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 2021 - 2022

Analisi di Bacino e Stratigrafia Sequenziale (426SM)

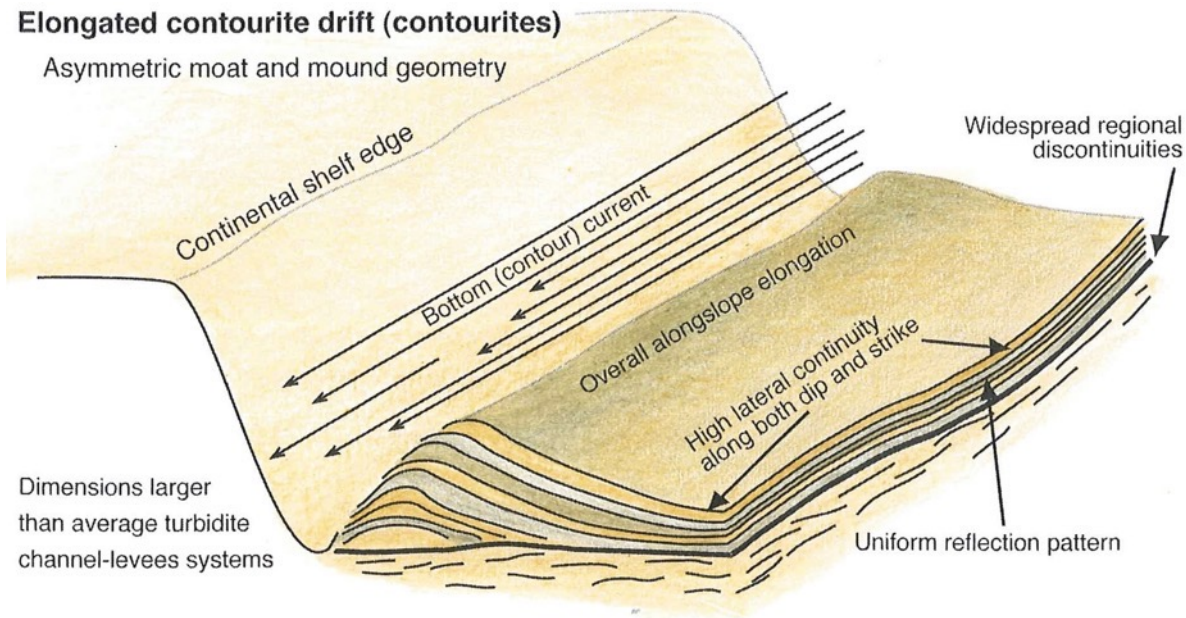
Docente: **Michele Rebesco**

Modulo 3.3
Contourites and sediment drifts

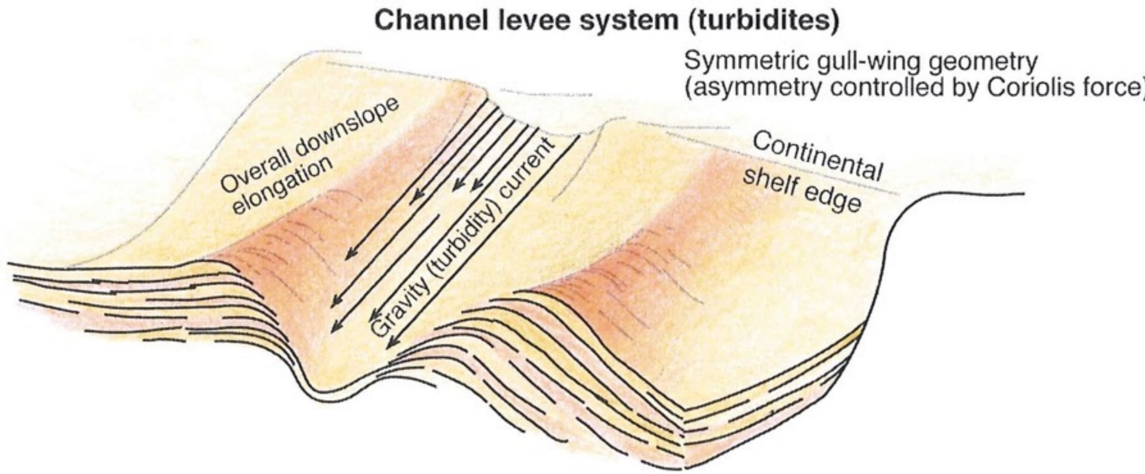
Docente: **Michele Rebesco**

Outline:

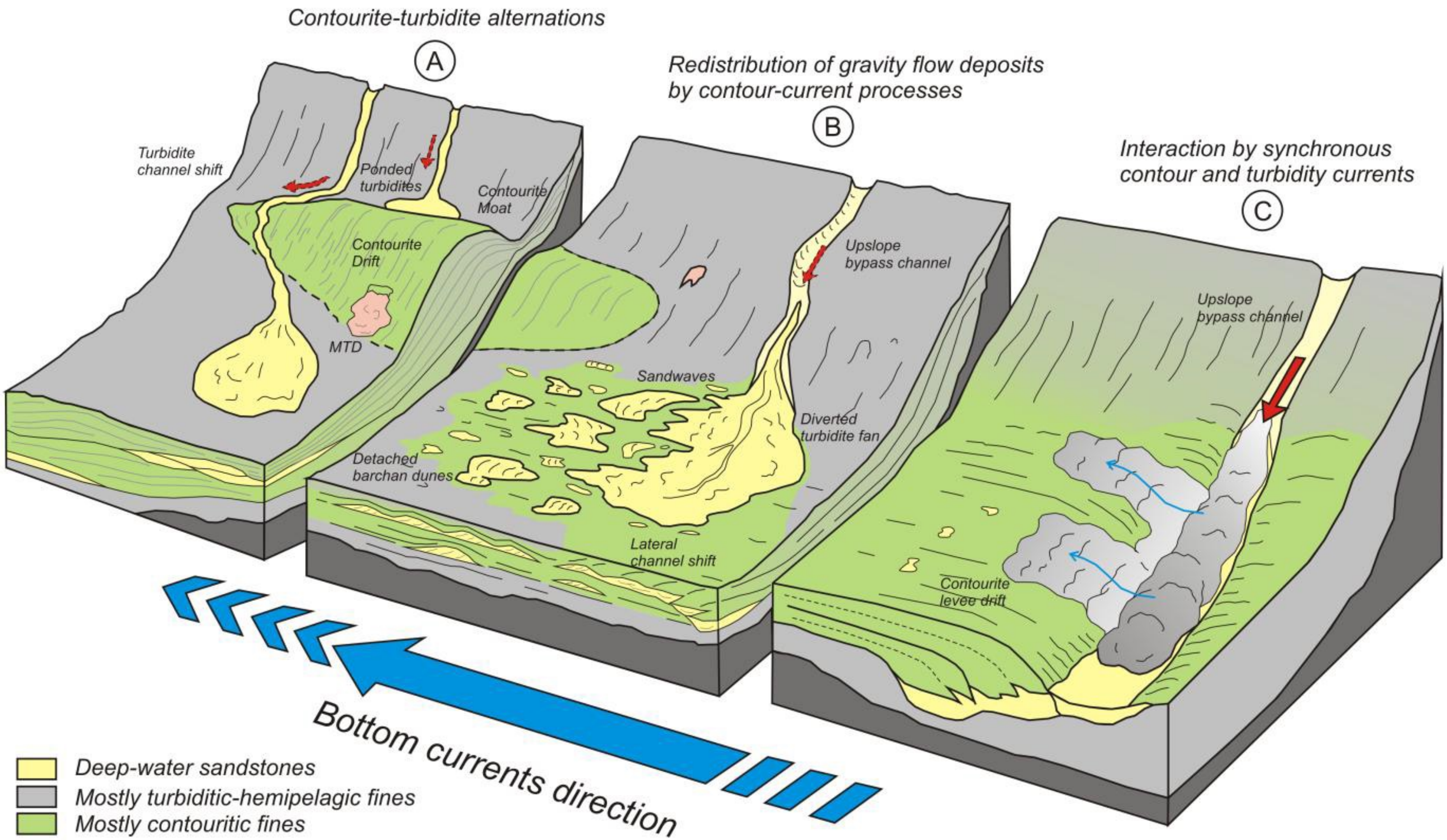
- Introduzione
- Sediment drifts
- Sedimentary structures
- Examples form cores
- Facies Model
- Exploration & Production case studies



Rebesco (2005)



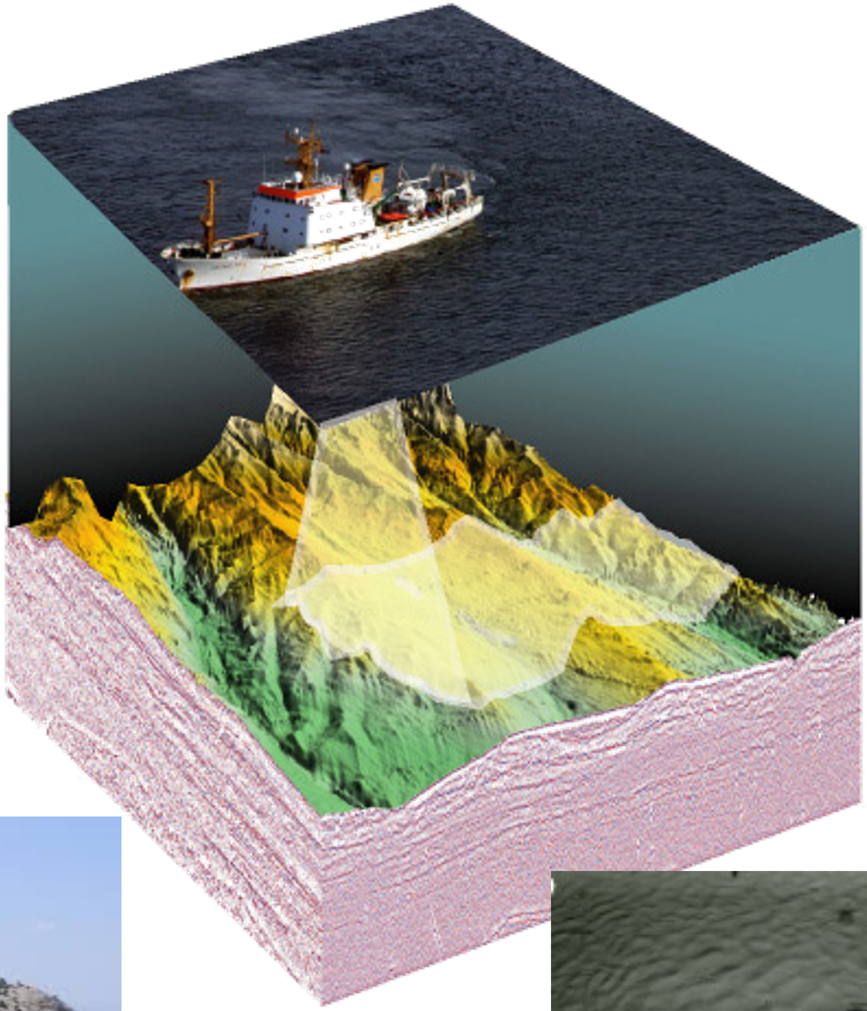
Bottom currents are capable of building thick and extensive accumulations of sediments ("contourite drifts"). Similarly to channel-levee systems generated by turbidity currents, such large bodies normally have a noticeable mounded geometry, which is generally elongated parallel, or lightly oblique to the margin. Besides this, bottom currents and associated processes generate also a wide range of other depositional and erosional or non-depositional structures at different scales.



(Fonnesu et al., 2019)

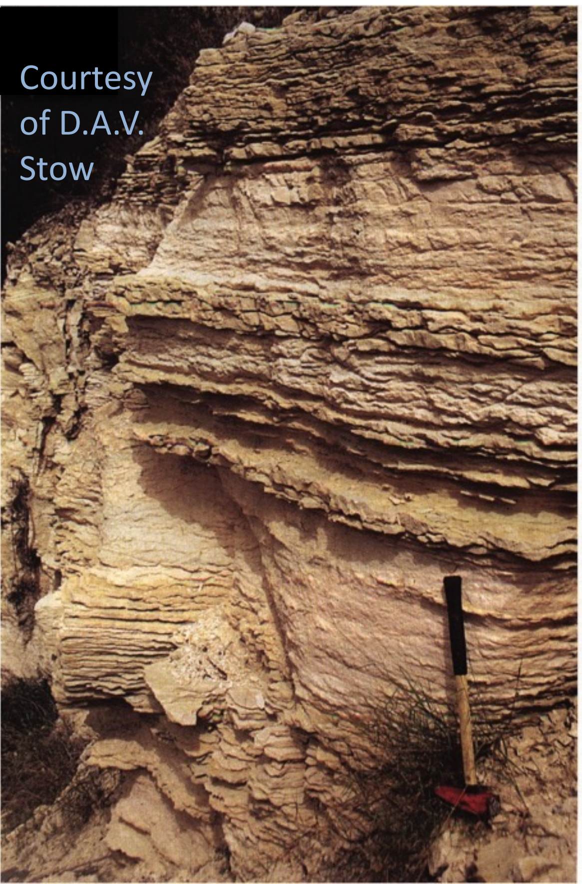
Istituto Nazionale di Oceanografia e di Geofisica Sperimentale

Methods to study contourite deposits

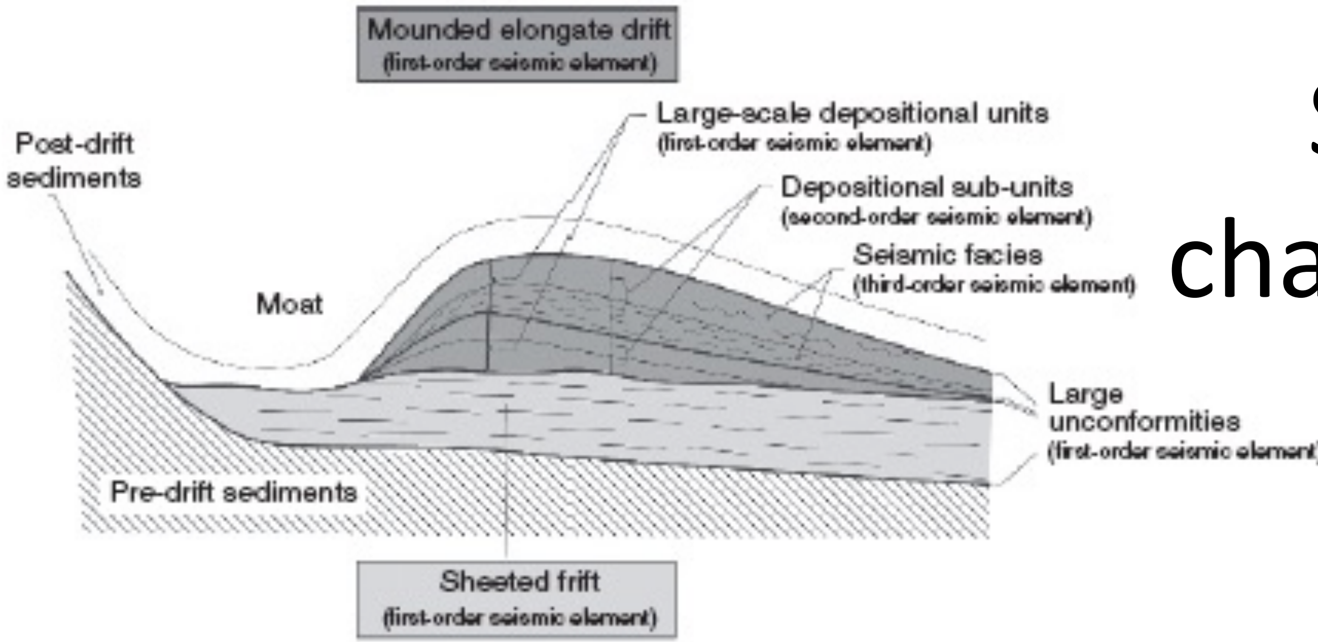


Three scale approach

Diagnostic criteria are their **facies and ichnofacies, texture and sequences, microfacies and composition**. **Sedimentary structures** are also “diagnostic indicators”, but for their interpretation its full context should always be considered. **Medium-scale criteria** (hiatuses and condensed deposits, variation in the thickness, geometry, palaeowater depth, geological context) can be definitive. **Large-scale criteria** (palaeoceanographic features and continental margin reconstructions) are essential, but generally more problematic to apply on outcrops.



Recognizing contourite deposits in ancient sedimentary series presently exposed on land, is a difficult task. The distinction between contourites and reworked turbidites is controversial.



Seismics characteristics

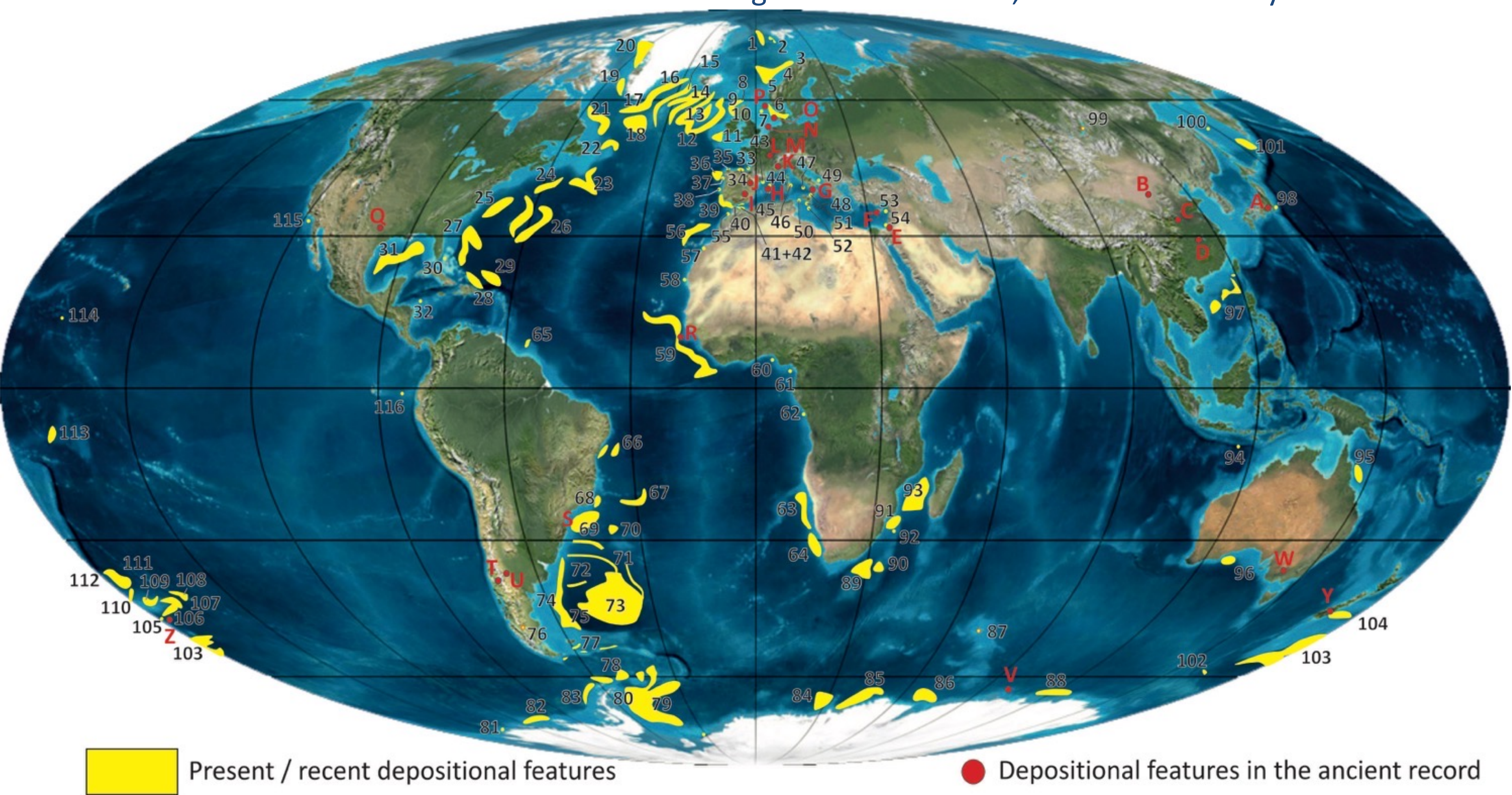
triple-scale approach that involves 3 ''orders of seismic elements''.

