Istituto Nazionale di Oceanografia e di Geofisica Sperimentale

Università degli studi di Trieste

LAUREA MAGISTRALE IN GEOSCIENZE

Classe Scienze e Tecnologie Geologiche

Curriculum: Esplorazione Geologica

Anno accademico 2023 - 2024

Analisi di Bacino e Stratigrafia Sequenziale (426SM)

Docente: **Michele Rebesco**

Istituto Nazionale di Oceanografia e di Geofisica Sperimentale

Modulo 2.3a
Density currents and mass transport
Docente: **Renata Lucchi**

Modulo 2.3b
Bottom currents
Docente: **Michele Rebesco**

Modulo 2.3a Density currents and mass transport

Docente: Renata G. Lucchi

OUTLINE

- Nomenclature of processes and deposits
- Deposit classification
- Mass transport: creep, slide / slump, debris avalanche
- Gravity flows: laminar flow (debris flow)
- Turbulent flow (turbidity currents)

Nomenclature

Depositional process → ***Deposit***

down-slope processes:

driven by gravity forces

» Mass Transport → ***MTDs***

» Turbidity currents → ***Turbidites***

» Riverine outflows → ***Hyper (Hypo)- picnites***

» Turbid meltwaters → ***Plumites***

along-slope:

driven by density forces (thermo-haline origin)

» Contour currents → ***Contourites***

Deposit's classification

- 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

STOPPANI	1871	MIYABE	1935	VENZO & LARGAIOLLI	1968
A. PENCK	1874	LADD	1935	HUTCHINSON	1968
BALTZER	1875	HENNES	1936	SAVAGE	1968
MOLITOR	1894	SHARPE	1938	ZARUBA & MENCL	1969
PANTANELLI	1897	DI TELLA & BAY	1939	SKEMPTON & HUTCHINSON	1969
NEUMAYR	1898	MONTANARI	1940	VENZO & ULCIGRAI	1970
GUNTHER	1899	PRINCIPI	1945	DESIO	1971
DE MARCHI	1903	BENDEL	1948	BRUGNER & VALDINUCCI	1972
BRAUN	1907	MARESCA	1948	NEMCOCK et alii	1972
HOWE	1909	GORTANI	1948	VALLARIO & COPPOLA	1973
STINY	1910	IPPOLITO & COTECCHIA	1954	BLYTH & DE FREITAS	1974
ALMAGIA'	1910	SCHULTZ & CLEAVES	1955	NICOTERA	1975
ISSEL	1910	KRYNINE & JUDD	1957	VENZO	1976
TRABUCCO	1913	VARNES	1958	VARNES	1978
ROTIGLIANO	1916	DESIO	1959	CORNIELLO et alii	1980
W. PENCK	1924	PENTA	1959	HUTCHINSON	1988
TERZAGHI	1925	VENZO	1960	SASSA	1989
HEIM	1932	GOGUEL	1967	CRUDEN & VARNES	1996

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.

- 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

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

mass slide → no failure surface, low deformation rate → creep

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

mass slide → isolated blocks or aggregates of blocks rapid movement → debris avalanche

soil creep

soil slide

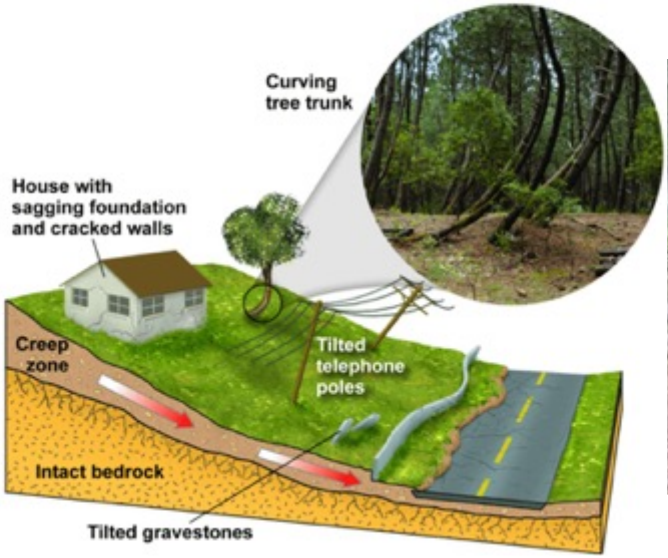
indistinct boundaries
pore fluid important
in triggering and
motion → gravity flow

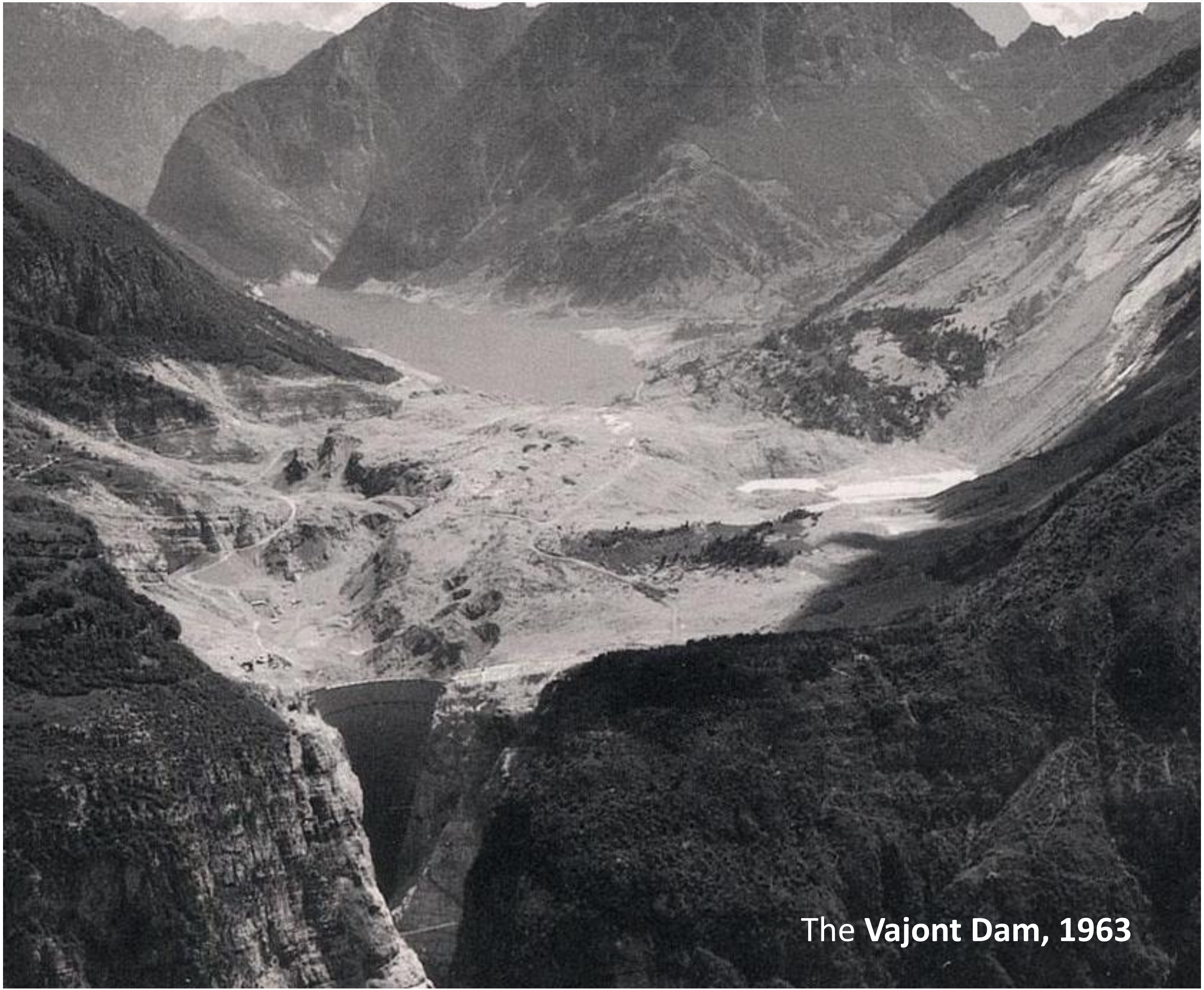
gravity flow → laminar flow → mass flow
- mass flow → matrix supported → debris flow
- mass flow → fluid supported → grain flow

gravity flow → turbulent flow → turbidity current
- turbidity current → low density
- turbidity current → high density

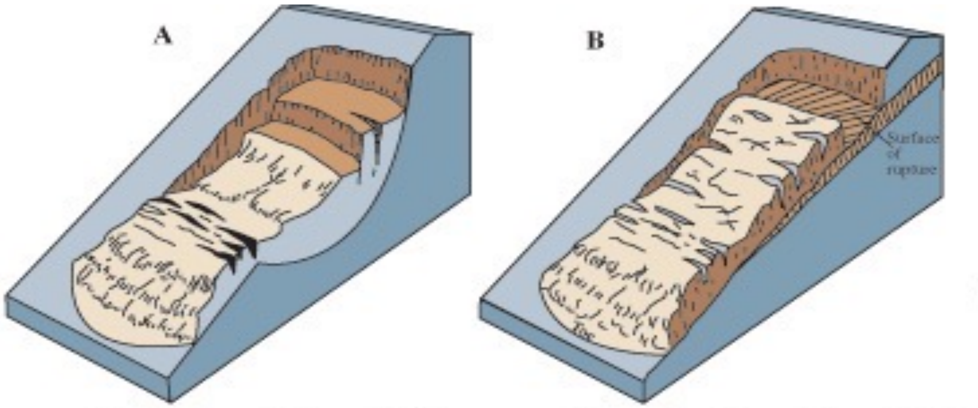
Masson et al. 2006

Creeping

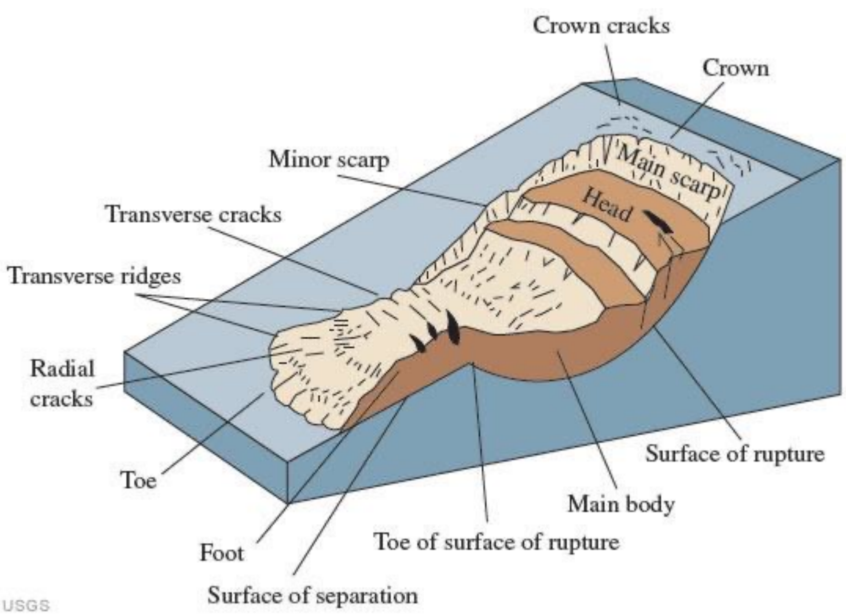

Curving
tree trunk
House with
sagging foundation
and cracked walls
Creep
zone
Tilted
telephone
poles
Intact bedrock
Tilted gravestones


The **Vajont Dam, 1963**

Slides/Slumps



Rotational landslide   Translational landslide

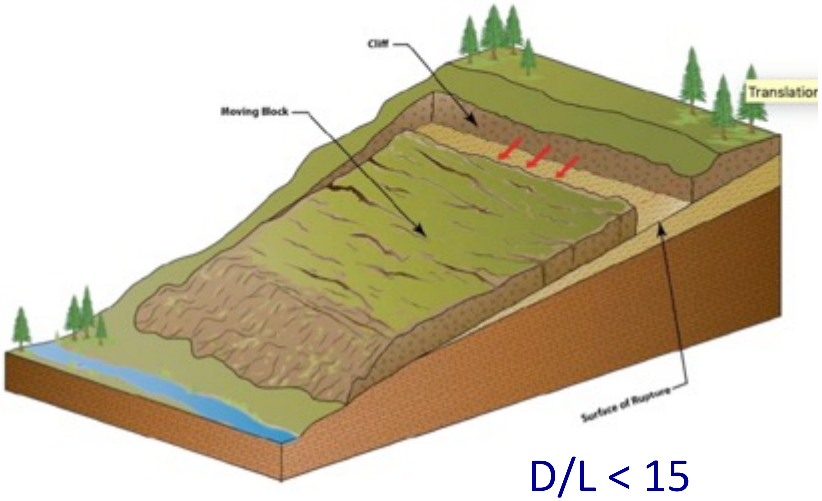


La Conchita, California 1995 (from Fanti, UniFI)

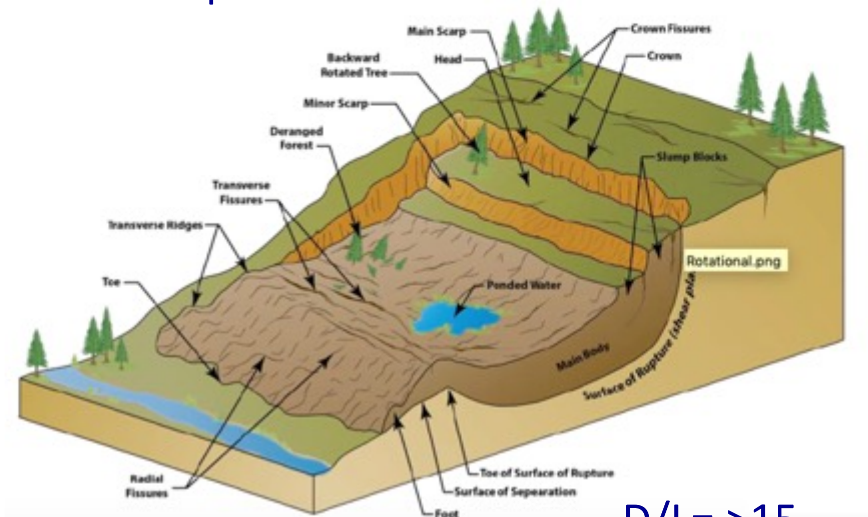
Cruden, 1981

Slides/Slump

Numero di Skempton (1953)
D= spessore massimo frana
L= lunghezza lungo massima pendenza



D/L < 15



D/L= >15

Romania, foto M. Cremaschi

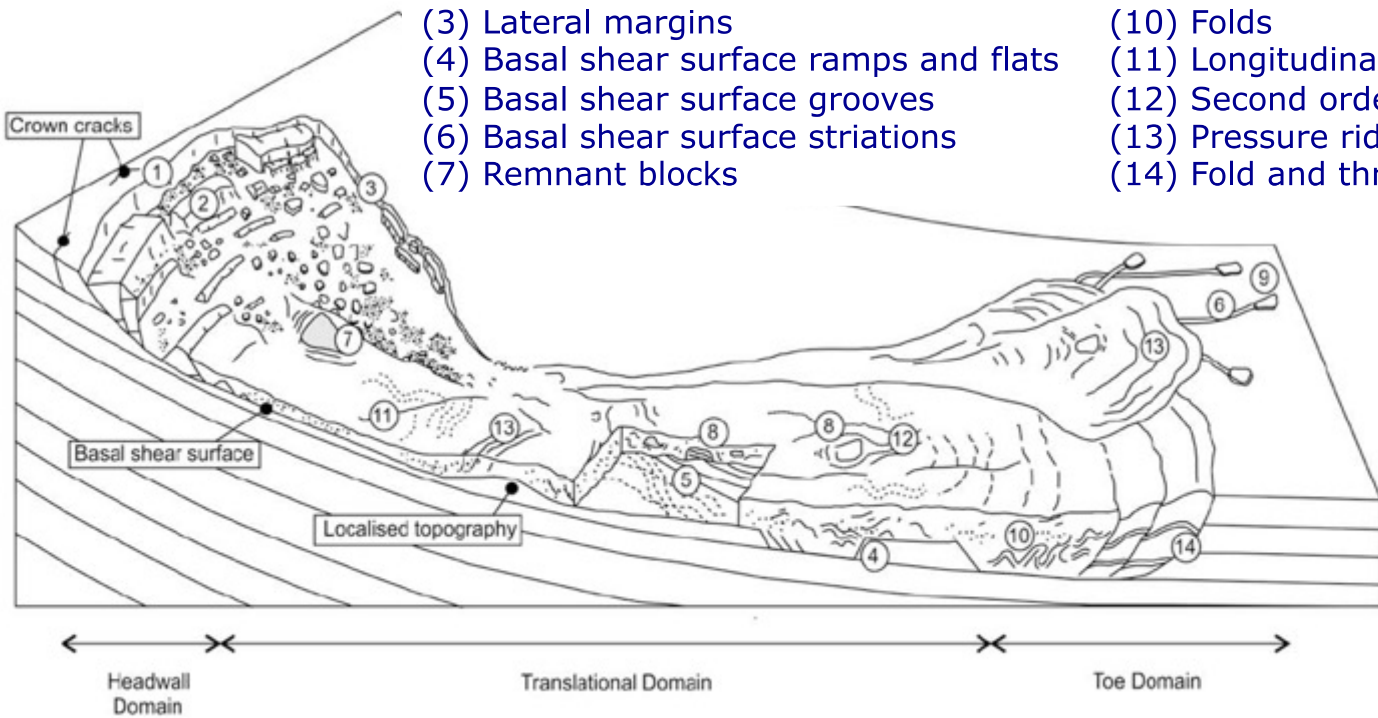
Pleistocene Submarine Landslides in the Boso Peninsula, Japan

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

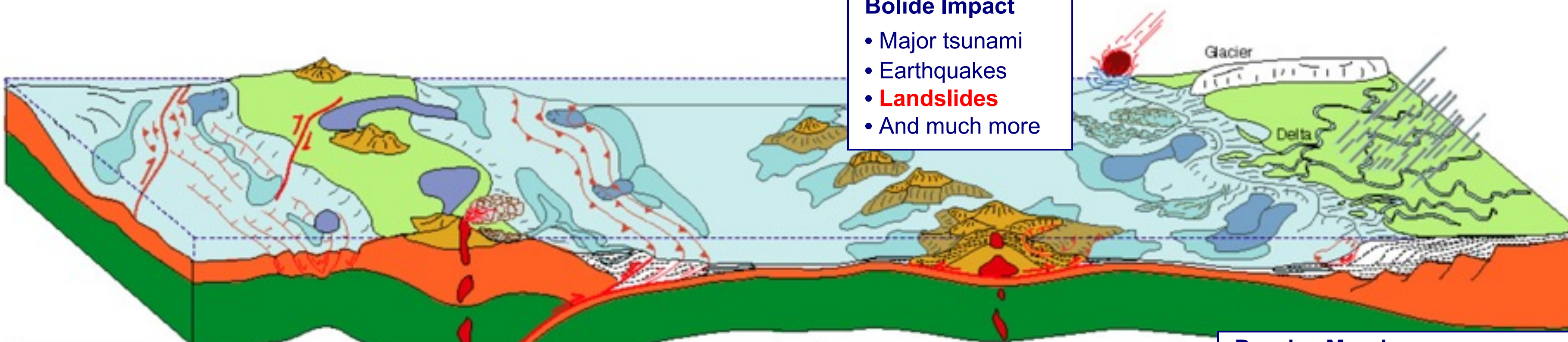


Modified after Prior et al. (1984)

Bull et al., 2009. Marine and Petroleum Geology

Submarine slides/slumps

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



Bolide Impact
- Major tsunami
- Earthquakes
- **Landslides**
- And much more

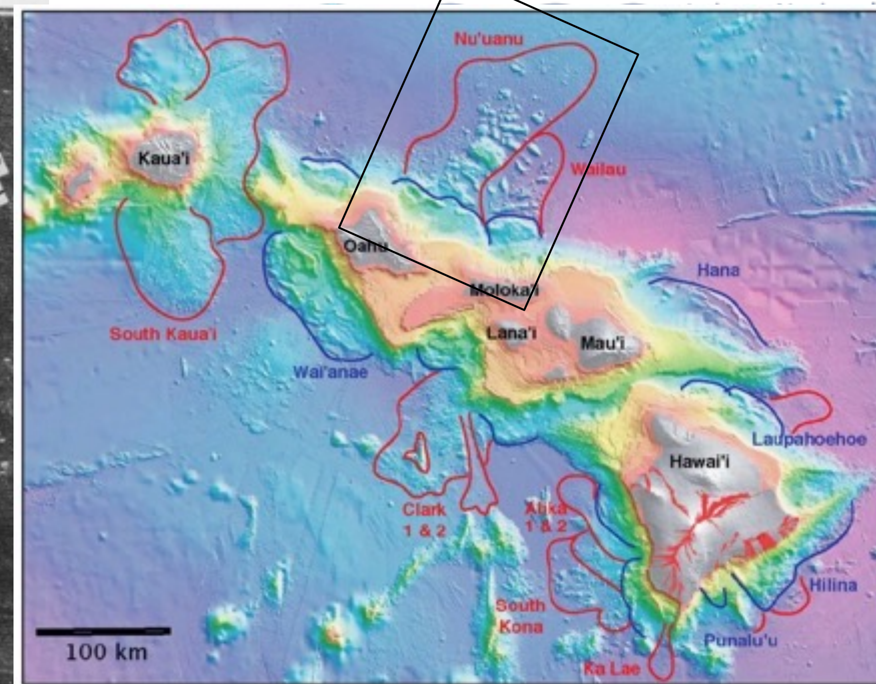
Rift & Transform Margins
- Moderate earthquakes
- **Submarine/subaerial landslides**
- Debris flows, turbidity currents
- Tsunamis
- Methane emissions

Subduction Margins
- Large earthquakes
- **Submarine/subaereal landslides**
- Explosive eruptions, lahrs
- Debris flows, turbidity currents
- Tsunamis
- Methane emissions

Oceanic Volcanoes
- **Submarine/subaerial landslides**
- Debris flows, turbidity currents
- Volcanic eruptions
- Earthquakes
- Tsunamis
- Methane emissions

Passive Margins
- **Submarine landslides**
- Debris flows, turbidity currents
- Modest earthquakes
- Tsunamis
- Methane emissions

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



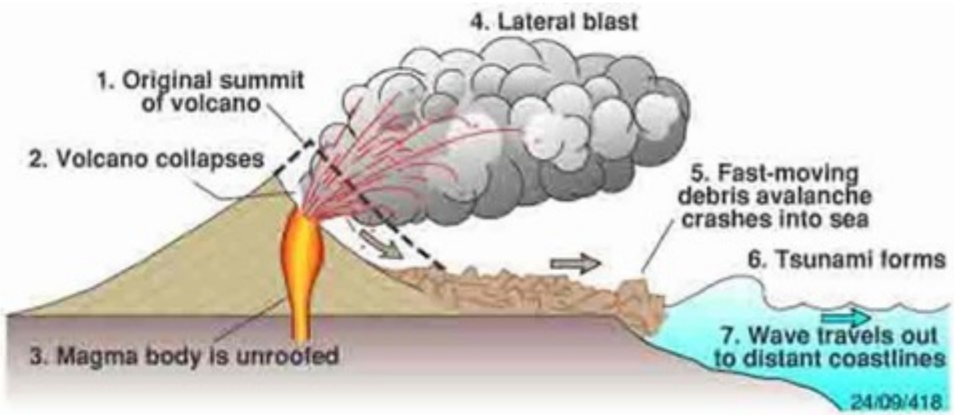
Morgan et al., 2009. Scientific Drilling

