



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 3.7

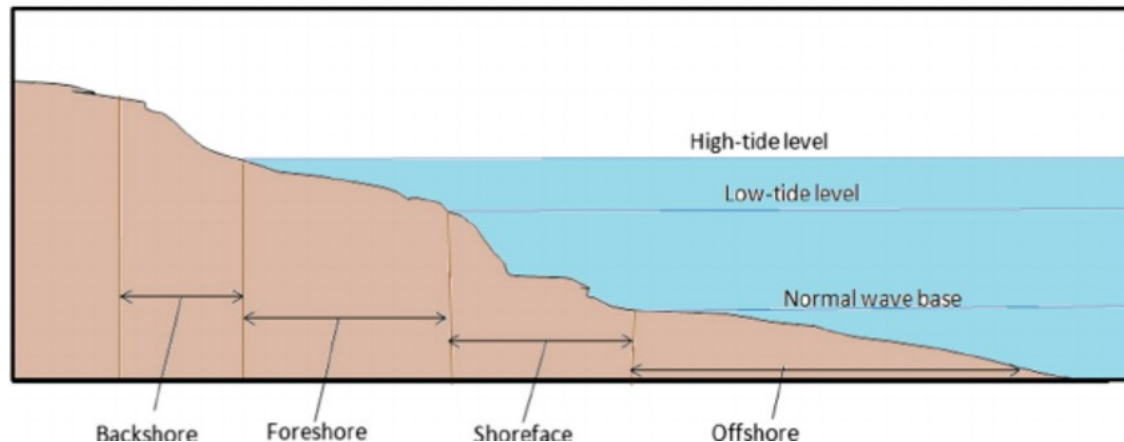
Barrier systems

Outline:

- Clinoforms
- Barrier systems
- Glossary
- Examples of Barrier system components

Shoreface versus Foreshore

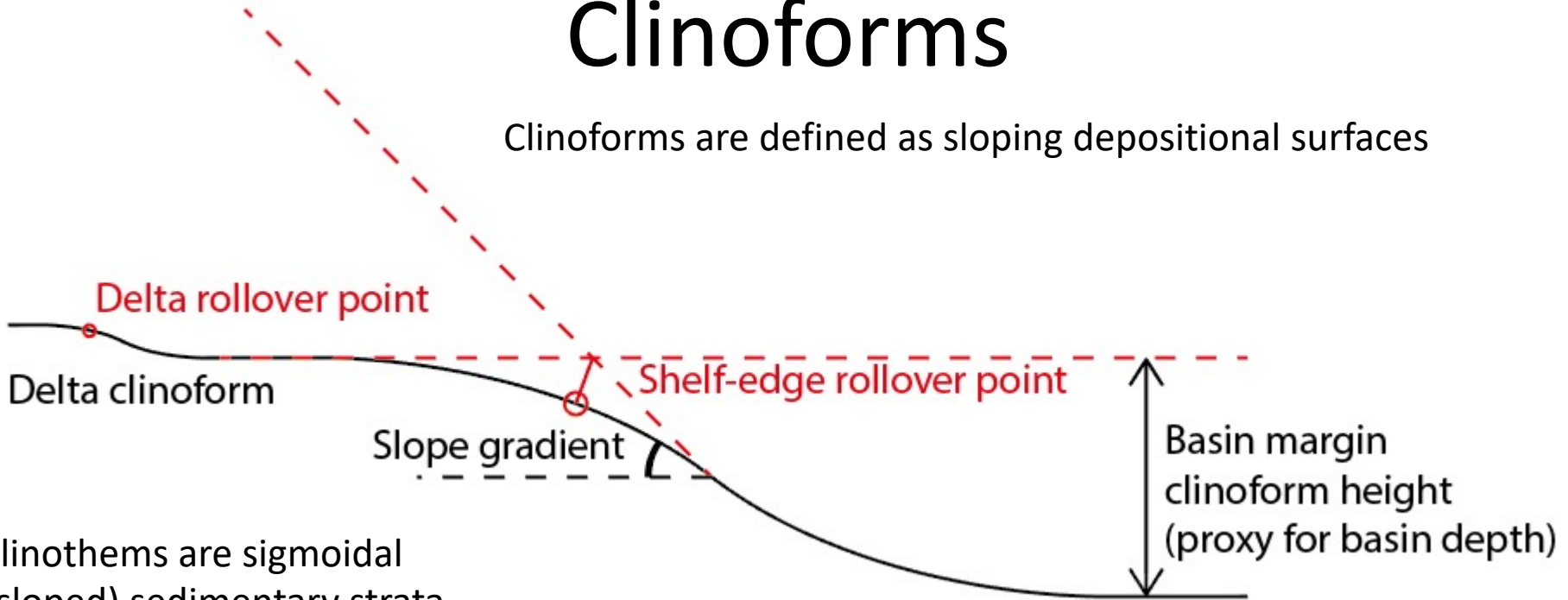
The shoreface is the nearshore zone of the inner continental shelf that is bounded landward by the low-water line and that extends seaward to where the influence of wave action on sediment transport is on average minor compared to other influences



