Università degli Studi di Trieste
Corso di Sedimentologia

Anno accademico 2015– 2016

Modern deep-sea sedimentary processes

Turbidity Flows
Contour Currents
Sediment Laden Plumes

Relatore
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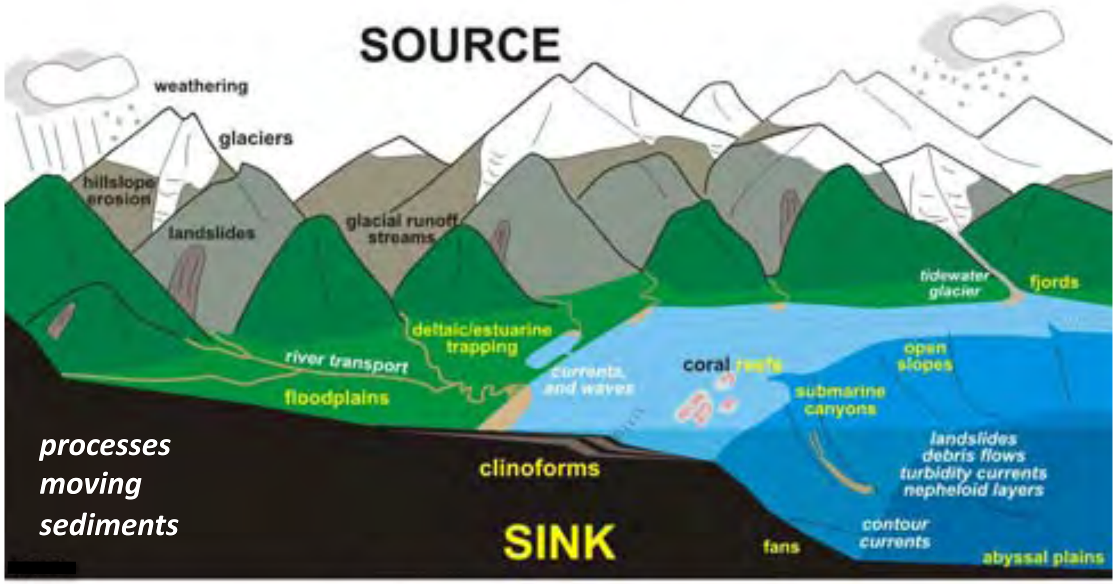
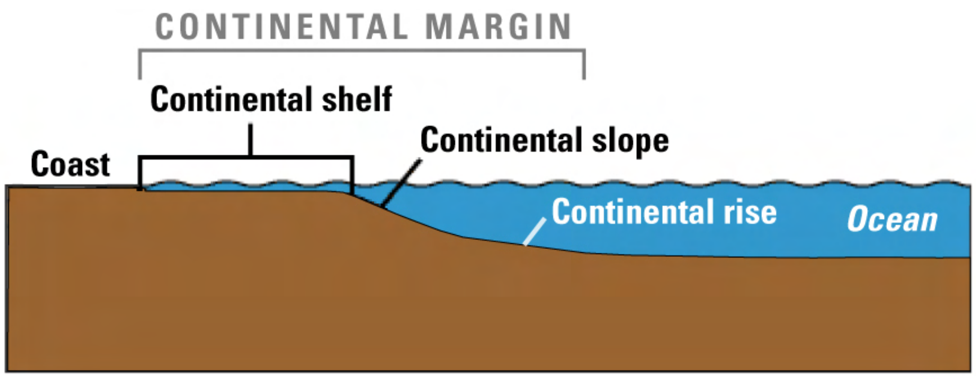
the Source to Sink System



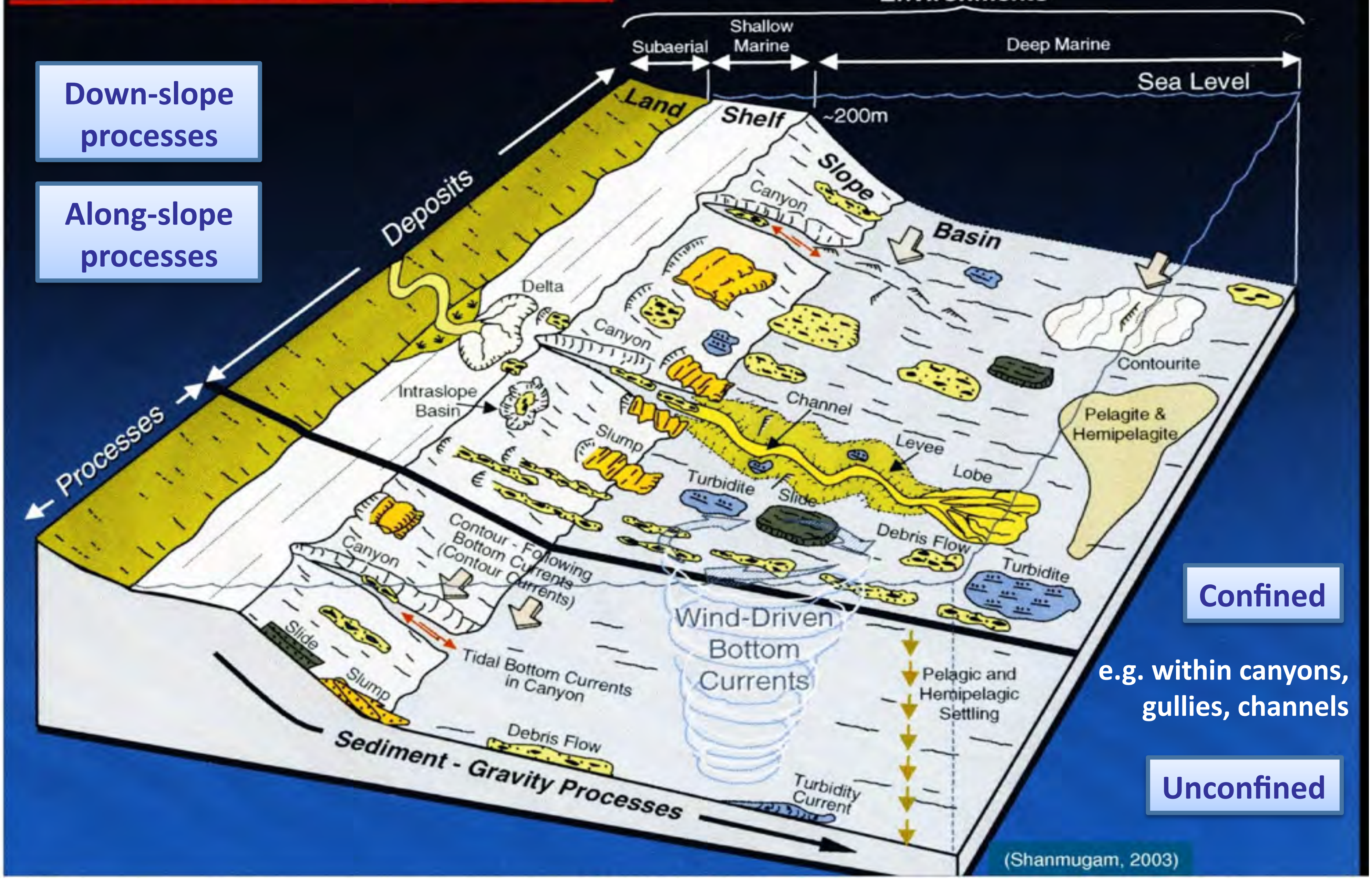
Sedimentary Processes on Continental Margins

<u>down-slope</u>: driven by gravity forces
<u>along-slope</u>: 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)

Deep-Marine Systems



Down-slope processes

Along-slope processes

Confined

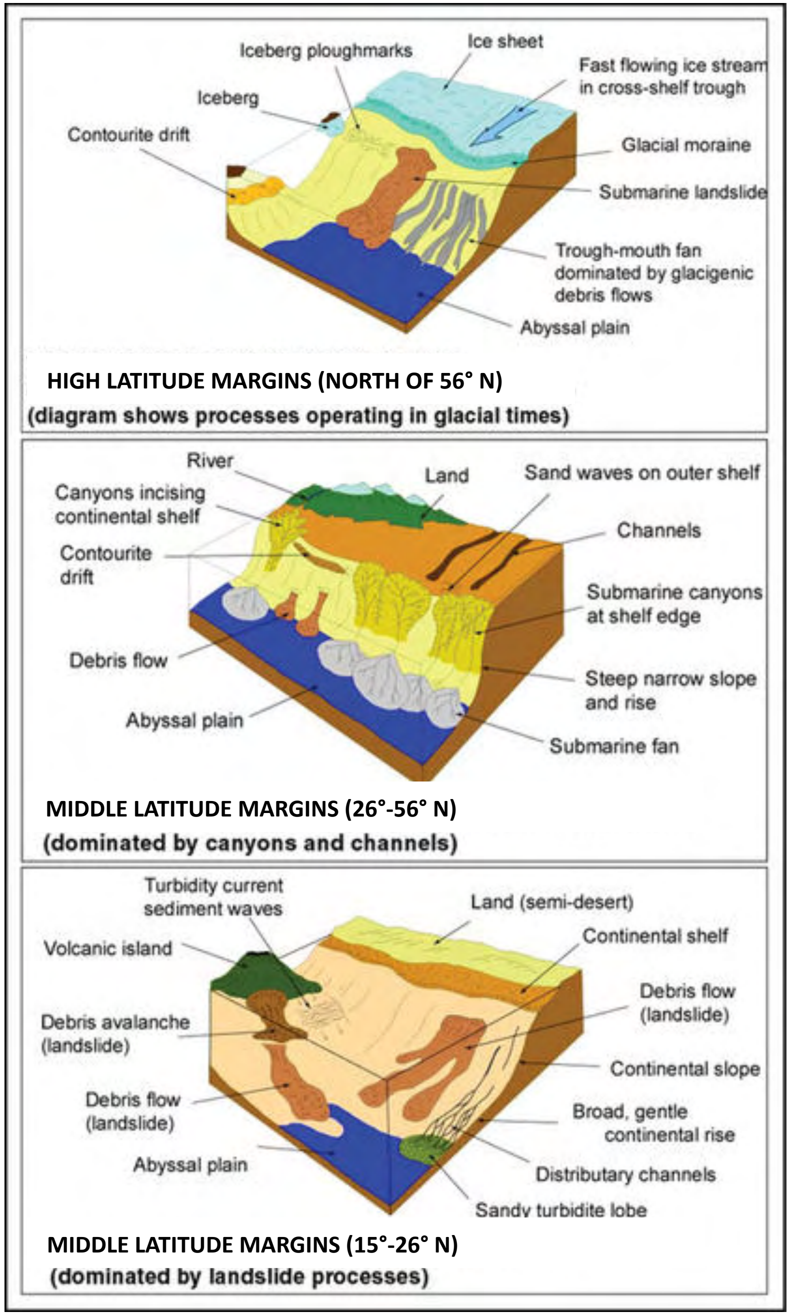
e.g. within canyons, gullies, channels

Unconfined

Glacial processes

River processes

Starving areas



Sedimentary processes on Continental Margins

Depositional process ➔ ***Deposit***

down-slope processes: driven by gravity forces

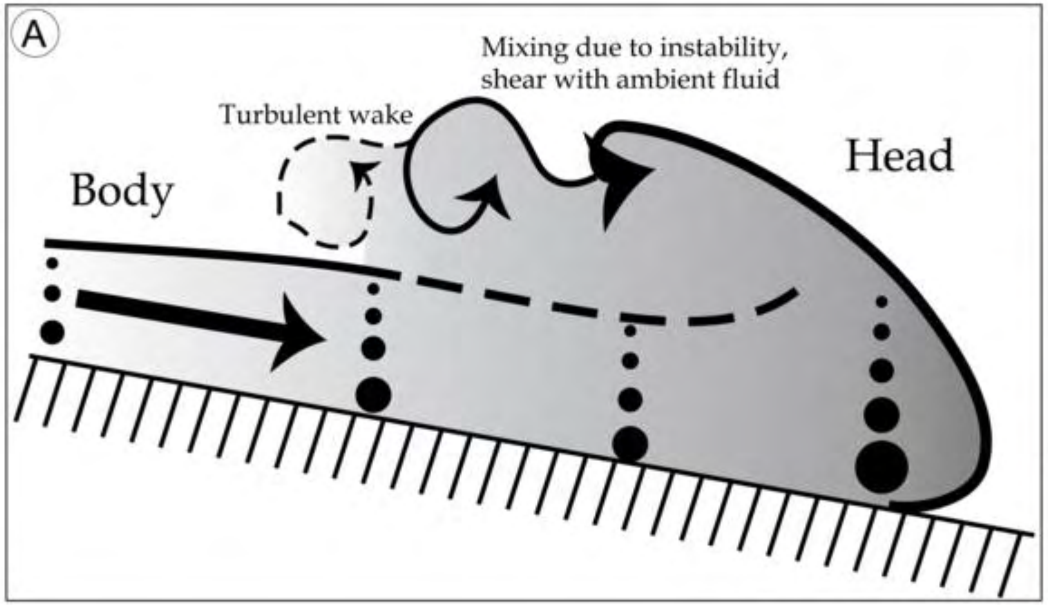
» Mass Transport Deposition ➔ ***MTDs***
» Turbidity currents ➔ ***Turbidites***
» Riverine outflows ➔ ***Hyper (Hypo)- picnites***
» Turbid meltwaters ➔ ***Plumites***
» Brine-related deposition

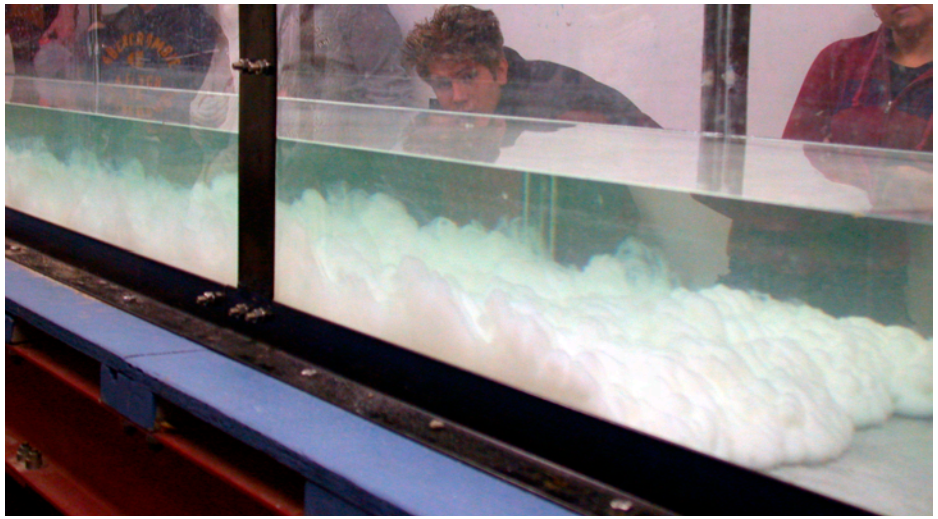
along-slope: driven by density forces (thermo-haline origin)

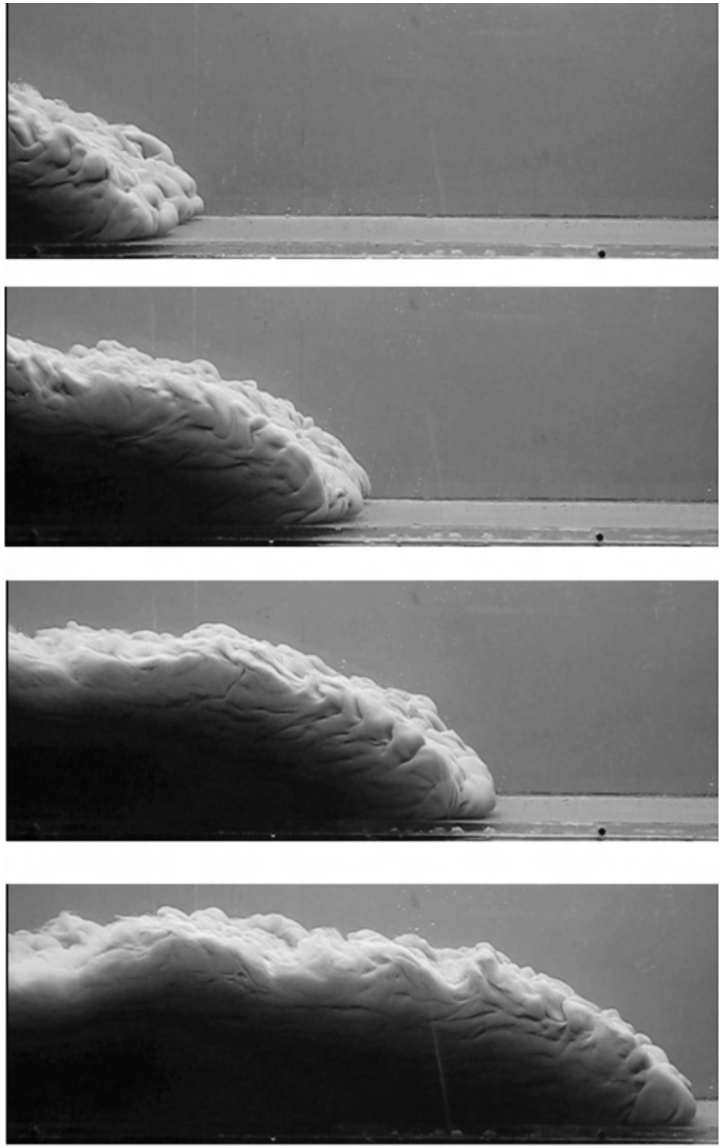
» Contour currents ➔ ***Contourites***

Turbidity flows

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

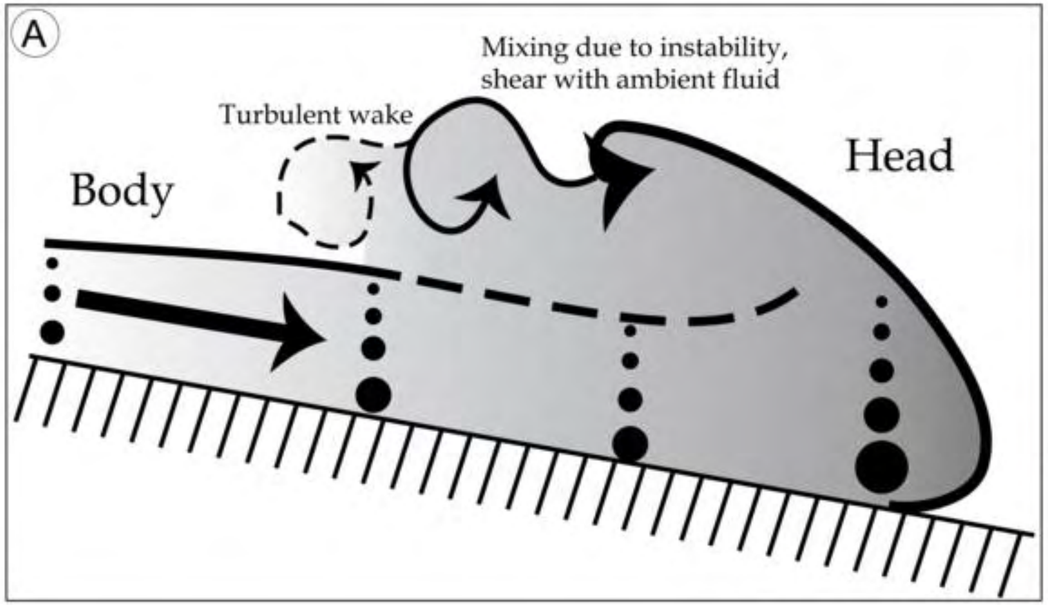


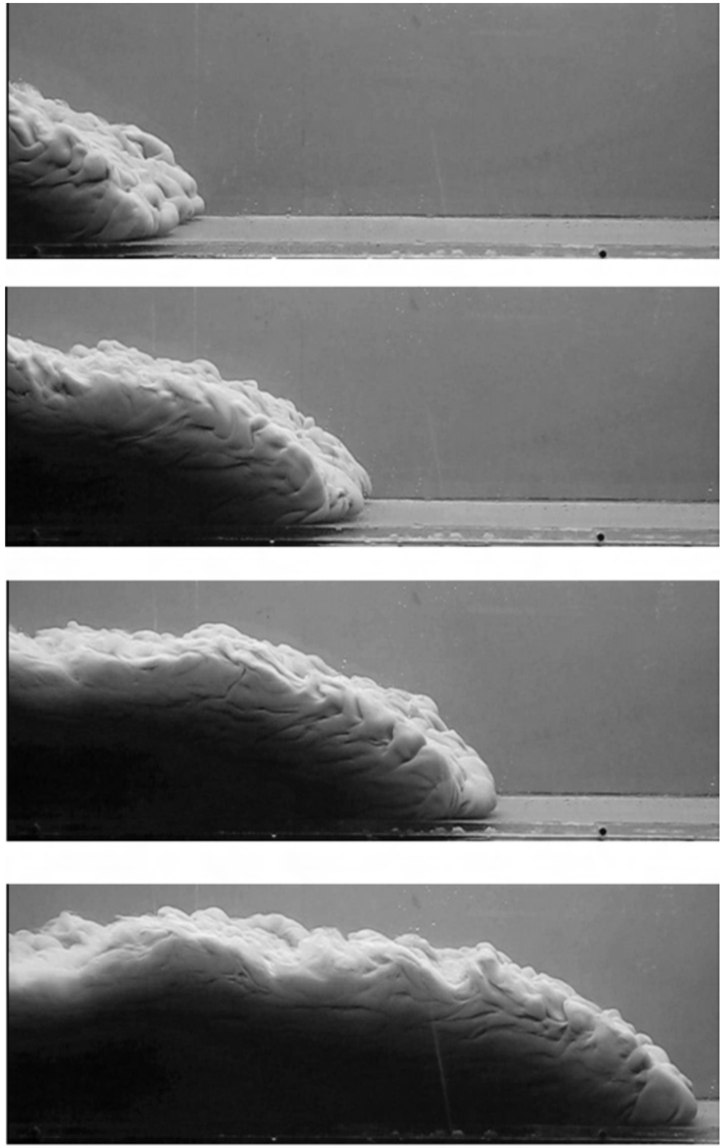




Turbidity flows

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

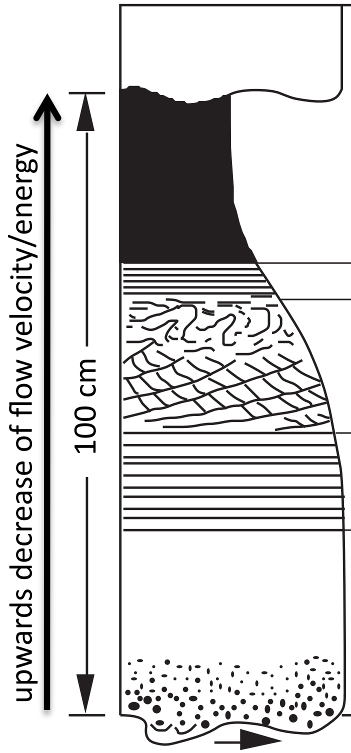




TYPE OF EVENT
Long steady flow (e.g. river fed)
Short surge-type (e.g. river floods, slope instability)