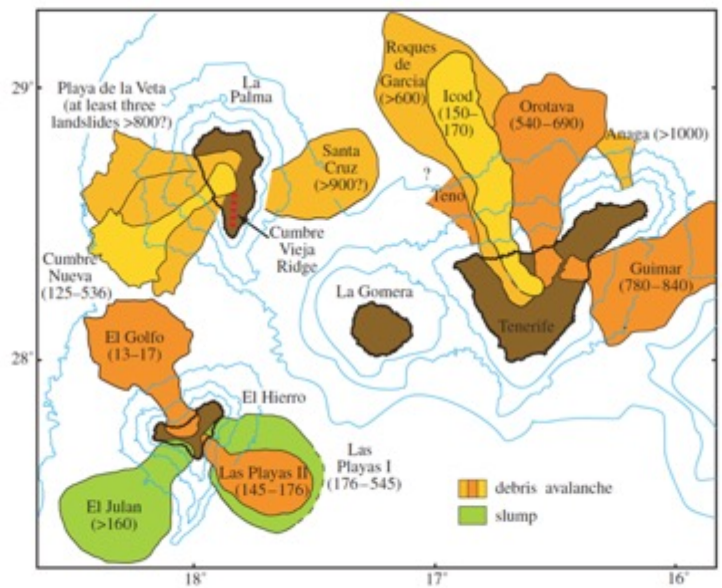
Submarine debris avalanches

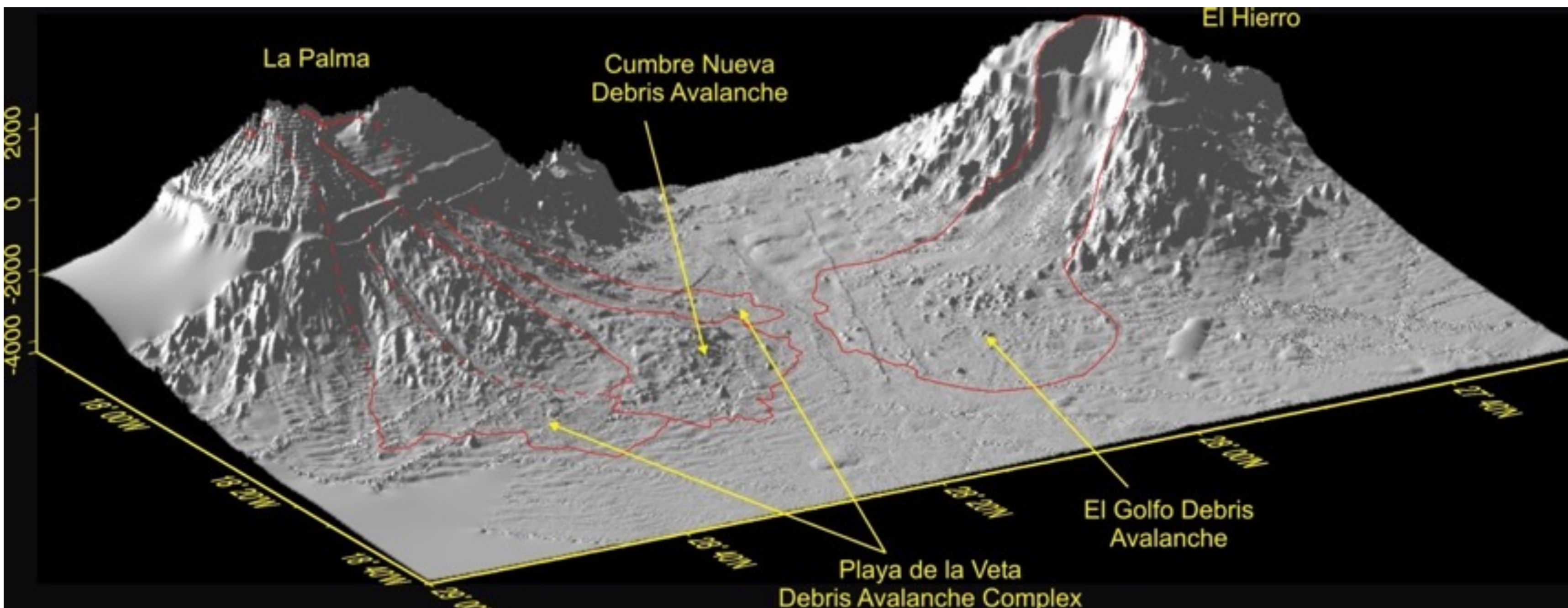
Volcanic Island Margins Hawaii

Moore et al., 1994. JGR

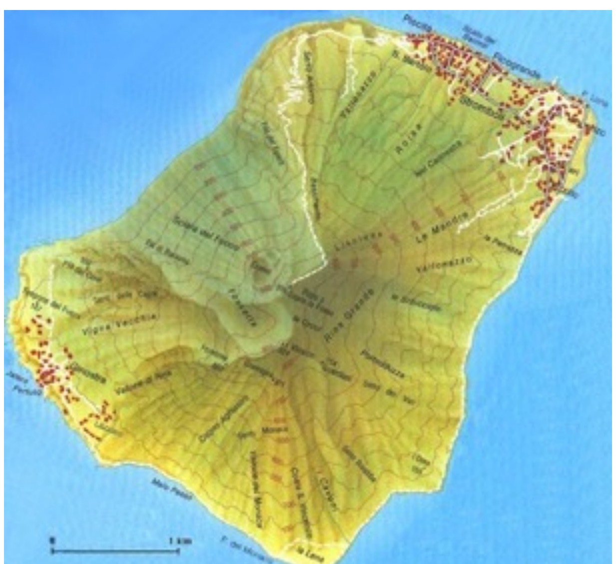
Volcanic Island Margins
Canarie

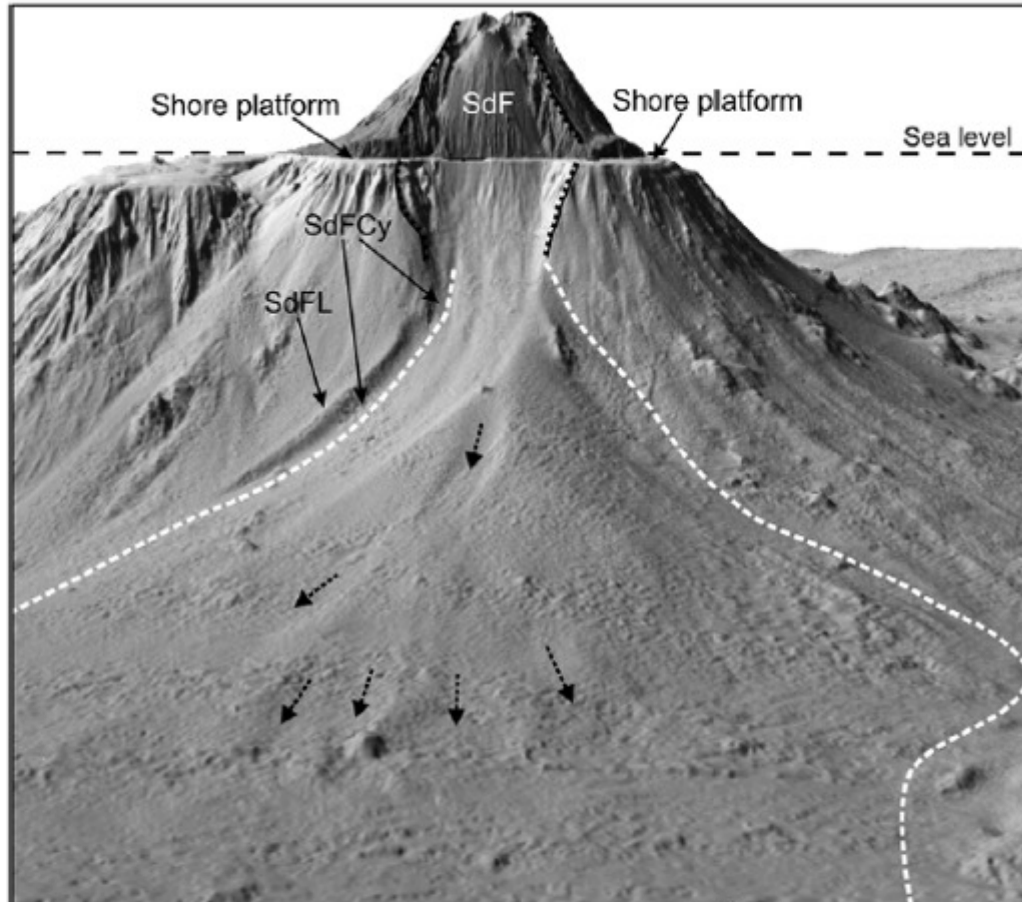






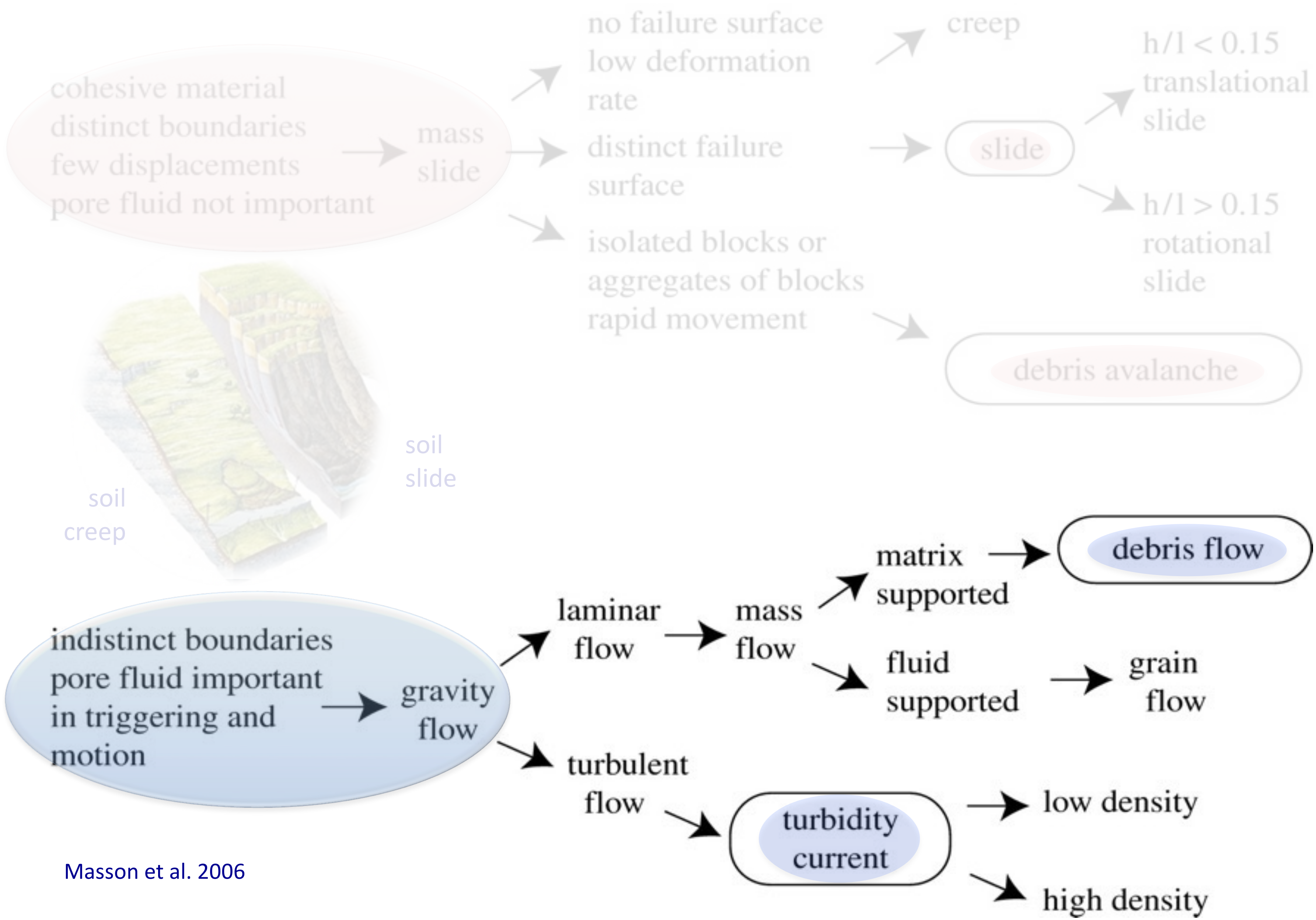
Volcanic Island Margins
Stromboli, Lipari Islands, Italy





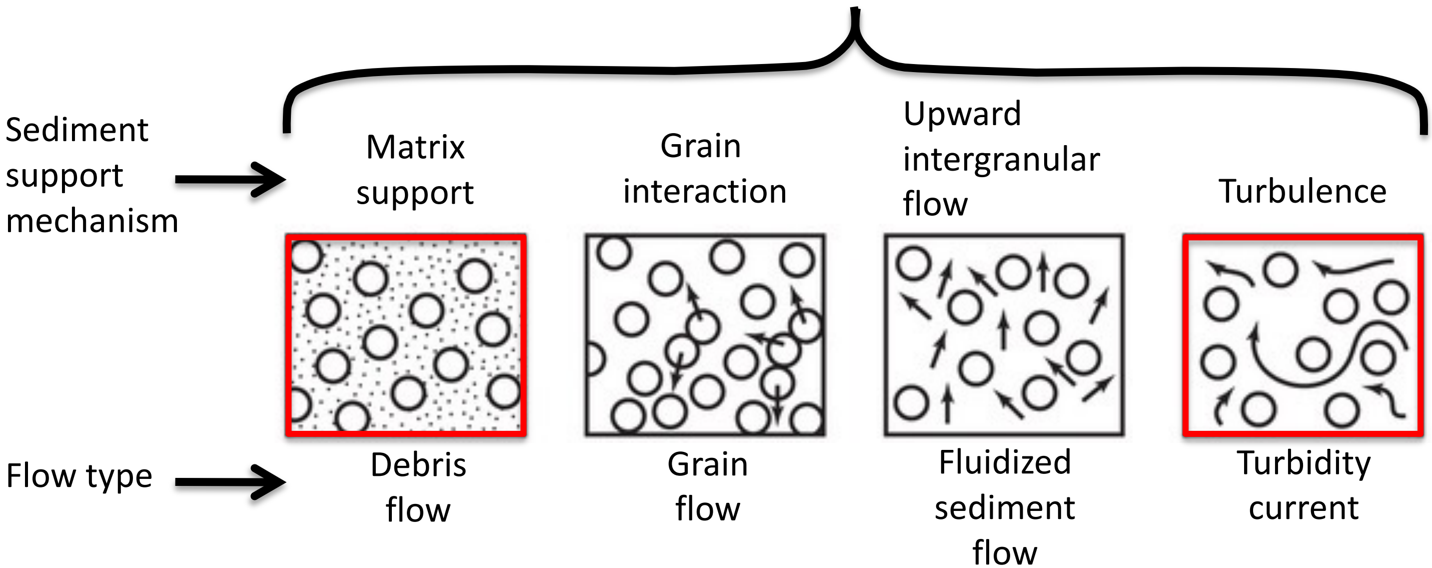
Stromboli Sciara di Fuoco
100.000 y

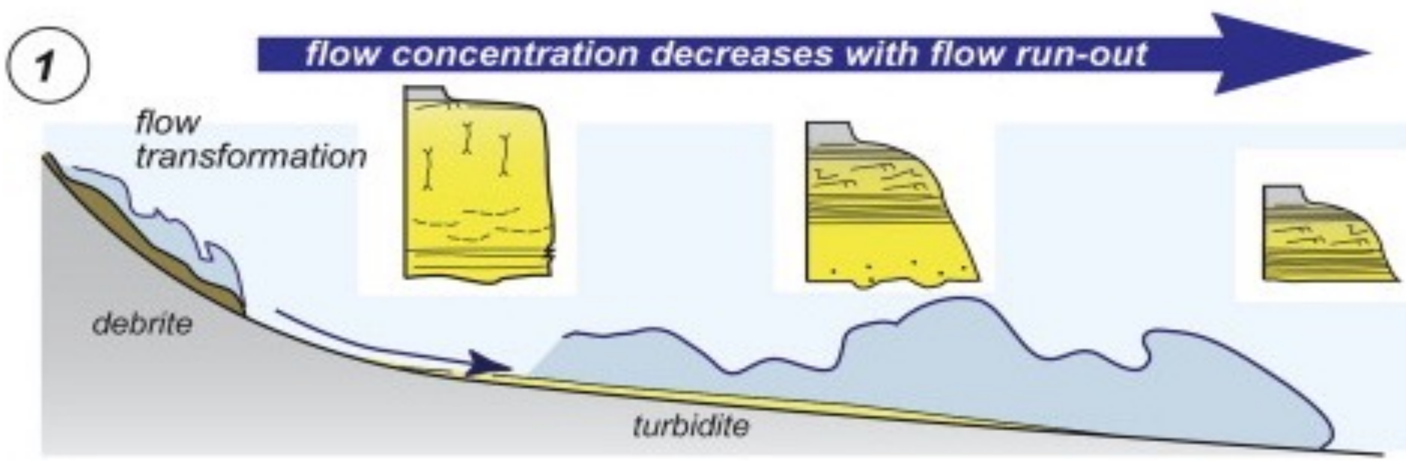
Romagnoli et al., 2009. Marine Geology



Masson et al. 2006

Gravity flows



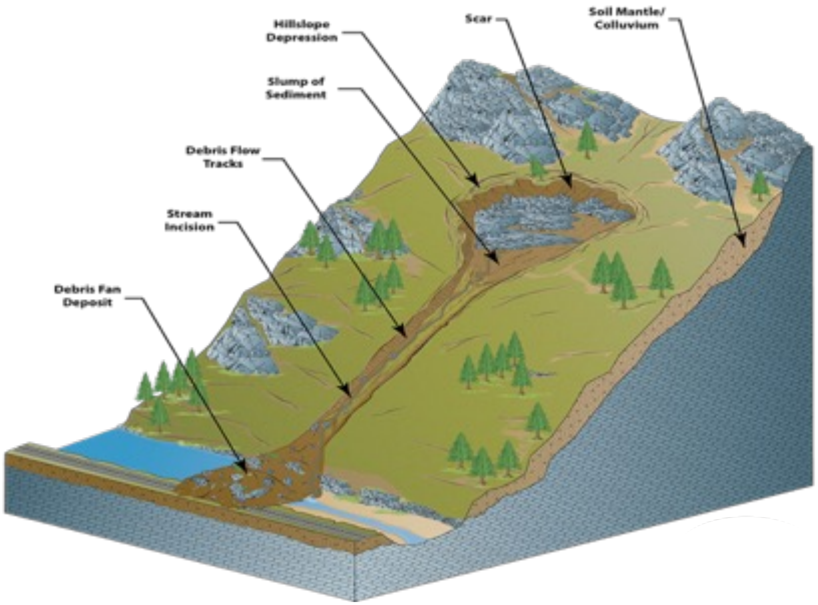


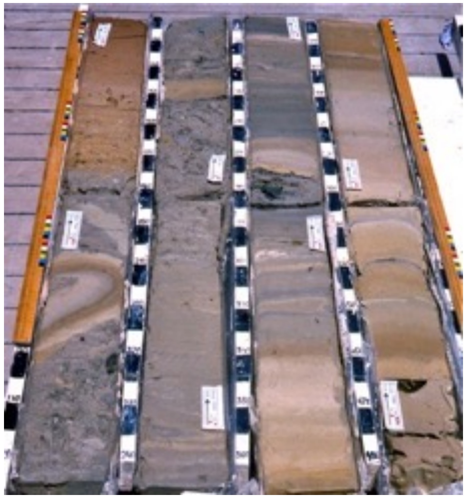
Debris flows

Laminar flux supported by the water-rich muddy matrix

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

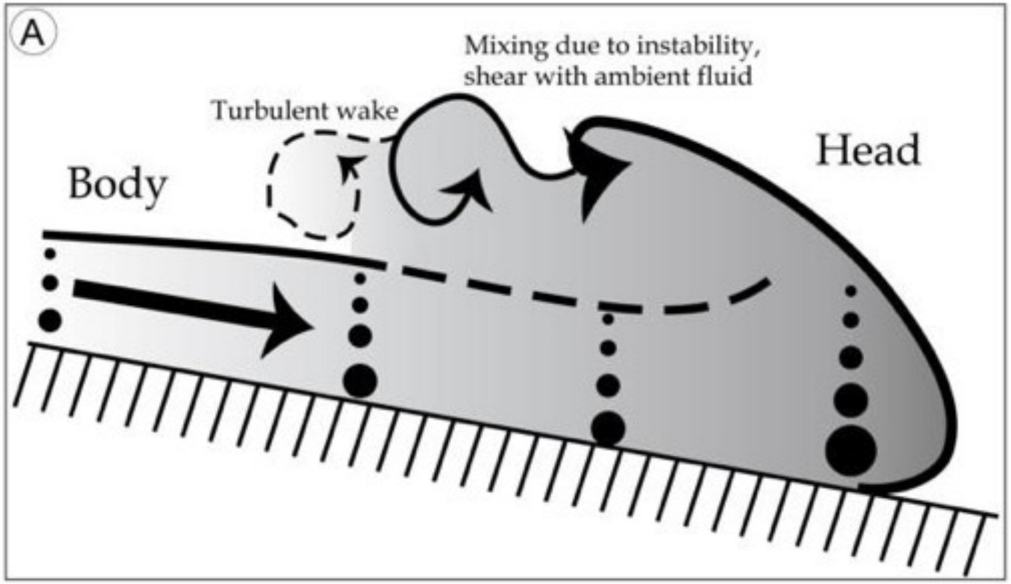
Mud flow: mud/sand >1; pebbles <5%

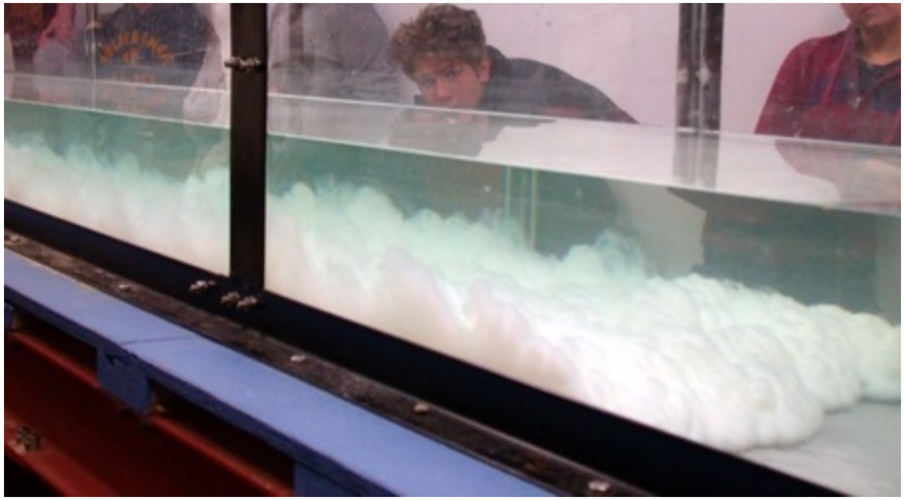




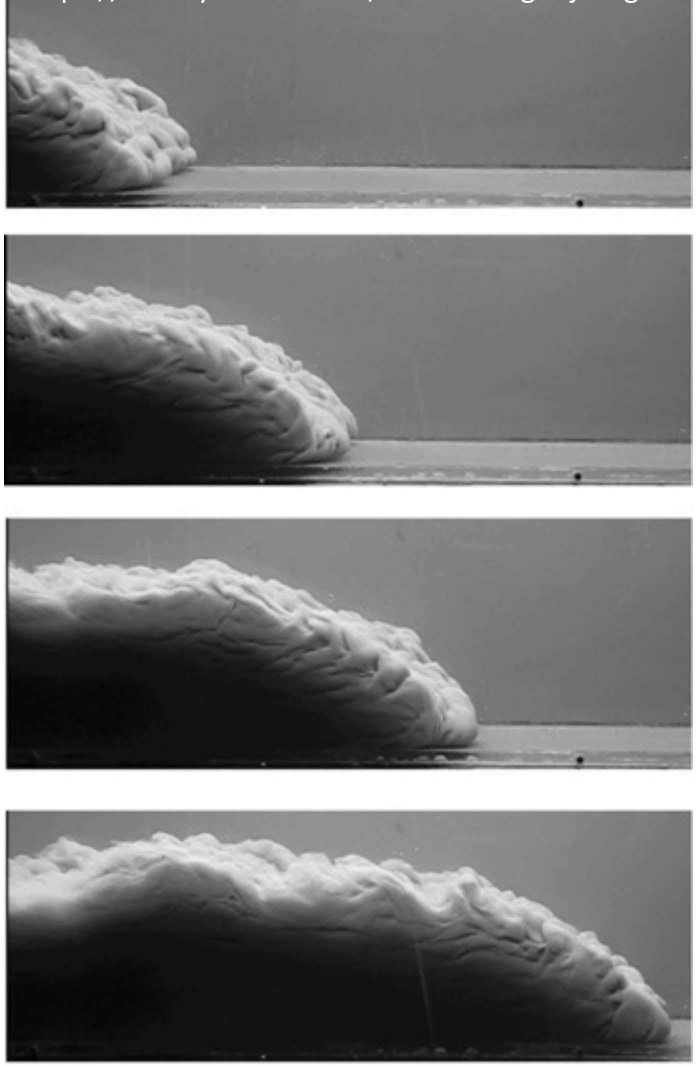
Turbidity flows

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



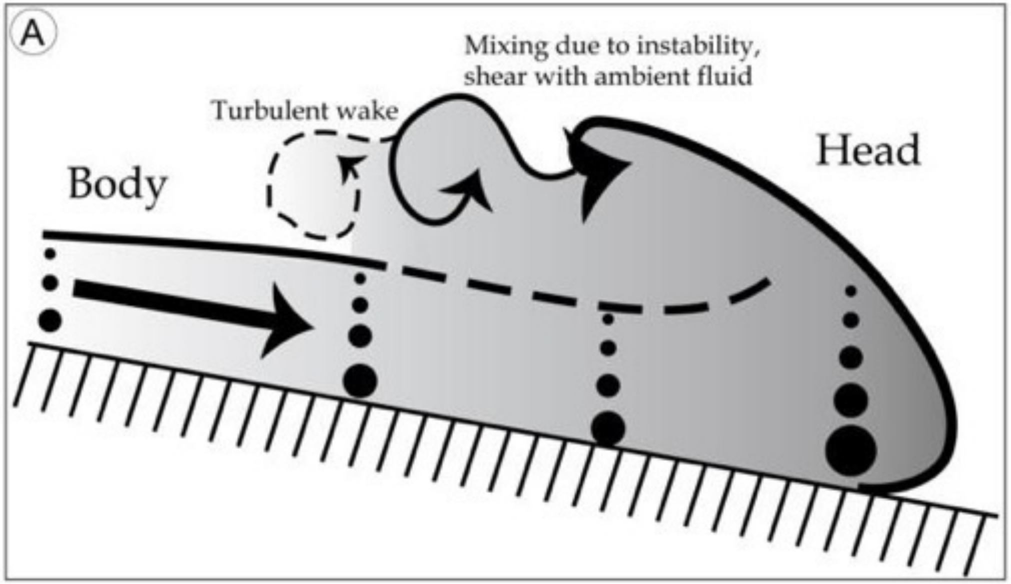


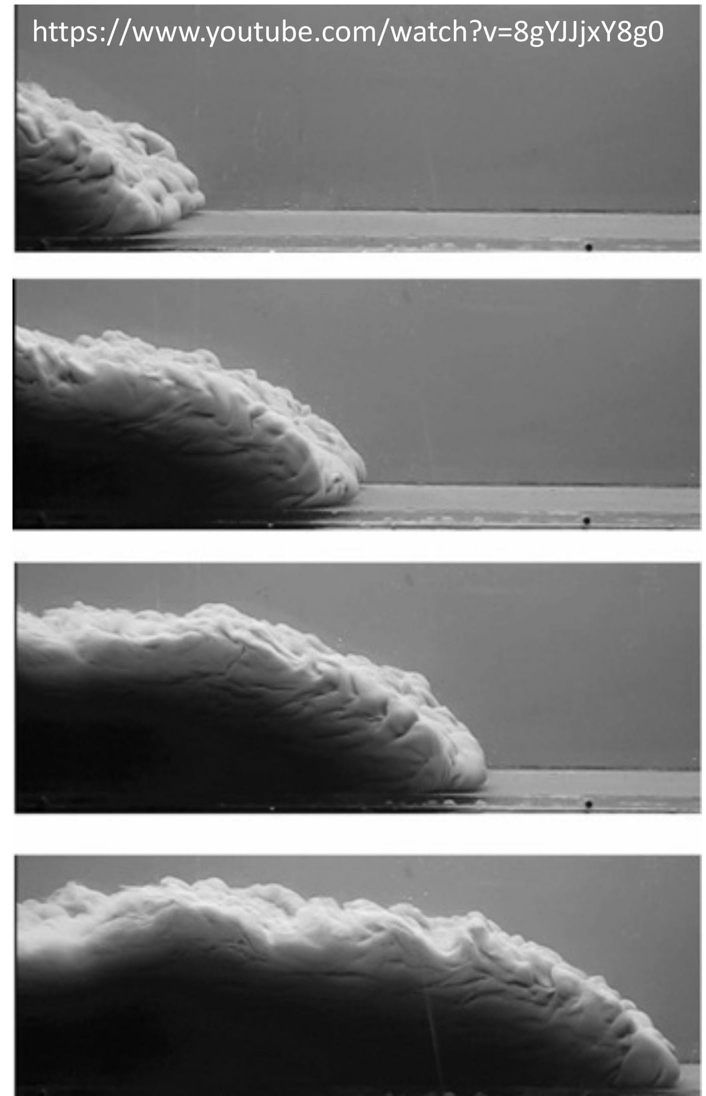
https://www.youtube.com/watch?v=8gYJJjxY8g0



Turbidity flows

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

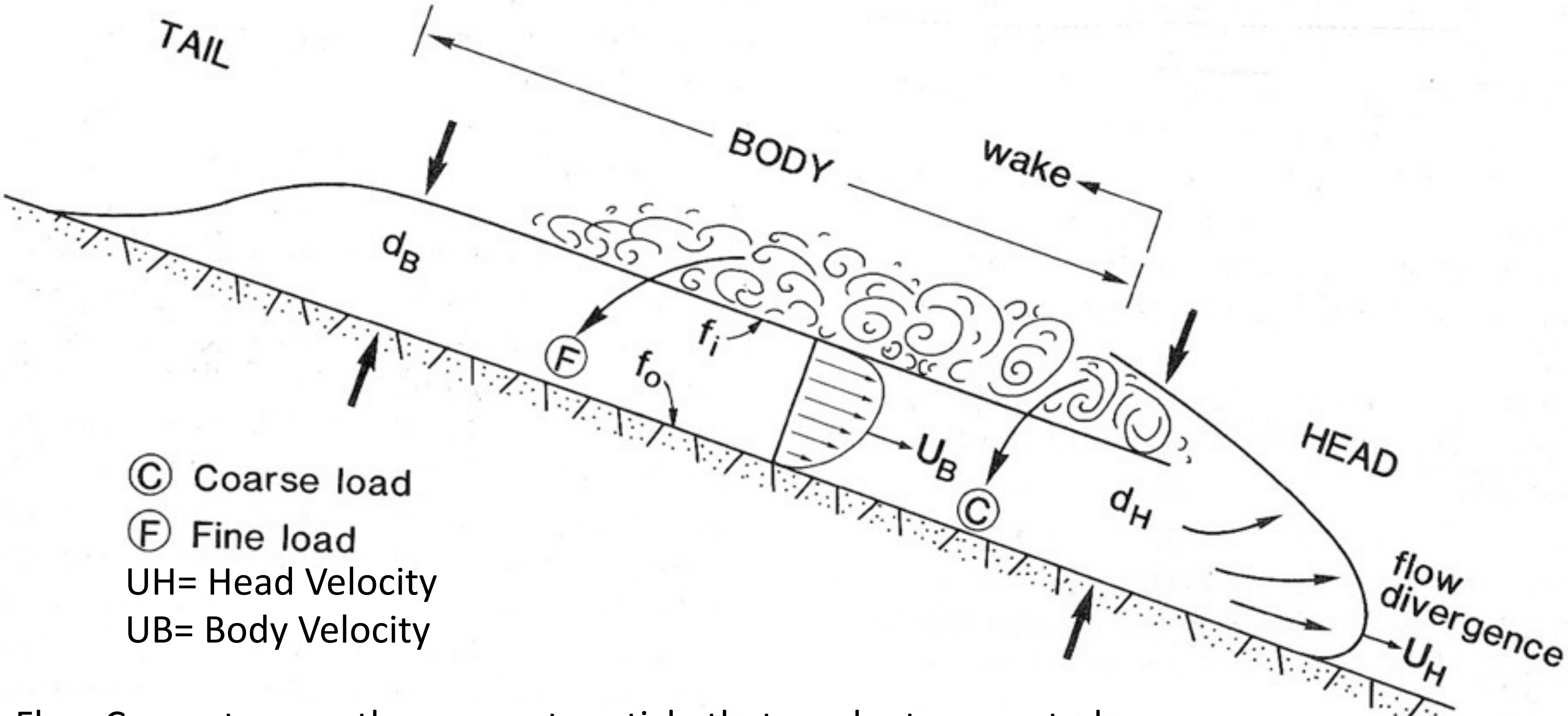




TYPE OF EVENT
Long steady flow (e.g. river fed)
Short surge-type (e.g. river floods, slope instability)

