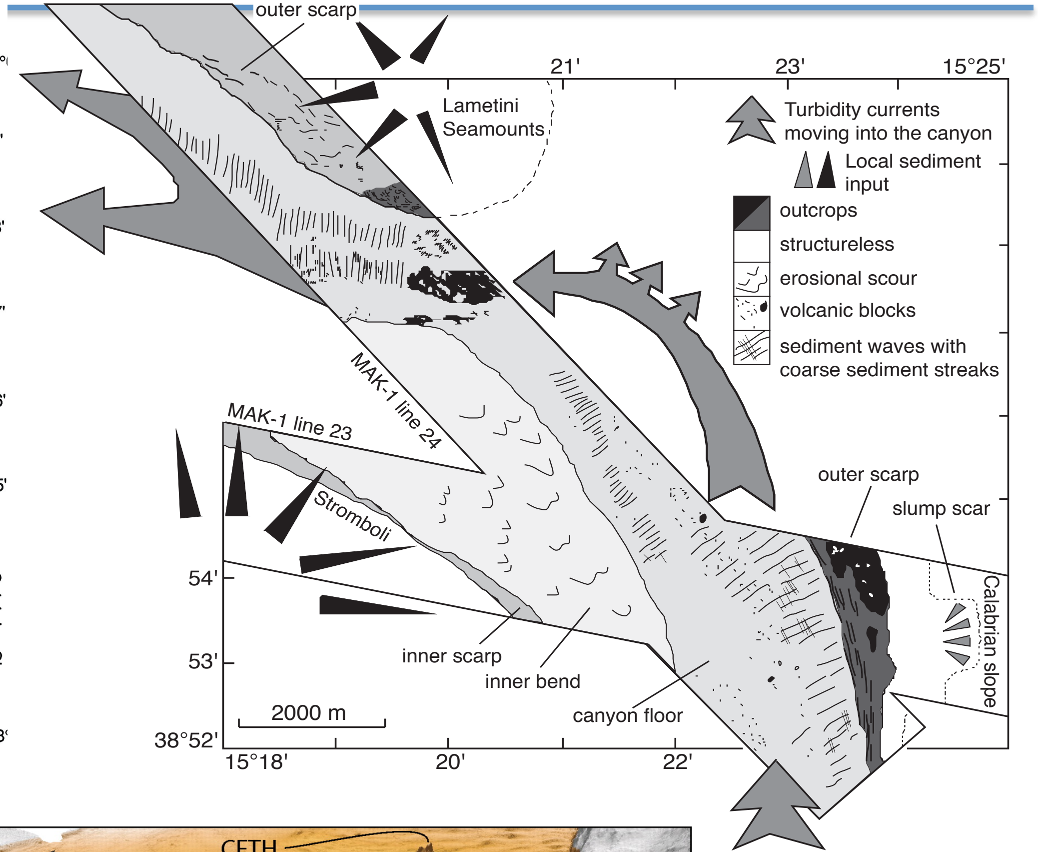
LARGE-SCALE BED FORMS: λ > 100 cm	40-100 cm/s + ~ 0-4 cm/s	40-100 cm/s + ~ 5-10 cm/s	40-100 cm/s + > 10 cm/s	0 cm/s + > ~ 40 cm/s
				 (adapted from Harms et al. 1982, fig.3.10)
Bed form	**Symmetric large ripples (SLR)** SLR: 2.5D, symmetrical, sharp discontinuous crests = to brink, straight flanks	**Hummocky (HM) + SLR + ALR** HM: 3D, symmetrical, no brink point, broad round crests, domal, convex-up flanks	**Asymmetric large ripples (ALR)** ALR: 2D-3D, asymmetrical, brink not always = to crest, round stoss with break in slope, can have scour pits on lower end of stoss	**Dunes** 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), 15-29° reverse large ripples (RLR)		"23-31° dip of lee side increases with increasing Uu	~ 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			12-22 (Harms 1969) 20-40 (Allen 1985a) ~ 5, fsa (Boggs 2001)
Orbital diameter/ wavelength	1-2	1-2	1-2	N/A