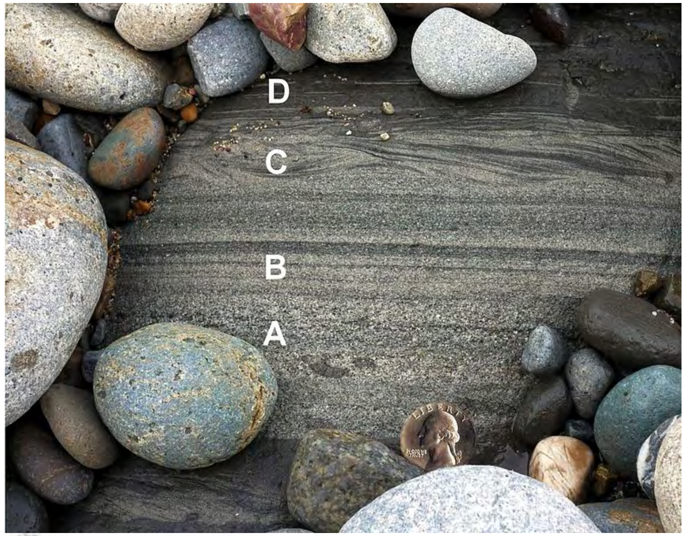
FLOW DENSITY
High density (higher velocity) >1.1 g/cm^3
Low density (lower velocity) <1.1 g/cm^3

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

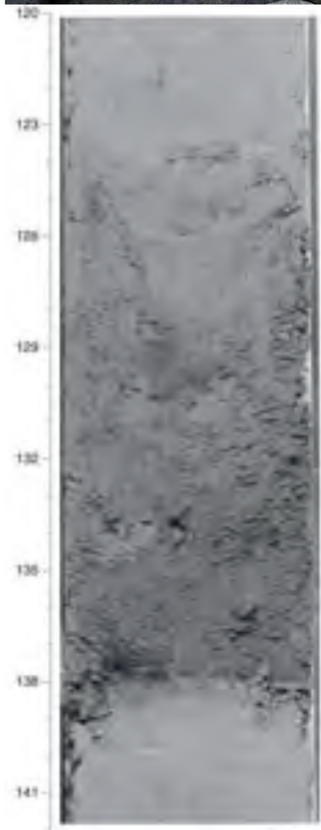


GRAIN SIZE	BOUMA (1962) DIVISION	INTERPRETATION
Mud	E - Laminated to homogeneus mud	Deposition from low-density tail or turbiditi current settling of pelagic or hemipelagic particels
Silt	D - Upper mud/silt laminae	Shear sorting of grains and flocs
Sand	C - ripples, climbing ripples wavy or convolute 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

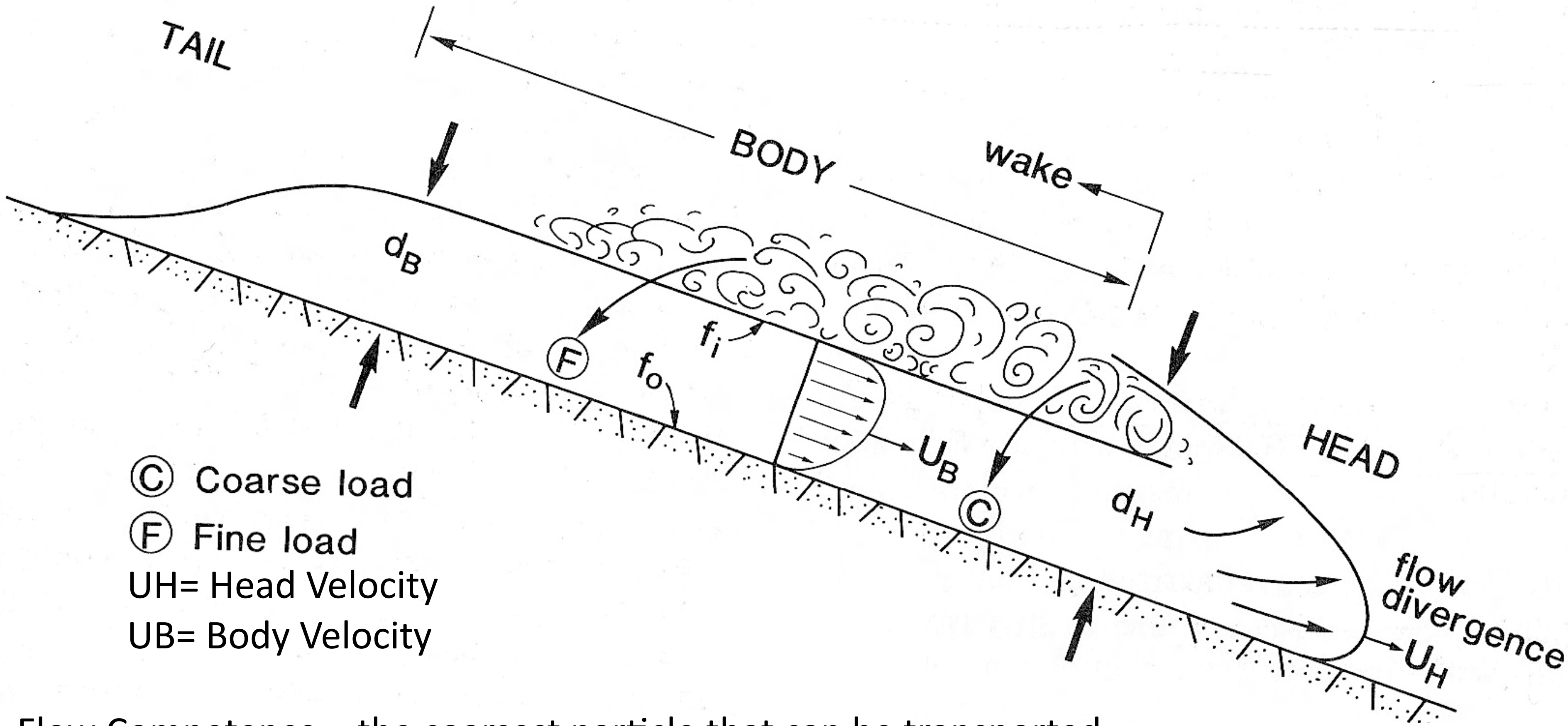
(after Pickering et al., 1989)



sandy turbidite



silty turbidite

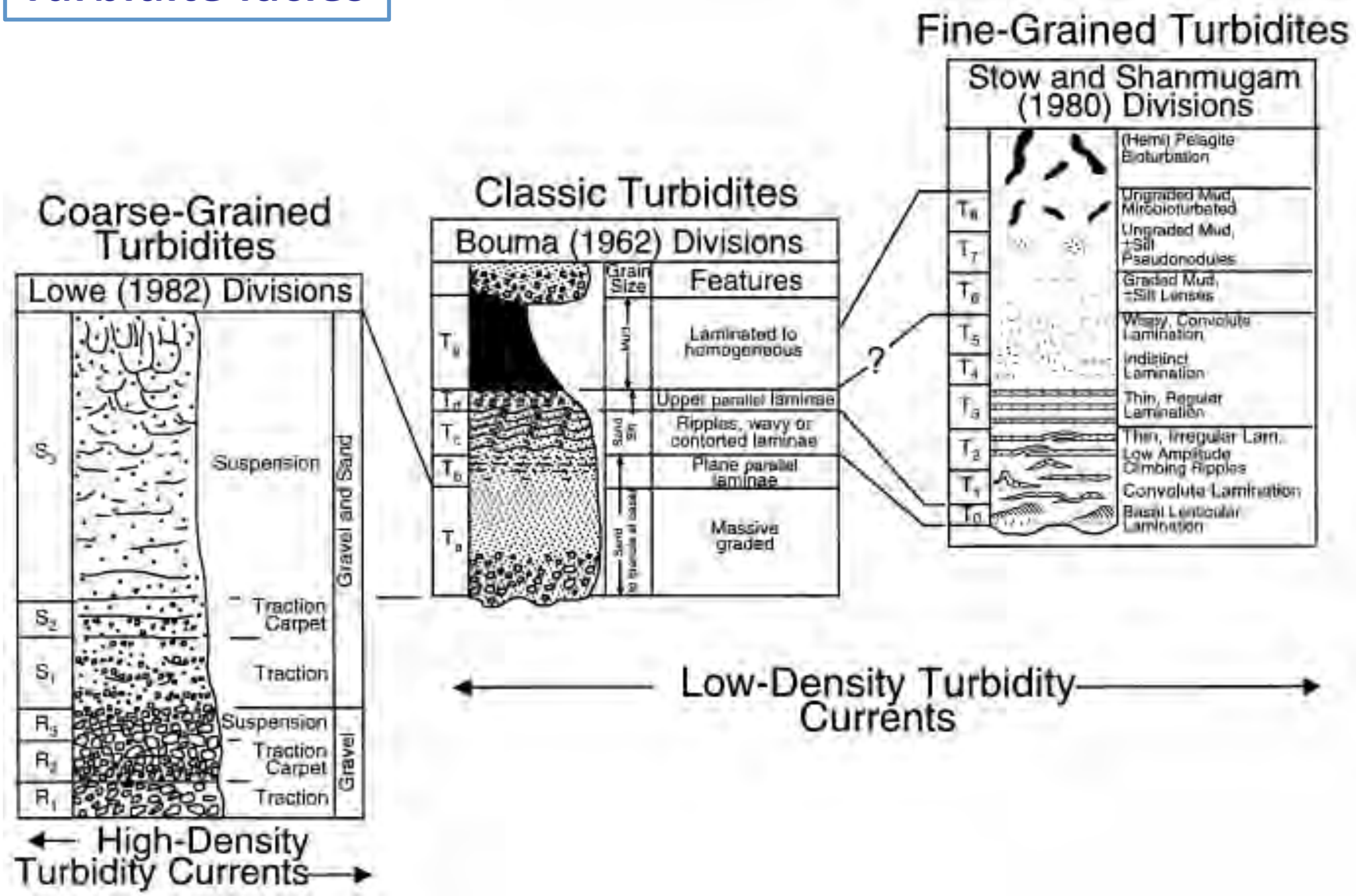


Flow Competence = the coarsest particle that can be transported

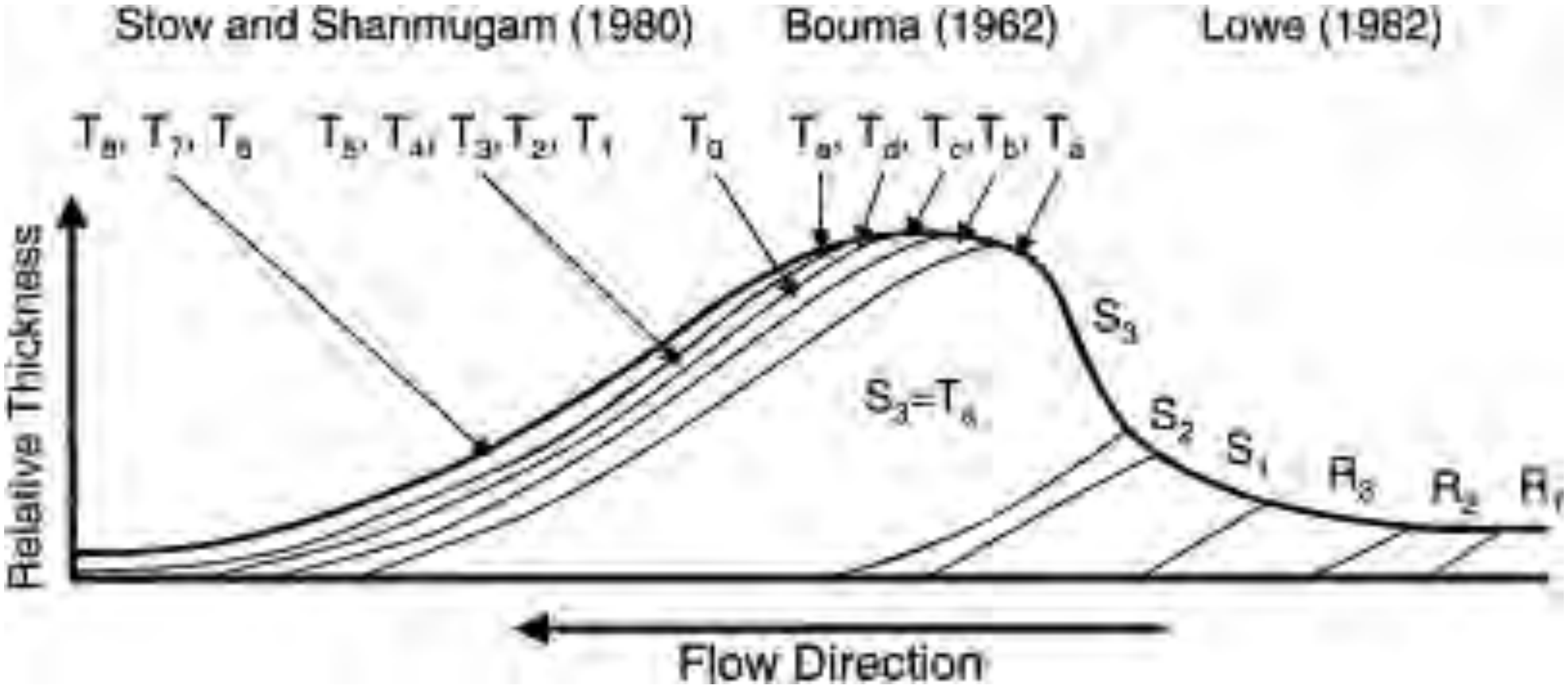
Flow divergence

- ➔ fluid ambient entrainment
  - ➔ flow dilution
    - ➔ reduced speed
      - ➔ reduced competence

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.