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



Flow Competence = the coarsest particle that can be transported

Flow divergence

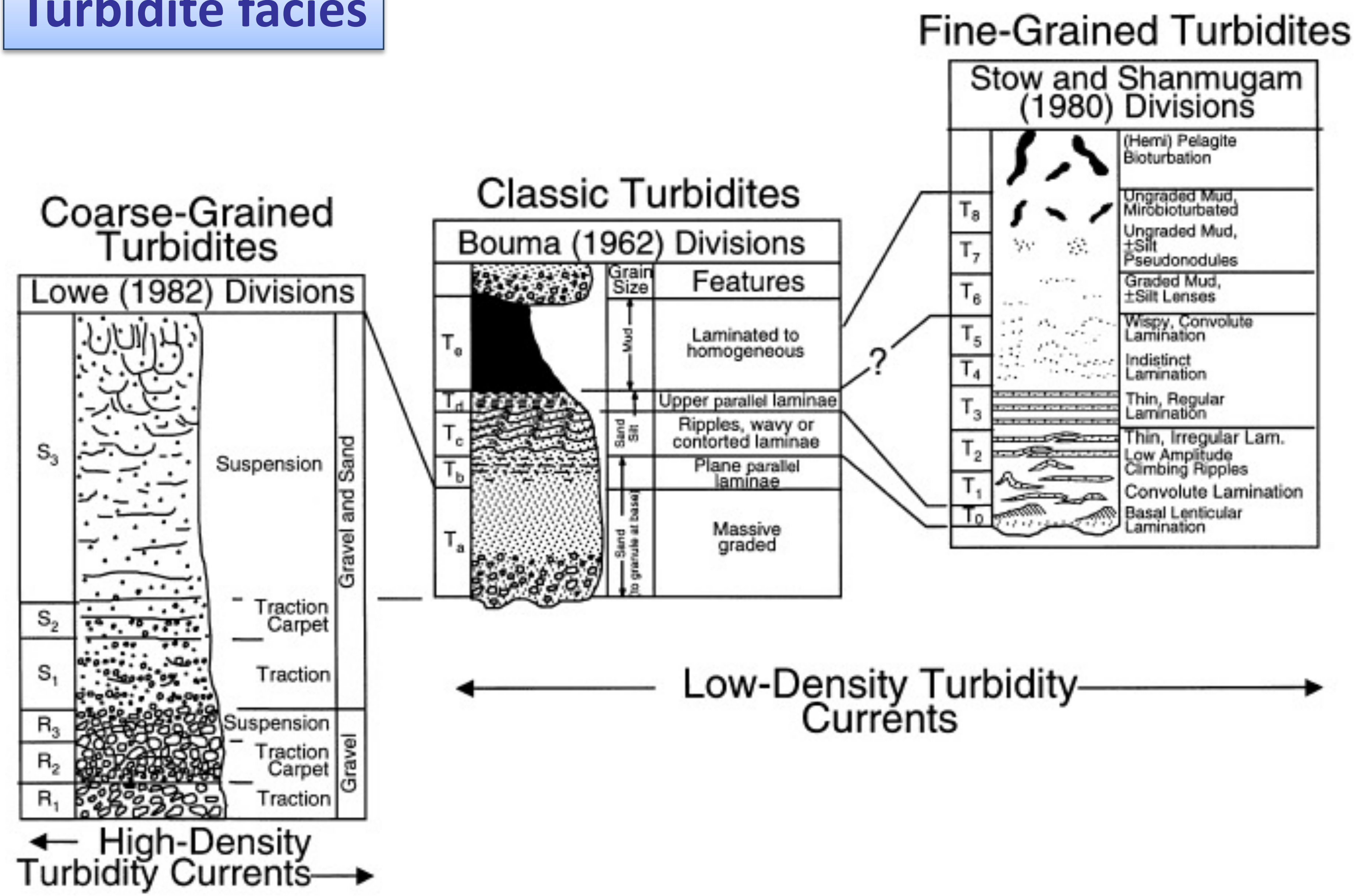
→ fluid ambient entrainment

→ flow dilution

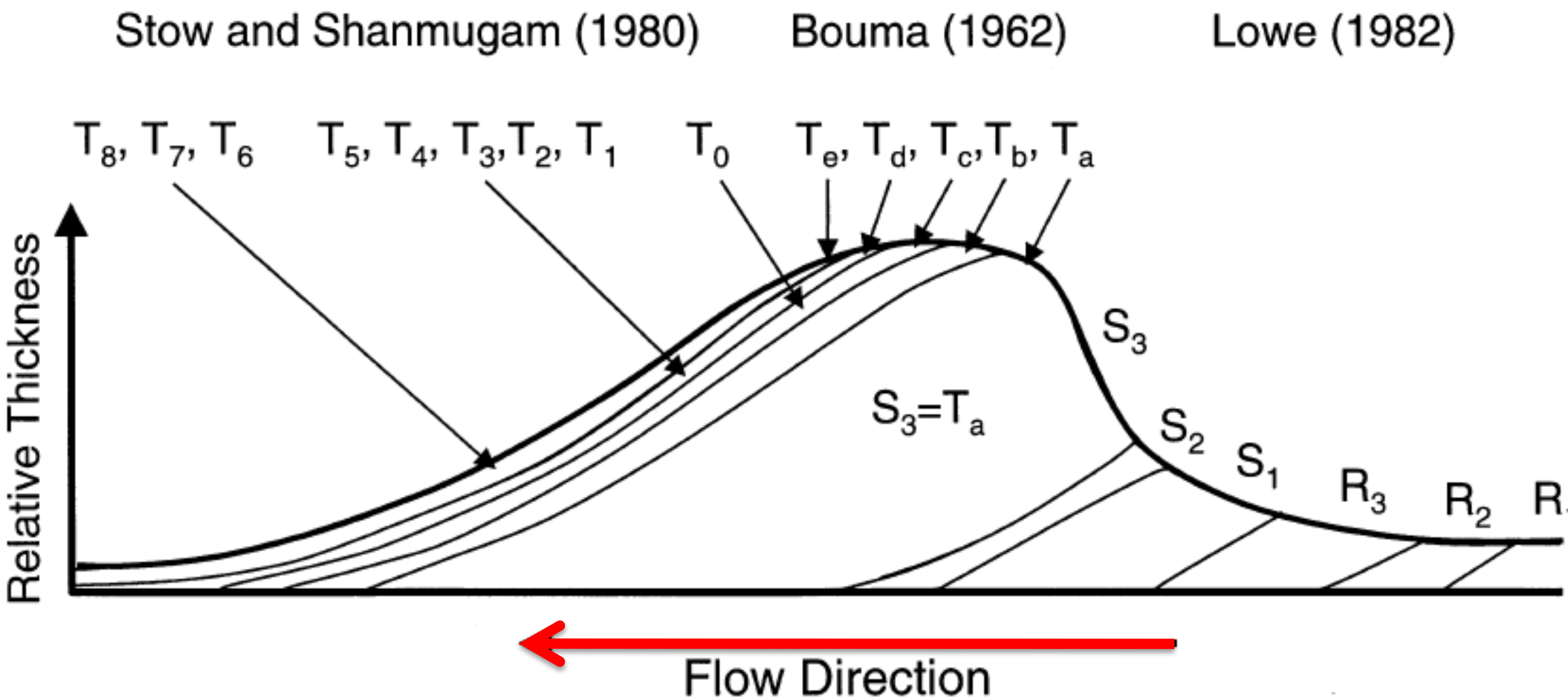
→ reduced speed

→ reduced competence

Turbidite facies

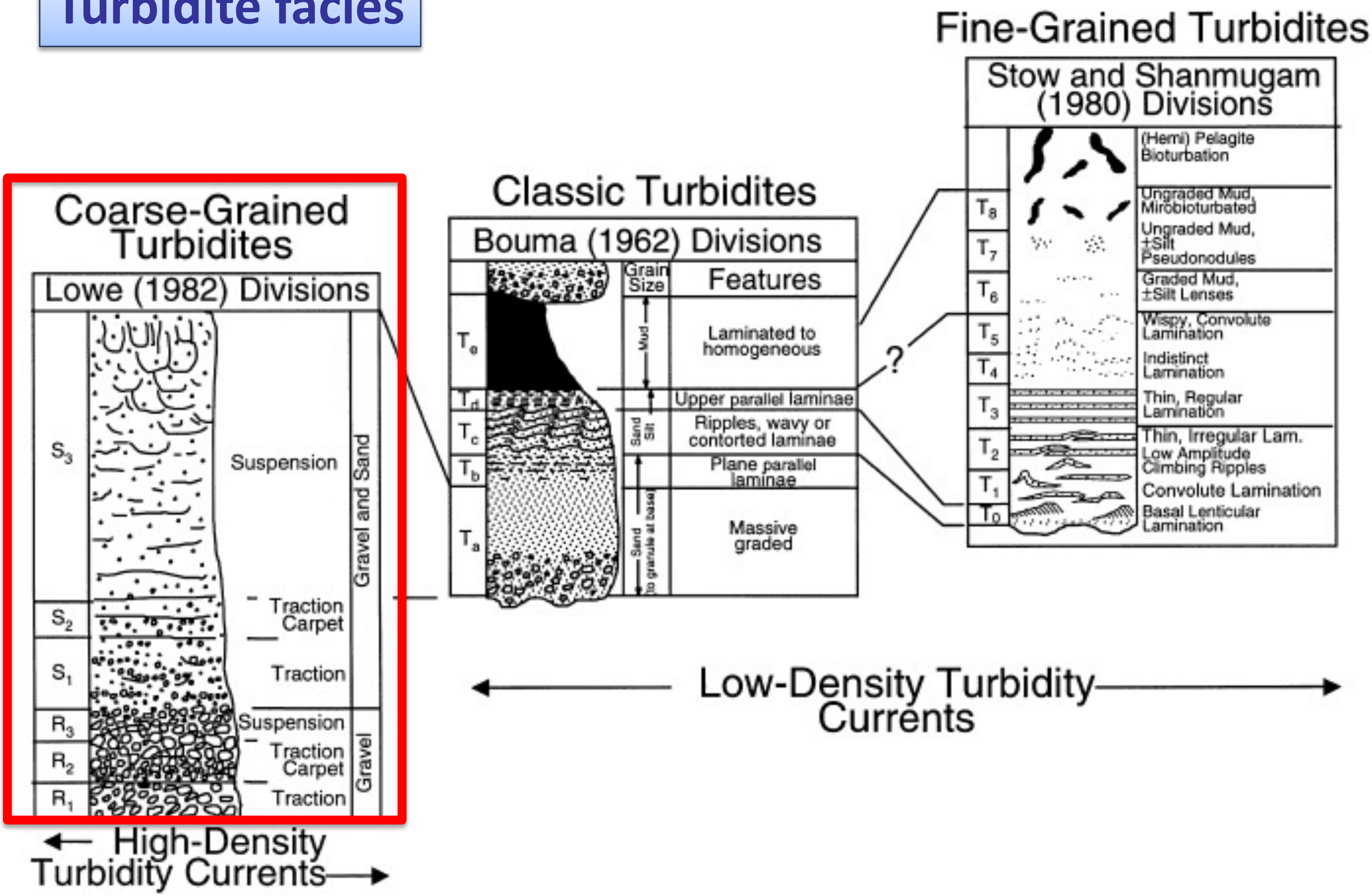


LOW DENSITY turbidity flows



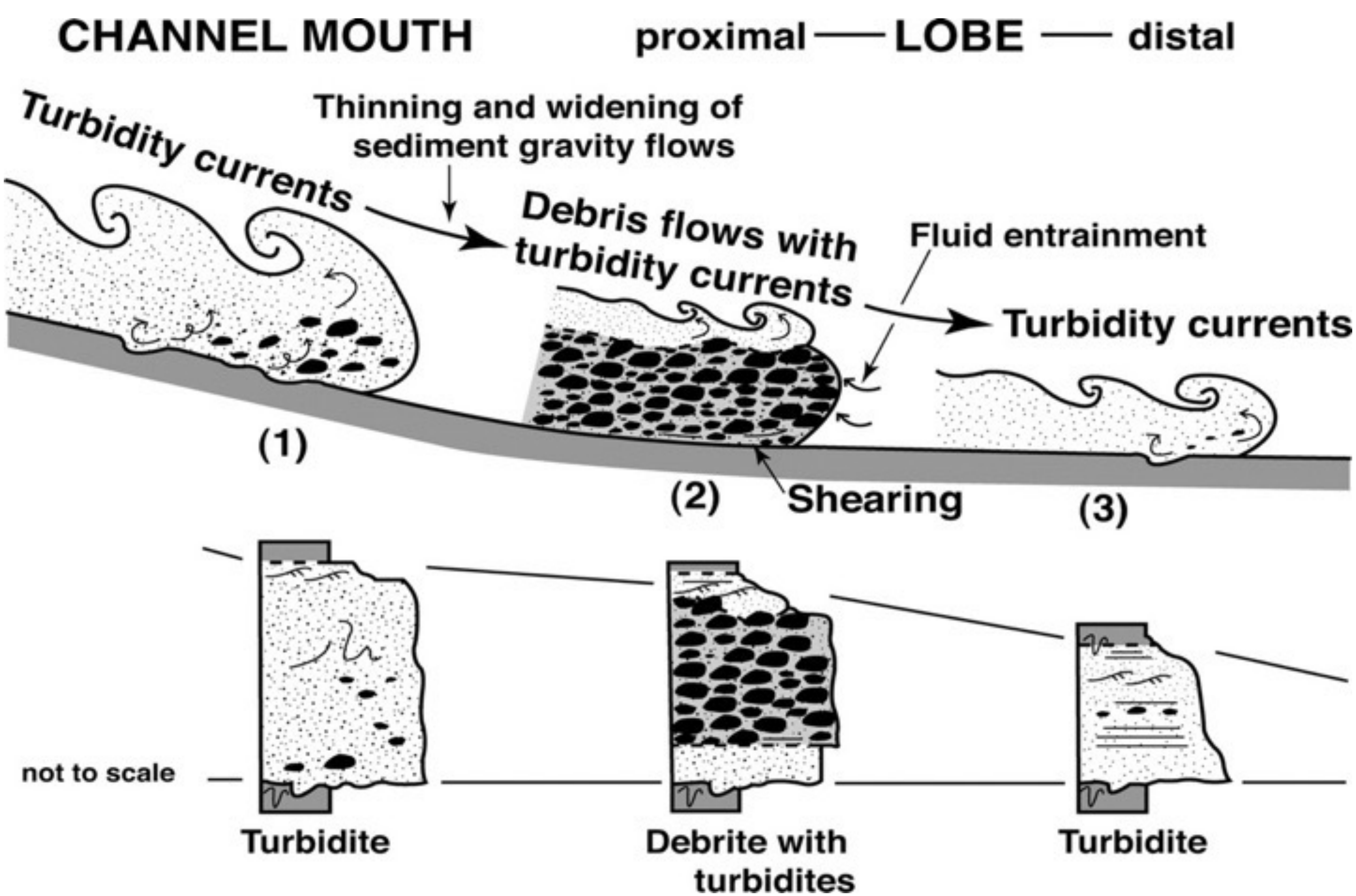
- Shanmugam, G., 2000. 50 years of the turbidite paradigm (1950s-1990s): deep-water processes and facies models – a critical perspective. Marine and Petroleum Geology 17, 285-342.
- Kevin Pickering, Richard Hiscott, 2014. Deep Marine Systems: Processes, Deposits, Environments, Tectonic and Sedimentation.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

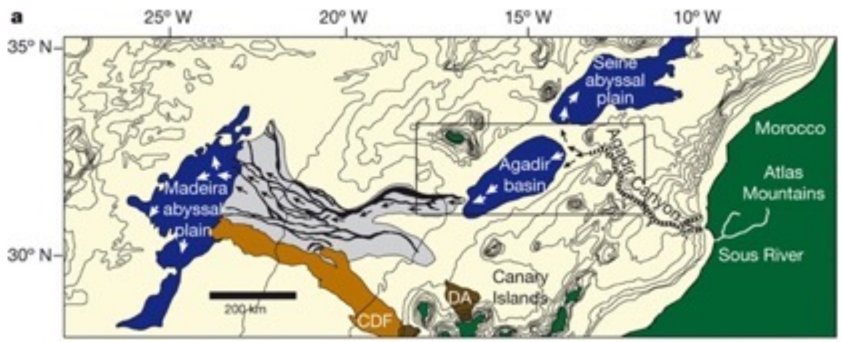
Turbidite facies

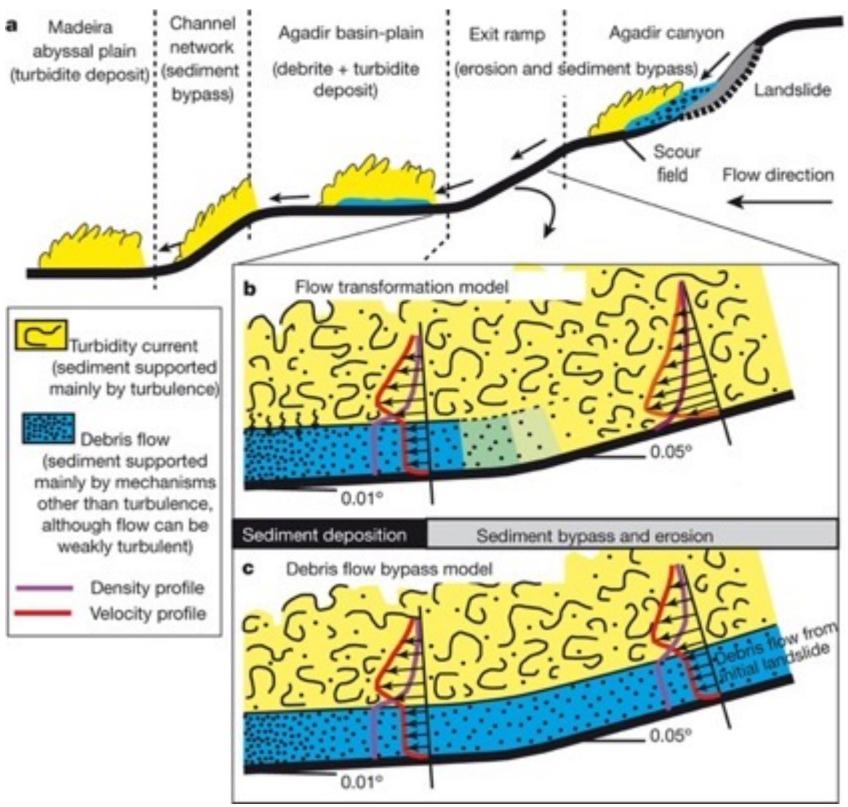


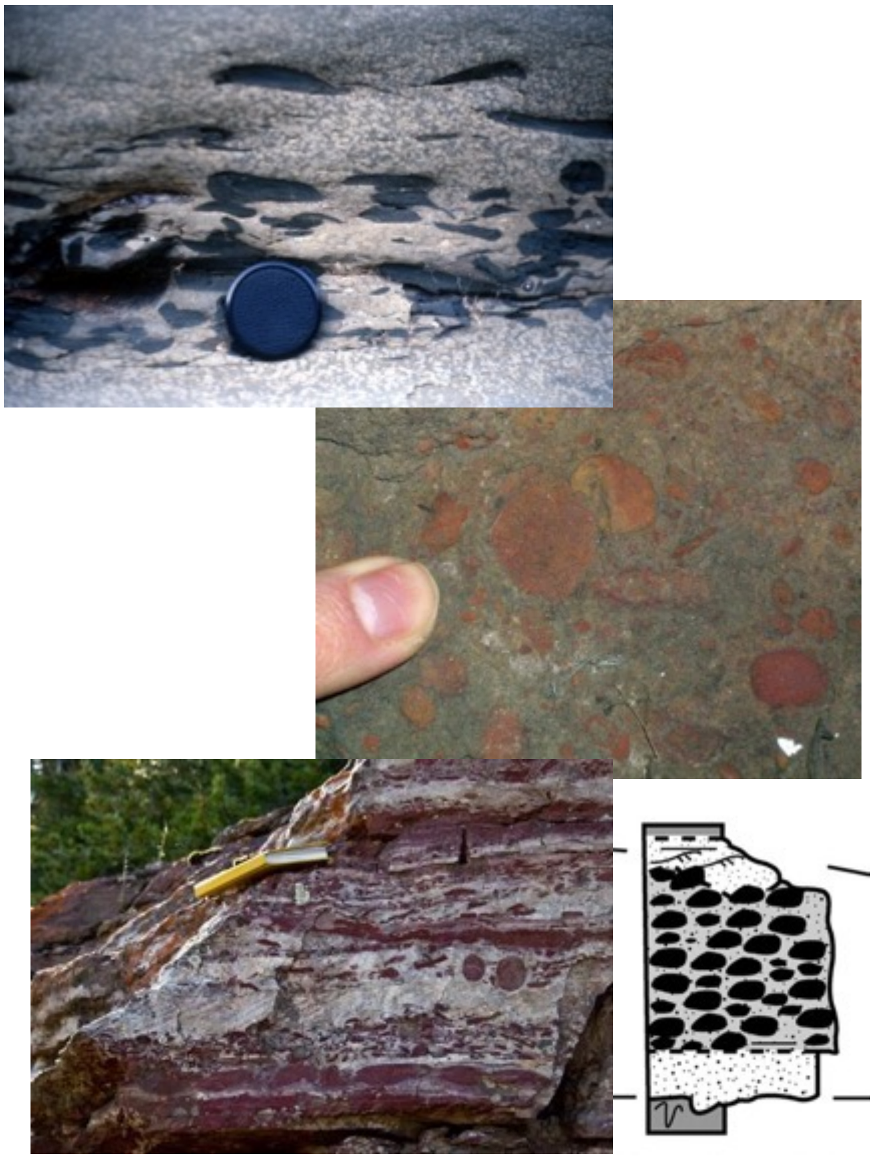
HIGH DENSITY turbidity flows

The *linked debrite*



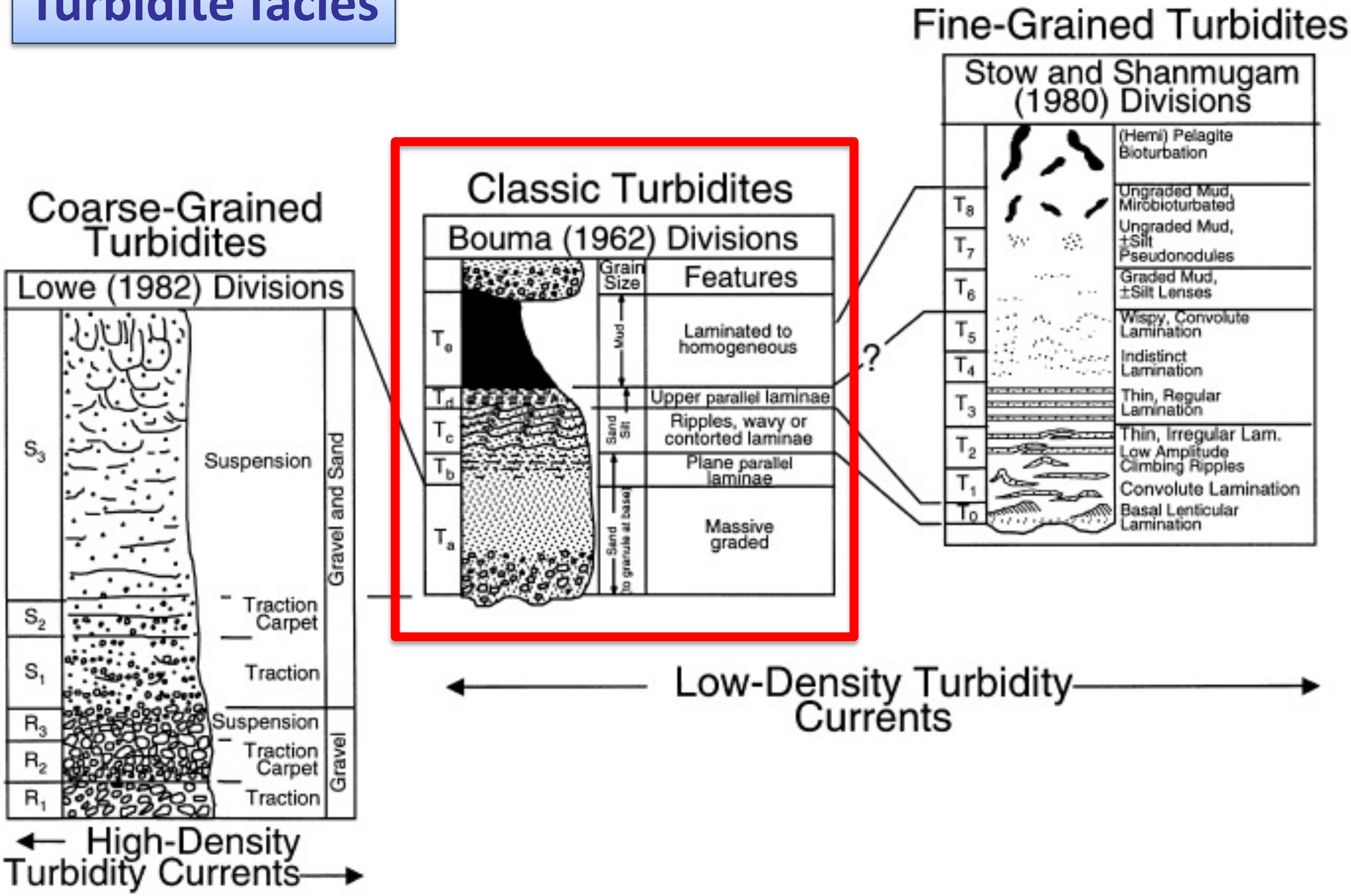


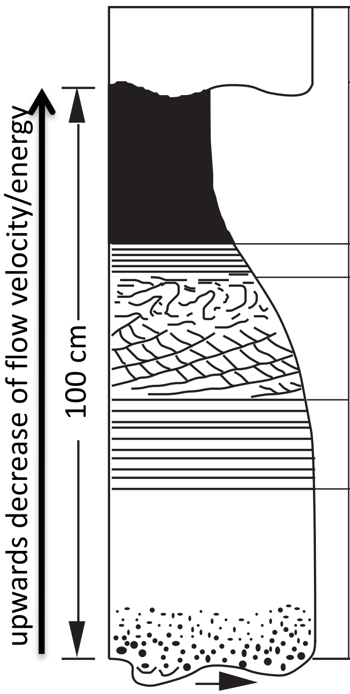




Talling et al., 2007. Nature 450, 541-544.