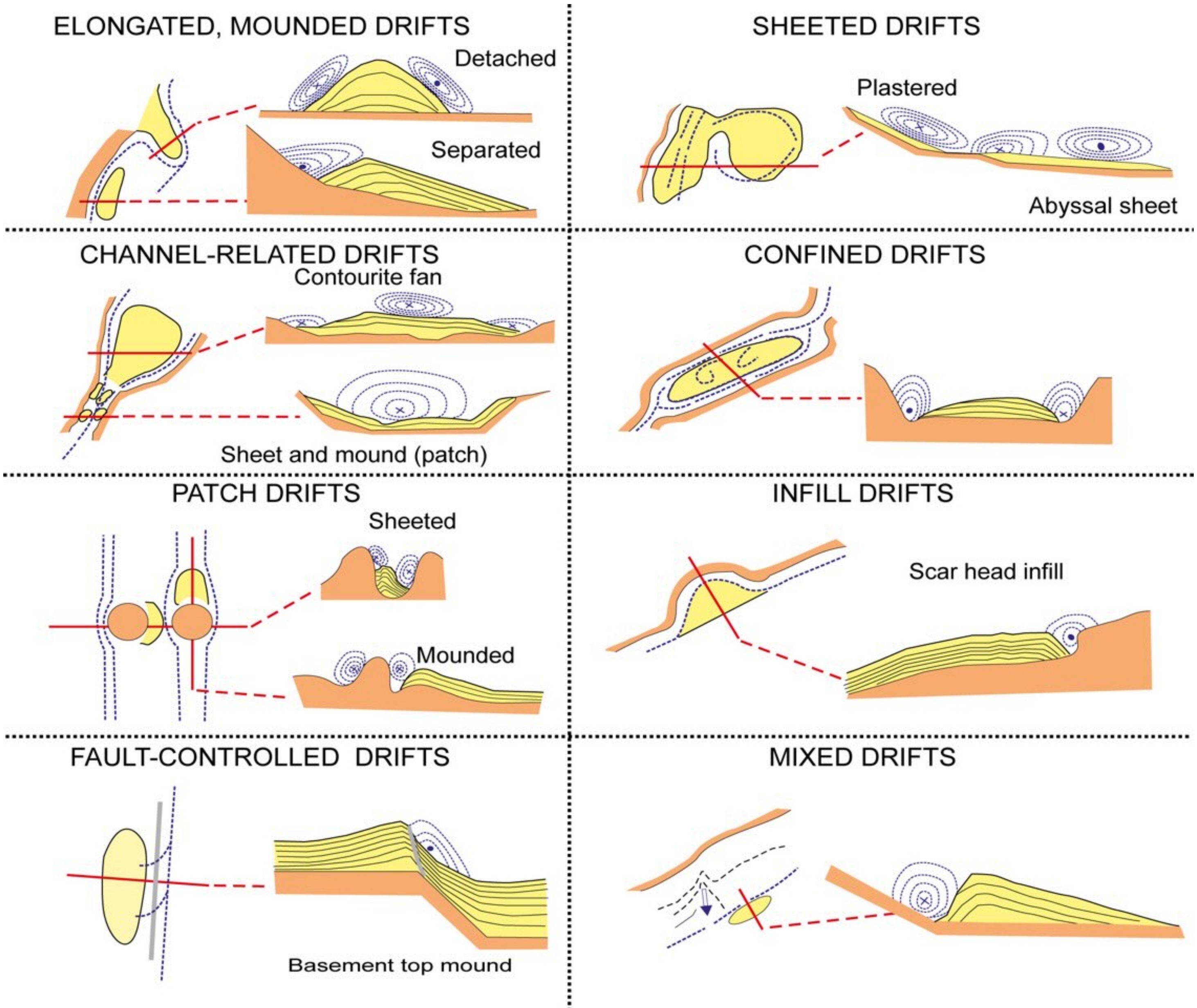
Large scale (overall architecture): I-order elements (major changes in current strength and sediment supply): External geometry, Bounding reflectors, Gross internal character.

Medium scale (internal architecture): II-order seismic elements (reflecting smaller fluctuations): lens-shaped, upward-convex geometry; uniform stacking pattern; down-current migration or aggradation;downlapping reflector terminations

Small scale (internal acoustic character): III-order seismic elements:
facies analysis (continuous, (sub)parallel, wavy, structureless),
and attribute analysis (bedforms).

This updated compilation of **contourite occurrence** was done specifically for the present review, but was subsequently archived and visualised on the Marine Regions website (http://www.marineregions.org). It demonstrates that contourite features are ubiquitous within the oceanic basins (different settings and different water masses from the outer shelf to the abyssal plains. The highest numbers of described large contourite depositional and erosional features are located in the western side of the largest oceanic basins, but not exclusively.

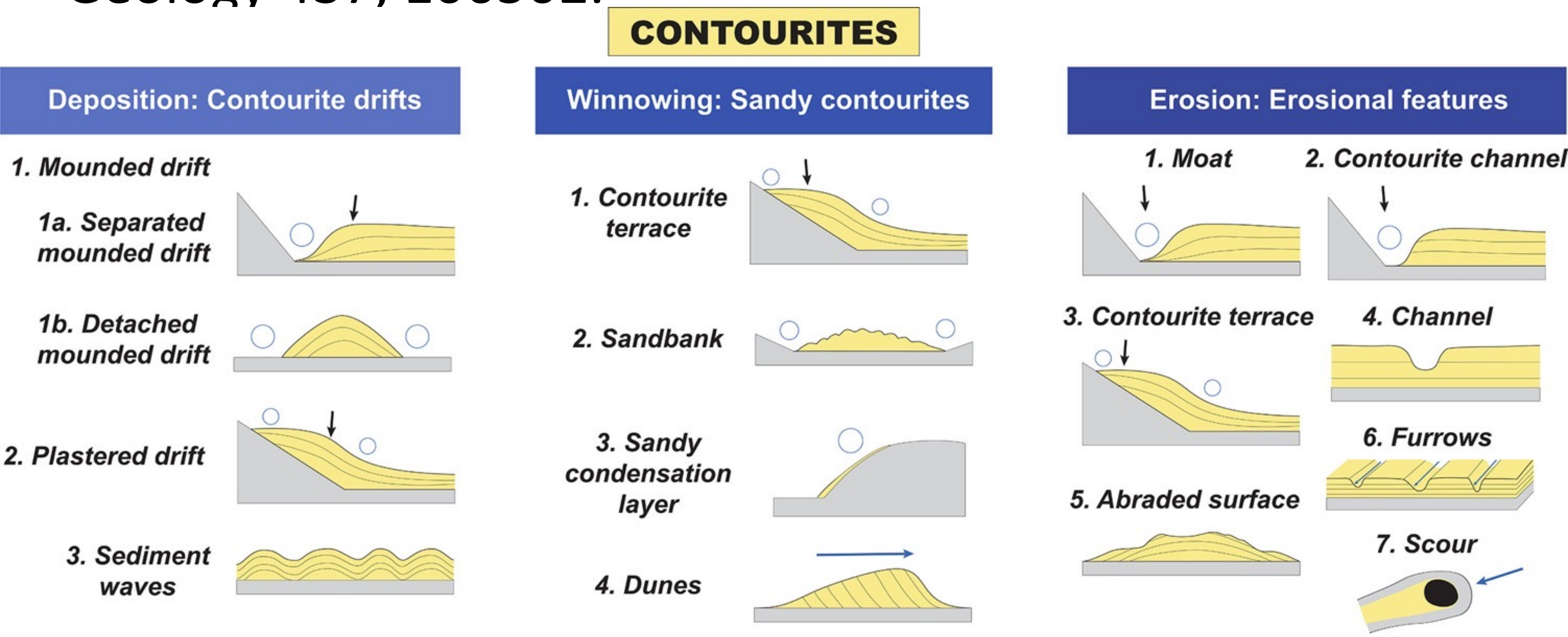




All **contourite drifts** are characterised by a variable degree of mounding and somewhat evident elongation

Sediment drift types and inferred bottom-current paths. From Rebesco (2005) after Stow et al., 2002).

Miramontes et al., 2021. Contourite and mixed turbidite-contourite systems in the Mozambique Channel (SW Indian Ocean): Link between geometry, sediment characteristics and modelled bottom currents. Marine Geology 437, 106502.

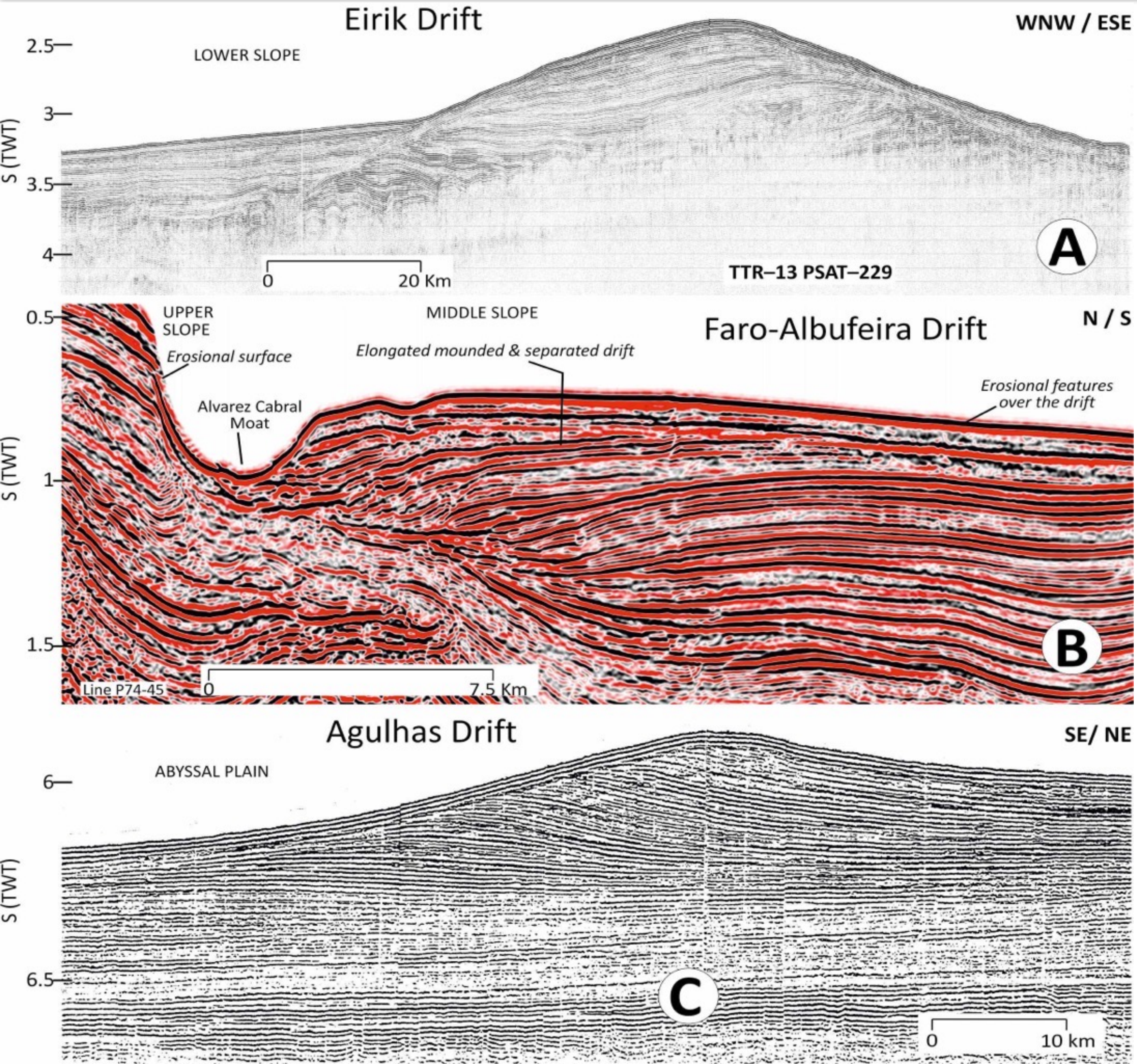


Faurgères and Stow, 2008: Factors controlling drift location, morphology and depositional pattern

Large-scale features of drifts are controlled by a number of interrelated factors, including

(1) the bathymetric framework (water depth and morphological context),
(2) the current conditions (velocity, variability, and Coriolis force),
(3) the sediment supply (amount, type, source, input, variability),
(4) interaction with other depositional processes (in time and space),
(5) sea level and sea-level fluctuations,
(6) climate and climate change,
(7) tectonic setting and activity and
(8) the length of time over which these various processes and controls have operated and varied.

It is not a simple matter to disentangle these various controls as many clearly overlap and are interrelated. Neither is it always certain just what effect a particular control exerts.



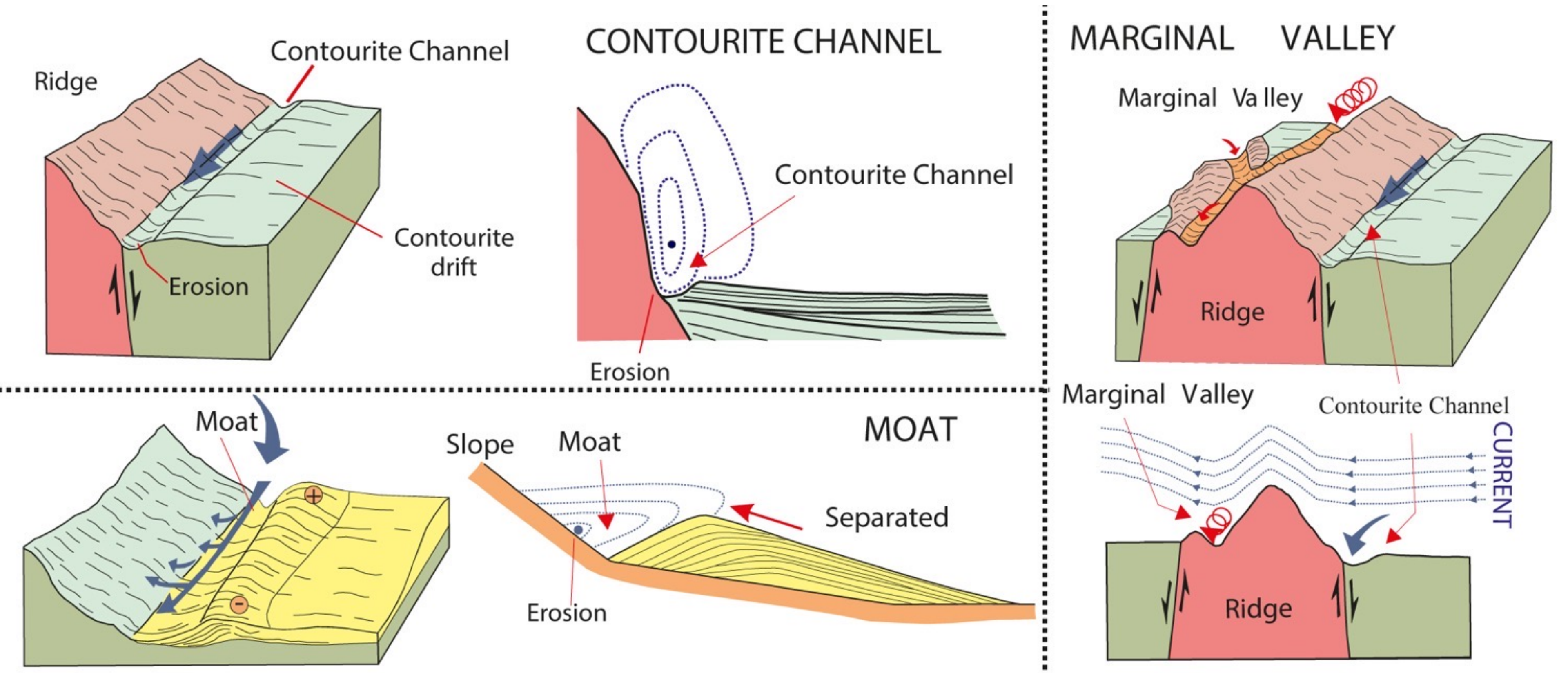
Examples of large contourite drifts:

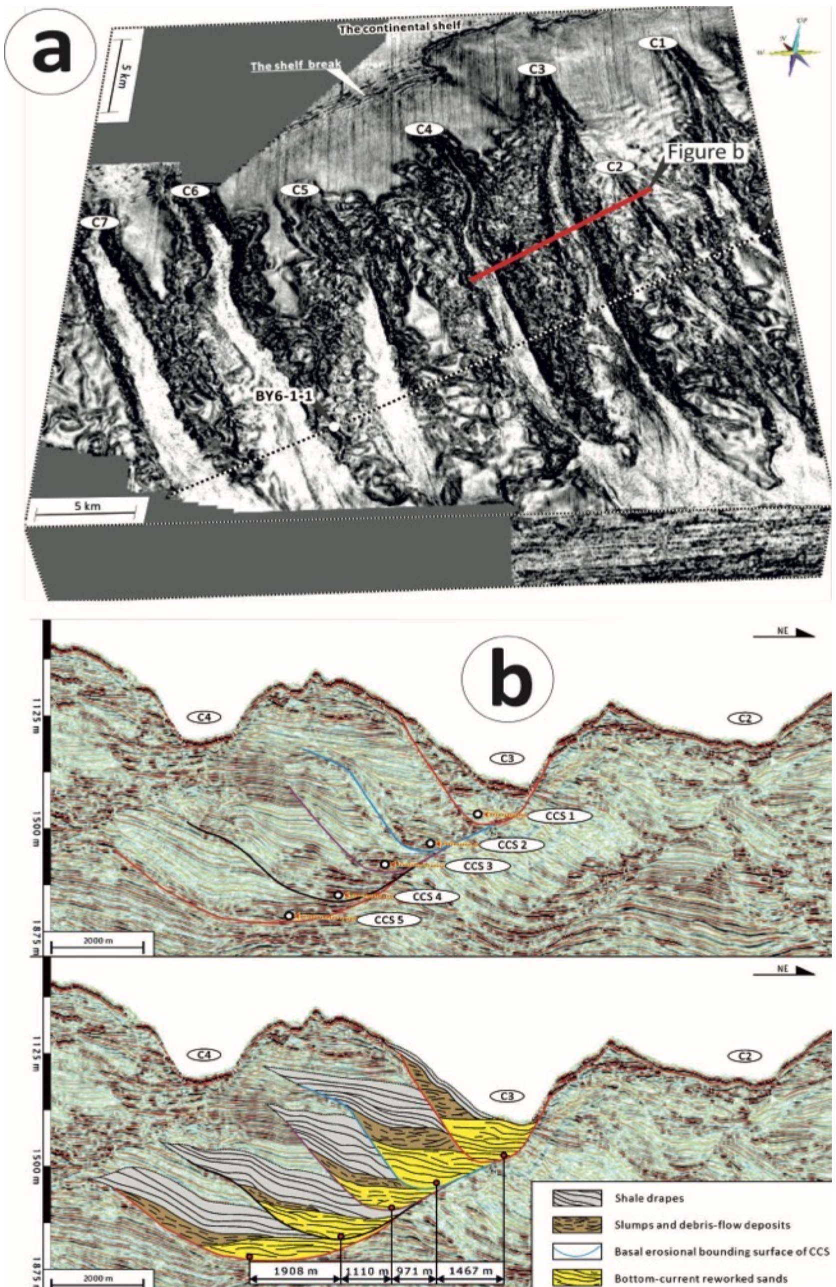
A) Eirik Drift, Greenland margin, northern hemisphere (Hunter et al, 2007);

B) Faro-Albufeira Drift, Gulf of Cádiz margin, northern hemisphere (courtesy of REPSOL Oil);

C) Agulhas Drift, Transkei Basin, southern hemisphere (Niemi et al., 2000).

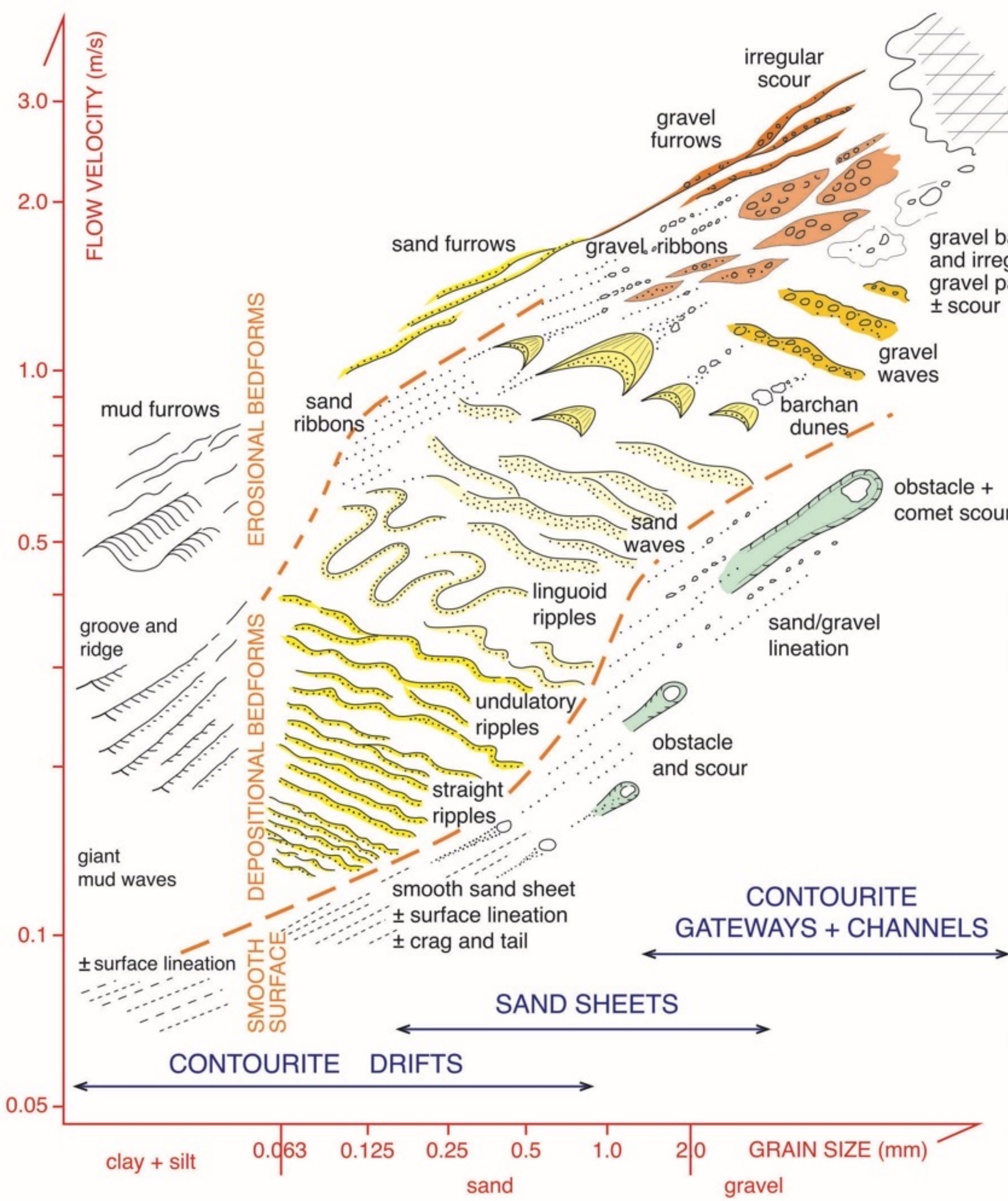
Large-scale **erosional features** are also common in Contourite Depositional Systems, though less studied with respect to depositional ones. Most commonly they occur just in association with contourite drifts, but may also characterize a broad area of continental slopes. We propose here a reconsideration of the only systematic classification of large-scale erosional features attempted so far (Hernández-Molina et al., 2008; García et al., 2009).