antidune formation

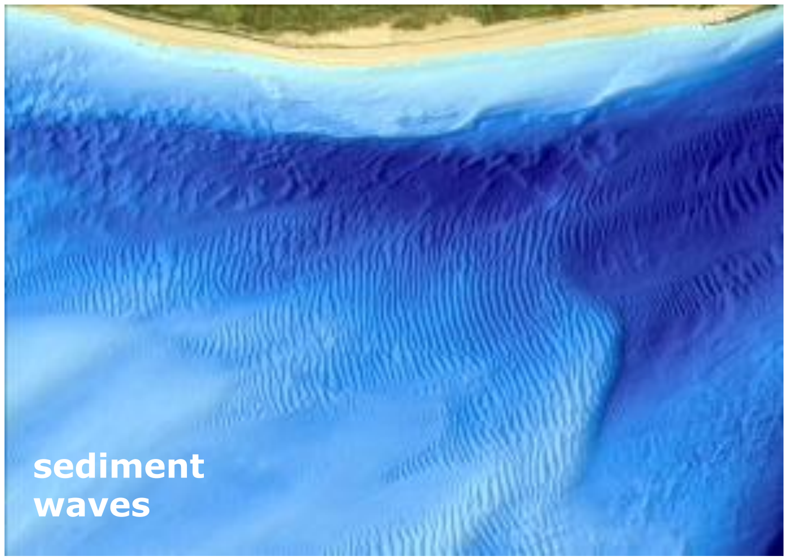


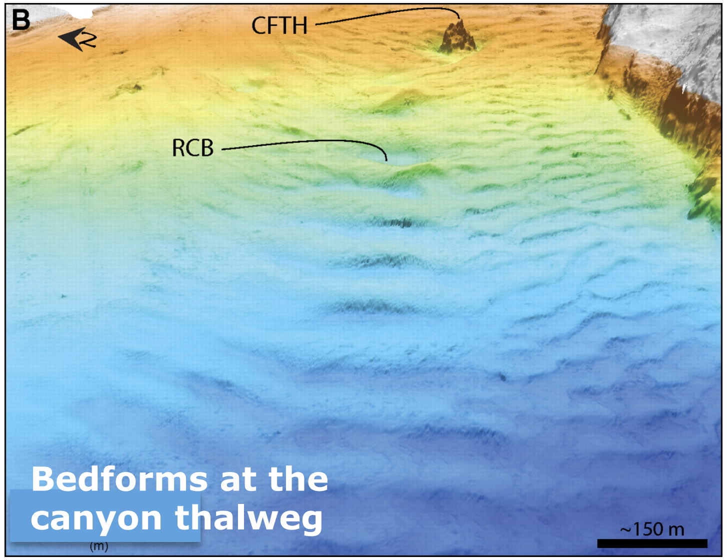
bedforms