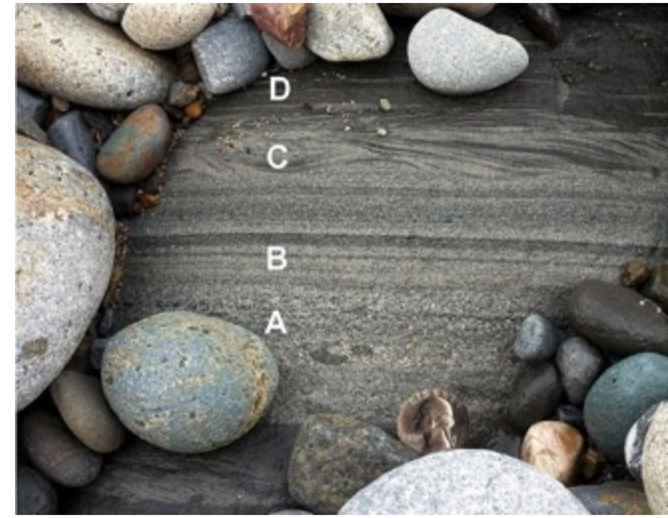
Turbidite facies



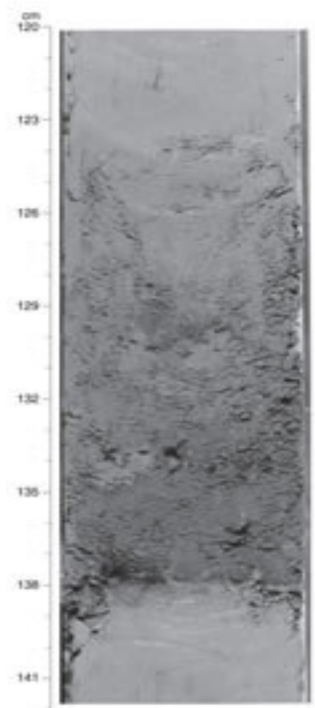


GRAIN SIZE	BOUMA (1962) DIVISION	INTERPRETATION
Mud	E - Laminated to homogeneus mud	Deposition from low-density tail or turbiditi current settling of pelagic or hemipelagic particels
Silt	D - Upper mud/silt laminae	Shear sorting of grains and flocs
Sand	C - ripples, climbing ripples wavy or convolute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

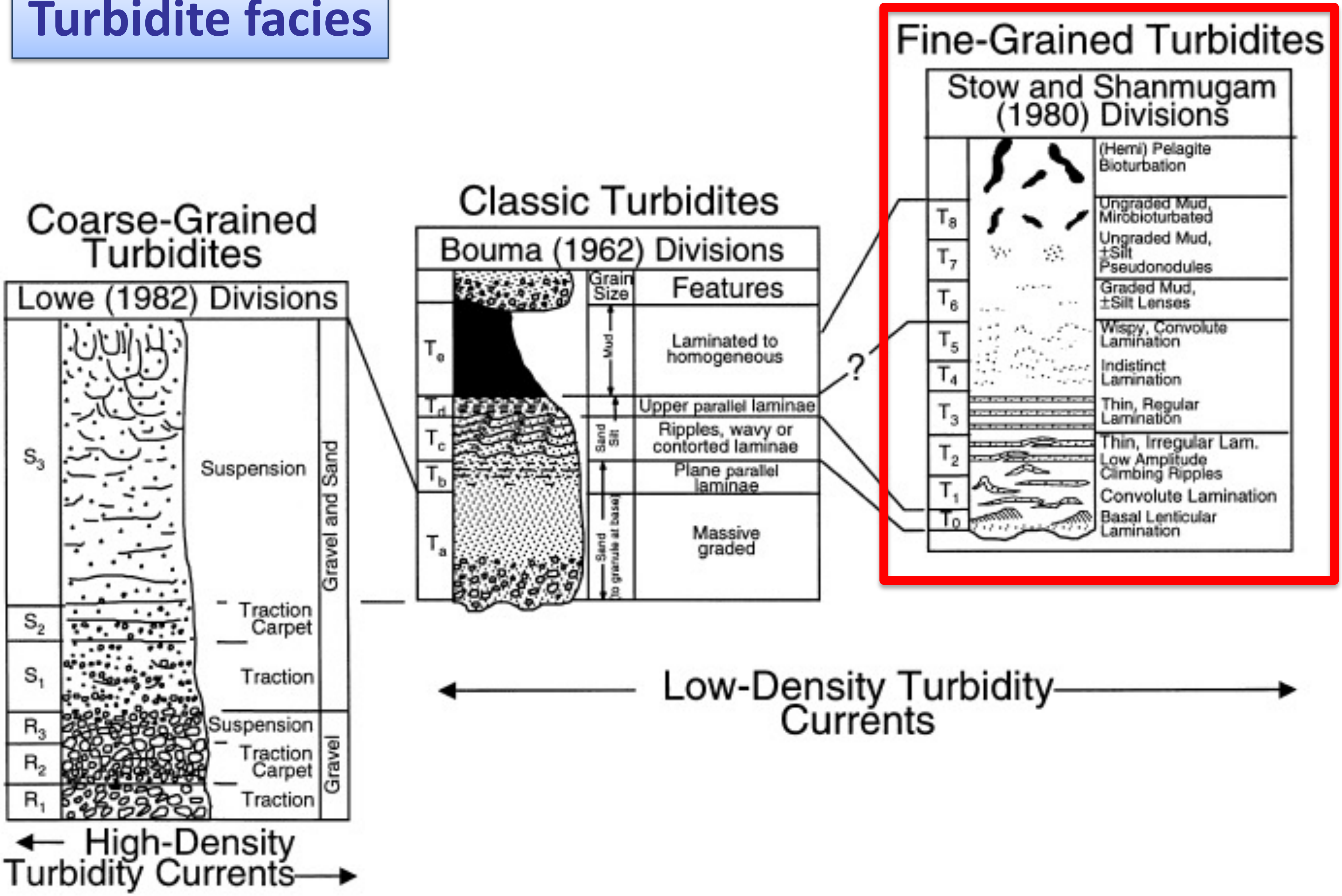


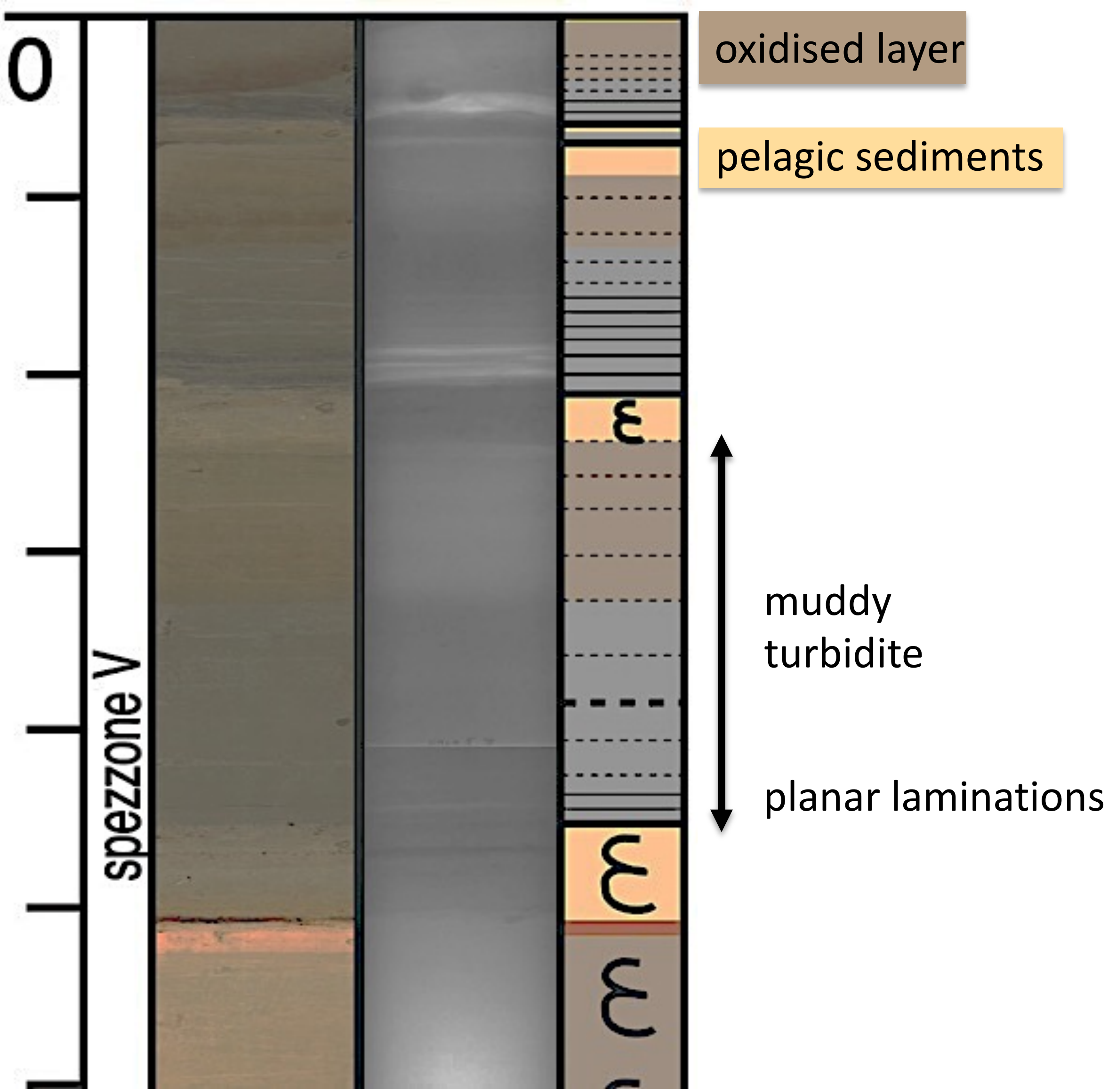
sandy turbidite



silty turbidite

Turbidite facies

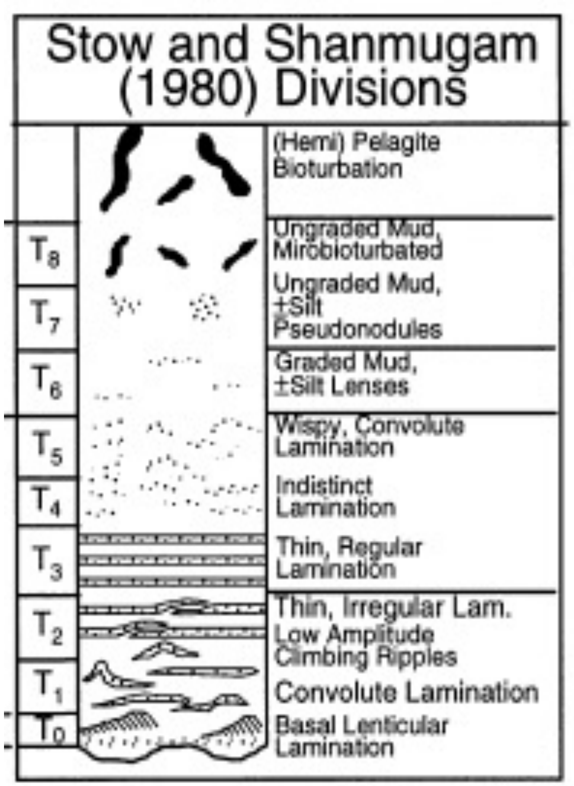


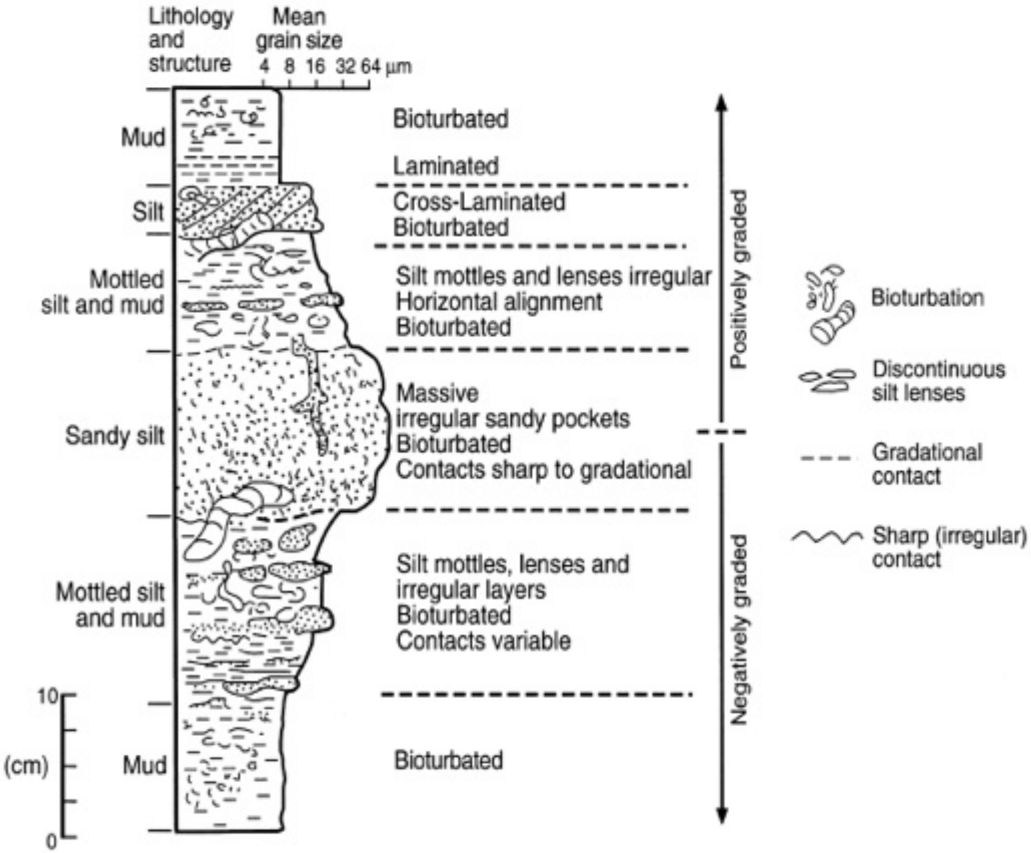

0
spezzone V
oxidised layer
pelagic sediments
muddy
turbidite
planar laminations

Fine-grained turbidites

versus

Contourites





Modulo 2.3b Bottom Currents. Docente: Michele Rebesco

Outline:

- Introduction
- Importance
- Thermohaline circulation
- Coriolis effect
- Sediment entrainment

Bottom currents

=

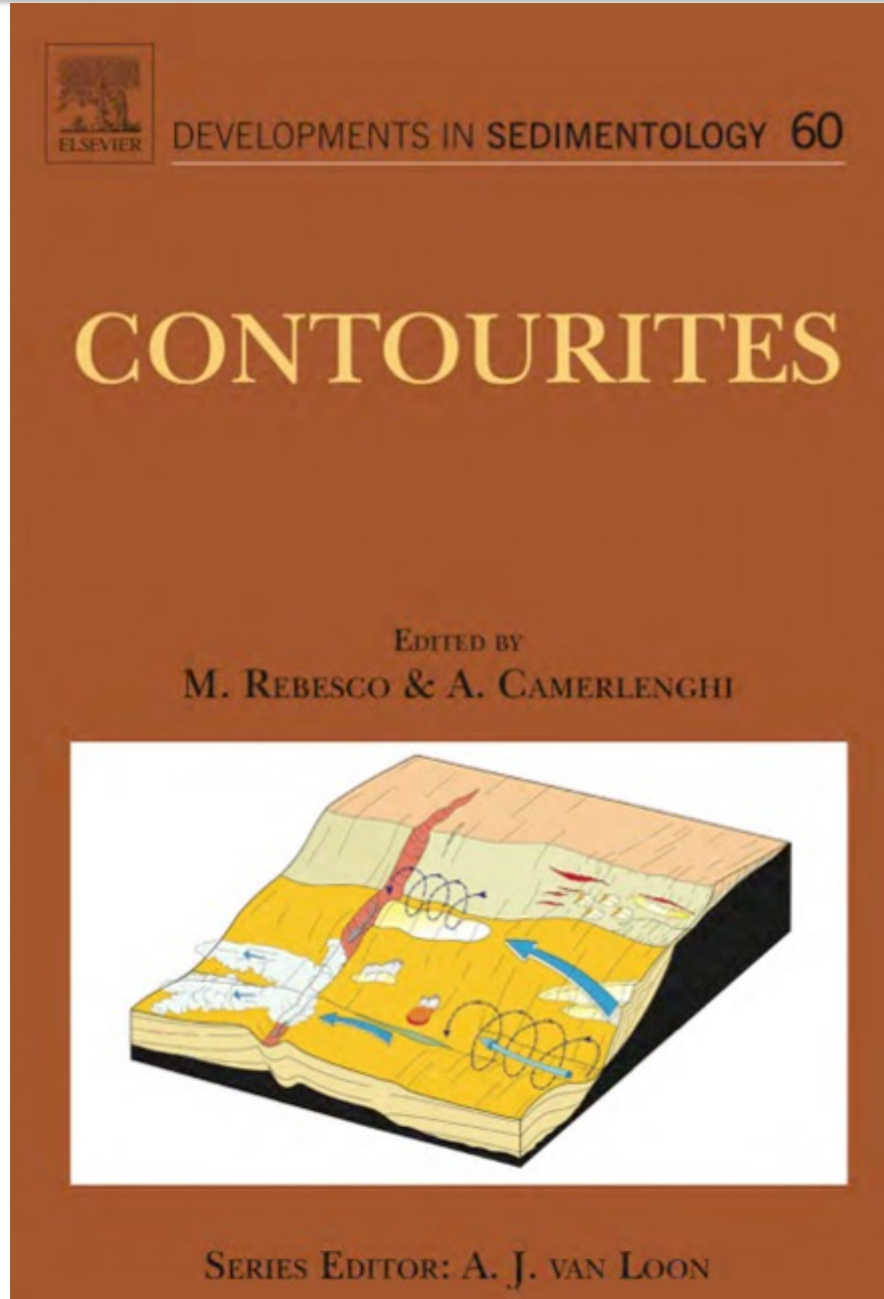
Along-slope currents

=

Contour currents

>

Contourites



Michele Rebesco, F. Javier Hernández-Molina, David Van Rooij, Anna Wåhlin

Contourites and associated sediments controlled by deep-water circulation processes: state-of-the-art and future considerations

A review for the 50th Anniversary Issue of *Marine Geology*
Volume 352, 2014
42 pages, 27 figures, 522 references

Istituto Nazionale di Oceanografia e di Geofisica Sperimentale

Royal Holloway University of London

Renard Centre of Marine Geology, Ghent University

University of Gothenburg

This contribution is a product of the IGCP-619 and INQUA-1204 projects

Glossary

for alongslope sedimentary processes

Bottom current:
any ’persistent’ water current near the sea-floor, generally with a net alongslope flow

Contourites:
sediments deposited or significantly affected by bottom currents.
Most widely accepted feature being the bioturbation. Discussion about the traction structures, which are present on the seafloor, apparently not preserved

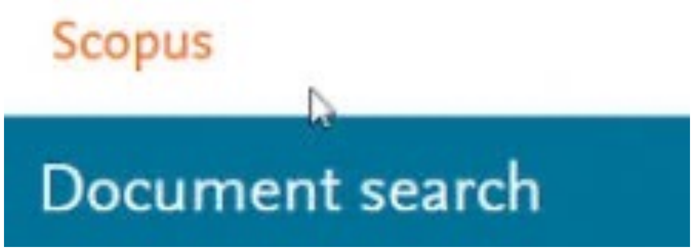
Sediment drift:
sediment body (sheeted or monded) produced by bottom currents.
Generally fine-grained, with large dimensions in many cases, typically separated from the slope by a moat

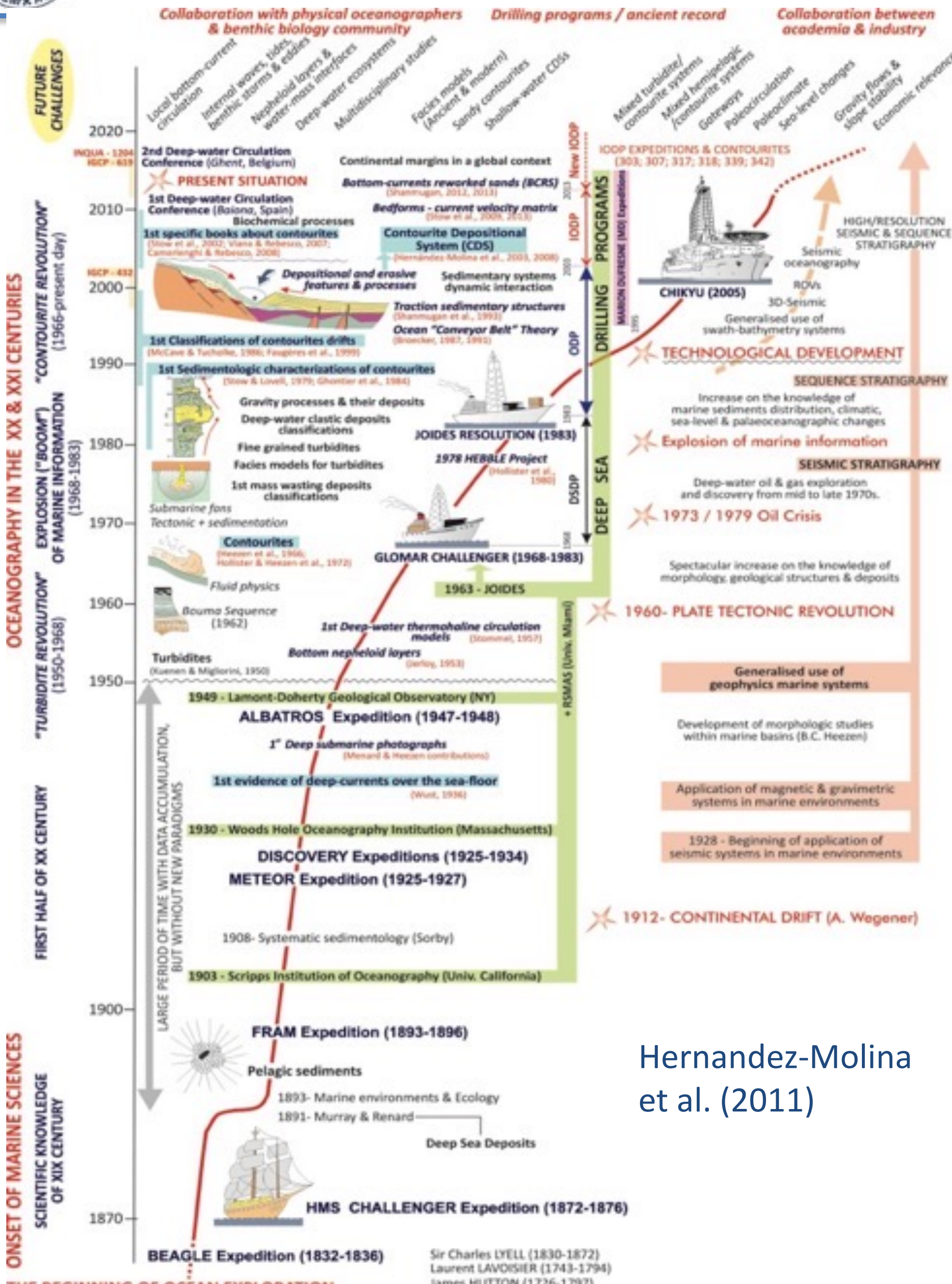
The research on contourites is maturing.

However, many uncertainties remain, such as lack of indisputable diagnostic criteria for identifying contourites.

This field is now advancing similarly to how turbidite research progressed in the 60s.

Indeed, there is still a glaring disparity in knowledge between the former and the latter: a recent (end of June 2020) online search for the term contourites yielded about 666 results on Scopus and 49,100 on Google, whereas the same search for turbidites gave about 9,936 and 590,000 results, respectively—about 15 times more in each case.





Hernandez-Molina et al. (2011)

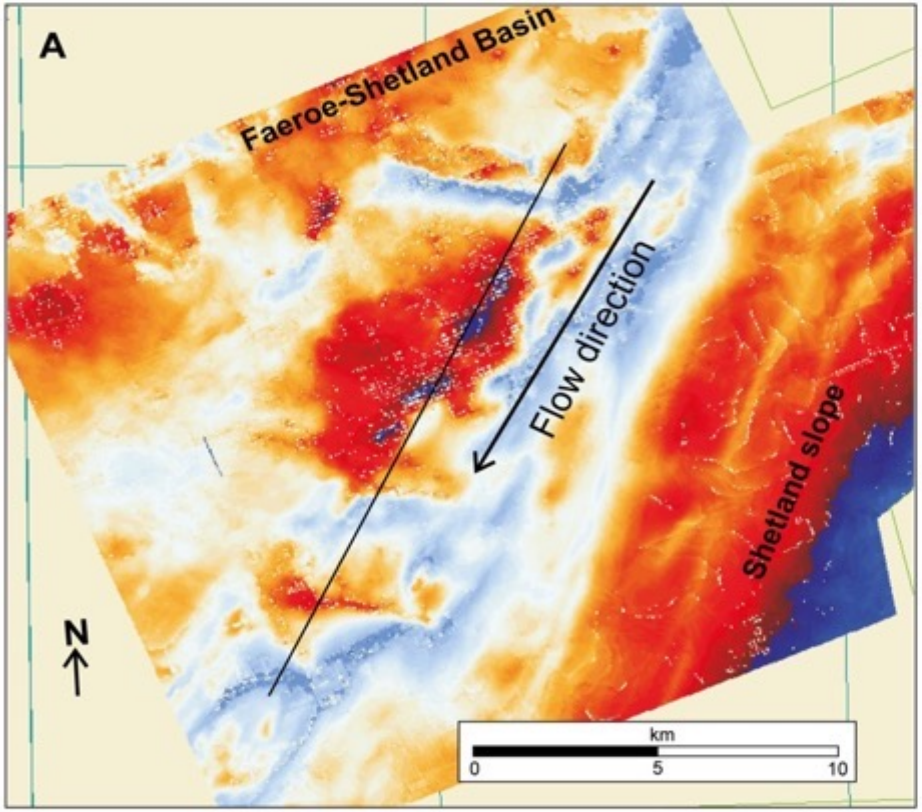
Evolution of knowledge

Since a seminal papers in early sixties, the contourite paradigm has progressed gradually.

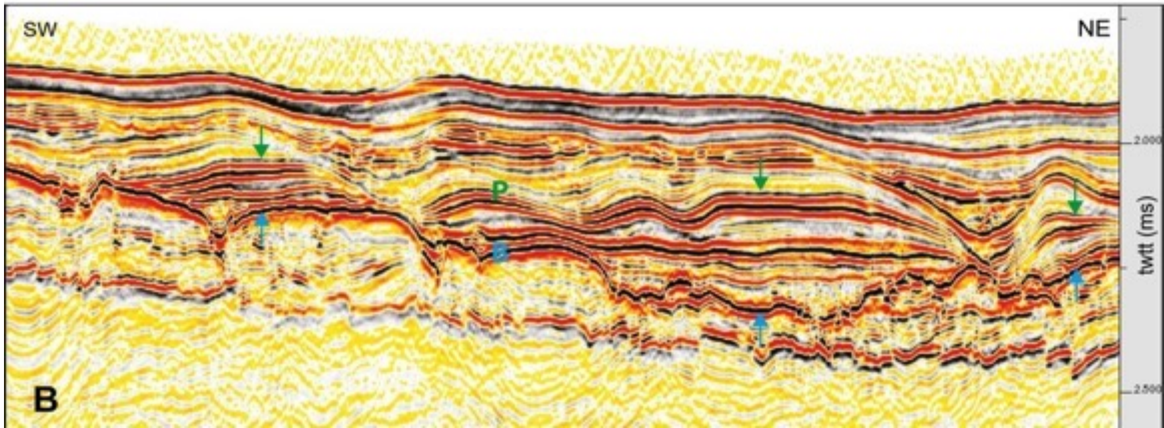
Though for many years associated research was the realm of a few specialists, contourites and bottom currents are of paramount importance in several areas of basic and applied research.

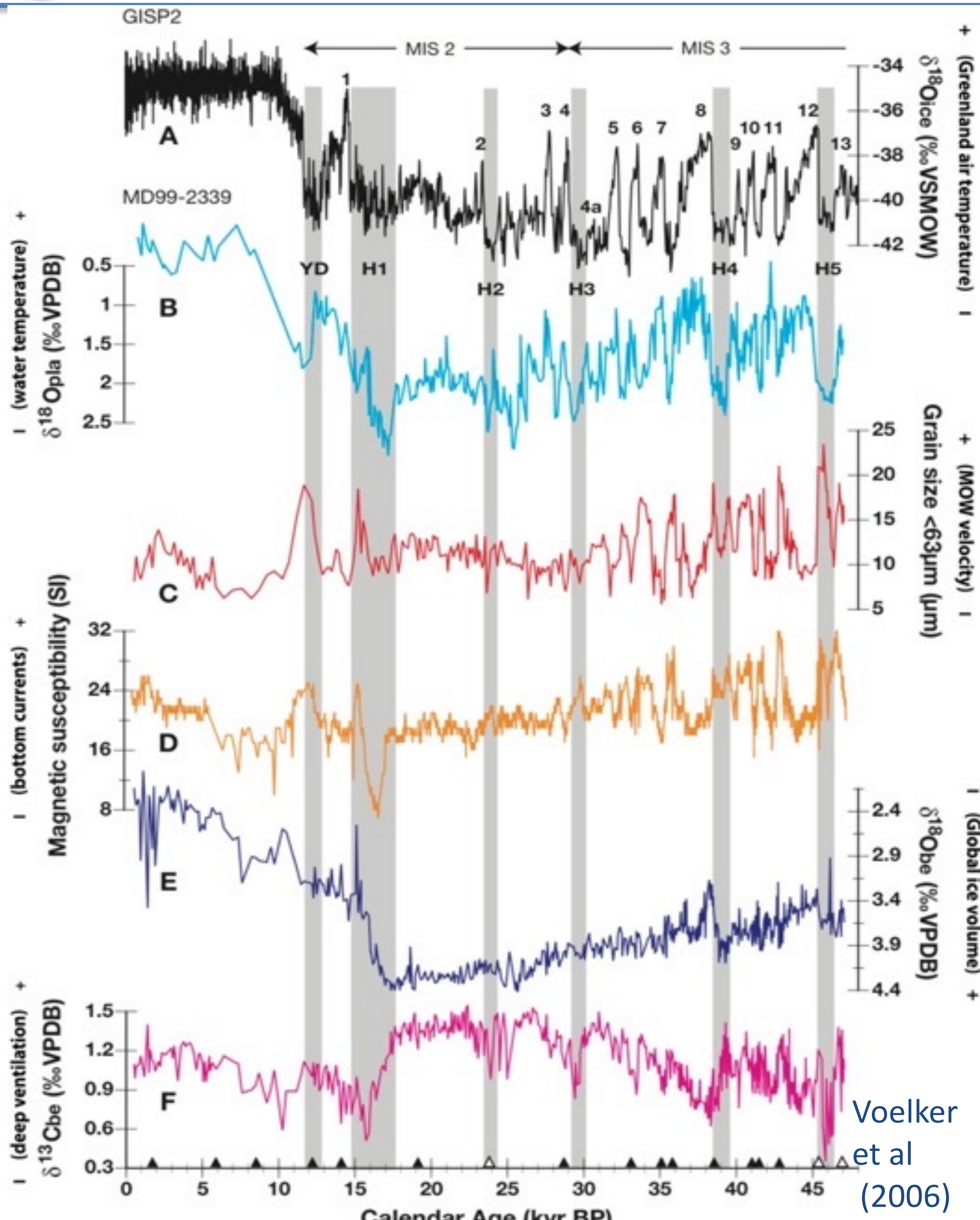
Significance for paloceanography (geophysics)

From contourite deposits, the history of ocean circulation and climate can be extracted using discrete sampling analyses (with geochemical, faunal, sedimentological techniques), continuous geophysical-chemical logging and seismic imaging. The latter allows to visualize drift geometry, internal reflections configuration and seismic facies, hence providing **palaeoceanographic information** about palaeo-current pathways and changes in current energy and direction on timescales from tens of thousands to millions of years.



Knutz (2008)





Voelker et al (2006)

Significance for paloceanography (geology)

Contourite research addresses a broad range of time scales including the human one (tens of years), like rapid ocean-climate variability in the North Atlantic. The reconstruction of leads and lags between various parameters of ocean-climate changes at multi-decadal time scales is allowed by the records from rapidly accumulating muddy contourite deposits. This information, whose **resolution approaches that from ice-core archives**, is crucial for a better understanding of global teleconnections, feedback thresholds and forcing mechanisms that determine the past and present climate system.

Significance for geohazard (slope stability)

The distribution, composition and physical properties of contourites are vital for the occurrence of **submarine slope instabilities**.

