Istituto di Geoscienze e Georisorse

09.04.2020

S T R E T T I   T I D A L I

identificarli, comprenderli, rimanerne affascinati

(criteri geologici di base per la loro identificazione nel rock record)

Sergio.G. Longhitano, University of Basilicata, Italy sergio.longhitano@unibas.it

With the contribution of:

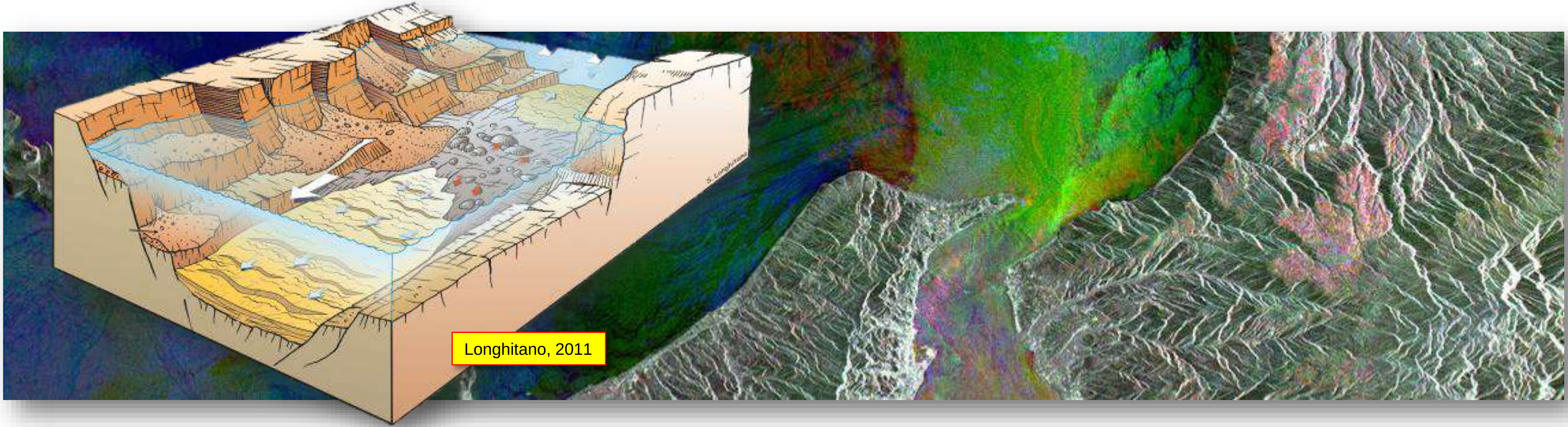
D. Chiarella, Royal Holloway University, London, UK; V.M. Rossi, CNR, Pavia, Italy; R.J. Steel & C. Olariu, Jackson School of Geosciences, Texas, USA; R.W. Dalrymple, Queen's University, Canada; D. Mellere, Faroe, Stavanger, Norway; A.W. Martinius, Equinor, Thrompso, Norway; S.A. Grundvåg, Department of Geosciences, Artic Univ. of Norway; P. Barrier, Université LaSalle Beauvais, France; M. Tropeano & L. Sabato, University of Bari, Italy; M. Pistis, University of Cagliari.

Sentinel-2 images of Tidal effects close to Augustus Island: a new island appears in low-tide conditions – Western Australia

Summary of the presentation

- Definition (geographical, geological) of a strait: why straits are important?
- Types of di straits (based on the observation of modern examples);
- Tidal Straits: Oceanographic, morphologic, bathymetric and sedimentological features;

- Criteria for recognising strait-fill successions in the rock record;
- What do we do not know yet about straits?



STRAITS ARE FUNDAMENTAL ELEMENTS OF MODERN GEOGRAPHY, AS THEY ARE *LOCI* AND ENGINE OF NATURAL PROCESSES AND PHENOMENA THAT TUNE AND SUSTAIN LIFE ON EARTH.

THEY ARE MORE ABUNDANT (AND RELEVANT) THAN PREVIOUSLY INFERRED!

Definition of STRAIT

The noun ‘strait’ derives from the Latin word *strictus*, meaning "to bind or draw tight", and it is commonly adopted for indicating a narrow passage of water or a tricky marine setting (Takeoka, 1990).

In Geography or Oceanography, ‘strait’ identifies **typically navigable waterways or shipping routes that connect two larger bodies of water that generate a restricted hydraulic cross-section, with phenomena of local water-mass convergence and related, often outstanding, sea-surface roughness and turbulences** (Defant, 1958; Pugh, 1987; Pratt, 1990).

Terms like ‘**channel**’, ‘**pass**’, ‘**passage**’, ‘**sound**’ or ‘**gateway**’ are often used interchangeably with strait, although they can be referred to variable bathymetric settings or environmental conditions (e.g., Harrison et al., 1983).

Uno stretto è un braccio di acqua tra due terre che collega due bacini di acqua contigui.
(Treccani.it – Enciclopedie on line, Istituto dell'Enciclopedia Italiana)

A **strait** is a naturally formed, narrow, typically navigable waterway that connects two larger bodies of water. Most commonly it is a channel of water that lies between two land masses. Some straits are not navigable, for example because they are too shallow, or because of an unnavigable reef or archipelago (Geology Dictionary).

A strait is a narrow body of water that connects two larger bodies of water. It may be formed by a **fracture in an isthmus**, a narrow body of land. Tectonic shifts can lead to straits like this (e.g., the Strait of Gibraltar, between the Mediterranean Sea and the Atlantic Ocean.

A strait can also be formed by **a body of water overflowing land that has subsided or has been eroded**. The Bosporus, which links the Black Sea and the Aegean Sea, was formed this way (National Geographic).

- What tidal straits are? **And why are they important?**

They are:

1. influence the local oceanography, inducing **climate and sedimentary changes** in the adjoining basins;
2. prolific **fishing zones** as current exchanges also promote fish migration of great diversity;
3. advantageous and economically profitable **shipping seaways** linking marine areas separated by extensive landmasses;
4. modern analogous for subsurface many **oil-productive areas** of the world which are revealing significant reservoirs;
5. Ideal *loci* for production of **renewable energy** generated by turbines capable to produce power from the strong tidal flows;
6. preferential zones for the installation of **plumbing or wiring** for technical uses (e.g., electricity/oil/gas cabling), although the high mobility of sediment masses on the bottom of straits may often represent unstable substrates and an unwarrantable setting;
7. crucial in the **history of sedimentary basins**, as they may rapidly evolve into land passageways in case of sudden sea-level falls, having a great potential impact in the spreading of terrestrial living species or, on the contrary, inducing water masses separation and consequent marine biological diversifi
8. Important for many other reasons …

G O A L:

DEFINITION OF A DEPOSITIONAL MODEL BASED ON THE COMPARISON OF ANCIENT TIDALLY-DOMINATED STRAIT-FILL SUCCESSIONS AND MODERN TIDAL STRAITS.

DO WE HAVE an UNIVOQUE CLASSIFICATION for STRAITS?

Whirlpools of the Maelstrom of Saltstraumen, Nordland, Norway

2016

Deflection of the progradational axis and asymmetry in tidal seaway and strait deltas: insights from two outcrop case studies

SERGIO G. LONGHITANO[1]* & RON J. STEEL[2]

[1]*Department of Sciences, University of Basilicata, Potenza, Italy*

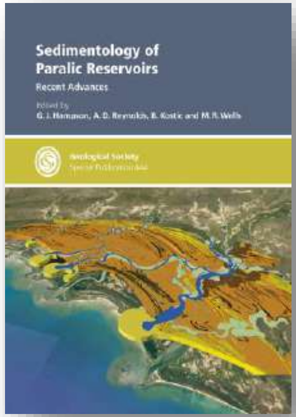
[2]*Jackson School of Geosciences, University of Texas at Austin, Texas, USA*

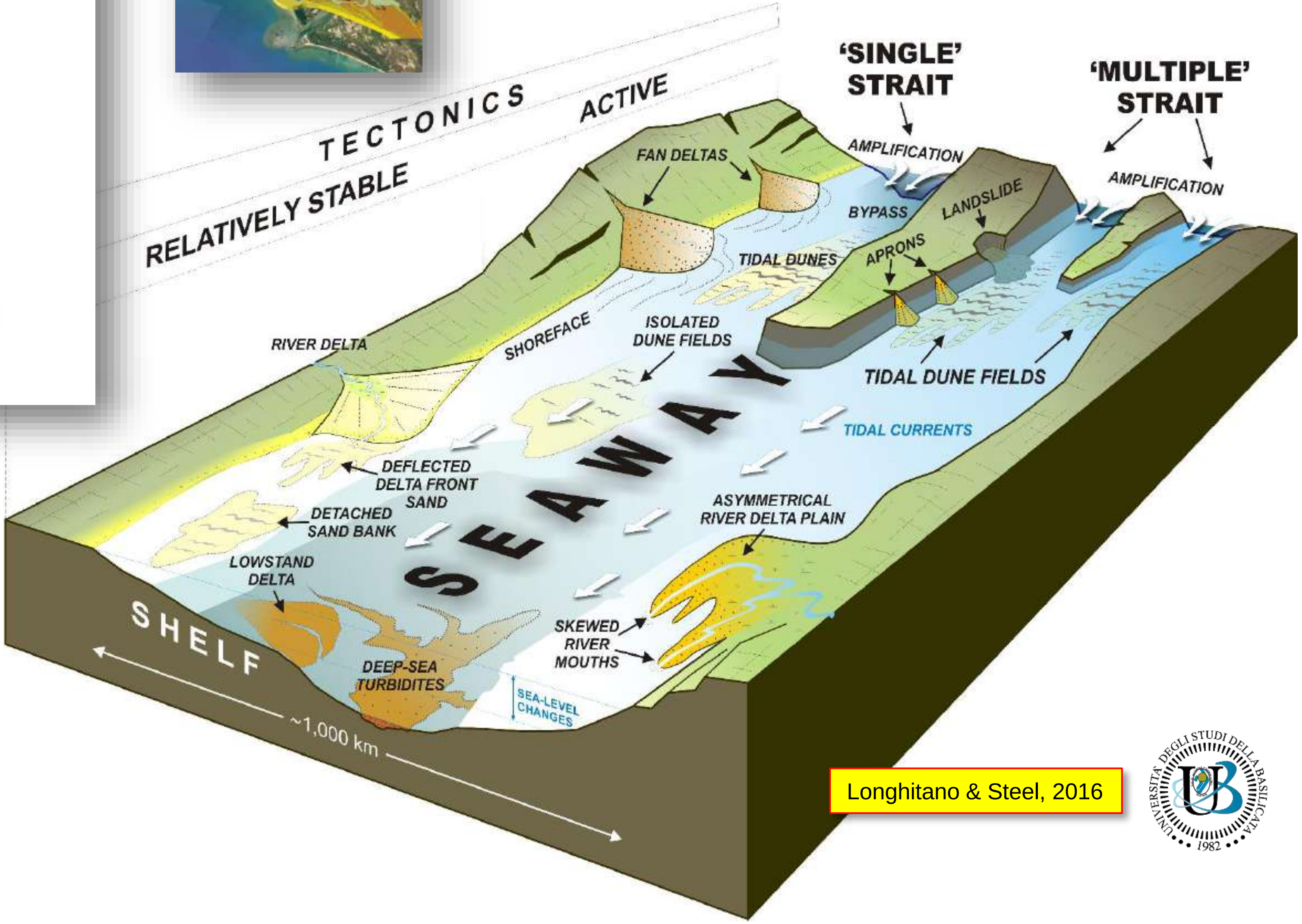
**Corresponding author (e-mail: sergio.longhitano@unibas.it)*

Abstract: Deltas represent the major sediment source for tectonically confined, tide-dominated seaways or straits. Modern examples show how along-shore tidal currents are able to modify the impinging delta shape, generating asymmetrical coastal plains, deflected delta fronts and elongate sandbanks. Seaway or strait deltas can become become tide-influenced or tide-dominated, assuming physical attributes that may depart from classical models. Ancient deltas in seaways and straits can also reveal unexpected facies stacking and stratigraphies, which can be misinterpreted or attrib- uted to … ongate basins … deltas is the p… in the delta fa… facies, wherea… e delta fronts a… v. This study p… tyle of these t… tion of many b… basins, the inte…

Tidal seaways and straits

Tidal seaways are elongate marine passageways, thousands of kilometres wide, connecting two wider basins. The dominant hydrodynamic force in tidal seaways results from tidal currents flowing parallel to strike. Tidal straits are narrower than seaways and are governed by the convergence and amplification of tidal currents as a result of narrowing of the cross-sectional area of the water body (Pugh 1987). Recent studies on ancient tidal strait-fill successions in southern Italy have attempted to demonstrate that a critical cross-sectional area is the fundamental quantitative condition through which a strait becomes dominated by the amplification of a tidal flow (Longhitano *et al.* 2014). This condition, favourable to the onset of a tidal circulation, can be also matched during late transgressive stages, as has occurred recently along many of the world's coastal systems at the end of the post-Last Glacial Maximum relative sea-level rise (e.g. Longhitano *et al.* 2016).

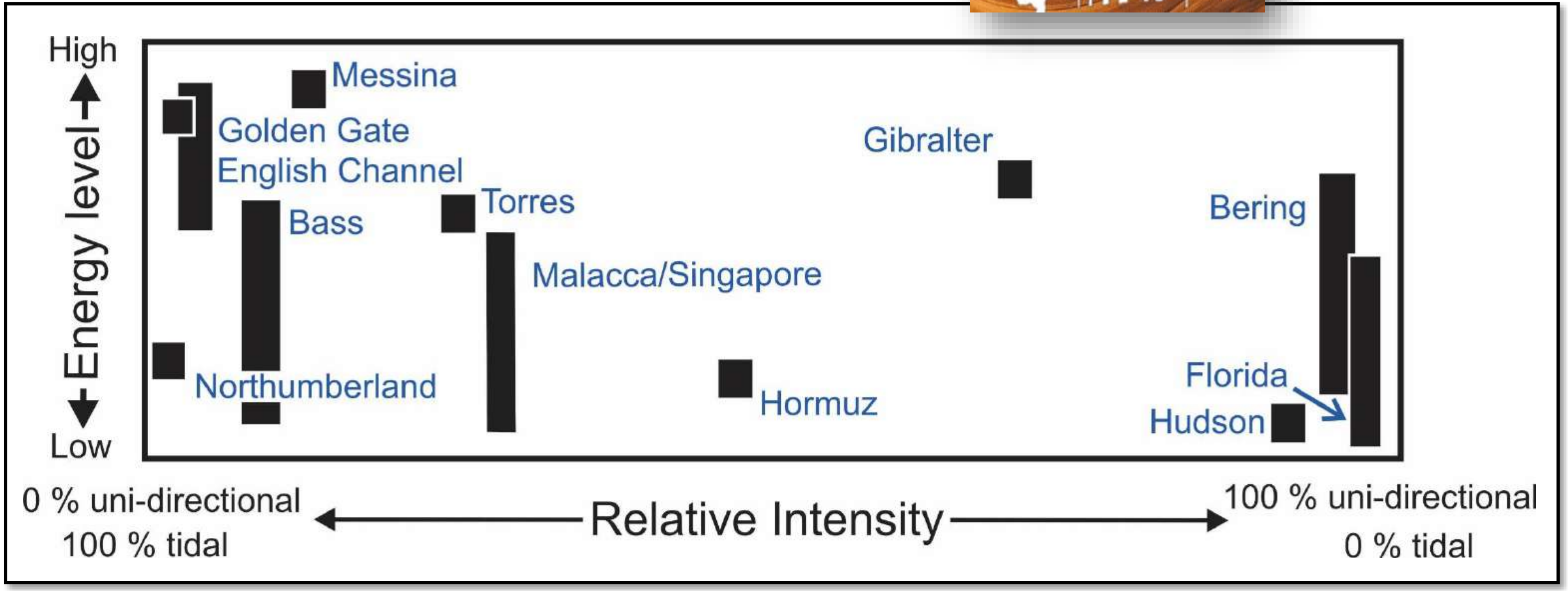




Longhitano & Steel, 2016

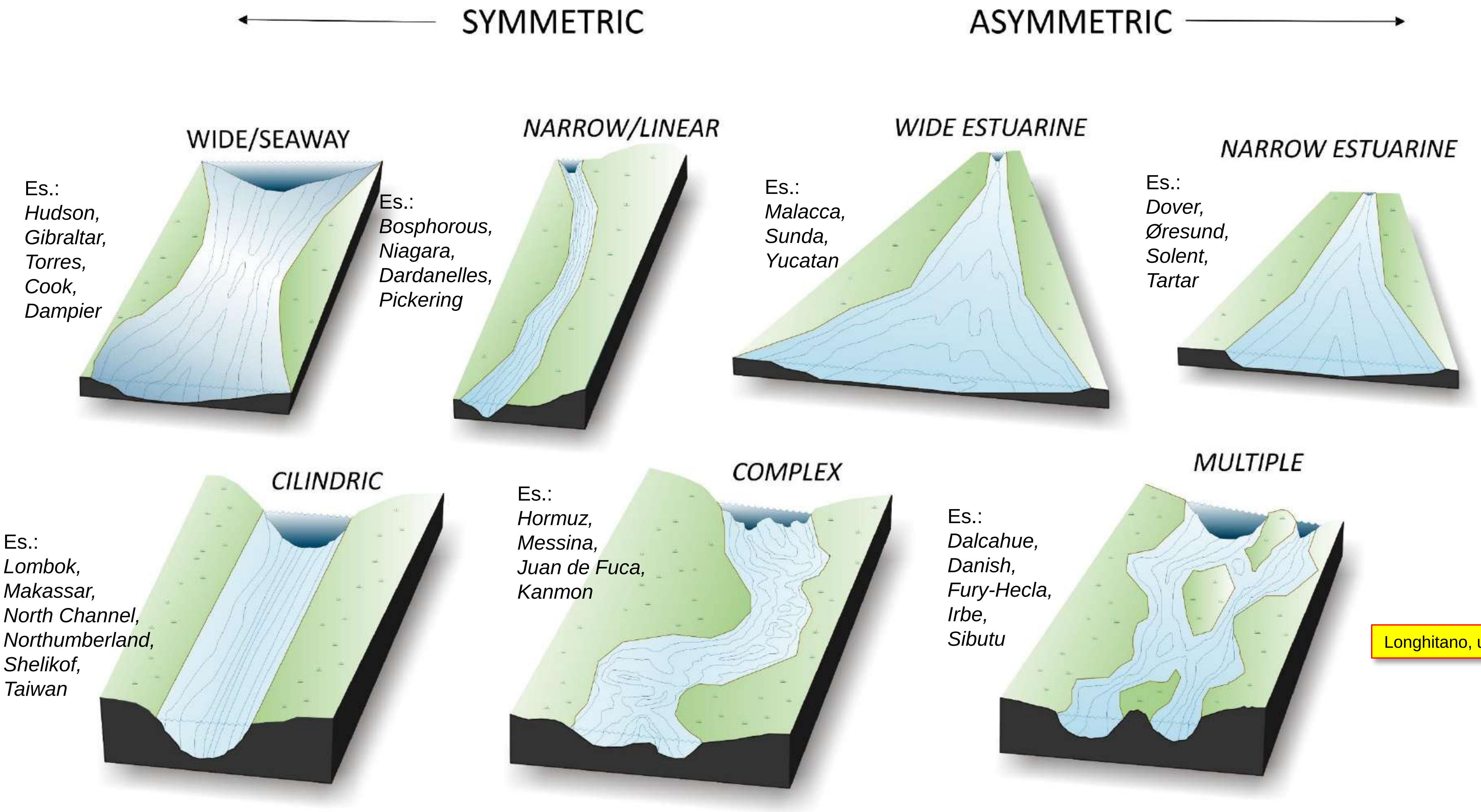
• Tipi di stretti (in base a ciò che oggi si osserva)

Framework for classifying and modeling straits based on the recognition of an interplay between reversing tidal flow and some type of uni-directional current. To create a 2D parameter space that captures the variability of strait sedimentation more comprehensively, the most important variable is the **general energy level**: those with high energy are expected to accumulate abundant coarse-grained deposits, whereas those with low energy are muddy.



courtesy of [Dalrymple, 2019]

Types of straits (based on what we observe today)



Longhitano, unpubl.

STRAITS DOMINATED by TIDAL CURRENTS
(*TIDAL STRAITS*)

• What tidal straits are? And why are they important?

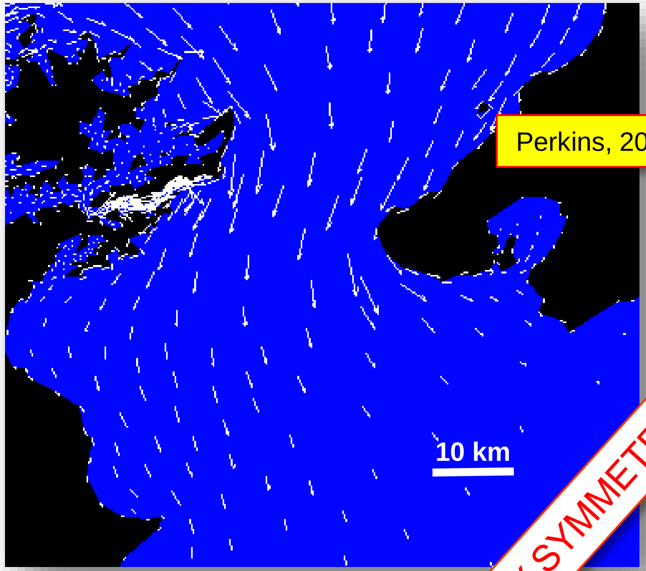
Where straits connect wider adjacent basins, whose oceanography is governed by **tidal phase opposition**, such as the modern Messina and Cook straits, the current hydrodynamics is time-dependent, responding to **a tidal cyclicity**. Tidal cycles exert a certain influence in **promoting water-mass transfers between the two interlinked basins** and a variety of associate hydrodynamics processes (e.g., turbulences, compensational flows, vortexes, etc.) (e.g., Wang, 1989; Pratt, 1990; Dalrymple, 2010).

These particular settings are thought to be characterised by **specific conditions for sediment transport and deposition**, which generally reflect a bedload divergence from a main by-pass zone, where erosion and non-deposition prevail, towards opposite zones of bedload convergence, where sediment accumulates reproducing specific bottom features (Harris et al., 1995)

• **Hydrodynamic model** (symmetric vs. asymmetric tidal systems)

The **tidal inversion** that characterizes many modern straits occurs through a change in the direction of the tidal currents. Alternations of high- vs. low-tide occurring at the same time but in the opposite, interlinked basins is the key-factor that moves large masses of water (*tidal prism*) in one direction and then in the opposite direction. This repeated cycle produces tidal currents with changing velocity/energy.

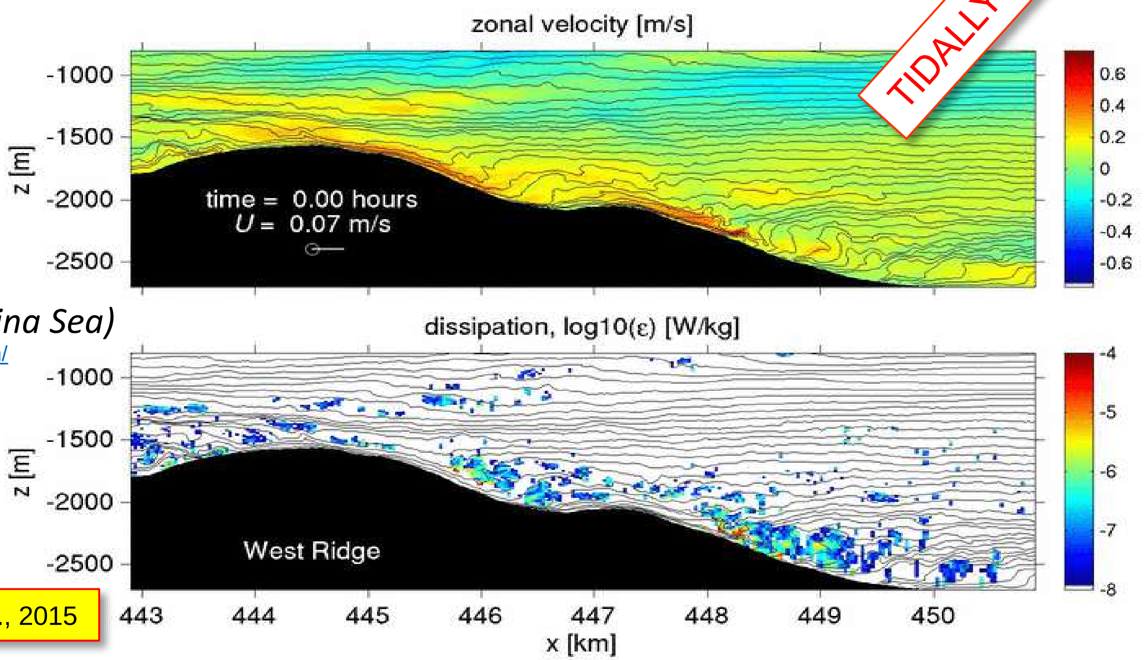
Cook Strait (New Zealand)