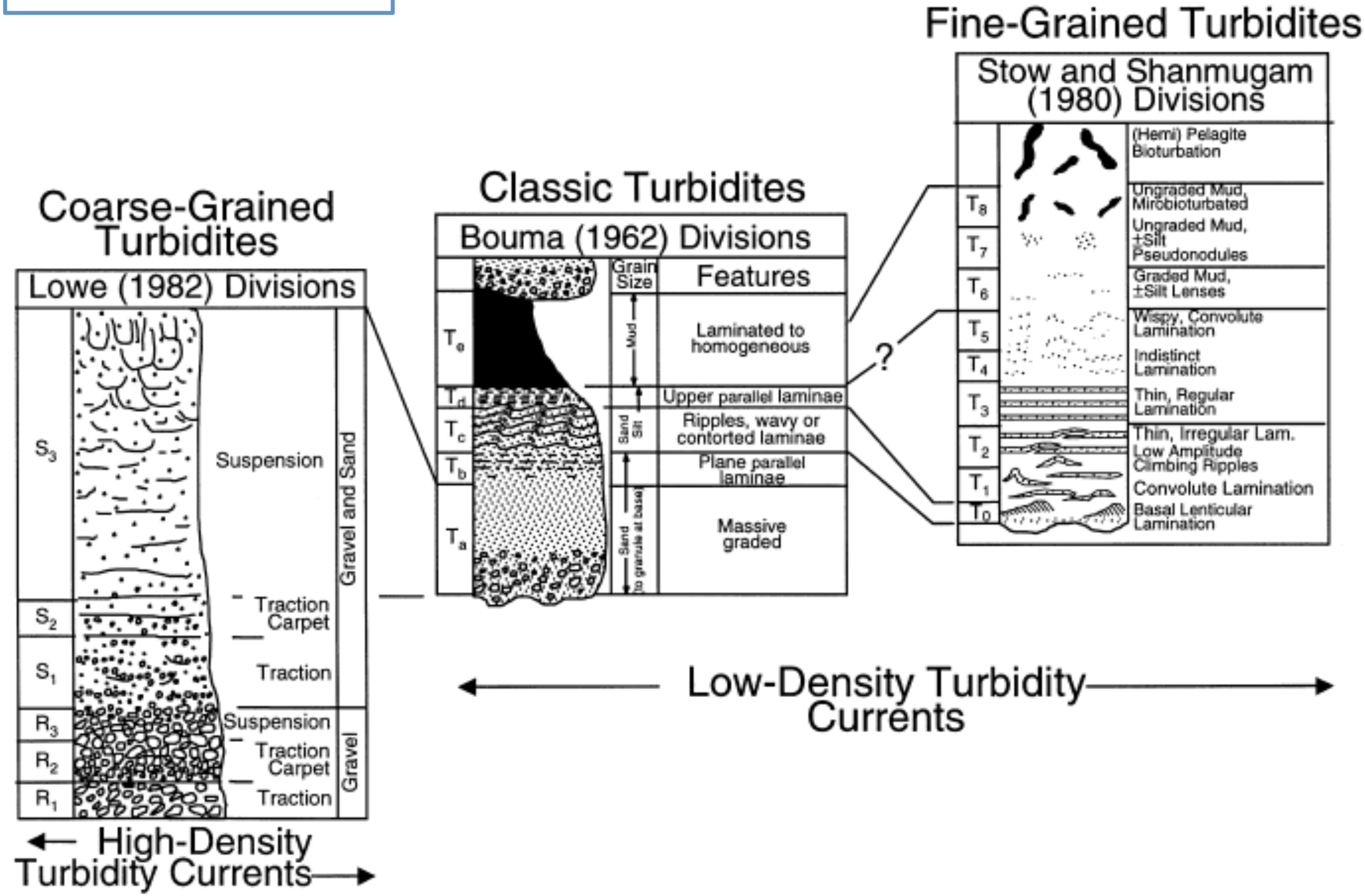


Lucchi, 1997. PhD Thesis, University of Cardiff



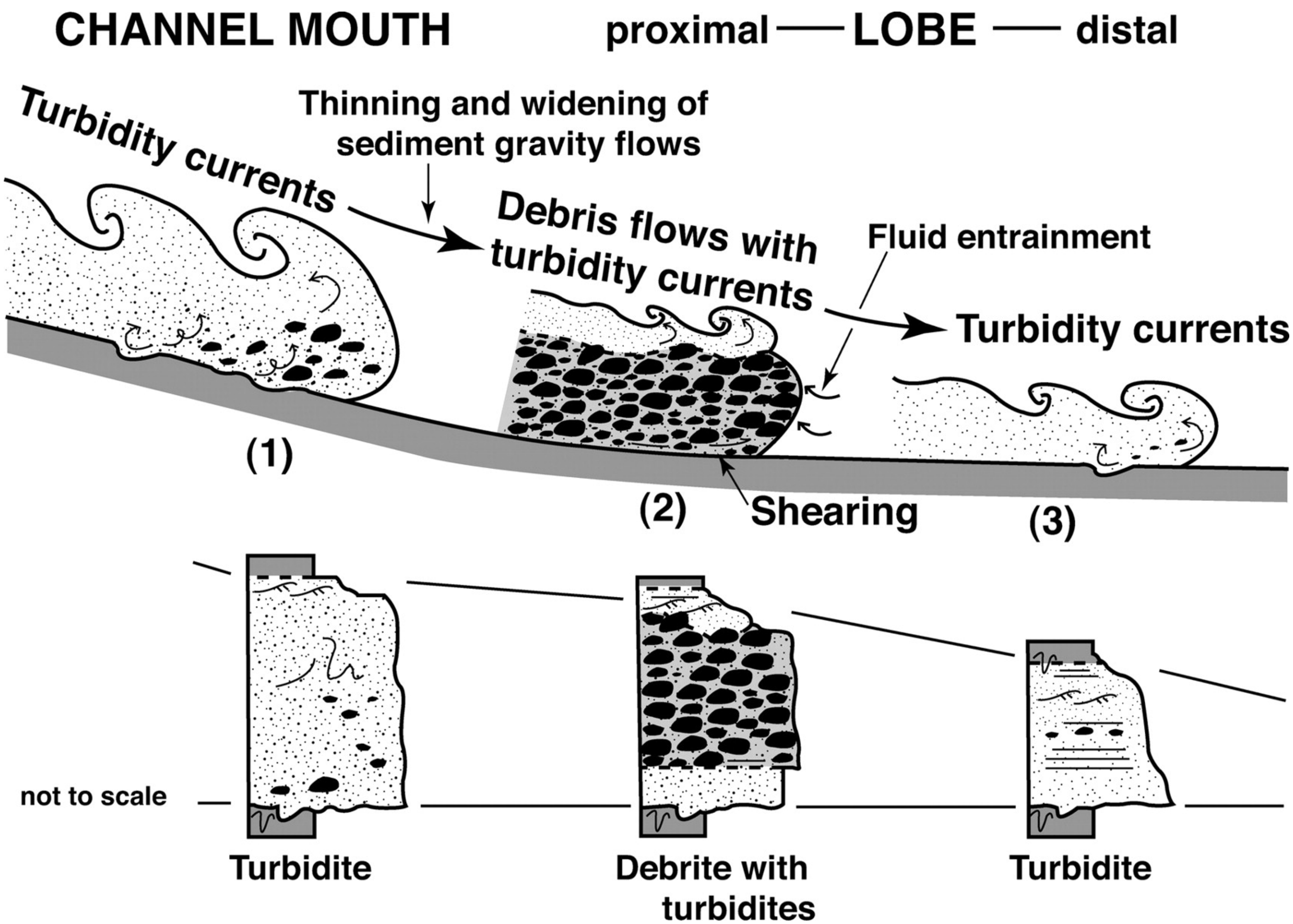