Three-dimensional (3D) coherence volume showing unidirectionally migrating deep-water channels (C1 to C7). B) Facies and architecture within unidirectionally migrating deep-water channel 3 (C3). Five channel-complex sets (CCS1 to CCS5), are identified, each of which comprises **bottom-current reworked sands** (BCRS) in the lower part, grading upward into slumps and debris-flow deposits and, finally, into shale drapes. The BCRS are represented by subparallel and high-amplitude reflections with external lens shapes and are systematically nested in the direction of channel migration (Gong et al., 2013; with permission from the AAPG).

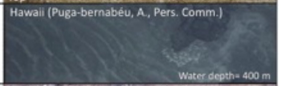
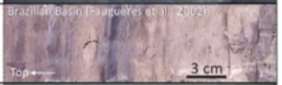
BCRS from previous turbiditic deposits may represent a pragmatic alternative to the application of conventional turbidite concepts, and a new concept for understanding the origin and predicting the distribution of deep-water sandstones. BCRS frequently contain different seismic facies and sedimentary structures.



Various depositional and erosional bedforms are generated by bottom currents. hey are highly variable in terms of sediment composition, morphology and dimension, from decimetres to kilometres. The detection of bedforms can be important for the reconstruction of bottom-current velocity and for geohazard assessment (where velocities can damage seafloor infrastructure, including pipelines and telecommunications cables).

From Stow *et al.*, 2013.

CLASSIFICATION FOR CONTOURITE DEPOSITS

	Type of deposits	Grain size	Characteristics	Sed. Structures	Examples
CLASTIC CONTOURITES	**Muddy contourites**	5 - 11 Ø < 0.31 mm	50 % Clays < 15 % of sands ≤20 -30 % of bioclastic and / or carbonate components Homogeneous & highly bioturbated Poor sorting	Rare laminations Bioturbatiion Indistinct mottled appearance	
CLASTIC CONTOURITES	**Silty contourites**	4 - 8 Ø 0.063-0.004 mm	40 - 60 % Silts Interbedded between muddy & sandy contourites Poor sorting Sharp to irregular tops and bases	Tractive structures (ripples, sed.waves) Bioturbational mottling Ichonofacies	
CLASTIC CONTOURITES	**Sandy contourites**	-1 - 4 Ø 2 - 0.063 mm Normally does not exceed fine sands	Sheeted to wedge beeding Well-sorted deposits, but can be poor to moderate Mixed siliciclastic / biogenic composition Heavy mineral concentration Both positive & negative grading Gradational or erosive contacts	Tractive sturctures (e.g.: horizontal lamination, cross-lamination, ripples, etc) Bioturbation (sub.vertical burrows) Massive layers (structureless) Erosional or gradational contacts	
CLASTIC CONTOURITES	*Bottom current reworked sands (BCRS)*		From previous turbiditic deposits Rhytmic layers Lenticular bedding Well sorted Coarsening upward sequences Sharp to gradational bottom contact and sharp (nonerosiona) upper contactl	Tractive sturctures (e.g.: horizontal lamination, low-angle cross lamination; mud-offshoots in ripples, mud-drapes, flaser, etc)	
CLASTIC CONTOURITES	**Gravel contourites**	< -1 Ø > 2 mm	Winnowing & erosion (channels, moats, etc) Irregular layer and lenses Poorly to very poorly sorted	Sandy gravel lag	
VOLCANOCLASTIC CONTOURITES		Mud, silt or sands	Similar to the siliciclastic facies Composition is dominated by volcaniclastic material	Similar to the clastic contourites	
SHALE-CLASTS OR SHALE-CHIP LAYERS		Shale clasts generally mm in size	Developed in muddy & sandy contourite facies From substrate erosion by strong bottom currents Burrowing on the nondeposition surface	Clats axes sub-parallel both to beeding and to the current direction	
CALCAREOUS CONTOURITES	**Calcareous muddy & silty contourites**	> 4 Ø < 0.063 mm Silty clay to clavey silts	>70 % of bioclastic and / or carbonate components Dominant biogenic input Poorly sorted Distint sand-size fractions (biogenic particles) Composition: pelagic to hemipelagic, including nannofossils & foraminifers as dominat elements Admixture of siliciclastic or volcanicclastic material	Bedding is indistint, but may be enhanced by cyclic variations in composition / grain size. Bioturbation	
CALCAREOUS CONTOURITES	**Calcareous sandy contourites**	-1 - 4 Ø 2 - 0.063 mm Sands	Equivalent of sandy contourites Both well-sorted to poorly sorted Particles from pelagic, benthic, off-shelf & off-reef sources Admixture of siliciclastic, volcanic & silicieous material	Thin-bedded cross-laminated foraminera contourite. Lenticularity Hardgrounds.non de`positional surfaces Bioturbation & burrowing	
CALCAREOUS CONTOURITES	**Calcareous gravel lag contourites**	< -1 Ø > 2 mm Gravel	Clasts or chips derived from erosion of the subtrate		
SILICEOUS BIOCLASTIC CONTOURITES		Mud, silt or sands	Rich in diatomaceous & radiolarian material	Laminated and / or cross-laminated sands	
CHEMOGENIC CONTOURITES	**Manganíferous contourites**		Manganiferous or ferro-manganiferous horizonts Areas with ferro-manganese nodules & pavements	Bioturbation & burrowing	
CHEMOGENIC CONTOURITES	**Chemogenic gravel-lag contourites**		Deep-water chenoherms (chemical - biogenic precipitates) of metal - carbonate chimneys, mounds & encrustations Winnowed and aligned into chemogenic gravel-lags	Strewn od debris Alineation of gravel-lag	

Stow and Faugères (2008) + BCRS from Shanmugam, 2012

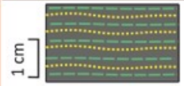
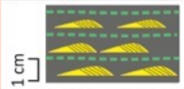
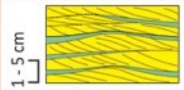
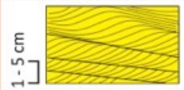
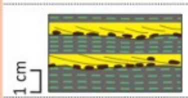
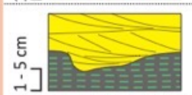
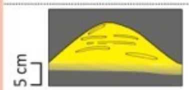
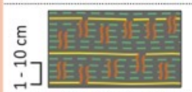
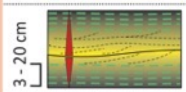
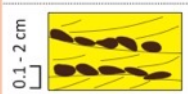
Martín-Chivelet et al., 2008 Traction structures

40 years of controversy
1950s: discovery of current ripples = establishment of the contourite facies
1970s: discovery of fine-grained turbidites = seed of controversy since similar sedimentary structures of contourites.
1980s: concept that bioturbation destroy traction structures = reinterpretion of contour-current deposits as fine-grained turbidites
1990s: few workers provided convincing evidence of traction structures = most workers reject this criterium

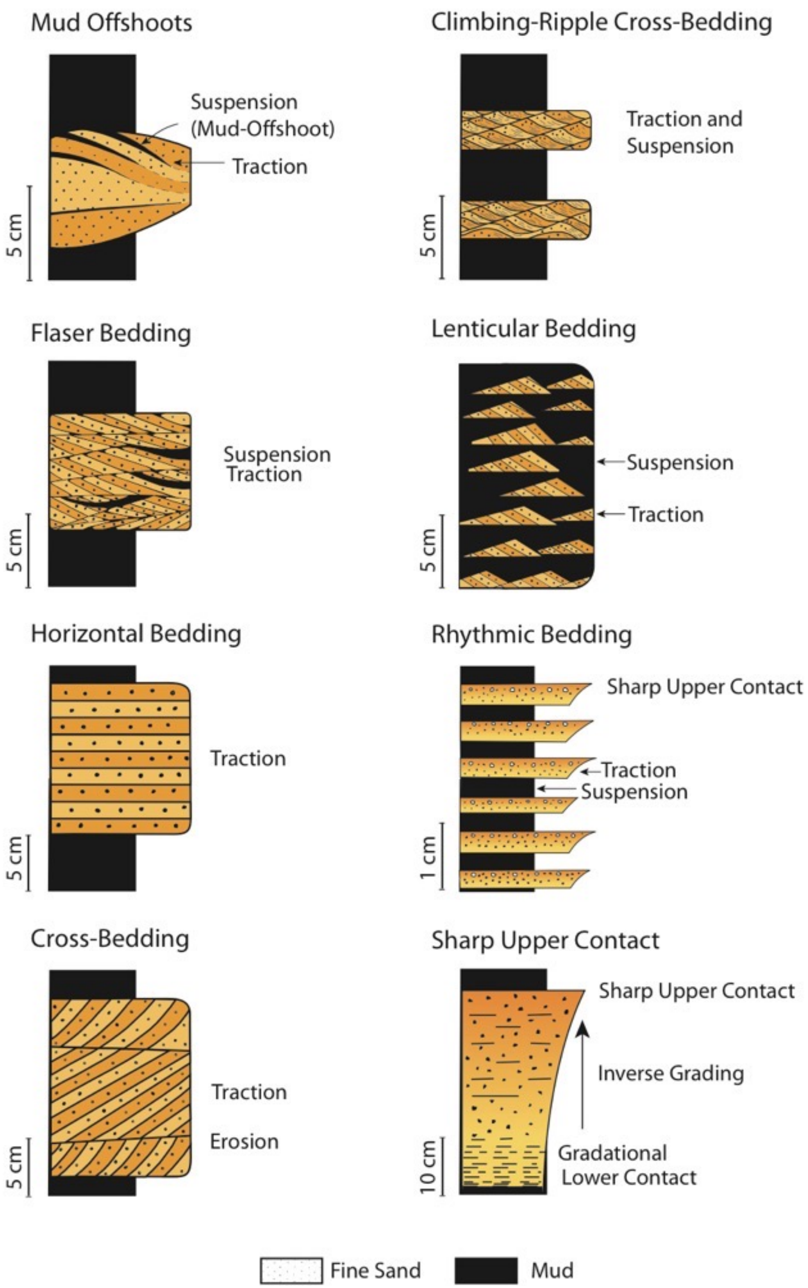
Setting the stage for sedimentary structures in contourites
In the time interval between deposition and significant lithification, burrowing can be sufficiently intense to destroy previous traction structures.
Traction structures are abundant on recent ocean floors.
Traction structures are more abundant and easily preserved in sandy contourites.
Thermohaline circulation in older, greenhouse times, was probably driven by active sinking of saline waters in intertropical seas
studies from boreholes or small outcrops might be biased by partial observation of bedform geometry,internal architecture and lateral arrangement.
turbidity currents are sediment gravity flows contour currents are water flows.

Various **sedimentary structures** have been described for contourites in present and ancient deposits (Martín-Chivelet *et al.*, 2008). However, in areas of intense bioturbation from benthic activity, the preservation potential of some of these structures can be low.

MAIN TYPES OF PRIMARY SEDIMENTARY STRUCTURES IN CONTOURITE DEPOSITS

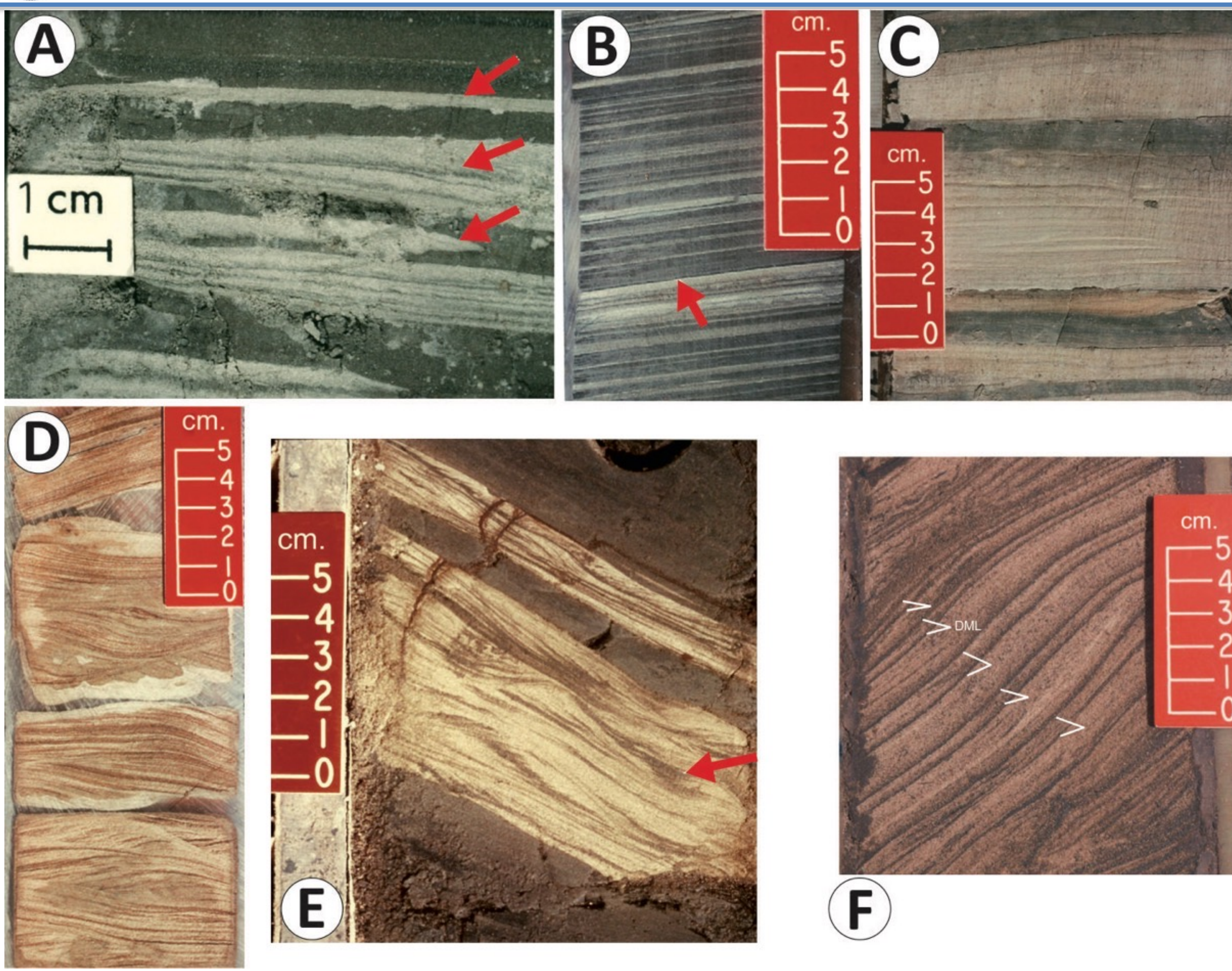
Sketch	Sed. structures	Dominant grain size	Enviromental implications
 1 cm	Horizontal or sinusoidal lamination, stripped, fine-grained deposits; “wispy” lamination	Fine sand, silt & mud < 2 Ø < 0.250 mm	Low current strength Predominance of deposition from suspension
 1 cm	Lenticular bedding starved ripples	Fine sand, silt & mud < 2 Ø < 0.250 mm	Alternating flow conditions, low to moderate current strength, winnowing
 1 cm	Wavy bedding, flaggy chalks	Fine sand, silt & mud < 2 Ø < 0.250 mm	Alternating flow conditions, low to moderate current strength
 1 - 5 cm	Flaser bedding, mud offshoots	Fine sand to silt 8 - 2 Ø 0.004 - 0.250 mm	Alternating flow conditions, Current speed = 10 - 40 cm / s
 1 - 5 cm	Climbing ripples (subcritical to supercritical)	Very fine to medium sands 4 - 1 Ø 0.063 - 0.5 mm	Current speed = 10 - 40 cm / s High suspension load
 10 - 50 cm	Large-scale cross-bedding, megaripples, dunes, sandwaves	Medium sands 2 - 1 Ø 0.250 - 0.5 mm	Current speed = 40 - 200 cm / s Barchan dunes usually form at 40-80 cm / s
 1 cm	Parallel lamination (upper stage plane beds), presence of primary current lamination	Very fine to medium sands 4 - 1 Ø 0.063 - 0.5 mm	Current speed = 40 - 200 cm / s
 1 cm	Minor erosive surfaces, mud rip-up clasts, upper sharp contacts	Sand, silt & mud < -1 Ø < 2 mm	Alternating flow conditions, low to moderate current strength
 1 - 5 cm	Sole marks: flutes, obstacle scours & longitudinal scours, cut & fill structures	Sand, silt & mud < -1 Ø < 2 mm	Flow speed peaks
 5 cm	Longitudinal ripples	Coarse sandy muds (20 % sand)	Low current speed = 2 - 5 cm / s Winnowing
 1 - 10 cm	Bioturbation (strongly variable)	Sand, silt & mud	Low current speed Strong paleoecological control, Low to moderate accumulation rates
 3 - 20 cm	Normal & reverse grading at different scales and within different types of deposits	From coarse sand to mud Usaully fine sand, silt & mud	Gradual changes in flow strength
 0.1 - 2 cm	Pebble lags, furrows	Coarse sand, microconglomerate	Current speed over 200 cm / s

Clay and / or mud | Silt | Sand | Pebbles & cobbles



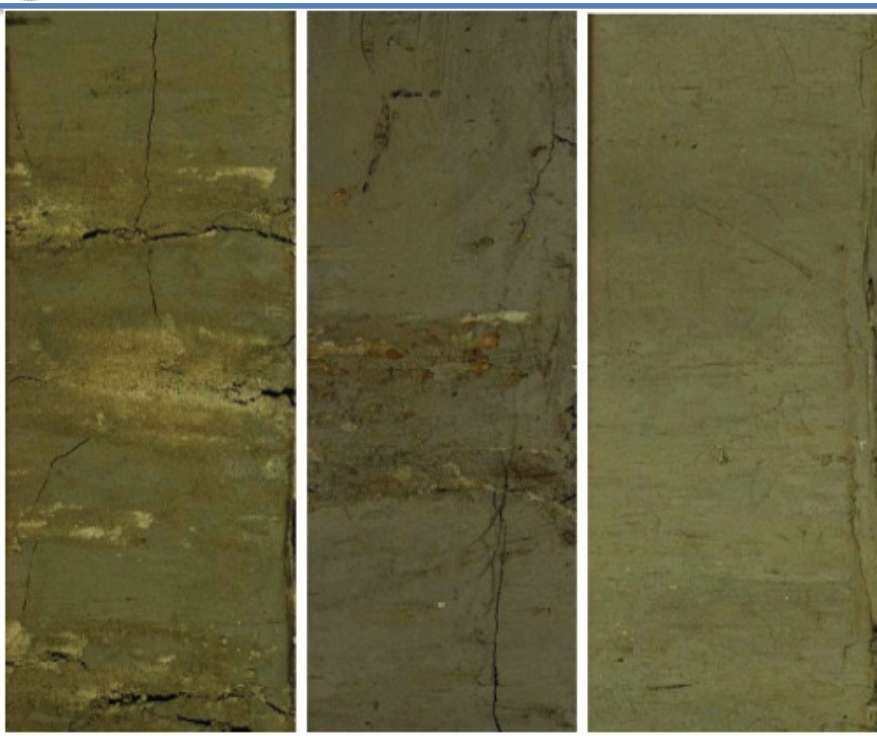
Most of these structures are also present in other deep-water deposits (*e.g.* turbidites), but some have been suggested to be a clear diagnostic feature for bottom-current deposits, such as: *negative grading*; *longitudinal triangular ripples*; and *double mud layers and sigmoidal cross-bedding*, which are unique to deep-water tidal deposits in submarine canyons (Shanmugam, 2006; 2012).