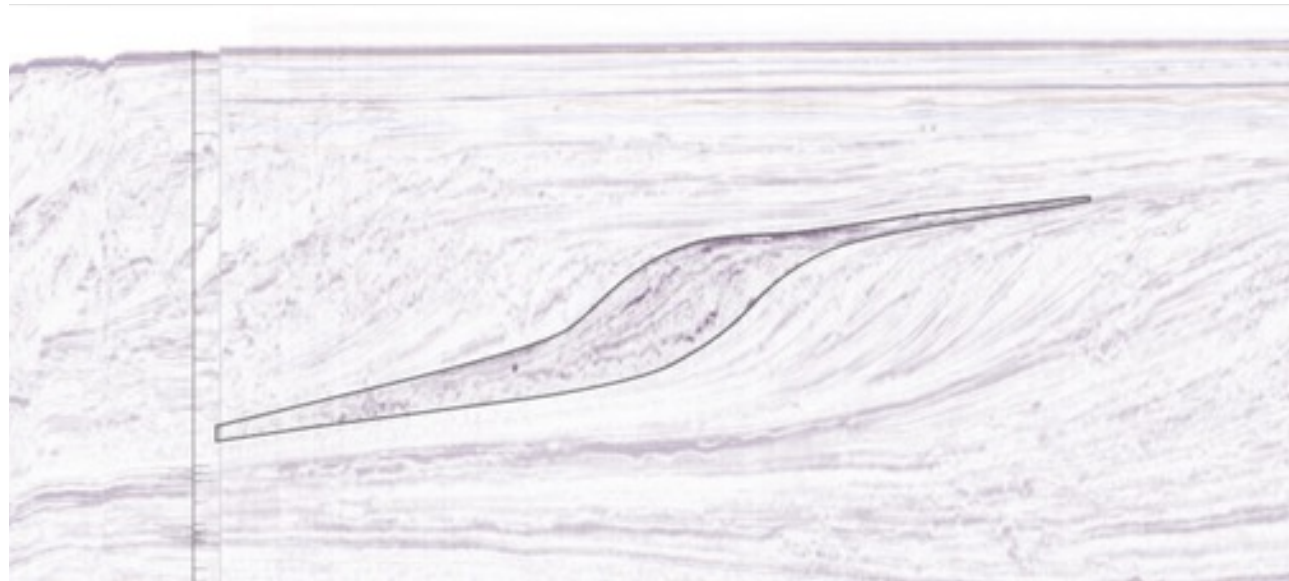
The foreshore is the part of the shore which is between the highest and lowest points reached by the water