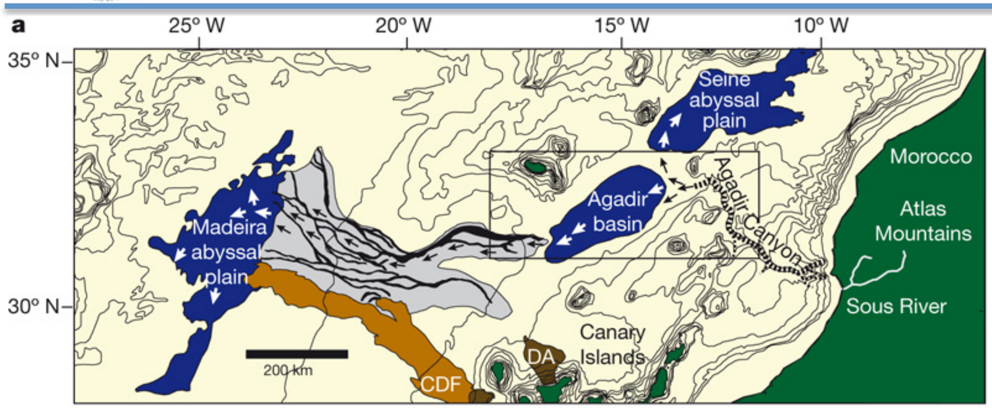
Turbidite facies

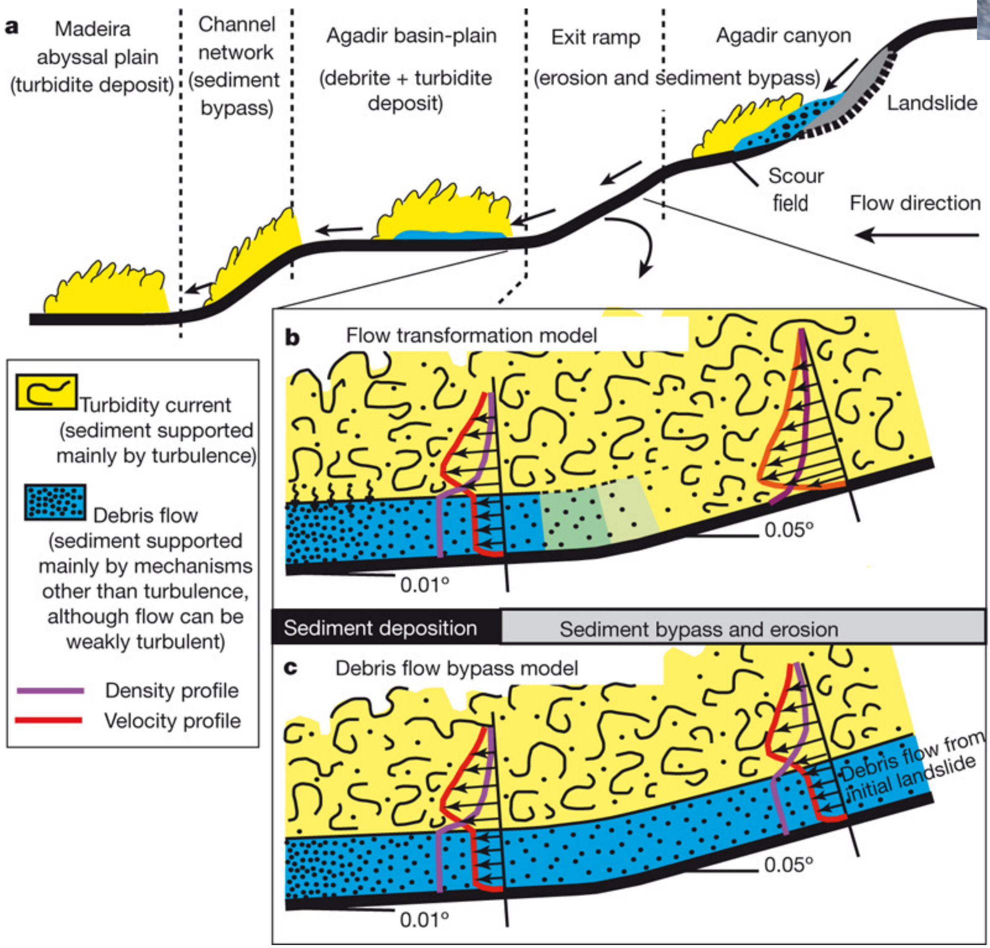


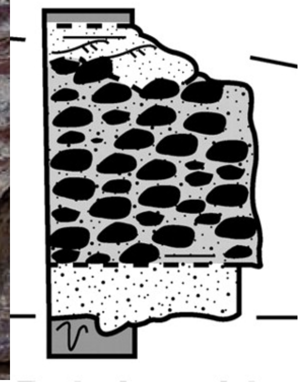