Shanmugam et al., 1993



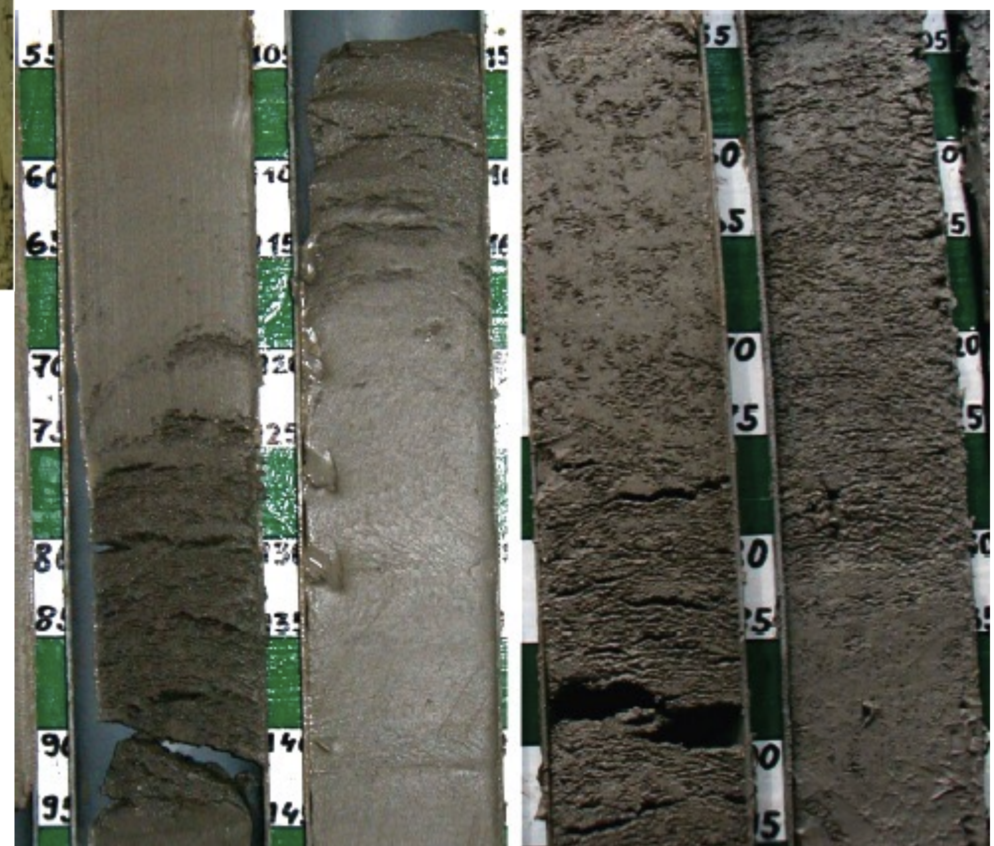
Sedimentary structures in bottom-current reworked sands (BCRS): A) Discrete thin sand layers with sharp upper contacts; B) Rhythmic layers of sand and mud, inverse grading, and sharp upper contacts; C) Horizontal lamination with gradational upper contact; D) Convex-up and concave-up laminae; E) Flaser bedding; and F) Double mud.

Shanmugan, 2008; Shanmugam *et al.*, 1993; Shanmugam, 2012



Stow and Faurgères, 2008: Silty-Muddy contourites

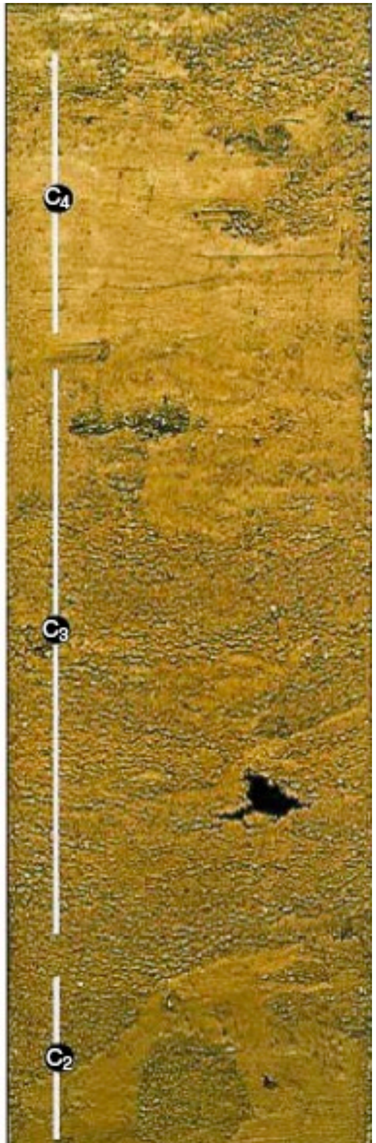
Homogeneous, featureless, poorly bedded units in some cases showing cm-dm banding marked by subtle colour and core logging changes.



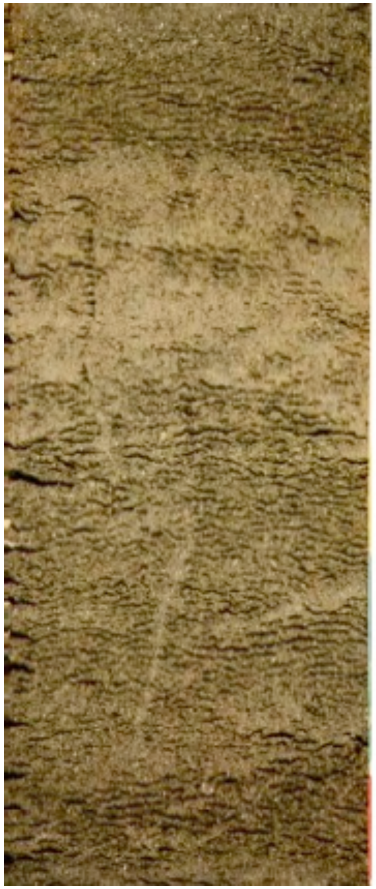
Highly bioturbated (mottled with burrows). Rare primary indistinct lamination (marked by colour change and/or irregular winnowed concentrations of coarser material). Rarely, remnants of thin cross-laminated beds. Silty–clay grain size and poor sorting, with dominantly siliciclastic composition with some biogenic fraction. Either local and far-travelled components

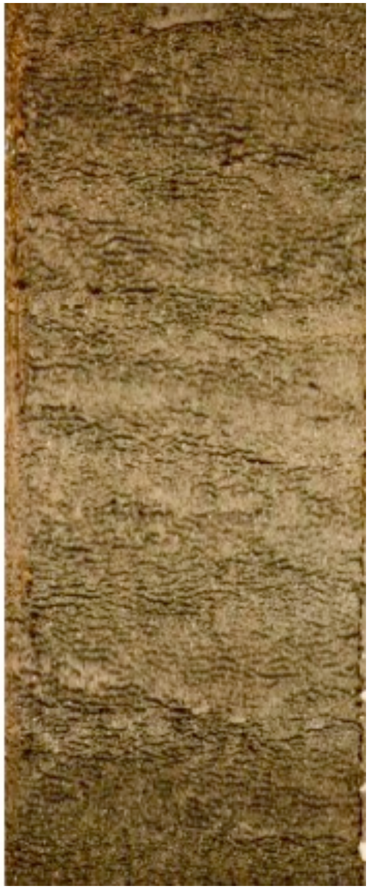
Sandy contourites

Either as thin irregular layers and much thicker units within the finer grained facies, may display either distinct or gradational contacts. Thoroughly bioturbated, appear massive (structureless). The mean grain size normally does not exceed fine sand (apart from coarser grained horizons and lags), and sorting is mostly poor to moderate, in part due to bioturbational mixing.



Both positive and negative grading may be present. A mixed siliciclastic–biogenic composition is typical, with evidence of abrasion, fragmented bioclasts and iron-oxide staining.

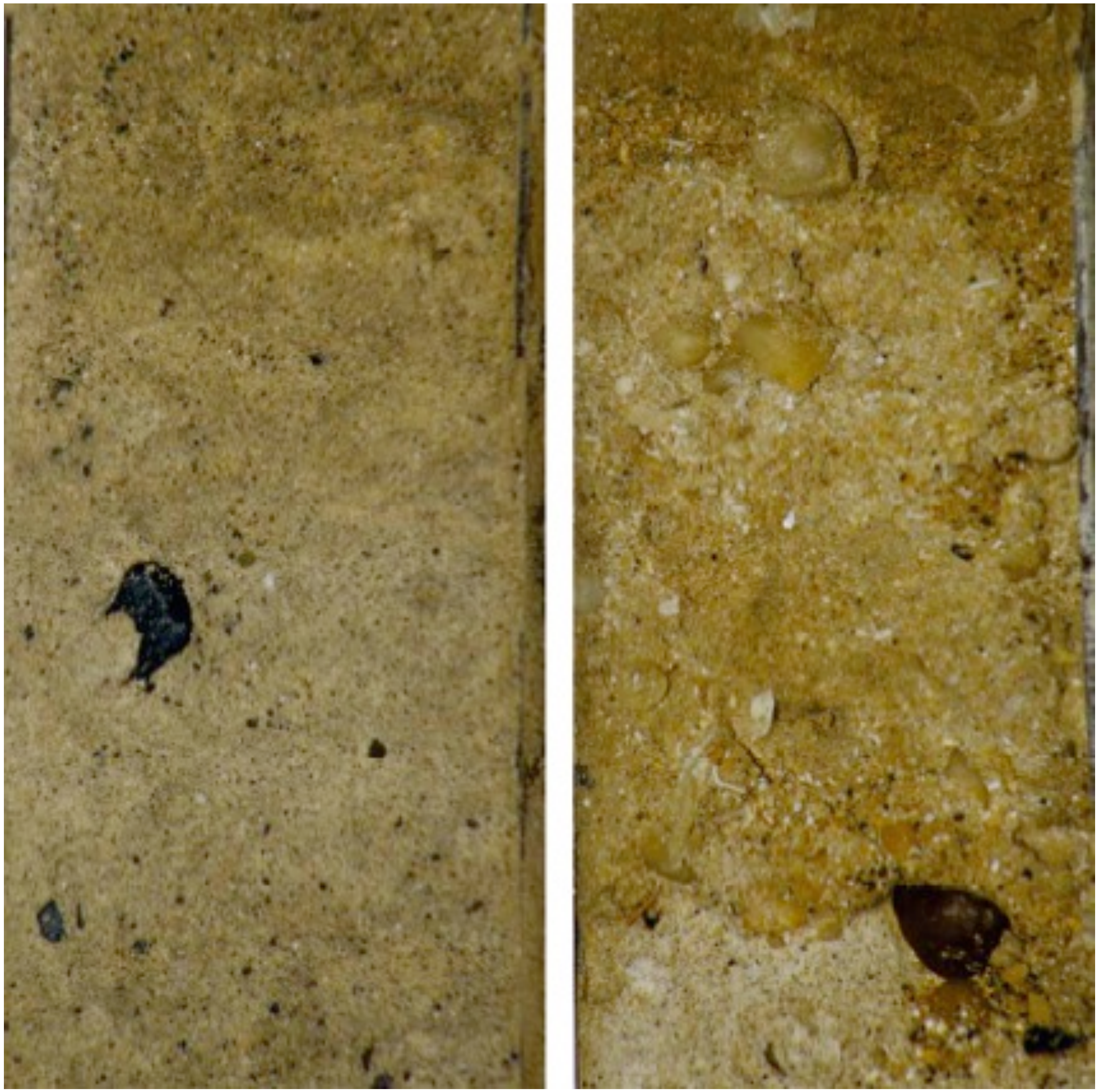




Laminated sandy contourites

Less common than their bioturbated counterparts and have been rarely documented, but do occur where high-energy (high-velocity) bottom currents are especially dominant and larger-scale bedforms (e.g. dunes) are evident on the sea floor. The few examples observed to date are thick to very thick-bedded and distinctly laminated. The lamination is relatively broad and diffuse, enhanced by slight colour variation, and parallel at the scale of the cores, although this may also be part of large-scale cross-bedding. Bioturbation is rare, but large sub-vertical burrows have been noted. The mean grain size is medium-grained sand, with moderately good sorting. The sediment has a mixed siliciclastic/biogenic composition, with evidence of abrasion, fragmented bioclasts and iron-oxide staining.

Gravel-rich contourites and gravel-bearing contourites



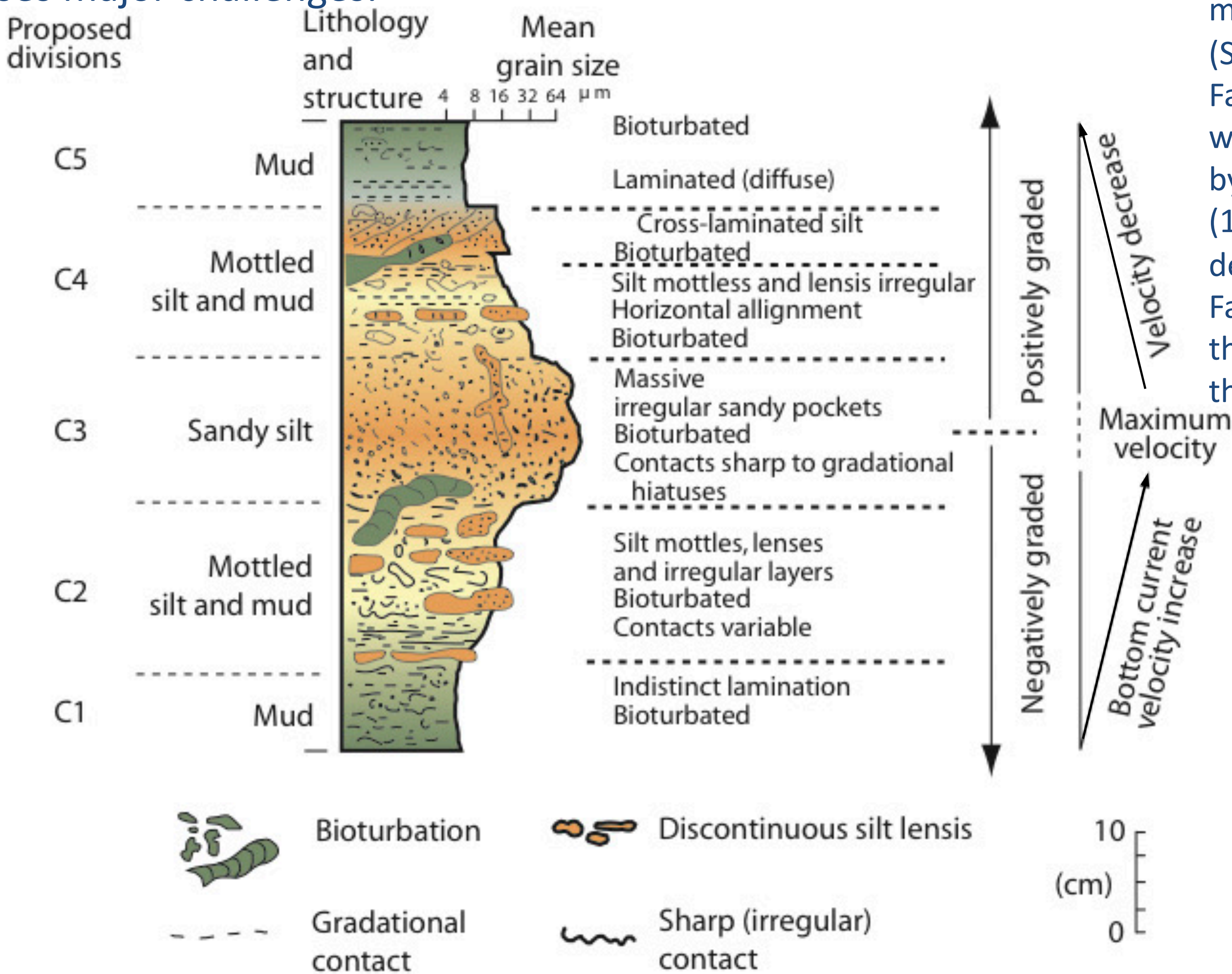
Common in drifts at high latitudes (ice-rafted debris). Under relatively low-velocity currents, IRD remains and is not subsequently reworked. This facies is often indistinguishable from glaciomarine hemipelagites.

Concentration of the coarser fraction occurs under higher-velocity currents and more extensive winnowing, yielding irregular layers and lenses of poorly to very poorly sorted, sandy gravel-lag.

Similar coarse-grained concentrations and gravel pavements are locally developed in response to high-velocity bottom-current activity in shallow straits, narrow contourite moats and passageways.

Break

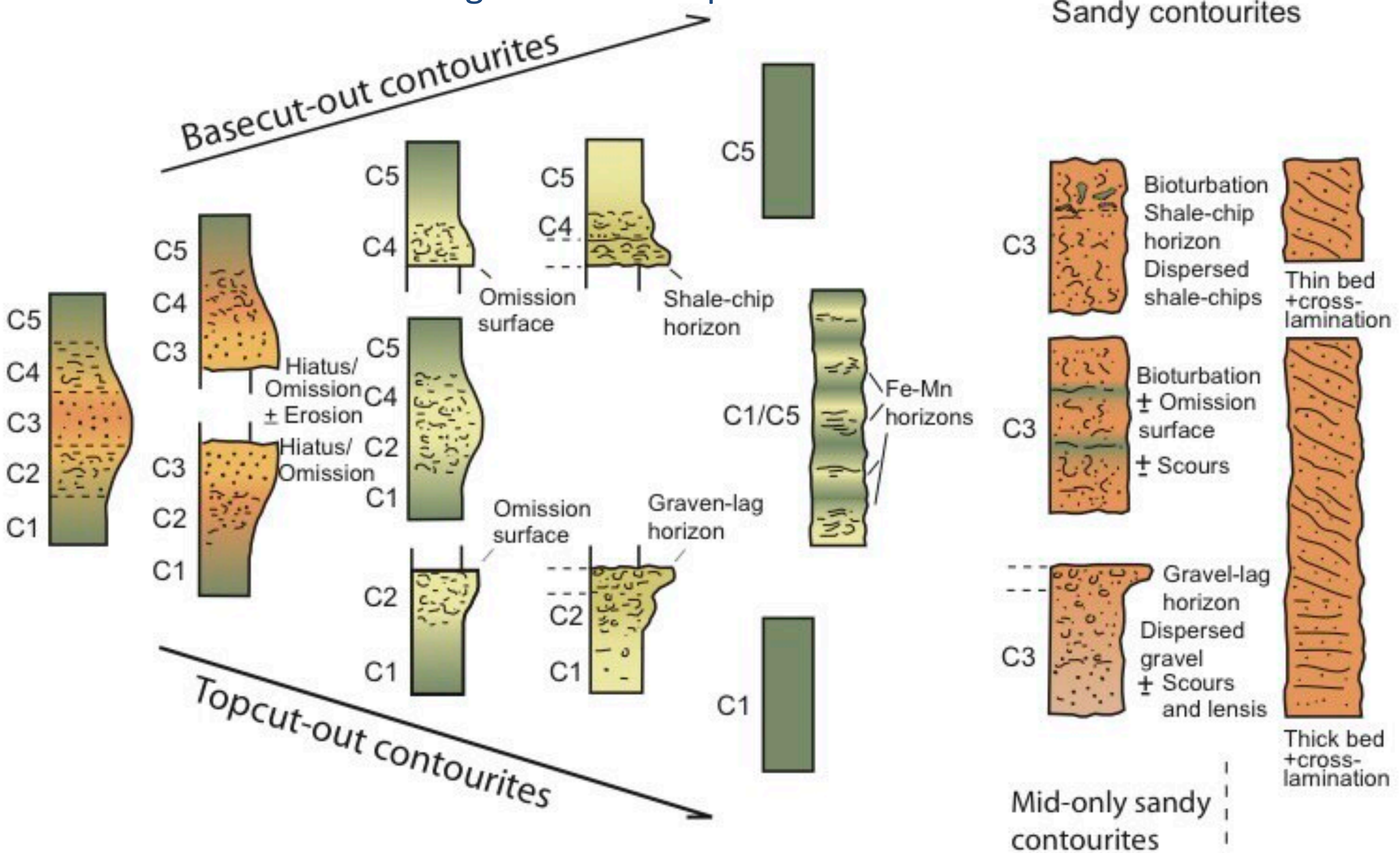
The creation of a definitive **facies model** for contourites poses major challenges.