TIDALLY SYMMETRIC

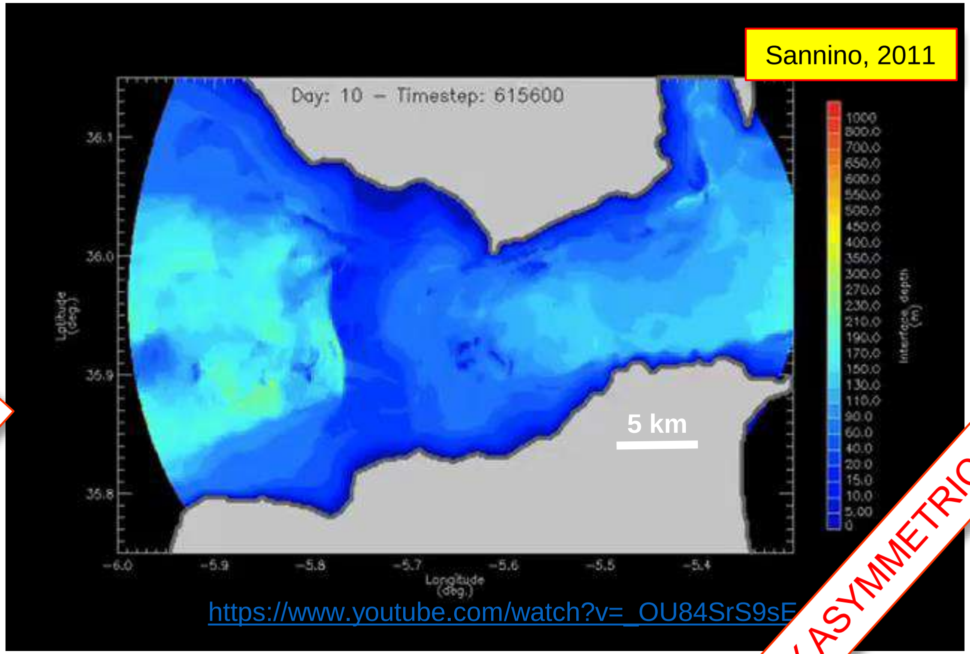
Luzon Strait (South China Sea)

https://blogs.princeton.edu/research/tag/oceanography/



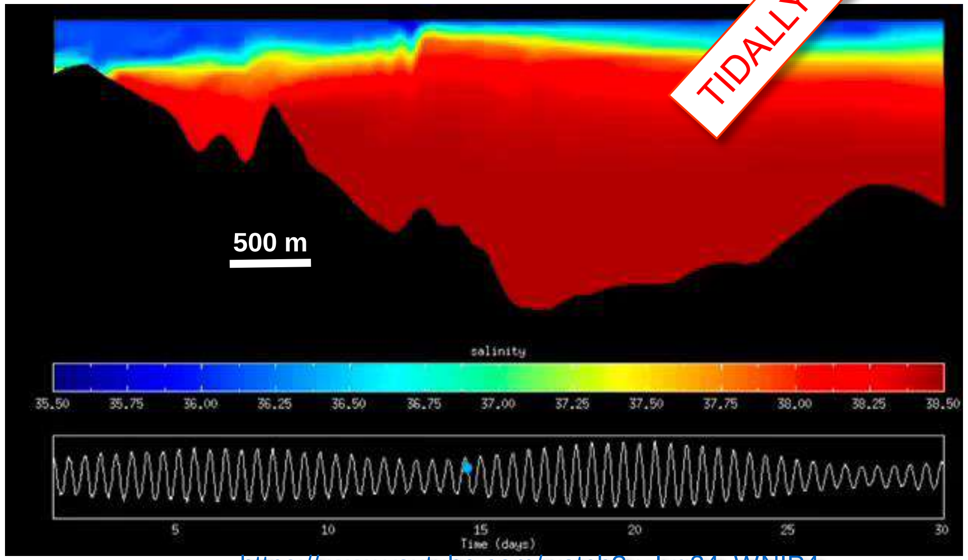
Matthew et al., 2015

Gibraltar Strait (western Mediterranean)

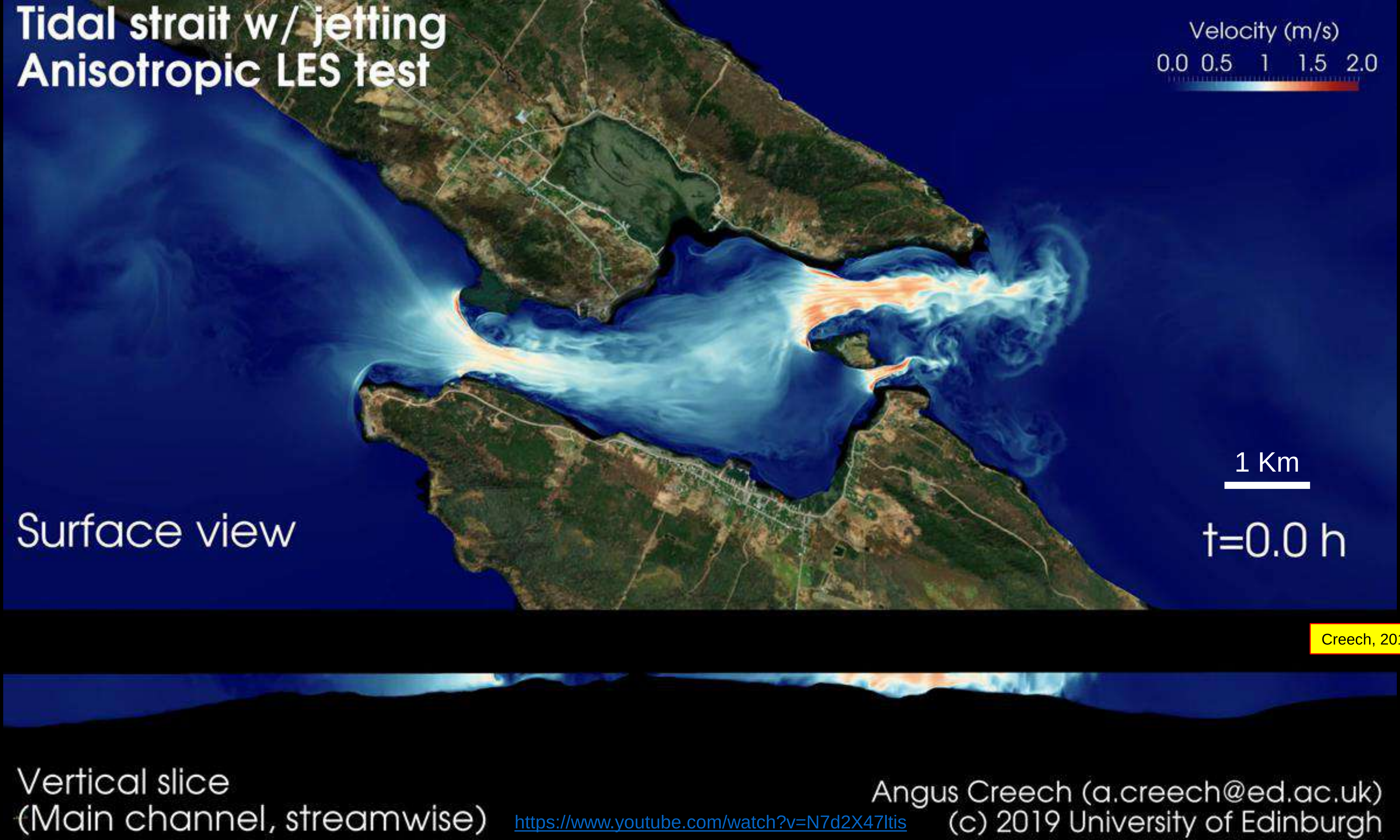


https://www.youtube.com/watch?v=_OU84SrS9sE

TIDALLY ASYMMETRIC

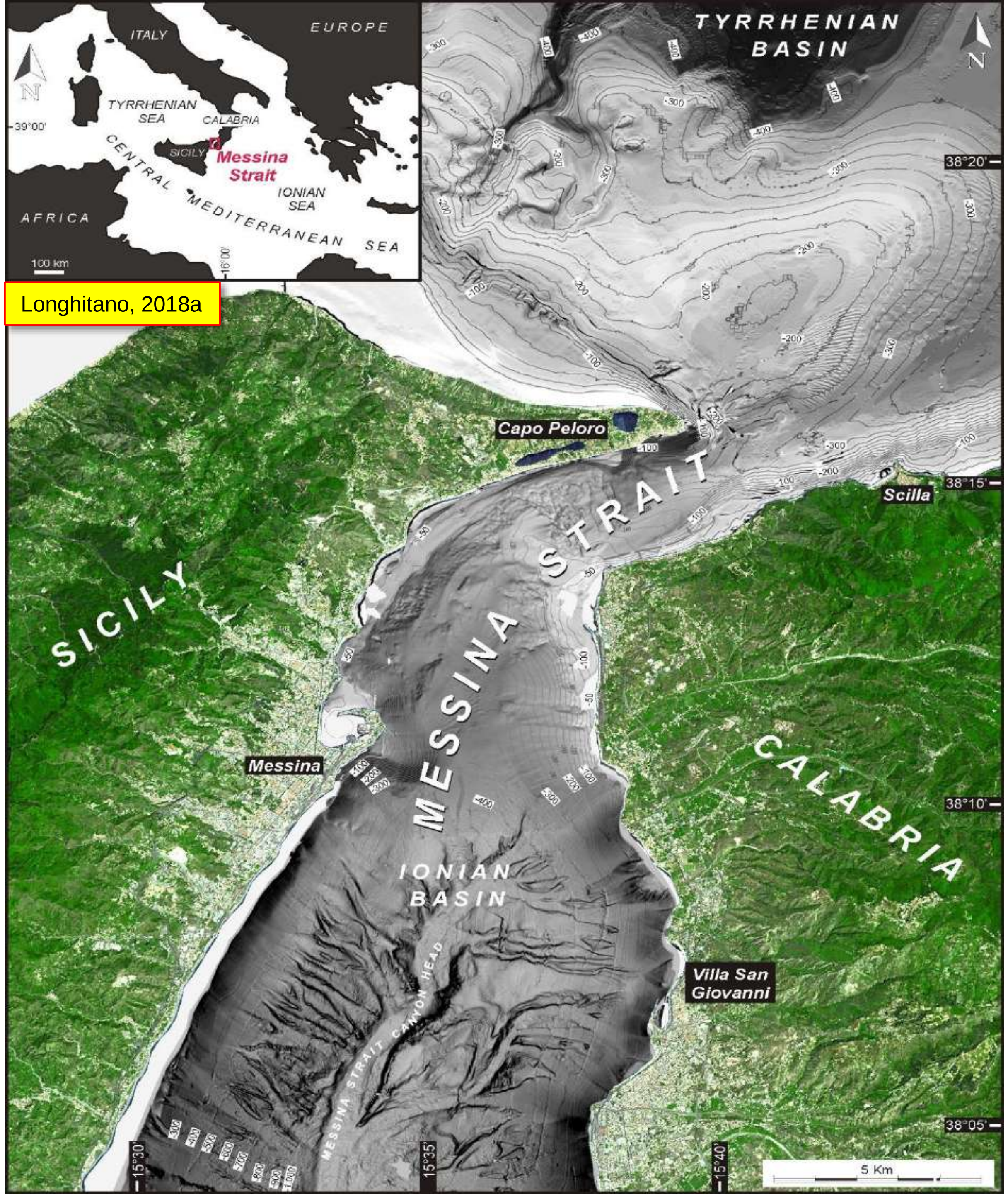


https://www.youtube.com/watch?v=lyg34_WNIP4



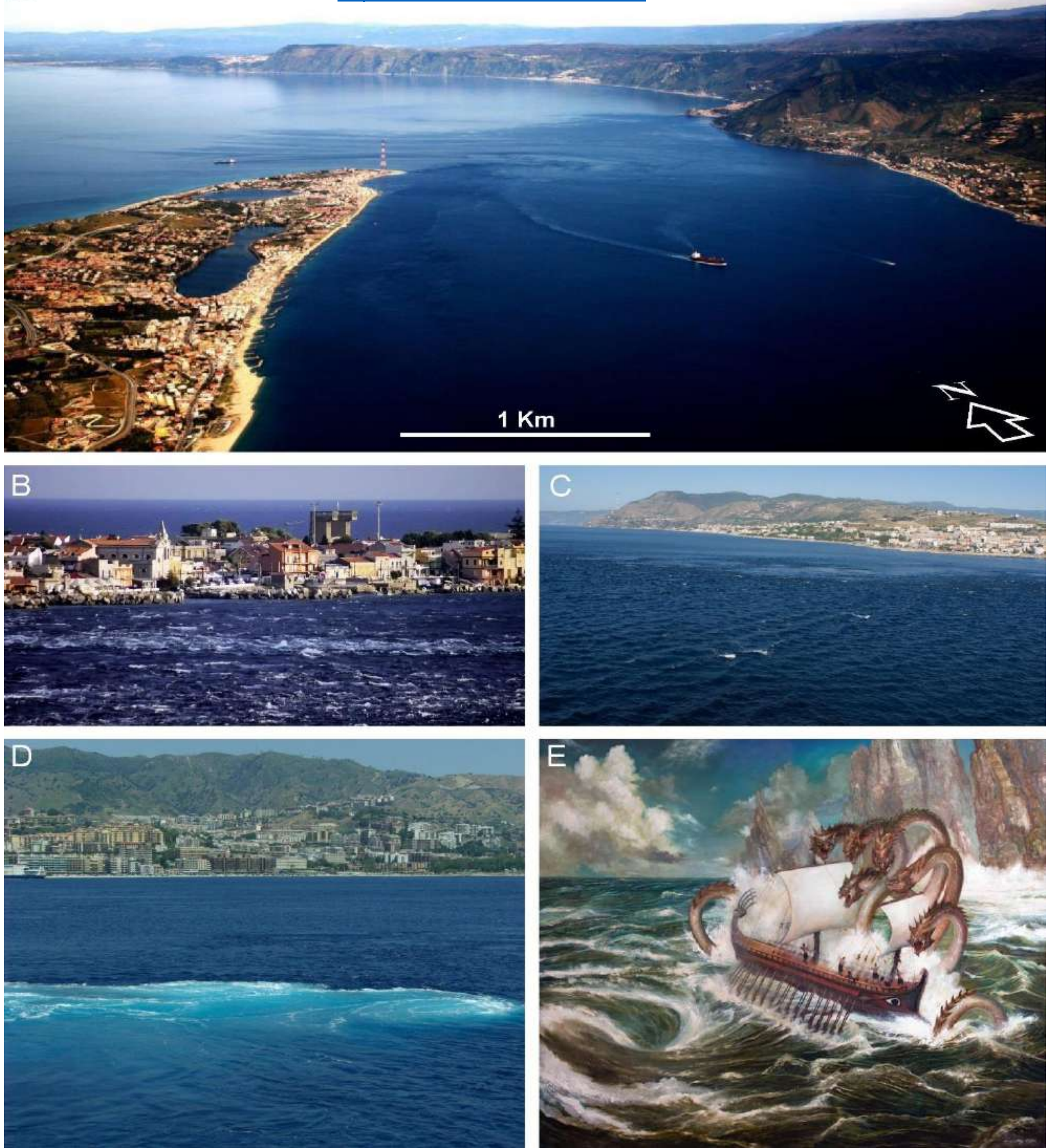
Creech, 2019

https://www.youtube.com/watch?v=N7d2X47Itis



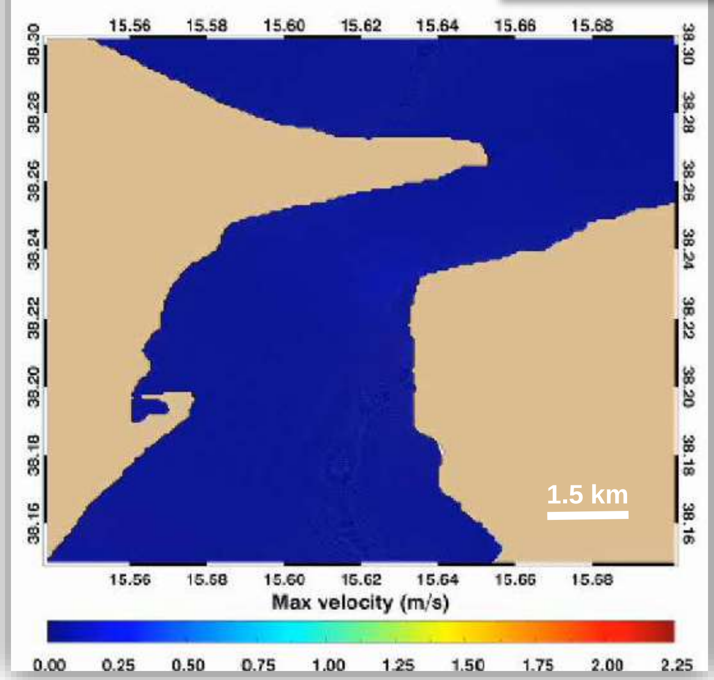
Longhitano, 2018a

http://www.correntidellostretto.it/

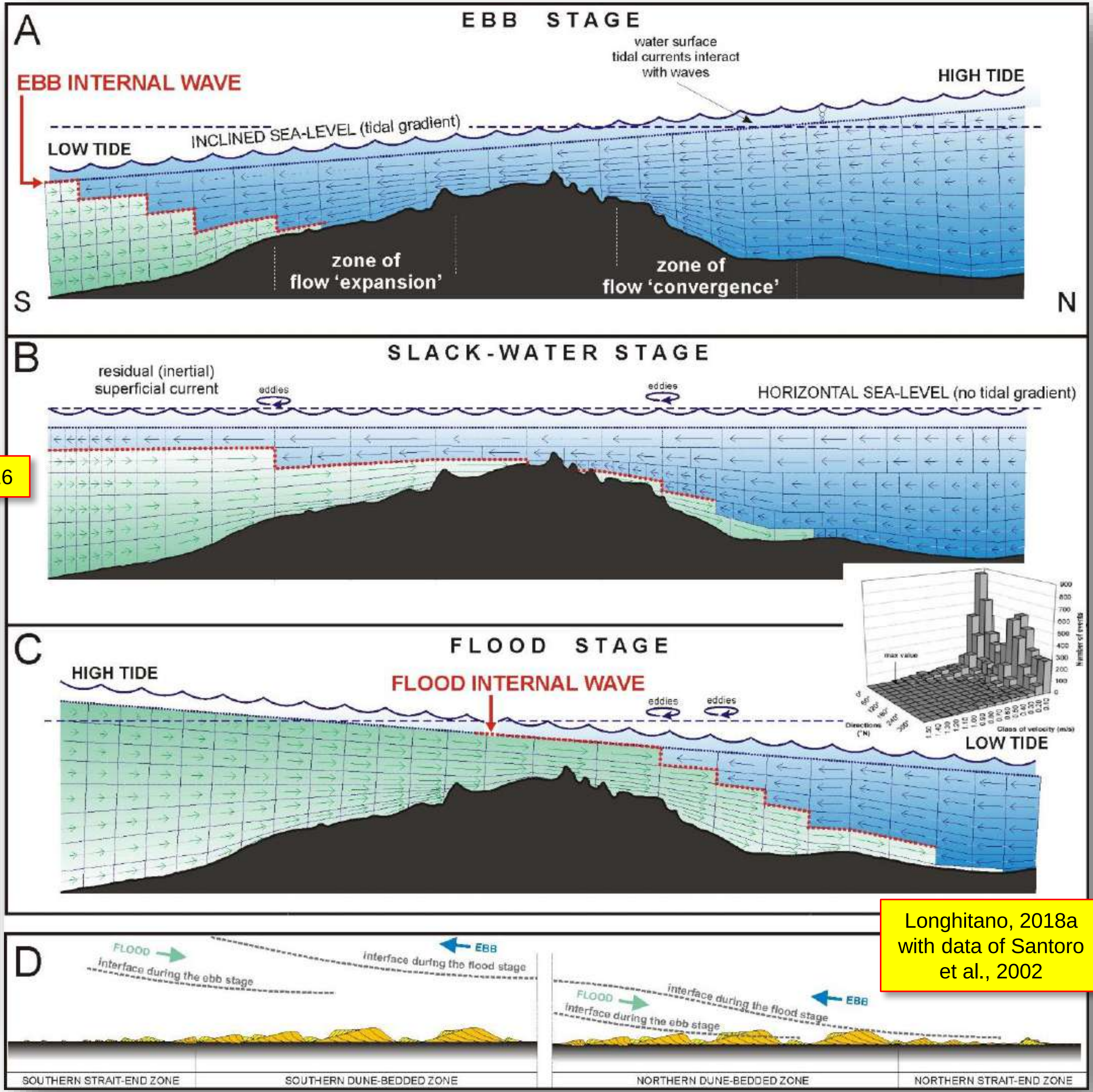


Messina Strait (central Mediterranean)

Droghei et al., 2016

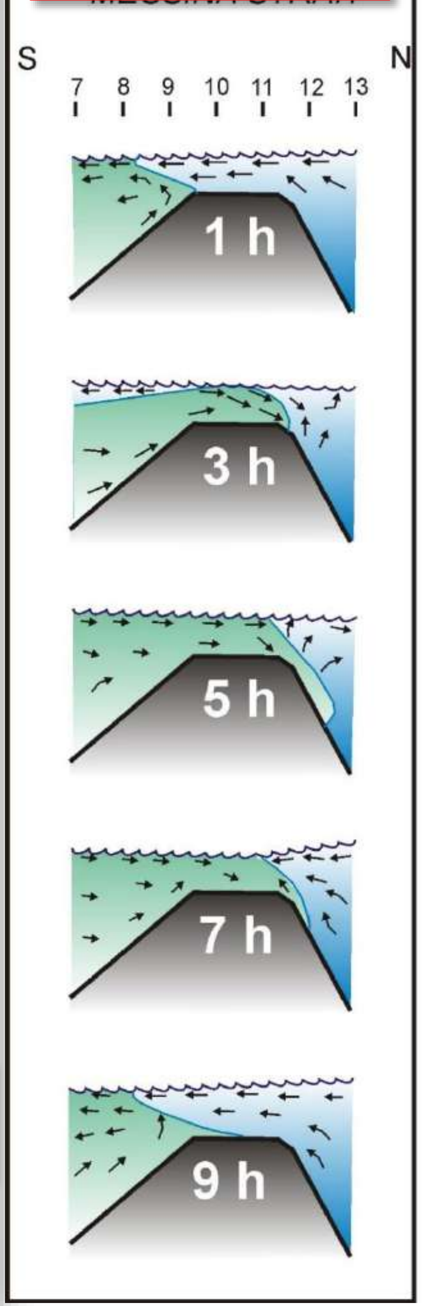


https://www.nature.com/articles/srep36376#Sec7



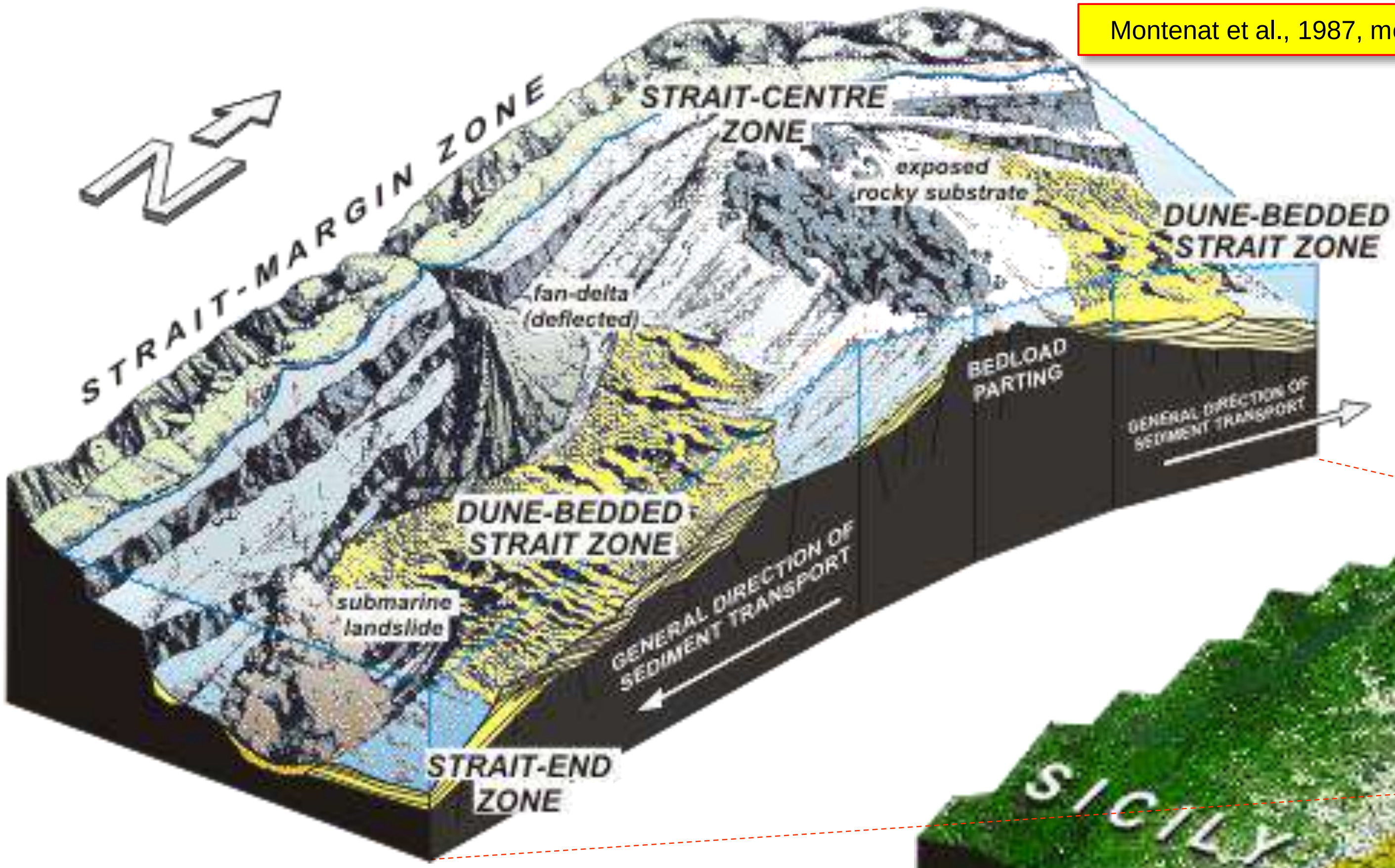
Longhitano, 2018a with data of Santoro et al., 2002

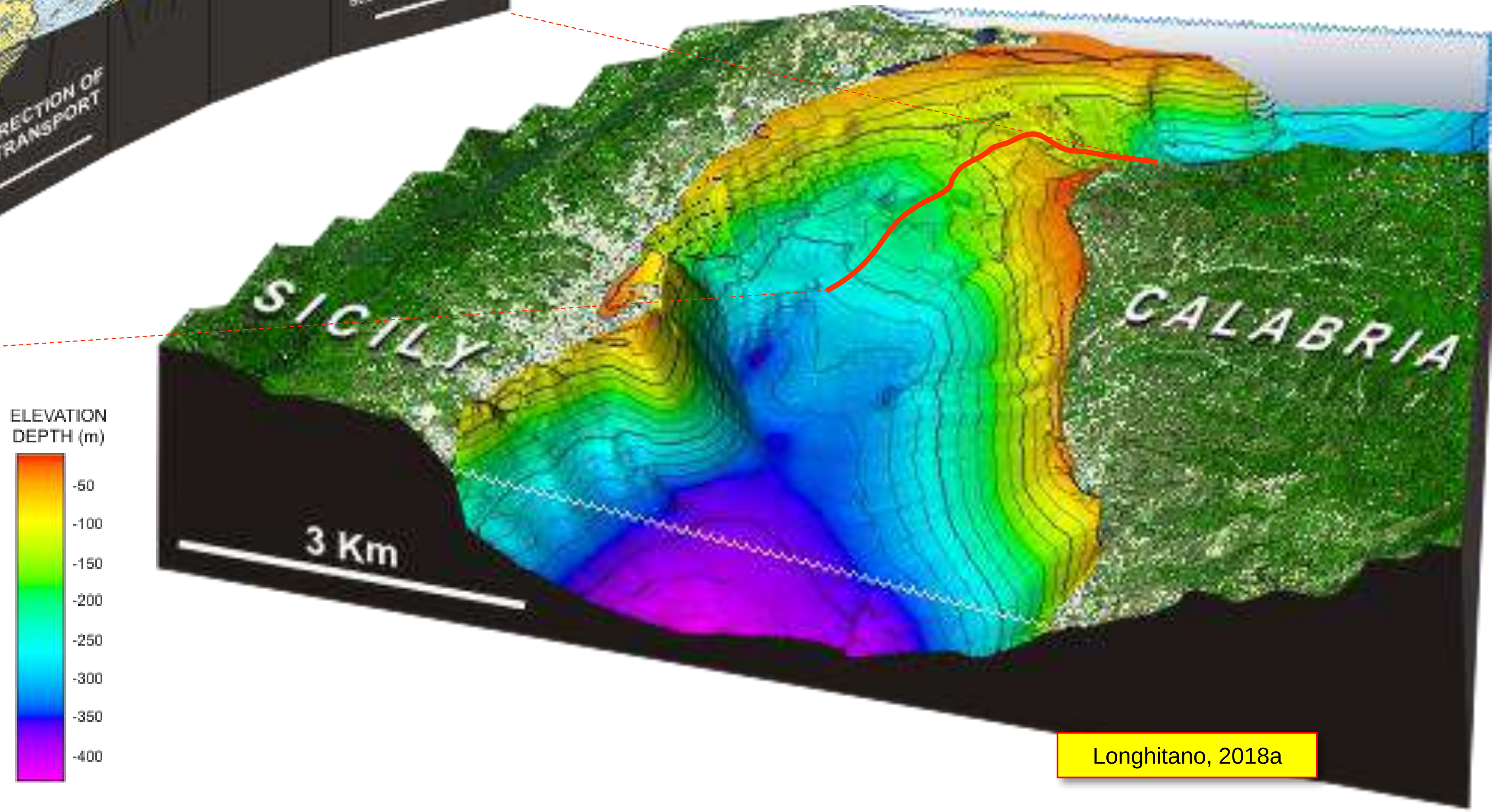
Defant, 1941, with data of Vercelli, 1925



HOW DOES THE TIDAL HYDRODYNAMICS OF THE MESSINA STRAIT IMPACT ON SEDIMENTS AT THE BOTTOM ?