HIGH DENSITY turbidity flows

The *linked debrite*



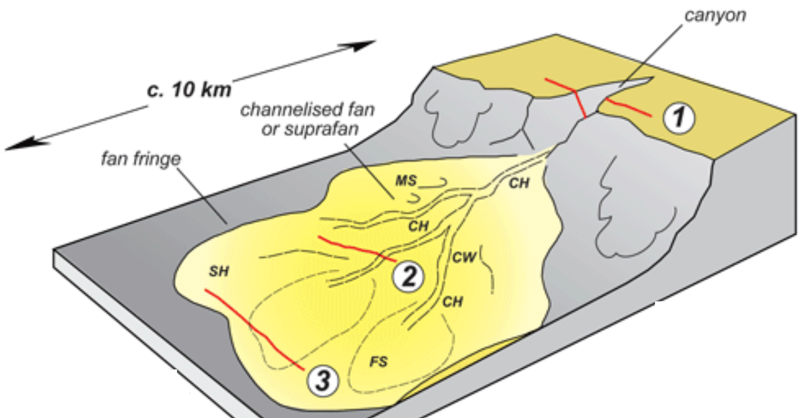




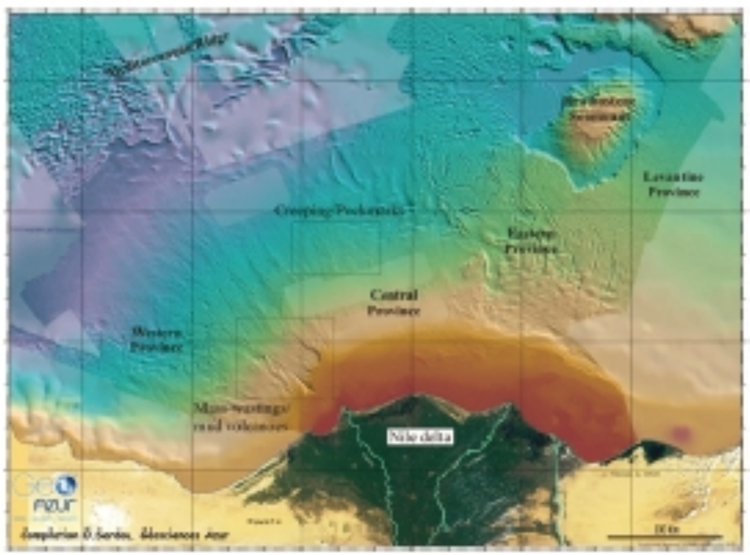