Muddy
turbidites

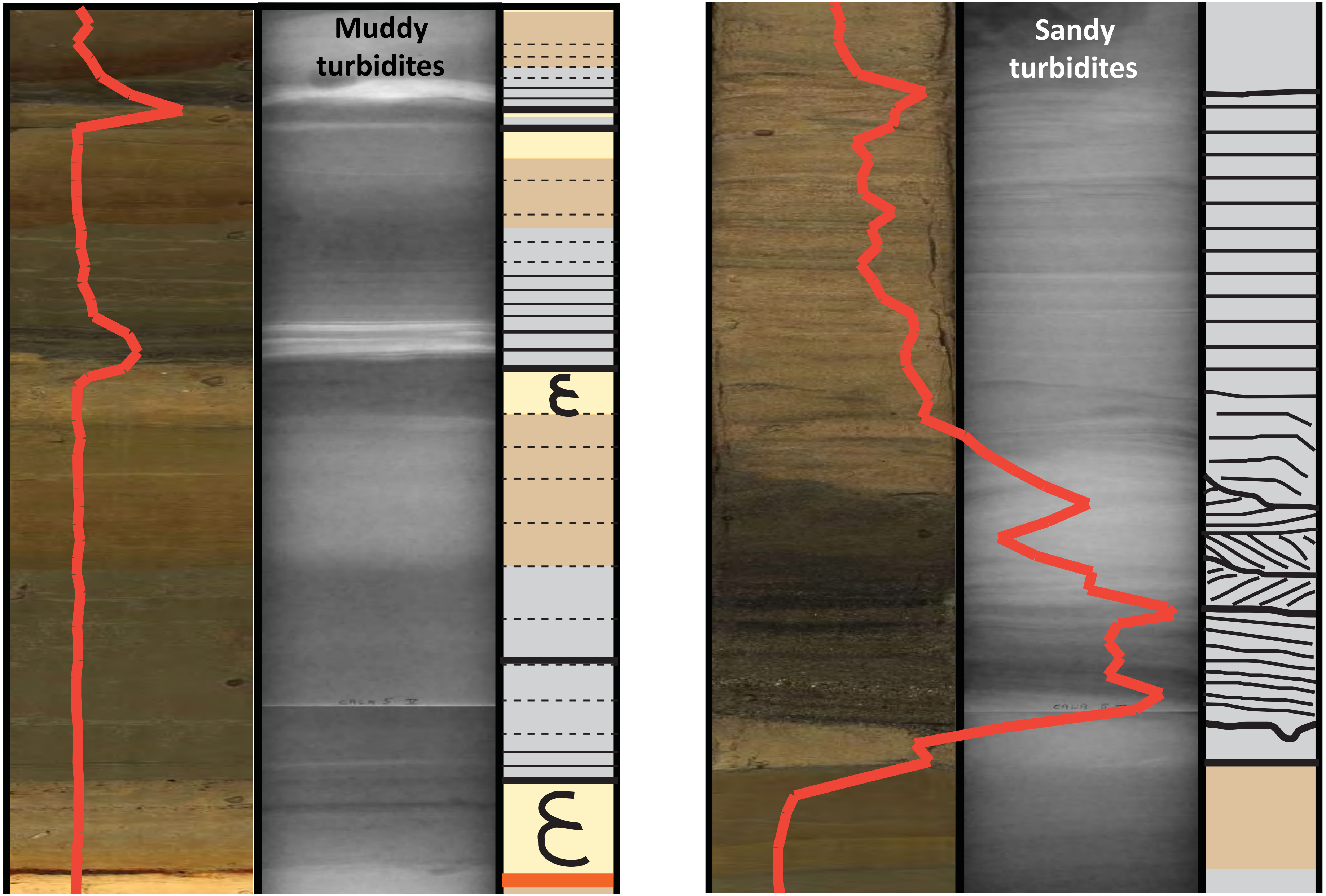

Sandy
turbidites

X-rays

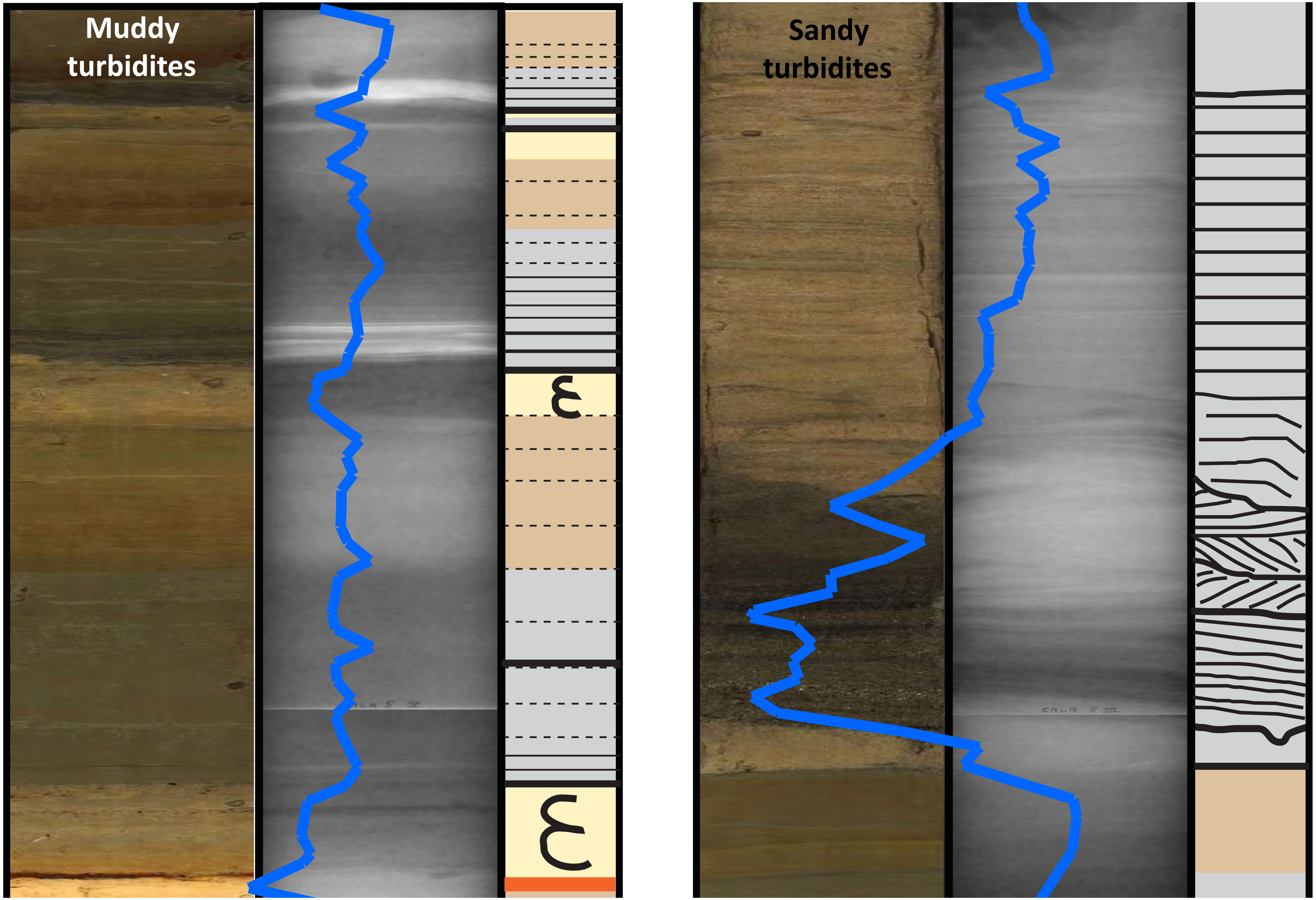

1 5 2004


silty turbidite

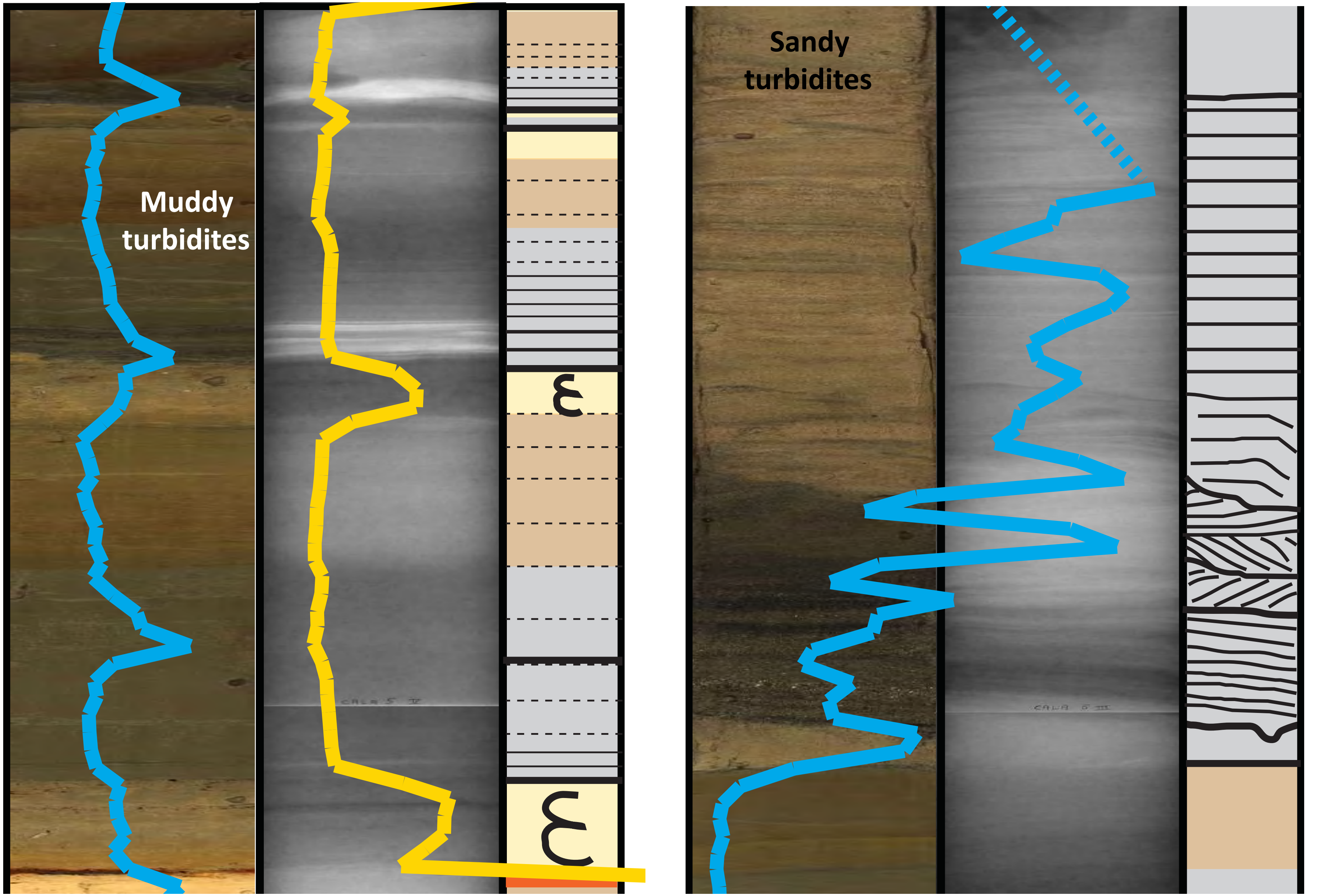
SAND DISTRIBUTION

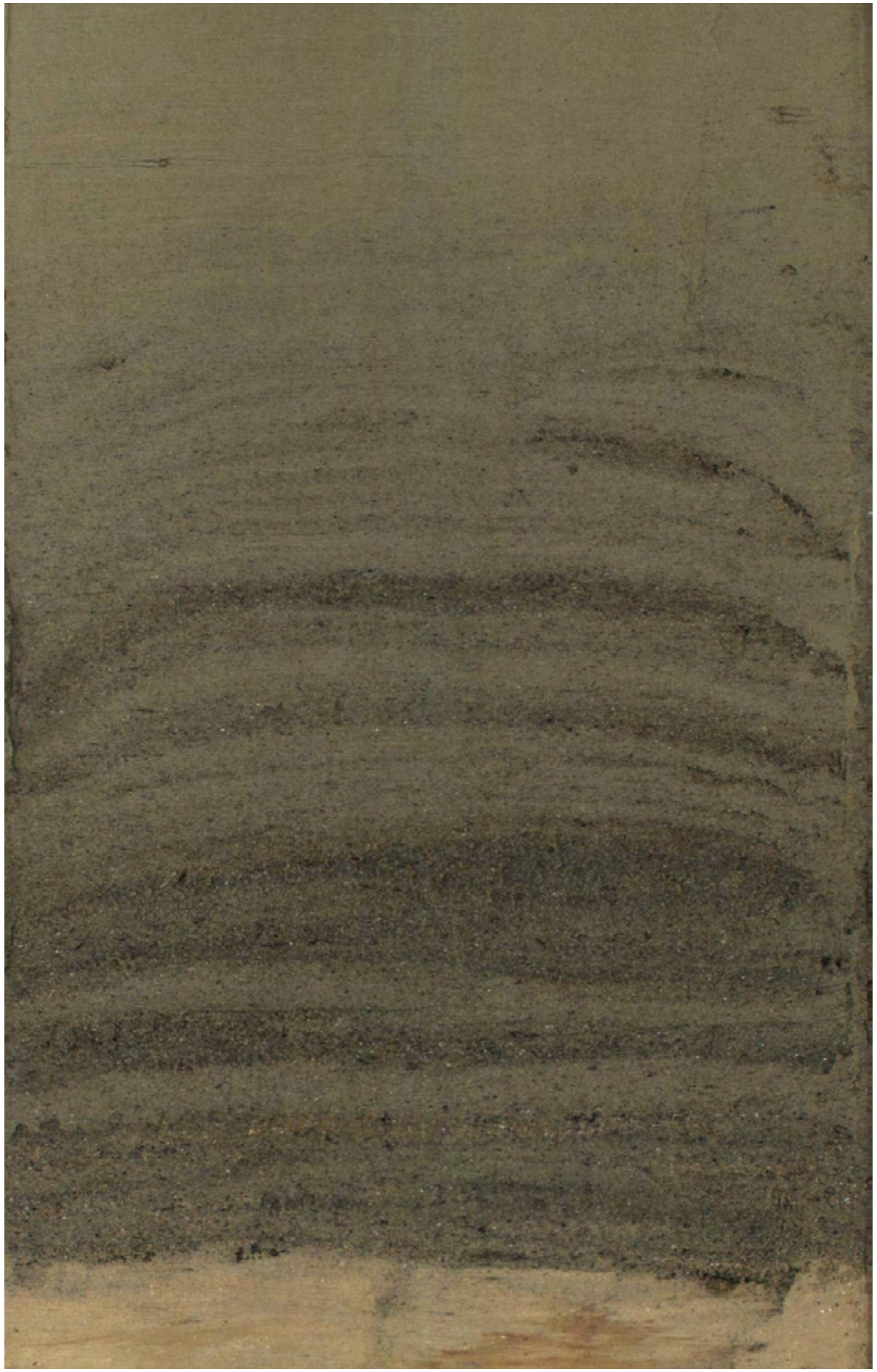


SILT DISTRIBUTION



XRF-scan Zr/Ti Ca/Fe





MOST COMMON FEATURES

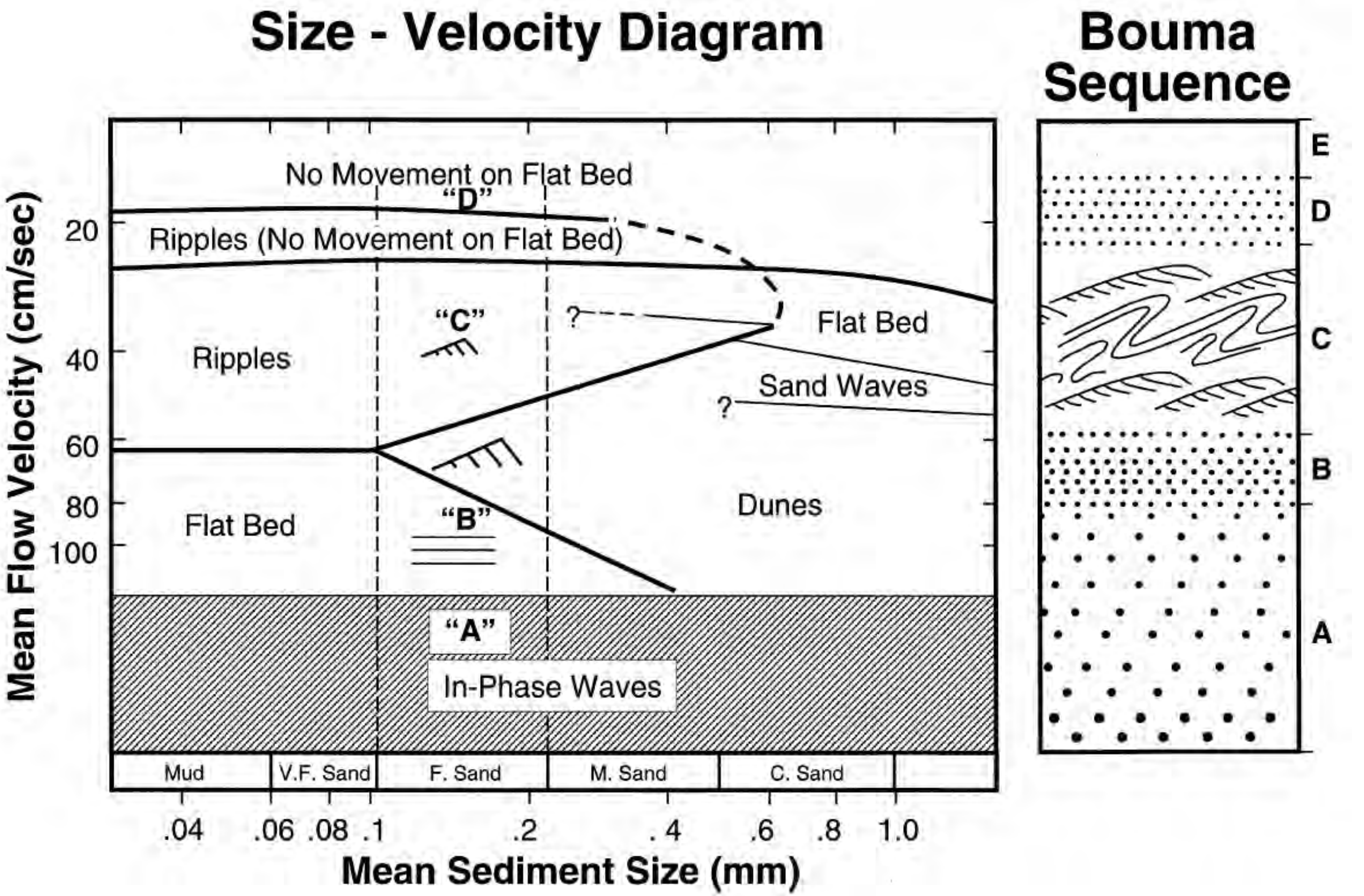
« Sharp base characterized by sharp grain size change often with sharp color change (careful with sediment oxidation)
« Planar laminations
« Bioturbated top

INDICATION OF SHEAR SORTING

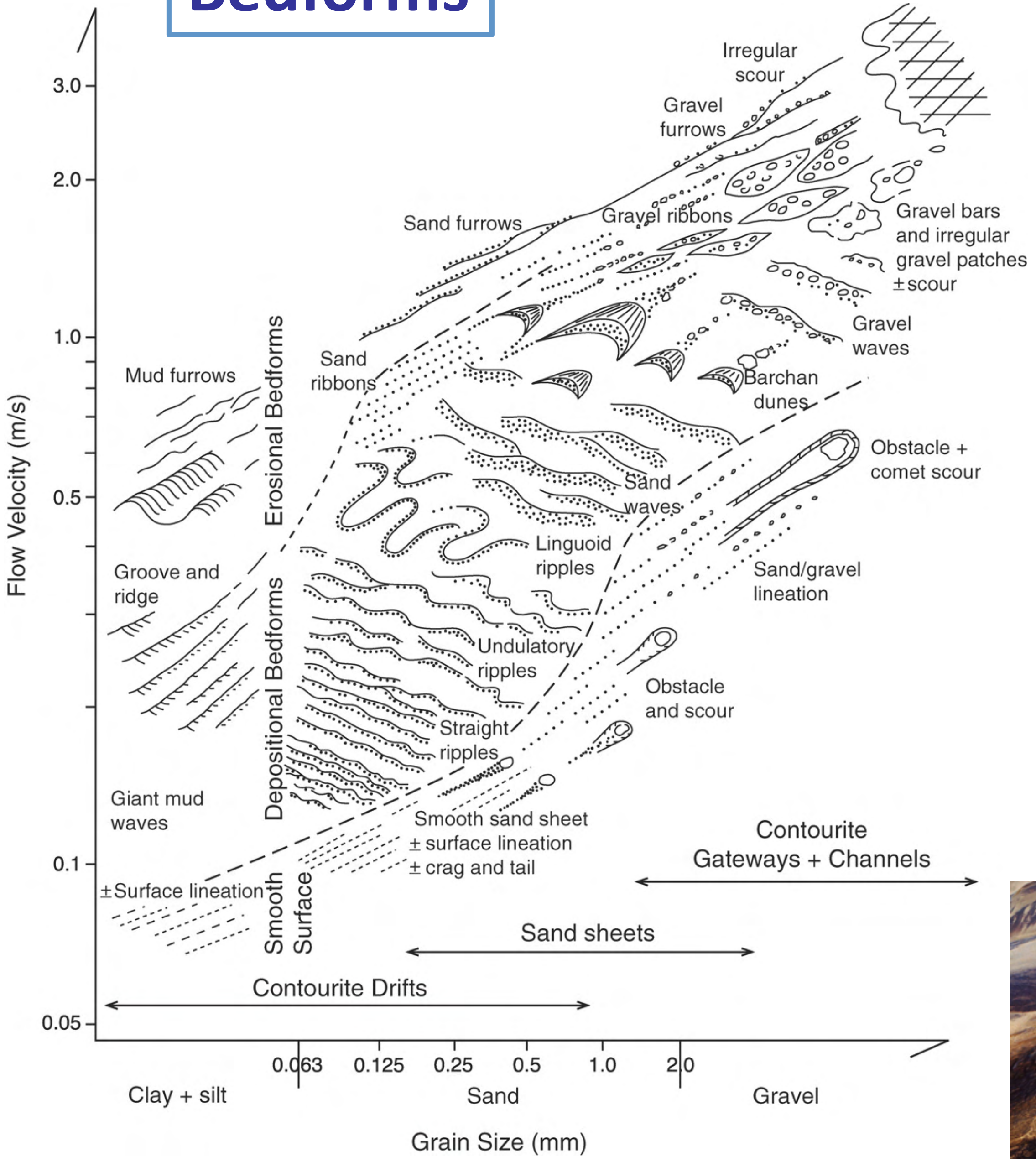
Grain size and compositional sorting trough the deposit. Sorting occur according to size and specific weight e.g. large forams with medium-size quartz with small-size pyroxene)

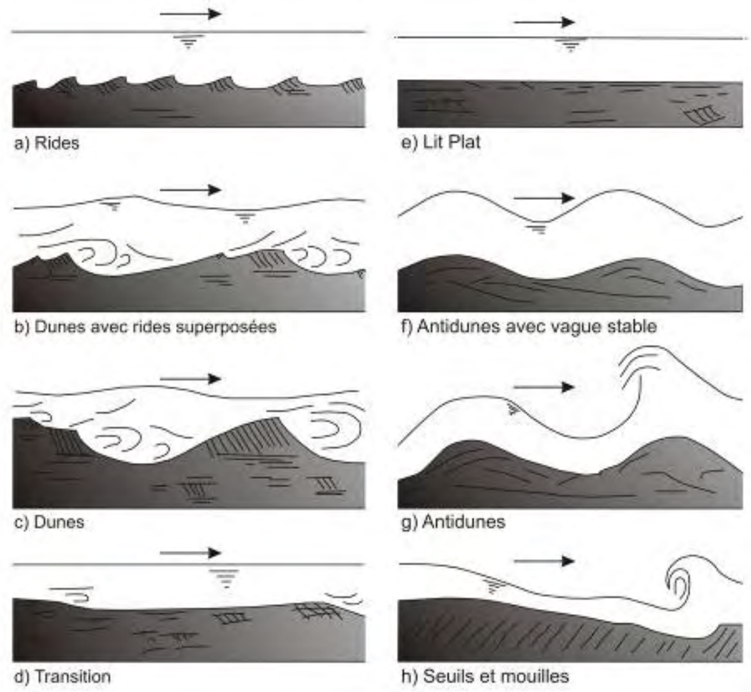
COMPOSITION

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

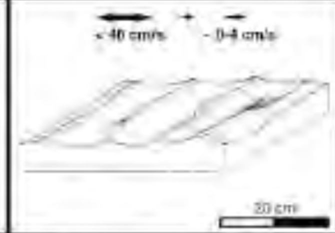
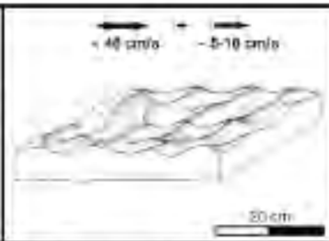
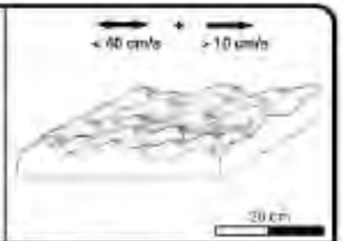
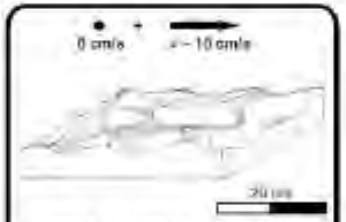

Size - Velocity Diagram
Bouma Sequence
No Movement on Flat Bed
"D"
Ripples (No Movement on Flat Bed)
"C"
?
Flat Bed
Ripples
Sand Waves
?
Dunes
Flat Bed
"B"
"A"
In-Phase Waves
Mud
V.F. Sand
F. Sand
M. Sand
C. Sand
.04
.06
.08
.1
.2
.4
.6
.8
1.0
Mean Sediment Size (mm)
Mean Flow Velocity (cm/sec)
20
40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

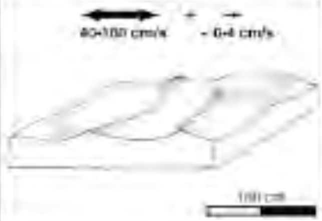
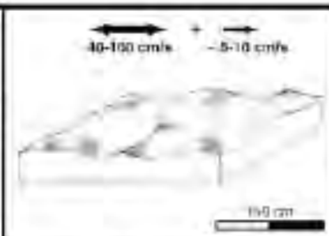
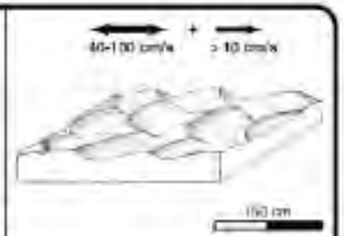
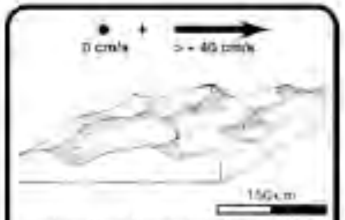
Bedforms

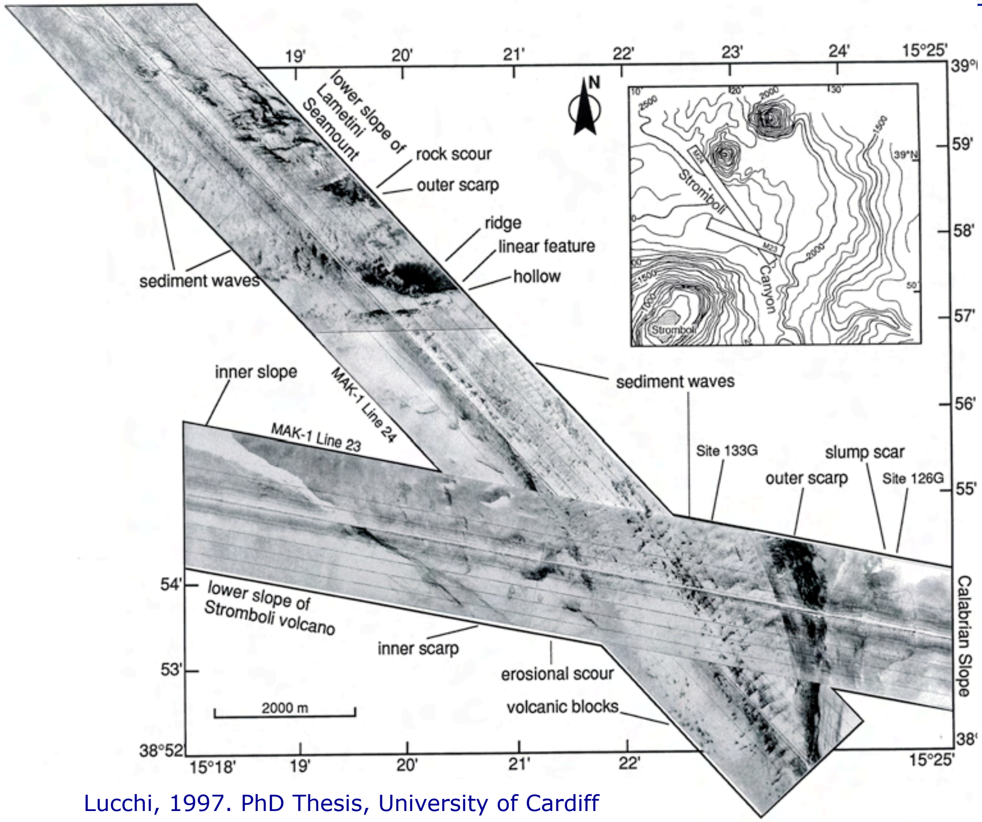


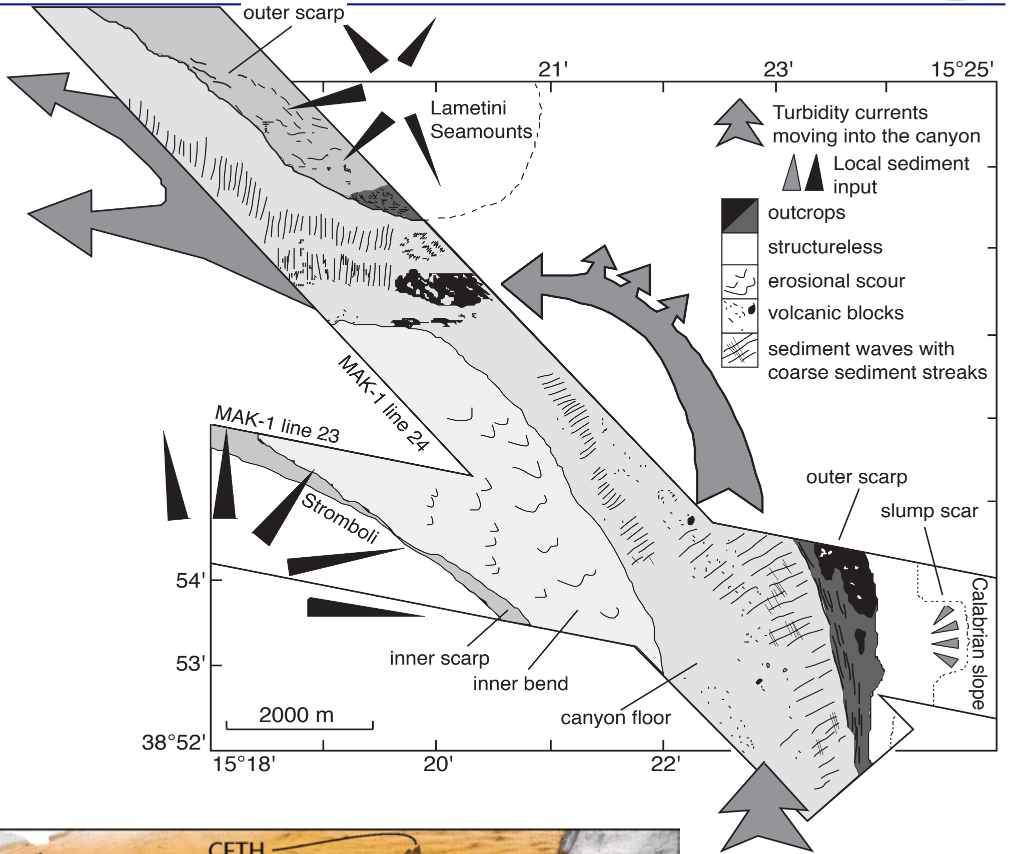


Antidune and Ripple formation

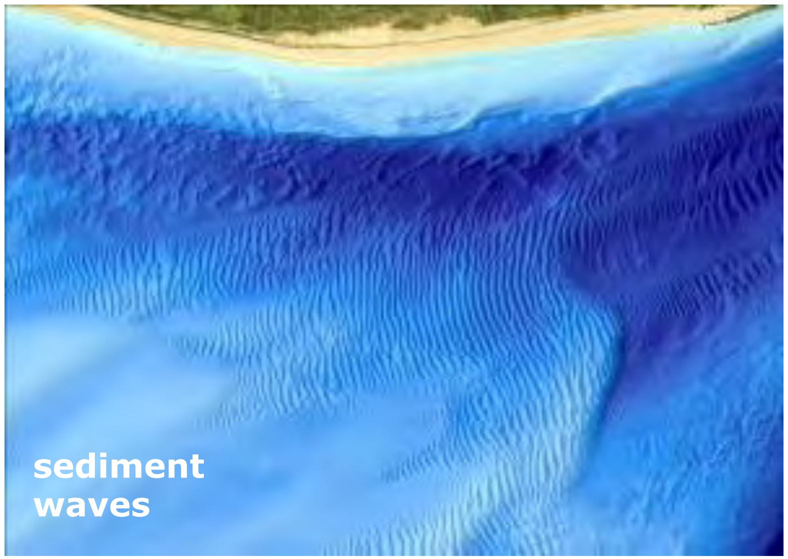
SMALL-SCALE BED FORMS: $\lambda \approx 20$ cm				 (adapted from Harms et al. 1982, fig 3.7a)
Bed form	**Symmetric small ripples (SSR)** regular, 2D, symmetrical, sharp crests, straight flanks, broad troughs	**SSR + asymmetric small ripples (ASR)** more irregular, 2-3D, still symmetrical rounder crests, 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	> 1.2		5-10 (Yokokawa 1995)
Dip of lee side	11-16°		~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 1968a) 8-11, fsa (Yokokawa 1995) ~20, fsa (Boggs 2001)
Orbital diameter/ wavelength	8-16	~8-15	8-15	N/A