Montenat et al., 1987, mod.

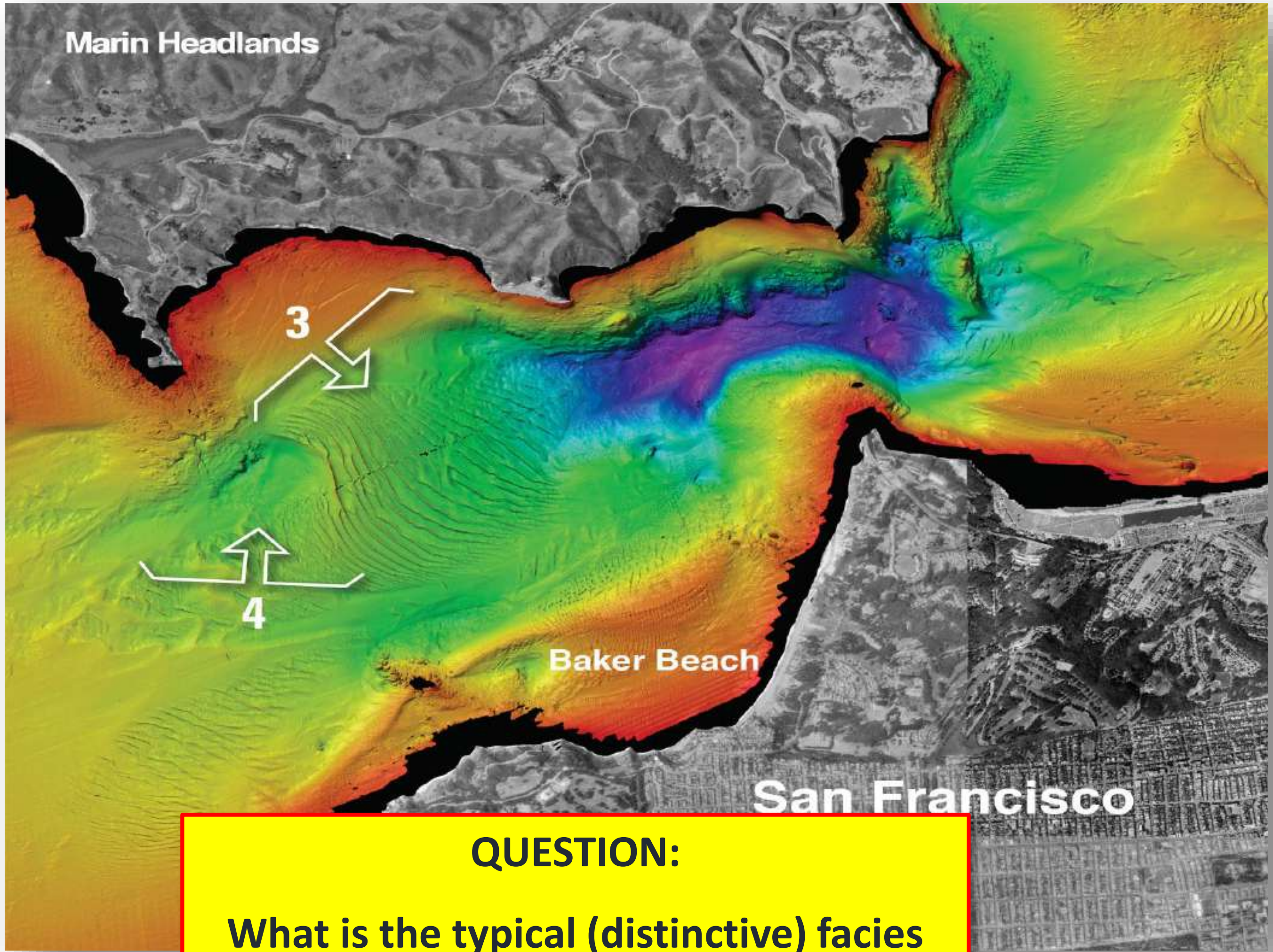




Longhitano, 2018a

• What is the sedimentary signature of tidal straits?

SEDIMENTARY BEDFORMS are typical features in strait bottoms. They may be **tidal sand ridges**, **sandwaves**, **dunes** and **ripples**, as result of the bed shear stress exerted by reversal tidal currents interacting with waves and other sea-water perturbations.

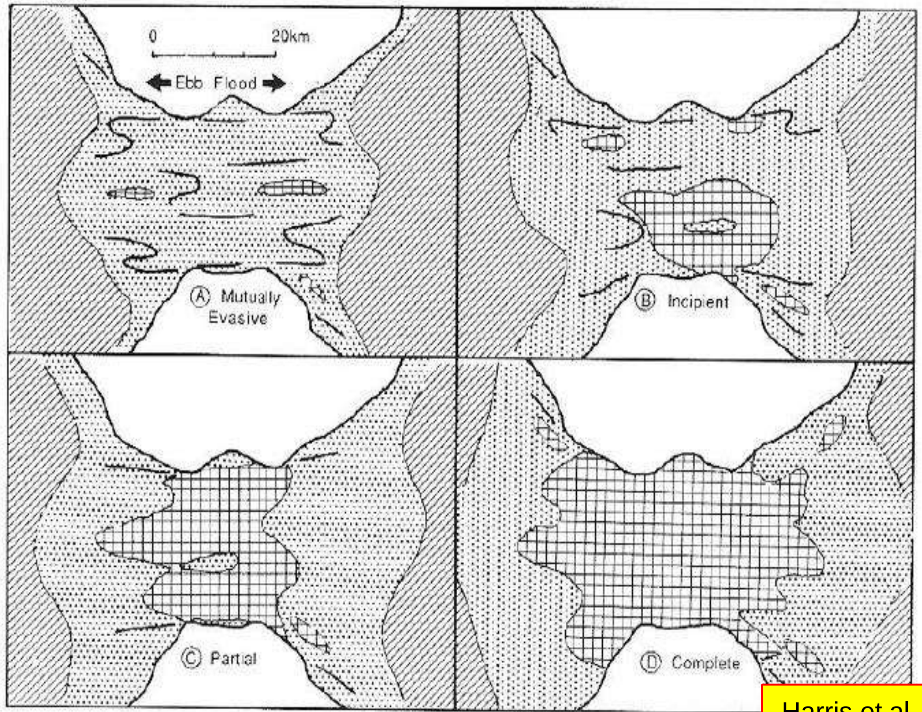


ht … -program?qt-

QUESTION:

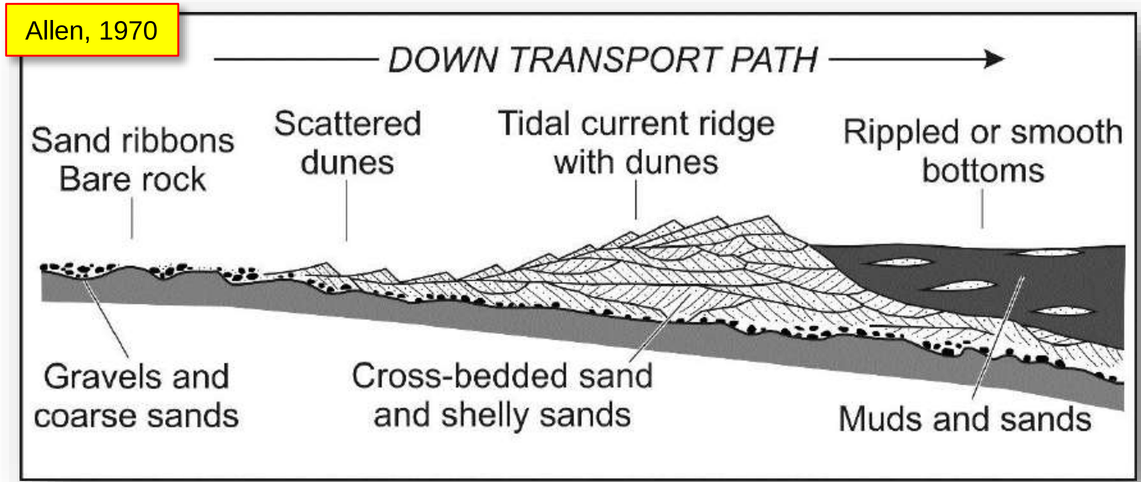
What is the typical (distinctive) facies tract of a tidal strait?

TIDAL STRAITS produce sediment **'bedload parting'**, which promotes the transport of bed material from the central (erosional) part toward either sides of the strait after flow expansion (Harris *et al.*, 1995). Bedload parting depends on the tidal phase dominance along the strait (e.g., the more symmetrical the reversal currents, the more volumetrically equivalent the depositional areas).

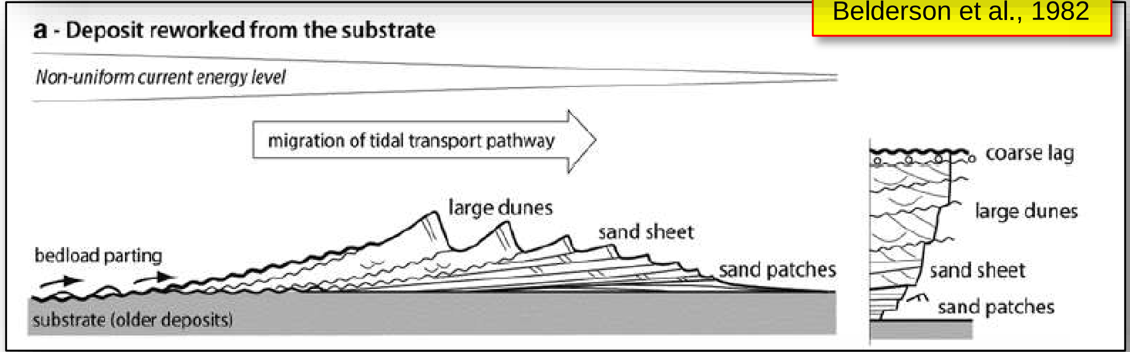


Harris et al., 1995

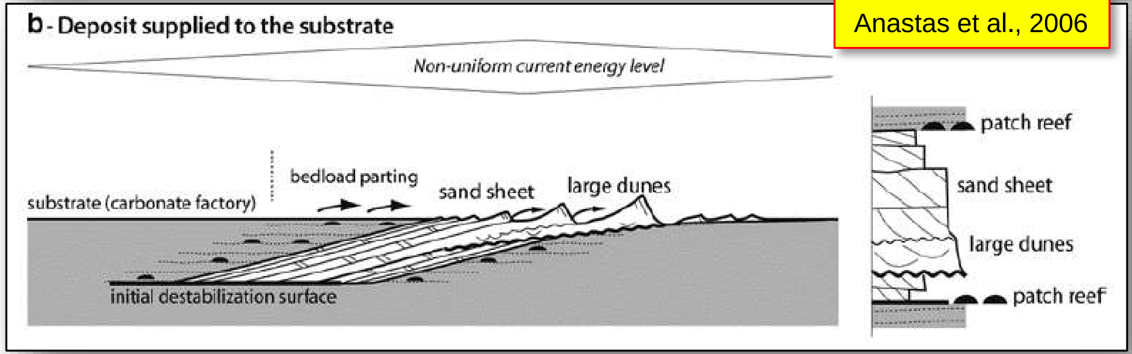
• Previous ‘embrional’ models and intuitions on tidal straits …



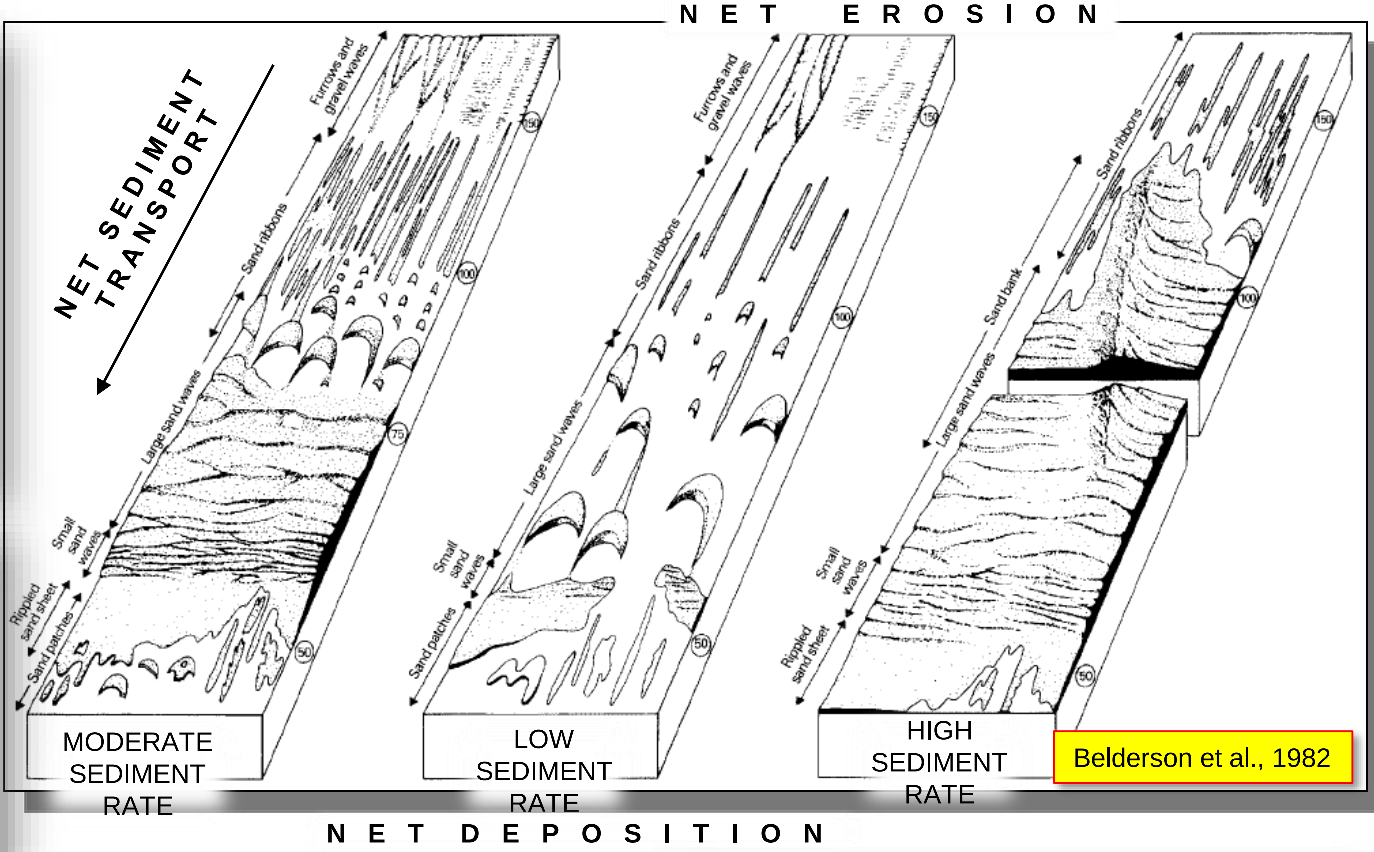
Allen, 1970



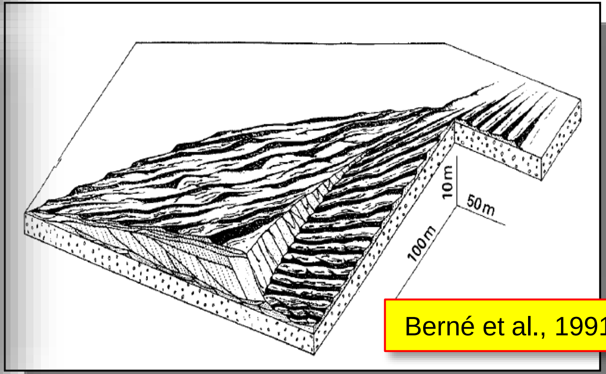
Belderson et al., 1982



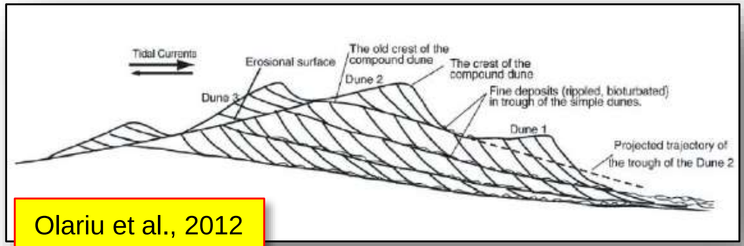
Anastas et al., 2006



Belderson et al., 1982



Berné et al., 1991

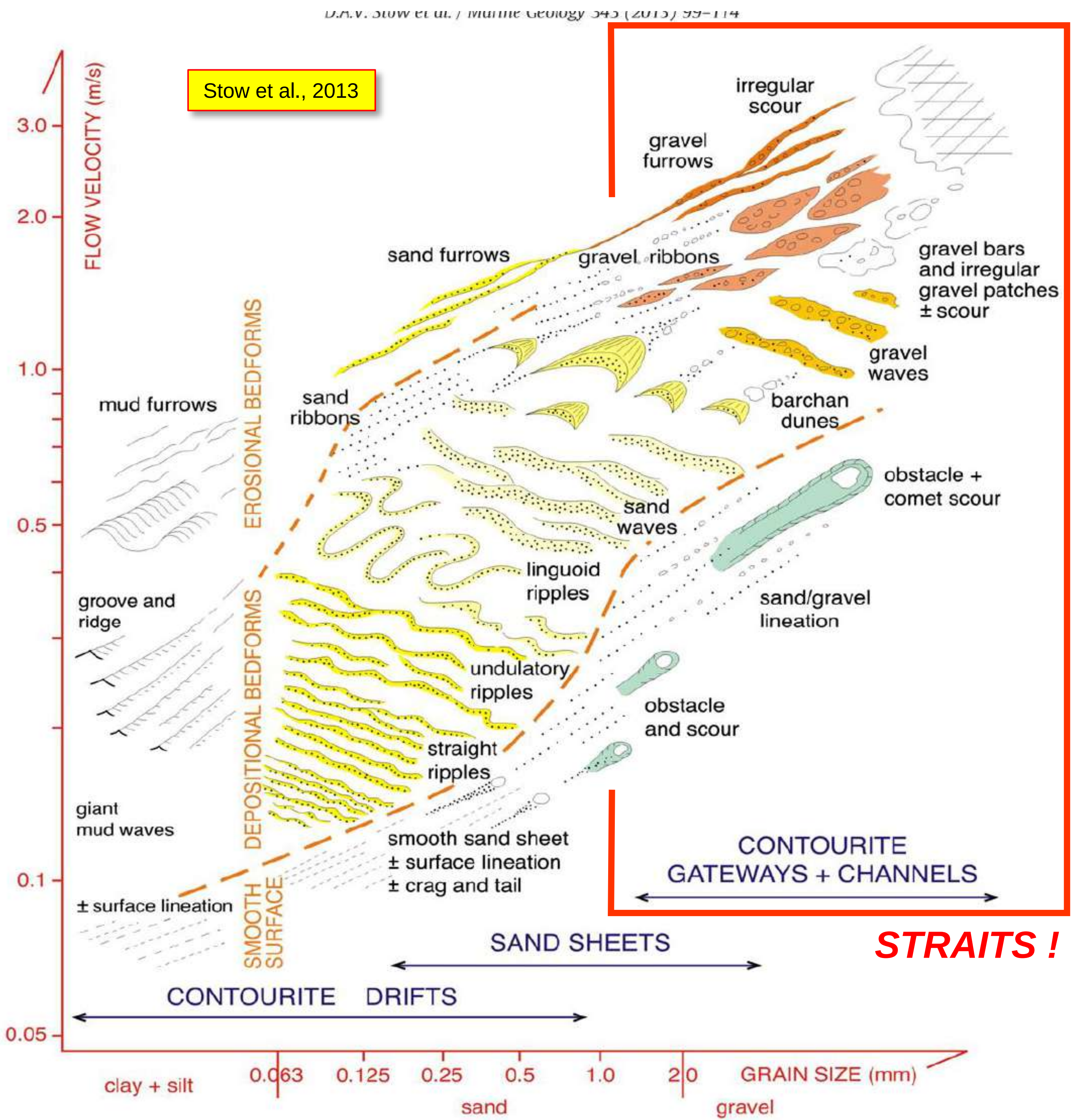


Olariu et al., 2012

Models available for modern straits have been intentionally neglected in favor of schemes, which refer to broader shelf segments. Here, typical and distinctive strait bedforms are attributed to the most proximal portions of (tidally-modulated) contouritic systems (e.g., Stow et al., 2013). This zone, here indicated as 'gateway + channels', perfectly **matches what we have observed in modern straits**.

However, these **bedform continuums are depth independent**. In other words, the **hydrodynamic amplification** due to lateral constraining seems to be the principal driving mechanism to shape mobile bottoms into predictable bedforms.

Therefore, **tidal straits do not have preferencial depth intervals to develop.**



Depositional Zone Partitioning in Modern Tidal straits

Detailed multi-beam images of modern tidal straits allow the identification of depositional zones, each characterized by common hydrodynamics, sediment grain sizes, bedforms, and morpho-bathymetric features.

These zones are:

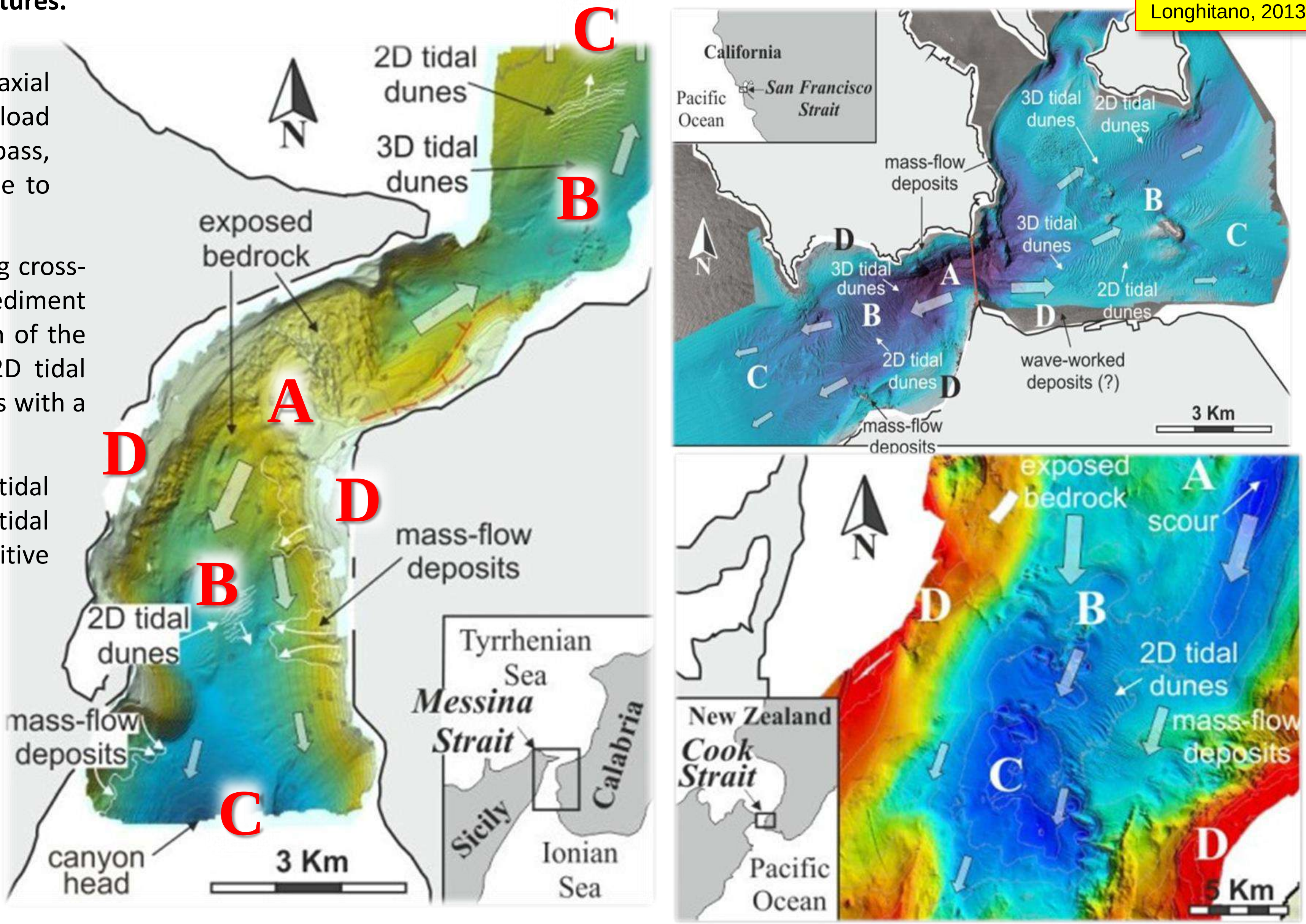
(i) the ***STRAIT-CENTER ZONE*** (A): the narrowest axial sector of a tidal strait, associated with bedload parting, tidal current maxima and sediment by-pass, with erosion or net deposition close to zero due to the highest bed shear stress;

(ii) the ***DUNE-BEDDED STRAIT ZONE*** (B): a widening cross-sectional area, is the zone of maximum sediment accumulation rate due to the initial deceleration of the tidal currents (medium to very large 3D and 2D tidal sand dunes associated with ripple-scale bedforms with a reversed or transverse direction of migration);