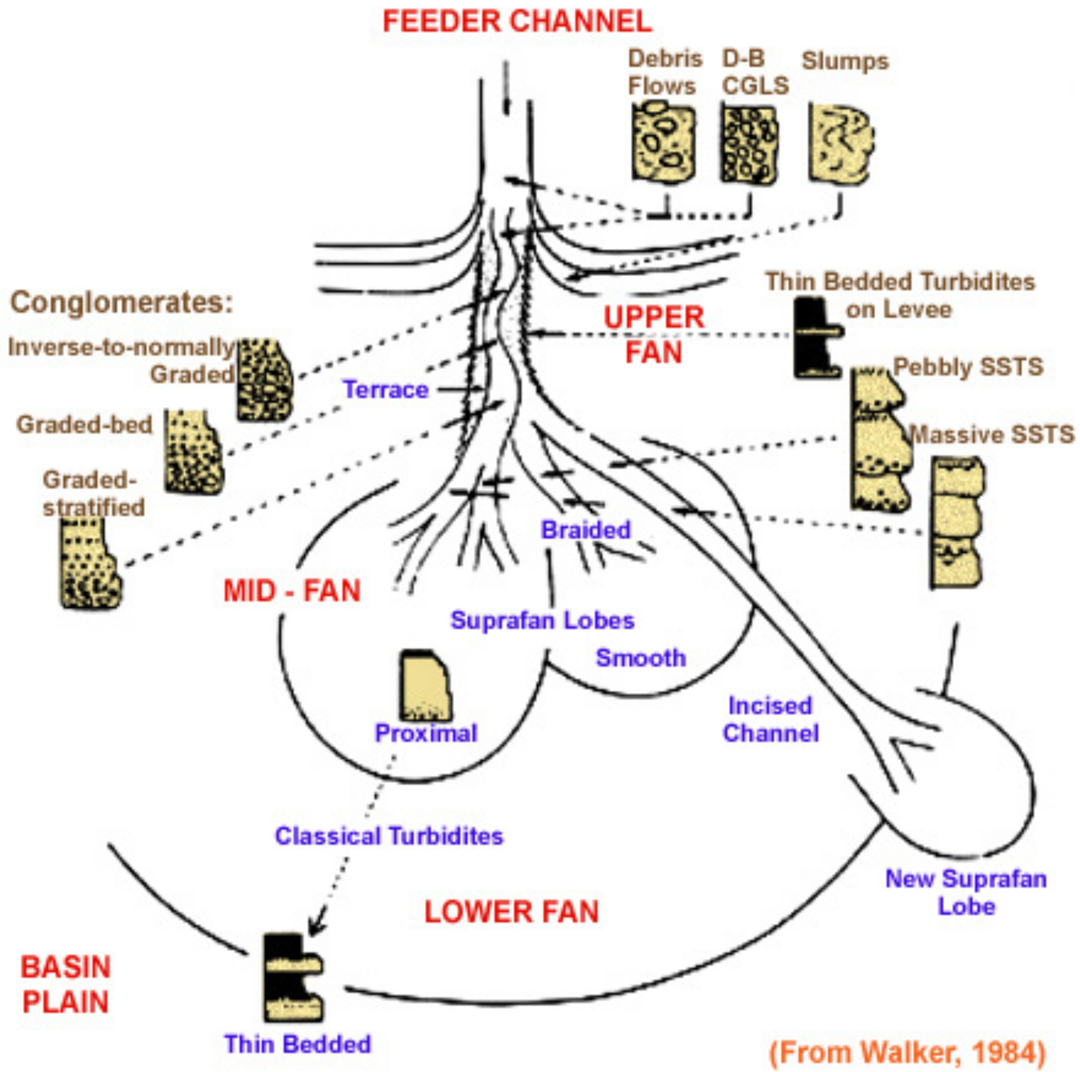
Talling et al., 2007. Nature 450, 541-544.

Confined systems: Canyons and