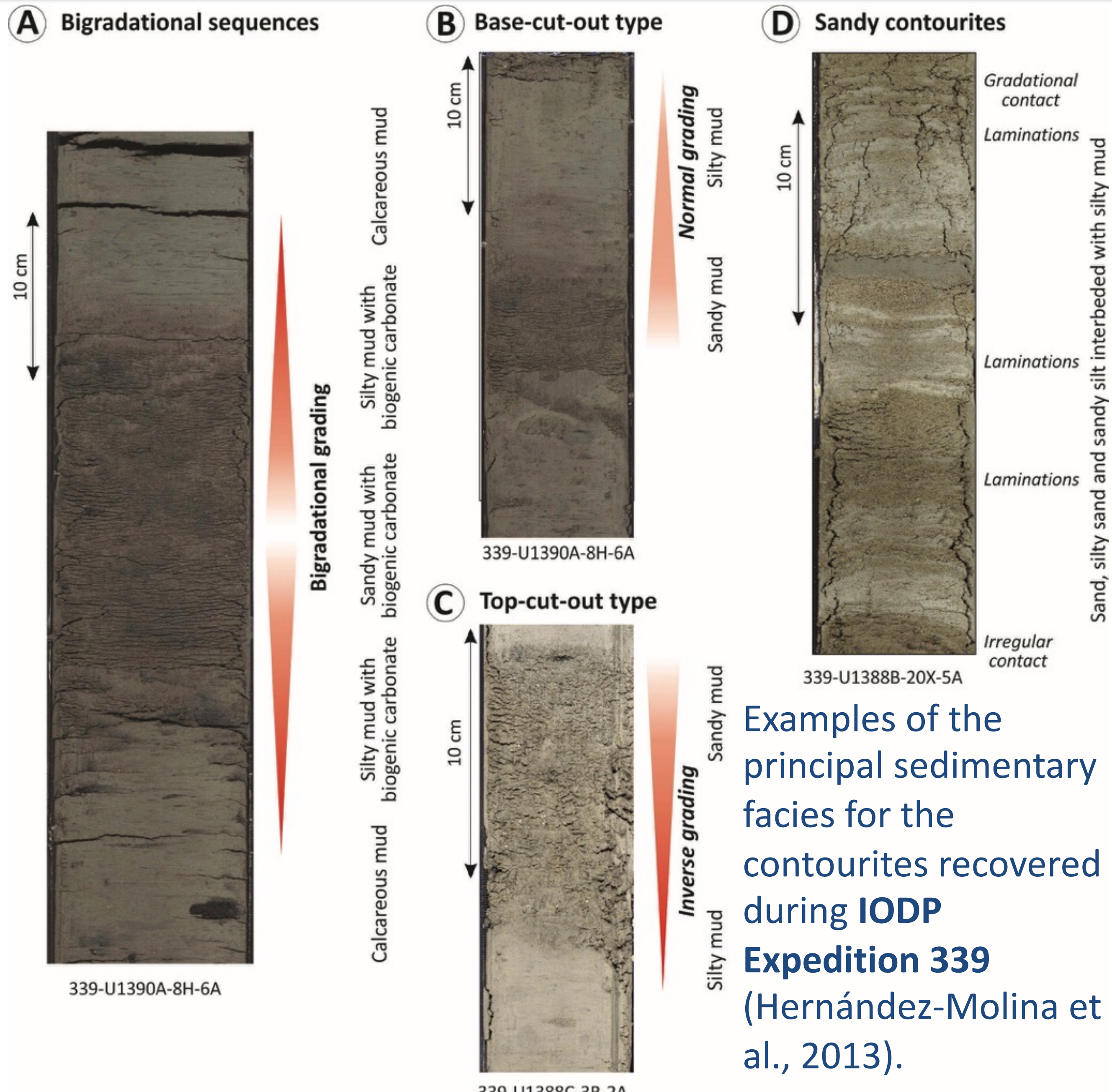
The standard contourite facies model sequence (Stow and Faugères, 2008) was first proposed by Gonthier *et al.* (1984) and was derived from the Faro Drift within the middle slope of the Gulf of Cádiz.

This model implies a cyclic trend, encompassing 3 main facies, linked to variation in contour-current velocity.

Facies and facies sequences associated to contourites vary greatly, making any singular, systematic characterisation of facies rather difficult for the moment. Stow et al. (2002) slightly modified the standard sequence by using five principal divisions (C1–C5), and Stow and Faugères (2008) later proposed a model for partial sequences ,which are equally or more common than the full bi-gradational sequence.



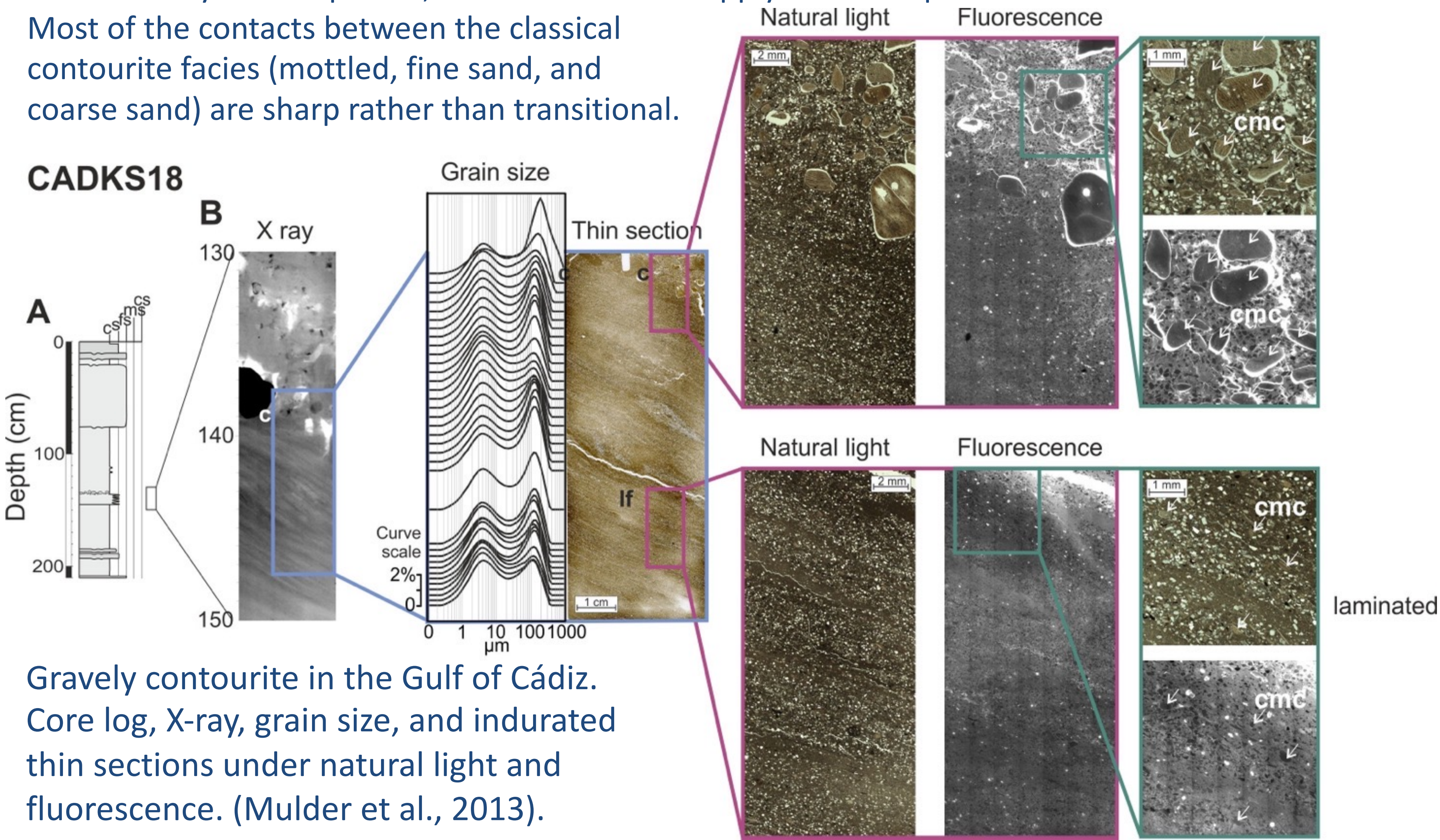
Preliminary results are in agreement with the previously proposed idea that there is a greater variety of facies sequences for bottom current deposits than what is presently represented in the most commonly accepted contourite facies model. Additionally, remarkable interactions between contourite and turbidite processes have been reported that are completely new and different from the current facies models.



Examples of the principal sedimentary facies for the contourites recovered during **IODP Expedition 339** (Hernández-Molina et al., 2013).

The main criticism for considering the Faro Drift deposits as the standard contourites facies sequence relates to two facts: this drift is predominantly muddy, and it is located in the distal part of a huge CDS. Moreover, other facies in other parts of the same depositional system have recently been reported, but it is difficult to apply the conceptual model to them.

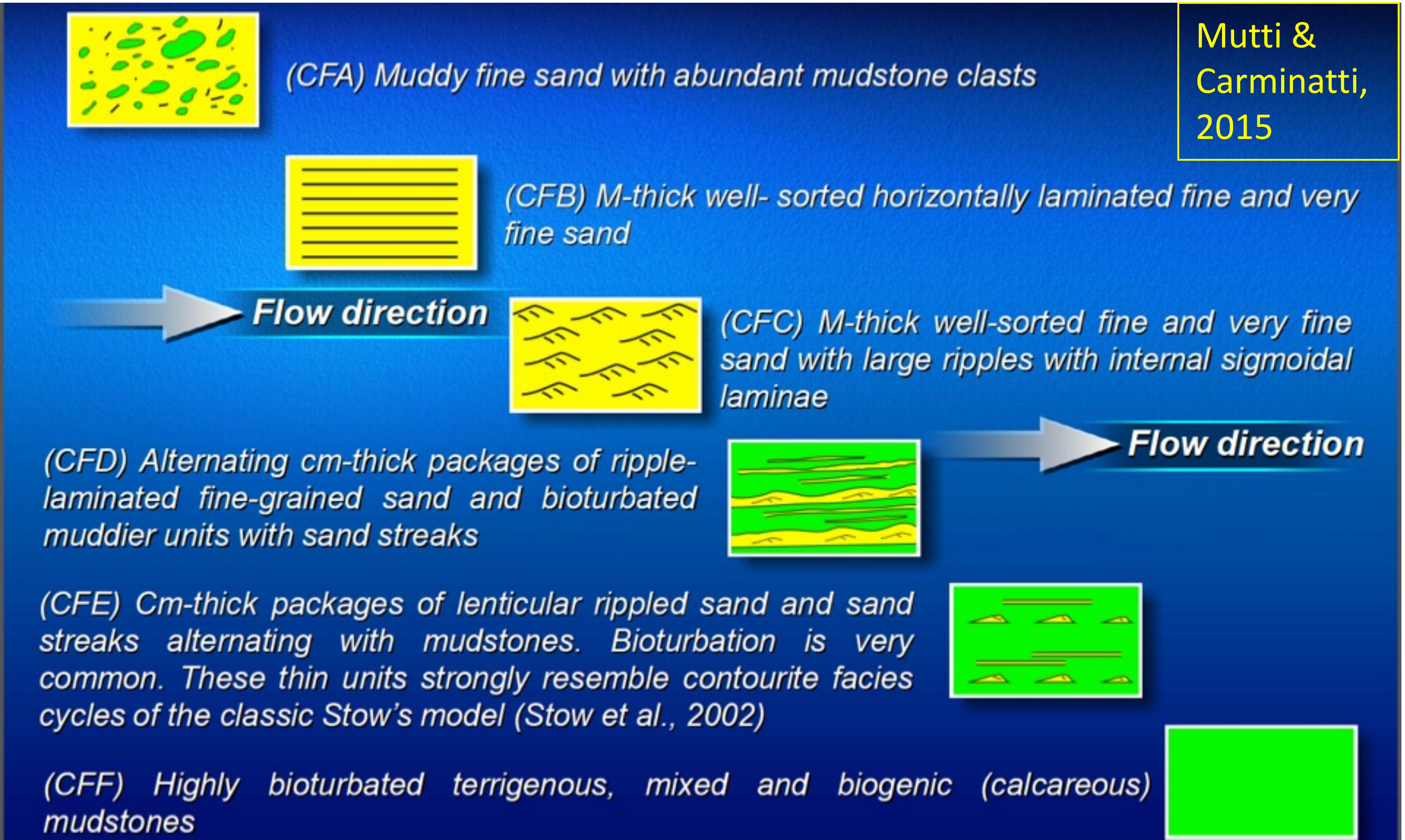
Most of the contacts between the classical contourite facies (mottled, fine sand, and coarse sand) are sharp rather than transitional.



Gravely contourite in the Gulf of Cádiz. Core log, X-ray, grain size, and indurated thin sections under natural light and fluorescence. (Mulder et al., 2013).

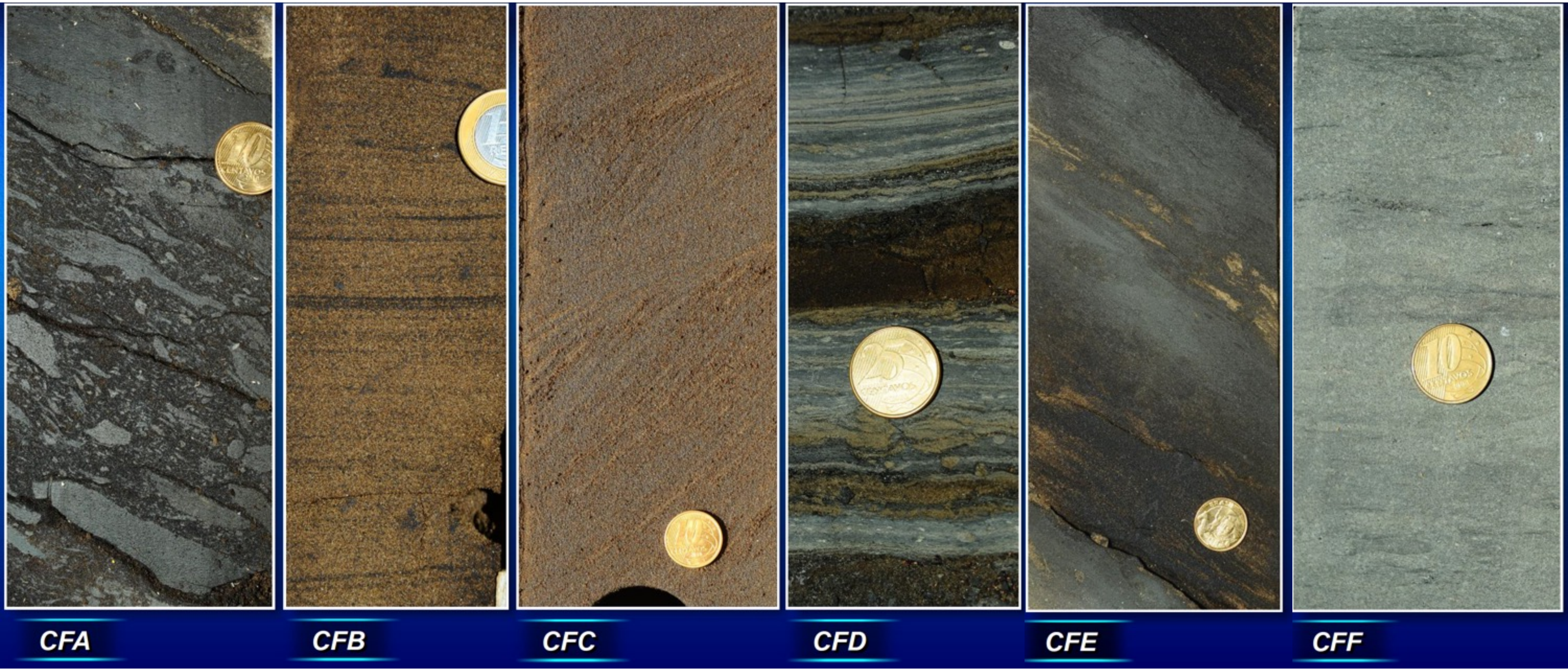
Preliminary contourite facies tract (?)

In the Campos Basin, bottom currents played a major role since late Cretaceous in reworking and redistributing turbidite fine sands derived from basin margins.



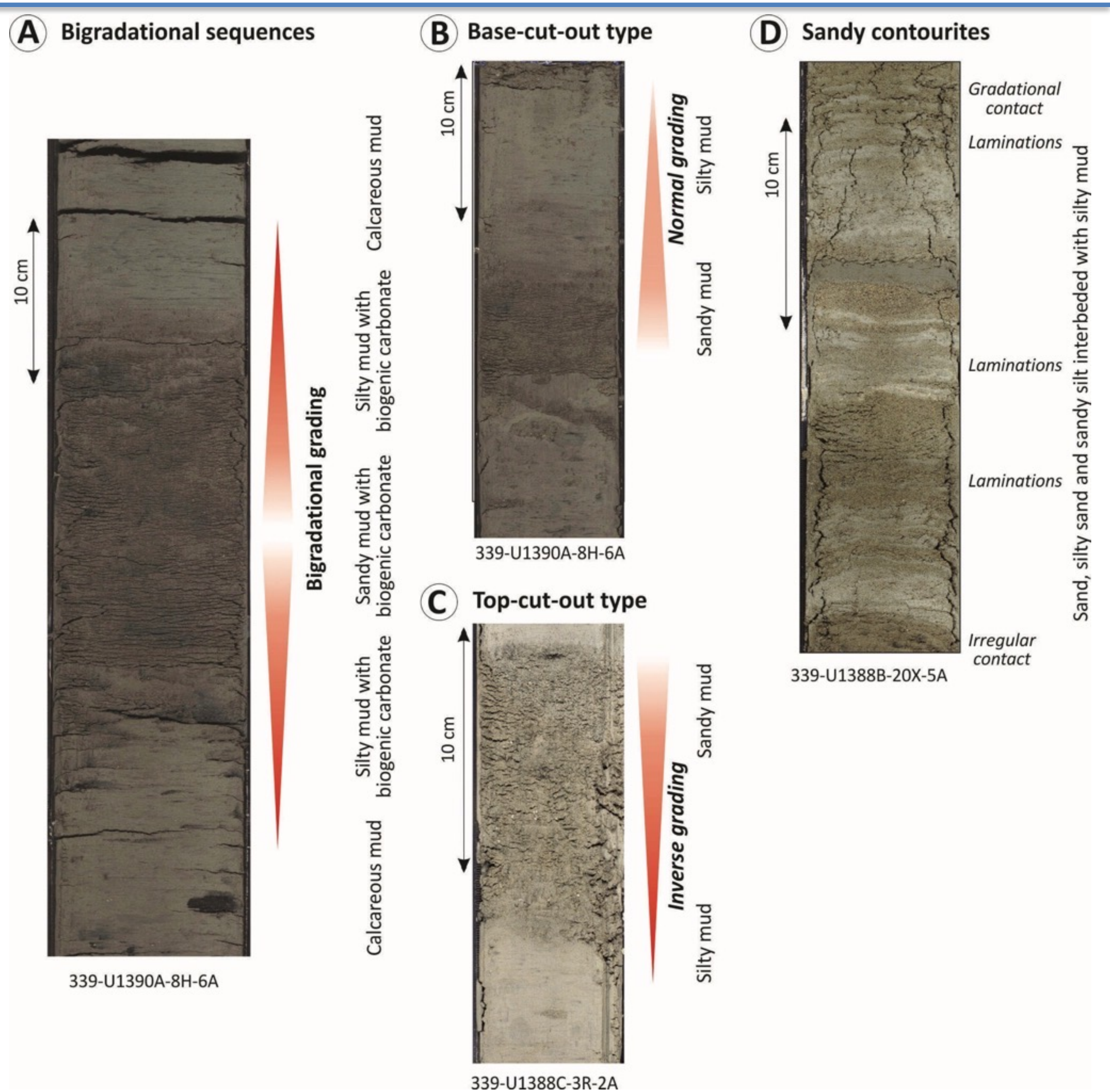
Currently available models for deep-water sedimentation are inadequate to describe and interpret the complexity of depositional patterns developed by the interaction of bottom currents and sediment gravity flows.

Photos of Contourite Facies A-F



Mutti & Carminatti, 2015

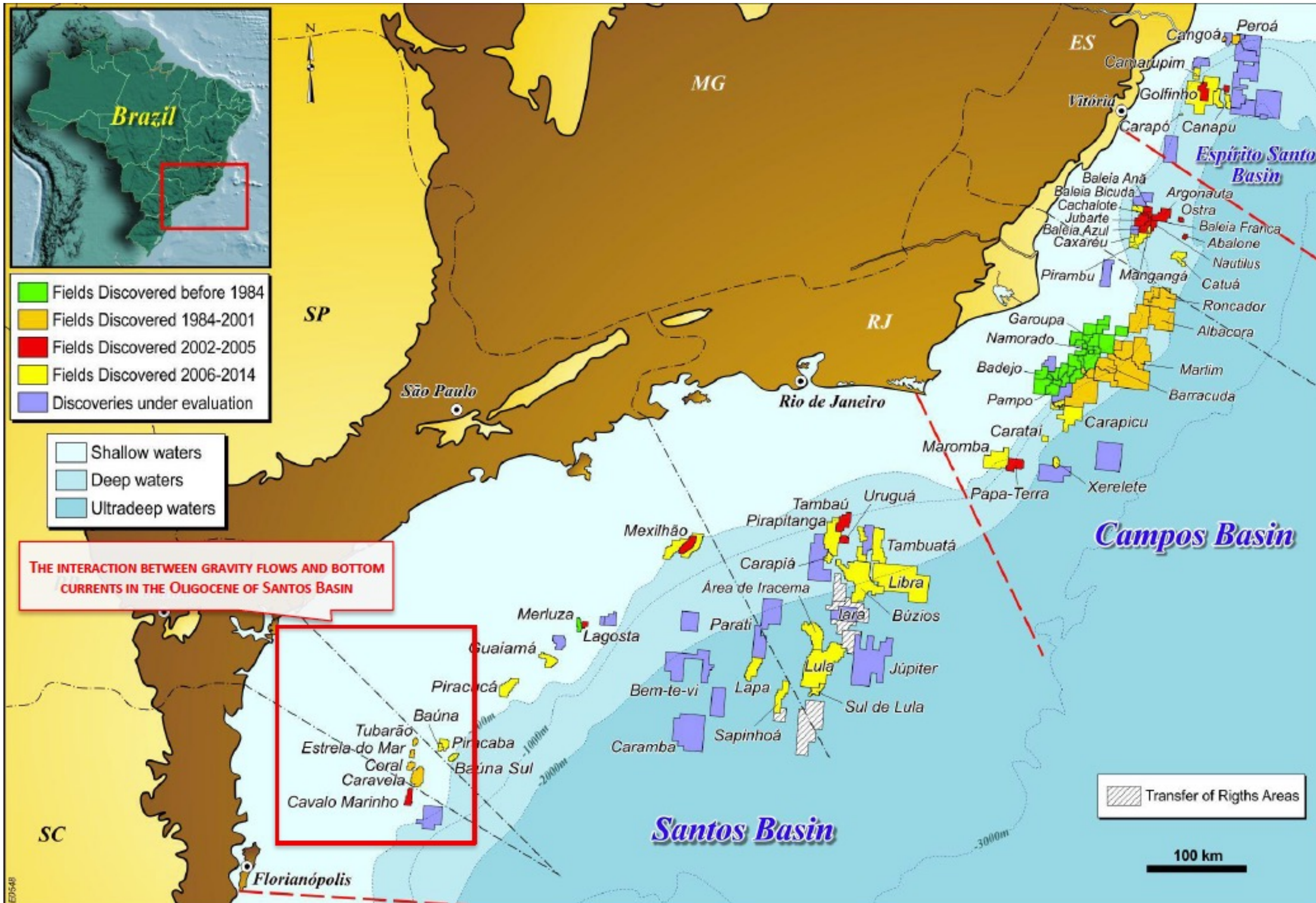
Examples of the principal sedimentary facies for the contourites recovered during **IODP Expedition 339** (Hernández-Molina et al., 2013).
Preliminary results are in agreement with the previously proposed idea that there is a greater variety of facies sequences for bottom current deposits than what is presently represented in the most commonly accepted contourite facies model. Additionally, remarkable interactions between contourite and turbidite processes have been reported that are completely new and different from the current facies models.