Clinoforms

Clinoforms are defined as sloping depositional surfaces



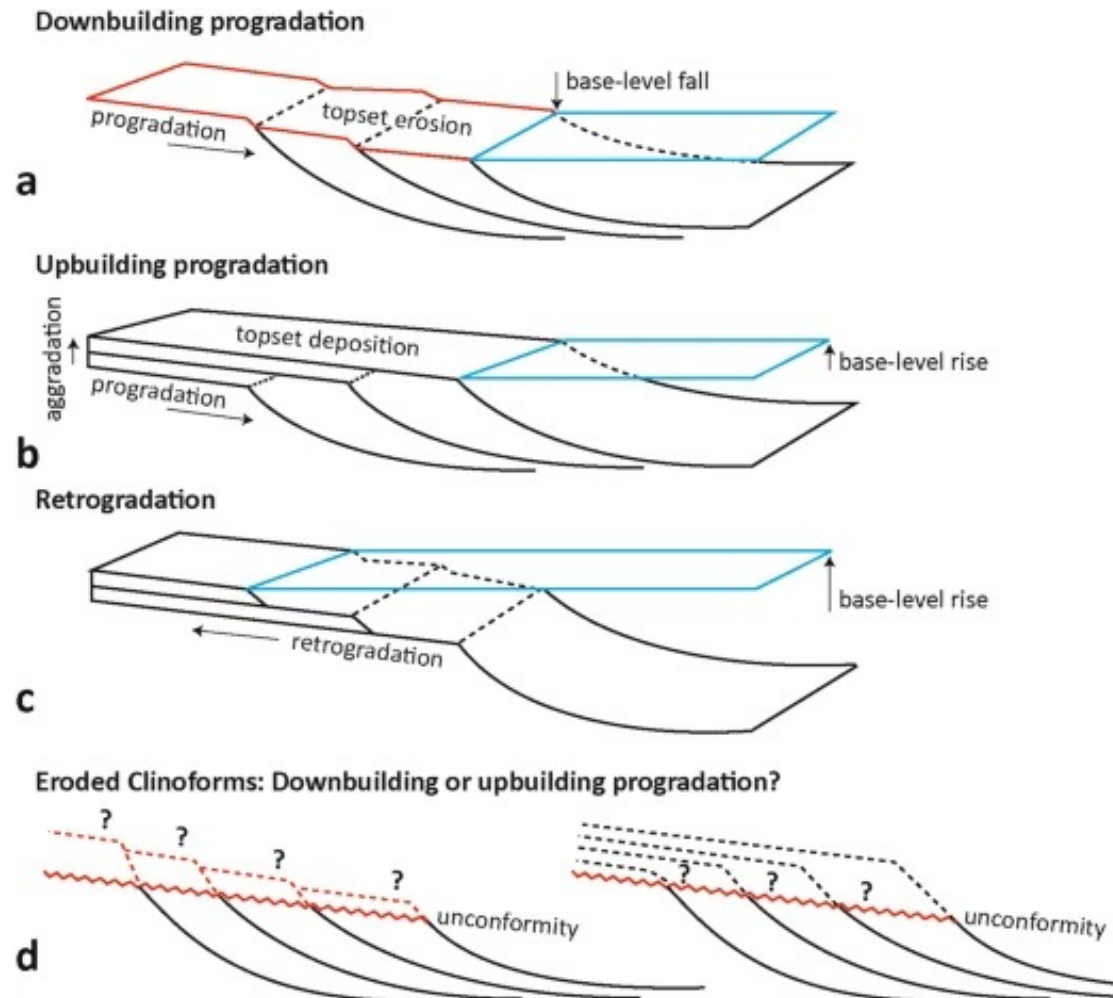
clinoforms are sigmoidal (sloped) sedimentary strata bounded by clinoforms and represent a span of geological time. They are formed when sediments prograde into the basin. clinoform volumes are often subdivided into topset, foreset and bottomset compartments, which are each associated with specific sedimentary facies