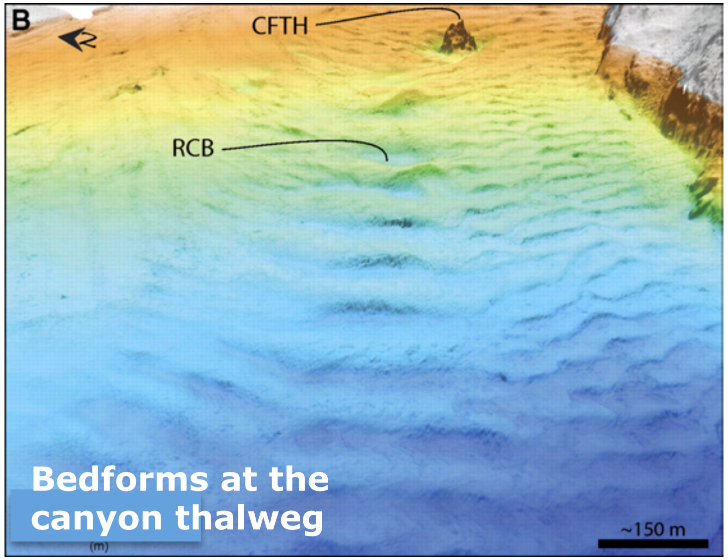
LARGE-SCALE BED FORMS: $\lambda > 100$ cm				 (adapted from Harms et al. 1982, fig 3.10)
Bed form	**Symmetric large ripples (SLR)** SLR: 2.5D, symmetrical, sharp discontinuous crests = no brink, straight flanks	**Hummocky (HM) + SLR + ALR** HM: 3D, symmetrical, no brink point, broad round crests, normal 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	1-2	-
Dip of lee side	14-24° (SLR), 15-19° low-rel 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	~0.40-0.60	~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 1968a) ~5, fsa (Boggs 2001)
Orbital diameter/ wavelength	1-2	1-2	1-2	N/A

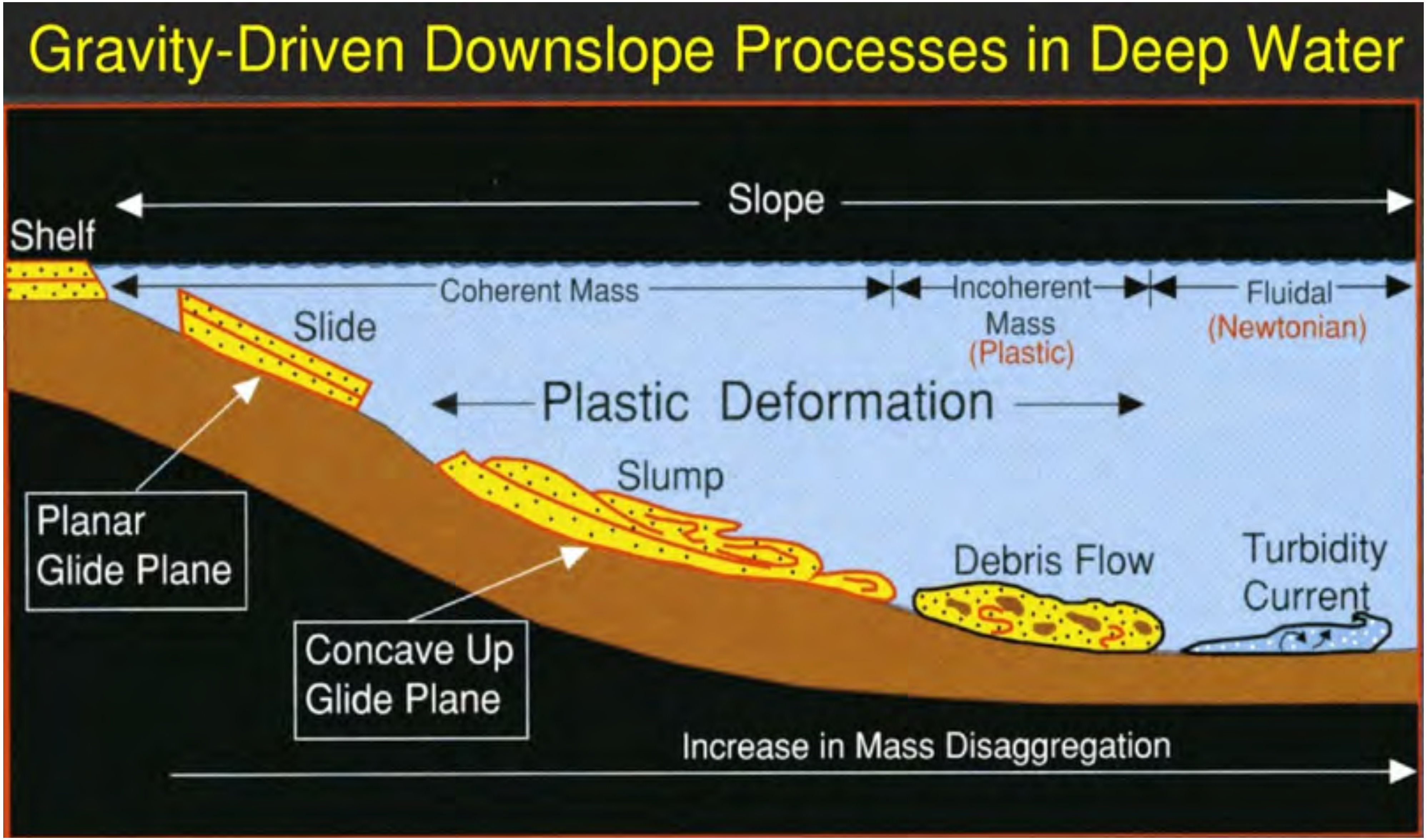




Lucchi, 1997. PhD Thesis, University of Cardiff

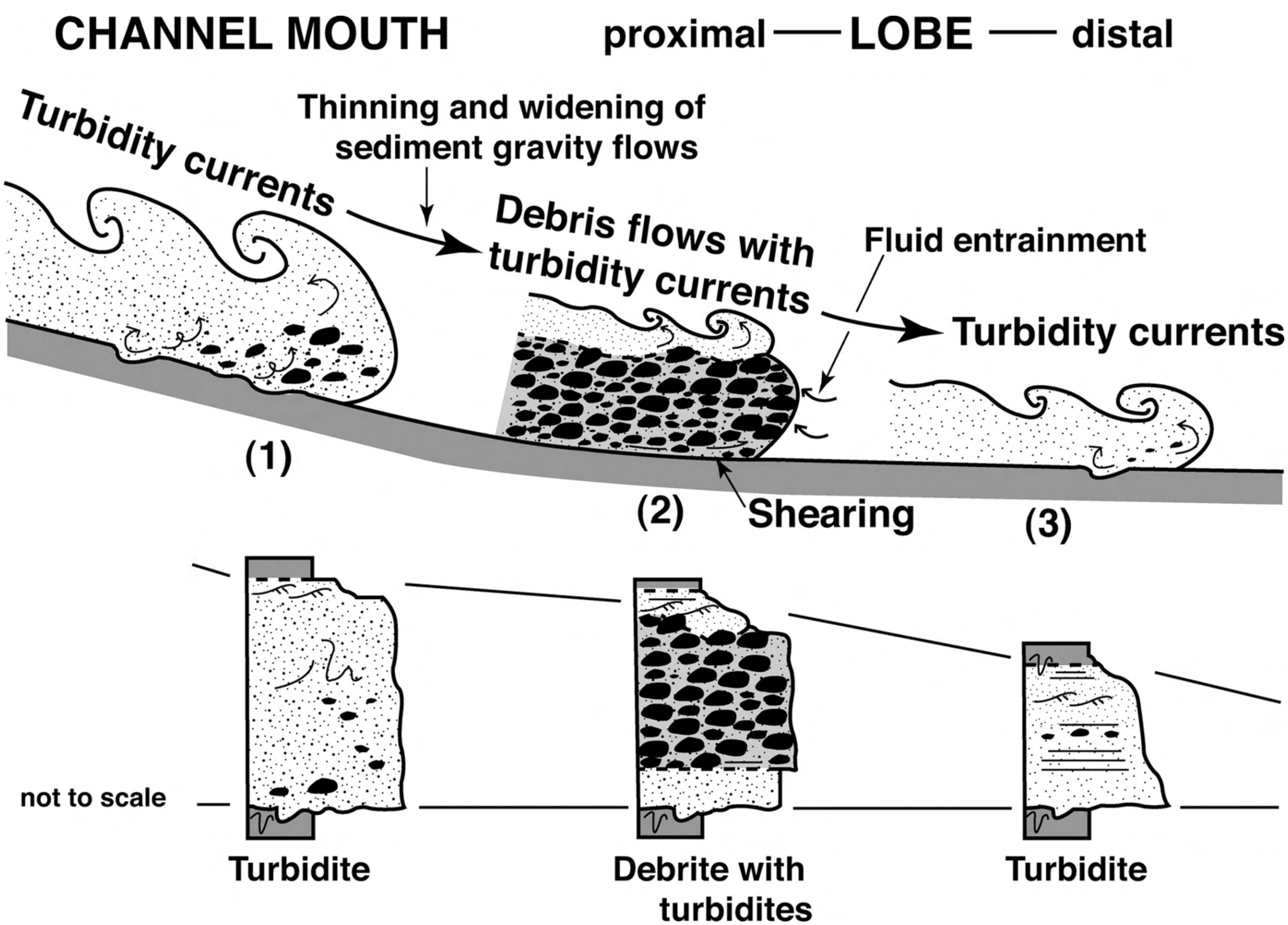


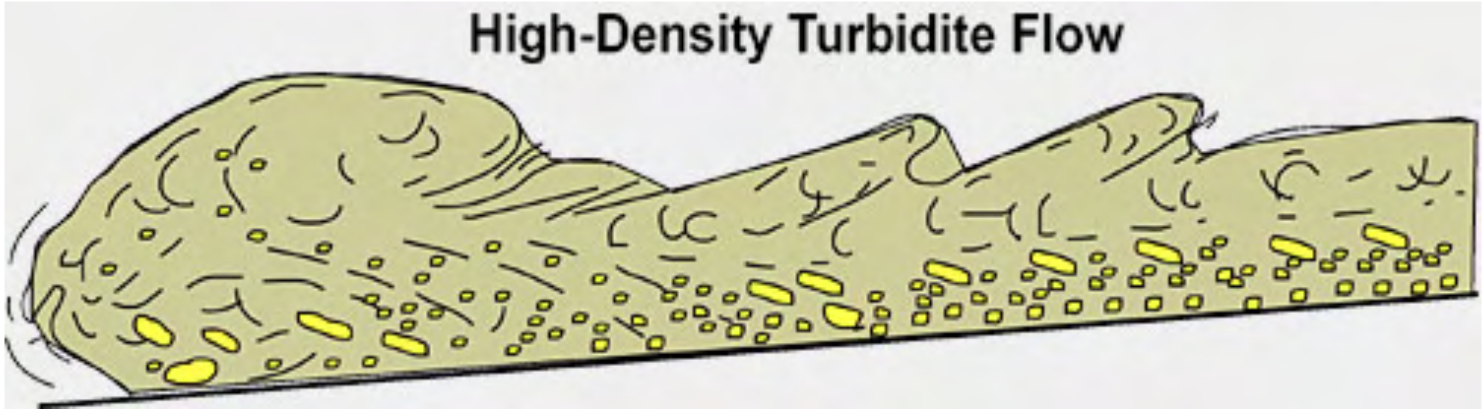


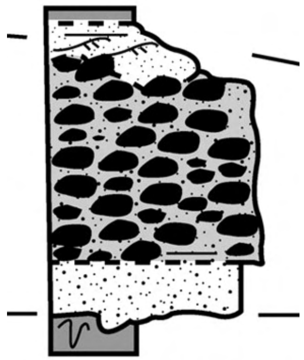

Gravity-Driven Downslope Processes in Deep Water
Slope
Shelf
Coherent Mass
Incoherent
Mass
(Plastic)
Fluidal
(Newtonian)
Slide
Plastic Deformation
Slump
Planar
Glide Plane
Debris Flow
Turbidity
Current
Concave Up
Glide Plane
Increase in Mass Disaggregation

HIGH DENSITY turbidity flows

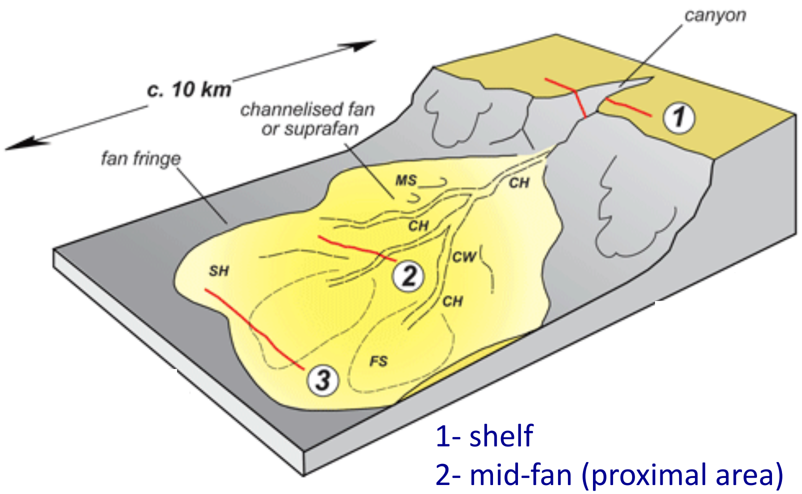
The *linked debrite*



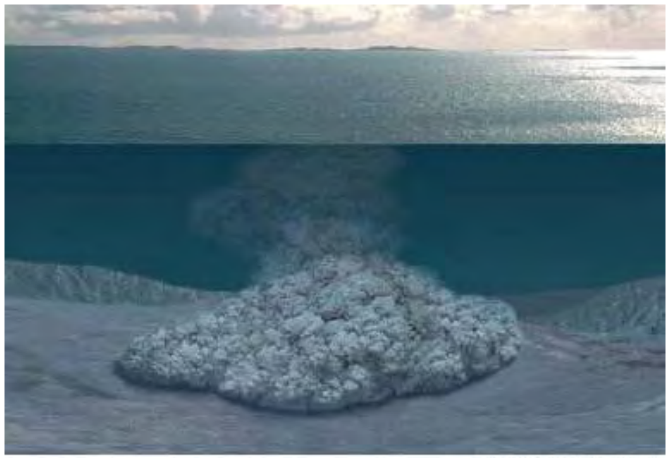

High-Density Turbidite Flow

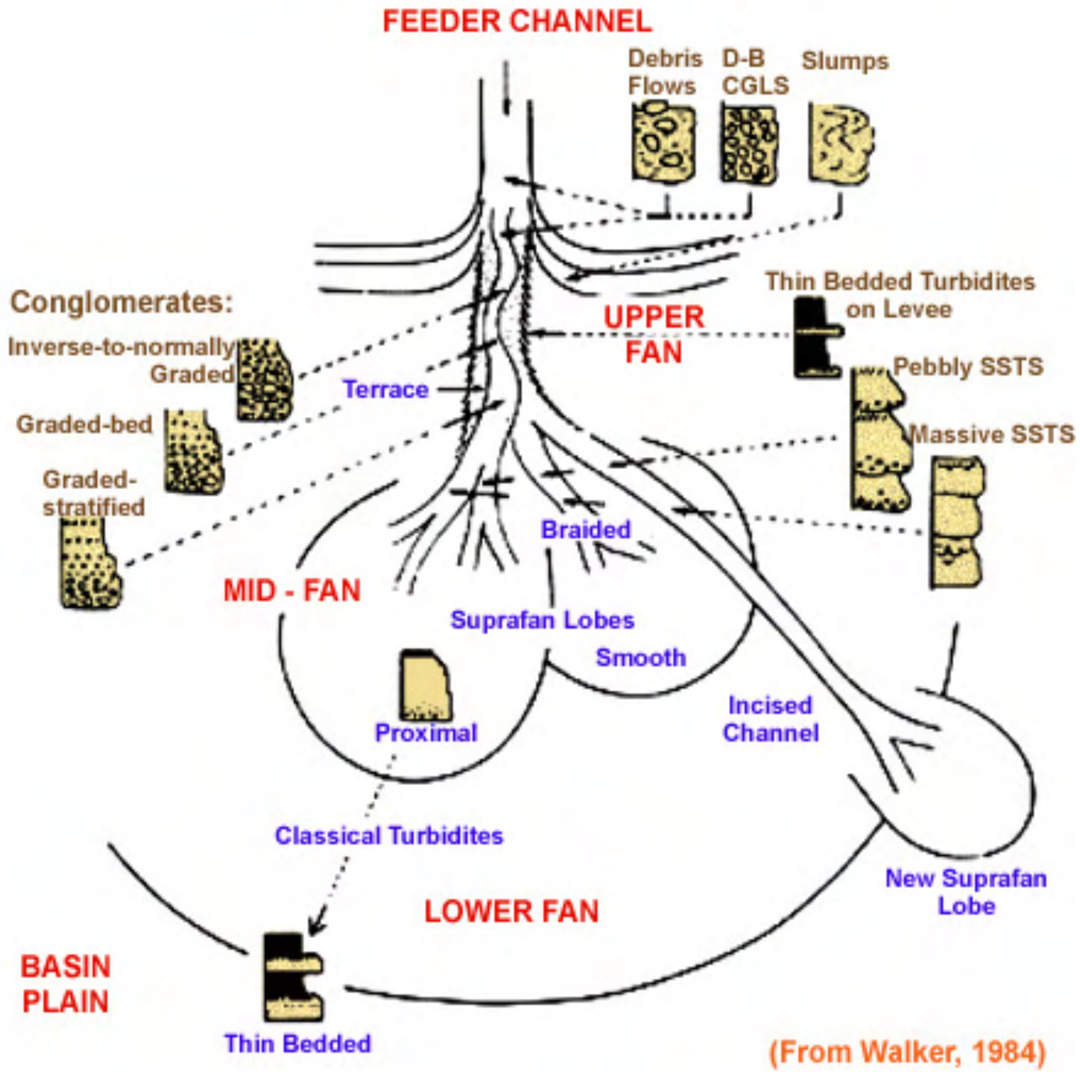


Confined systems: Canyons and associated deep see fans



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





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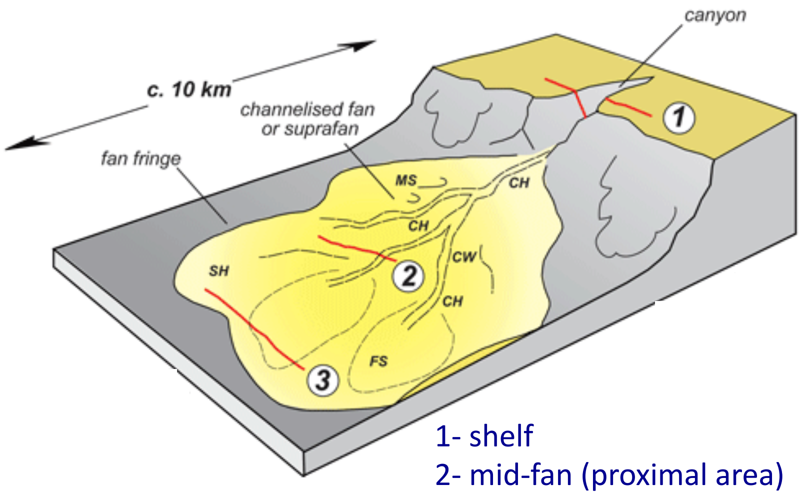
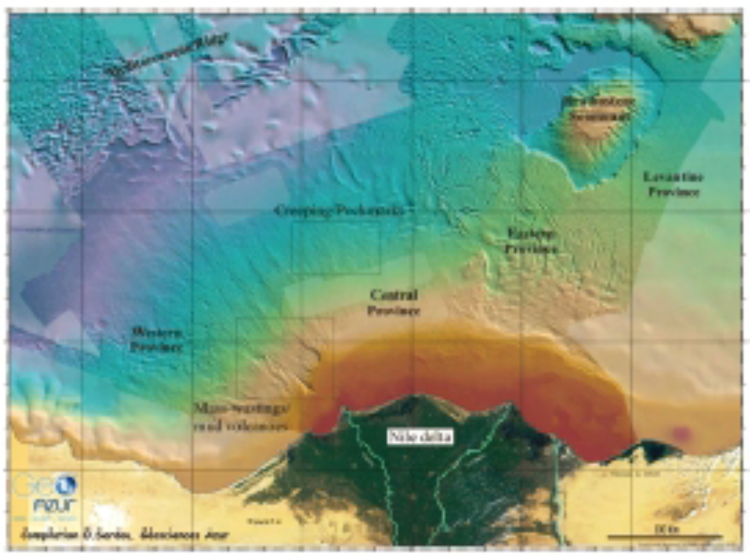
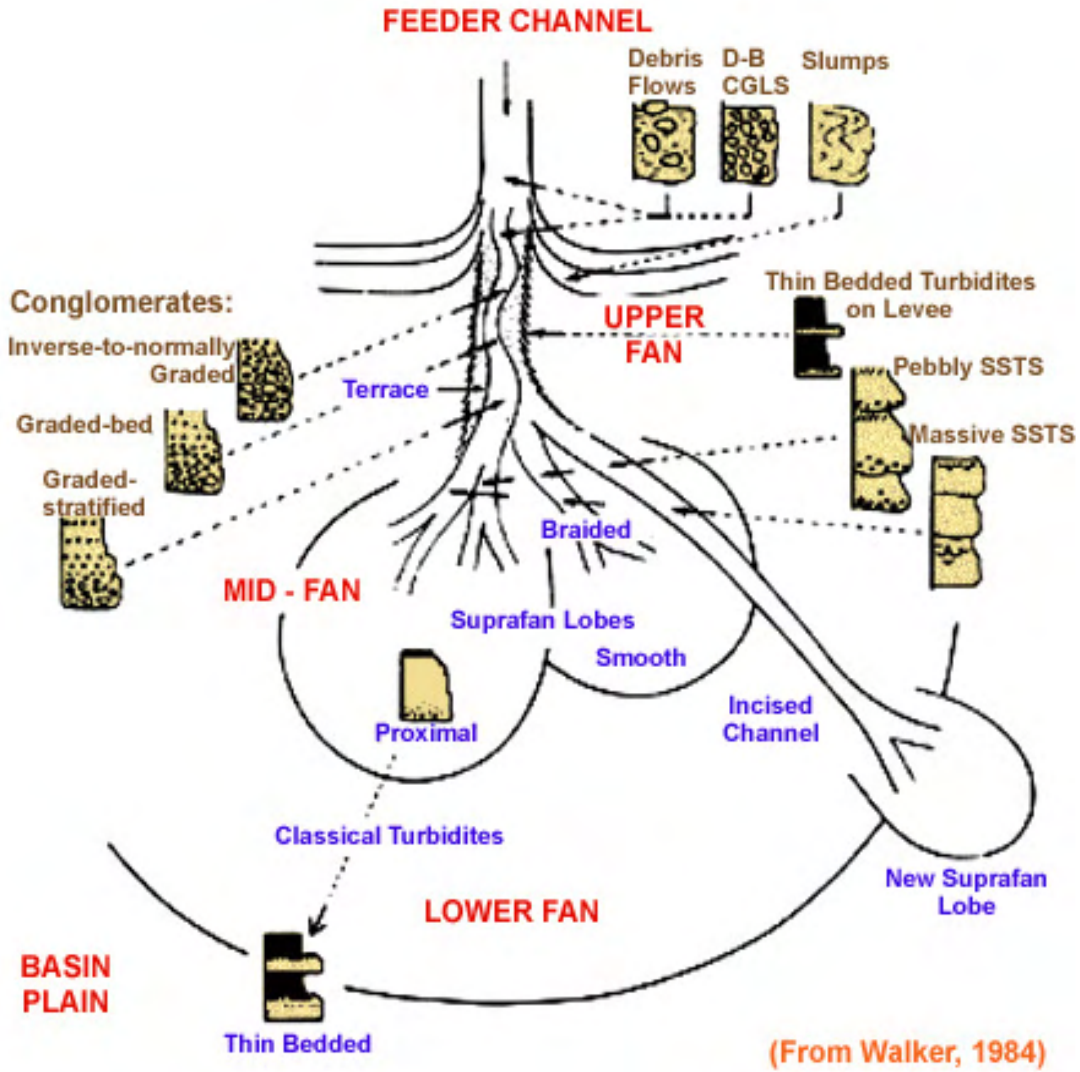
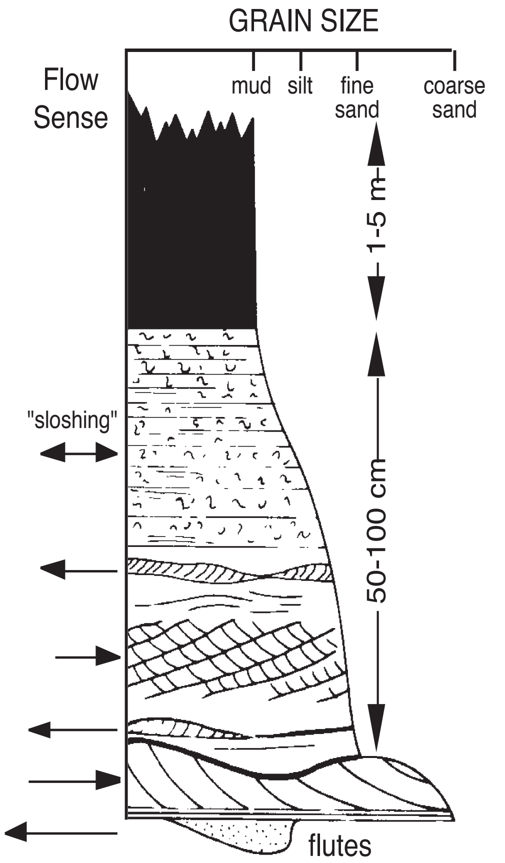