E & P case study: Santos Basin
Location map

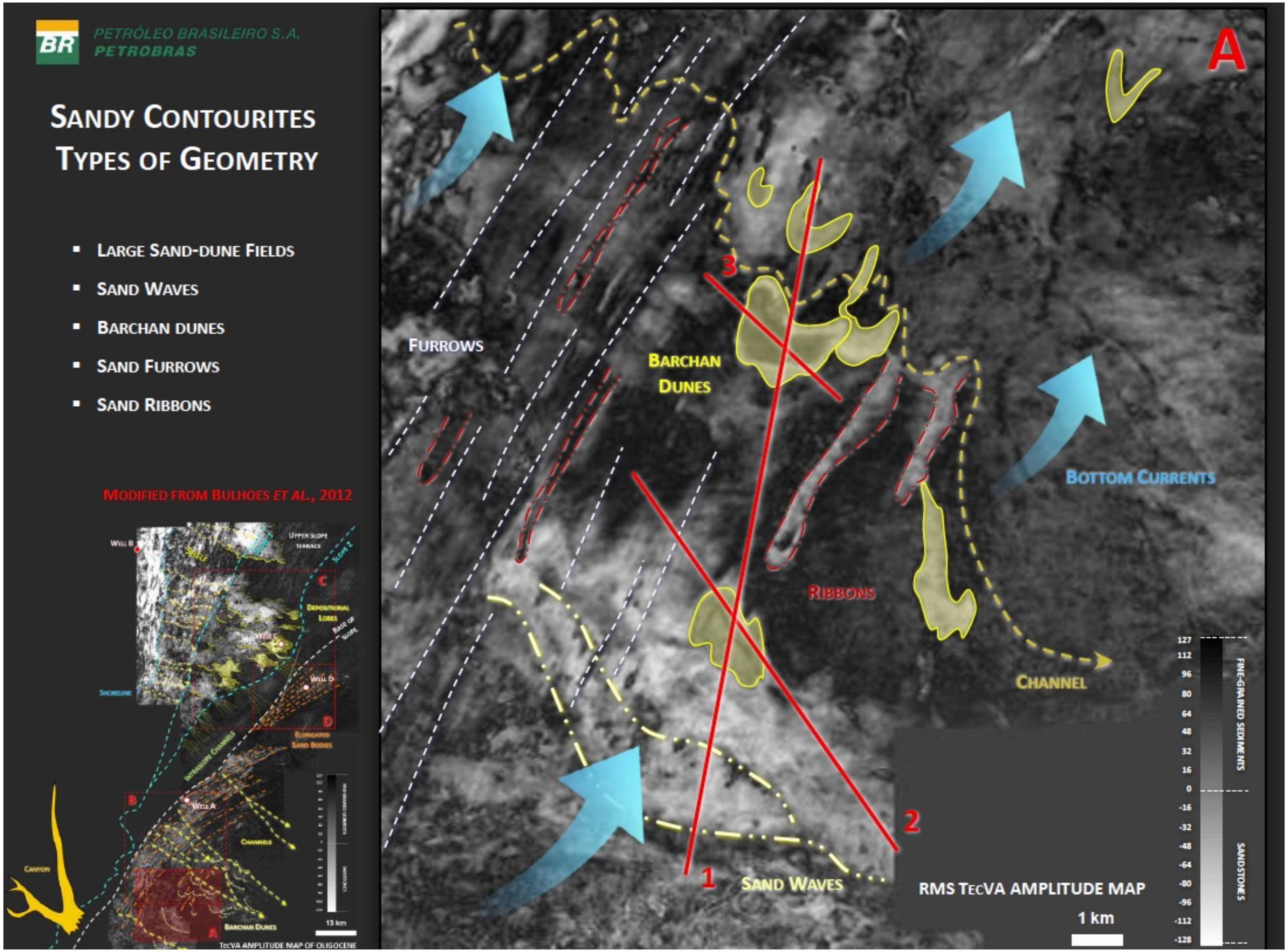
Location map of Santos Basin within Brazilian Margin where sediment transported in suspension by turbidity currents was removed by bottom currents resuting in Contourites and Turbidites which are highly prolific oil reservoirs

(Mutti et al., 2014)



Santos Basin sandy contourites

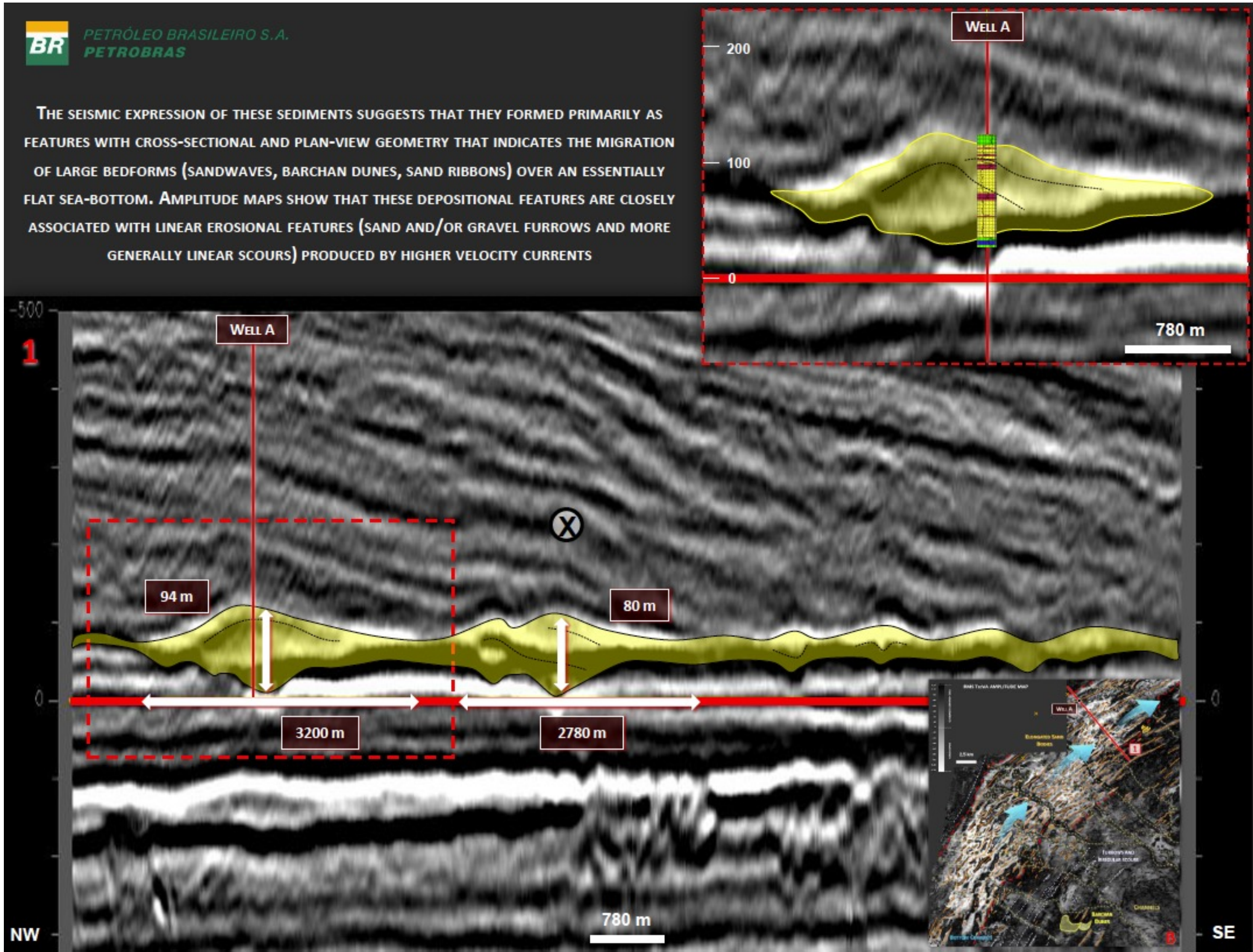
Example of barchan dunes, sand waves, sand furrows and ribbons in plan view: evidence of bottom current action



(Mutti et al., 2014)

Santos Basin: seismic section through sandy contourites

Seimic section showing that these large bedforms migrated on a flat sea-bottom under the action of high velocity bottom currents

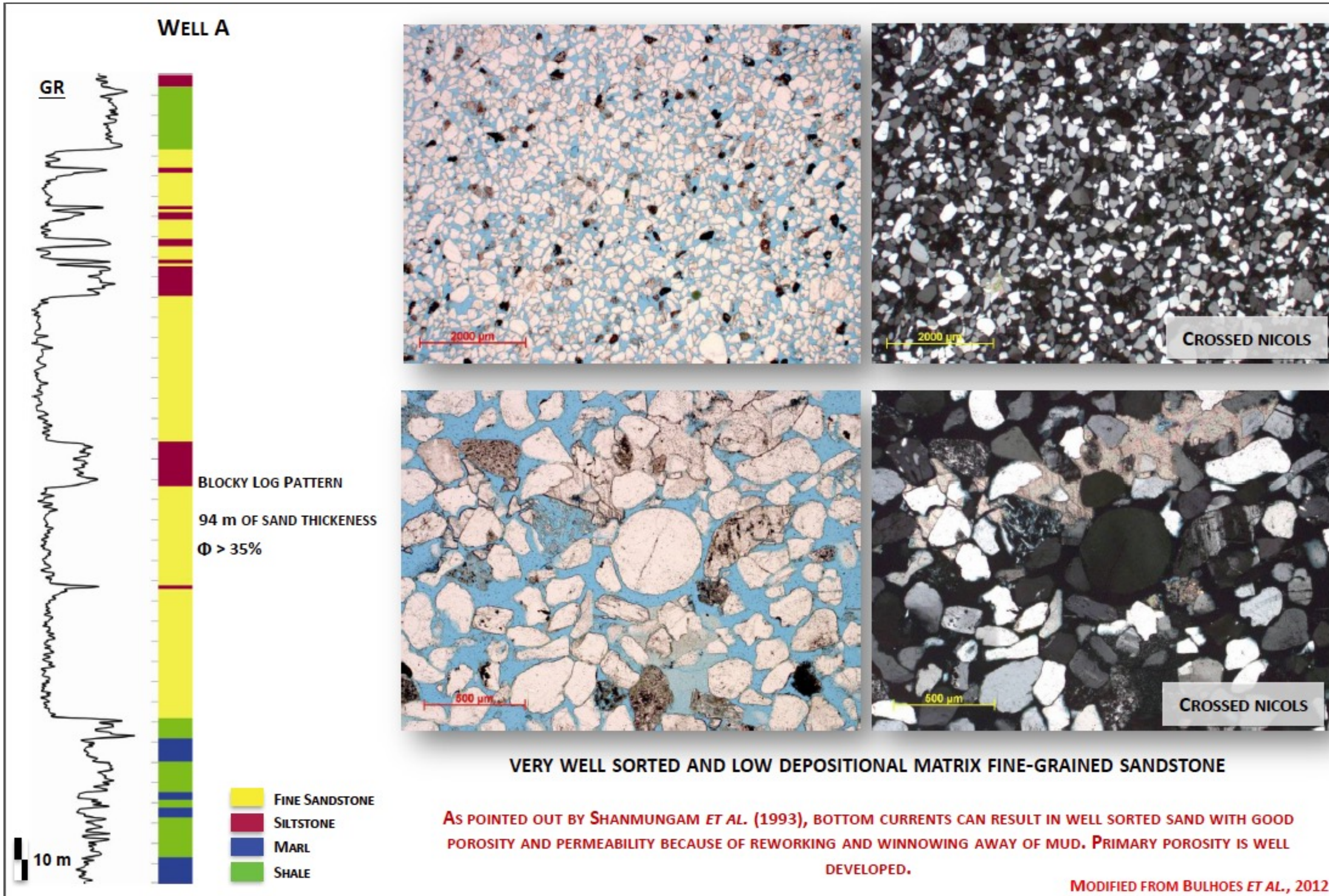


(Mutti et al., 2014)

Santos Basin: well log and petrophysical properties

The well log shows the large thickness of the sand bodies and the photos show that sandstone is very well sorted (low depositonal matrix) with good porosity and permability thanks to winnowing away of mud.

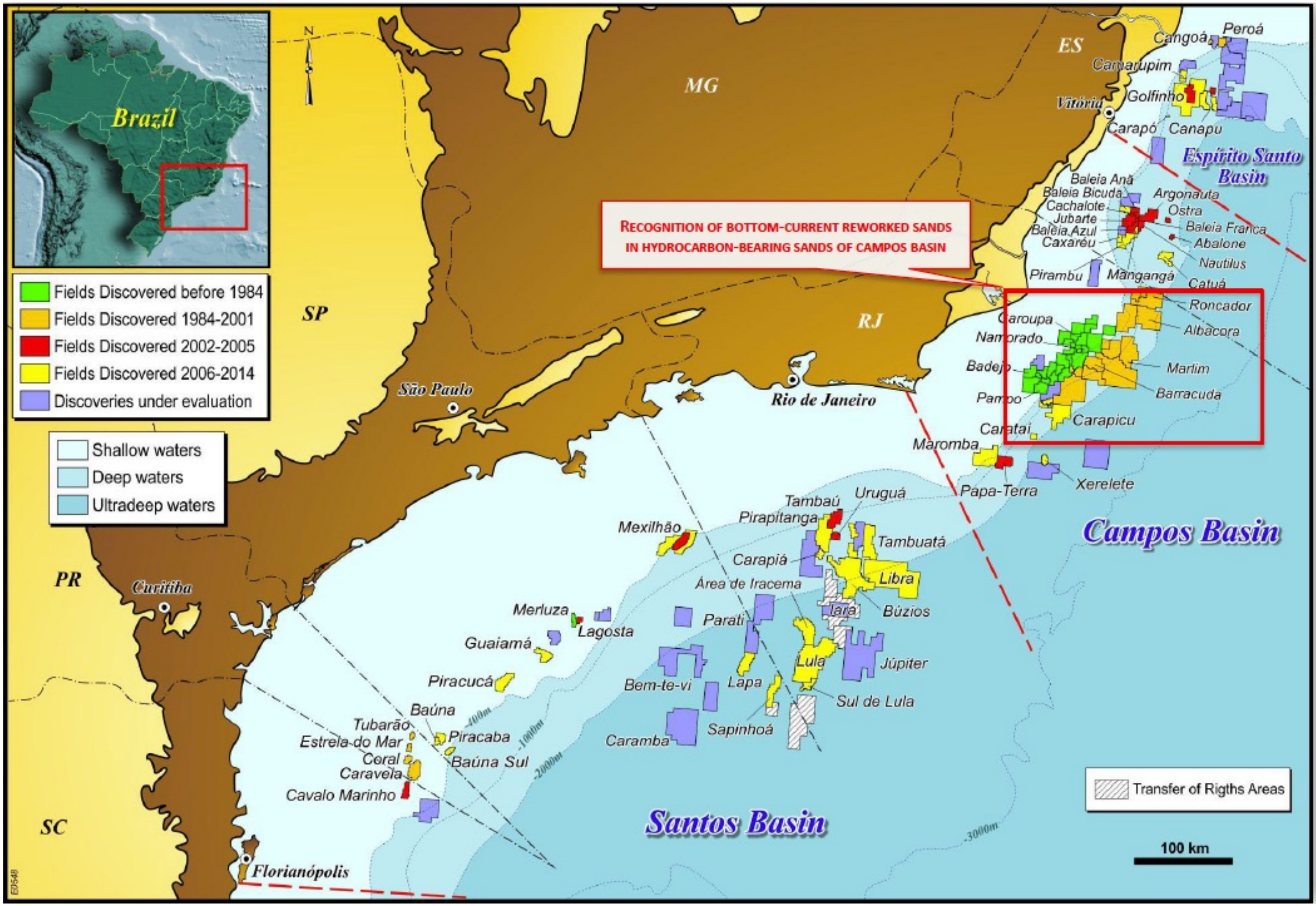
(Mutti et al., 2014)



Campos Basin Location map

Location map of Campos Basin within Brazilian Margin where there are clear evidence of bottom-current reworking of hydrocarbon-bearing turbidites

(Mutti et al., 2014)

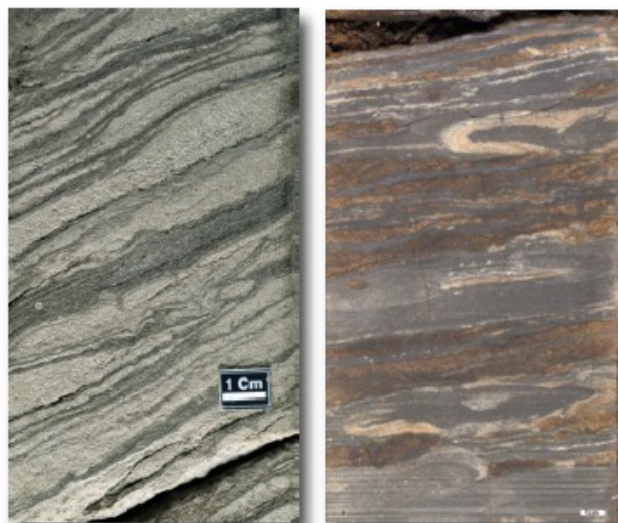


Campos Basin: Contourites occur primarily in 3 settings:

within channels where bottom currents moved up and down

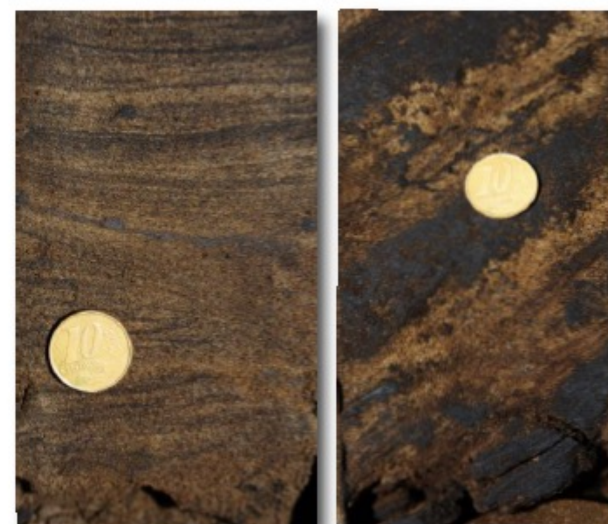
COARSE-GRAINED TURBIDITE BEDS REWORKED BY TIDAL BOTTOM CURRENTS (HYBRID FACIES ASSOCIATION)

in open slope settings, with quasi-permanent geostrophic thermohaline flow



CYCLICALLY STACKED THIN-BEDDED CONTOURITES

within channels or in turbidite fan remnants



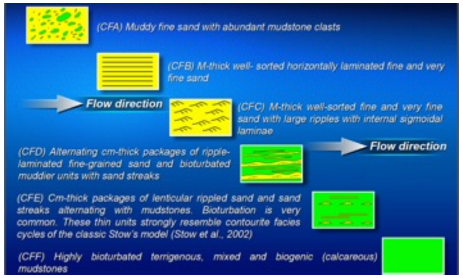
CURRENT-LAMINATED SANDY CONTOURITES

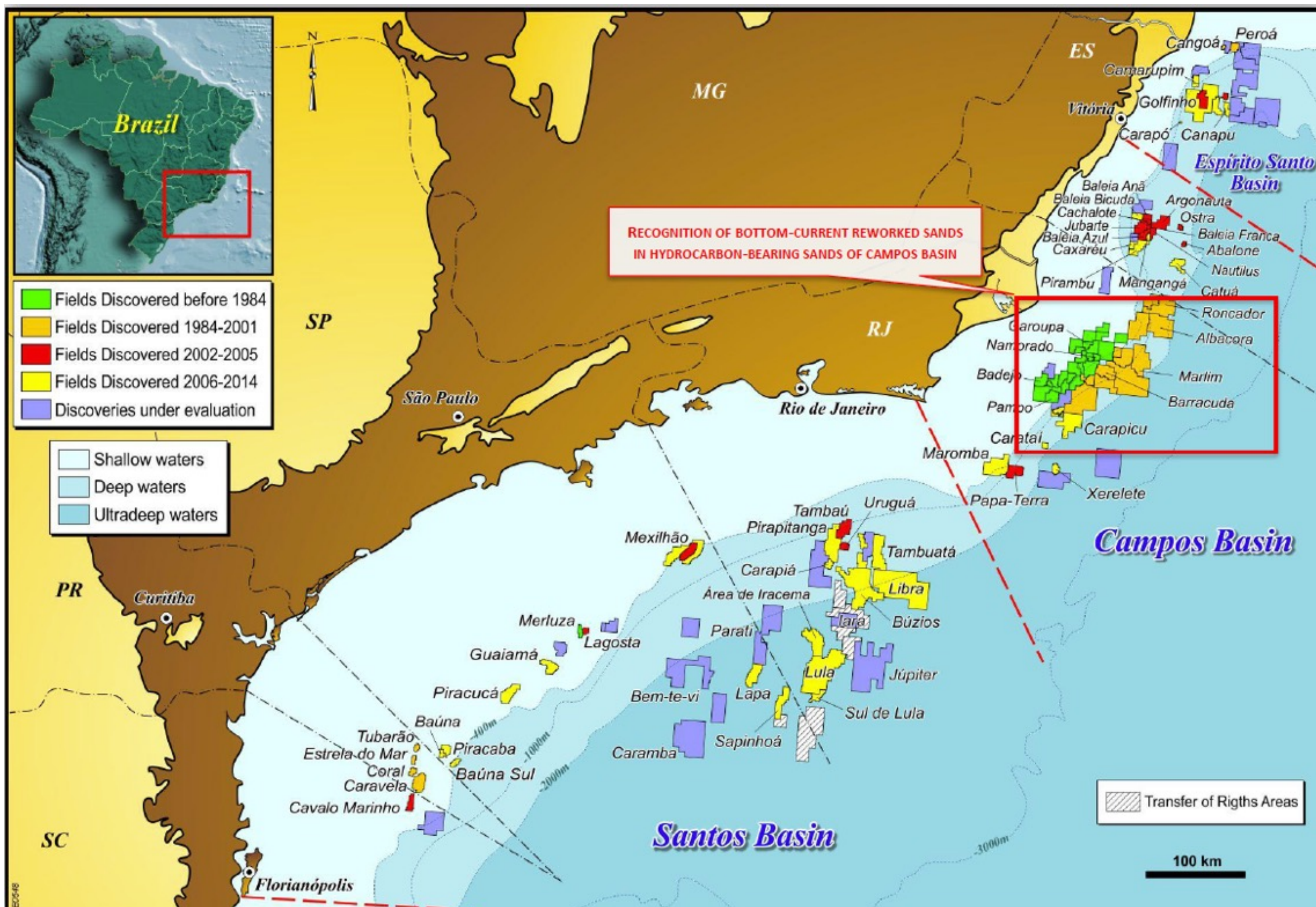
patterns controlled by local and regional topography that moved large amounts of fine sand through migrating large-scale sand-dune fields and sand waves, and smaller bedforms.