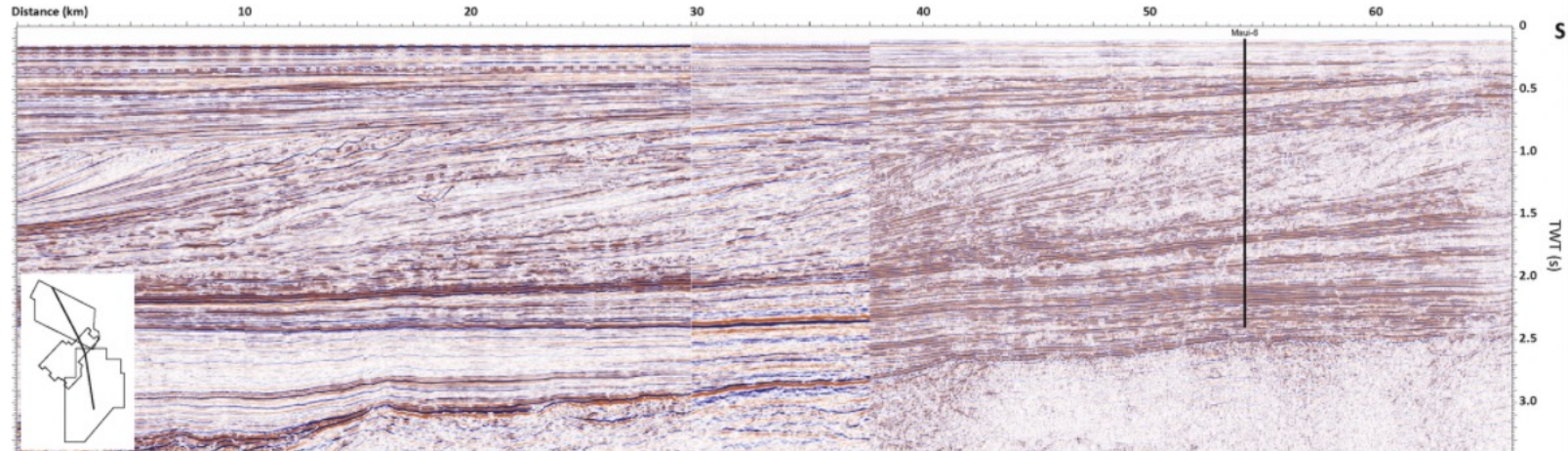
Franzel & Back (2019) Int J Earth Sci. Three-dimensional seismic sedimentology and stratigraphic architecture of prograding **clinoforms**, central Taranaki Basin, New Zealand

Key stratal associations that result from the interplay of accommodation and sedimentation: downbuilding progradation, upbuilding progradation, and retrogradation.

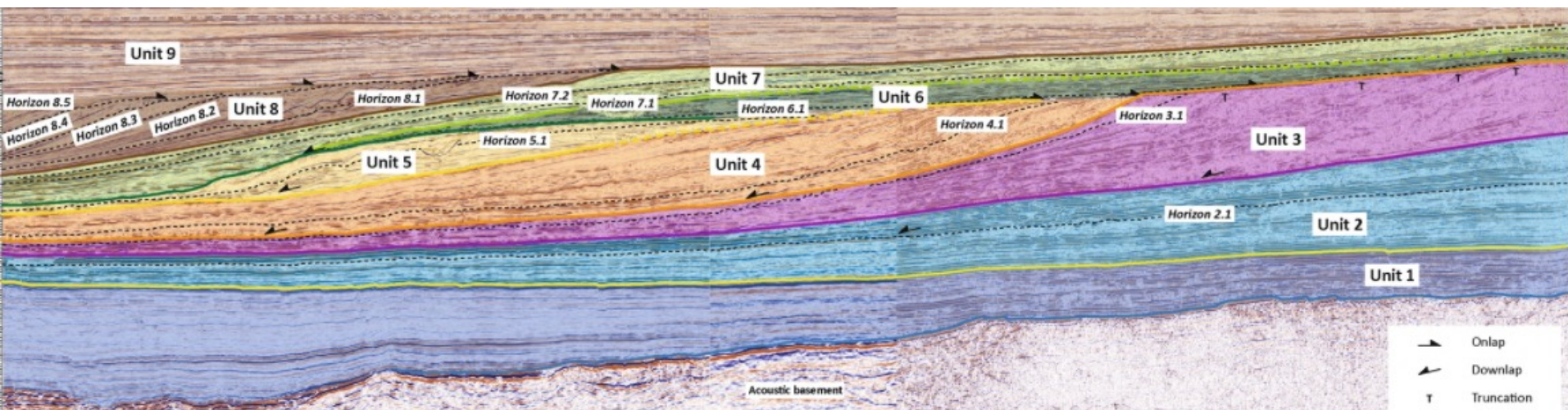
a Downbuilding progradation results from a base-level fall and the seaward migration of a shoreline independent of sediment supply. b Upbuilding progradation is driven by sediment supply, in which the sedimentation rate outpaces the rates of base-level rise at the shoreline. c Retrogradation of depositional systems results from a base-level rise, in which the rates of base-level rise outpace the sedimentation rates at the shoreline. d Erosion of clinoform topsets hampering the differentiation between downbuilding and upbuilding progradation