associated deep see fans

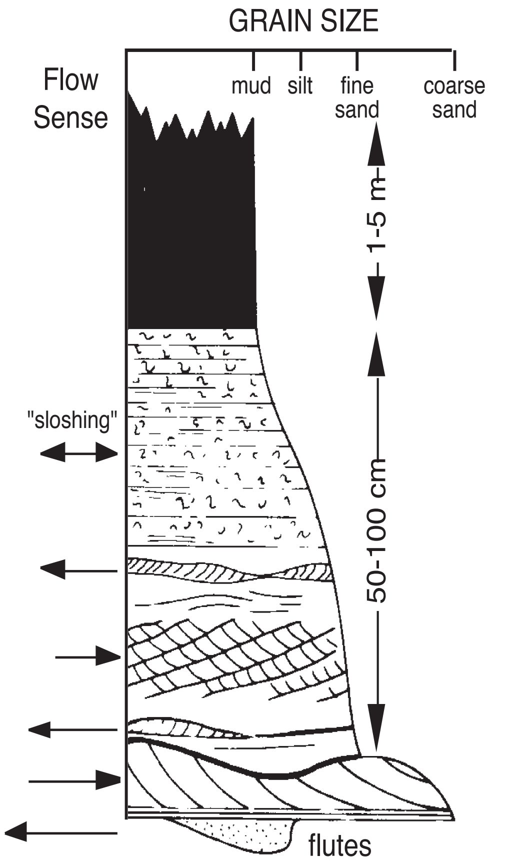


1- shelf
2- mid-fan (proximal area)
3- lower fan (distal area)