(Mutti et al., 2014)

Espirito Santo Basin Location map

Location map of Espirito Santo Basin within Brazilian Margin where the preliminary contourite system tract of Mutti and Carminatti (2012) was conceived



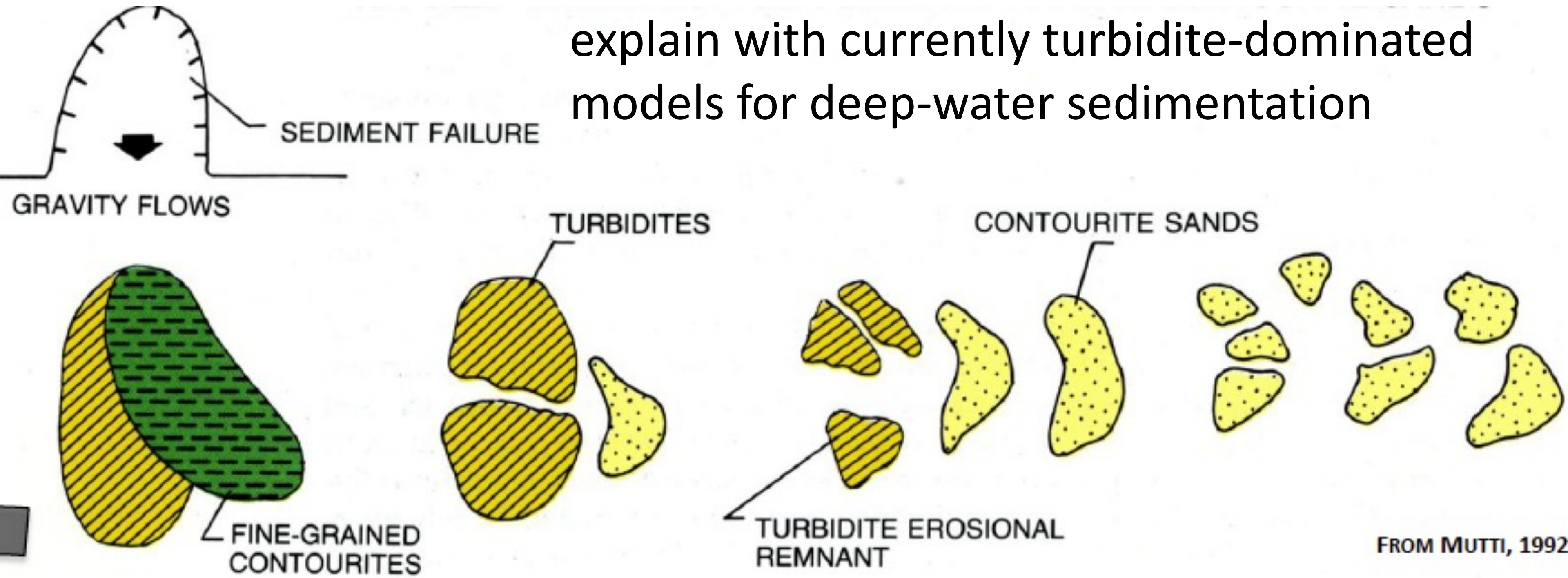


(Mutti et al., 2014)

Espirito Santo: Basin hybrid facies associations

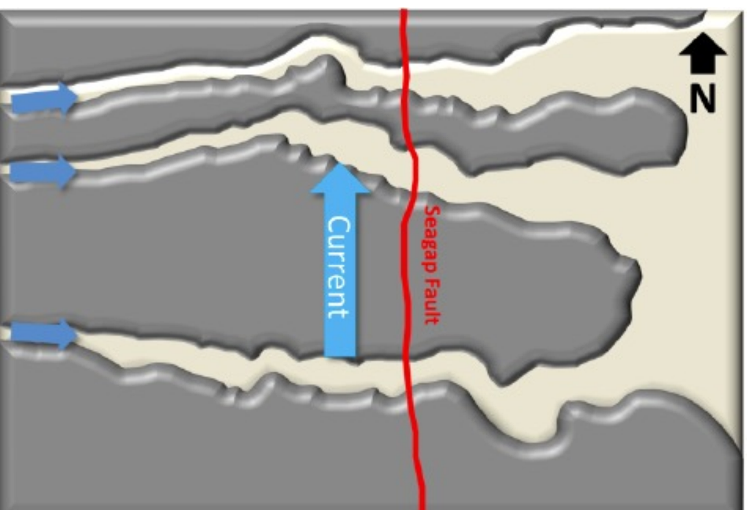
(Mutti et al., 2014)

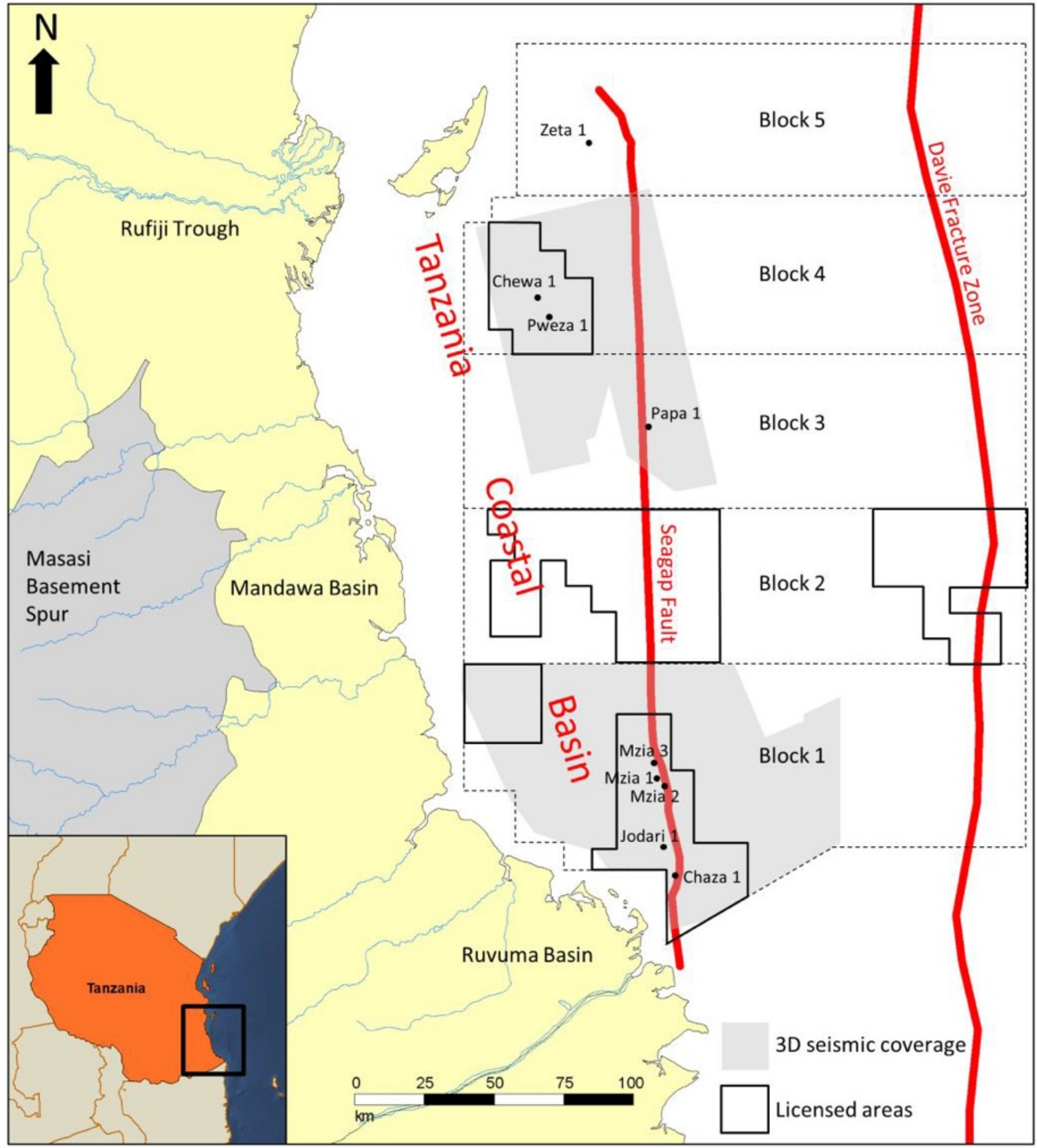
Turbidite sands winnowed, eroded and redistributed by deep-marine bottom currents to form contourite sands which are difficult to explain with currently turbidite-dominated models for deep-water sedimentation



Tanzania Location map

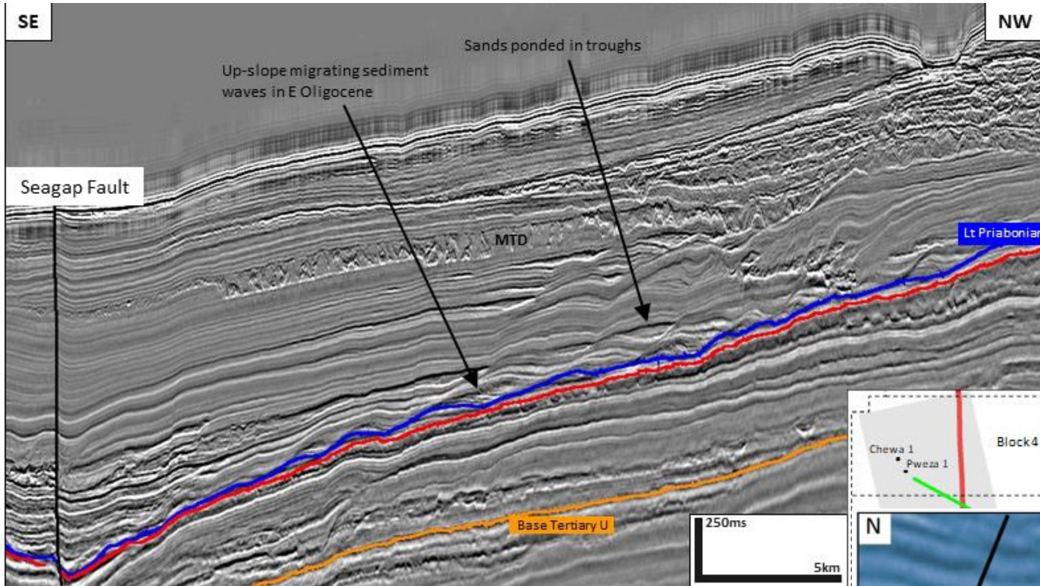
Location map of the Tanzanian margin where Hybrid turbidite-contourite systems have been identified

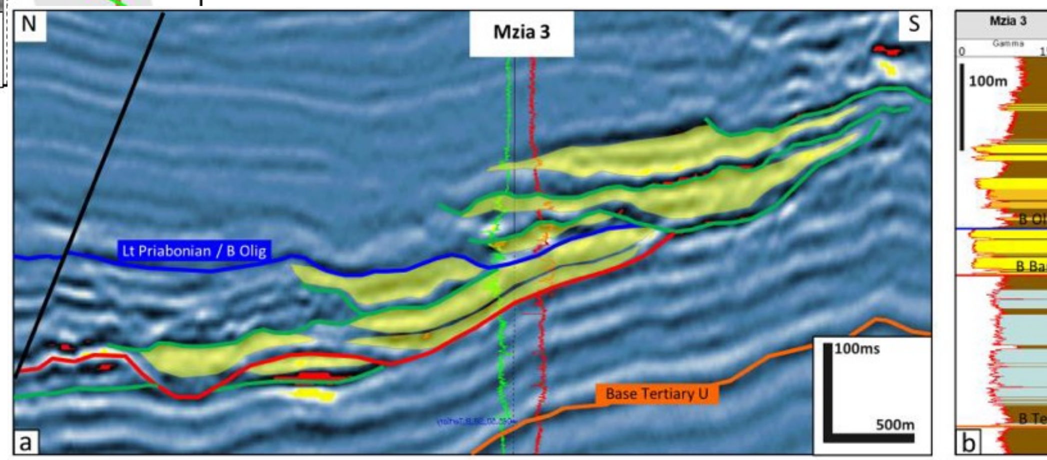




(Sansom, 2018)

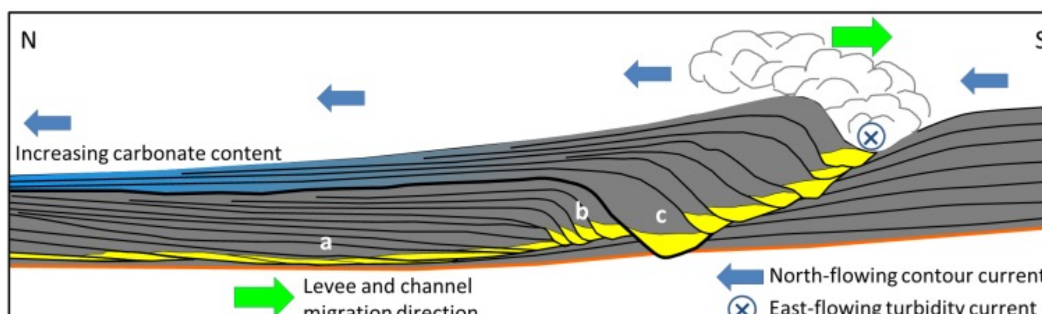
Tanzania: migrating channel-levee complexes





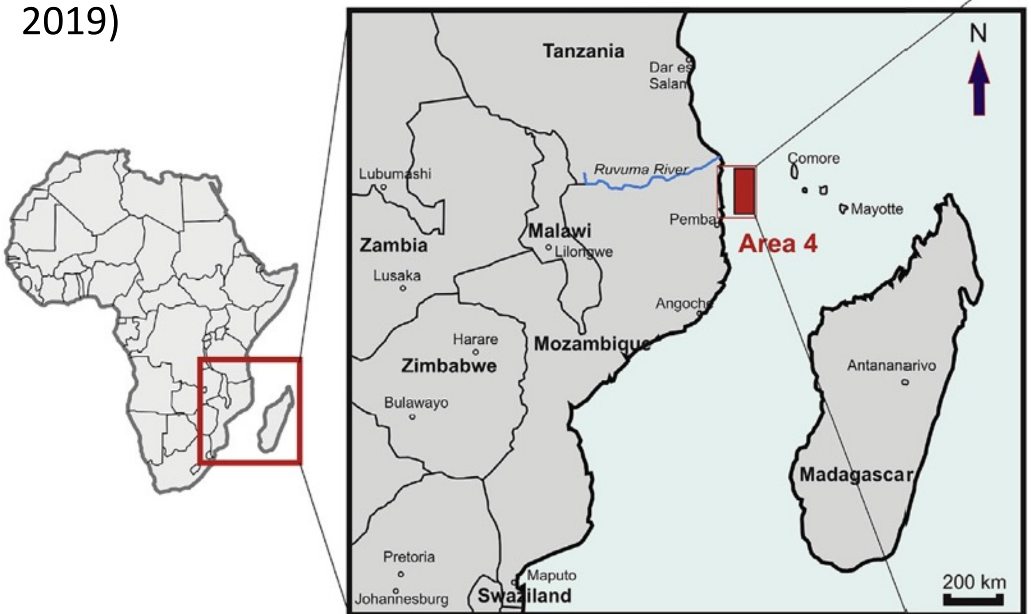
In response to flow-stripping of the suspended load of the turbidity current, the northern levee migrates upstream with respect to contour current, and the channel displaced to the south

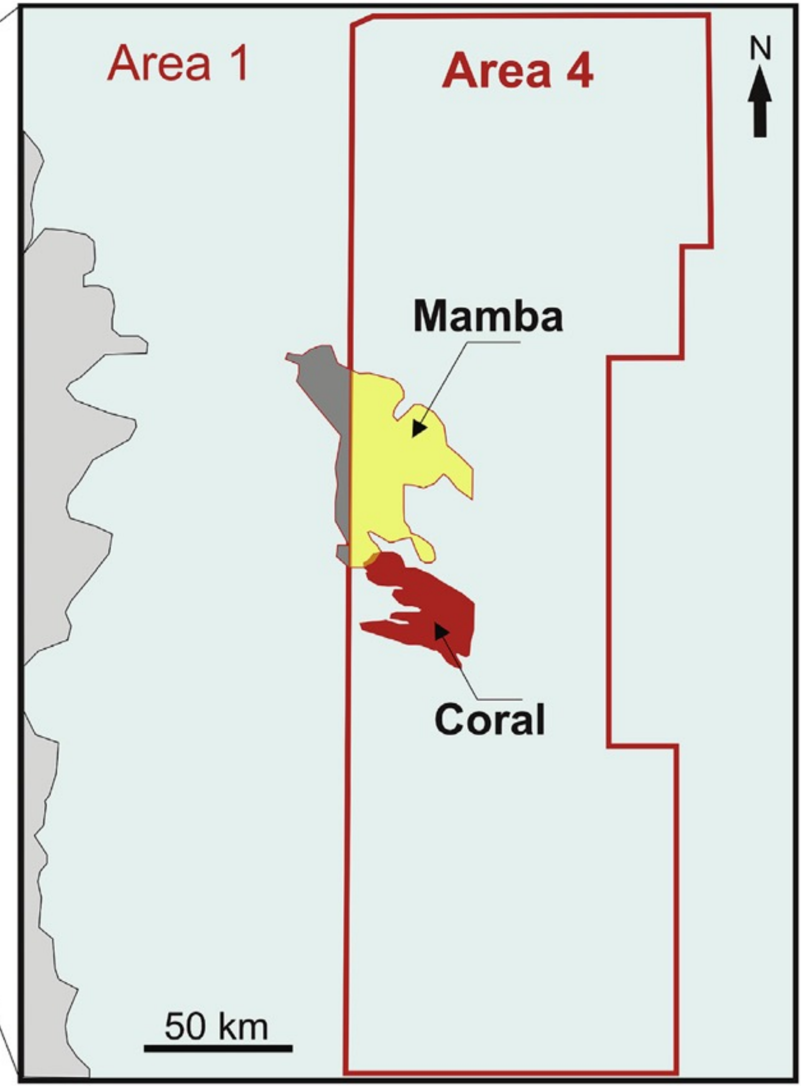
(Sansom, 2018)



Mozambique: Location map

(Fonnesu et al., 2019)