Contouritic sediments are prone to failure because of five main factors:

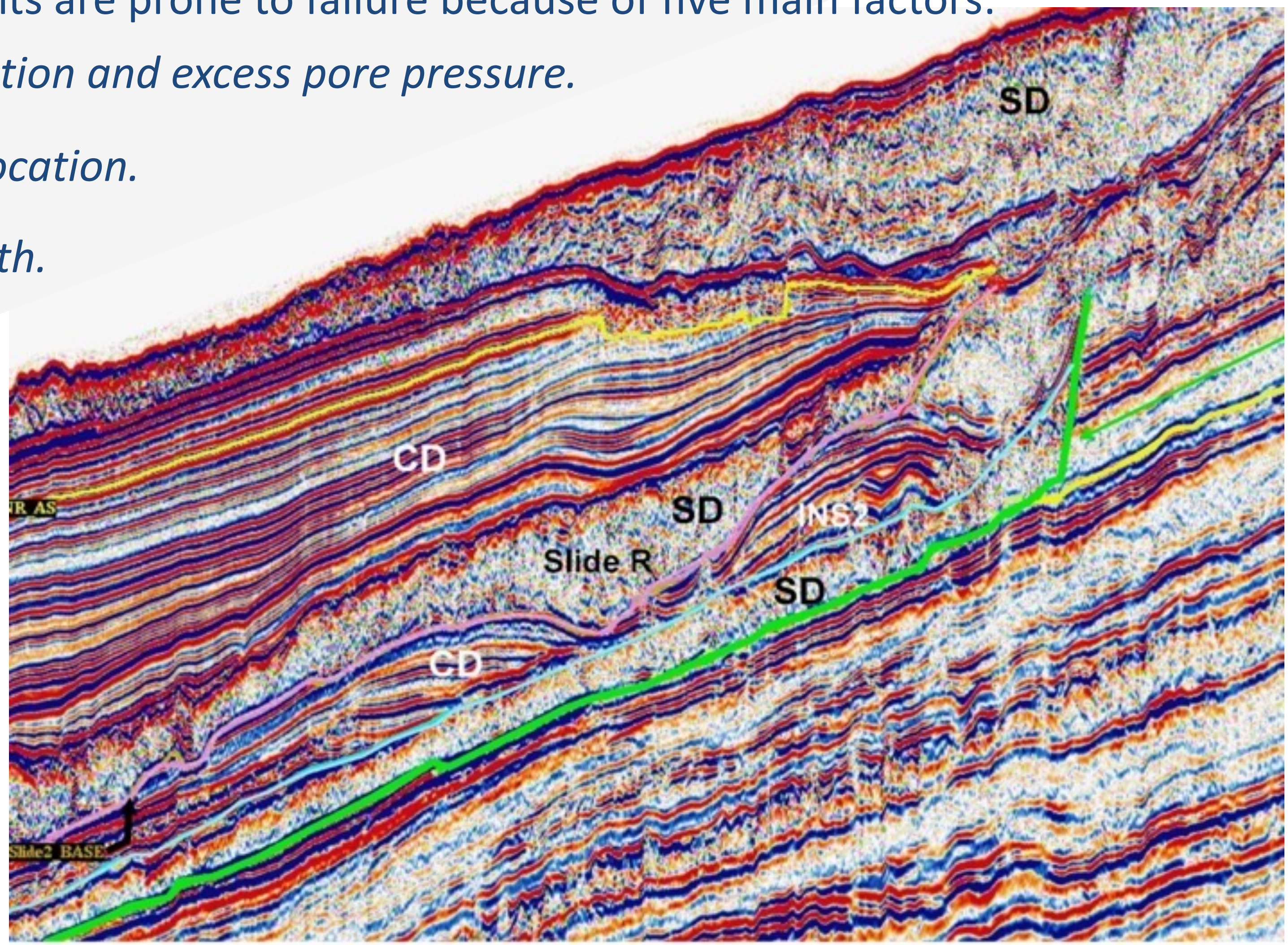
(a) under-consolidation and excess pore pressure.

(b) geometry and location.

(c) low shear strength.

(d) gas charging.

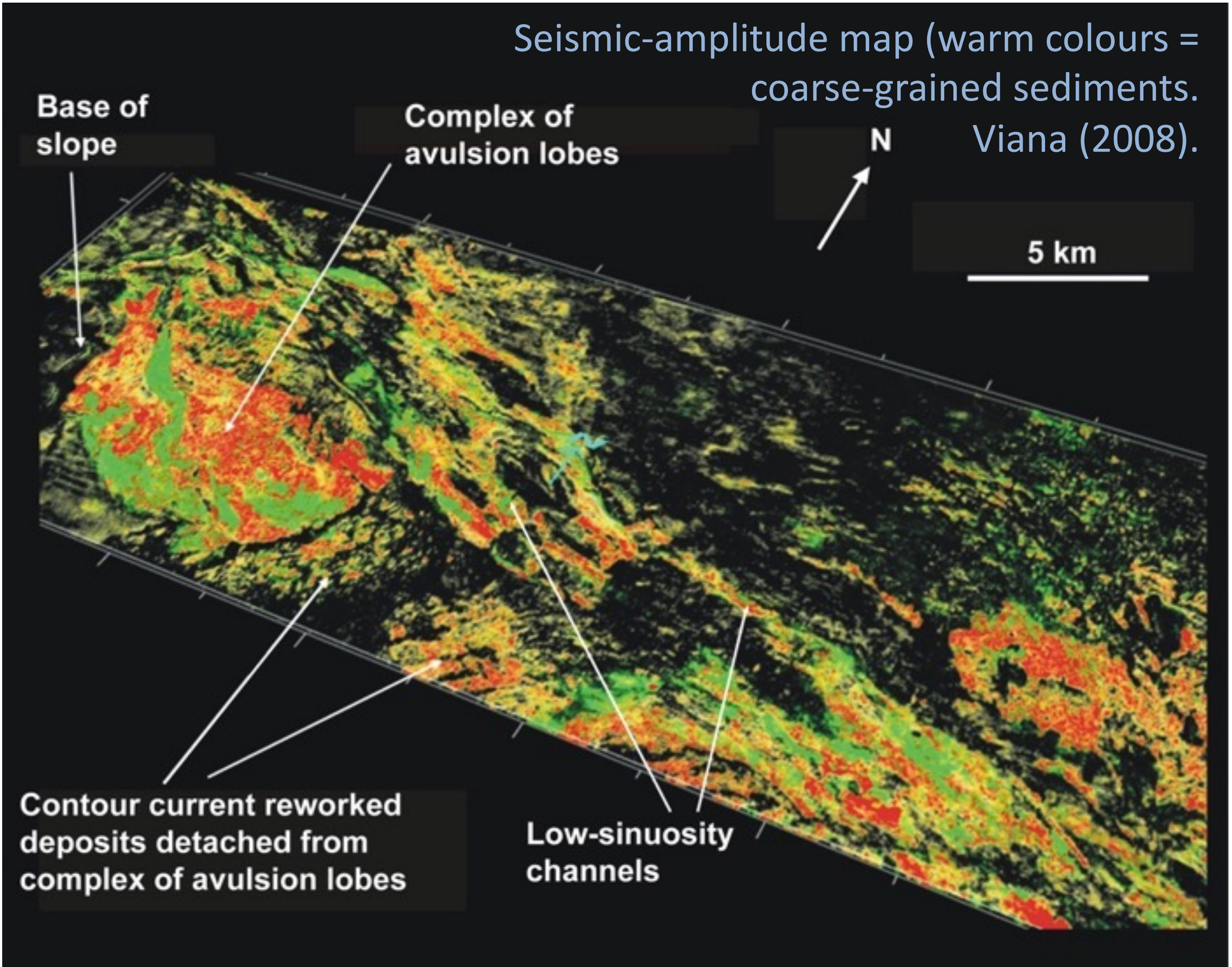
(e) loading.



Laberg and Camerlenghi (2008)

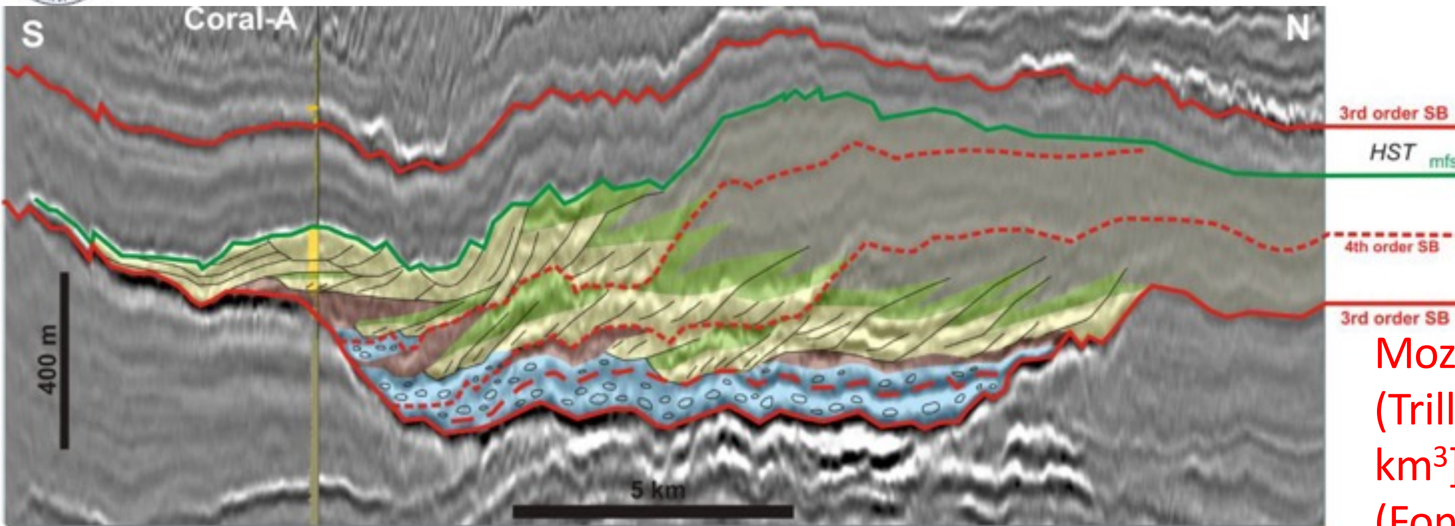
Significance for hydrocarbon exploration

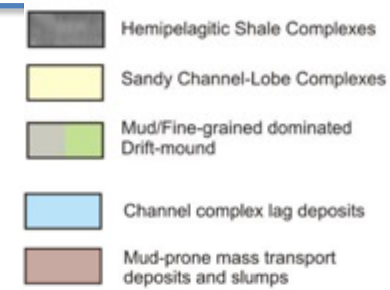
The action of contour currents has an impact on the petroleum systems in many aspects, including reservoir geometry and quality, and the distribution of sealing rocks.



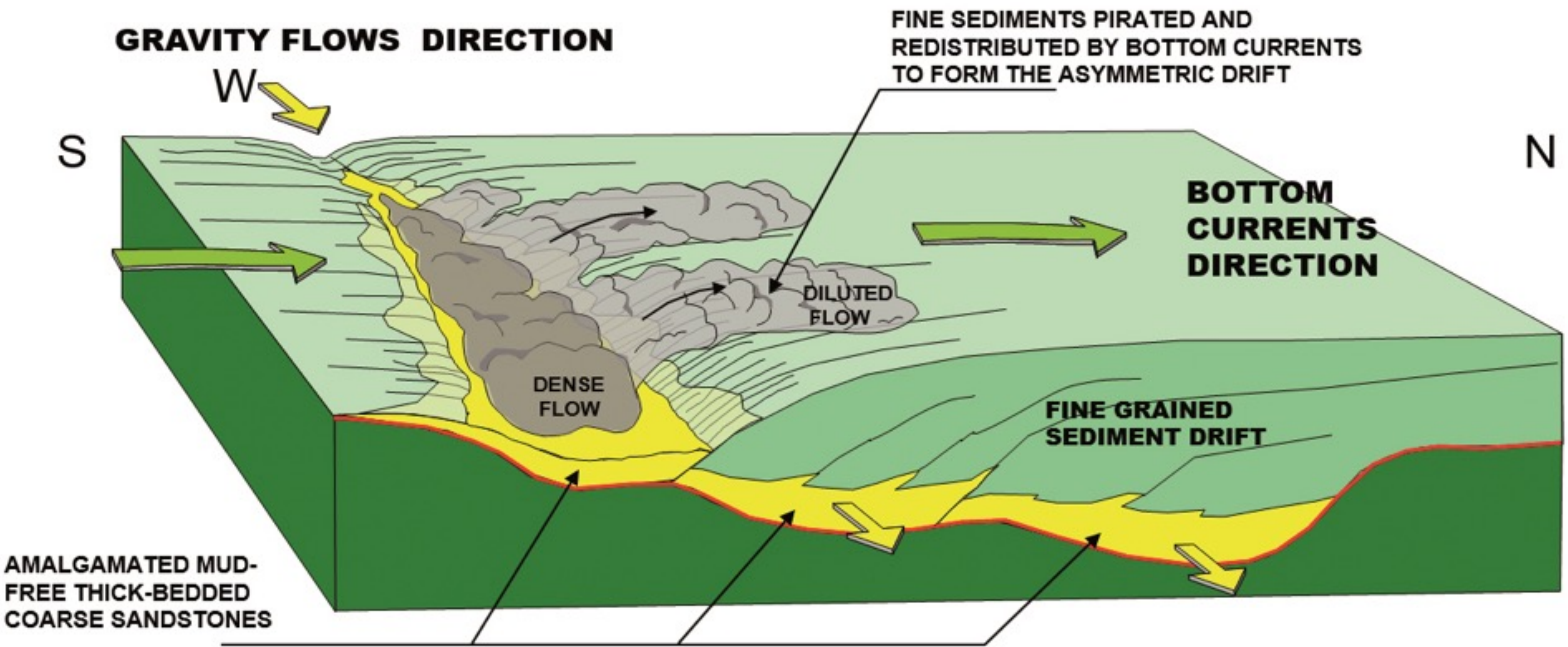
Changes of the seafloor topography by erosion or deposition induced by bottom currents can result in a re-adjustment of the sediment accommodation space and the creation of sub-basins, which act as sediment traps or gateways for sediment transfer.

Coarse-grained contourites deposited by robust flows may represent hydrocarbon reservoirs, whereas fine-grained contourites accumulated by weak bottom currents may provide sealing (and source) rocks.





Mozambique: >80TCF (Trillion Cubic Feet) [2.265 km³] of natural gas (Fonnesu et al., 2019)

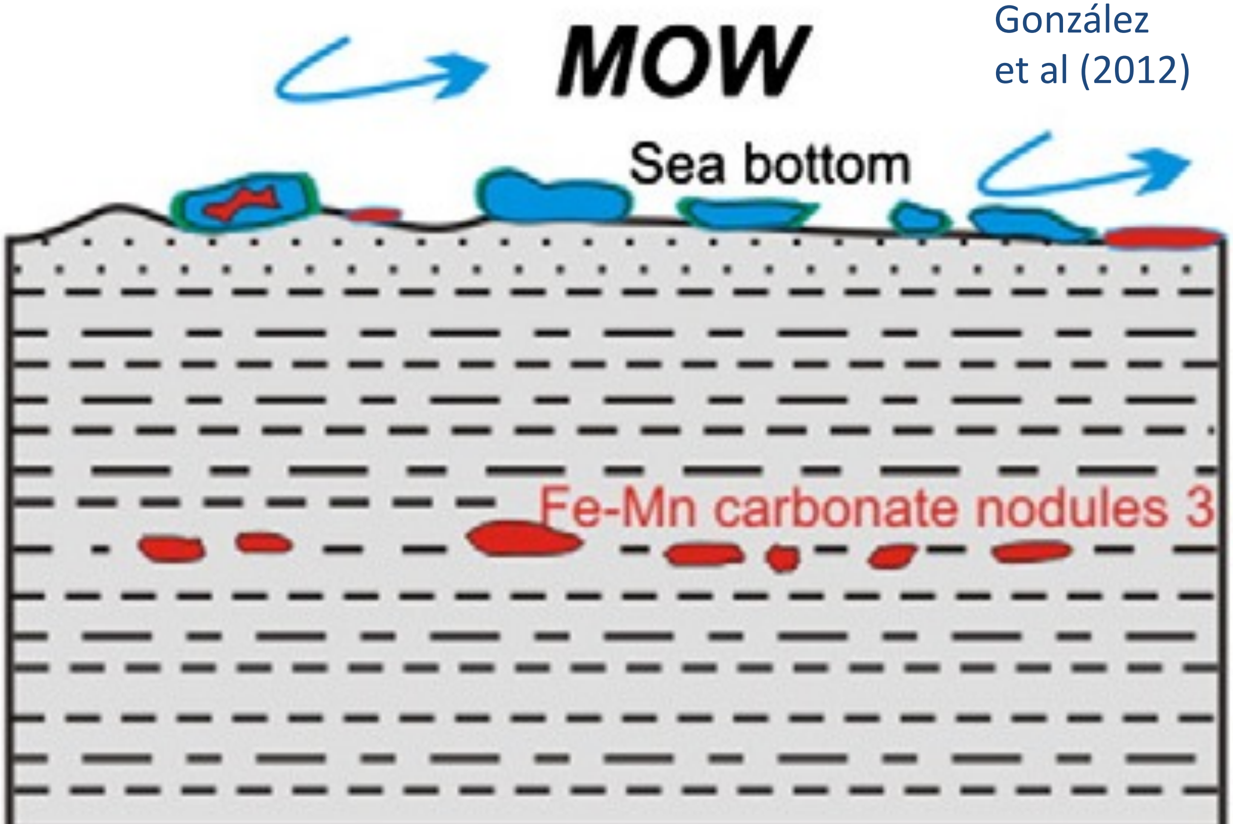


Significance for polymetallic nodules

The nodule may grow below the redox boundary within the sediments, forming an original concretion composed essentially of Fe–Mn carbonates. The erosive action of the Mediterranean Outflow Water (MOW) during the glacial periods produces the exhumation of Fe–Mn carbonate nodules that are replaced by Fe–Mn oxides through the action of the oxidising sea-bottom water. In eroding areas, the oldest nodules will be concentrated as an erosionall lag on the seafloor, while the newest ones will form at depth.

Contourite research reveals as a tool with an interesting potential for ferromanganese nodule exploration (Juan et al., 2018)

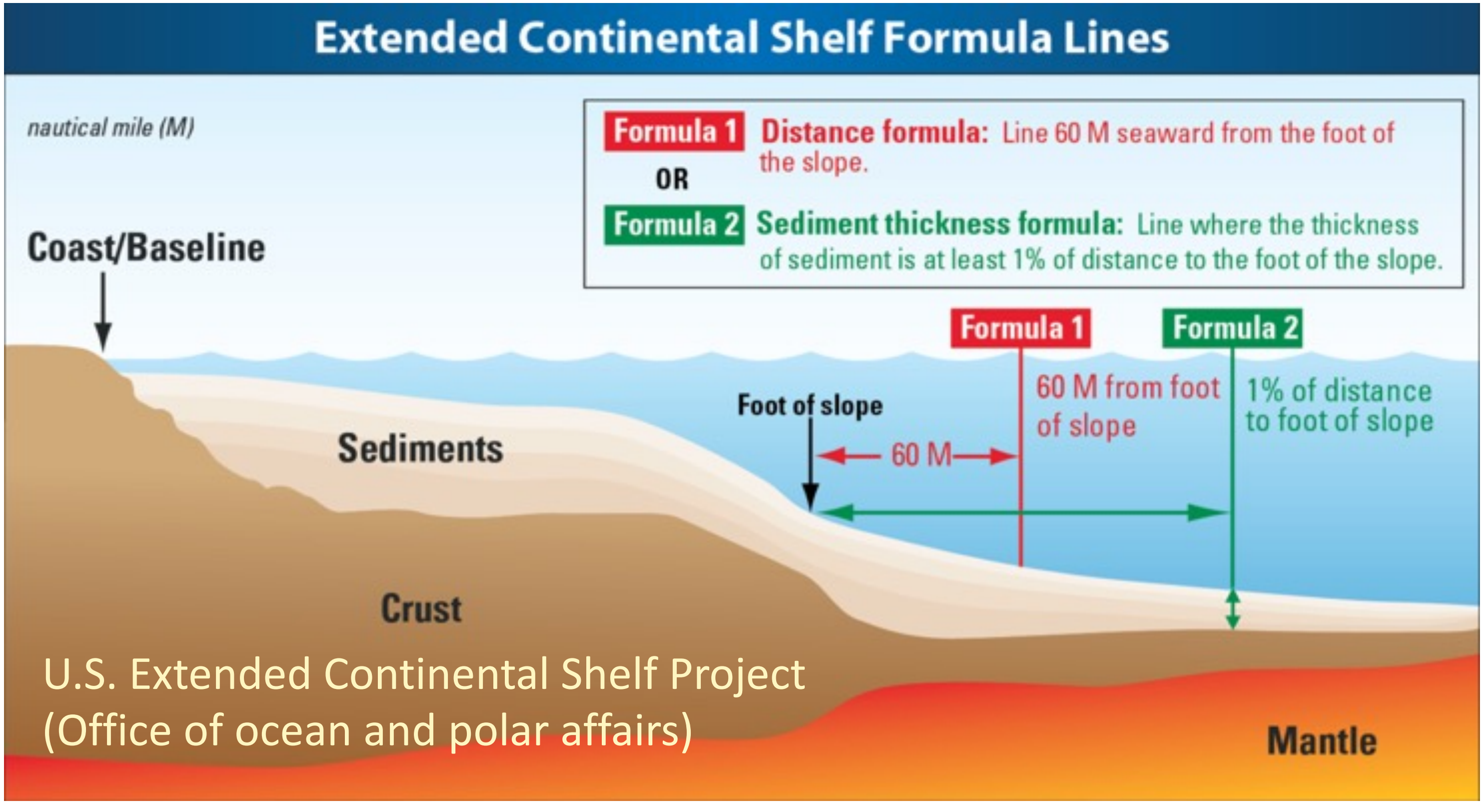
González et al (2012)



Significance for the definition of the "extended continental shelf"

The "**extended continental shelf**" is the portion of the continental shelf beyond 200 nautical miles under the Law of the Sea Convention. It is an important maritime zone that holds many resources and vital habitats for marine life: knowledge of it exact extent is necessary for national security and good management. Large sediment bodies deposited by contour-following currents are developed all along the margin. These drifts tend to form bathymetric steps in profile, where they onlap the margin.

Stacked drifts create several steps. Understanding the geomorphological consequences of deep sea sedimentation processes is important to extended continental shelf mapping (Mosher et al., 2016)

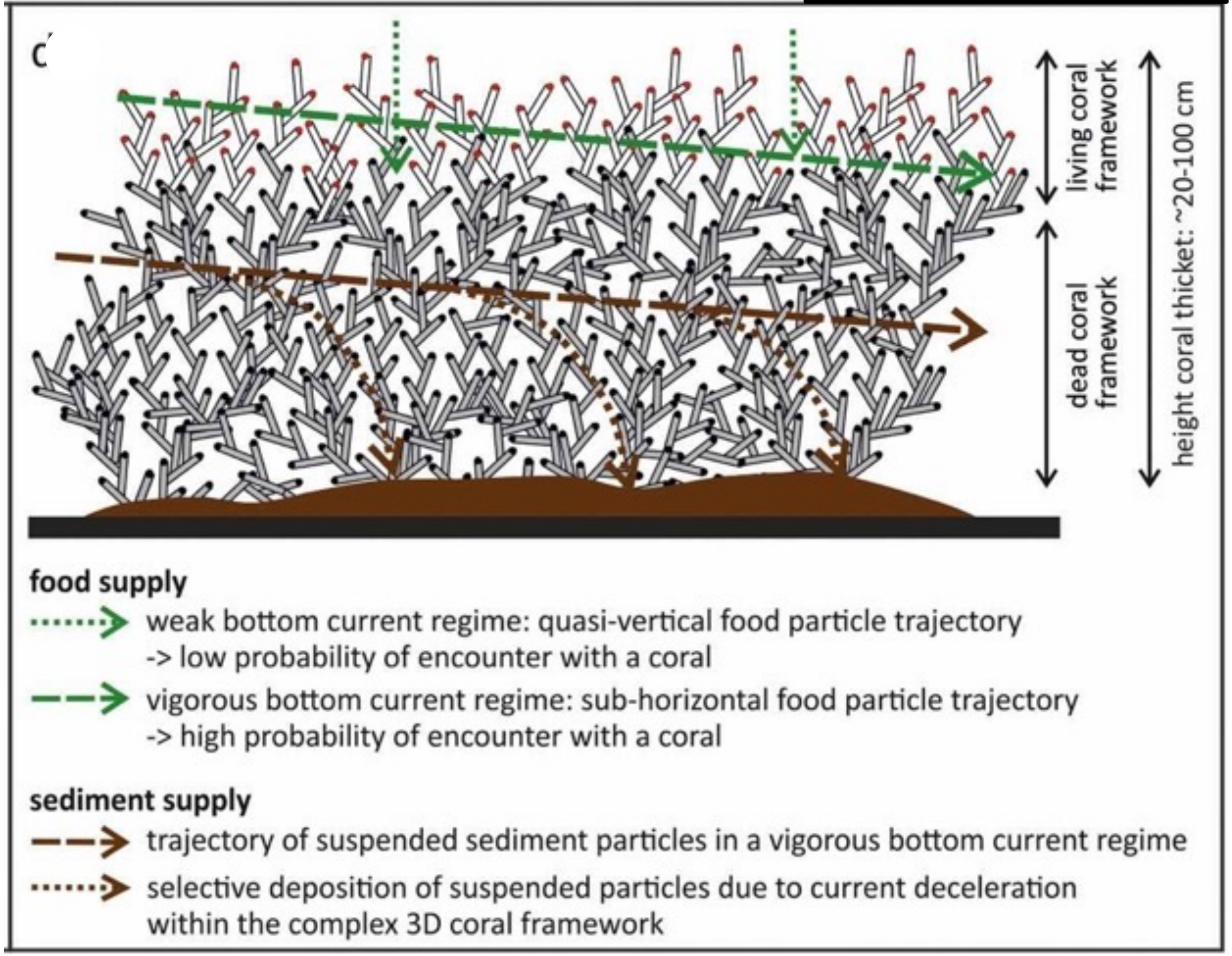


U.S. Extended Continental Shelf Project (Office of ocean and polar affairs)

Bottom currents are one important factor controlling deep-water ecosystems. The likelihood for a coral to catch **food particles** sinking through the water column is appreciably enhanced when their trajectory is sub-horizontal in response to the action of a sideways bottom current flow. Currents also help promoting **hardground** substrates eventually suitable for coral colonization, limit excess silting, and help coral **dissemination** over long distances (Rebesco & Taviani, 2016)

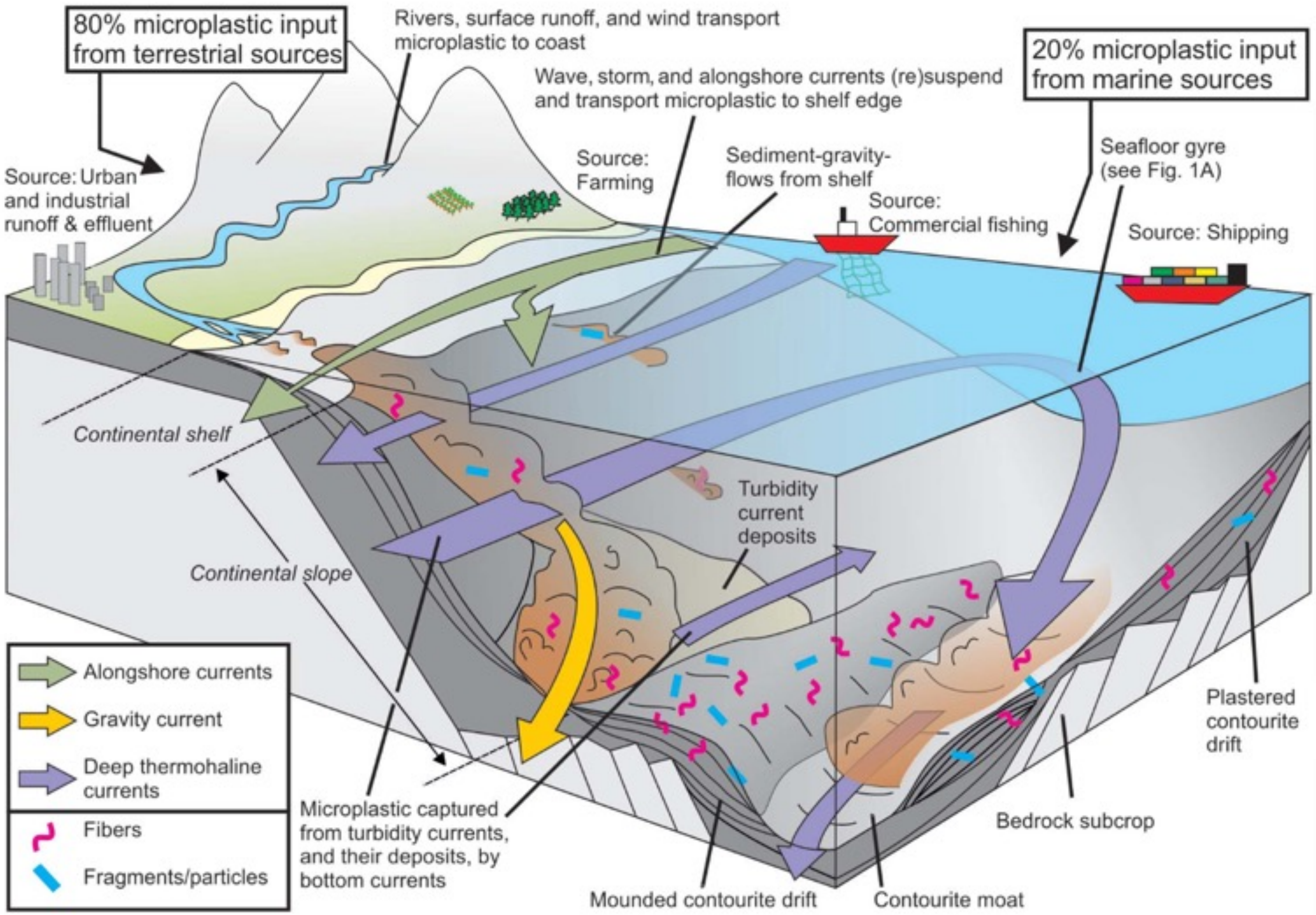
Significance for the ecological health of deepwater ecosystems