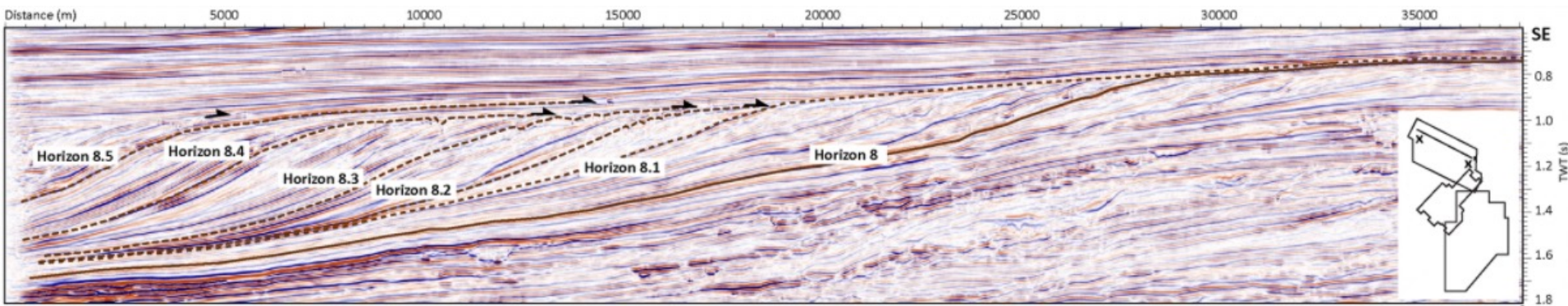
Franzel & Back (2019) Seismic overview



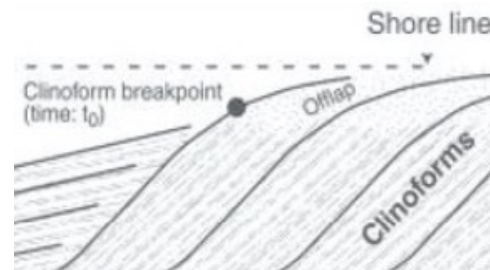
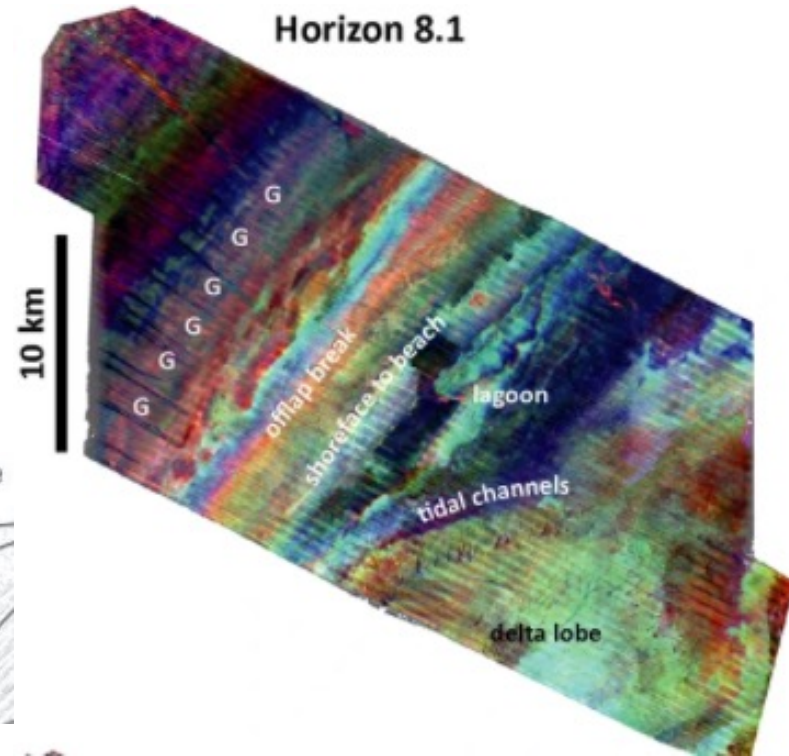
Dashed lines indicate areas in which downbuilding progradational, upbuilding progradational, and retrogradational units are separated by zones of reflection termination instead of a single sharp, precisely defined bounding reflection



Vertical reflectivity section across Pliocene–Pleistocene downbuilding clinoforms of Unit 8. Black arrows mark onlap reflection terminations.