1- shelf
2- mid-fan (proximal area)
3- lower fan (distal area)

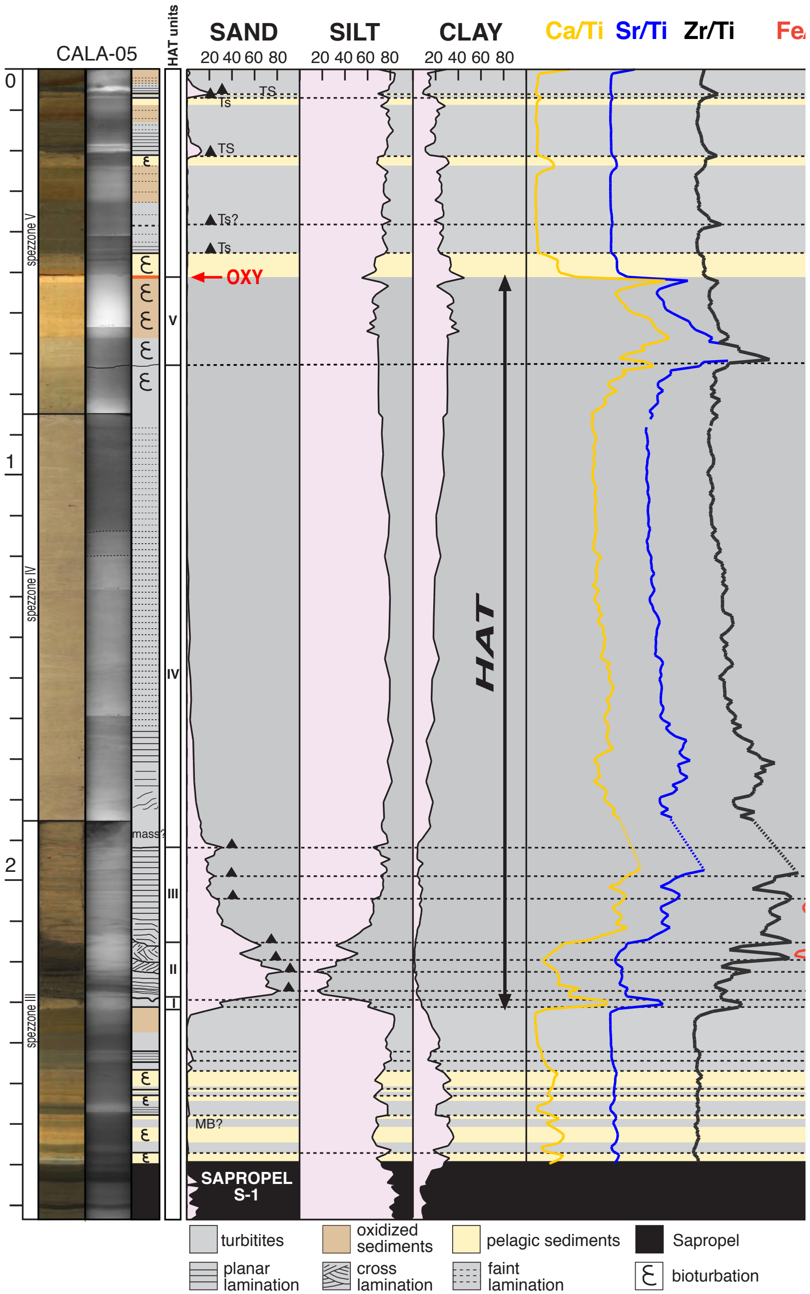




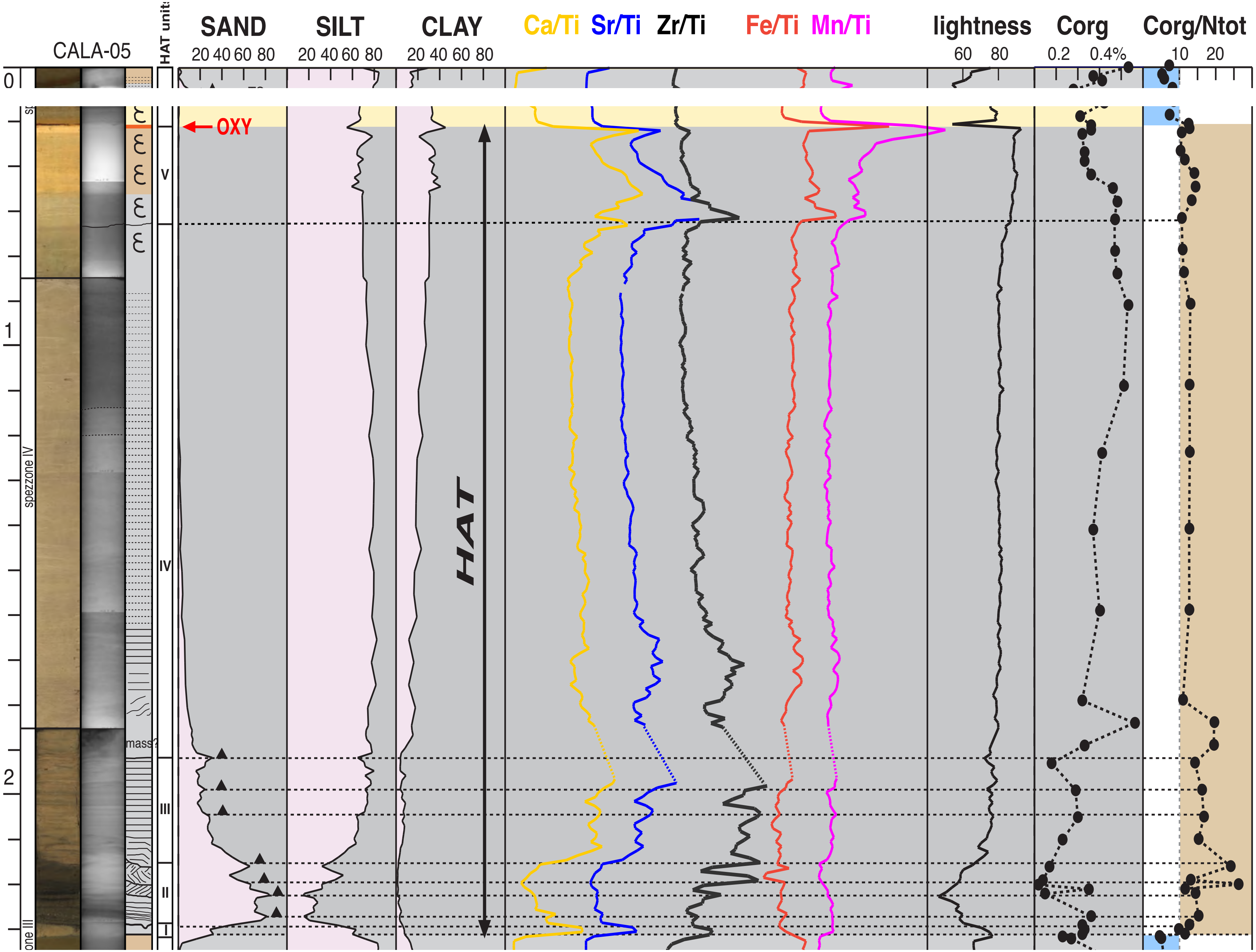
Reflected turbidites and Multi-sources turbidites



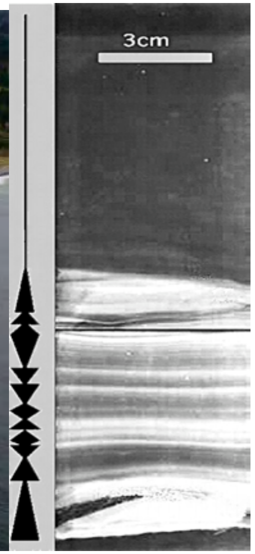
DIVISIONS	INTERPRETATION
Homogeneous silty mudstone cap, with scattered load balls near the base	Rapid deposition of mud flocs under ponded suspension
Alternating laminated and pseudonoduled very fine sand and silt in couplets that thin upward	Gradual decay of reversing flow in an enclosed basin, leading 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

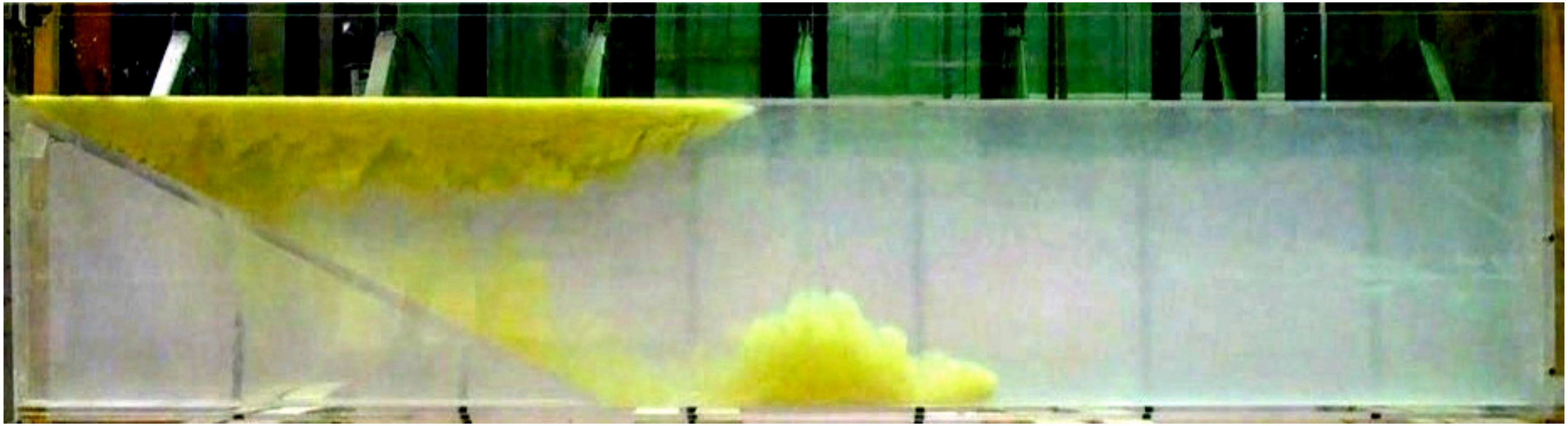

CALA-05
HAT units
SAND
SILT
CLAY
Ca/Ti
Sr/Ti
Zr/Ti
Fe/Ti
Mn/Ti
lightness
Corg
Corg/Ntot
20 40 60 80
20 40 60 80
20 40 60 80
60 80
0.2 0.4%
10 20
OXY
HAT
V
IV
III
II
I
0
1
2
spezzone IV
mass?

Turbid sediment-laden plumes



RIVERINE OUTPUT

GLACIAL MELTING



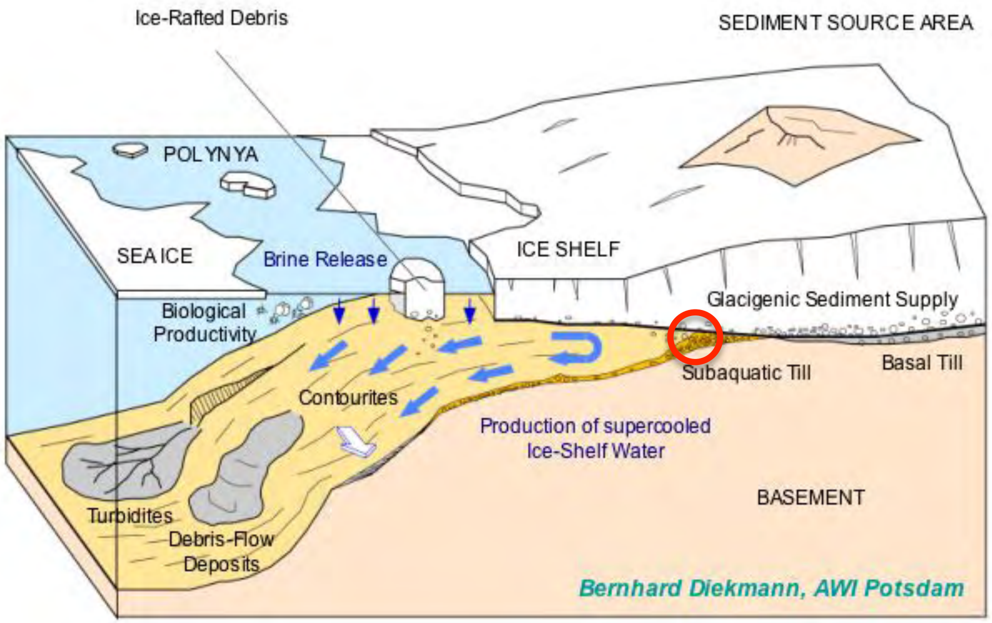
THE DEPOSITIONAL PROCESS

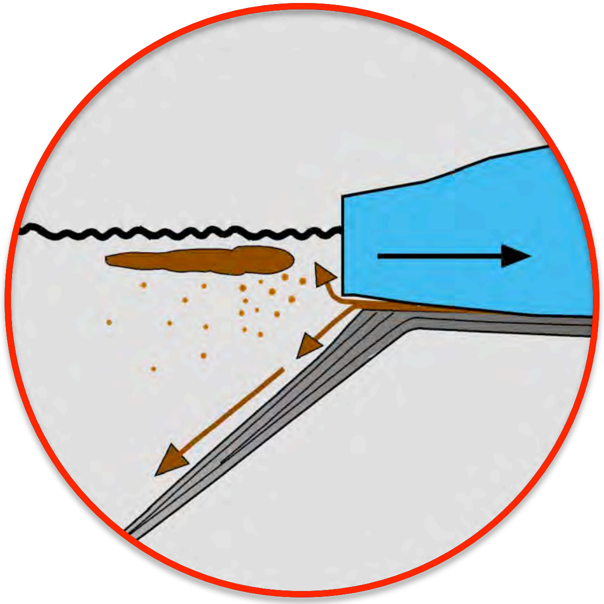
The turbid density flow deriving from subaereal or shallow water environment splits into 2 secondary flows at the entrance point:

» Low-density, buoyant flow (HYPOPYCNAL FLOW), formed by very-fine grained sediments. Deposition by vertical settling (Hemipelagite-like facies).

» High-density, deep flow (HYPERPYCNAL FLOW), formed by the coarser, heavier fraction. Down-slope settling as a low-density gravity flow (Turbidite-like facies).

High-latitude margins

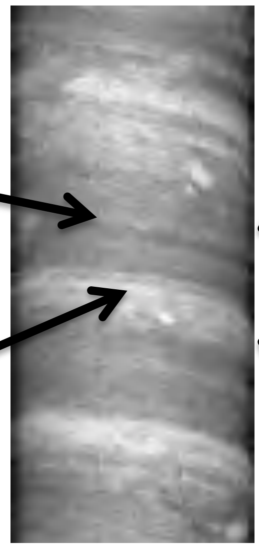




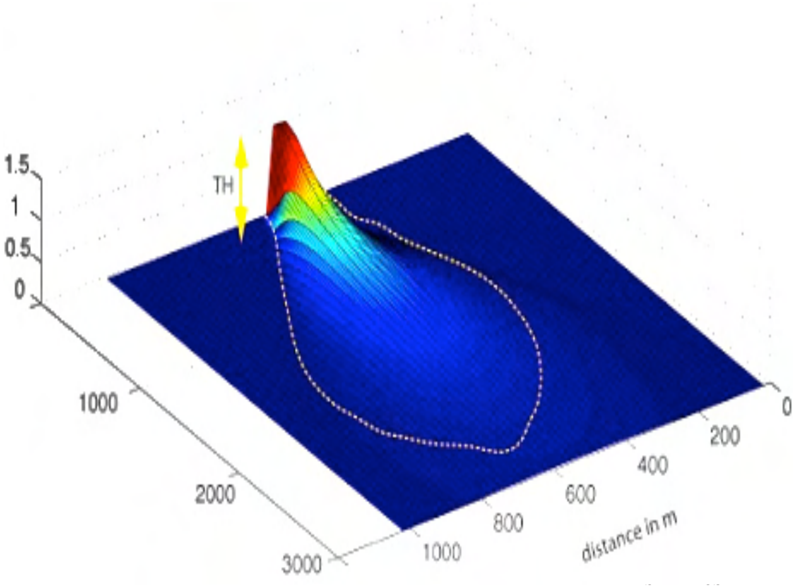
SEDIMENTATION FROM SUBGLACIAL TURBID MELTWATER PLUMES

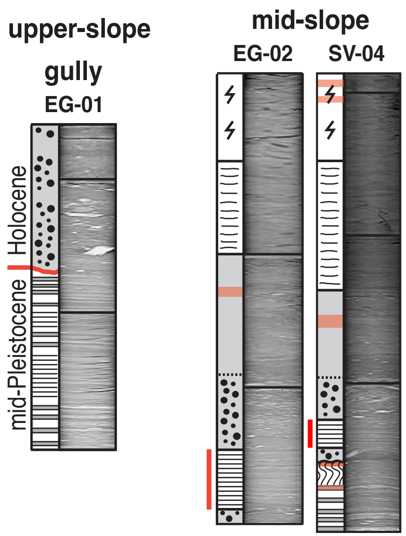
fine-grained overflows/inflows (**hypopycnal flow**) settle through the water column
LAMINATED MUD

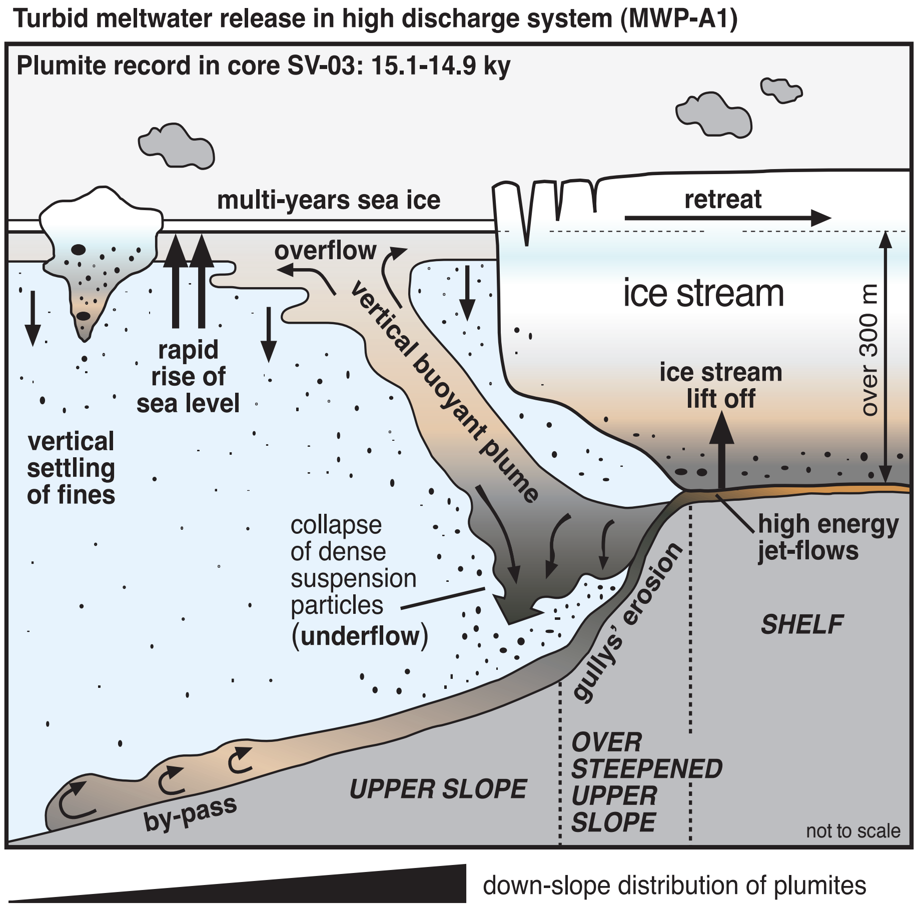
coarse-grained underflows (**hyperpycnal flow**) move down slope as gravity flows
SANDY/SILTY LAYERS