(iii) the ***STRAIT-END ZONE*** (C): the distal part of a tidal strait, commonly characterized by decelerating tidal currents and deposition of fines, due to the definitive enlargement of the strait cross-section;

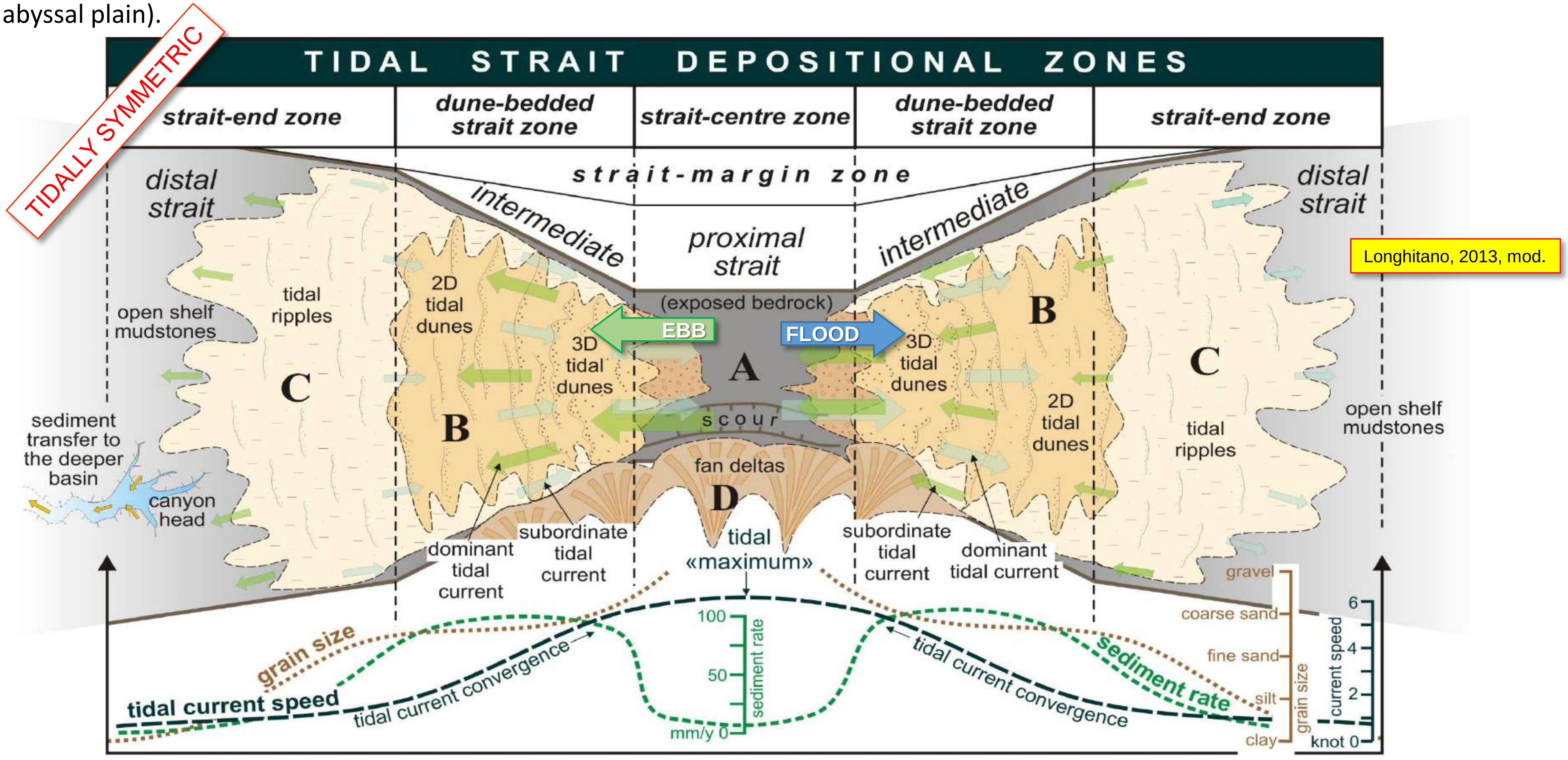
(iv) the ***STRAIT-MARGIN ZONE*** (D): the flanks of a tidal strait, influenced by wave reworking processes in gently-sloping strait margins (e.g., the Torres Strait), or gravity-driven, sediment mass flows in straits with steeper margins (e.g., the Messina Strait). The deepest part of this zone is also influenced by tidal currents flowing along the axis of the strait.

Longhitano, 2013



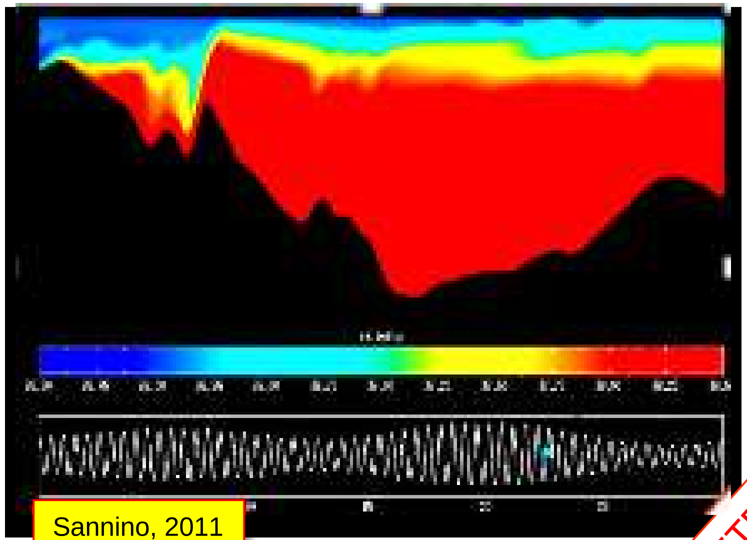
TIDAL STRAIT: ZONE PARTITION

Modern tidal straits can be either symmetrical and asymmetrical. Examples of symmetrical systems are the Messina, San Francisco and Cook straits, where the depositional zones are equally divided by the center; the Malacca Strait is asymmetrical (its southeastern side rapidly descends into an abyssal plain).



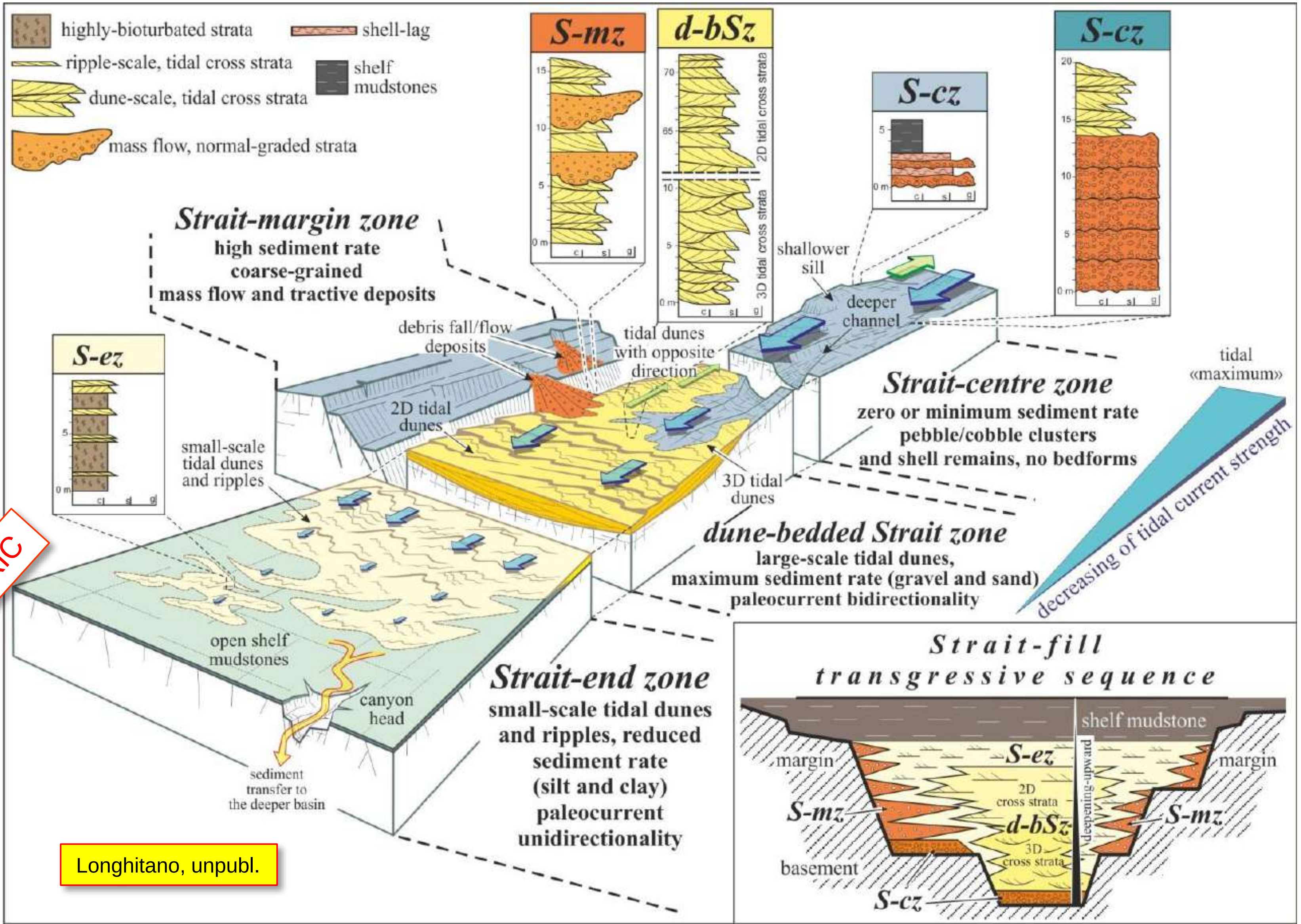
TIDAL STRAIT: ZONE PARTITION

A symmetrical or asymmetrical configuration, which is mostly governed by the tectonic evolution of the seaway, is key in the reconstruction of ancient tidal straits, because symmetrical or asymmetrical systems generate very different volumes and distributions of dune-bedded, sand-prone deposits.

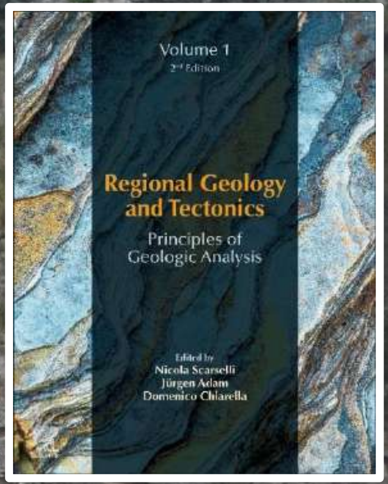


Sannino, 2011

TIDALLY ASYMMETRIC



Longhitano, unpubl.

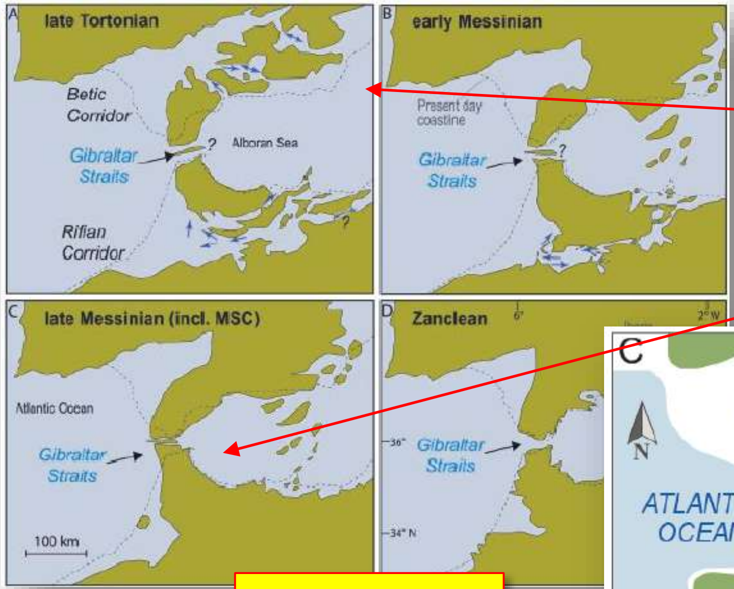


CRITERIA FOR RECOGNIZING TIDAL STRAITS IN OUTCROP OR SUBSURFACE SUCCESSIONS

Siderno Strait, Calabria, southern Italy

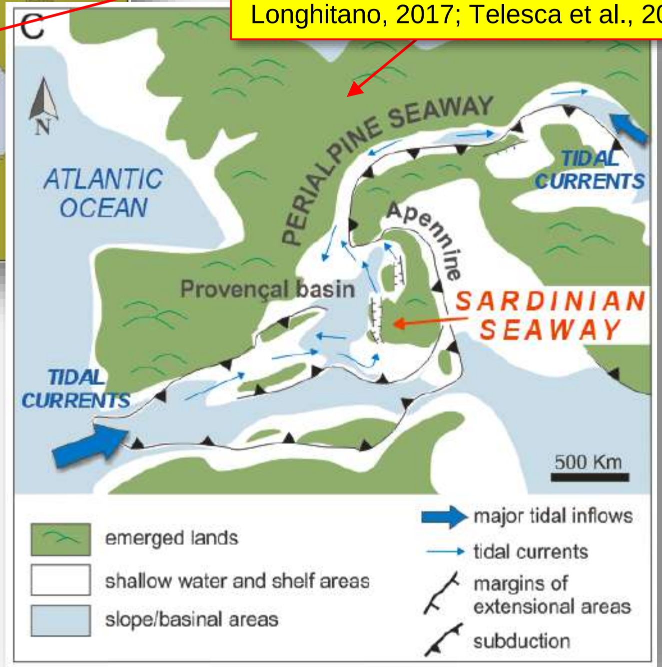
• Main areas of outcrop investigations

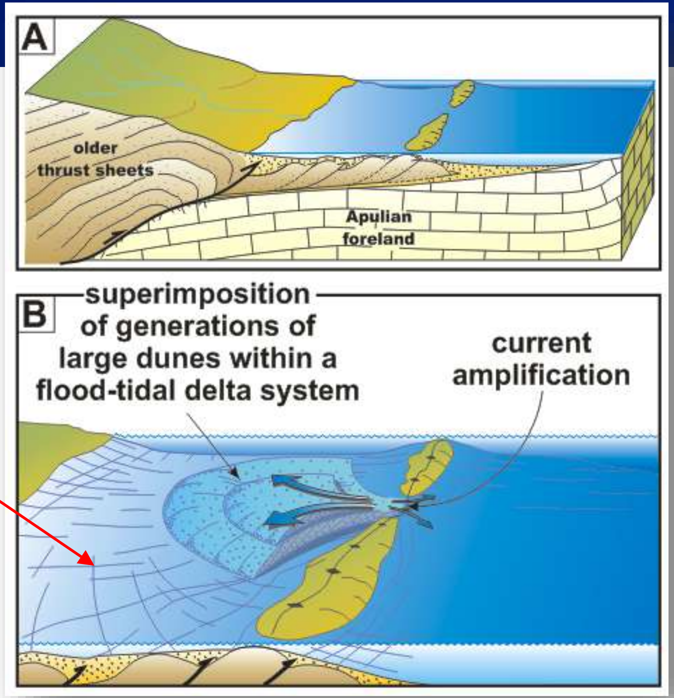
Stratigraphic interval: **Neogene-Quaternary**
Areas: **western Mediterranean basin**
Settings: **compressional, transtensional**
Investigated thicknesses: **25 to 200 m**