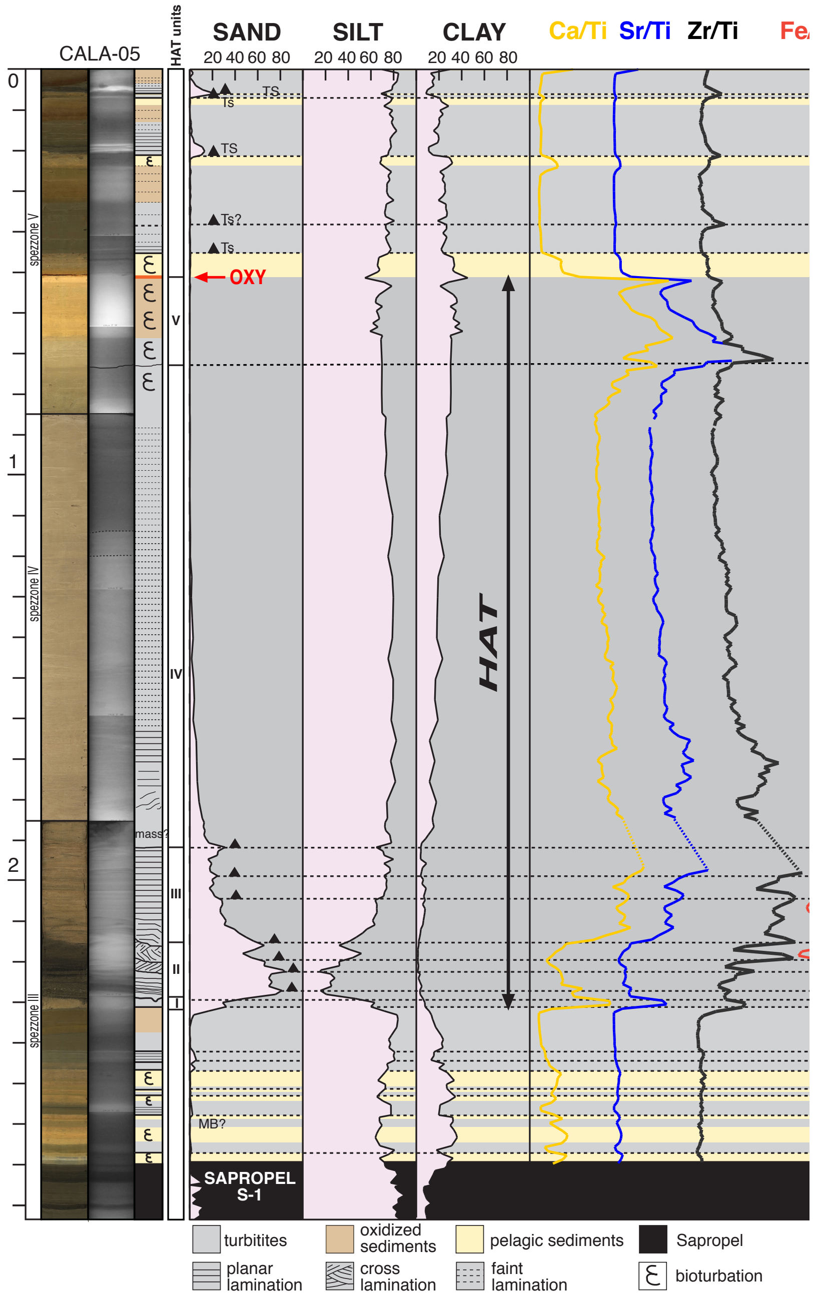




Reflected turbidites and Multi-sources turbidites



DIVISIONS	INTERPRETATION
Homogeneous silty mudstone cap, with scattered load balls near the base	Rapid deposition of mud flocs 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	



Polonia, et al., 2013. Nature

Contourites or Fine-grained turbidites