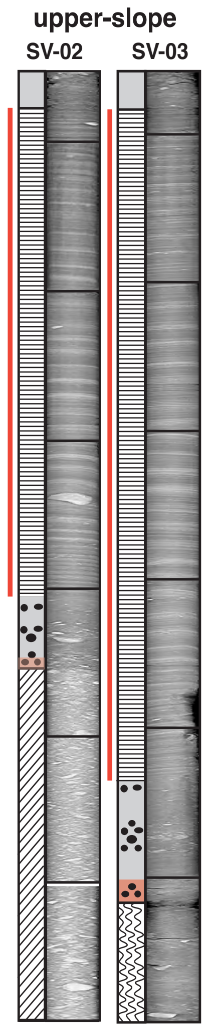
PLUMITE



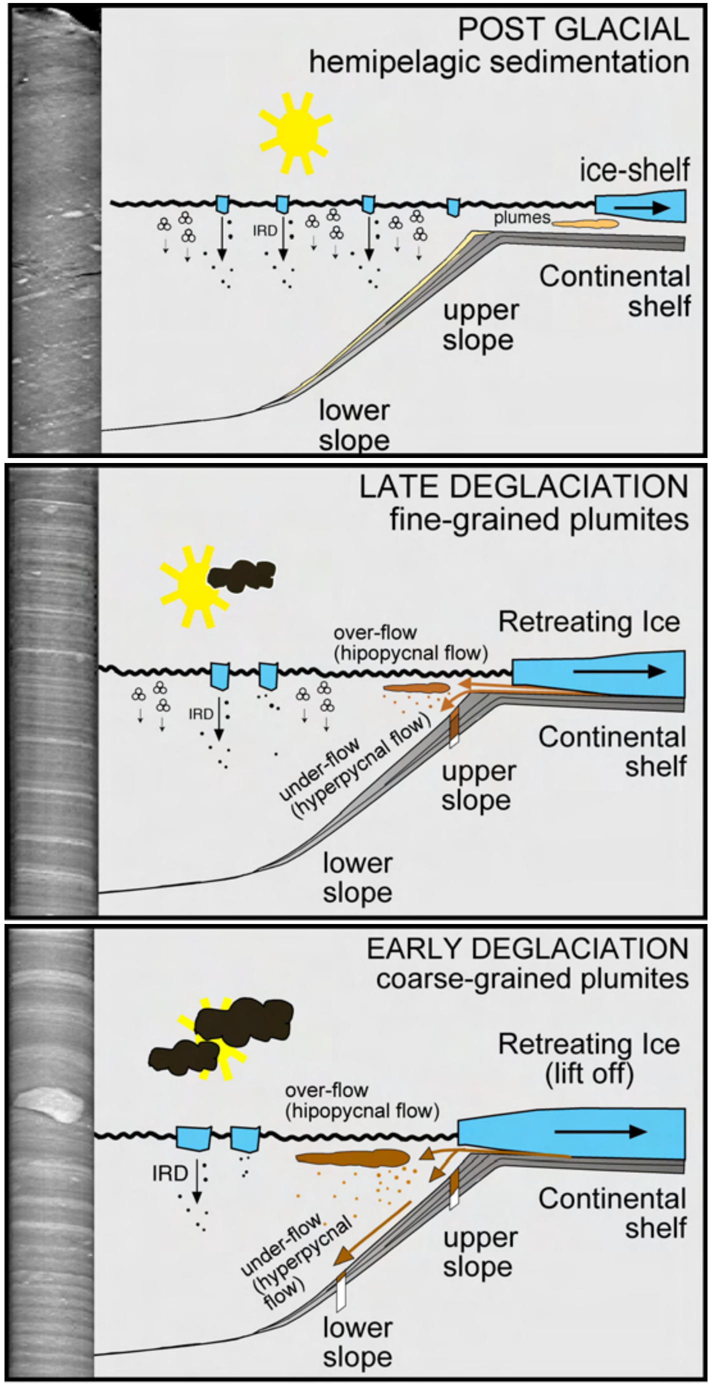




extreme sediment input: 3.4 cm y^{-1}
MWP-A1 sea level rise of 20 m (Alley *et al.* 2005, Science)



Lucchi, et al.,2013. Global and Planetari Change 111, 309-326.



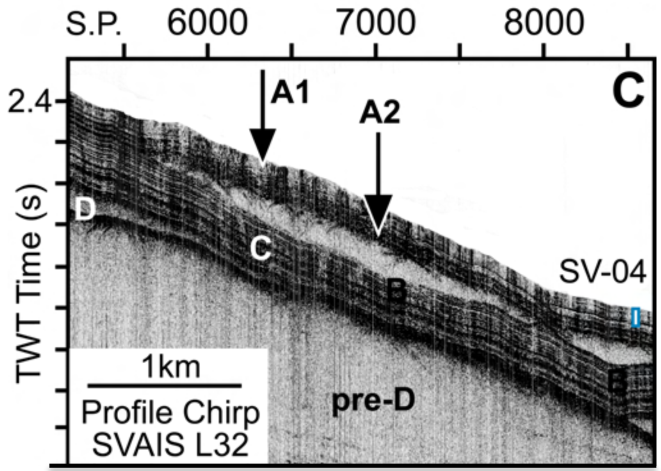
In the **post glacial** with a retreating ice-shelf, sediments from meltwater plumes settle on the continental shelf

In a **later stage** of deglaciation meltwater hyperpycnal flows can reach only the upper slope (finer-grained sandy layers)

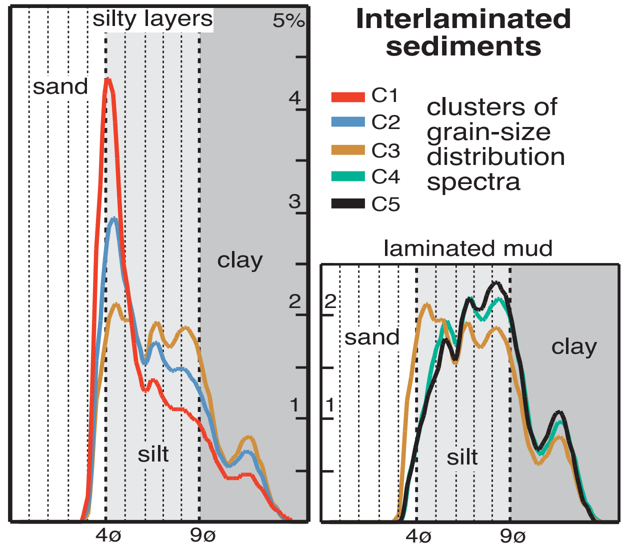
In the **early stage** of deglaciation, when the grounded ice is at the shelf break, meltwater hyperpycnal flows can reach the lower slope

USEFUL INDICATOR FOR GLACIAL HISTORY RECONSTRUCTIONS IN POLAR MARGINS

Seismic characteristics

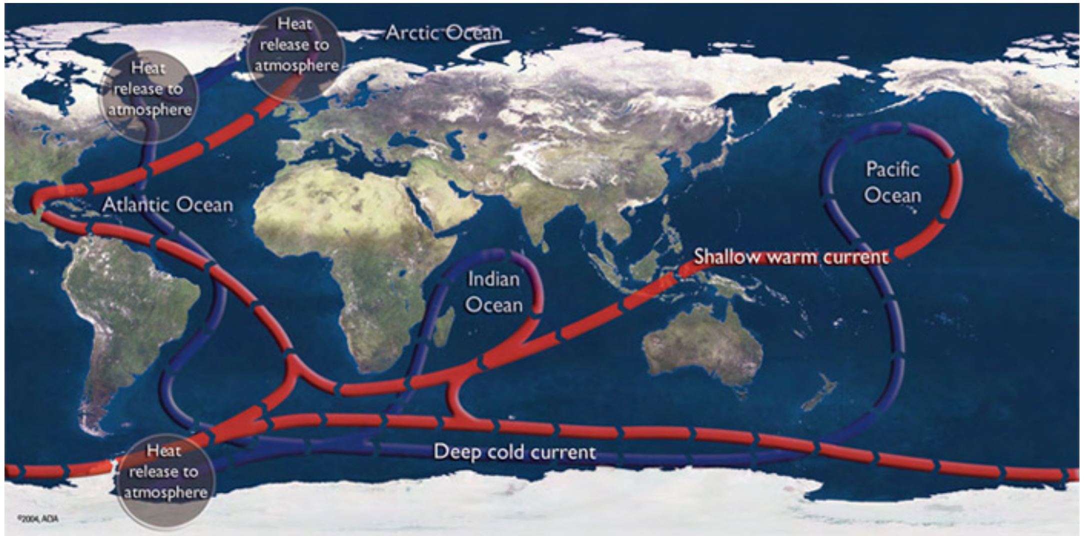


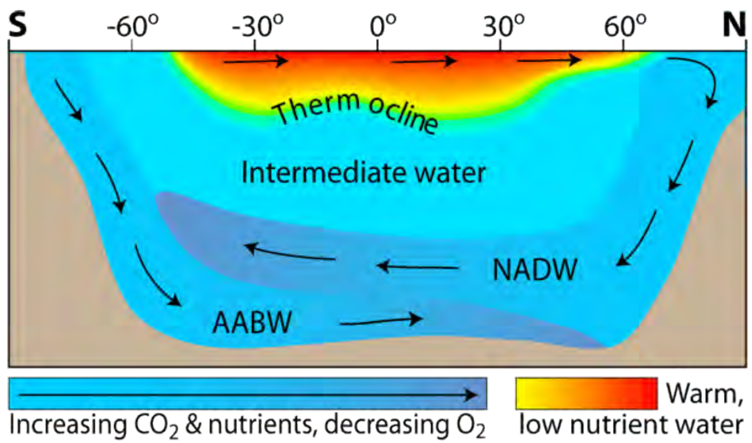
Grain size characteristics

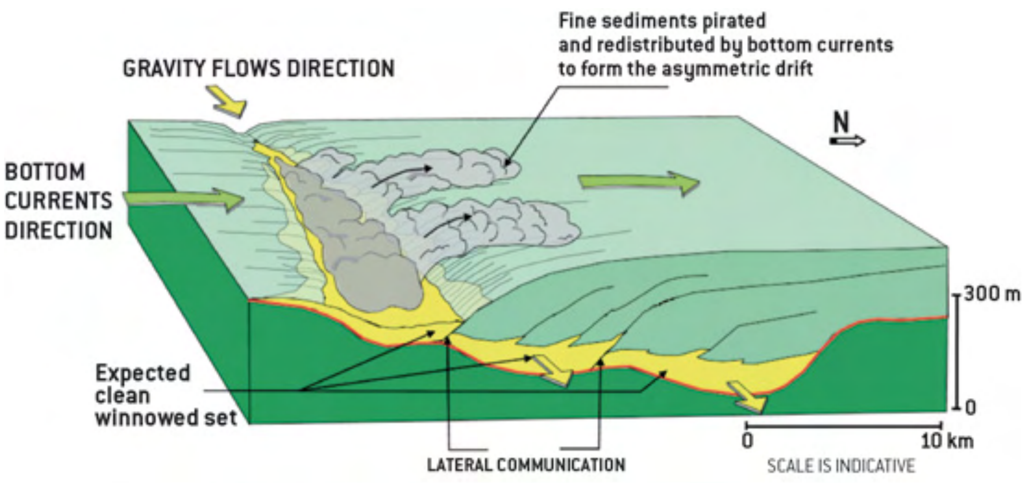


Contour currents

Persistent near the sea-floor water current with a net along-slope flow direction driven by **density forces** (thermo-haline)







Predictive sedimentological modelling for the Mamba complex

Contour currents strength (velocity)
2-3 cm/sec up to over 1 m/sec
(tipically 5-6 cm/sec)
Depending on the strenght they can transport sediments delivered to the depositional system by other processes (e.g. turbidity currents, nepheloyd layers) or generate substrate erosion.

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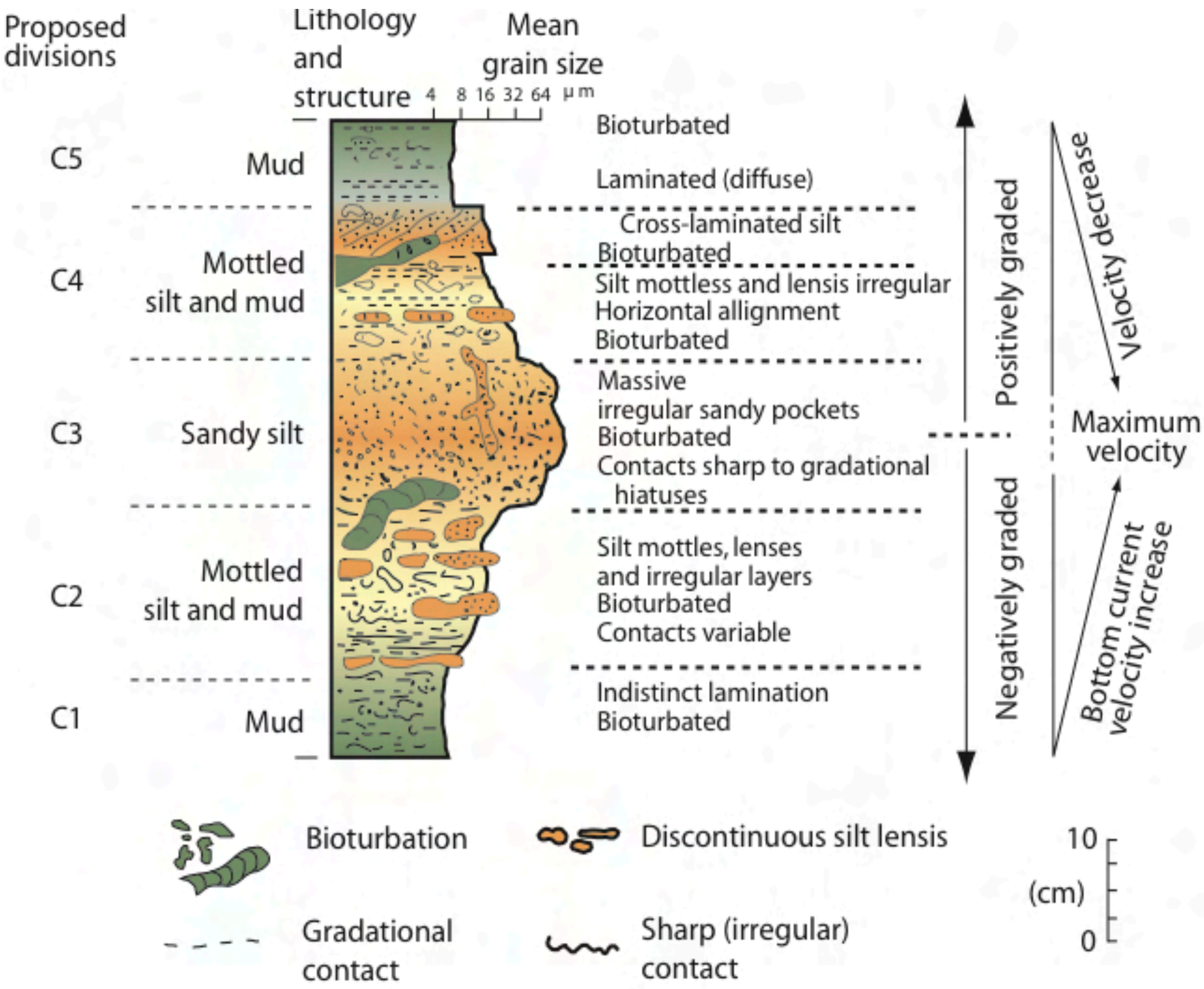
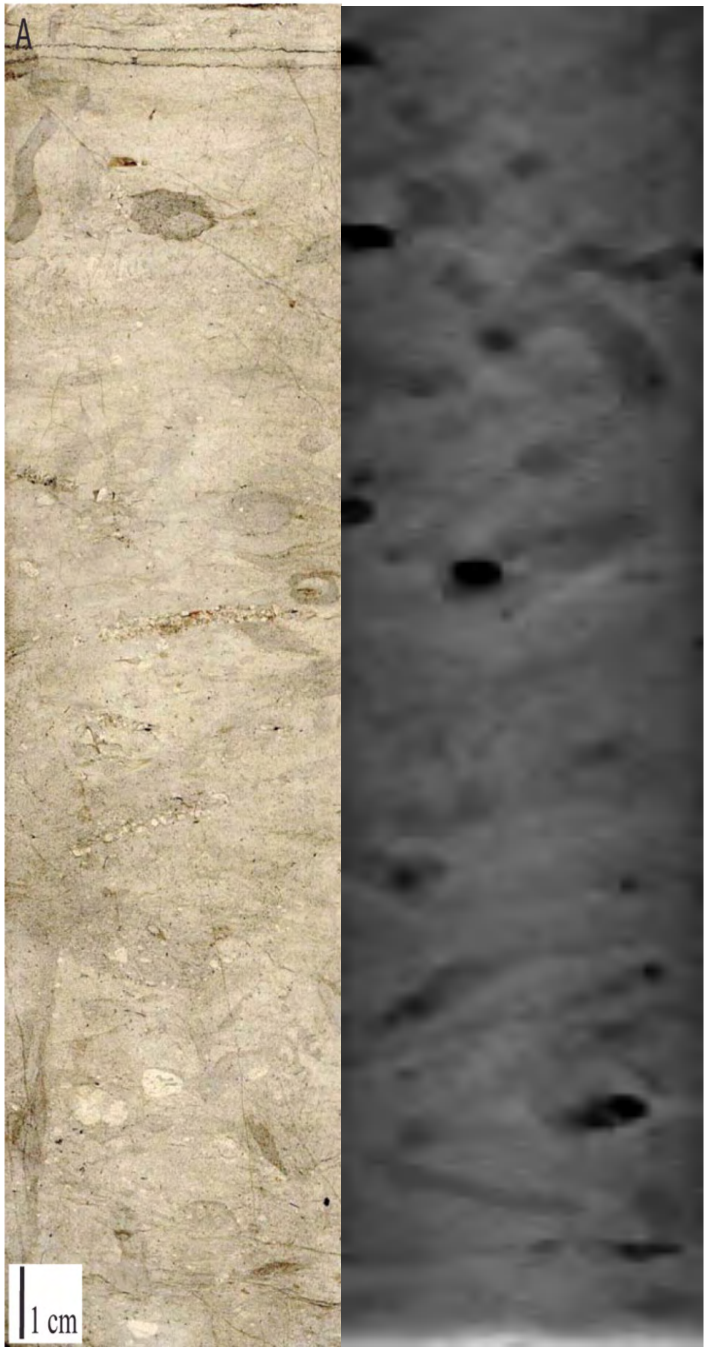
Sediment facies

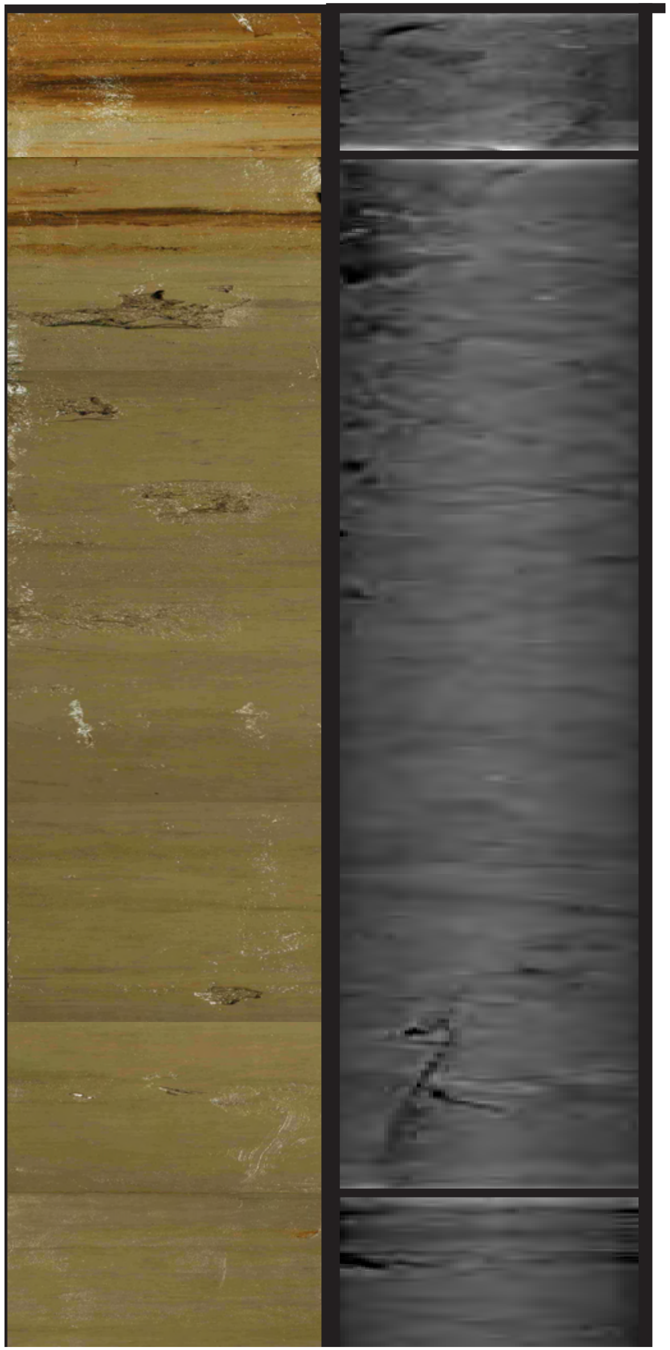


SANDY CONTOURITES
SILTY CONTOURITES
MUDDY CONTOURITES

HEAVY BIOTURBATION
SILTY MOTTLING
SANDY/SILTY LENSES
FINE LAMINATIONS
CRUDE LAMINATIONS

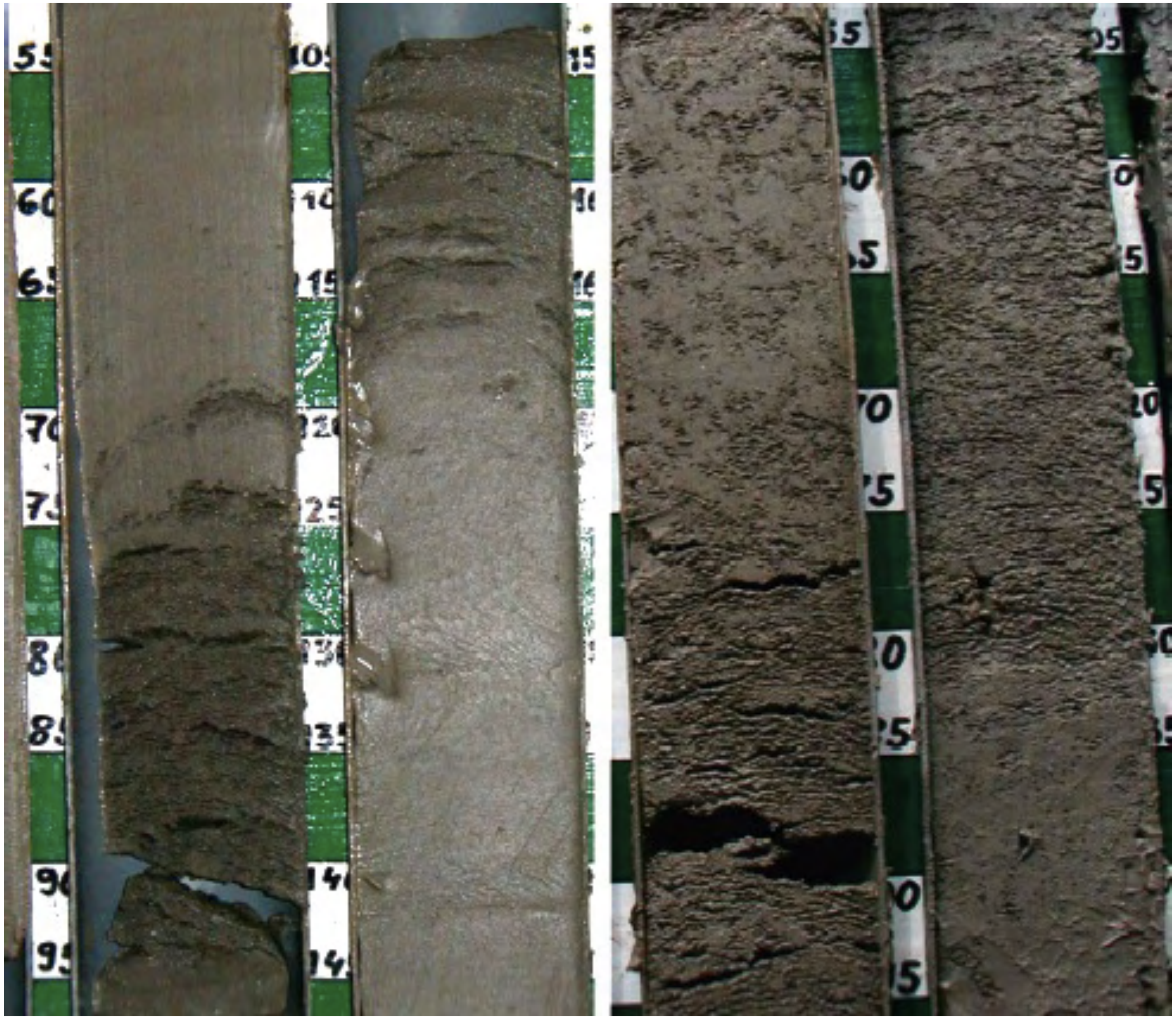
EROSIVE OR SHARP BASES
GRADUAL BASES





MUDDY CONTOURITES

Heavy Bioturbation



SILY
CONTOURITES

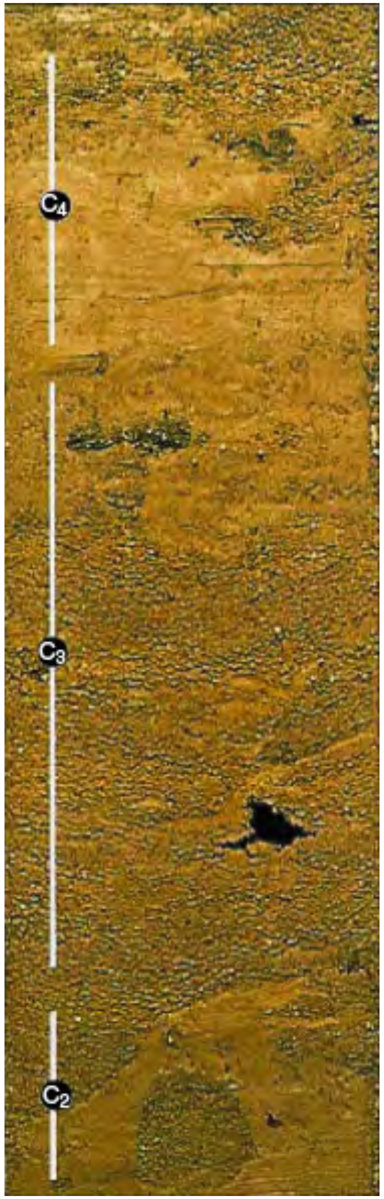
Bioturbation
Poor bedding
Sparse silt patches