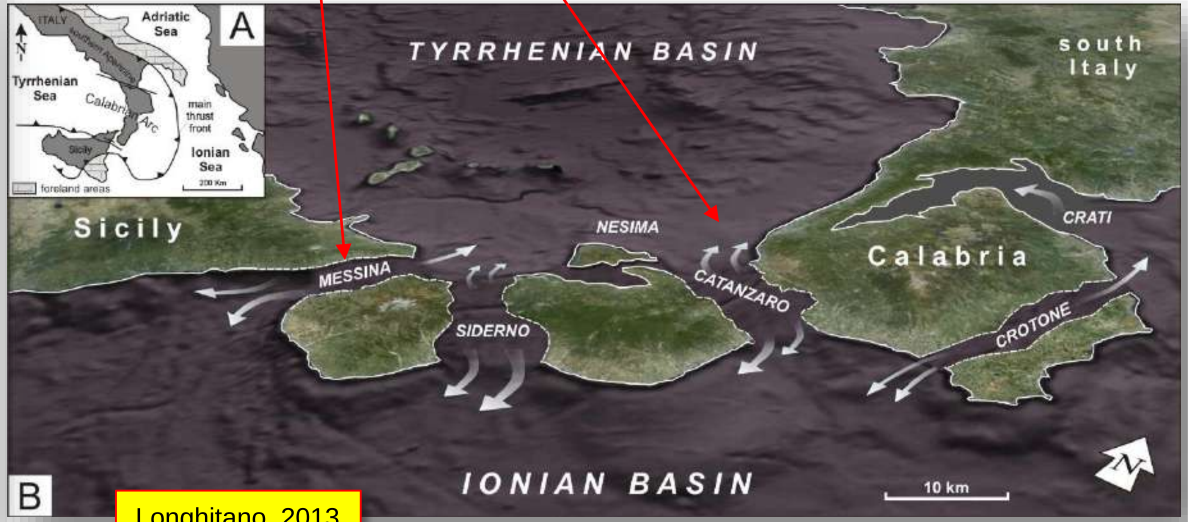


Capella et al., 2016

Longhitano, 2017; Telesca et al., 2020

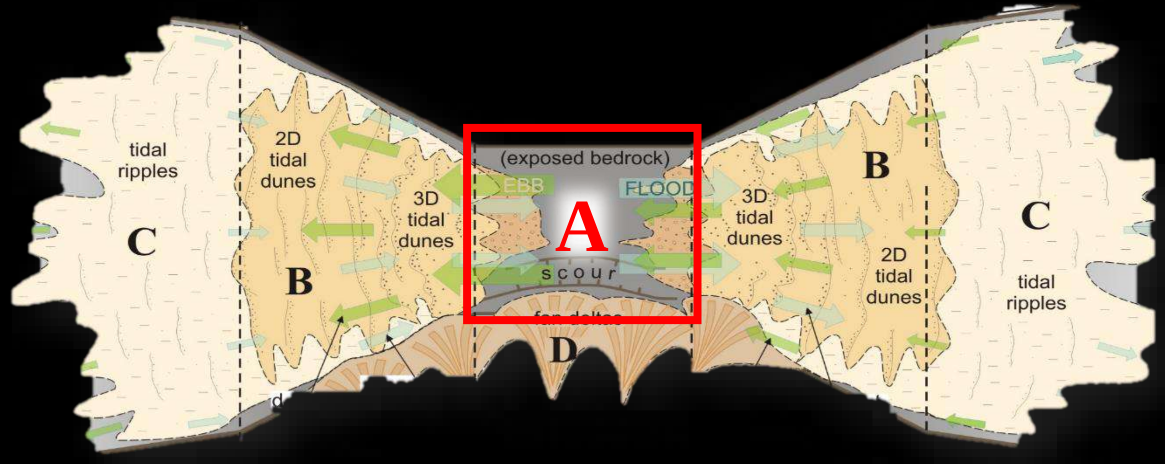




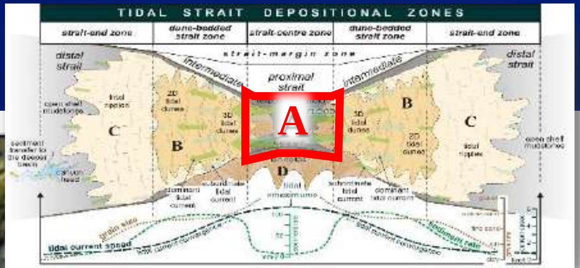


Longhitano, 2013

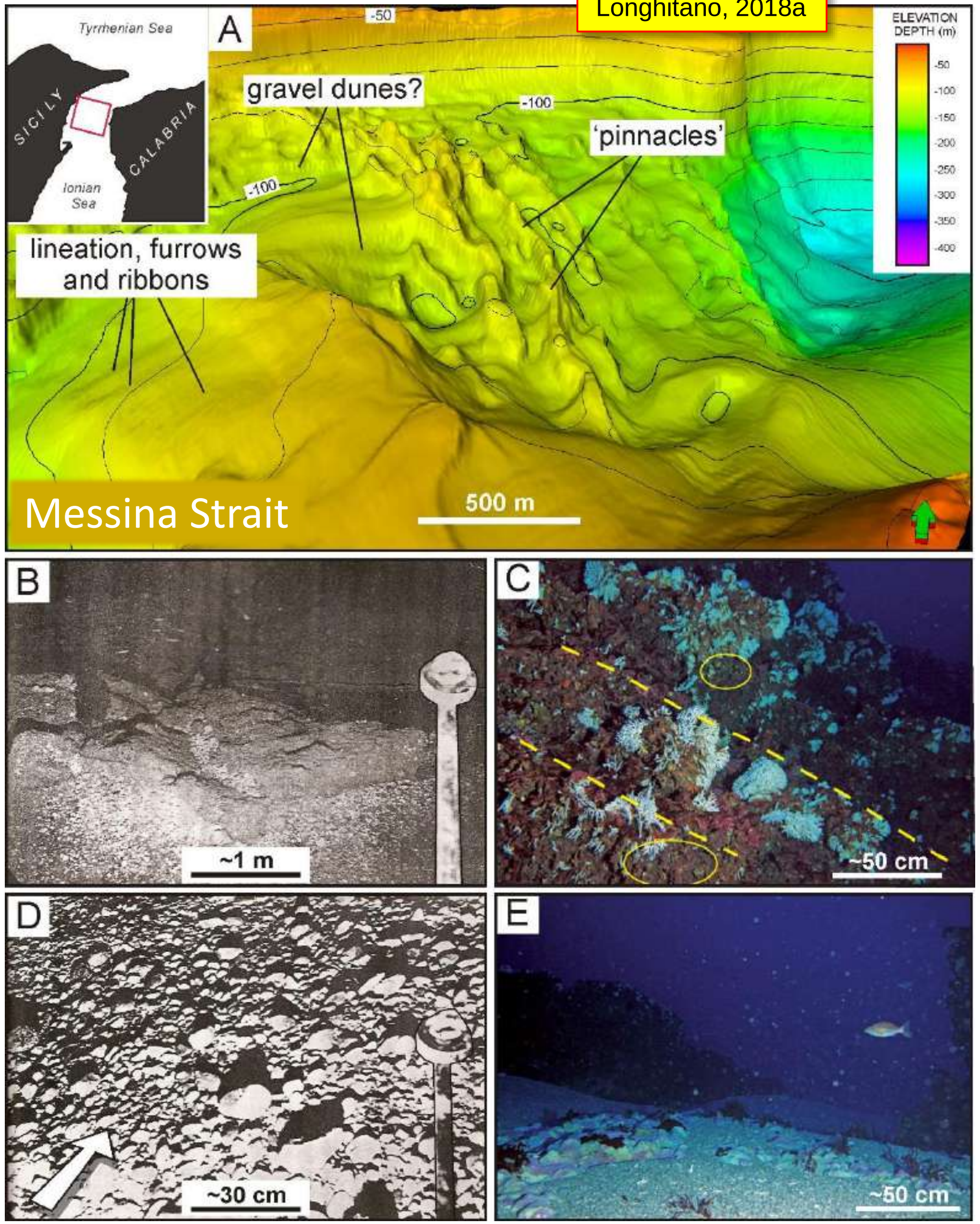
The strait-center zone

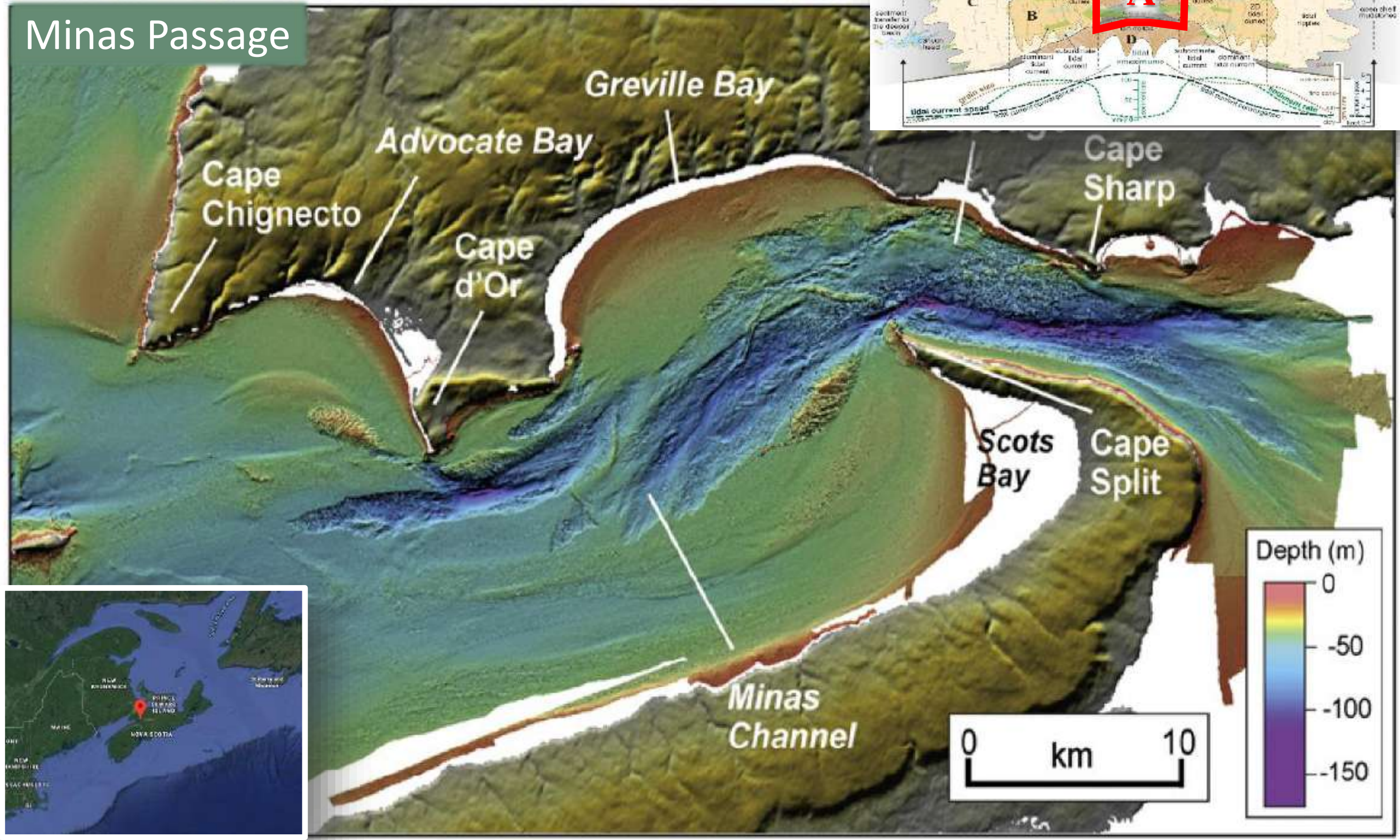


• The Strait-Center Zone



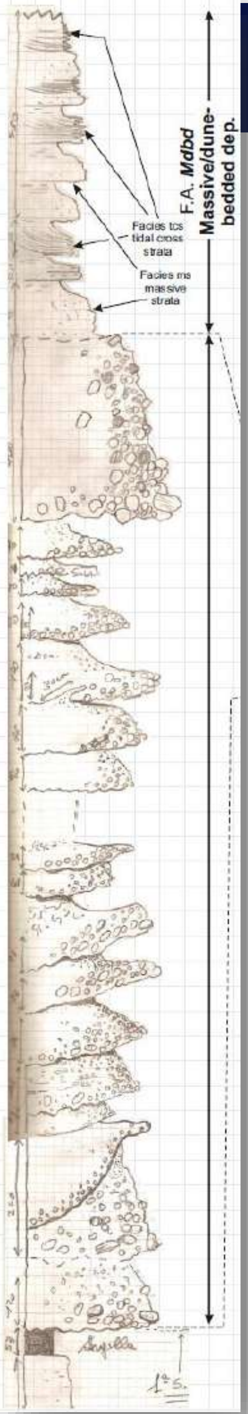
Longhitano, 2018a

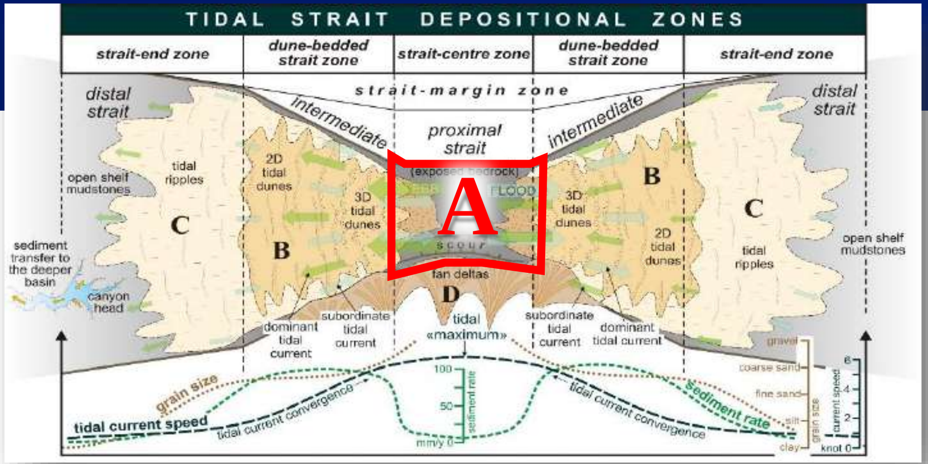




Shaw et al., 2012

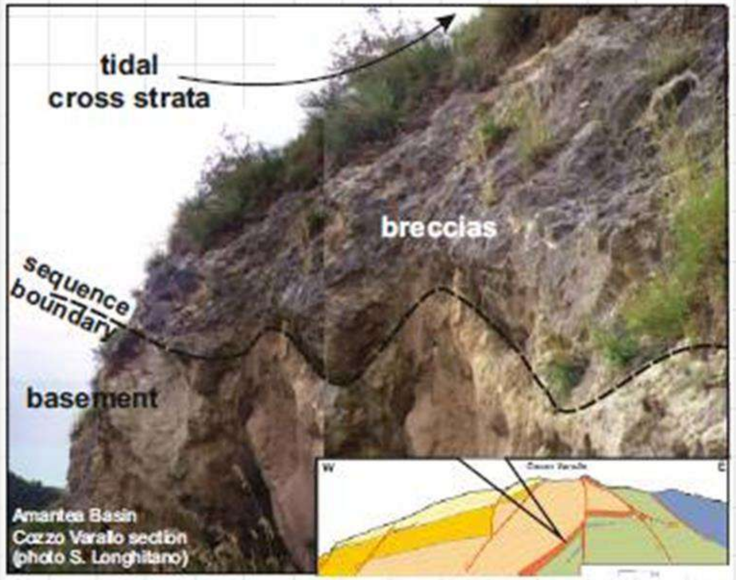
• The Strait-Center Zone

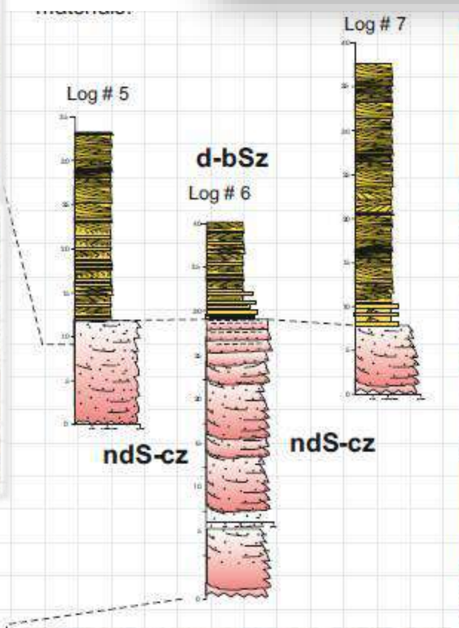




1) **GRAVEL/SHELL LAGS: THE STRAIT-CENTER ZONE**

laterally-discontinuous lags 1-2 m thick of massive assemblages of fossil fragments, pebbles and cobbles, immersed in a siliciclastic gravel-size matrix very rich in glaucony. Alternatively, this sector can be highly depositional and represented by coarse-grained sediments derived from the strait margins.



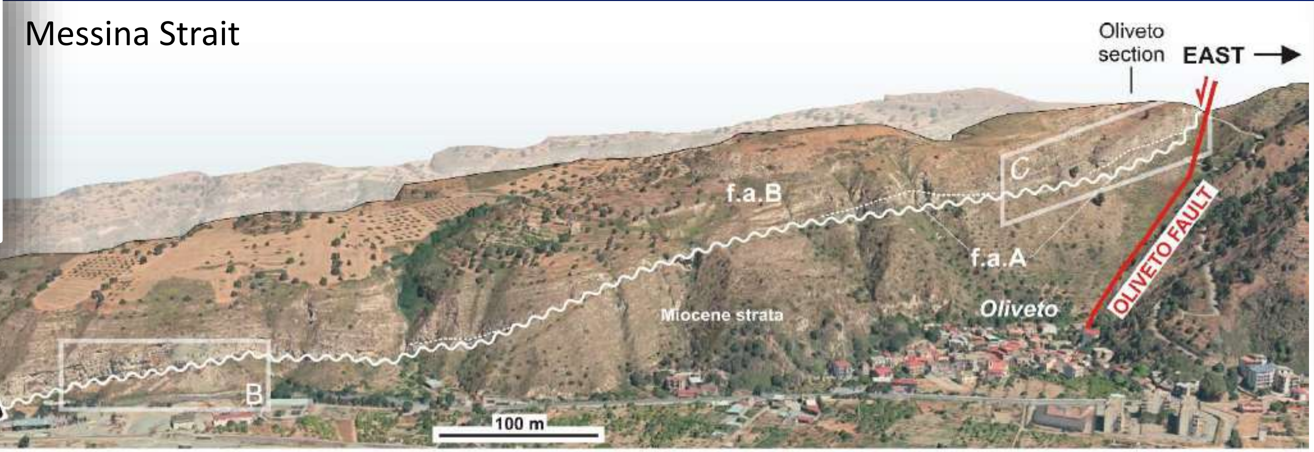


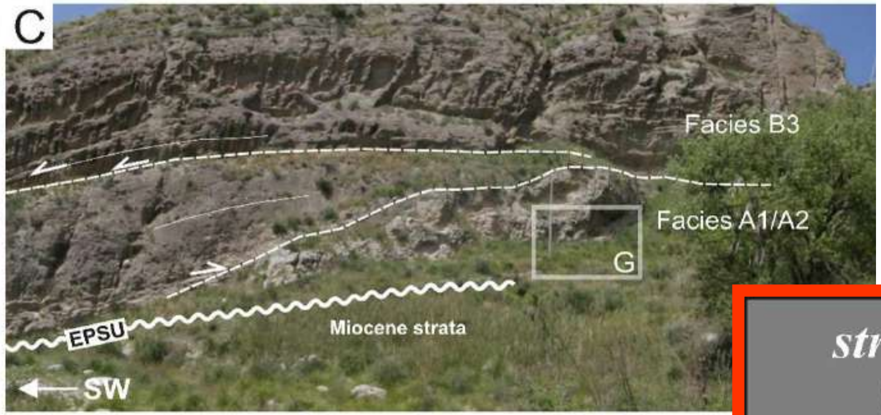
Faunal associations are represented by disarticulated mollusk shells associated with highly-weathered fragments of red algae, *Corallia errinecea* and *Laminaria*, indicating high-energy environments subjected to vigorous currents.sequences.

TORTONIAN, AMATEA BASIN

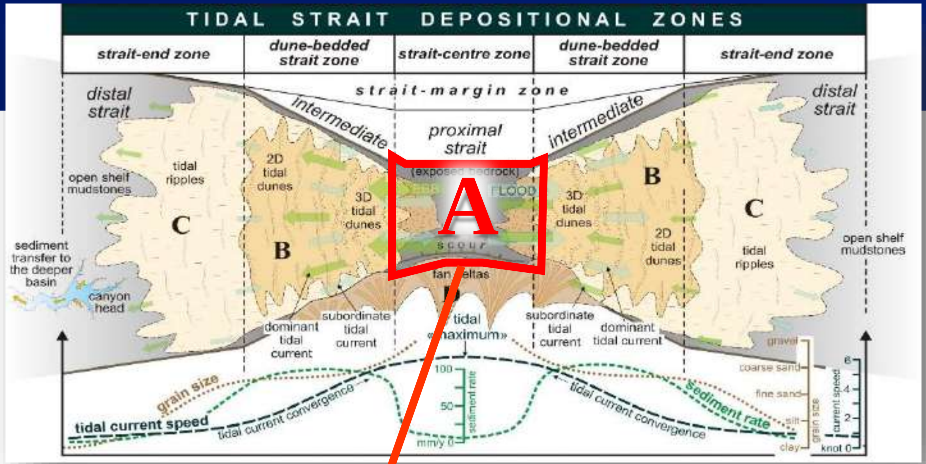
• The Strait-Center Zone

Messina Strait



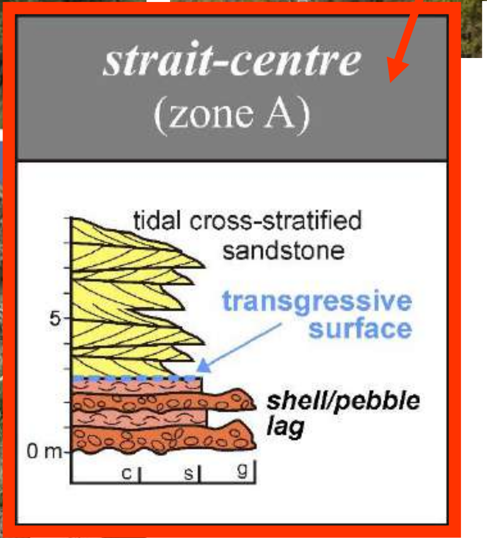


Longhitano, 2018b

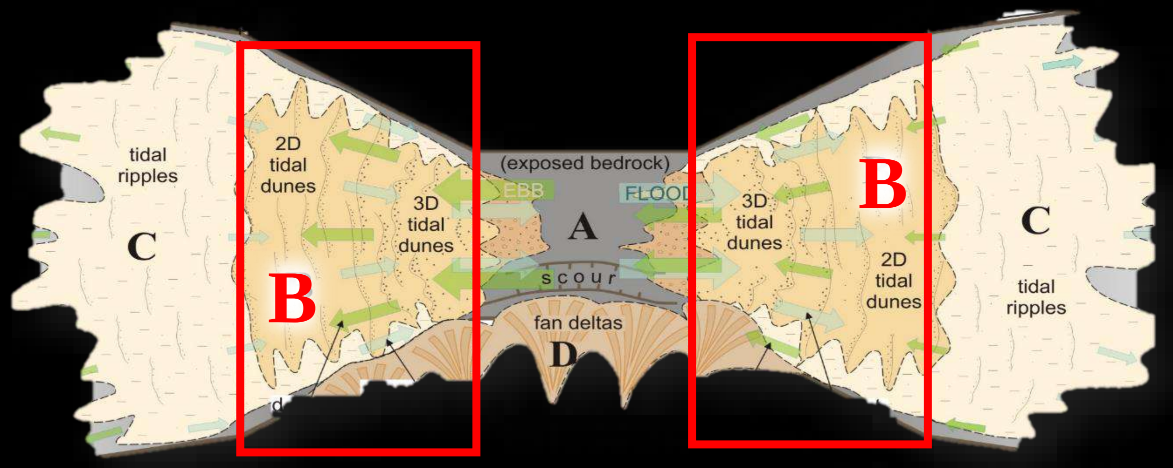


Martìn et al., 2014

The Miocene North Betic Strait

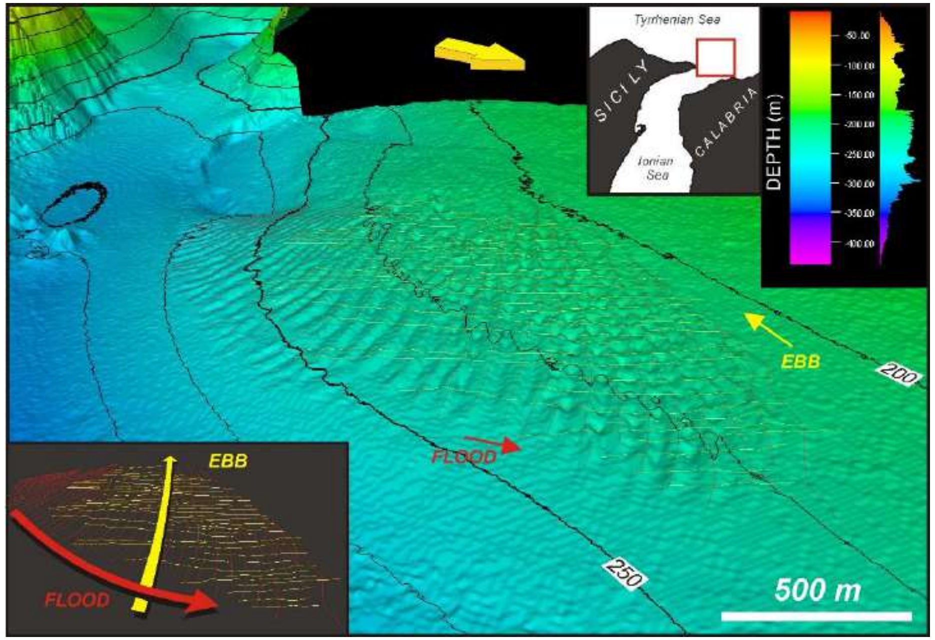


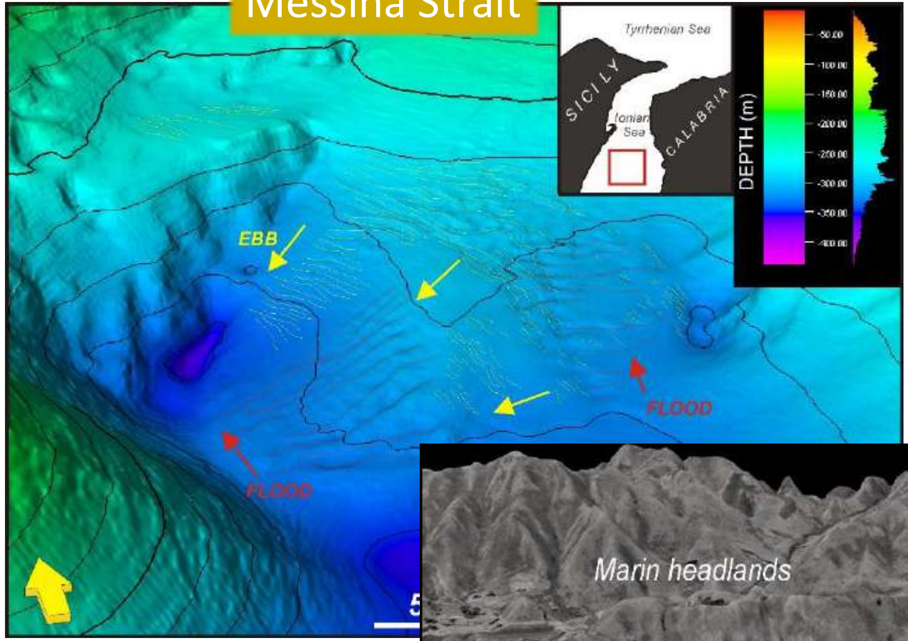
The dune-bedded strait zones

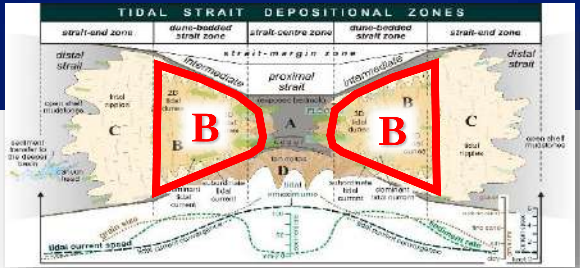


• The Dune-Bedded Strait Zones

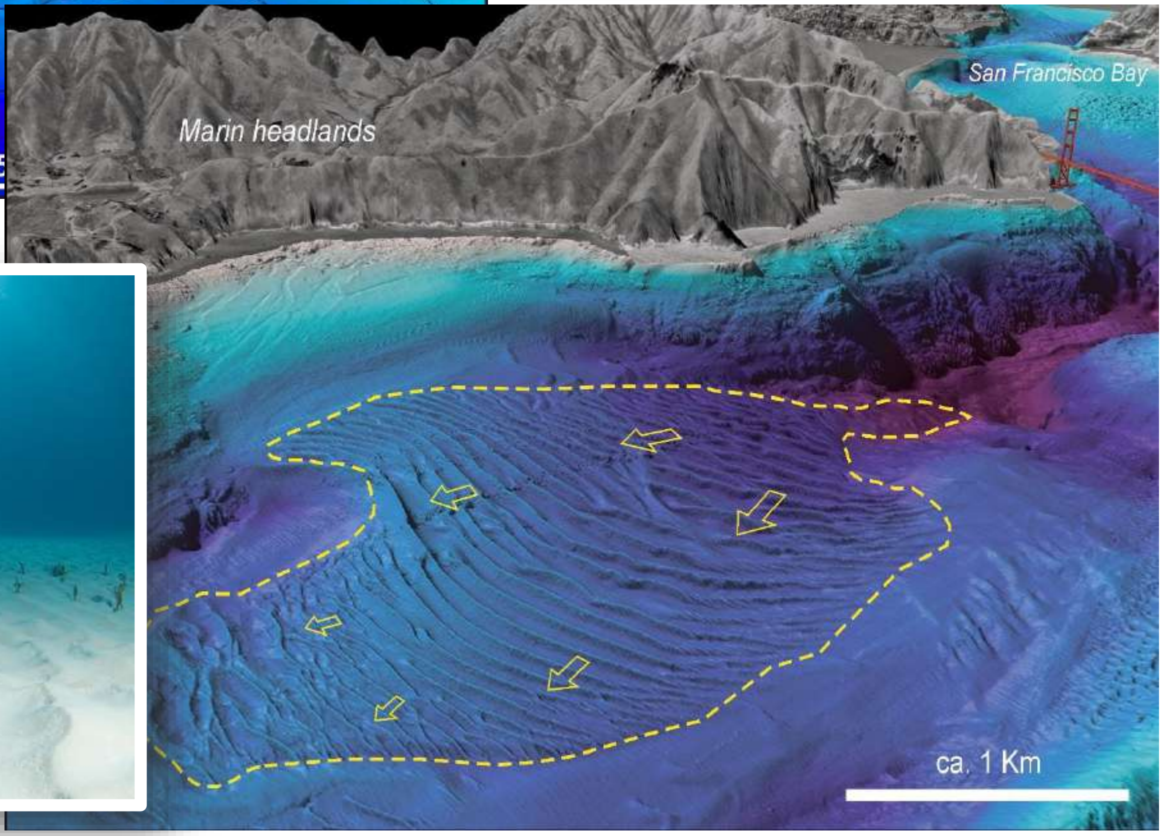
Messina Strait

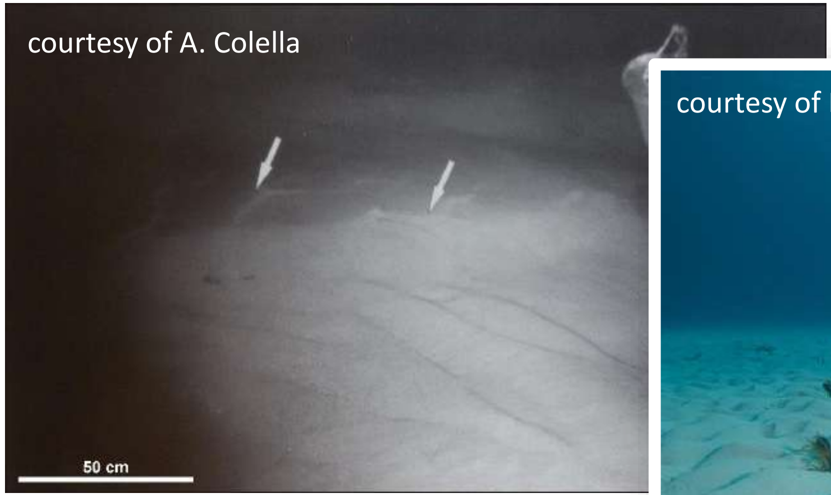






Dartnell et al., 2006





Longhitano, 2018a

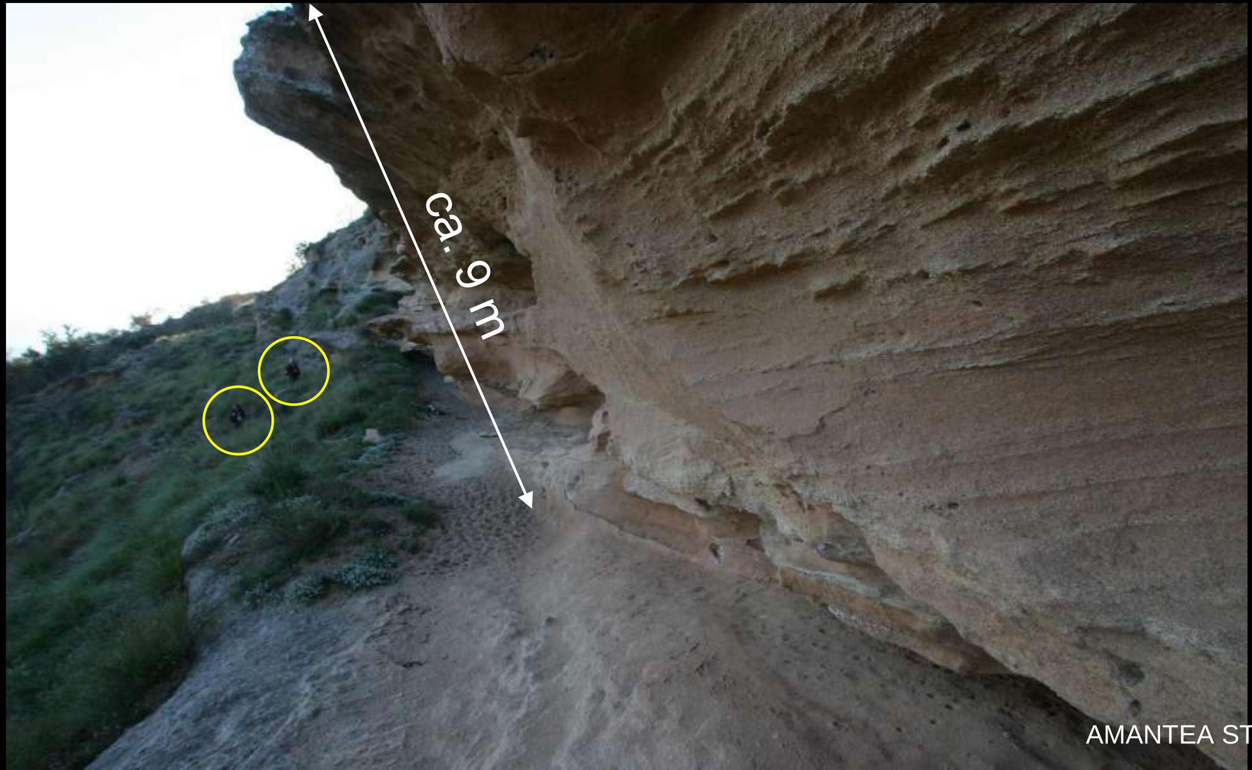

AMANTEA STRAIT, TORTONIAN

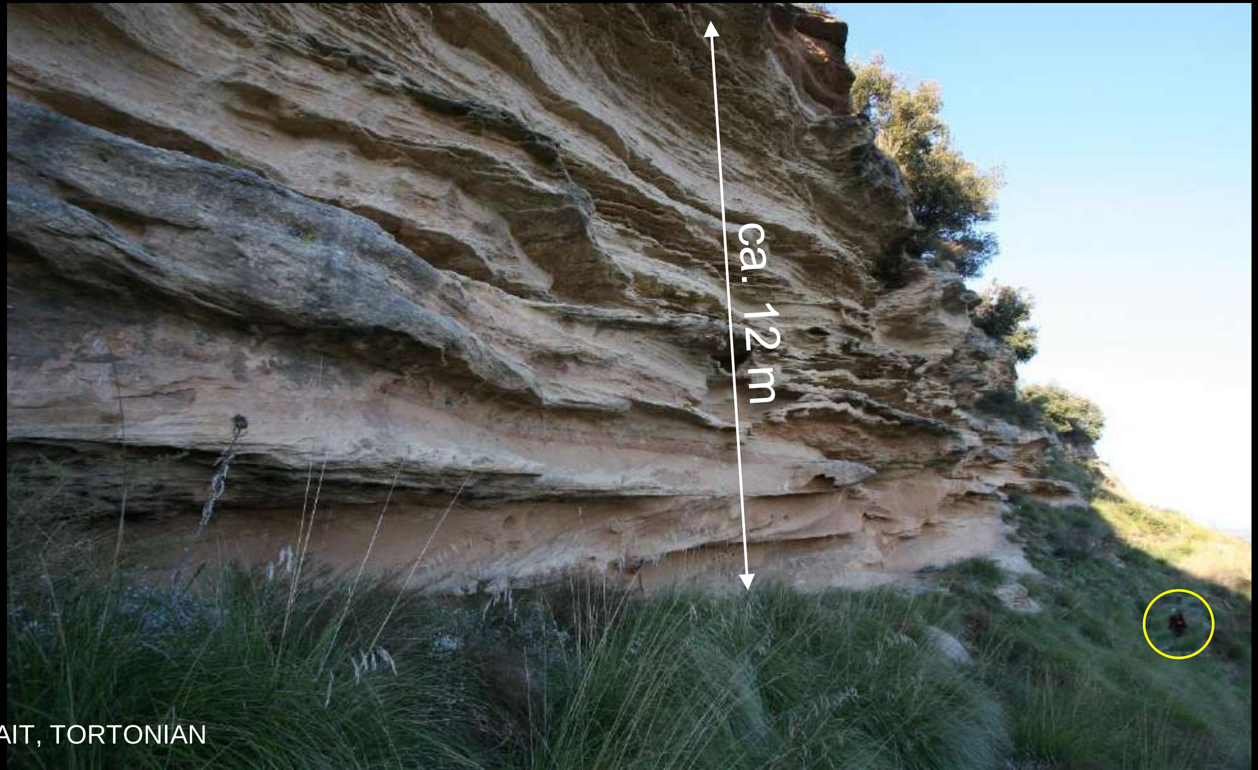
CATANZARO STRAIT, EARLY PLEISTOCENE

MESSINA STRAIT, EARLY PLEISTOCENE

SIDERNO STRAIT, EARLY PLEISTOCENE

CATANZARO STRAIT, EARLY PLEISTOCENE

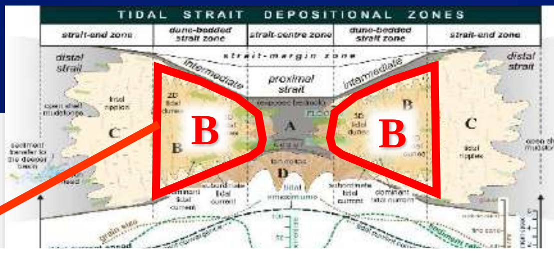




AMANTEA STRAIT, TORTONIAN

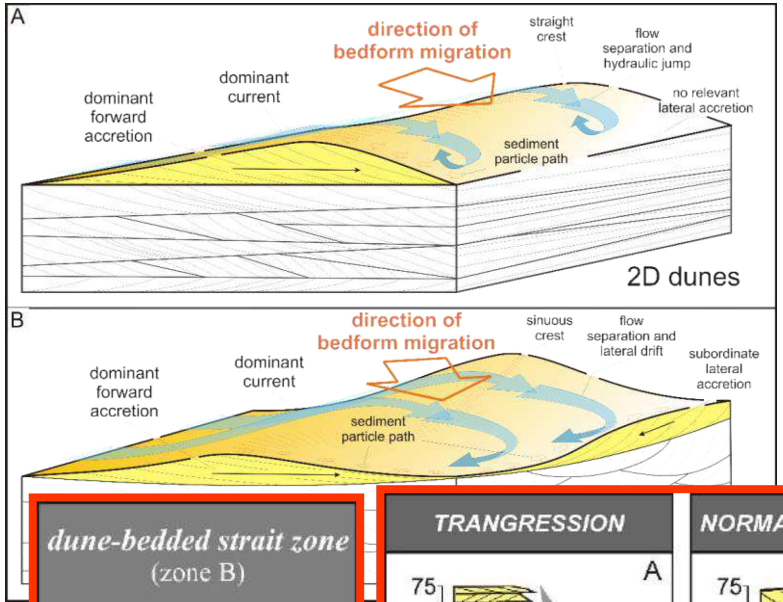
A VARIETY OF INTERNAL SEDIMENTARY STRUCTURES CONCUR IN SUPPORTING THE INTERPRETATION OF **TIDE-DOMINATED DEPOSITS**