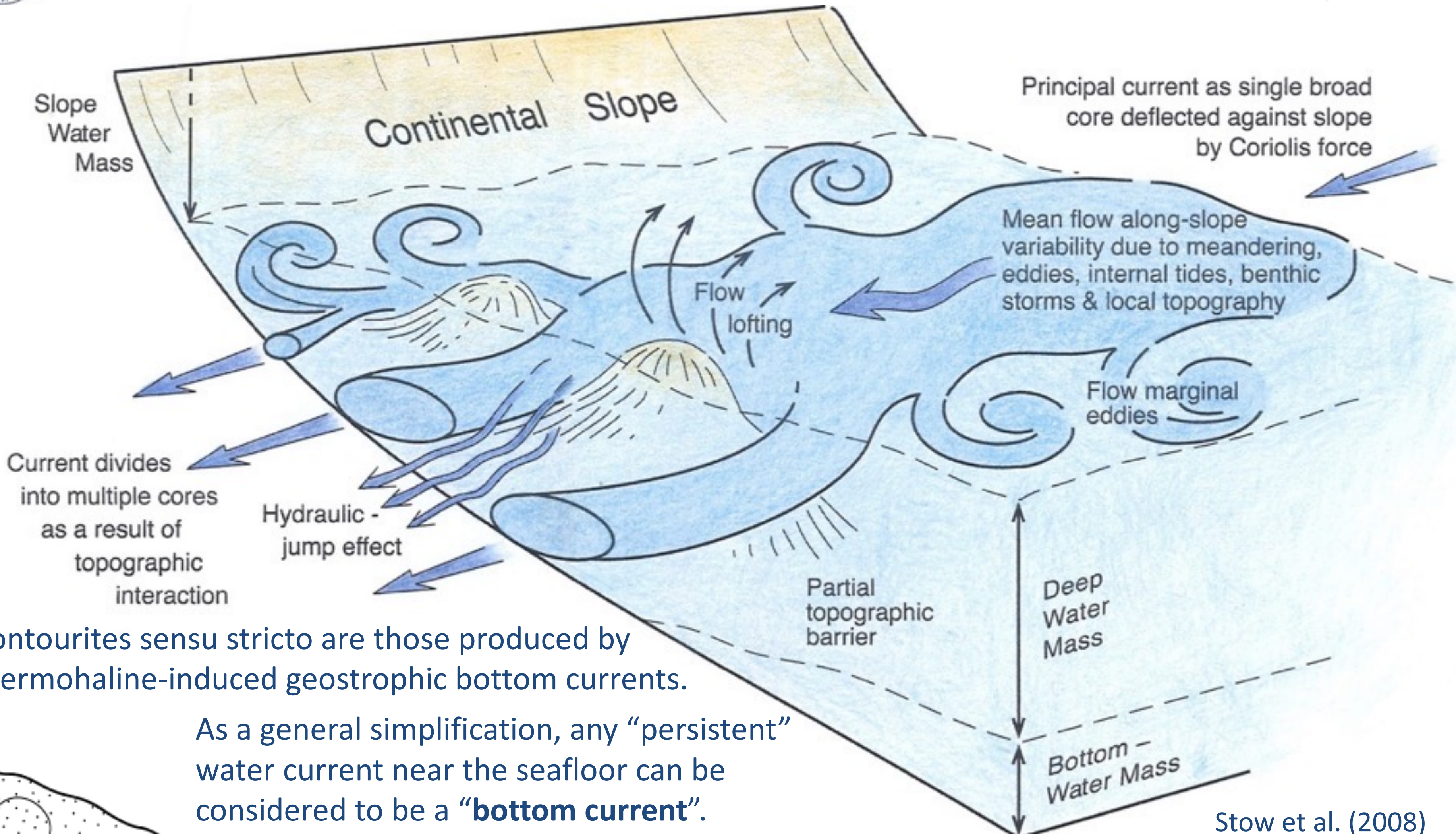
Hebbeln et al. (2016)



Significance for accumulation of microplastics and contaminants

Thermohaline-driven currents, which build extensive seafloor sediment accumulations, can control the distribution of microplastics and create hotspots with the highest concentrations reported for any seafloor setting (Kane et al., 2020)

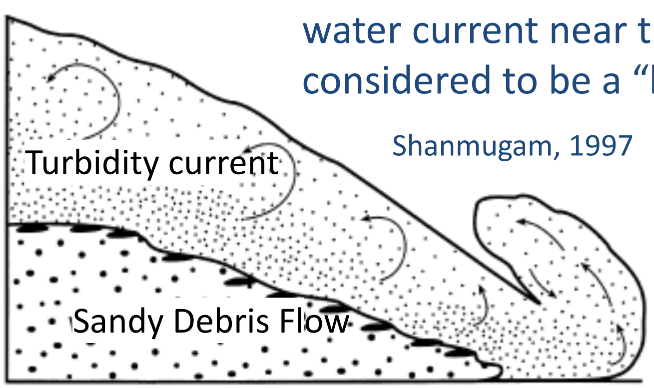




Stow et al. (2008)

Contourites sensu stricto are those produced by thermohaline-induced geostrophic bottom currents.

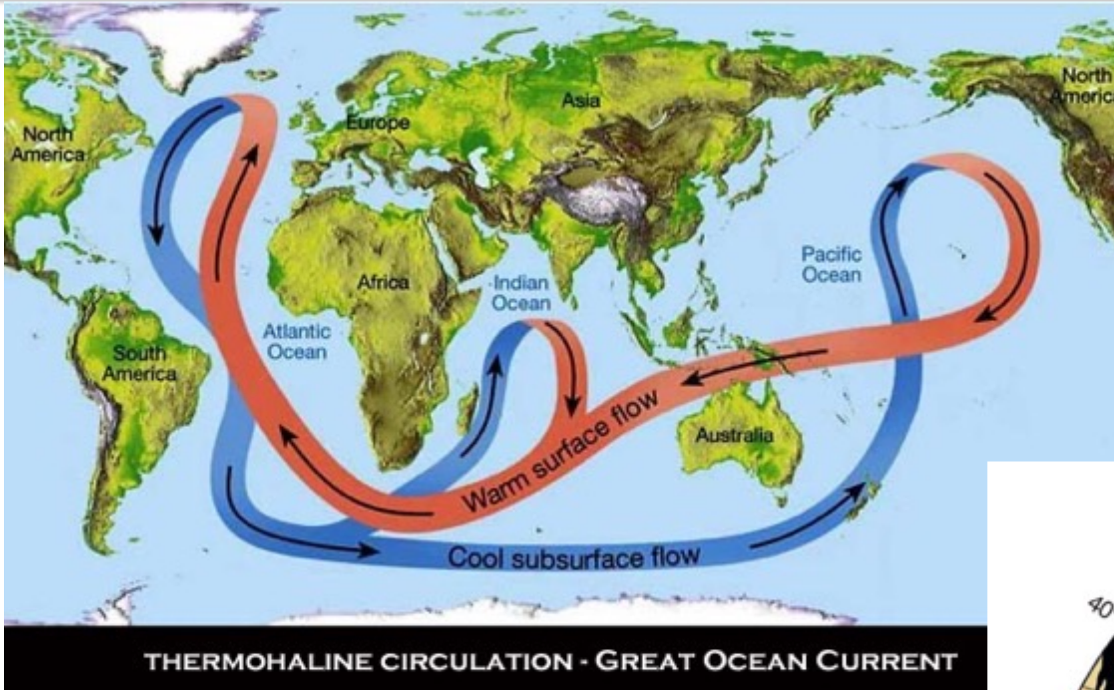
As a general simplification, any “persistent” water current near the seafloor can be considered to be a “**bottom current**”.

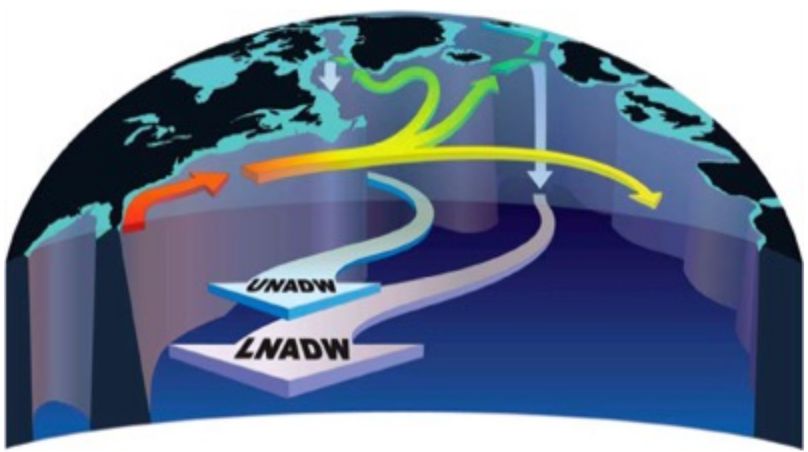


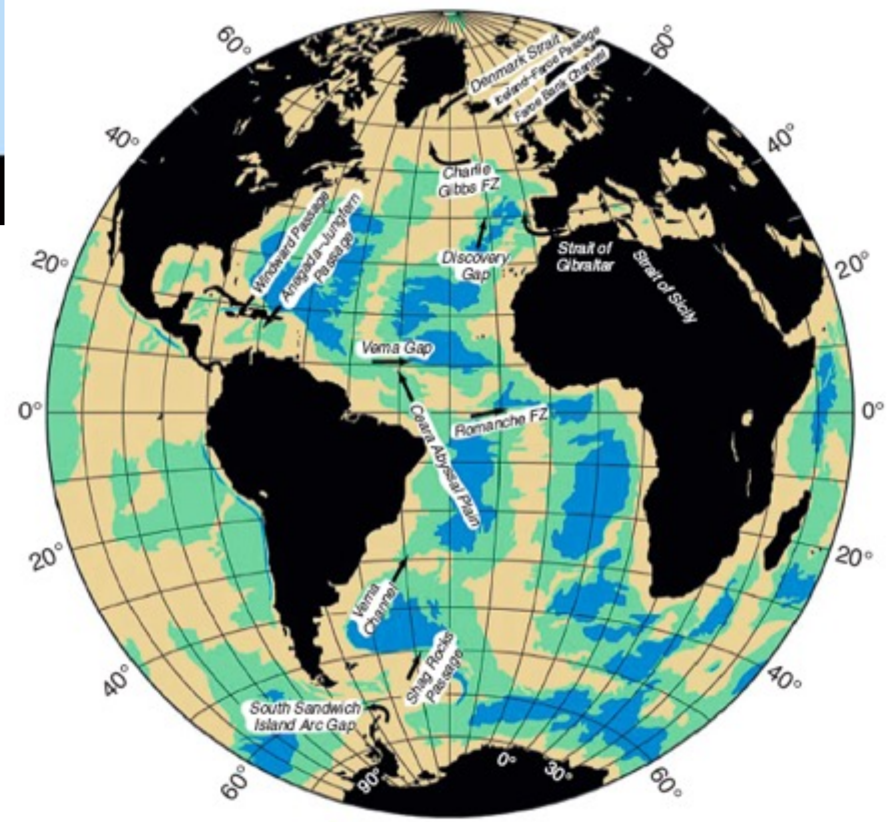
Shanmugam, 1997

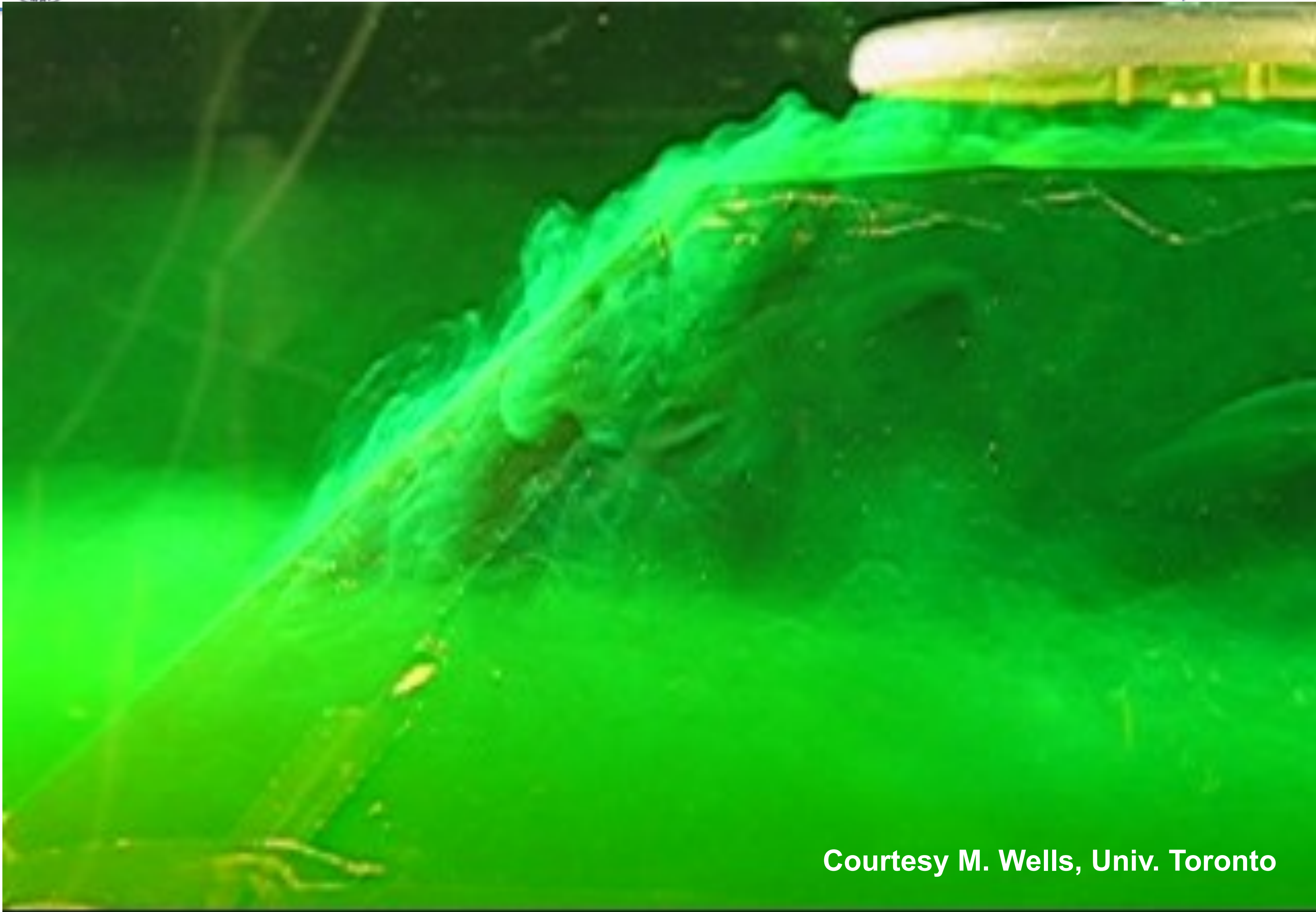
In addition, a number of associated processes are: benthic storms; overflows; interfaces between water masses; vertical eddies; horizontal vortices; tides and internal tides; internal waves and solitons; tsunami related traction current and rogue or cyclonic waves.

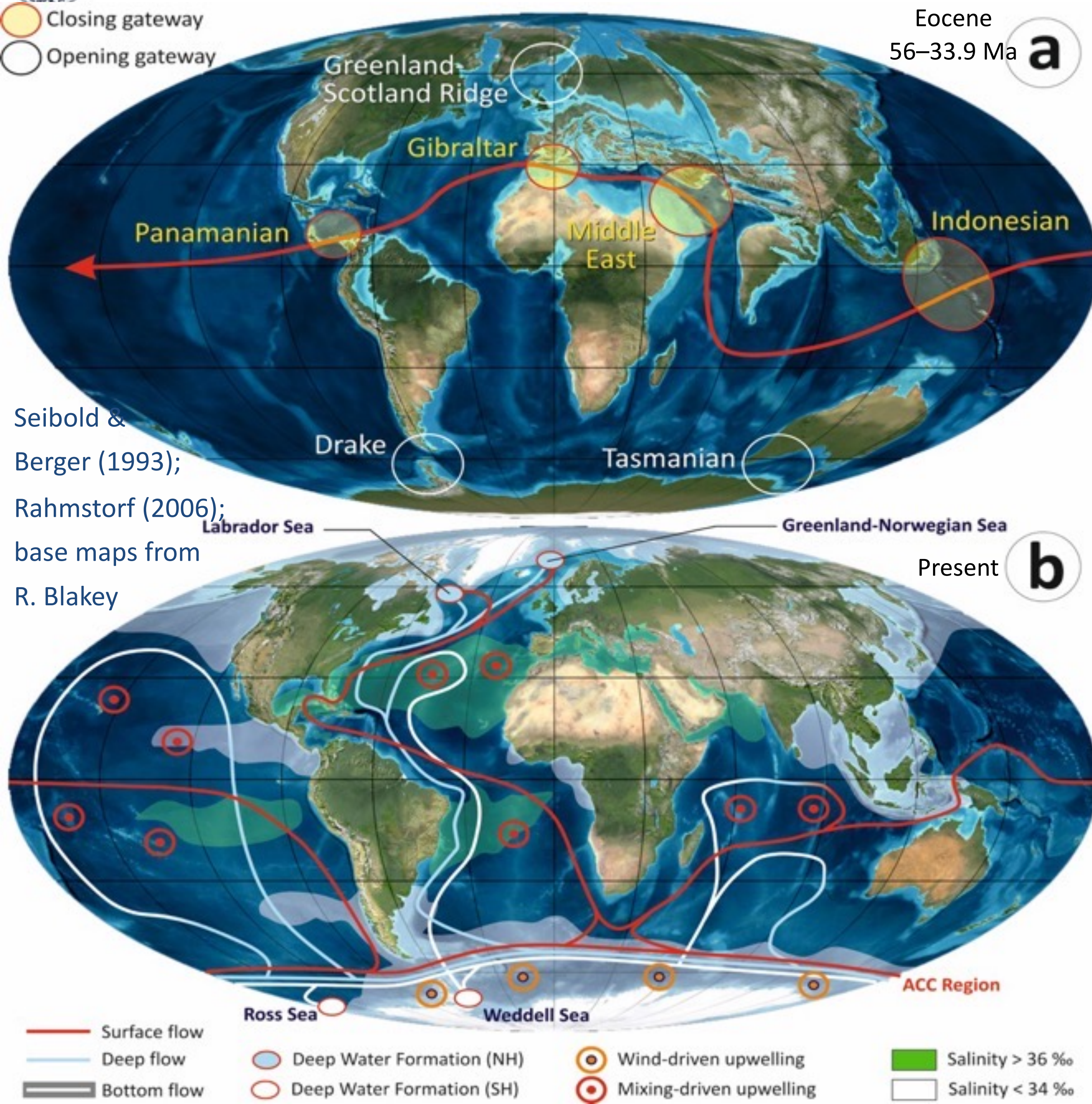
Thermoaline circulation







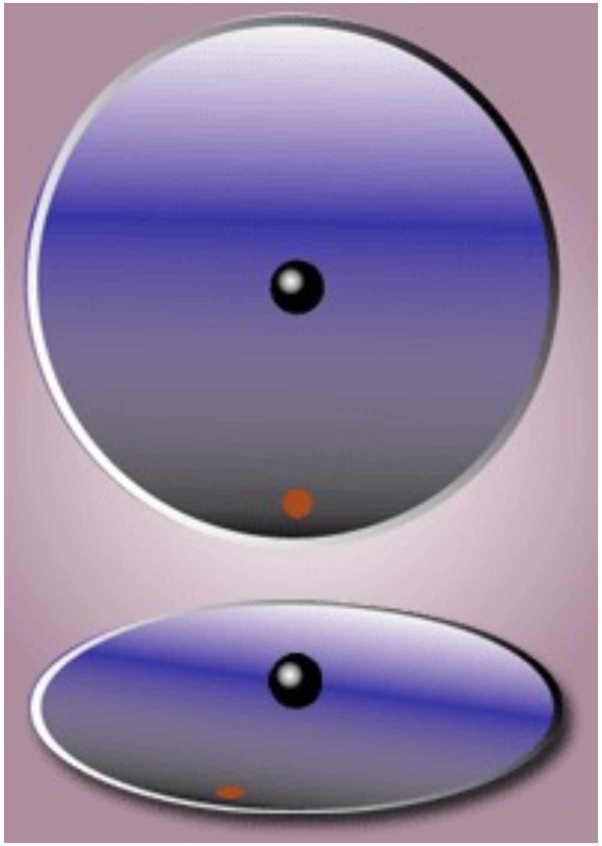

Courtesy M. Wells, Univ. Toronto

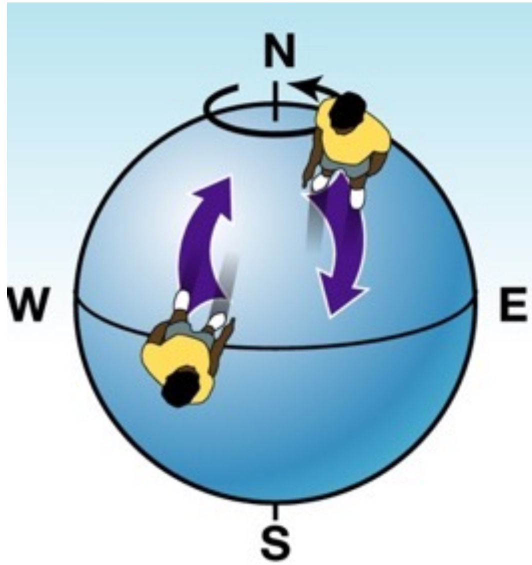


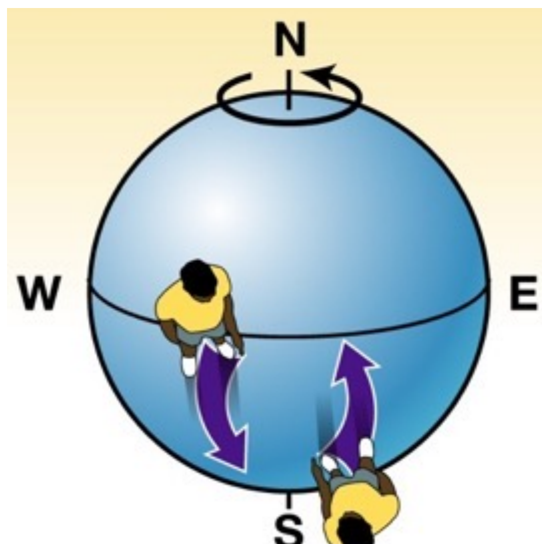
Seibold & Berger (1993); Rahmstorf (2006); base maps from R. Blakey

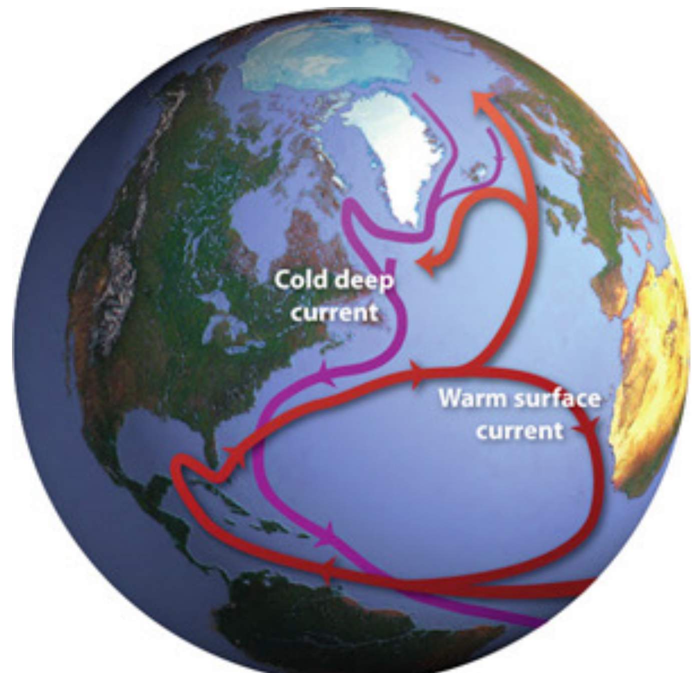
The deep waters of the oceans are primarily formed in marginal seas or shallow shelf regions where cooling and/or ice formation makes the water cold and dense, or strong evaporation makes the water highly saline. The relatively dense water thus formed flows out into the ocean via narrow or shallow straits or over the continental margin, steered to the right (in the Northern Hemisphere) by Earth's rotation. When it is no longer constricted by the topography it reshapes into a wider structure, and adjusts under the forces of gravity, Earth's rotation, and bottom friction.