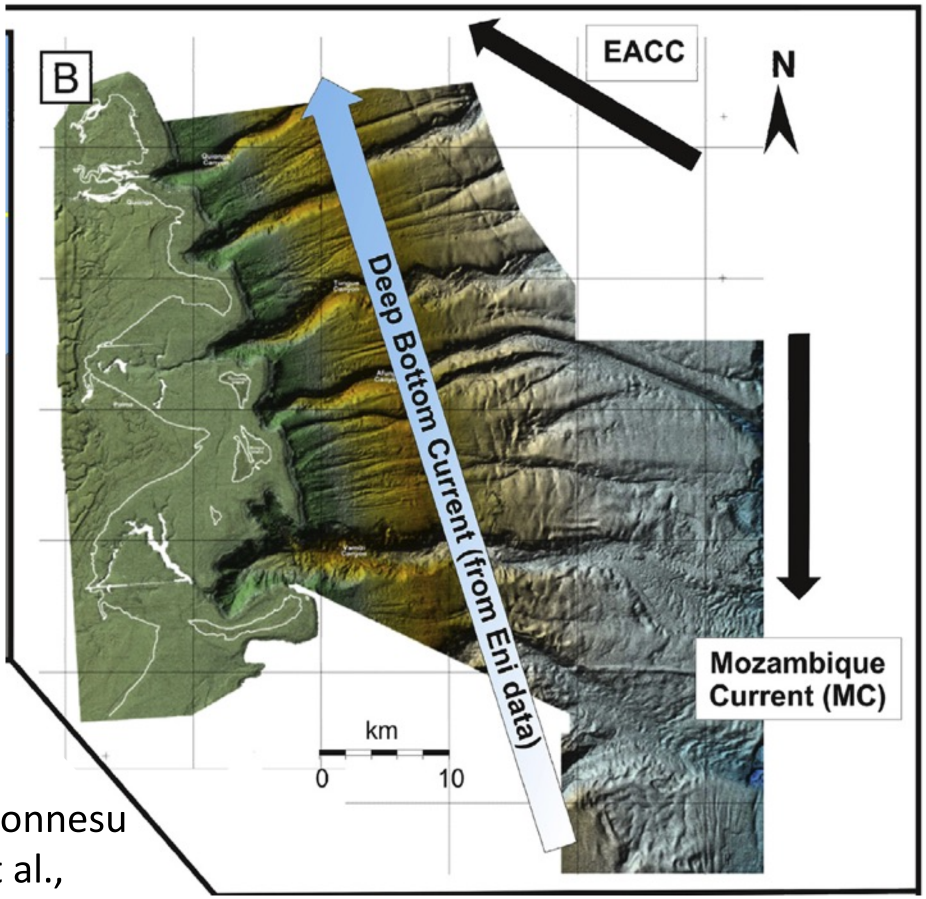
Location map of Area 4 off the coast of Northern Mozambique. Eocene and Oligocene Mamba and Coral systems are indicated including their straddling equivalents in the Area 1

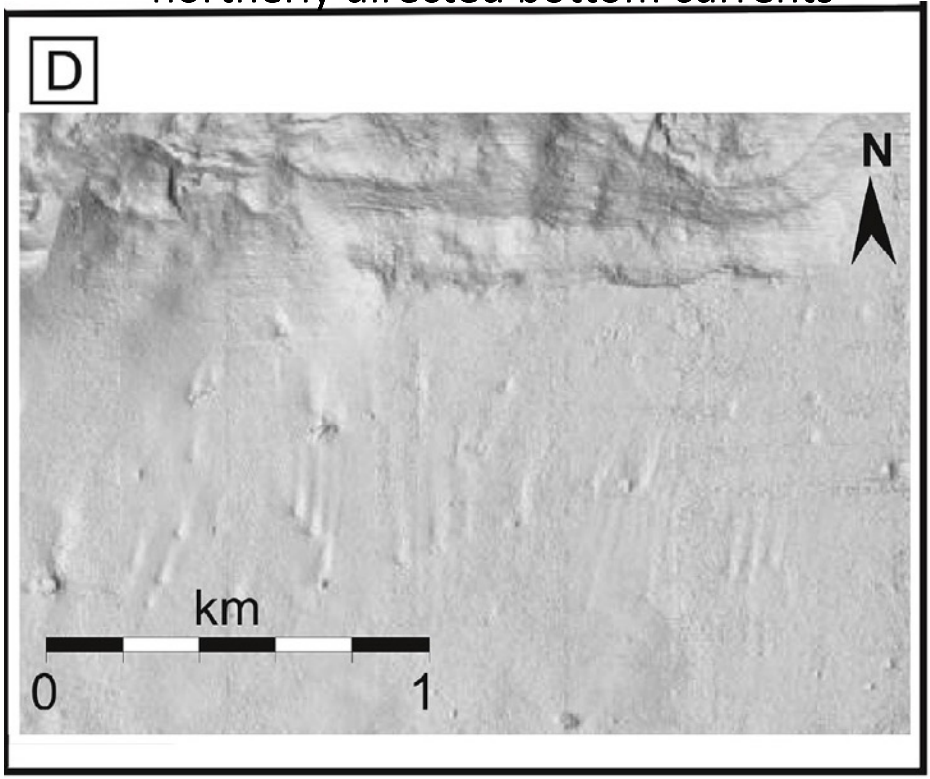
Mozambique: Ocean floor bathymetry

(B) Shaded relief map overlain by bathymetry of modern deep-water fans and deep undercurrents flowing northwards along the continental slope.

The basin is located in the offshore of northern Mozambique, within the Mozambique Channel.

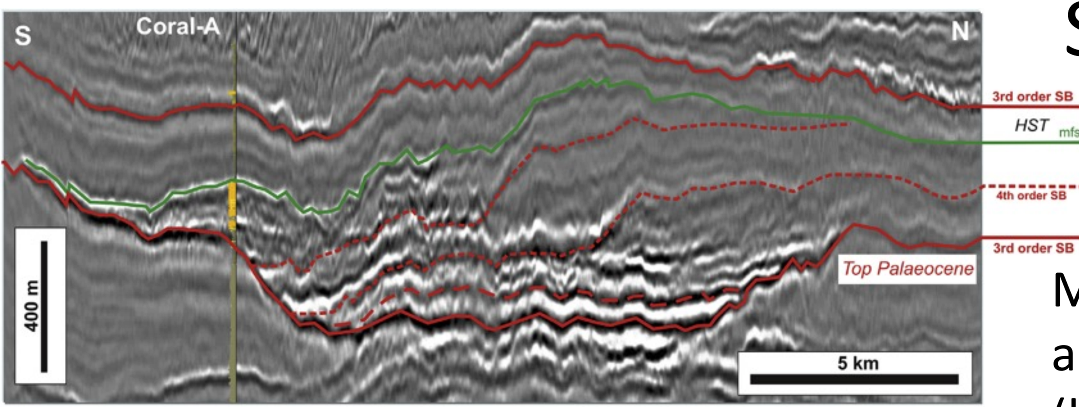
(D) Detail of seafloor features including large-scale scour marks (flutes and crescent) created by northerly directed bottom currents

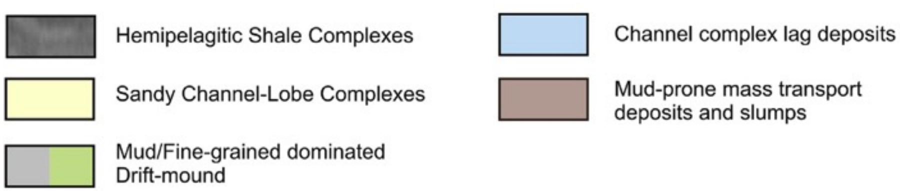




(Fonnesu et al., 2019)

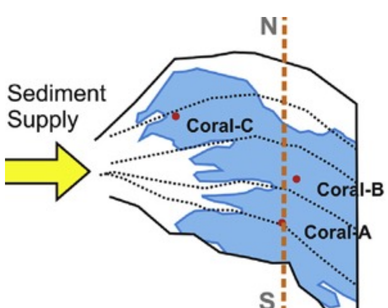
Seismic section through the Coral sequence



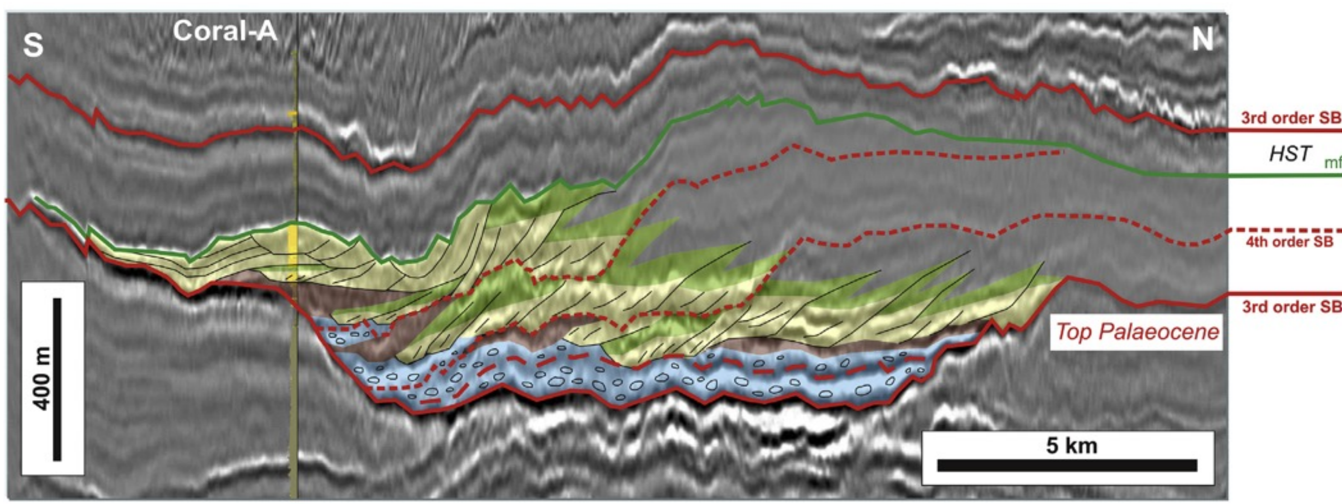


Main stratigraphic surfaces (above) and seismic facies interpretation (below). Overall southwards migration and offset stacking pattern with channel complexes flanked by prominent asymmetric drift-mounds on the N side of the fans.

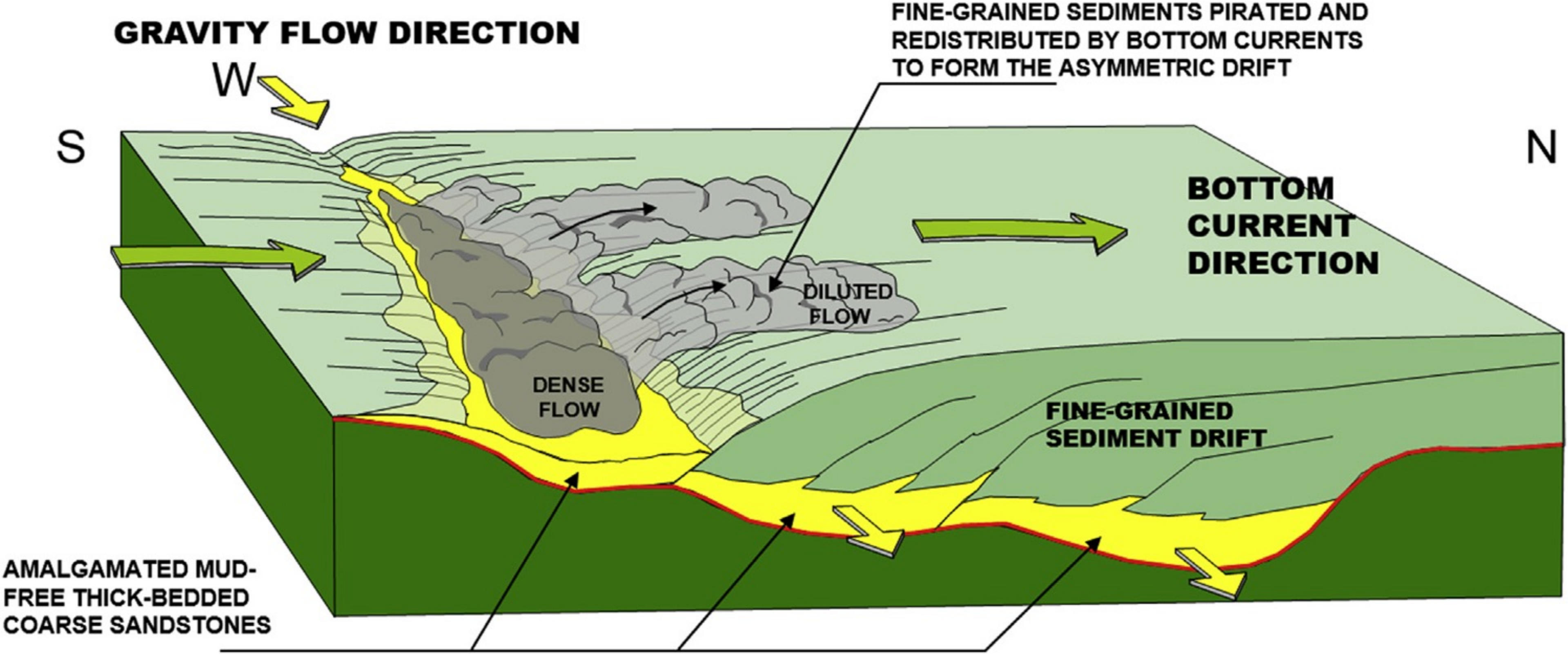
The reservoir shows a systematic internal organization linked to 4th and 5th order base level



(Fonnesu et al., 2019)



Block-diagram of depositional processes affecting the Coral system



(Fonnesu et al., 2019 after Fonnesu, 2013)

Most of the **future perspectives** in contourite research strongly depend on continuous technological advances.

Use of numerical or sand-box modelling, indurated thin sections, Ichnological Digital Analysis Images Package, CT scanning, HR 3D seismics, observations from AUV, seismic oceanography, fingerprinting of water masses using isotopic tools are steadily expanding techniques.

A more intensive collaboration between physical oceanographers and geologists!!!

Scale will be an especially important factor:

- high-resolution to elucidate the relationship currents and smaller contourite deposits;
- increased resolution to detail spatial and temporal variability within a single deposit;
- larger-scale perspective on CDS sharing the same basin, water masses and time scale.

The advances expected in contourite research should lead to the establishment of better diagnostic criteria for contourite identification.

CONCLUSIONS

Contourite processes are not as simple as initially thought.

Contourite nomenclature might need to be reconsidered.

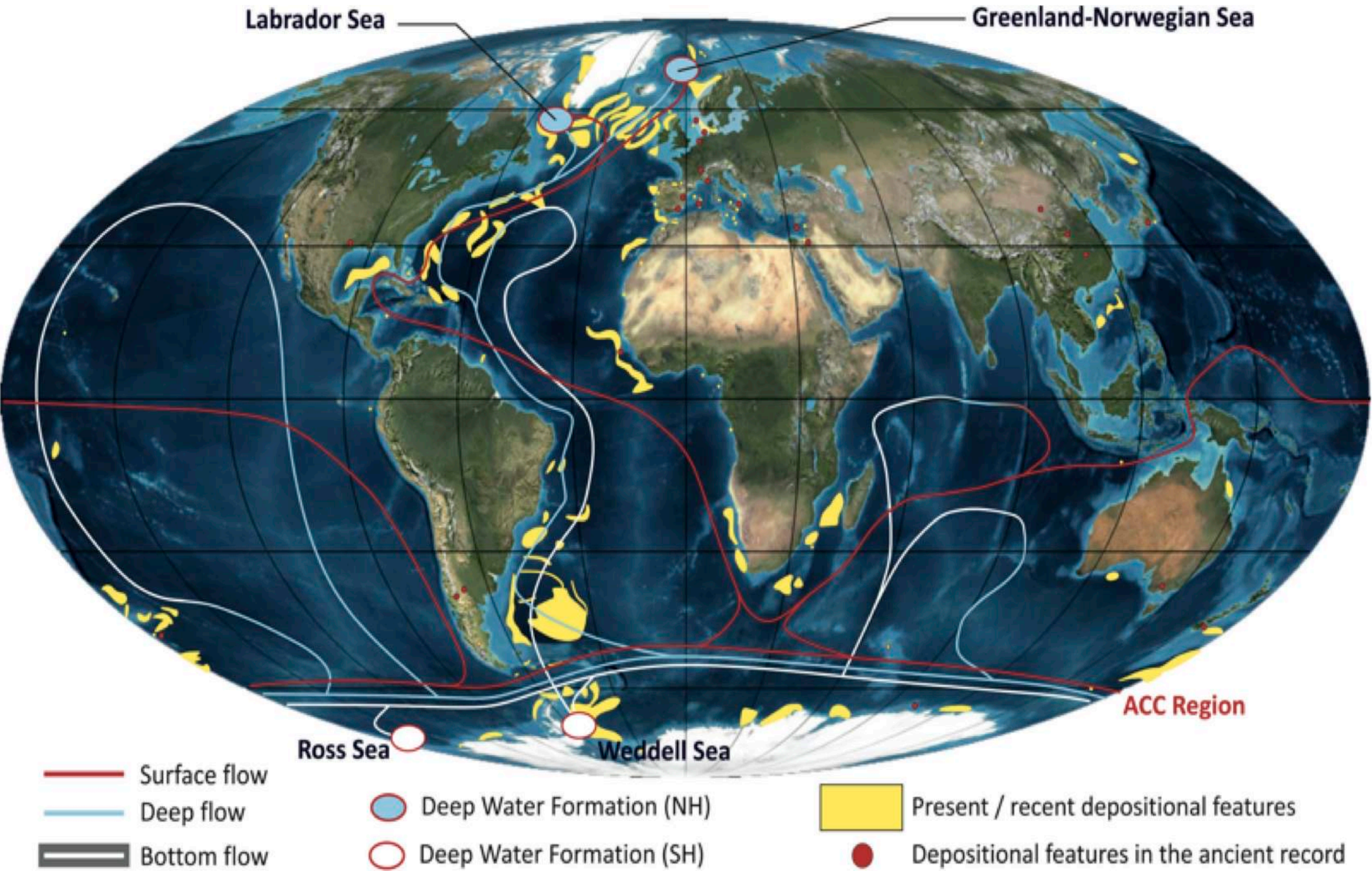
New facies models must be established.

More work is needed to understand sandy contourites.

Integrated studies will be essential for an holistic perspective.

Pervasiveness of bottom-water circulation to be reconsidered.

Future discoveries?



Take home message

Bottom currents,'persistent' water current near the sea-floor, are influenced by a series of factors and pervasively affect the seafloor sediments.

Contourites, sediments deposited or significantly affected by bottom current, begin to be perceived as a fundamental component of deep sea depositional systems.

Contourite drifts generally composed of fine sediments, are large sedimentary accumulations produced by bottom currents, which can allow us to reconstruct their evolution and paloceaonography.

The **sedimentary facies** are manifold and the diagnostic sedimentary characteristics are still under discussion.

Bottom currents and contourites are of **great importance** for paleoclimatic reconstructions, investigations on continental slopes and their stability, the exploration of hydrocarbons and polymetallic nodules, definition of the "extended continental shelf", ecological health of deepwater ecosystems, accumulation of microplastics and contaminants .

Modulo	Argomento	Docente	Data
1.1	introduzione al corso e argomenti	Rebesco	05/10/21
1.2	metodi (geofisica, affioramenti, geologia marina, ambienti attuali)	Volpi/Rebesco	06/10/21
1.3	meccanismi di formazione dei bacini (geodinamica, tettonica…)	Lodolo	12/10/21
1.4	Interpretazione sismica, facies e strutture primarie	Rebesco	13/10/21
	Martedì 19 Ottobre non c'è lezione		
1.5	Energy storage e CCS	Volpi/Donda	20/10/21
2.1	Processi sedimentari nei fiumi e nei delta	Rebesco	26/10/21
2.2	Azione di maree e onde, del ghiaccio e del vento	Rebesco	27/10/21
	Martedì 2 Novembre non c'è lezione		
	Mercoledì 3 Novembre non c'è lezione		
2.3	Correnti di densità e correnti di fondo, trasporto di massa	Lucchi/Rebesco	09/11/21
3.1	pianure abissali (decantazione emipelagica) e margini continentali	Rebesco	10/11/21
3.2	Conoidi sottomarine (flussi gravitativi dalla scarpata continentale)	Lucchi/Rebesco	16/11/21
3.3	Sediment drifts (correnti di fondo lungo la scarpata continentale)	Rebesco	17/11/21
3.4	Mass transport deposits (accenni a risoluzione/penetrazione)	Ford	23/11/21
3.5	piattaforme continentali (onde, tempeste, tsunami)	Rebesco	24/11/21
3.6	calotte glaciali e ghiacciai marini	De Santis	30/11/21
3.7	Delta, estuari e spiagge e ambienti deposizionali carbonatici	Rebesco	01/12/21
3.8	faglie, vulcani e corpi intrusivi	Civile	07/12/21
	Mercoledì 8 Dicembre non c'è lezione		
3.9	fiumi, laghi e deserti	Rebesco	14/12/21
4	esercitazione	Rebesco	15/12/21
5.1	stratigrafia sequenziale	Zecchin	21/12/21
5.2	livello del mare e spazio di accomodamento	Zecchin	22/12/21
	Dal 23 Dicembre al 9 Gennaio non c'è lezione		
5.3	discontinuità e paraconformità e altre superfici significative	Zecchin	11/01/22
5.4	system tracts (apparati deposizionali) e diversi modelli	Zecchin	12/01/22
5.5	applicazioni (es. reservoirs di idrocarburi)	Zecchin	18/01/22
6	visita a CoreLoggingLAB e/o SEISLAB (assieme a Geologia Marina)	Rebesco	19/01/22