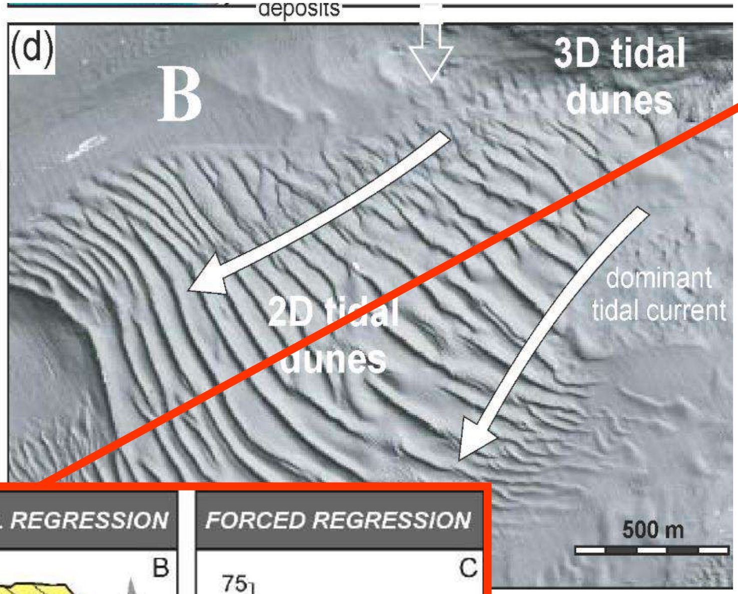
• The Dune-Bedded Strait Zones

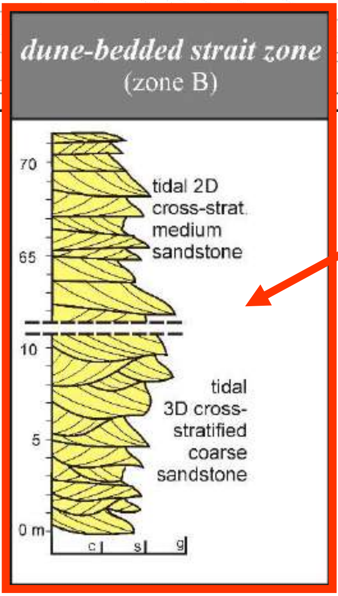


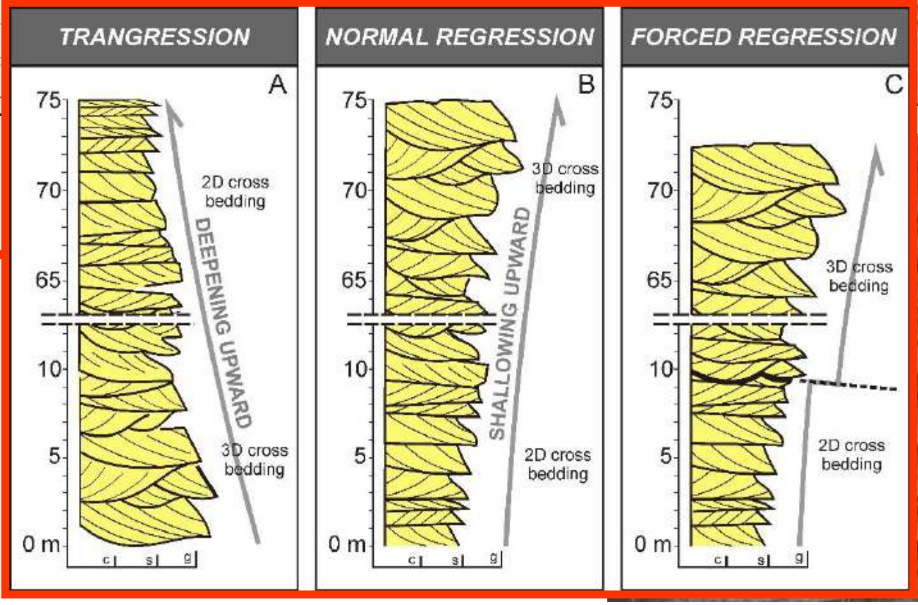
2D/3D TIDAL CROSS STRATA

Cross strata sets can be differentiated into **trough** and **planar** architectures, indicating sinuous- and straight-crested bedforms (i.e., three- vs. two-dimensional) as they are believed to represent **energetic transitional flow stages**.





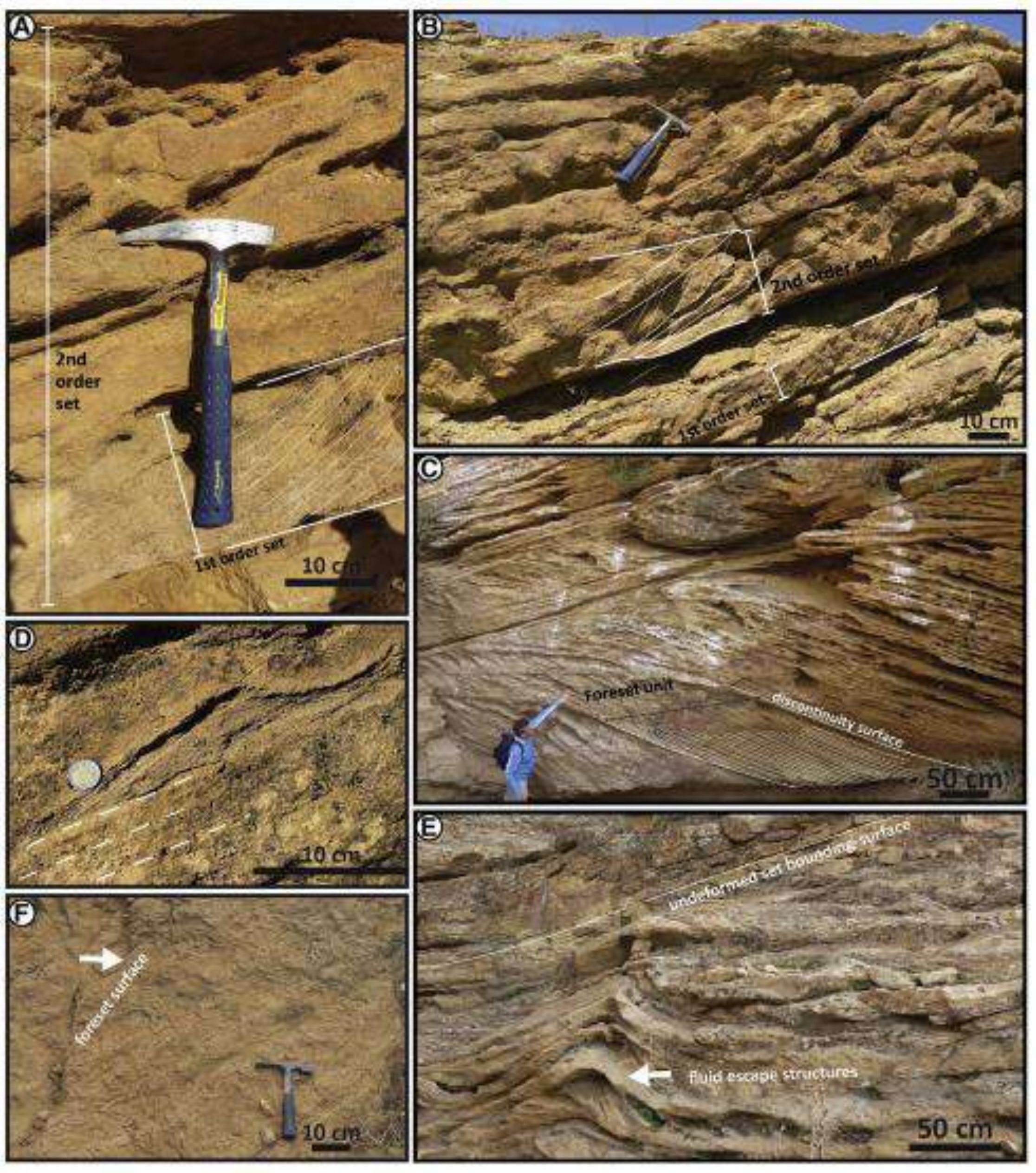




Middle Jurassic of the Isles of Skye and Raasay, NW Scotland

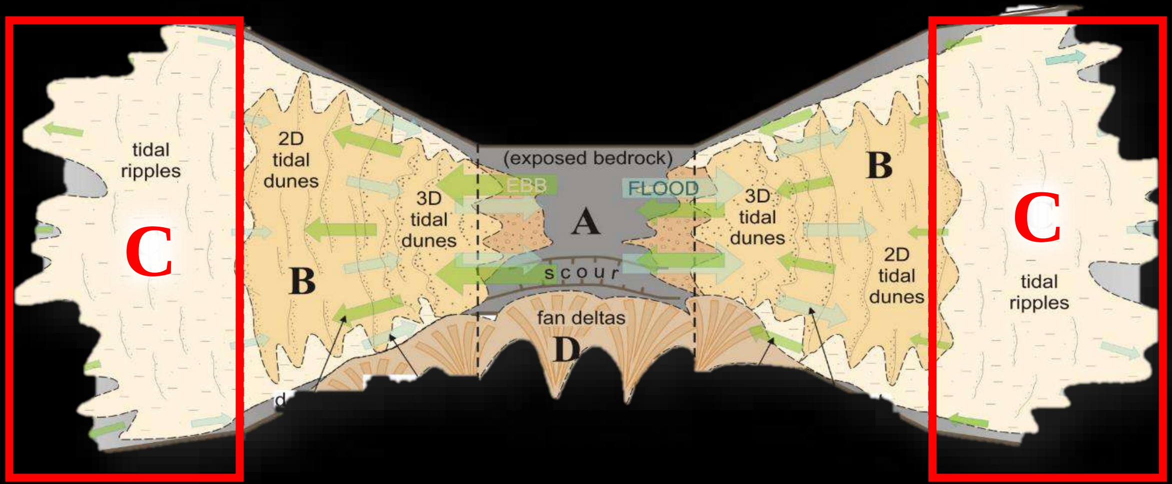
Mellere & Steel, 1996; Archer et al., 2019

Upper Miocene of the Rifian Corridor, northern Morocco

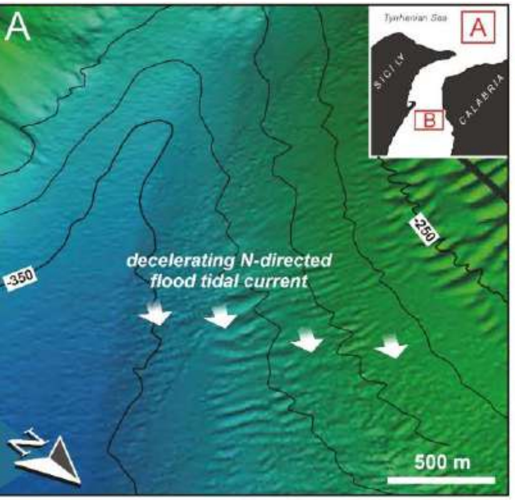


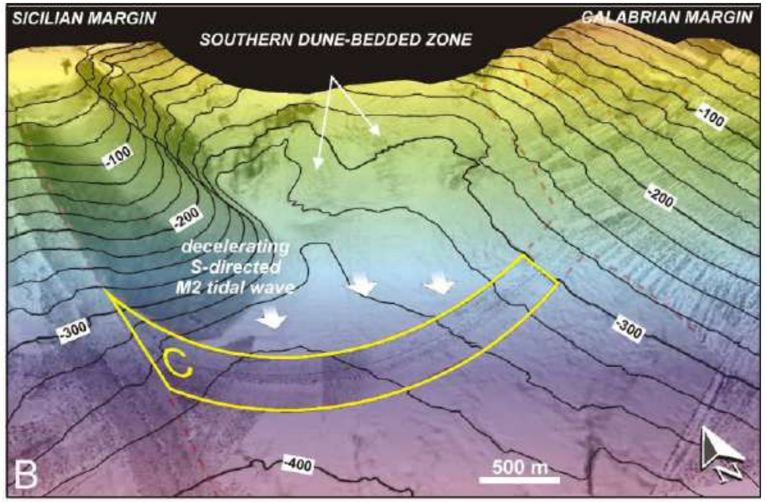
Capella et al., 2017

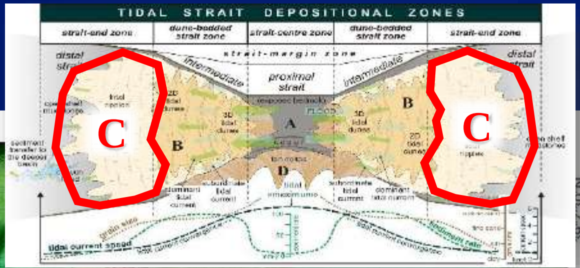
The strait-end zones

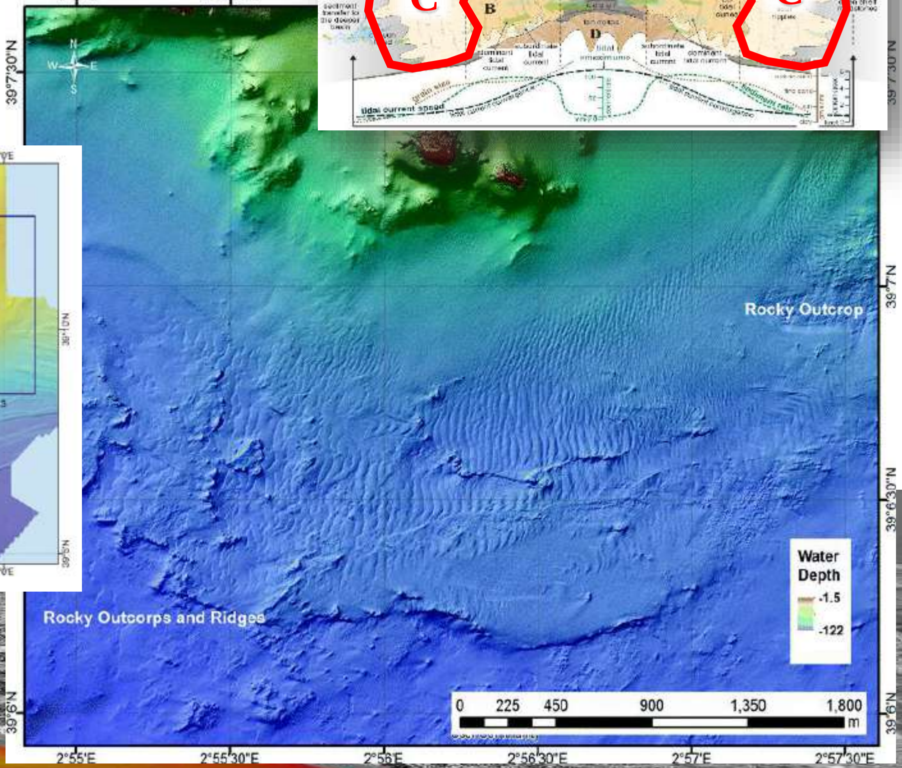


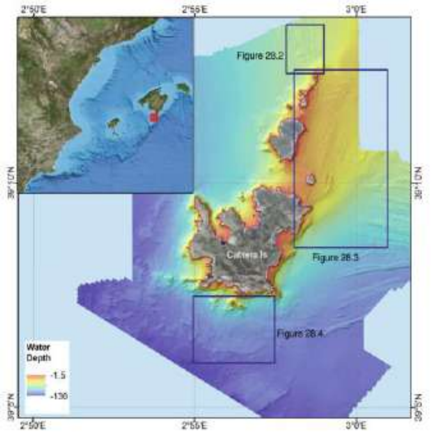
• The Strait-End Zones

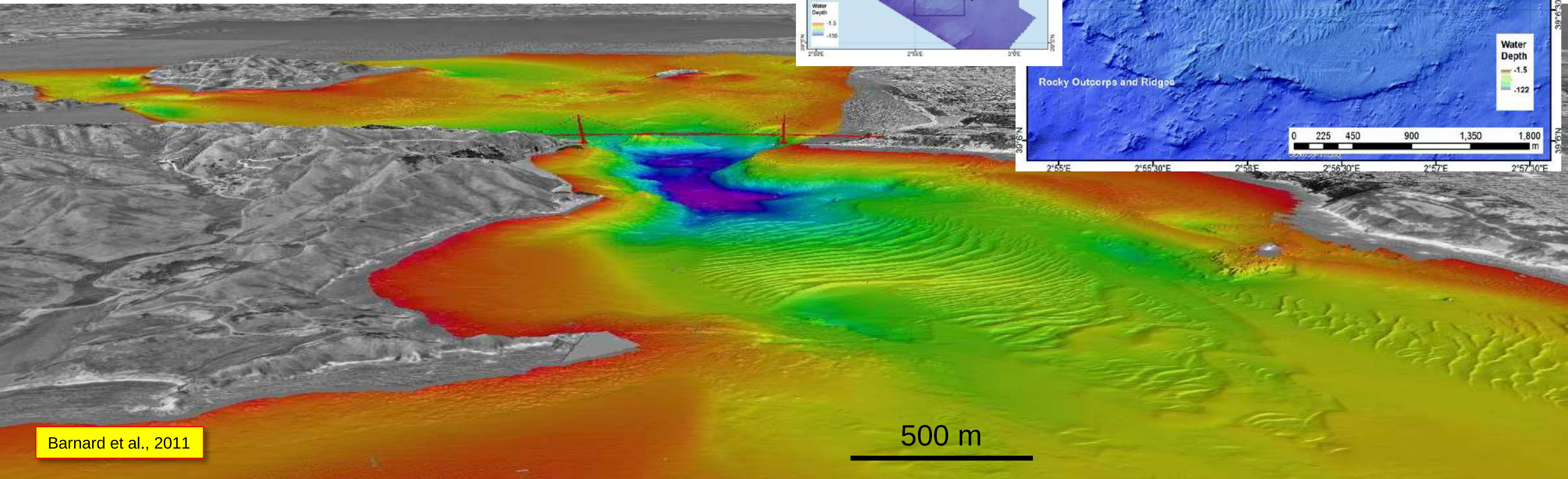






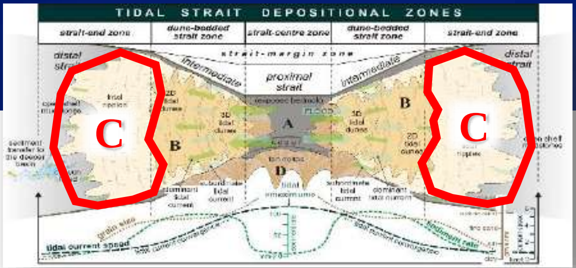


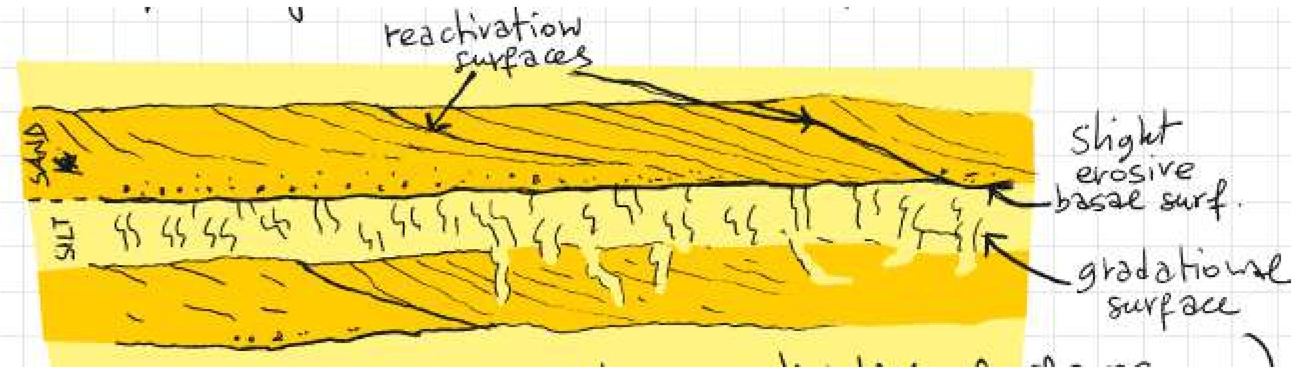




Barnard et al., 2011

• The Strait-End Zones

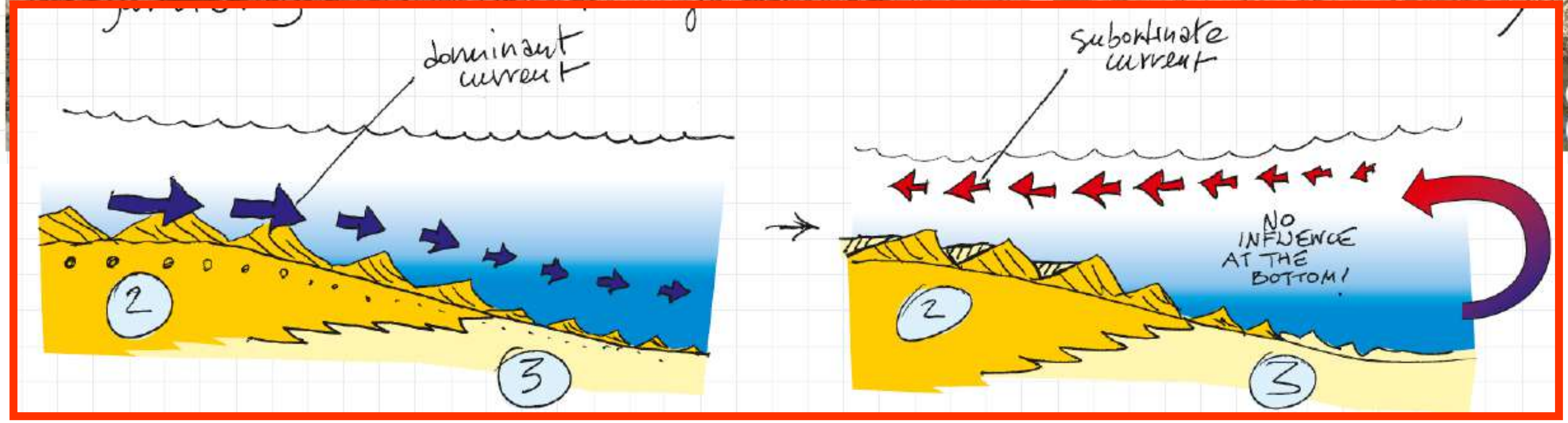




Skolithos, *Thalassinoides*, *Psilonichnus* and *Arenicolites* trace fossils

Catanzaro Strait (photo D. Chiarella)

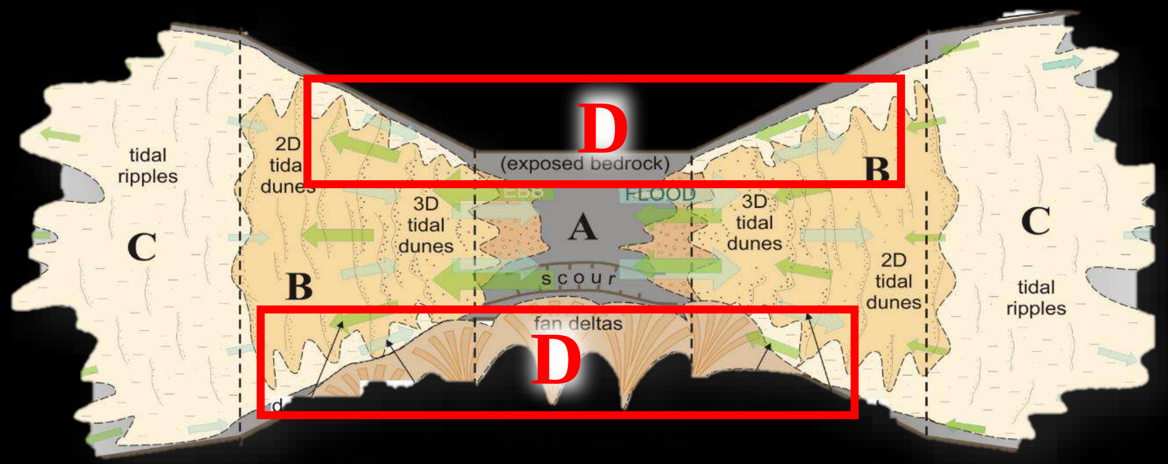
Catanzaro Strait (photo D. Chiarella)