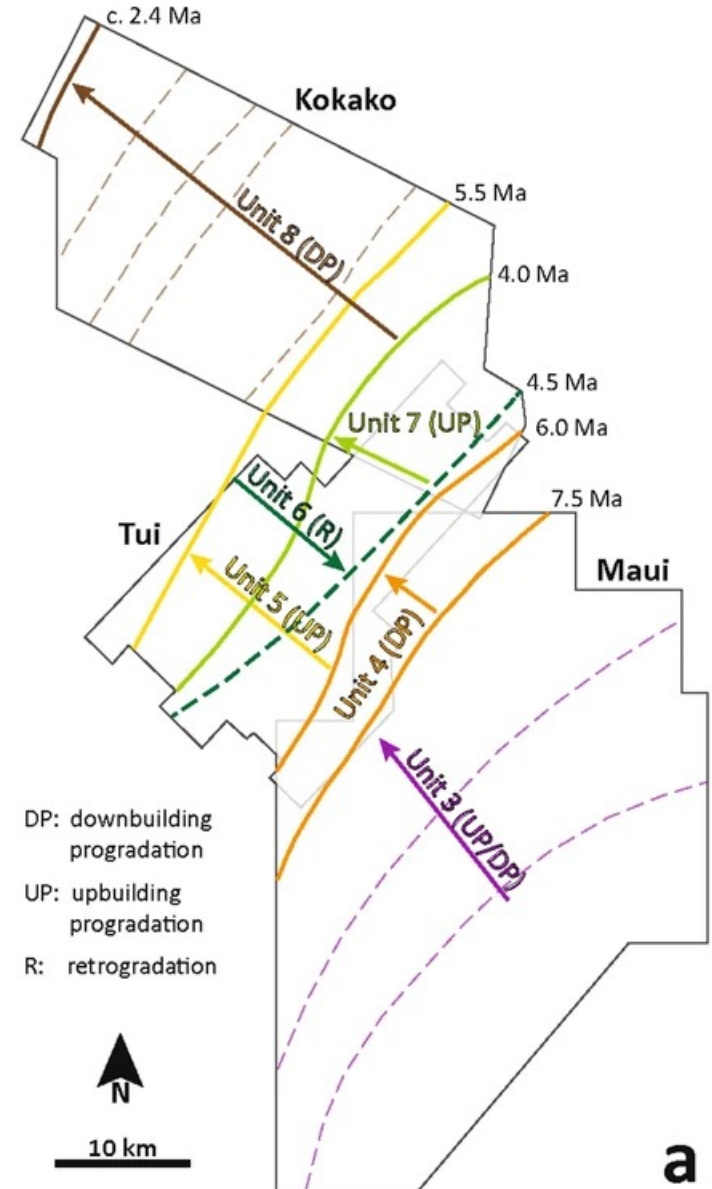
At and landward of the clinoform breakpoint, which was in the downbuilding clinoform unit 8 likely in the shoreface depositional environment, foreshore processes (tidal currents and waves) as well as backshore and coastal-plain erosional systems seem to have controlled the respective gully position, and, therefore, sediment supply to the clinoform foresets.



Cliniform breakpoint migration

Cliniform breakpoint migration and depositional elements of units 3 to 8. a
 Cliniform breakpoint trajectories and approximate stratigraphic ages. Coloured lines indicate maximum progradation or retrogradation in each unit. Purple dashed lines in the Maui area show truncated cliniform foresets and brown dashed lines in the Kokako area indicate offlap breaks of individual cliniform packages.

Franzel & Back (2019)



Cliniform breakpoint trajectories (c. 11.0 - 2.4 Ma)

Barriers are wave-built accumulations of sediment that accrete vertically due to wave action and wind processes. Most are linear features that tend to parallel the coast, generally occurring in groups or chains.

Barrier system

A chain of barrier islands and spits along an open-ocean coast, composed of several distinct island

The subaerial expression of an accumulation of wave-, wind-, and/or tide-deposited sediments between two active tidal inlets and this sediment accumulation (barrier island) lies between the shoreface and the back-barrier estuary (Oertel, 1985).