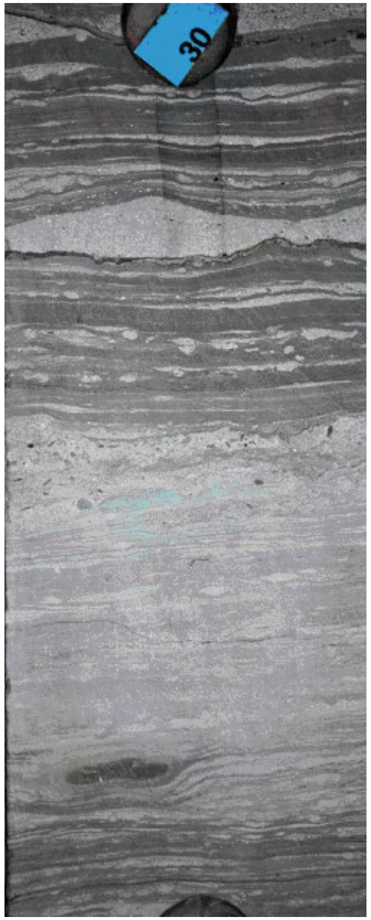
SANDY CONTOURITES

Bioturbation

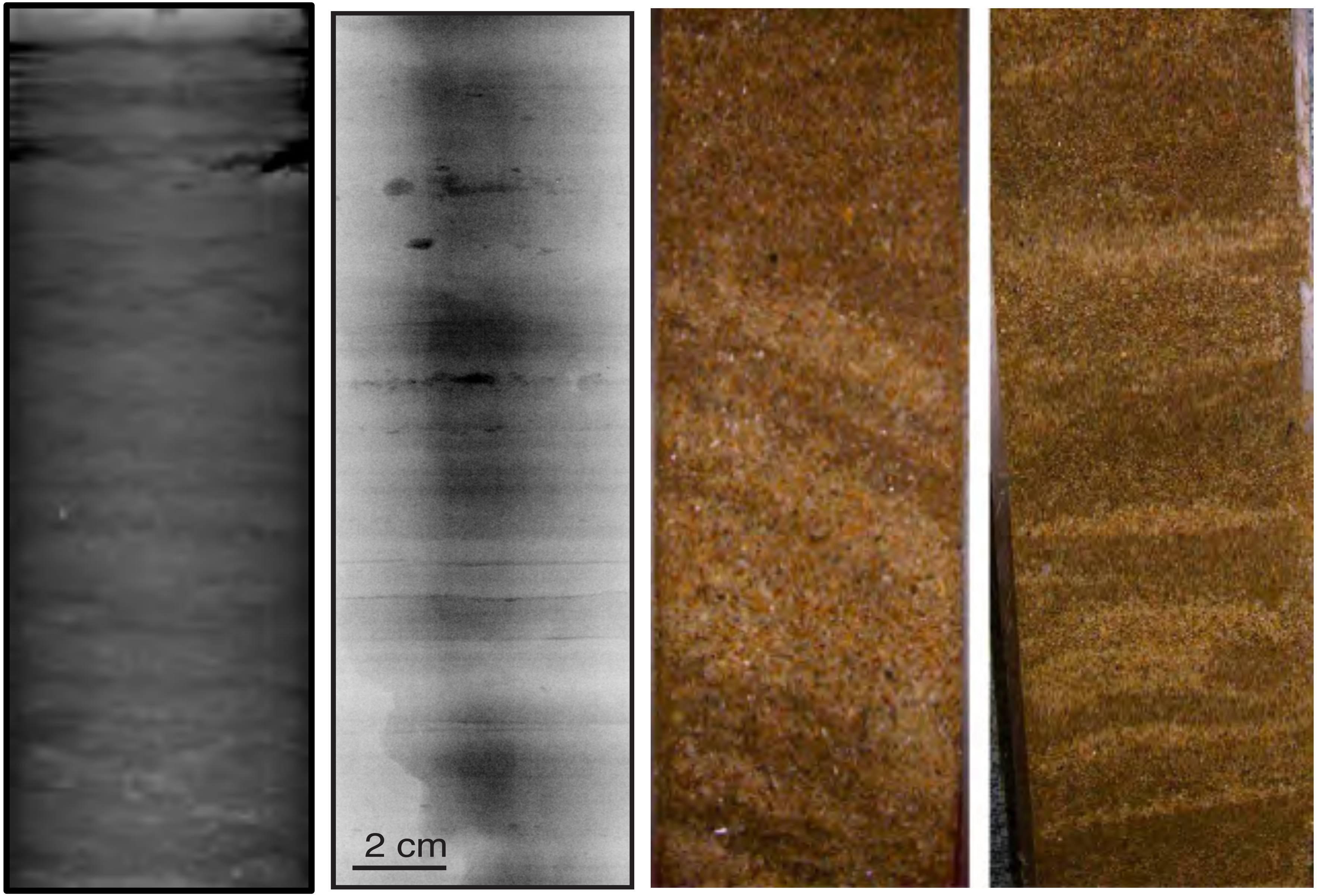
Poor bedding

Sparse silt patches and lenses

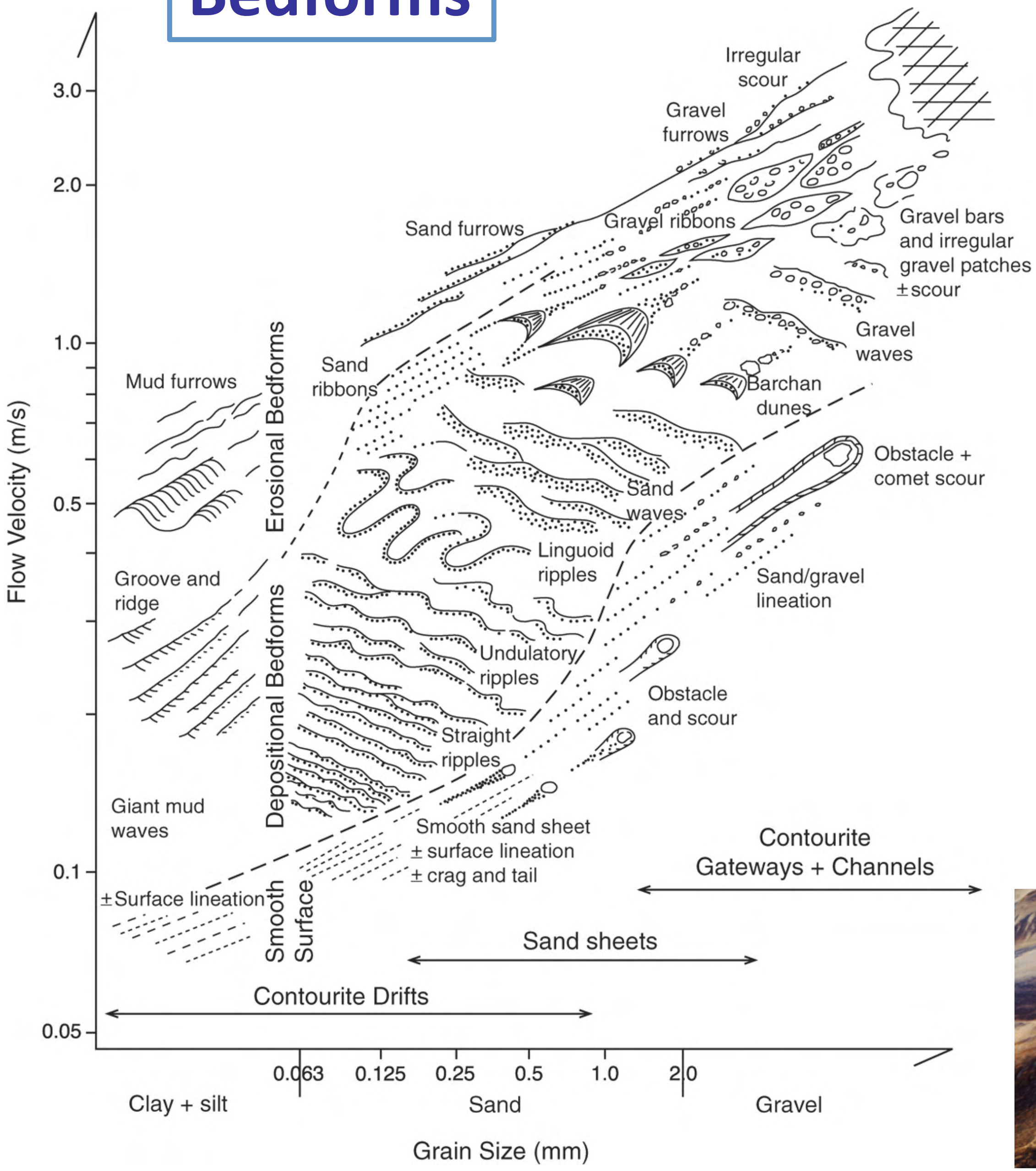


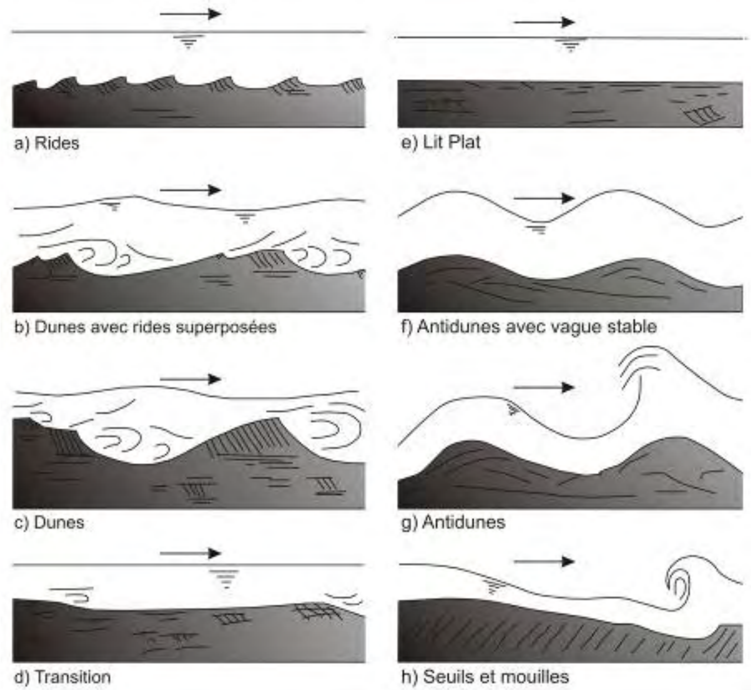


MUDDY and SANDY CONTOURITES: laminations



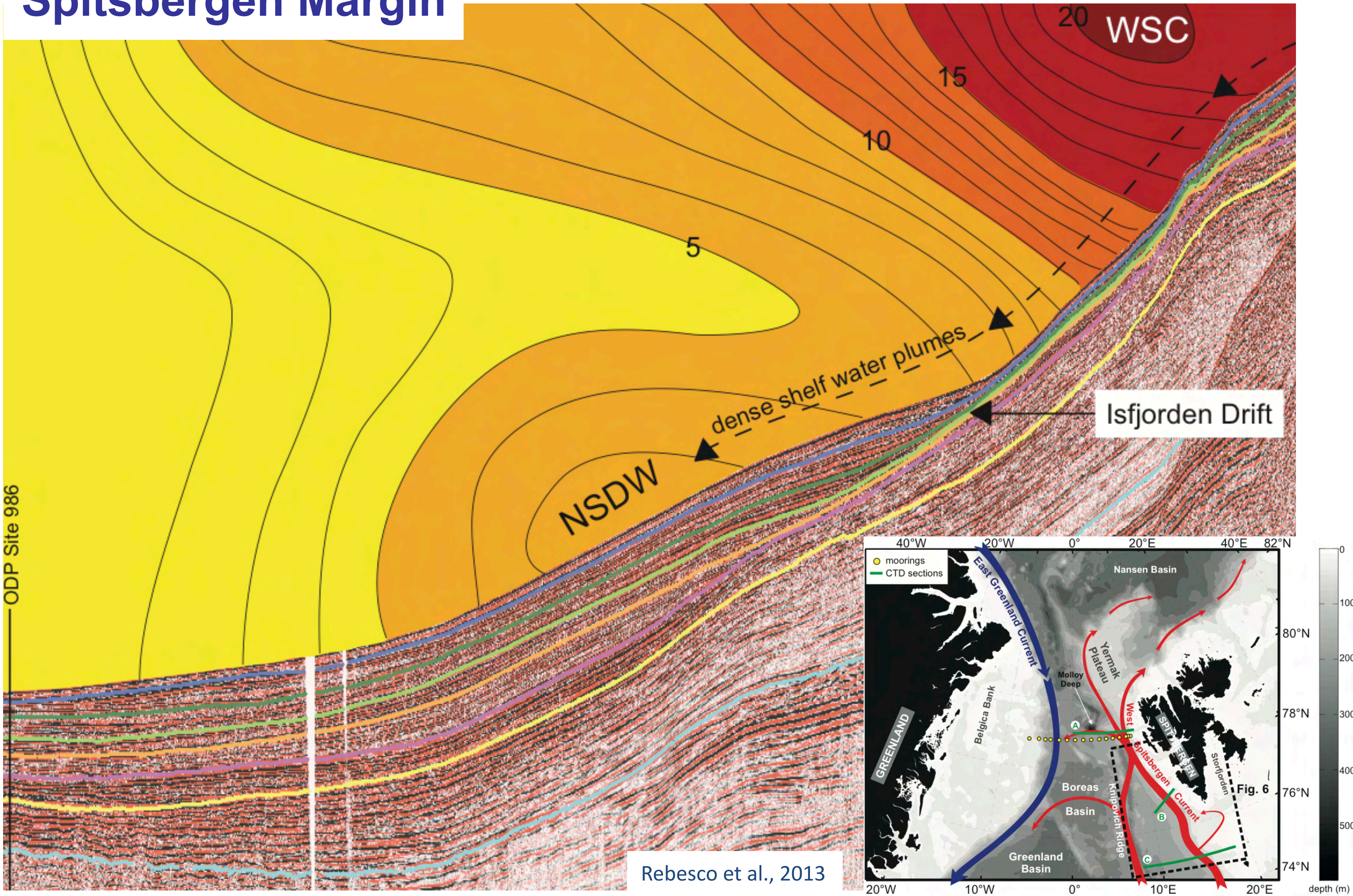
Bedforms





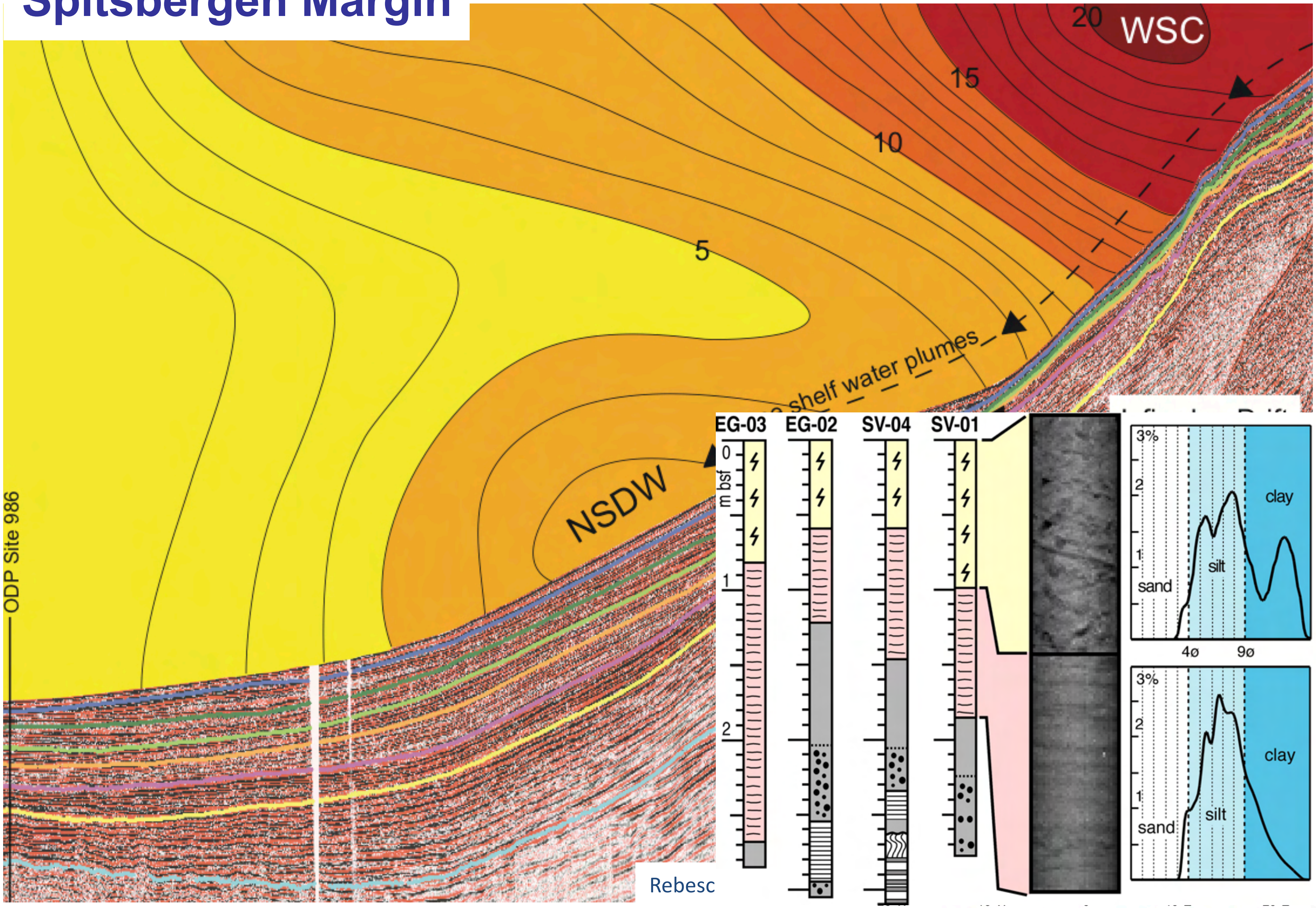
Antidune and Ripple formation

Spitsbergen Margin

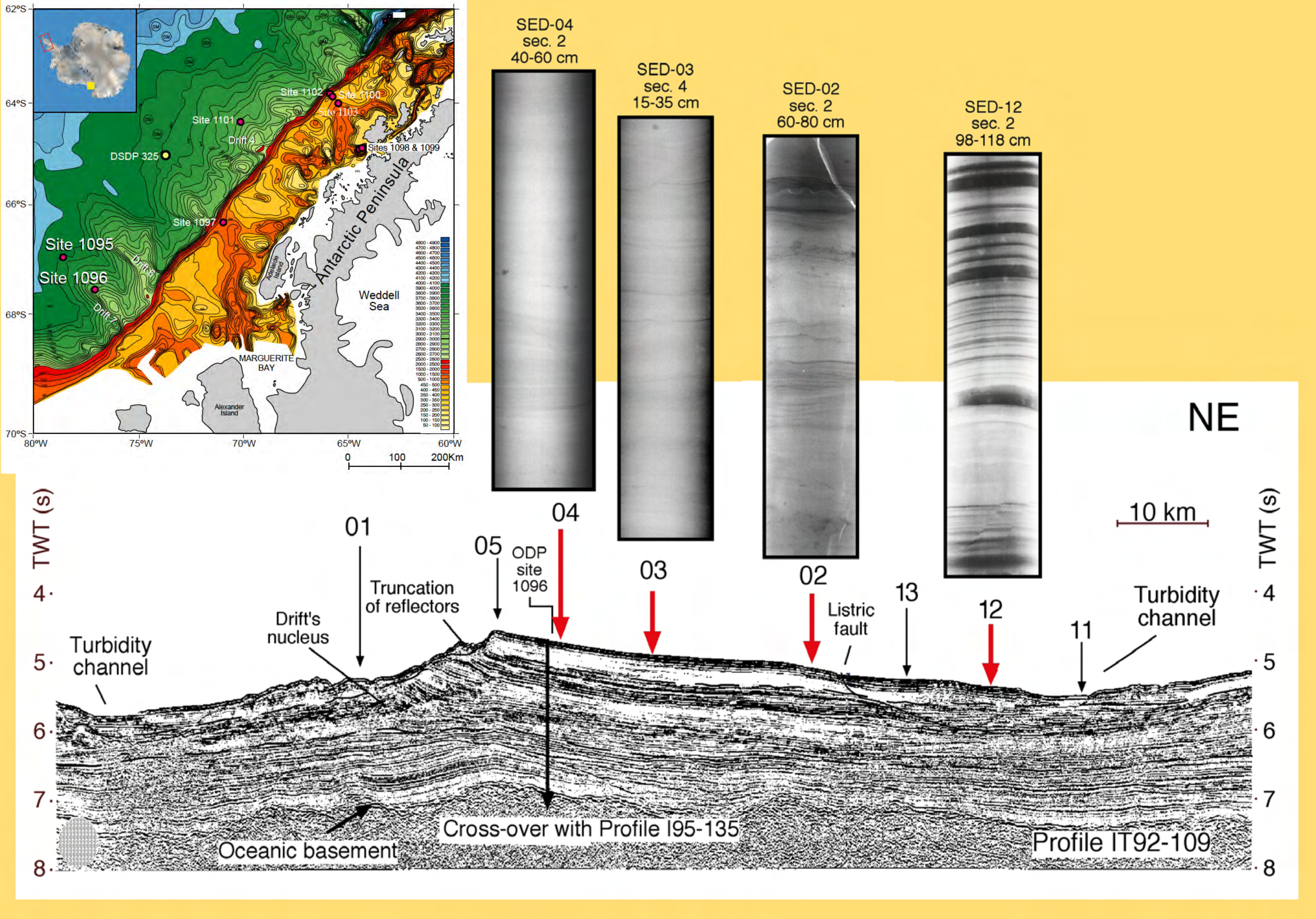


Rebesco et al., 2013

Spitsbergen Margin

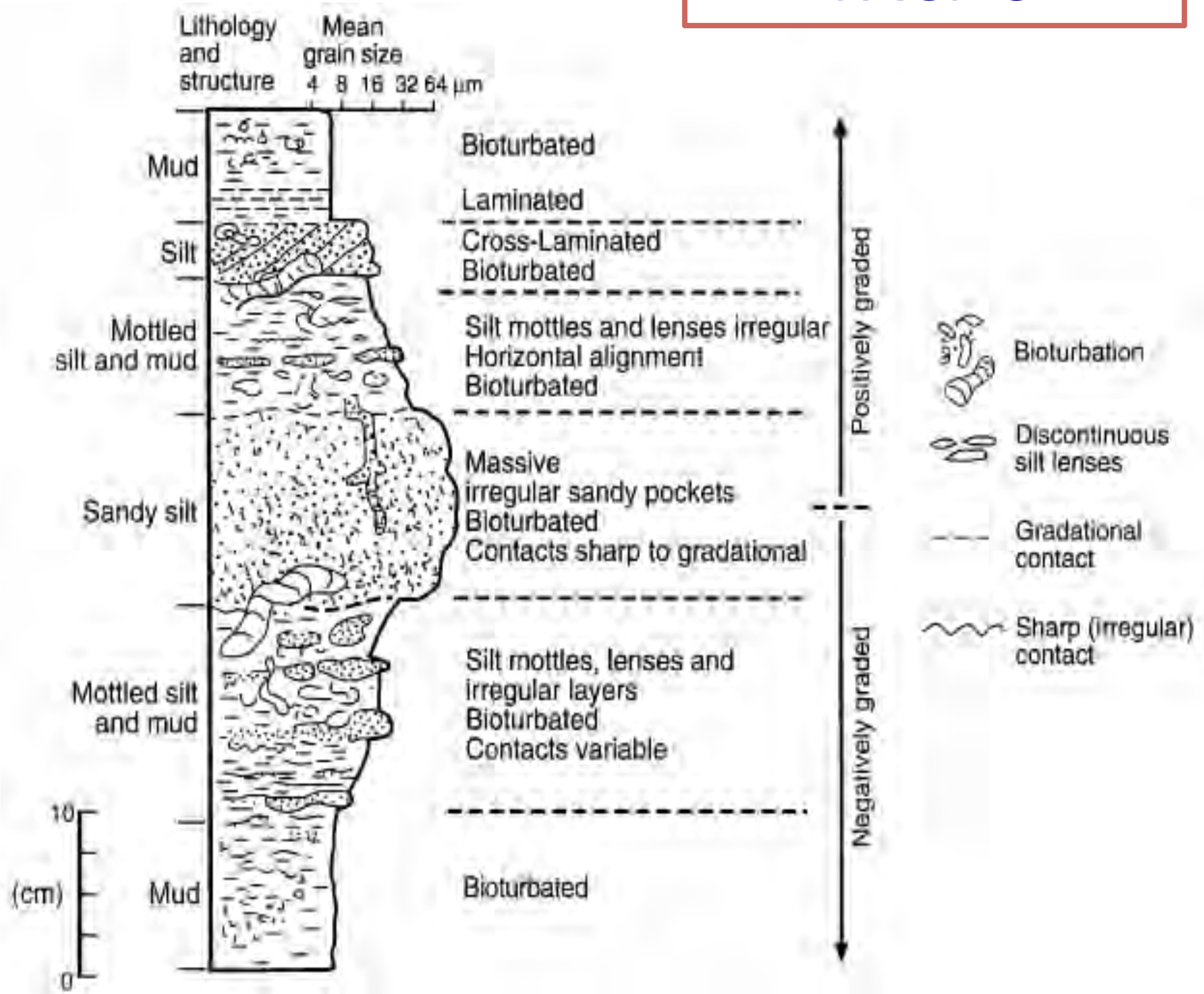


Rebesc

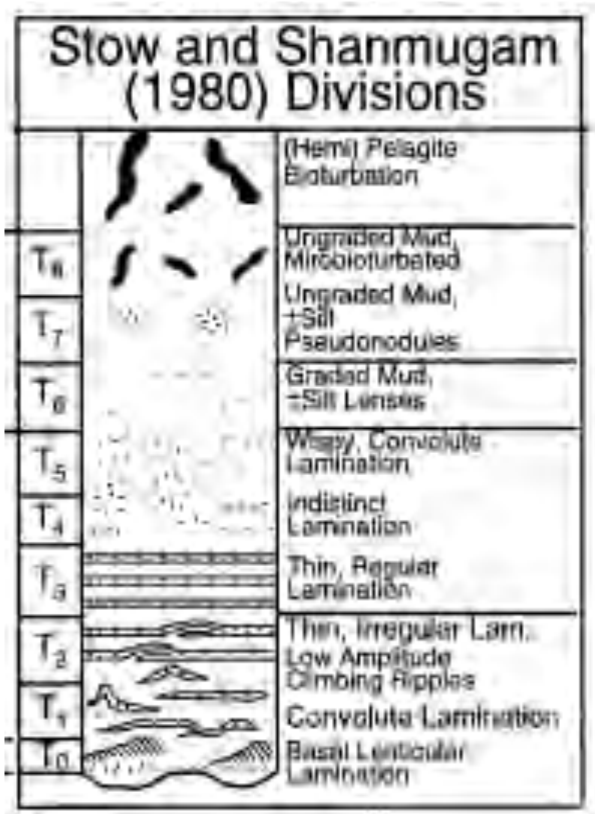

62°S
64°S
66°S
68°S
70°S
80°W
75°W
70°W
65°W
60°W
0
100
200Km
Site 1102
Site 1100
Site 1103
Site 1101
Drift 4
Sites 1098 & 1099
DSDP 325
Antarctic Peninsula
Site 1097
Site 1095
Site 1096
Drift 6
Drift 7
Weddell Sea
MARGUERITE BAY
Alexander Island
SED-04
sec. 2
40-60 cm
SED-03
sec. 4
15-35 cm
SED-02
sec. 2
60-80 cm
SED-12
sec. 2
98-118 cm
NE
10 km
TWT (s)
4
5
6
7
8
04
01
05
ODP site 1096
03
02
13
12
11
Truncation of reflectors
Drift's nucleus
Turbidity channel
Listric fault
Turbidity channel
Cross-over with Profile I95-135
Oceanic basement
Profile IT92-109

SEDIMENTARY FACIES

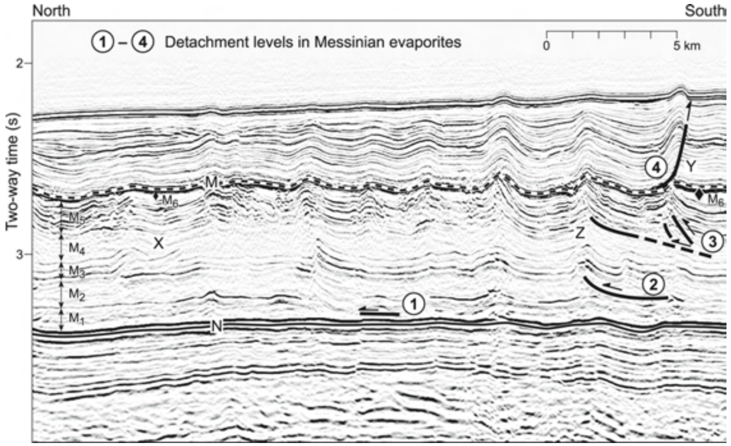
Contourites



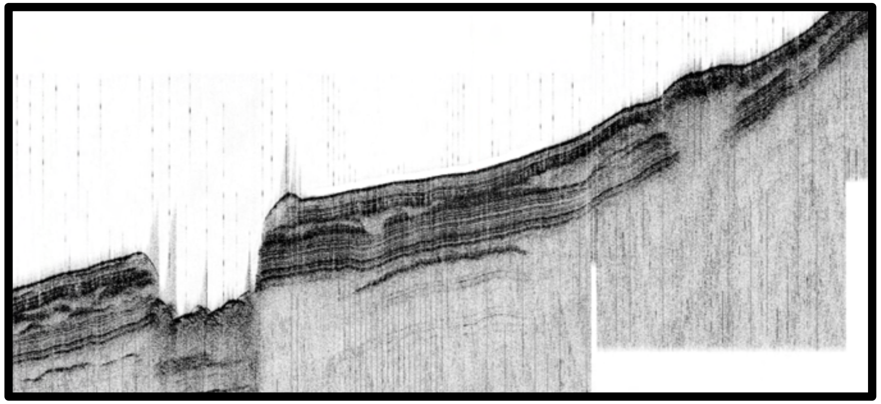
Fine-grained turbidites



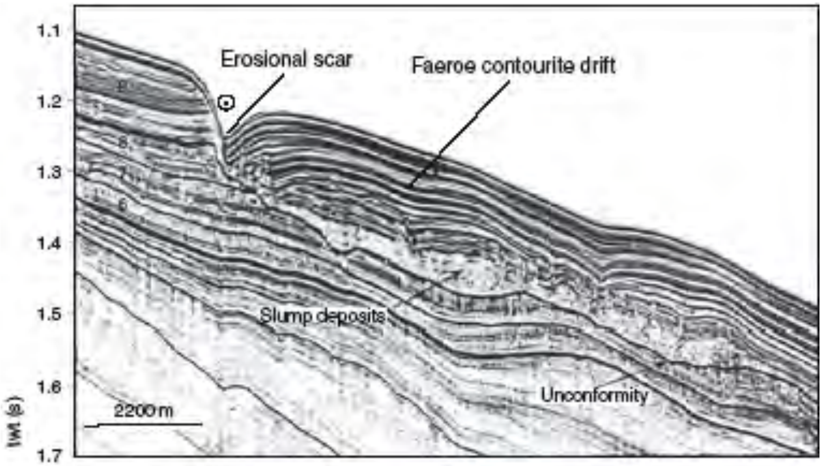
SEISMIC FACIES



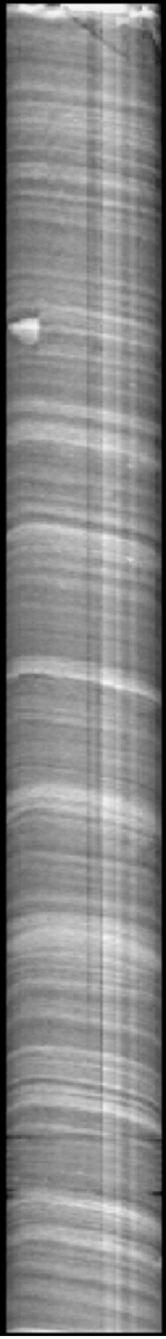
TURBIDITES



PLUMITES

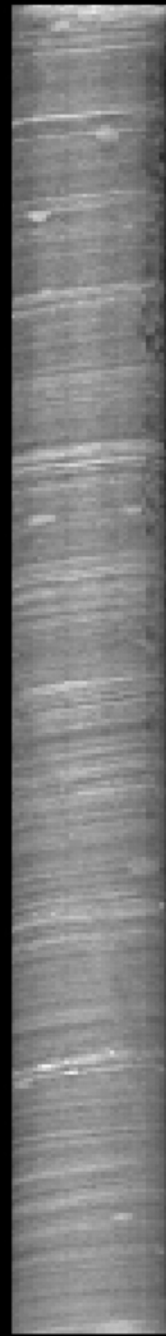


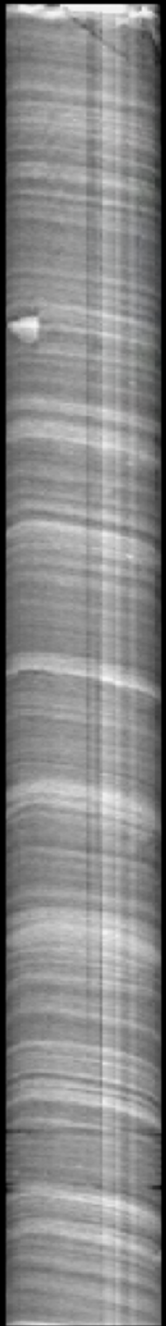
CONTOURITES



LAMINATED SEDIMENTS

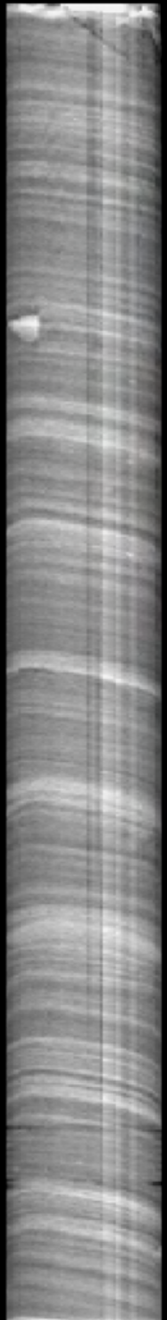
SEDIMENTARY PROCESSES	TRIGGER	SEDIMENTARY FACIES	SEDIMENT COMPOSITION





LAMINATED SEDIMENTS

SEDIMENTARY PROCESSES	TRIGGER	SEDIMENTARY FACIES	SEDIMENT COMPOSITION
low-density turbidity flows	slope instability	• sharp/irregular bases • massive/graded sands • laminations • gradual/bioturbated top	• admixture of terrigenous and bioclastic (reworked) components • sould not contain IRD at least not sistematically (fast deposition)



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SEDIMENTARY PROCESSES	TRIGGER	SEDIMENTARY FACIES	SEDIMENT COMPOSITION
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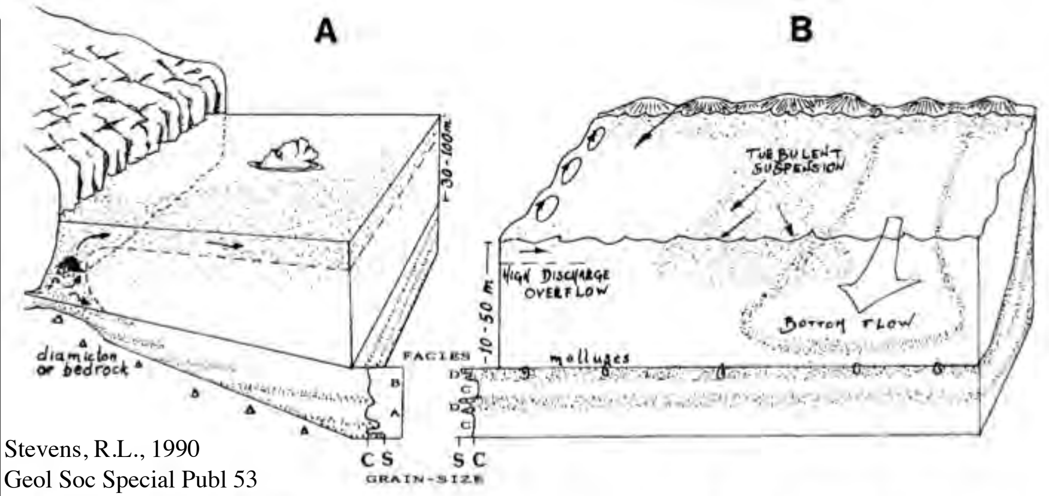
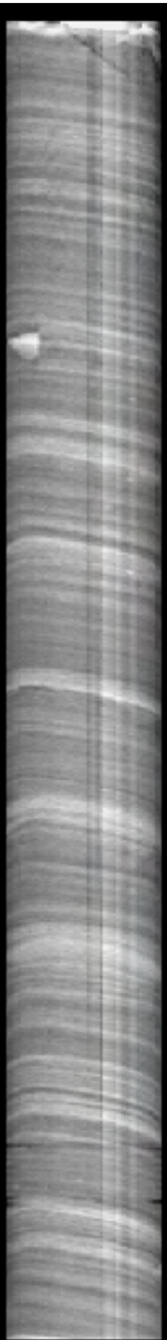
sediment-laden water plumes	sub-glacial meltwater		