Coriolis effect



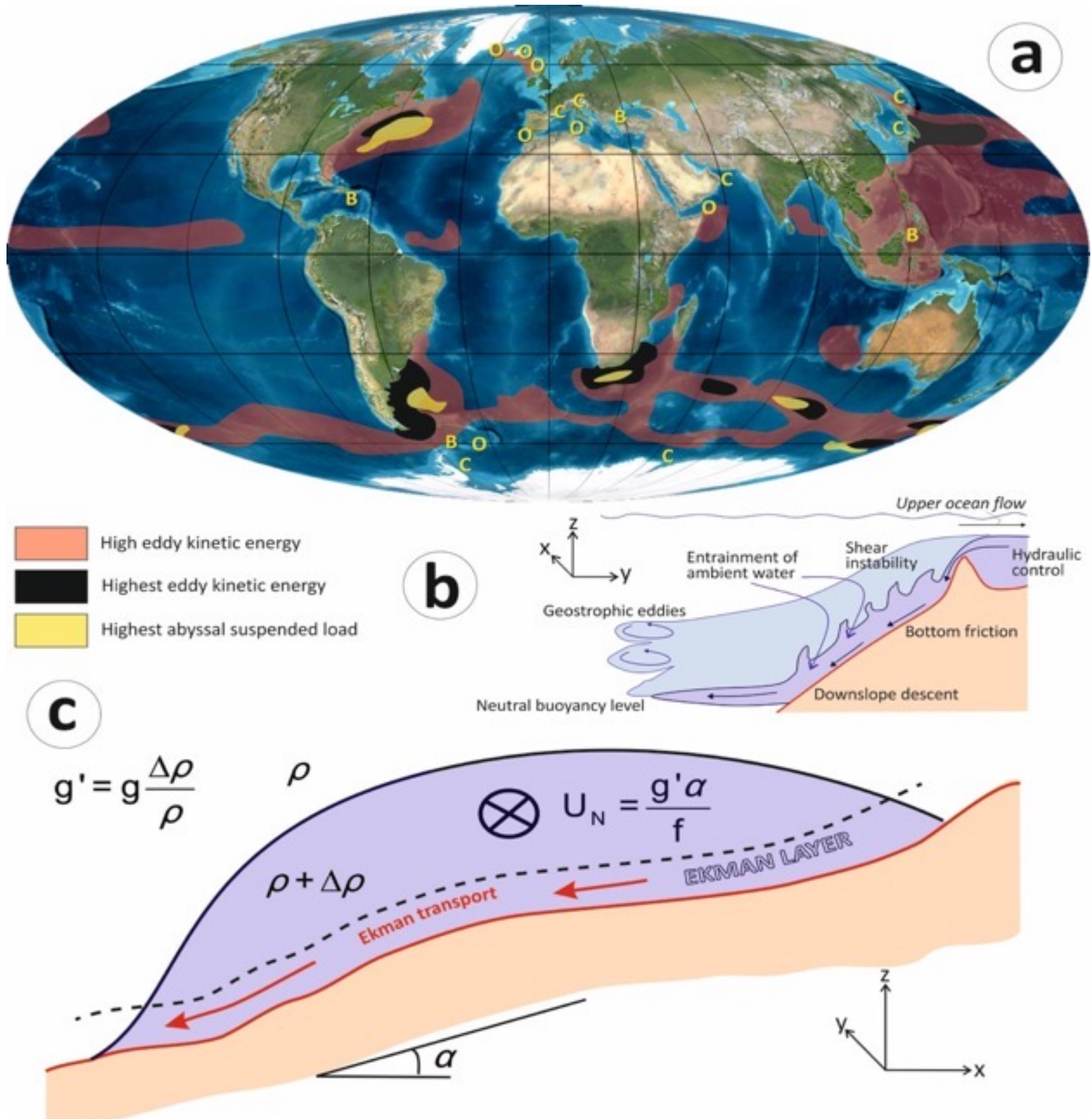






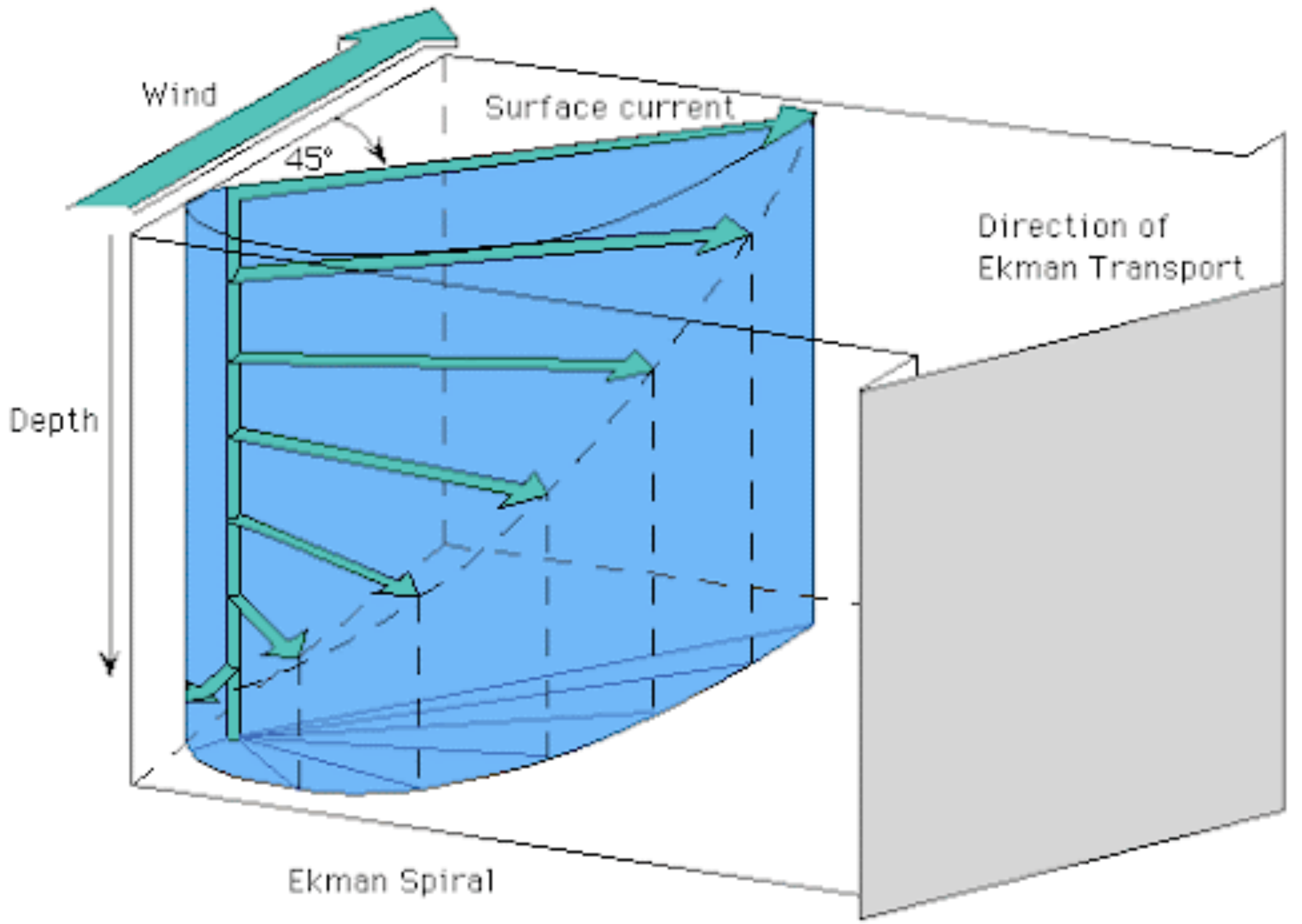
In physics, the Coriolis effect is a deflection of moving objects when they are viewed in a rotating reference frame

a) Map showing the relationship between kinetic energy and suspended load (Legg et al., 2009, base map from R. Blakey). O: Overflow; B: Open-ocean overflow; C: Cascading. b) Physical processes acting in overflows. c) Sketch of a dense overflow showing the coordinate System and some of the notations used (ambient density: ρ; plume density: ρ+Δρ; reduced gravity: g′; bottomslope: α; Coriolis parameter: f; and Nof velocity: UN). Also shown are the Ekman layer and the benthic Ekman transport.



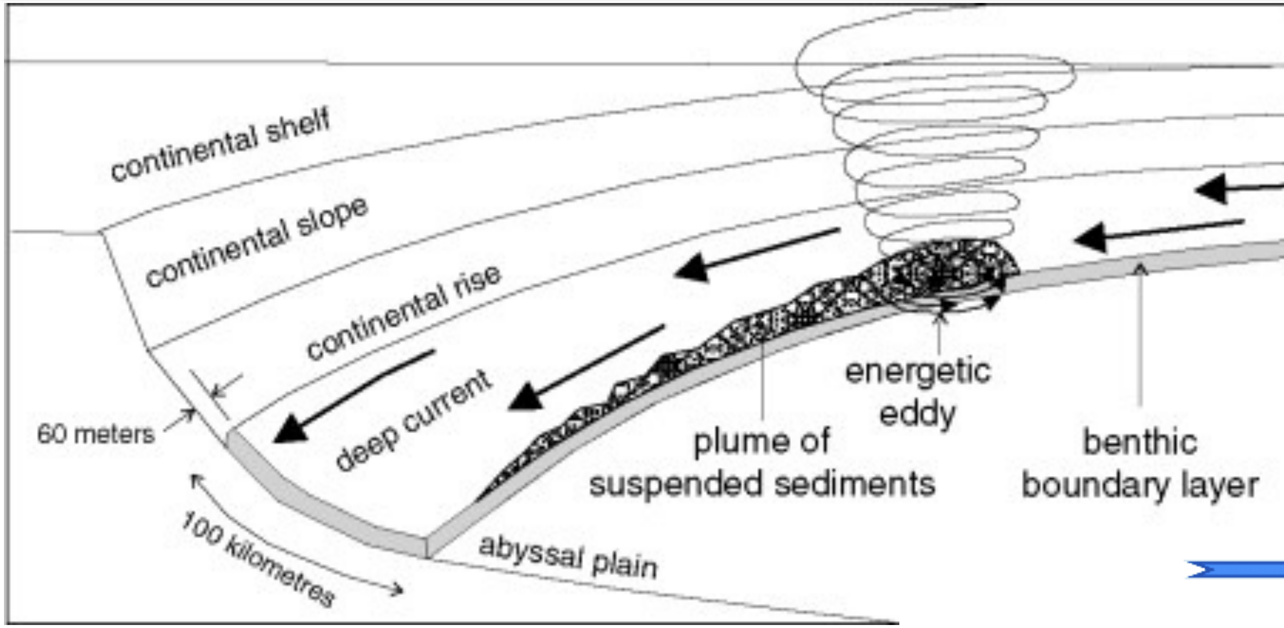
Ekman layer

The Ekman layer is the layer in a fluid where the flow is the result of a balance between pressure gradient, Coriolis and turbulent drag forces. In the picture above, the wind blowing North creates a surface stress and a resulting Ekman spiral is found below it in the column of water.

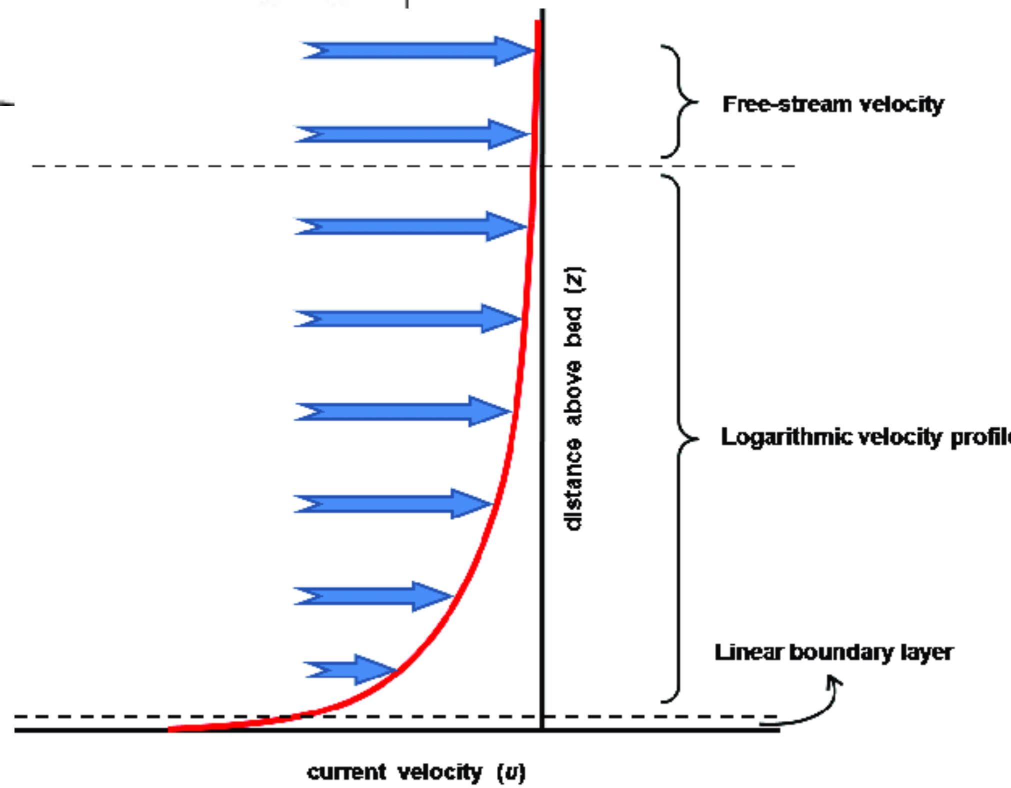


Adapted from Thurman, Harold V. **Essentials of Oceanography, 5th ed.** Prentice-Hall, Inc., 1996.

Benthic boundary layer



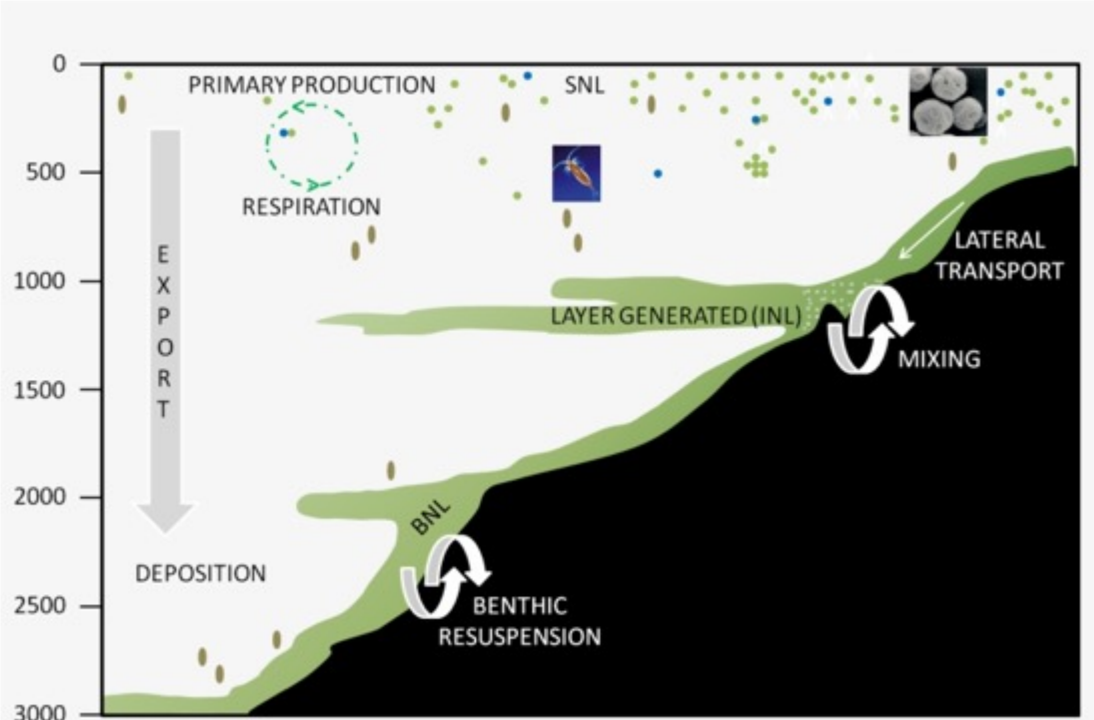
The benthic boundary layer (BBL) is the layer of water directly above the sediment at the bottom of a body of water. It is generated by the friction of the water moving over the surface of the substrate.



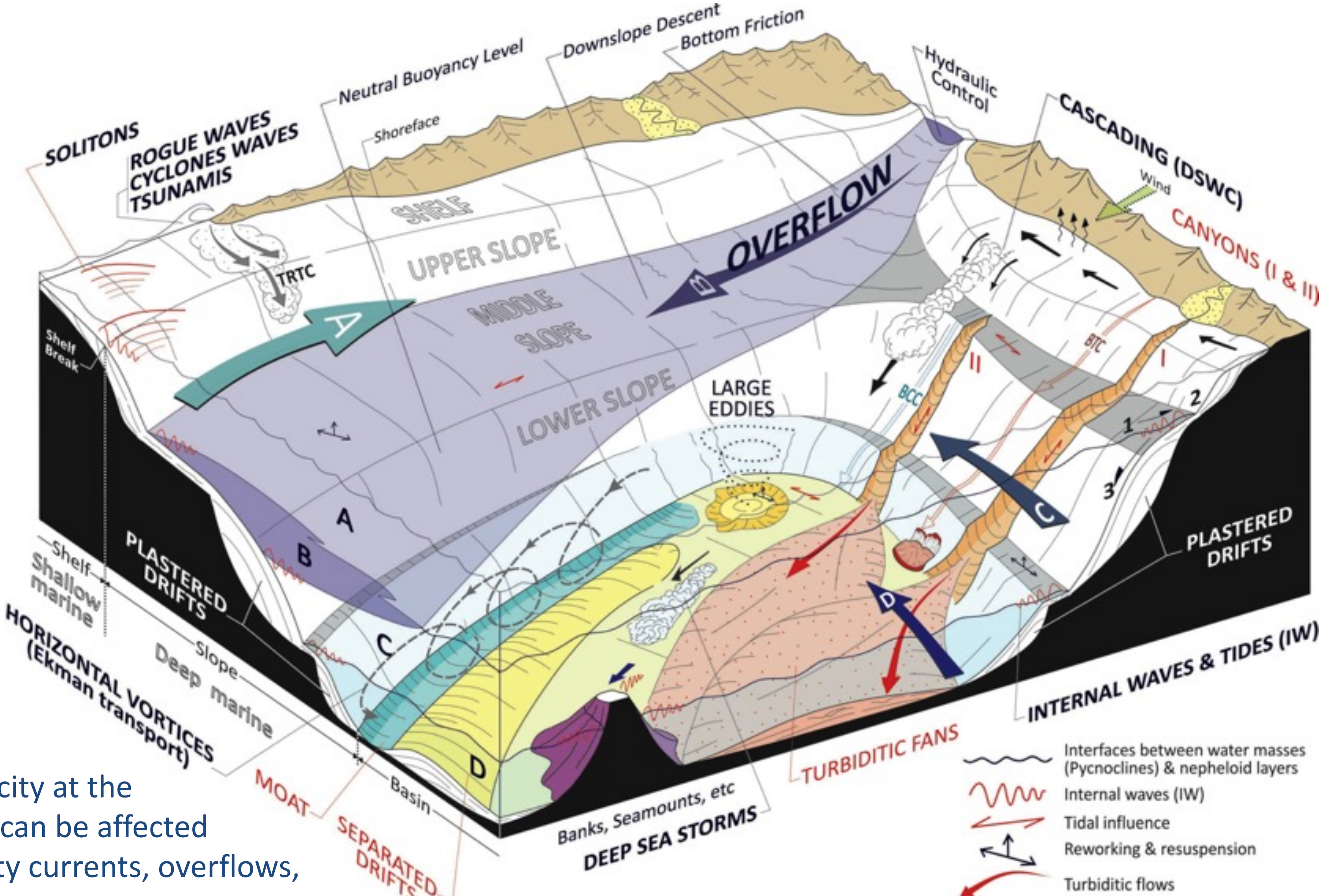
Nepheloid layers

Nepheloid layers (NLs) are zones of increased turbidity relative to waters above and/or below in the oceans. NL thickness is mainly in the range 50–1000 m. The turbidity is conferred by particulate matter and most commonly detected by light scattering or attenuation (hence `nepheloid' meaning cloudy). Most material in NLs is produced by resuspension of bottom sediments, often on continental margins, and also from ridges and seamounts, due to bottom shear stress from thermohaline currents and internal waves and tides.

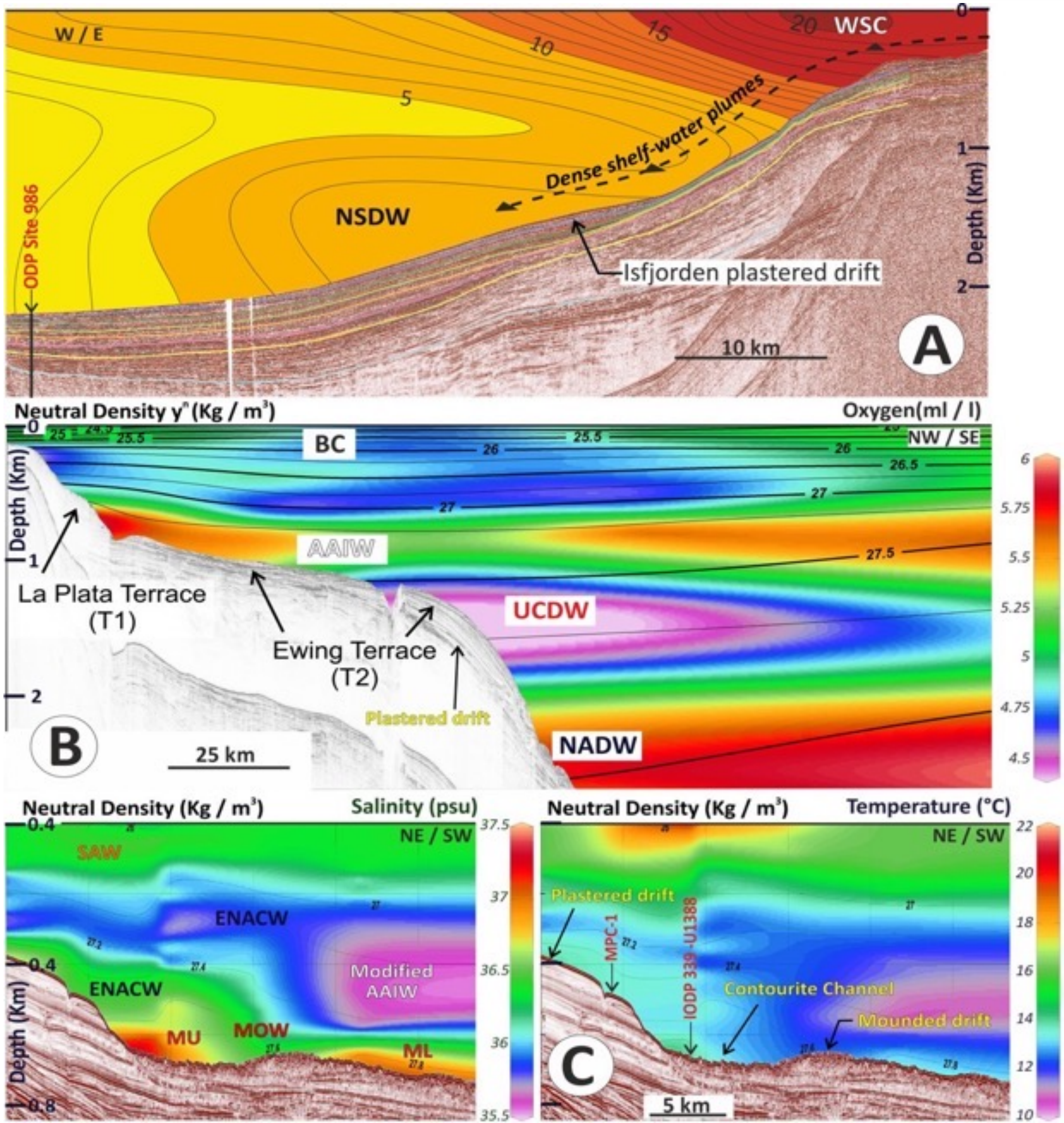
Resuspended material is diffused upward in bottom mixed layers which periodically separate and spread away from their source. As they spread they lose particles through aggregation and sinking of larger particles. This confers a generally decreasing turbidity upward from the ocean bottom because higher layers have usually separated farther away.



McCave, in Encyclopedia of Ocean Sciences, 2009



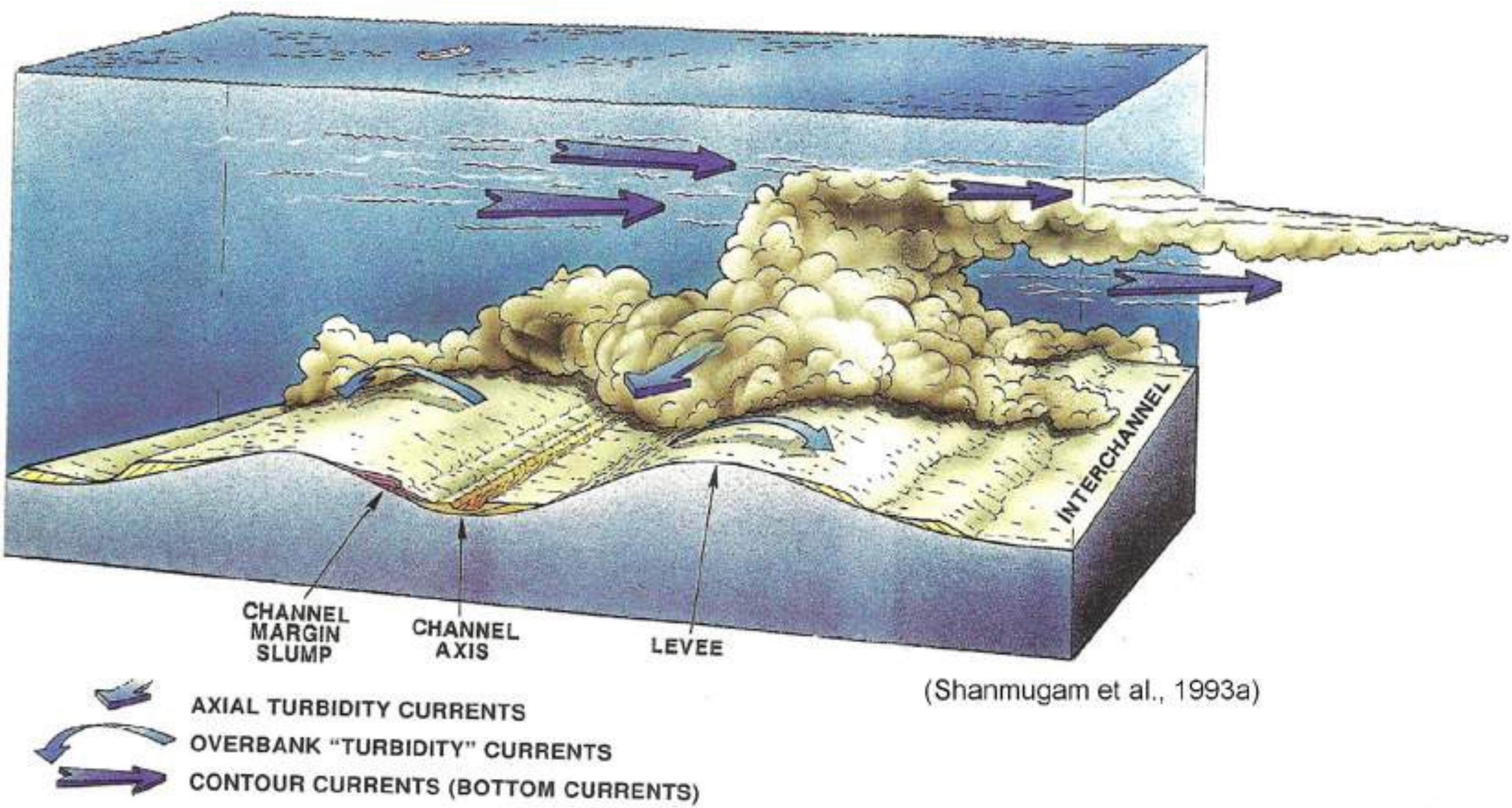
The velocity at the seafloor can be affected by density currents, overflows, barotropic currents and intermittent processes (cascading, giant eddies, deep sea storms, vortices, internal waves, internal tides, tsunamis, cyclone waves, and rogue waves)



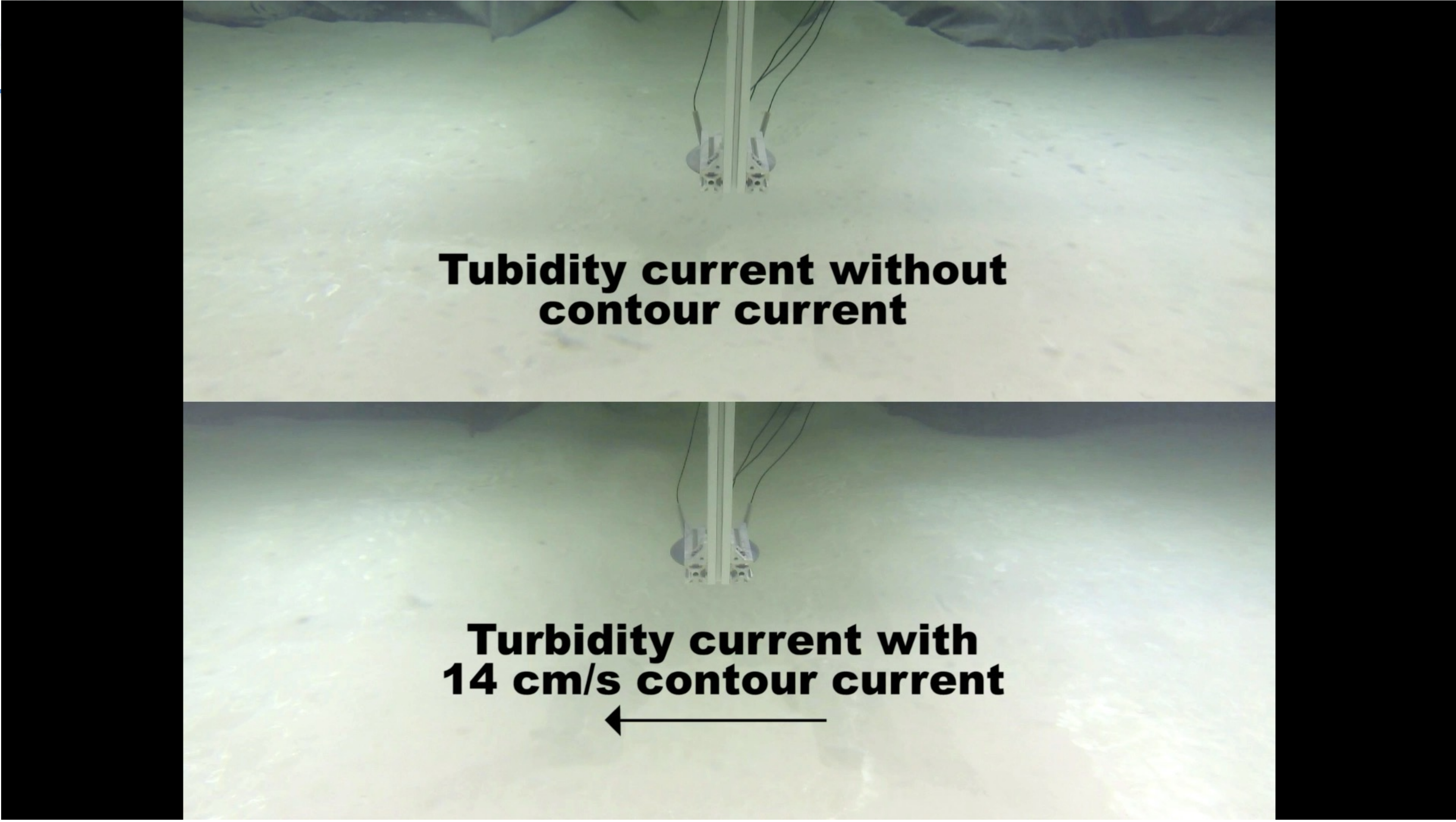
Examples of combining physical oceanographic data with geologic/geophysical data, showing the relationship amongst the long-term current regime, the seafloor morphology and the sub-bottom sediment geometry. A) Western Spitsbergen margin (Rebesco et al., 2013); B) Argentine margin, North of the Mar del Plata Canyon (Preu et al., 2013); and C) Gulf of Cádiz, from the exit of the Strait of Gibraltar (Hernández-Molina et al., 2014) .

The black numbers and lines in (A) refer to current velocity (cm/s), but in (B) and (C) they refer to isopycnals and neutral density (kg/m3).