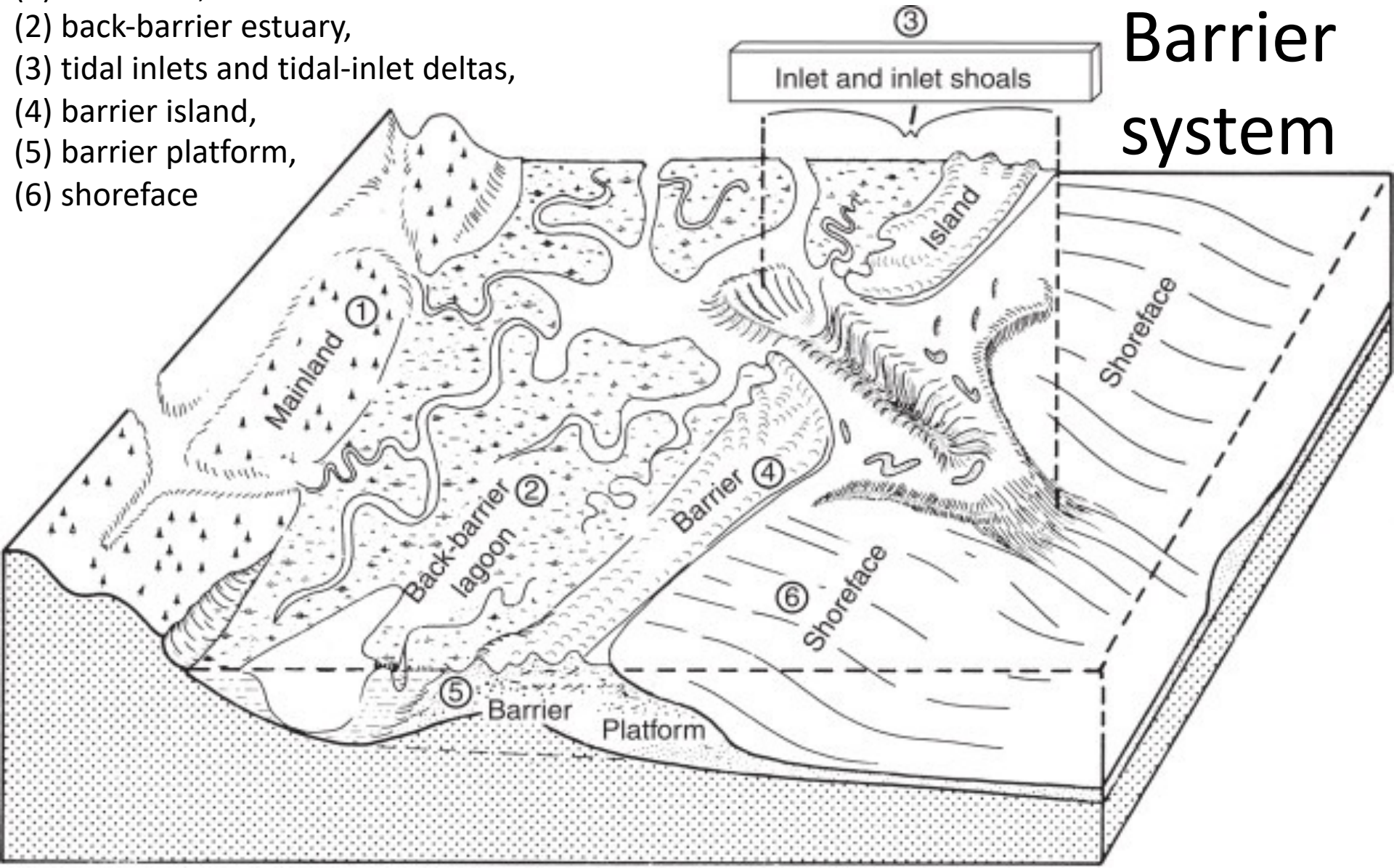
Morphodynamics of Barrier Systems: A Synthesis.