A) underflow turbid plume behavie as a turbidity flow	the coarser fraction moves on the sea floor	similar to turbidites	• prevailing terrigenous • can contain IRD (associated process)
B) overflow and/or interflow turbid plumes	the finer fraction moves at the sea surface or within the sea water masses	suspended sediments settle as pelagic rain • normal grading • bioturbated top	• proximal areas: prevailing terrigenous • distal areas: mixed terrigenous and bioclasic (not reworked)

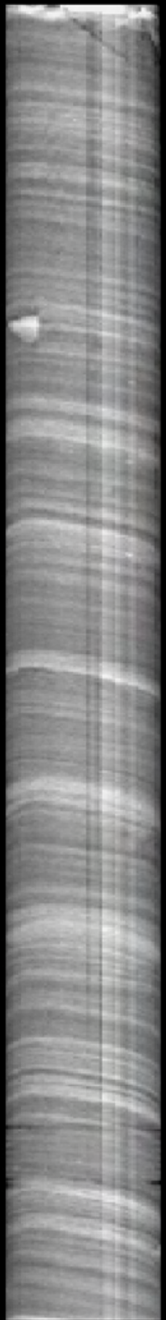


Stevens, R.L., 1990
Geol Soc Special Publ 53

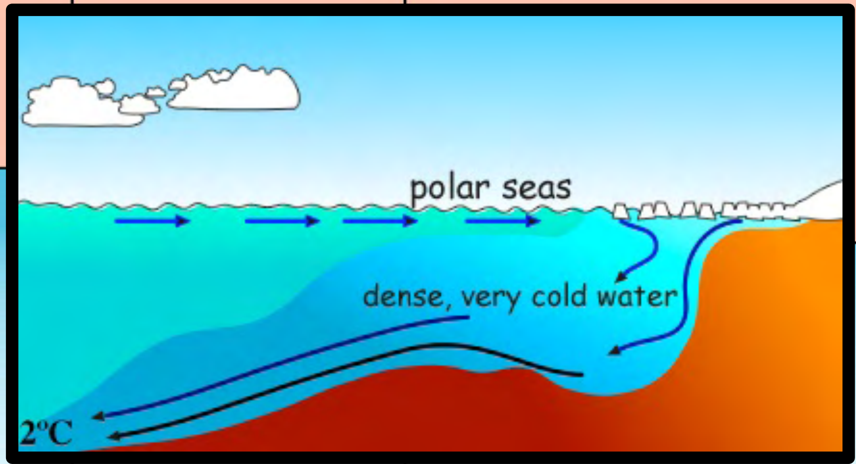


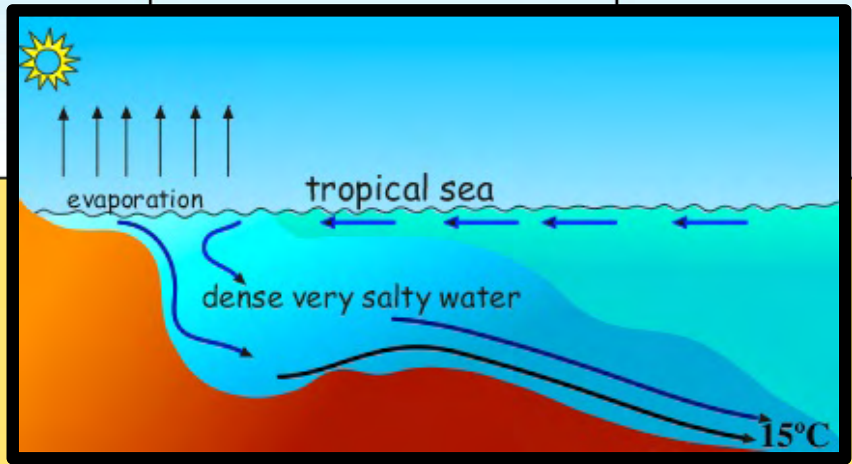
LAMINATED SEDIMENTS

SEDIMENTARY PROCESSES	TRIGGER	SEDIMENTARY FACIES	SEDIMENT COMPOSITION
low-density turbidity flows	slope instability	• sharp/irregular bases • massive/graded sands • laminations • gradual/bioturbated top	• admixture of terrigenous and bioclastic (reworked) components • sould not contain IRD at least not sistematically (fast deposition)
sediment-laden water plumes **A)** underflow turbid plume behavie as a turbidity flow	sub-glacial meltwater the coarser fraction moves on the sea floor	similar to turbidites	• prevailing terrigenous • can contain IRD (associated process)
〃 **B)** overflow and/or interflow turbid plumes	〃 the finer fraction moves at the sea surface or within the sea water masses	suspended sediments settle as pelagic rain • normal grading • bioturbated top	• proximal areas: prevailing terrigenous • distal areas: mixed terrigenous and bioclasic (not reworked)
along-slope bottom currents	geostrophic contour currents	• irregular/erosive bases and tops • grading • laminations • intense bioturbation (in polar margins the facies associated to glacials can be not bioturbated)	• mainly bioclastic (if are avaible) • can contain IRD (long lasting depositional process)

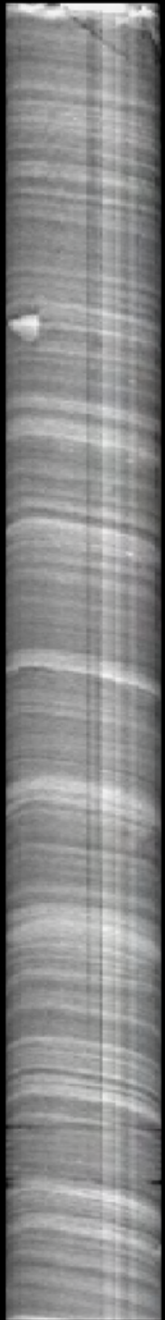


LAMINATED SEDIMENTS





SEDIMENTARY PROCESSES	TRIGGER	SEDIMENTARY FACIES	SEDIMENT COMPOSITION
down-slope density currents	brine cascading	• erosional surfaces • ripples, dune, laminations	• terrigenous and mixed



LAMINATED SEDIMENTS

SEDIMENTARY PROCESSES	TRIGGER	SEDIMENTARY FACIES	SEDIMENT COMPOSITION
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down-slope density currents	brine cascading	• erosional surfaces • ripples, dune, laminations	• terrigenous and mixed