Sediment entrainment



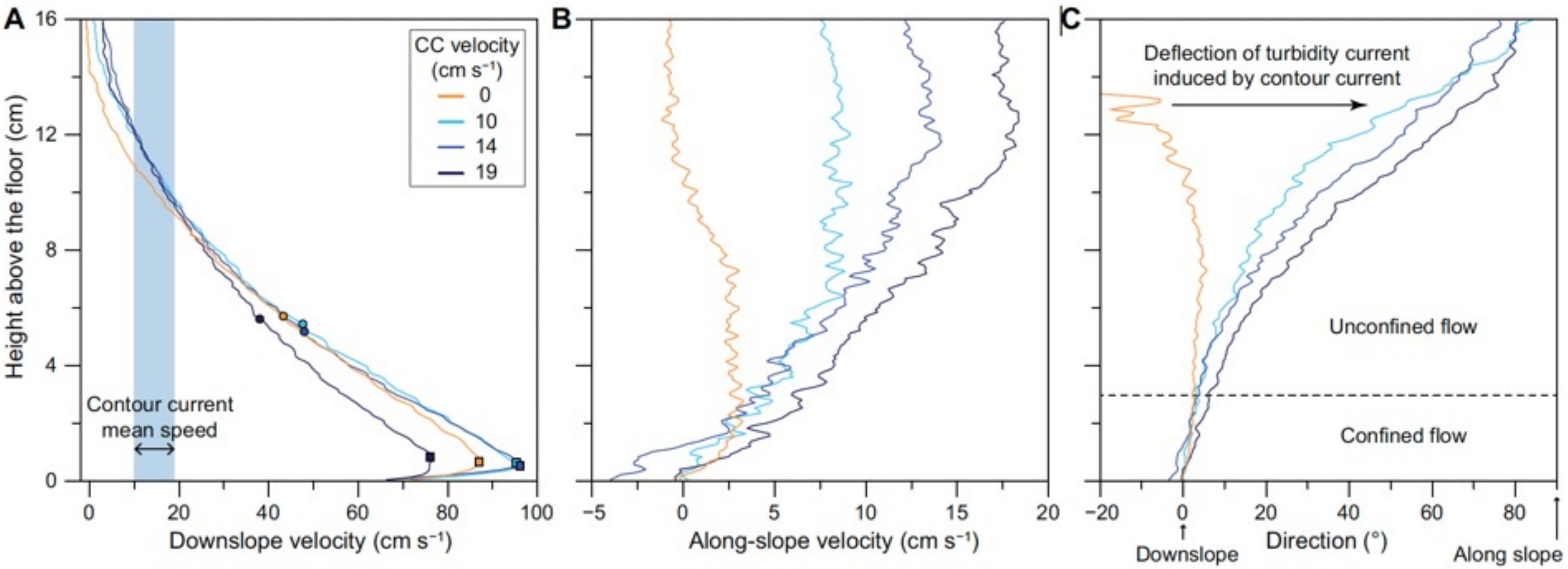
(Shanmugam et al., 1993a)



video of a turbidity current during two experiments: a turbidity current flowing in standing water without a contour current (A); and a turbidity current interacting with a contour current of 14 cm s^{-1} (B). The UDOP 4000 velocimeter, used to measure velocity profiles during experiments, can be observed in the center of the images

Velocity profiles and deflection

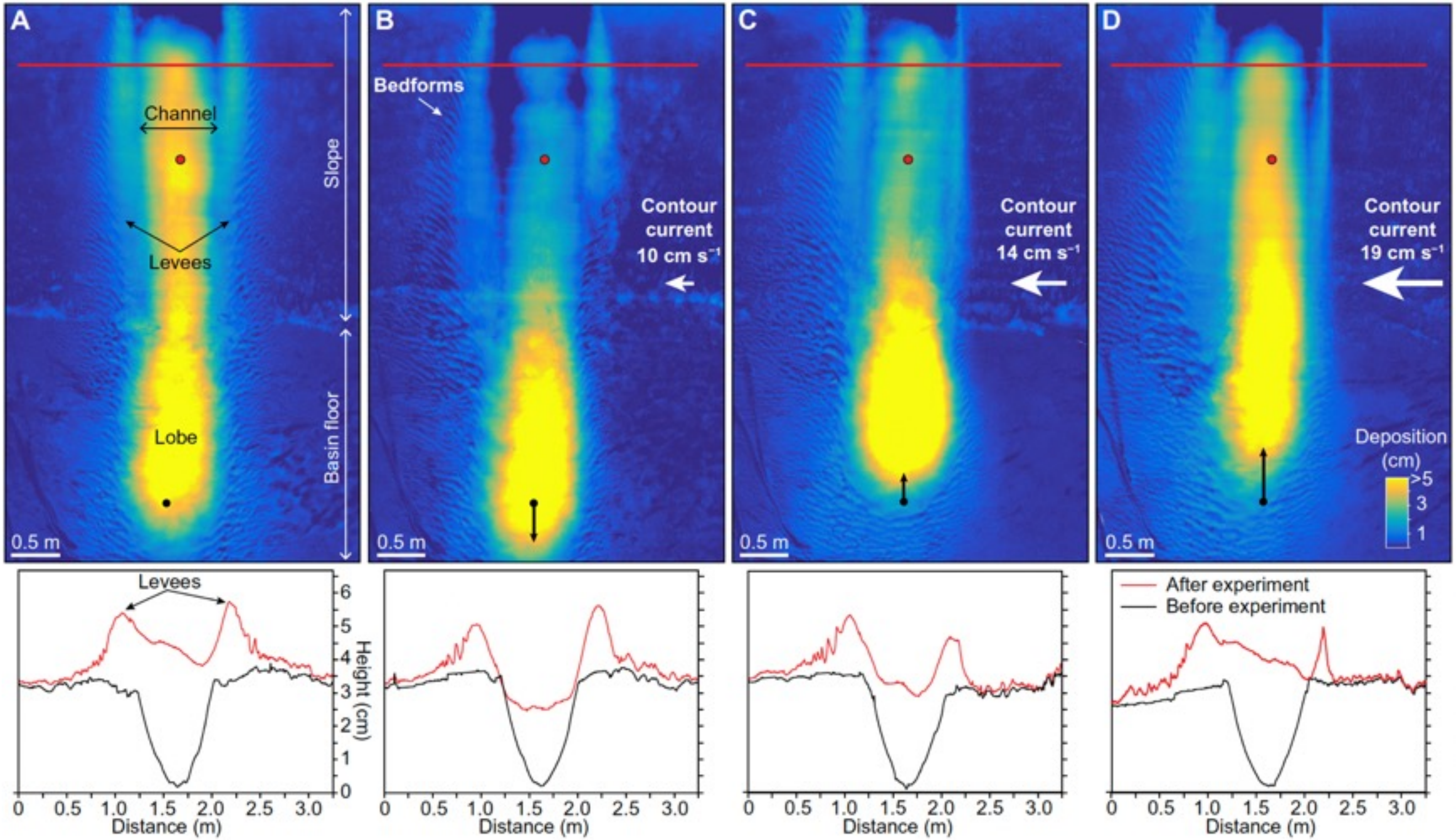
(A) Time-averaged downslope velocity profile for all experiments. Squares represent maximum velocity of turbidity currents, and circles represent flow thickness, which is here defined as the height at which the velocity is half the velocity maximum. Vertical light-blue band indicates the range of mean contour current speed used in the experiments (10–19 cm s−1). (B) Time-averaged, along-slope velocity profile for all experiments. (C) Time-averaged direction of turbidity current for each experiment. CC—contour current.



Miramontes et al., 2020

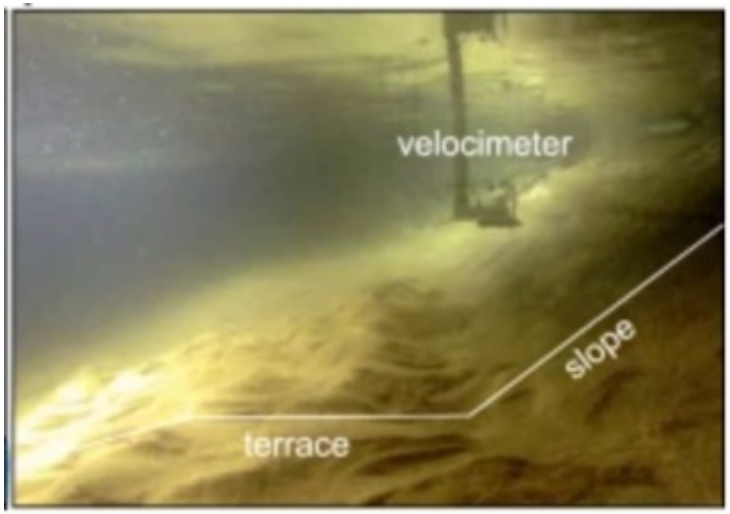
Deposition maps and cross sections during experiments of turbidity currents.

Red lines represent location of cross sections. Red dot represents the point of current velocity measurements. Black dots and black arrows represent how the frontal part of the deposit with sediment deposition >5 cm was displaced compared to the experiment in standing water. In the cross sections, black and red lines indicate the profile before and after the experiment, respectively.

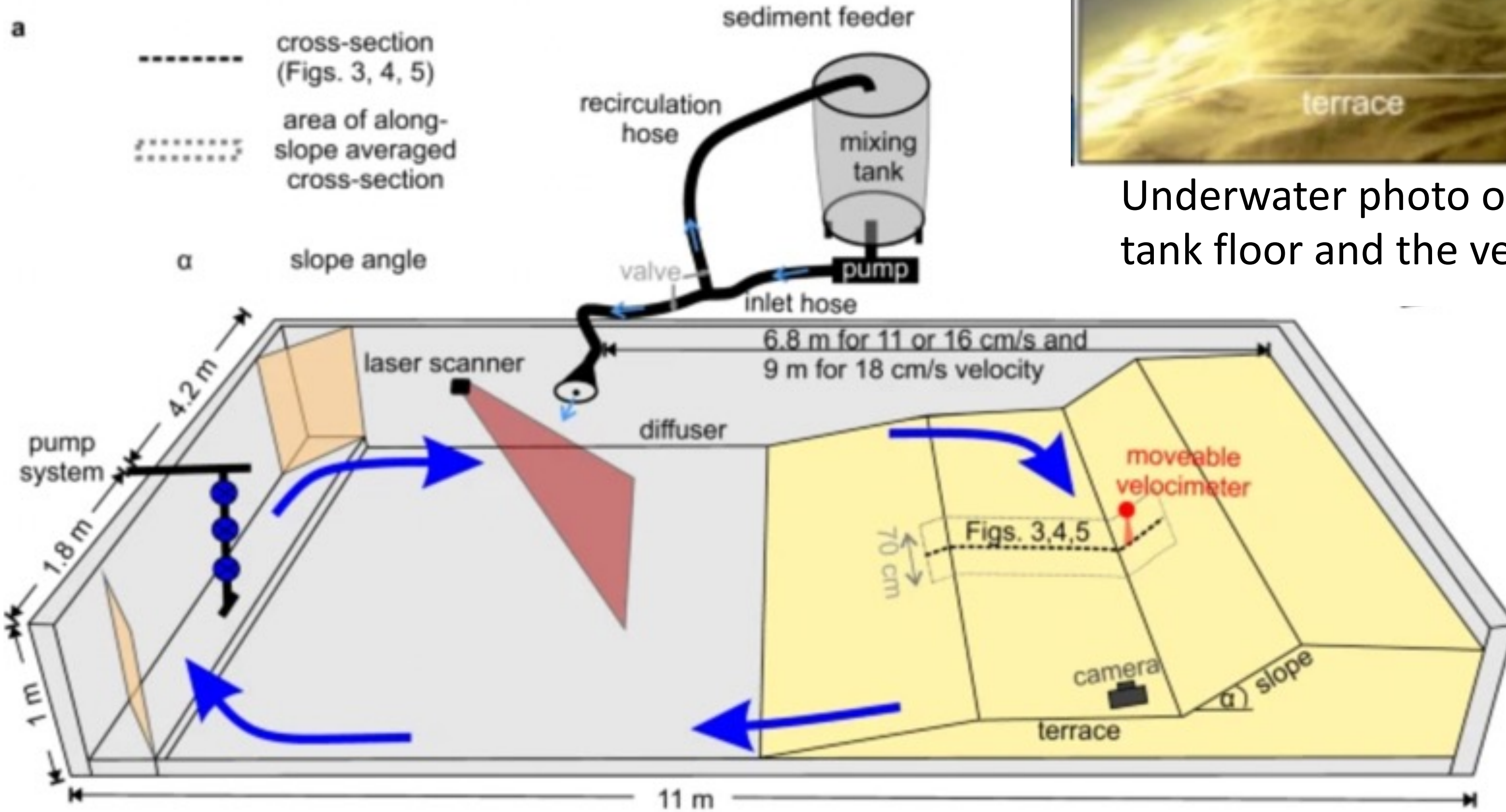


Miramontes et al. 2020

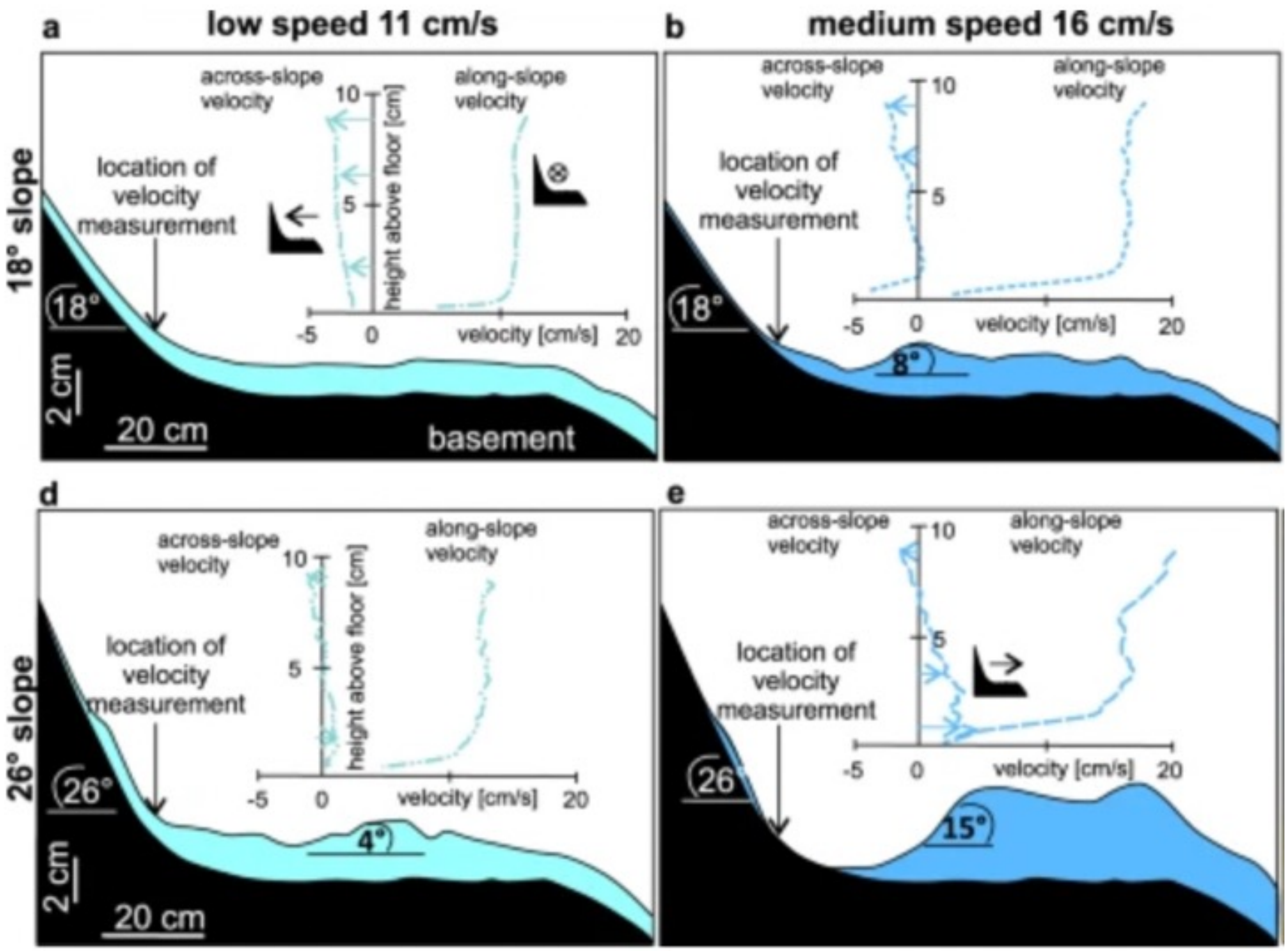
Wilckens et al. (2023) **Secondary flow in contour currents controls the formation of moat-drift contourite systems**. Commun Earth Environ 4, 316



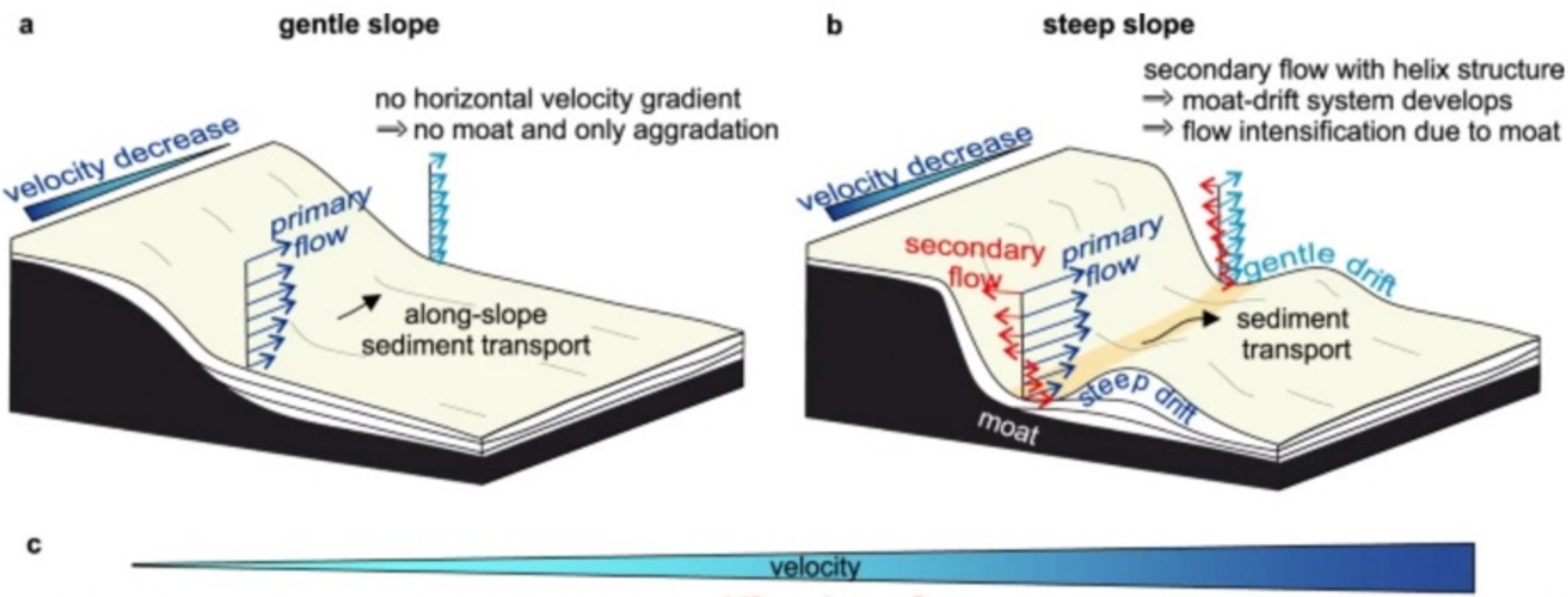
Underwater photo of the flume tank floor and the velocimeter



Schematic drawing of the experimental setup



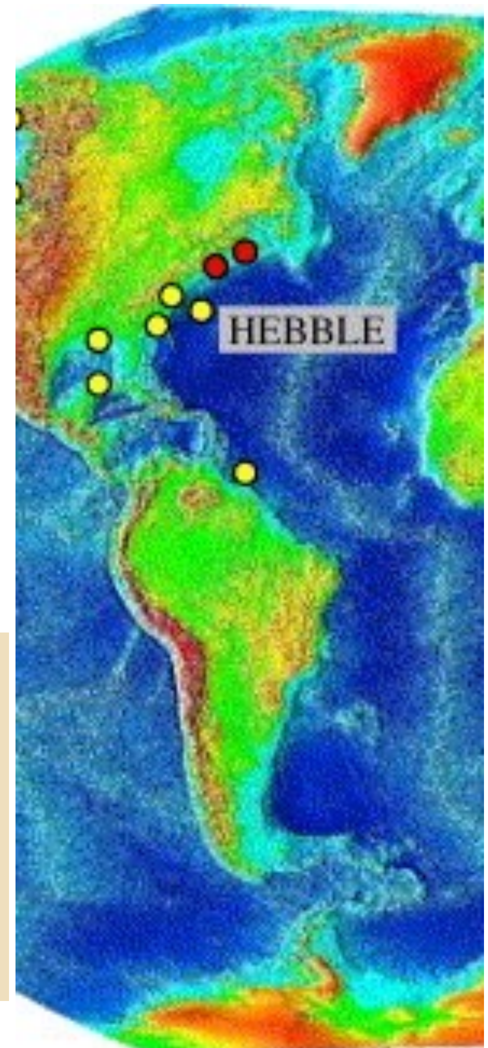
Measured cross-sections from moat-drift systems show that the morphology depends on current speed and slope gradient



At a gentle slope with a low current speed only aggradation occurs. The moat-drift system forms if there is a secondary flow near the seafloor that transports sediment from the slope toward the drift. In three dimensions, the current has a helicoidal structure and is confined inside the moat. The secondary flow decreases with lower speeds and more gentle slopes. The current speed and the slope's steepness influence the drift's steepness

Benthic Storms

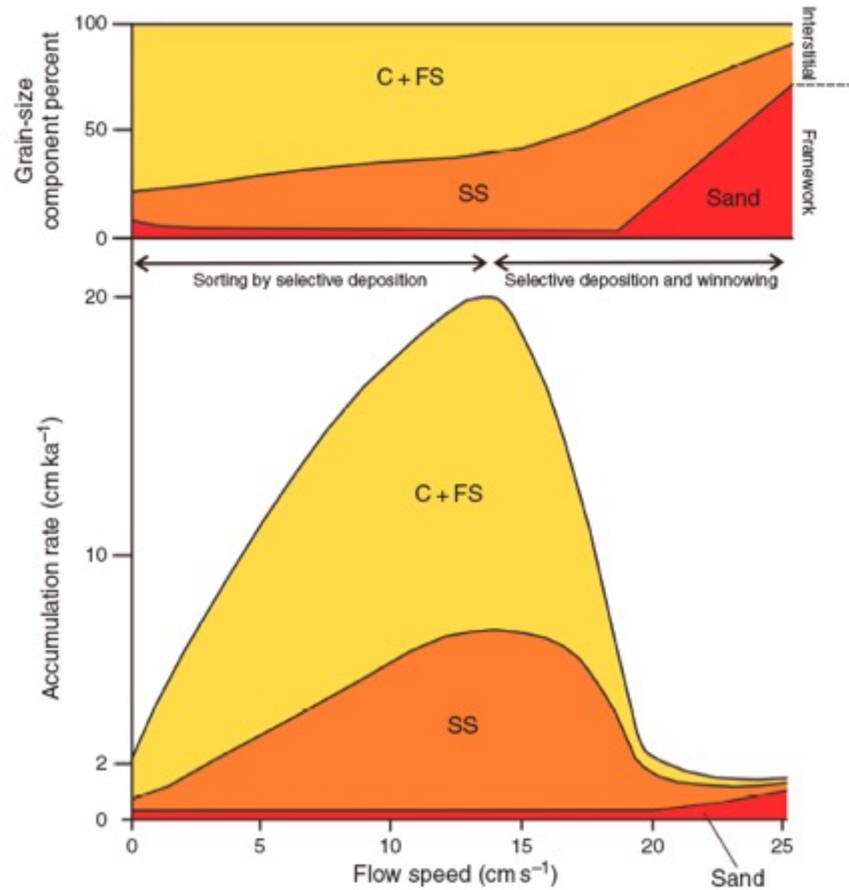
Hollister and Nowell (1991) HEBBLE epilogue. Marine Geology, 99 445-460

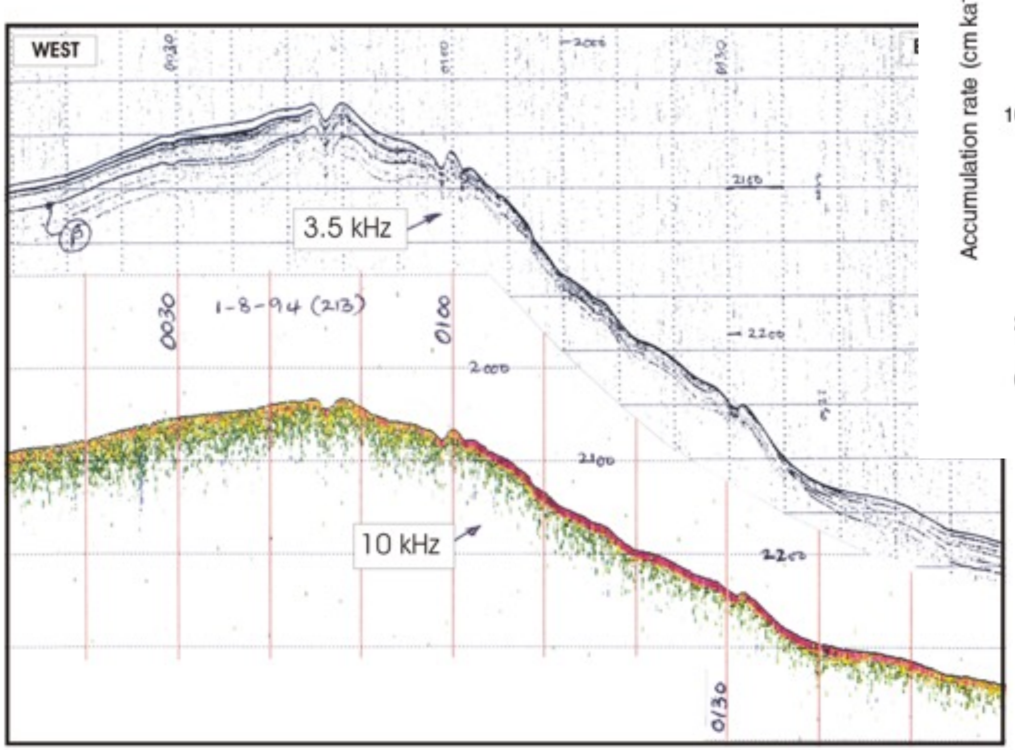


Benthic storm characteristics in the HEBBLE area

Duration	2–20 days (most last about 3–5 days)
Frequency	8–10 storms per year
Maximum velocities measured 10–50m above bottom	15–40 cm/s
Maximum concentrations 1–5m above bottom	3500–10 000m g/l
Direction of highest energy events	Westerly, parallel to contours
Estimated sediment flux rates during storms	20–200 cm3 /m2 per day

Sediment properties vary over mud waves because flow near the bed is strongly controlled by local topography. Mud waves can be either like dunes migrating in the direction of flow, or, more commonly, like anti-dunes responding to in-phase lee-wave disturbances in the stratified water column. In the latter case, the flow slows down on the upstream face, yielding a maximum deposition rate and speeds up over the downstream face, resulting in slower deposition or even erosion and coarser silt.

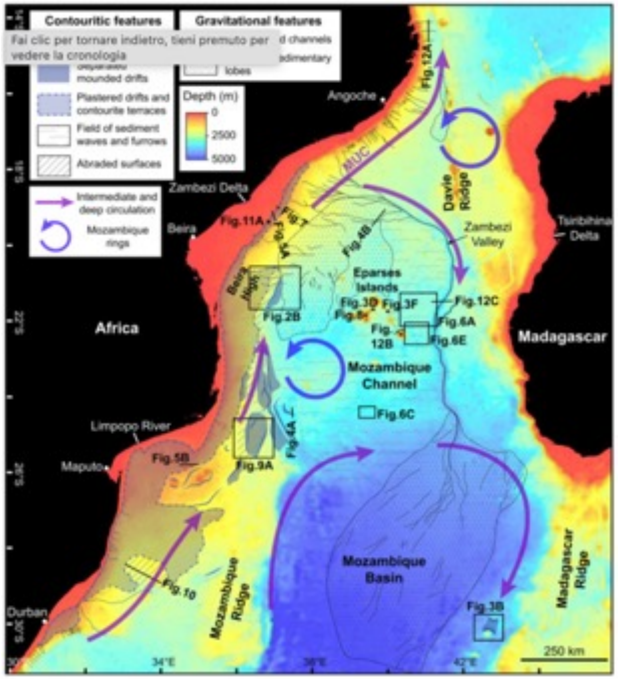




Deposits from currents

Link between geometry, sediment characteristics and modelled bottom currents,

Mozambique Channel (Miramontes et al., 2021. Marine Geology 437, 106502.



Multi-channel seismic reflection profile showing a separated mounded drift and a moat (courtesy of WesternGeco and partner. (B) Mean modelled bottom-current velocity at the foot of the Mozambican slope (modified from Thiéblemont et al., 2019).

SEPARATED MOUNDED DRIFT and MOAT