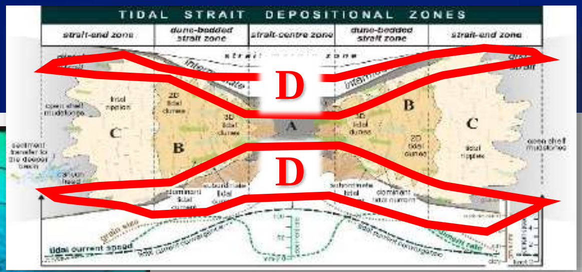

CATANZARO STRAIT, EARLY PLEISTOCENE

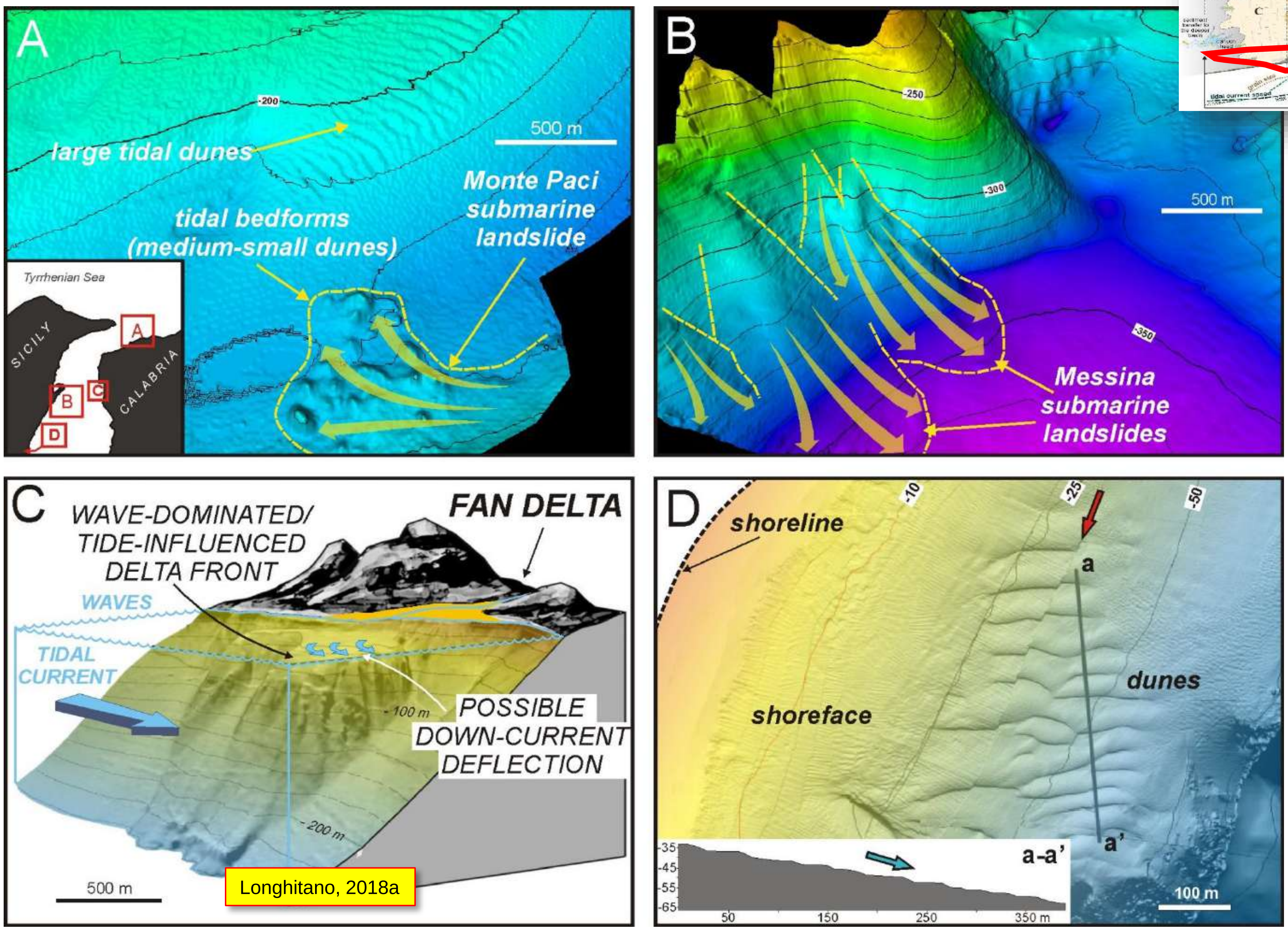
- The Strait-End Zones

The strait-margin zones



• The Strait-Margin Zones

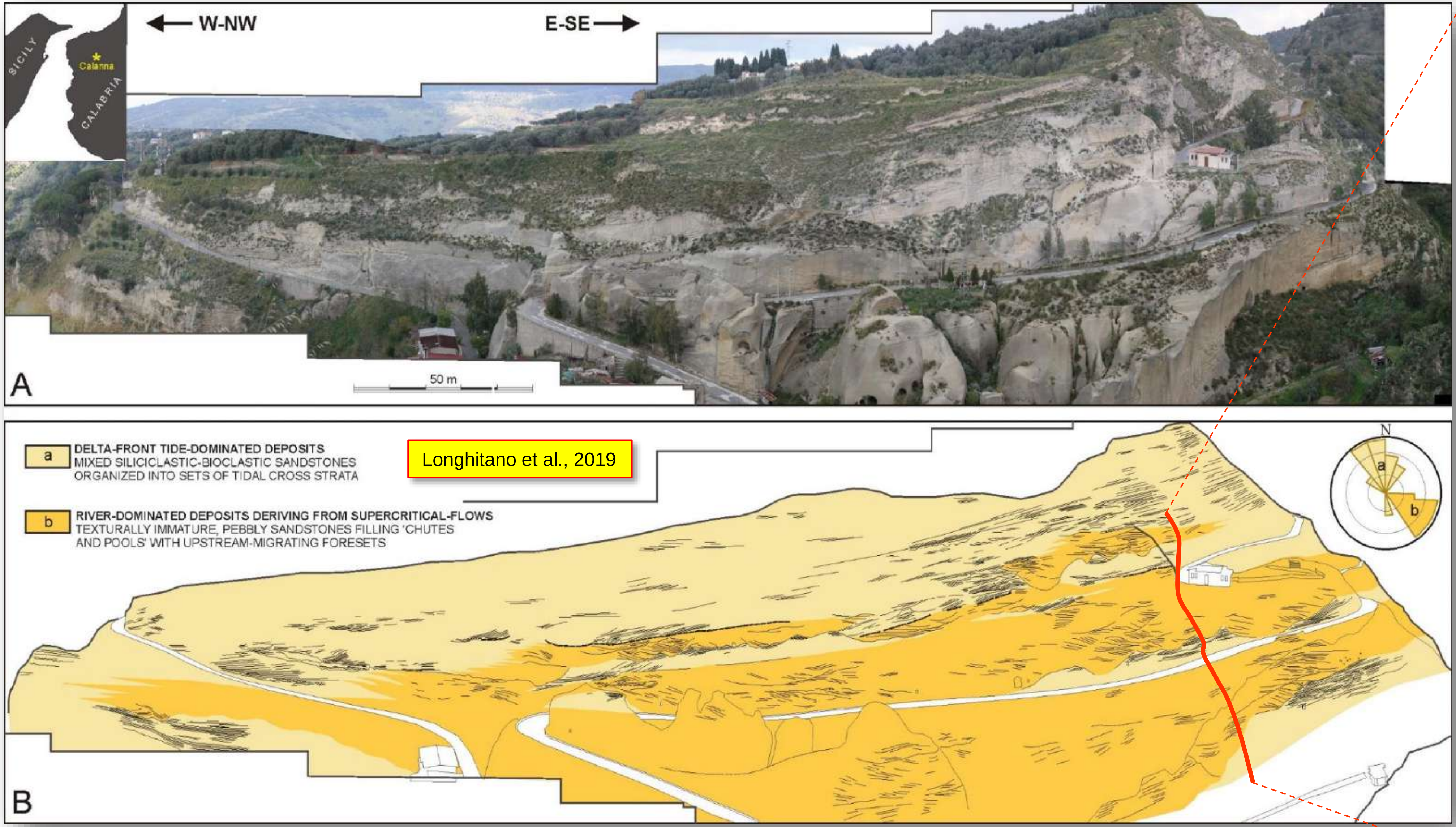


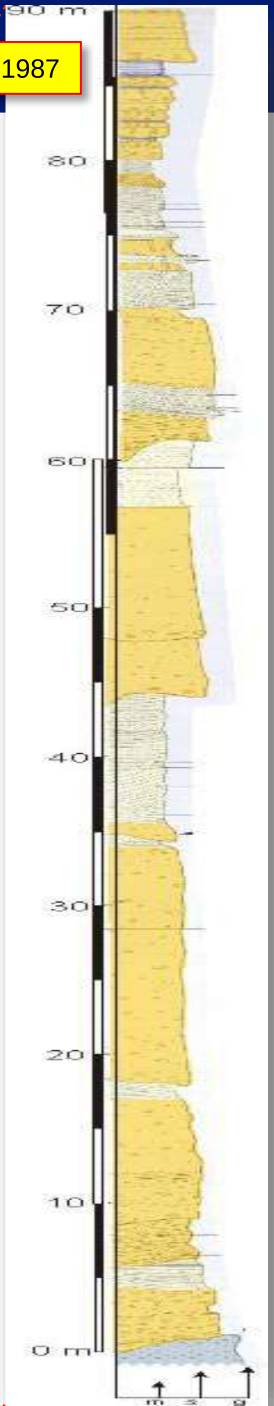


Longhitano, 2018a

• The Strait-Margin Zones

MESSINA STRAIT, EARLY PLEISTOCENE



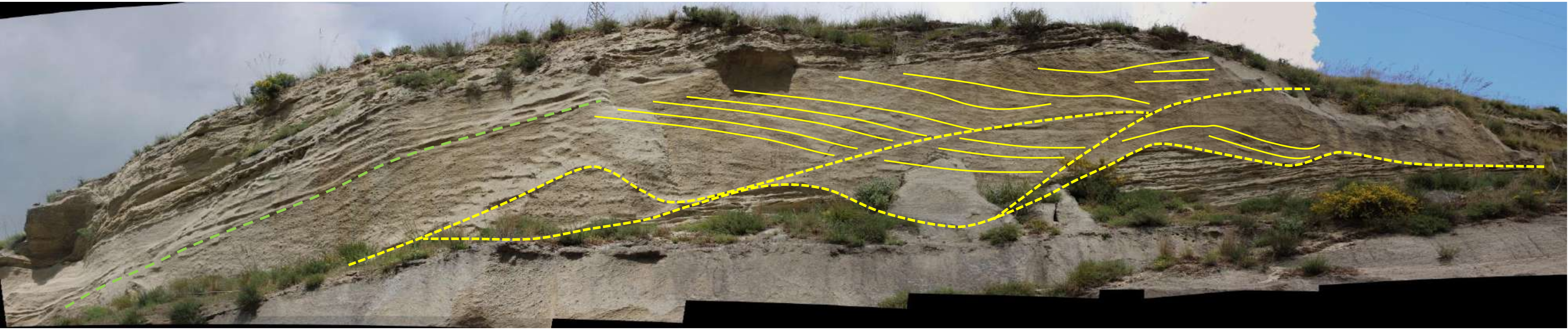


Two main stratigraphic surfaces:

a. erosional (i.e., scour and fill, some m deep, multiple scours, irregularly spaced)

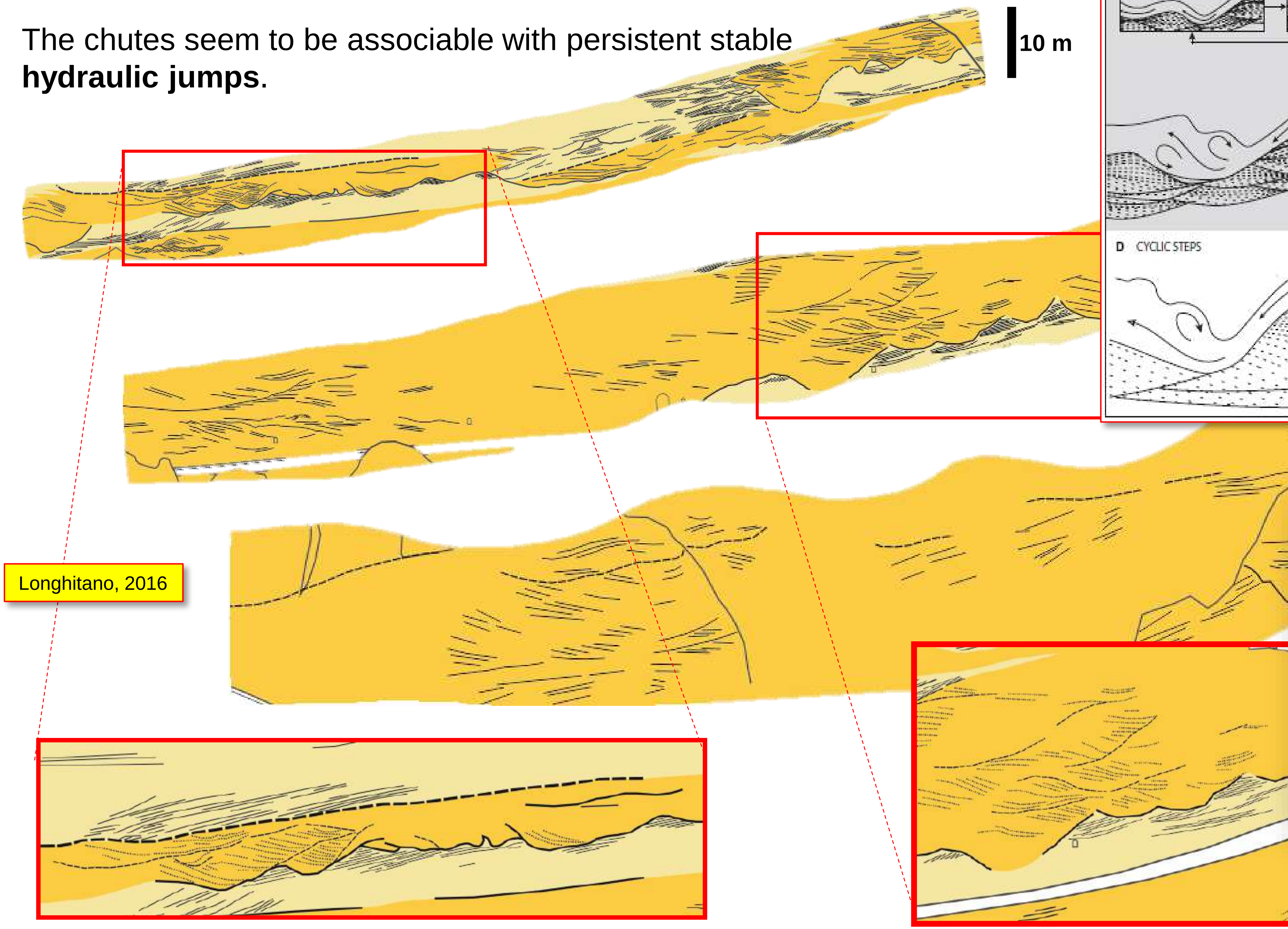
b. depositional (i.e., tidal reworking, unidirectional foresets)

MESSINA STRAIT, EARLY PLEISTOCENE

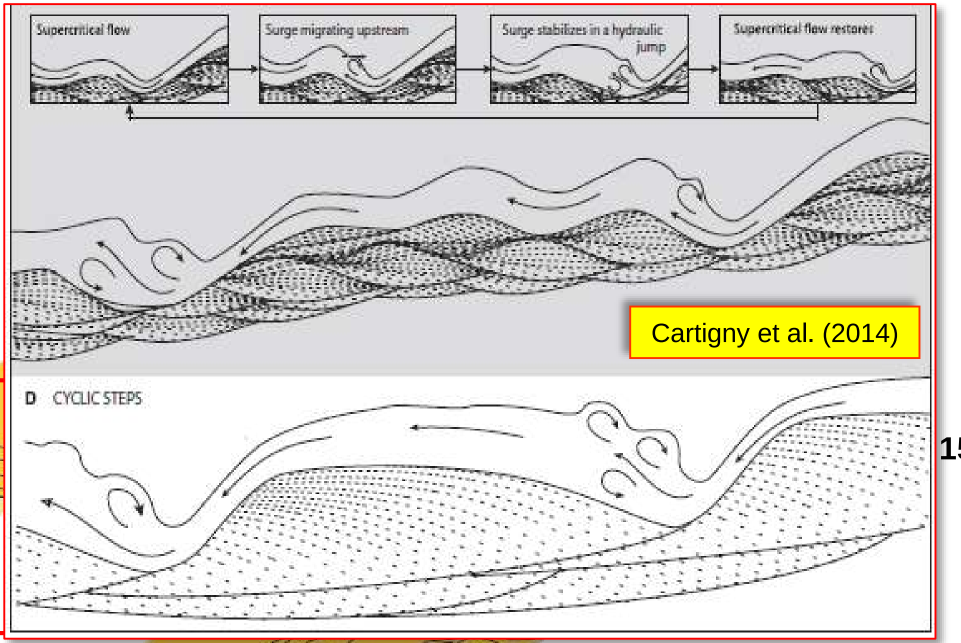


Upstream migrating chutes that end downstream in a series of unstable antidunes. These features indicate repeated hydraulic jumps and surges suggesting **chutes-and-pools** structures.

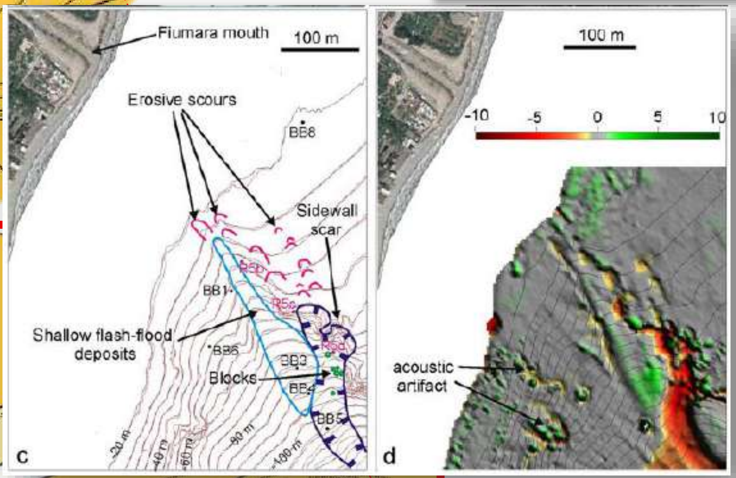
The chutes seem to be associable with persistent stable **hydraulic jumps**.



Longhitano, 2016

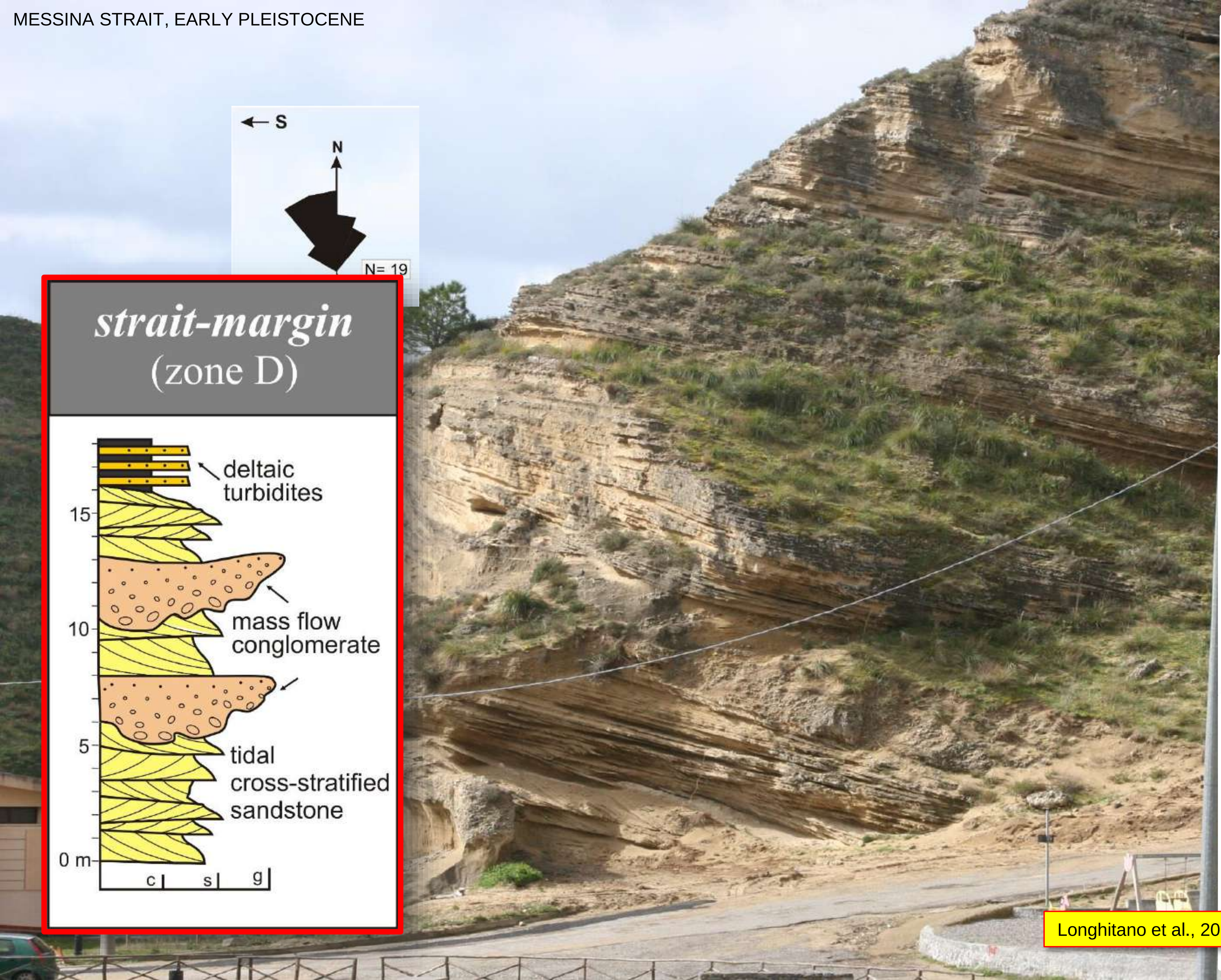


Cartigny et al. (2014)



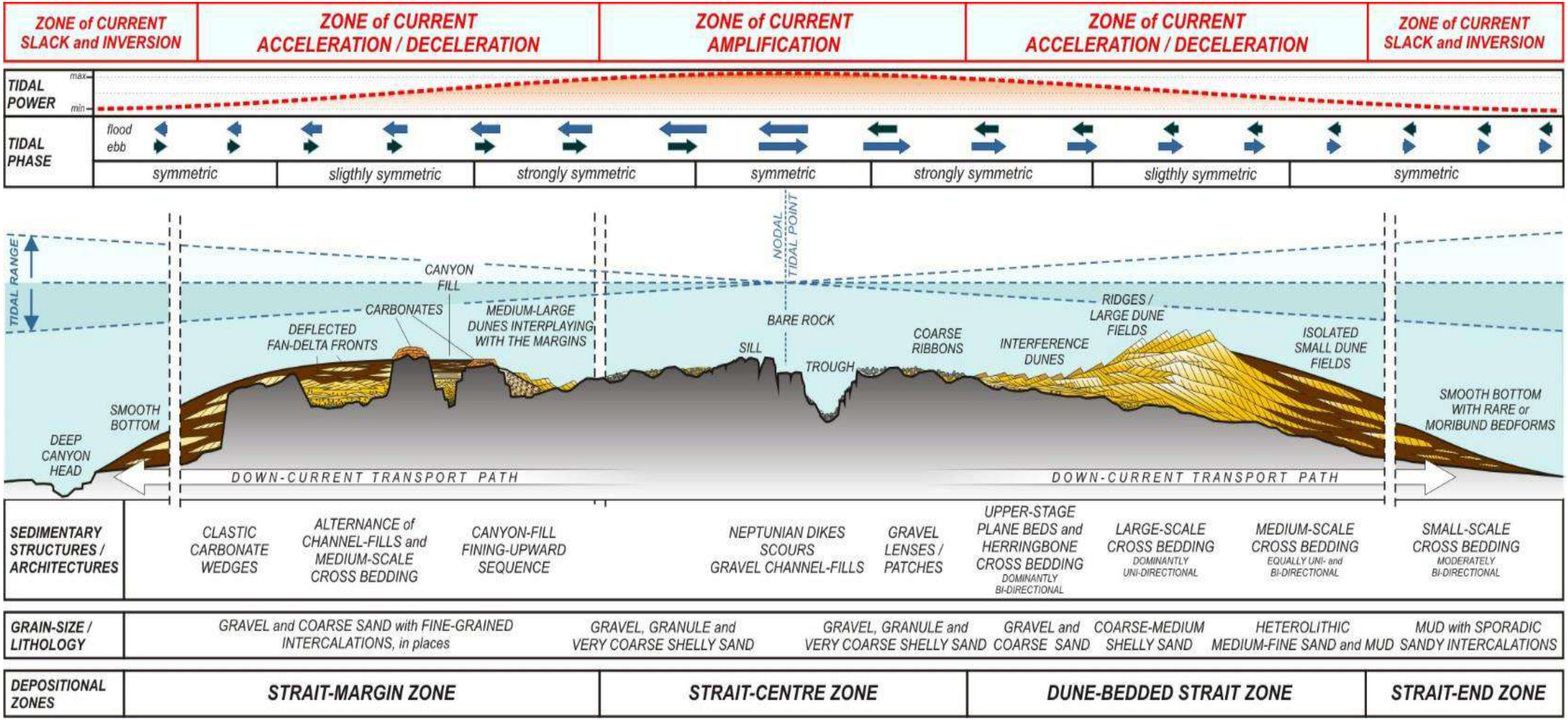
Casalbore et al. (2011)

MESSINA STRAIT, EARLY PLEISTOCENE



Longhitano et al., 2012b

SUMMARIZING ALL WE TODAY KNOW ABOUT THE SEDIMENTARY DYNAMIC OF TIDAL STRAITS …



Longhitano & Chiarella, 2020

• Concluding remarks

STRAITS (TIDAL AND NON-TIDAL) ARE **INDIVIDUAL DEPOSITIONAL SYSTEMS** STILL POORLY KNOWN.
ALTHOUGH WE KNOW EVEN MORE ON SUCH SYSTEMS, THEY STILL SUFFER OF **A GENERAL ABSENCE OF UNIVERSALLY APPLICABLE MODELS**, NECESSARY TO INTERPRET MODERN AND ANCIENT EXAMPLES.

HOWEVER …

- WE KNOW THEIR HYDRODYNAMICS AND TIDAL MOTION IN A QUITE ACCURATE WAY AND PROBABILISTIC NUMERICAL MODELS SEEM TO WORK WELL.

- STRAIT BEDFORMS INDICATE *CONTINUUM* OF TYPES AND GEOMETRIES/SIZES, BUT THERE ARE STILL POORLY KNOWN ELEMENTS, PORBABLY REFERABLE TO THE RECENT GEOLOGICAL HISTORIES OF OUR MODERN STRAITS.

- THE POTENTIAL OF THE STUDY OF ANCIENT ANALOGUES IS HUGE: STRAIT-FILL SUCCESSIONS MAY REVEAL, INDEED, PROCESSES NOT OBSERVABLE AT HUMAN TIME-SCALE AND ALLOW INTEGRATING/IMPROVING KNOWLEDGE OF SUCH COMPLEX SYSTEMS.

Courtesy of
Silvia Messina
UNIBAS Erasmus student at Université de la Normandie,
Caen, France

Selected readings

MODERN STRAITS

Barnard, P.L., Hanes, D.M., Rubin, D.M. and Kvitek, R.G., 2011. Giant sand waves at the mouth of San Francisco Bay. EOS, 87, 1–3.

Berné, S., Trentesaux, A., Stolk, A., Missiaen, T., de Batist, M., 1994. Architecture and long term evolution of a tidal sandbank: The Middelkerke Bank (southern North Sea). Marine Geology, 121, 1–2, 57-72.

Bignami, F., Salusti, E., 1990. Tidal currents and transient phenomena in the Strait of Messina: a review. In: Pratt, L.J. (ed), The physical oceanography of sea straits, p. 95–124.

Bouilloux, A., Valet, J-P., Bassinot , F., Joron, J.L., Dewilde, F., Blanc-Valleron, M-M., Moreno, E., 2013. Influence of seawater exchanges across the Bab-el-Mandeb Strait on sedimentation in the Southern Red Sea during the last 60 ka. Paleoceanography and Paleoclimatology, 28, 675-687.

Chiocci, F.L., Catalano, R., et al. 2008. Note illustrative aree sommerse della carta geologica d'Italia alla scala 1:50 000, Foglio 601, 'Messina – Reggio di Calabria'. Agenzia per la protezione dell'ambiente e i servizi tecnici (APAT), Roma.

Colella, A., 1996. I depositi dello Stretto di Messina, un'area ad elevata instabilità ambientale. Guida all'escursione della Riunione del Gruppo informale di Sedimentologia (GIS), pag. 7-20.

Dalrymple, R.W., 1984. Morphology and internal structure of sand waves in the Bay of Fundy. Sedimentology 31, 365-382.

Dalrymple, R.W., 2010. Tidal depositional systems. In: James NP, Dalrymple RW (eds) Facies models 4. Geological Association of Canada, St John's, pp 201–231.

Dalrymple, R.W., 2019. Morphology, processes and facies of modern straits: Variability and complexity dominate. Proceedings of the 34th Meeting of the International Association of Sedimentologists, 10-13 September 2019, Rome, 637.

Daniell, J.J., 2015. Bedform facies in western Torres Strait and the influence of hydrodynamics, coastal geometry, and sediment supply on their distribution. Geomorphology, 235, 118-129.

Di Geronimo, S.I., 1987. Bionomie des peuplements benthiques des substrats meubles et rocheux plio-quaternaires du Détroit de Messine. Documents et Travaux d'Institut Geologique A. De Lapparent, Paris, 11, 153-170.

Di Geronimo, I., Rosso, A., Sanfilippo, R., 1992. Bryozoans as sedimentary instability indicators. Rivista Italiana di Paleontologia e Stratigrafia, 98, 229-242.

Evans, P., Mason-Jones, A., Wilson, C., Wooldridge, C., O'Doherty, T., O'Doherty, D., 2015. Constraints on extractable power from energetic tidal straits. Renewable Energy, 81, 707-722.

Frey, S.E., Dashtgard, S.E., 2011. Sedimentology, ichnology and hydrodynamics of strait-margin, sand and gravel beaches and shorefaces: Juan de Fuca Strait, British Columbia, Canada. Sedimentology, 58, 1326-1346.

Gandhi, M.S., Kasilingam K., Suresh, N., 2017. Textural Studies a Tool to Decipher the Depositional Environment: a Case Study off Palk Strait, Tamil Nadu, Southeast Coast of India. Journal of Indian Association of Sedimentologists, 34, 141-155.

Gibbard, P.L., 1995. The formation of the Strait of Dover. Geological Society, London, Special Publications, 96, 15-26.

Gökaşan, E., Algan, O., Tur, H., Meriç, E., Türker, A., Şimşek, M., 2005. Delta formation at the southern entrance of Istanbul Strait (Marmara sea, Turkey): a new interpretation based on high-resolution seismic stratigraphy. Geo-Marine Letters, 25, 370-377.

Guerra-García, J., Cabezas, P., Baeza-Rojano, E., Espinosa, F., García-Gómez, J., 2009. Is the north side of the Strait of Gibraltar more diverse than the south side? A case study using the intertidal peracarids (Crustacea: Malacostraca) associated to the seaweed Corallina elongata. Journal of the Marine Biological Association of the United Kingdom, 89(2), 387-397.

Gupta, S., Collier, J.S., Garcia-Moreno, D., Oggioni, F., Trentesaux, A., Vanneste, K., De Batist, M., Camelbeeck, T., Potter G., Van Vliet-Lanoe, B., Arthur, J.C.R., 2017. Two-stage opening of the Dover Strait and the origin of island Britain. Nature Communications, 8(15101), 12p.

Harris, P.T., 1988. Large scale bedforms as indicators of mutually evasive sand transport and the sequential infilling of wide-mouthed estuaries. Sedimentary Geology, 57, 273-298.

Harris, P.T., Collins, M.B. 1991. Sand transport in the Bristol Channel: bedload parting zone or mutually evasive transport pathways? Marine Geology, 101, 1–4, 209-216.

Harris, P.T., Pattiaratchi, C.B., Collins, M.B., Dalrymple, R.W., 1995. What is a Bedload Parting? in: Flemming, B.W., Bartholoma, A. (Eds.), Tidal Signatures in Modern and Ancient Sediments. International Association of Sedimentologists Special Publication 24, pp. 3-18.

Harrison, P.J., Fulton, J.D., Taylor, F.J.R., Parsons T.R., 1983. Review of the Biological Oceanography of the Strait of Georgia: Pelagic Environment. Canadian Journal of Fisheries and Aquatic Sciences, 40(7), 1064-1094.

Hill, P.R., Conway, K., Gwyn Lintern, D., Meulé, S., Picard, K., Vaughn Barrie, J., 2008. Sedimentary processes and sediment dispersal in the southern Strait of Georgia, BC, Canada. Marine Environmental Research, 66, S39-S48.

Hüsing, S.K., Oms, O., Agustí, J., Garcés, M., Kouwenhoven, T.J., Krijgsman, W., Zachariasse, W.-J., 2010. On the late Miocene closure of the Mediterranean–Atlantic gateway through the Guadix basin (southern Spain). Palaeogeography, Palaeoclimatology, Palaeoecology, 291, 3–4, 167-179.

Keene, J.B., Harris, P.T., 1995. Submarine cementation in tide generated bioclastic sand dunes: epicontinental seaway, Torres Strait, northeast Australia. In: Flemming B.W. & Bartholoma A. eds. Tidal Signatures in Modern and Ancient Sediments, pp. 225-236. International Association of Sedimentologists Special Publication 24.

Keller, G.H., and Richards, A.F., 1967. Sediments of the Malacca Strait, Southeast Asia. Journal of Sedimentary Petrology, 37, 102-127.Klein, G.D. and Ryer, T.A., 1978. Tidal circulation patterns in PreCambrian, Paleozoic and Cretaceous epeiric and mioclinal shelf seas. Geological Society American Bulletin, 89, 1050–1058.

Lamarche, G., Lurton, X., Verdier, A.-L., Augustin, J.-M., 2011. Quantitative characterization of seafloor substrate and bedforms using advanced processing of multibeam backscatter - Application to Cook Strait, New Zealand. Continental Shelf Research, 31, 93-109.

Le Bot, S., Trentesaux, A., 2004. Types of internal structure and external morphology of submarine dunes under the influence of tide- and wind-driven processes (Dover Strait, northern France). Marine Geology, 211, 143–168.

Li, M.L., Shaw, J., Todd, B.J., Kostylev, V.E., Wu, Y., 2014. Sediment transport and development of banner banks and sandwaves in an extreme tidal system: Upper Bay of Fundy, Canada. Continental Shelf Research, 83, 86-107.

Lockhart, E.A., Scourse, J.D., Praeg, D., Van Landeghem, K.J.J., Mellett, C., Saher, M., Callard, L., Chiverrell, R.C., Benetti, S., Cofaigh, C.Ó., Clark, C.D., 2018. A stratigraphic investigation of the Celtic Sea megaridges based on seismic and core data from the Irish-UK sectors. Quaternary Science Reviews, 198, 156-170.

Loget, N., Van Den Driessche, J., 2006. On the origin of the Strait of Gibraltar. Sedimentary Geology, 188–189, 341-356.

Longhitano, S.G., 2018a. Between Scylla and Charybdis (part 1): the sedimentary dynamics of the modern Messina Strait (central Mediterranean) as analogue to interpret the past. Earth-Science Reviews, 185, 259-287.

McCave, I.N., Langhorne, D.N., 1982. Sand waves and sediment transport around the end of a tidal sand bank. Sedimentology, 29, 1, 95-110.

Montenat, C., Barrier, P., Di Geronimo, I., 1987. The Strait of Messina, past and present: a review, Documents et Travaux d'Institut Geologique A. De Lapparent, Paris, 11, 7-13.

Pattiaratchi, C.B., Collins, M.B., 1984. Sediment transport under waves and tidal currents: A case study from the northern Bristol Channel, U.K. Marine Geology, 56, 1–4, 27-40.

Santoro, V. C., Amore, E., Cavallaro, L., De Lauro, M., 2004. Evolution of sand waves in the Messina Strait, Italy. Ocean Dynamics, 54, 3–4, 392–398.

Selli, R., Colantoni, P., Fabbri, A., Rossi, S., Borsetti, A.M., Gallignani, P., 1978. Marine geological investigation on the Messina Straits and its approaches. Giornale di Geologia, 42, 2, 1–22.

Shaw, J., Todd, B.J., Li, M.Z., Wu Y., 2012. Anatomy of the tidal scour system at Minas Passage, Bay of Fundy, Canada. Marine Geology, 323–325, 123-134.

Stow, D.A.V., Hernández-Molina, F.J., Llave, E., Bruno, M., García, M., Díaz del Rio, V., Somoza, L., Brackenridge, R.E, 2013. The Cadiz Contourite Channel: Sandy contourites, bedforms and dynamic current interaction. Marine Geology, 343, 99-114.

ANCIENT STRAITS

Aberhan, M., 2002. Opening of the Hispanic Corridor and Early Jurassic bivalve biodiversity. Geological Society, London, Special Publications, 194, 127-139.

Allen P.A., Bass J.P., 1993. Sedimentology of the Upper Marine Molasse of the Rhone-Alp region, Eastern France: Implications for basin evolution. Eclogae Geol. Helv., 86, 121-172.

Anastas, A., Dalrymple, R.W., James, N.P. and Nelson, C.S., 1997. Genesis of subaqueous, cool-water carbonate dunes in an Oligo-Miocene seaway, North Island, New Zealand. Sedimentology, 44, 869–891.

Anastas, A.S., Dalrymple, R.W., James, N.P., Campbell, S.N., 2006. Lithofacies and dynamics of a cool-water carbonate seaway: mid-Tertiary, Te Kuiti Group, New Zealand. In: Cool-Water Carbonates: Depositional Systems and Palaeoenvironmental Controls (H.M. Pedley and G. Carannante, eds), Geol. Soc. London Spec. Publ., 255, 245–268.

Antonioli, F., Lo Presti, V., Gasparo Morticelli, M., Bonfiglio, L., Mannino, M.A., Palombo, M.R., Sannino, G., Ferranti, L., Furlani, S., Lambeck, K., Canese, S., Catalano, R., Chiocci, F.L., Mangano, G., Scicchitano, G., Tonielli, R., 2014. Timing of the emergence of the Europe–Sicily bridge (40–17 cal ka BP) and its implications for the spread of modern humans. In: Harff, J., Bailey, G. & Lu¨th, F. (eds) Geology and Archaeology: Submerged Landscapes of the Continental Shelf. Geological Society, London, Special Publications, 411, 111-144.

Archer, S.G., Steel, R.J., Mellere, D., Blackwood, S., Cullen, B., 2019. Response of Middle Jurassic shallow-marine environments to syn-depositional block tilting: Isles of Skye and Raasay, NW Scotland. Scottish Journal of Geology, 55, 35-68.

Benson, R. H., Rakic-El Bied, K., Bonaduce, G., 1991. An important current reversal (influx) in the Rifian Corridor (Morocco) at the Tortonian-Messinian boundary: The end of Tethys Ocean. Paleoceanography, 6, 1), 165-192.

Blanc, P-L., 2002. The opening of the Plio-Quaternary Gibraltar Strait: assessing the size of a cataclysm. Geodinamica Acta, 15, 5–6, 303-317.

Brenner, R.L., 1980. Construction of Process-Response Models for Ancient Epicontinental Seaway Depositional Systems Using Partial Analogs. AAPG Bulletin, 64, 8, 1223-1244.

Capella, W., Hernández-Molina, F.J., Flecker, R., Hilgen, F.J., Hssain, M., Kouwenhoven, T.J., van Oorschot, M., Sierro, F.J., Stow, D.A.V., Trabucho-Alexandre, J., Tulbure, M.A., de Weger, W., Yousfi, M.Z., Krijgsman, W., 2017. Sandy contourite drift in the late Miocene Rifian Corridor (Morocco): Reconstruction of depositional environments in a foreland-basin seaway. Sedimentary Geology, 355, 31–57.

Cavazza, W., DeCelles, P.G., Fellin, M.G., Paganelli, L., 2007. The Miocene Saint-Florent Basin in northern Corsica: stratigraphy, sedimentology, and tectonic implications. Basin Research, 19, 507-527.

Chiarella, D., Moretti, M., Longhitano, S.G., Muto, F., 2016. Deformed cross-stratified deposits in the Early Pleistocene tidally-dominated Catanzaro strait-fill succession, Calabrian Arc (Southern Italy): Triggering mechanisms and environmental significance. Sedimentary Geology, 344, 77-289.

Flecker, R., Krijgsman, W., Capella, W., de Castro Martíns, C., Dmitrieva, E., Mayser, J.P., Marzocchi, A., Modestou, S., Ochoa, D., Simon, D., Tulbure, M., van den Berg, B., van der Schee, M., de Lange, G., Ellam, R., Govers, R., Gutjahr, M., Hilgen, F., Kouwenhoven, T., Lofi, J., Meijer, P., Sierro, F.J., Bachiri, N., Barhoun, N., Alami, C., Chacon, B., Flores, J.A., Gregory, J., Howard, J., Lunt, D., Ochoa, M., Pancost, R., Vincent, S., Zakaria Yousfi, M., 2015. Evolution of the Late Miocene Mediterranean–Atlantic gateways and their impact on regional and global environmental change. Earth-Science Reviews, 150, 365-392.

Förster, R., 1978. Evidence for an open seaway between northern and southern proto-Atlantic in Albian times. Nature, 272, 158–159.

Krijgsman, W., Capella, W., Simon, D., Hilgen, F.J., Kouwenhoven, T.J., Meijer, P.T., Sierro, F.J., Tulbure, M.A., van den Berg, B.C.J., van der Schee, M., Flecker, R., 2018. The Gibraltar Corridor: Watergate of the Messinian Salinity Crisis. Marine Geology, 403, 238-246.

Hodell, D.A., Curtis, J.H., Sierro, F.J., Raymo, M.E., 2001. Correlation of Late Miocene to Early Pliocene sequences between the Mediterranean and North Atlantic, Paleoceanography, 16, 2, 164– 178.

Livermore, R., Nankivell, A., Eagles, G., Morris, P., 2005. Paleogene opening of Drake Passage. Earth and Planetary Science Letters, 236, 1–2, 459-470.

Lawver, L.A., Gahagan, L.M., 1998. Opening of Drake Passage and its impact on Cenozoic ocean circulation. In: Tectonic Boundary Conditions for Climate Reconstructions (Crowley, T.J., Burke, K., Eds.). New York, Oxford University Press, 213 pp.

Longhitano, S.G., Nemec, W., 2005. Statistical analysis of bed-thickness variation in a Tortonian succession of biocalcarenitic tidal dunes, Amantea Basin, Calabria, southern Italy. Sedimentary Geology, 179, 195–224.

Longhitano, S.G., 2011. The record of tidal cycles in mixed silici–bioclastic deposits: examples from small Plio-Pleistocene peripheral basins of the microtidal Central Mediterranean Sea. Sedimentology, 58, 691–719.

Longhitano, S.G., Chiarella, D., Di Stefano, A., Messina, C., Sabato, L., Tropeano, M., 2012b. Tidal signatures in Neogene to Quaternary mixed deposits of southern Italy straits and bays. 279, 20, 74-96.

Longhitano, S.G., Chiarella, D., Muto, F., 2014. Three-dimensional to two-dimensional cross-strata transition in the lower Pleistocene Catanzaro tidal strait transgressive succession (southern Italy). Sedimentology, 61, 2136-2171.

Longhitano, S.G., Steel, R.J., 2016. Deflection of the progradational axis and asymmetry in tidal seaway and strait deltas: insights from two outcrop case studies. Paralic Reservoir, Geological Society, Special Publication, London, 444, 141-172.

Longhitano, S.G., Telesca, D., Pistis, M., 2017. Tidal sedimentation preserved in volcaniclastic deposits filling a peripheral seaway embayment (early Miocene, Sardinian Graben). Marine and Petroleum Geology, 87, 31-46.

Longhitano, S.G., 2018b. Between Scylla and Charybdis (part 2): the sedimentary dynamics of the ancient, Early Pleistocene Messina Strait (central Mediterranean) based on its modern analogue. Earth-Science Reviews, 179, 248-286.

Nicholls, E.L., Russell, A.P., 1990. Paleobiogeography of the Cretaceous Western Interior Seaway of North America: the vertebrate evidence. Palaeogeography, Palaeoclimatology, Palaeoecology, 79, 1–2, 149-169.

Olariu, C., Steel, R.J., Dalrymple, R.W., Gingras, M.K., 2012. Tidal dunes versus tidal bars: The sedimentological and architectural characteristics of compound dunes in a tidal seaway, the lower Baronia Sandstone (Lower Eocene), Ager Basin, Spain. In: Modern and Ancient Tidal Depositional Systems: Perspectives, Models and Signatures (S.G. Longhitano, D. Mellere and B. Ainsworth, eds), Sediment. Geol. Spec. Issue, 279, 134–155.

Martín, J.M., Braga, J.C., Betzler, C., 2001. The Messinian Guadalhorce corridor: the last northern, Atlantic-Mediterranean gateway. Terra Nova, 13, 418–424.

Martín, J.M., Puga-Bernabéu, A., Aguirre, J., Braga, J.C., 2014. Miocene Atlantic-Mediterranean seaways in the Betic Cordillera (southern Spain). Revista de la Sociedad Geológica de España, 27, 175-186.

Martín, J.M., Braga, J.C., Betzler, C., Brachert, T., 1996. Sedimentary model and high-frequency cyclicity in a Mediterranean, shallow-shelf, temperate-carbonate environment (uppermost Miocene, Agua Amarga Basin, Southern Spain). Sedimentology, 43, 263-277.

Mitchell, A.J., Allison, P.A., Gorman, G.J., Piggott, M.D., Pain, C.C., 2011. Tidal circulation in an ancient epicontinental sea: the Early Jurassic Laurasian Seaway. Geology, 39, 207–210.

Soria, J.M., Fernández, J., Viseras, C., 1999. Late Miocene stratigraphy and palaeogeographic evolution of the intramontane Guadix Basin (Central Betic Cordillera, Spain): implications for an Atlantic–Mediterranean connection. Palaeogeography, Palaeoclimatology, Palaeoecology, 151, 4, 255-266.

Steel, R.J., Plink-Bjorklund, P. and Aschoff J., 2012. Tidal Deposits of the Campanian Western Interior Seaway, Wyoming, Utah and Colorado, USA. In: Principles of Tidal Sedimentology (A. Davis Jr. and R.W. Dalrymple Eds.), Springer, 437-472.

Reynaud, J-Y., Ferrandini, M., Ferrandini, J., Santiago, M., Thinon, I., André, J., Barthet, Y., Guennoc, P., Tessier, B., 2013. From non-tidal shelf to tide-dominated strait: The Miocene Bonifacio Basin, Southern Corsica. Sedimentology, 60, 599-623.

Rossi, V.M., Longhitano, S.G., Mellere, D., Dalrymple, R.W., Steel, R.J., Chiarella, D., Olariu, C., 2017. Interplay of tidal and fluvial processes in an early Pleistocene, delta-fed, strait margin (Calabria, Southern Italy). In: Sedimentology in Italy: new advances and insights (S.G. Longhitano, R.J. Steel and L. Pomar, eds), Marine and Petroleum Geology Special Issue, 87, 14-30.

Telesca, D., Longhitano, S.G., Pistis, M., Pascucci, V., Tropeano, M., Sabato, L., 2020. Sedimentology of a transgressive middle-upper Miocene succession filling a tectonically confined, current dominated seaway (the Logudoro Basin, northern Sardinia, Italy). Sedimentary Geology, 400, https://doi.org/10.1016/j.sedgeo.2020.105626.

MODELLING

Androsov, A.A., Kagan, B.A., Romanenkov, D.A., Voltzinger, N.E., 2002. Numerical modelling of barotropic tidal dynamics in the strait of Messina. Advances in Water Resources, 25, 401–415.

Grochowski, N.T.L., Collins, M.B., Boxall, S.R., Salomon, J-C., 1993. Sediment transport predictions for the English Channel, using numerical models. J. Geol. Soc. Lond., 150, 683–695.

Longhitano, S.G., 2013. A facies-based depositional model for ancient and modern, tectonically–confined tidal straits. Terra Nova 25, 446-452.

Wells, M.R., Allison, P.A., Piggott, M.D., Gorman, G.J., Hampson, G.J., Pain, C.C., Fang, F., 2007. Numerical modeling of tides in the late Pennsylvanian Midcontinent seaway of North America with implications for hydrography and sedimentation. J. Sed. Res., 77, 843–865.

Longhitano, S.G., Mellere, D., Steel, R.J. & Ainsworth, R.B. 2012a. Tidal depositional systems in the rock record: a review and new insights. Sedimentary Geology, 279, 2–22.

Longhitano S.G., Chiarella, D., 2020. Tidal straits: basic criteria for recognizing ancient systems from the rock record. In: (Scarselli, N., Adam, J., Chiarella, D., Eds.) Regional Geology and Tectonics. Principles of Geologic Analyses. Vol. 1, 2nd Ed., Elsevier, in press.

Kurogi, M., Hasumi, H. Tidal control of the flow through long, narrow straits: a modeling study for the Seto Inland Sea. *Sci Rep* **9,** 11077 (2019). https://doi.org/10.1038/s41598-019-47090-y.

Martel, A.T., Allen, P.A., Slingerland, R., 1994. Use of tidal-circulation modeling in paleogeographical studies: An example from the Tertiary of the Alpine perimeter. Geology, 22, 10, 925–928.

WEB SITES AND VIDEOS

https://en.wikipedia.org/wiki/Strait
https://www.youtube.com/watch?v=_OU84SrS9sE
https://www.youtube.com/watch?v=Iyg34_WNIP4
https://www.youtube.com/watch?v=N7d2X47ltis
https://www.nature.com/articles/srep36376#Sec7
https://www.youtube.com/watch?v=Kjqi-vYOBIE
http://www.correntidellostretto.it/
https://www.tidetech.org/news/2012/8/23/24-new-straits-of-gibraltar-tidal-model/
https://blogs.princeton.edu/research/tag/oceanography/

OCEANOGRAPHY

Baines P.G., Granek H., 1990. Hydraulic Models of Deep Stratified Flows over Topography. In: Pratt L.J. (eds) The Physical Oceanography of Sea Straits. NATO ASI Series (Mathematical and Physical Sciences), 318. Springer, Dordrecht.

Bryden, H.L., A.J. Nurser, 2003. Effects of Strait Mixing on Ocean Stratification. Journal of Physical Oceanography, 33, 1870–1872.

de la Vara, A., Topper, R.P.M., Meijer, P.T., Kouwenhoven, T.J., 2015. Water exchange through the Betic and Rifian corridors prior to the Messinian Salinity Crisis: A model study, Paleoceanography, 30, 548–557.

Defant, A., 1958. Ebb and Flow - The tides of Earth, air and water. Ann Arbor, The University of Michigan Press, 121 p.

Gibson, R., 2003. Go with the flow: tidal migration in marine animals. Hydrobiologia, 503, 153-161.

Gunawan, B., Neary, V.S., Colby, J., 2014. Tidal energy site resource assessment in the East River tidal strait, near Roosevelt Island, New York, New York. Renewable Energy, 71, 509-517.

Wang, D-P., 1989. Model of mean and tidal flows in the Strait of Gibraltar, Deep Sea Research Part A. Oceanographic Research Papers, 36, 10, 1535-1548.

Shaffer, G., Bendtsen, J., 1994. Role of the Bering Strait in controlling North Atlantic Ocean circulation and climate. Nature volume 367, 354–357.

Takeoka, H., 1990. Criterion of tidal fronts around narrow straits. Continental Shelf Research, 10, 7, 605-613.

Vennell, R., 1998. Observations of the Phase of Tidal Currents along a Strait. Journal of Physical Oceanography, 28, 1570–1577.

Pratt, L.J., 1990. The physical oceanography of sea straits. Kluwer Academic Publishers, Dordrecht, Boston, London, 587 pp.

Morozov, E.G., K. Trulsen, M.G. Velarde, Vlasenko, V.I. 2002. Internal Tides in the Strait of Gibraltar. Journal of Physical Oceanography, 32, 3193–3206.

MacMillan, D.H., 1966. Tides. American Elsevier, New York. 240.

Matthew H. Alford, et al. 2015. The formation and fate of internal waves in the South China Sea. *Nature*. Article published online in-advance-of-print May 7, 2015. DOI: 10.1038/nature14399