McBride et al., Treatise on Geomorphology, Academic Press, 2013

For a littoral sand body to be designated a barrier island, six required sedimentary environments must be present:

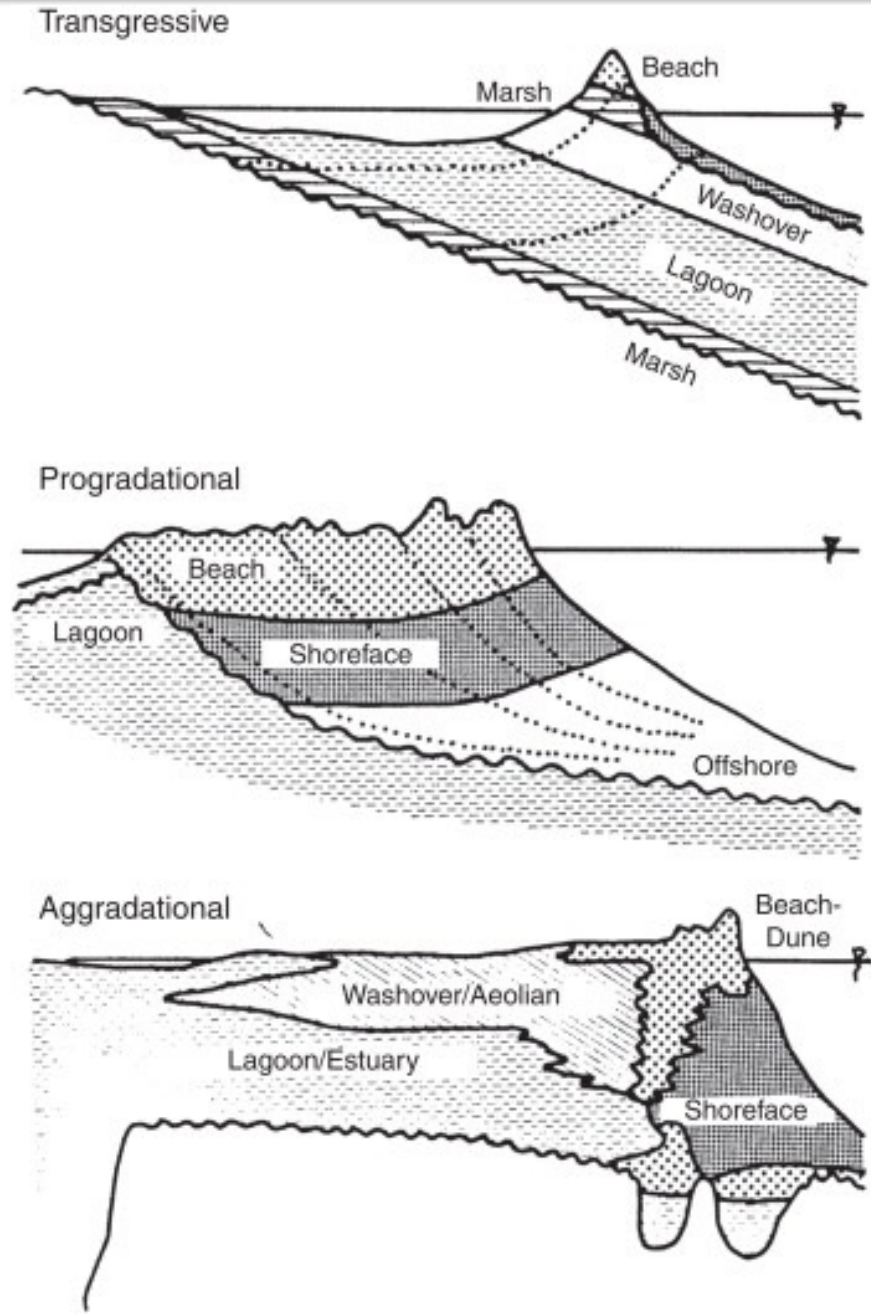
- (1) mainland,
- (2) back-barrier estuary,
- (3) tidal inlets and tidal-inlet deltas,
- (4) barrier island,
- (5) barrier platform,
- (6) shoreface

Barrier system



Morphodynamics of Barrier Systems: A Synthesis. McBride et al., Treatise on Geomorphology, Academic Press, 2013

Generalized stratigraphic models of coastal response for transgressive, progradational, and aggradational barrier systems because of changes in relative sea level, sediment budget, coastal processes, and/or other factors



Glossary

Strandplain: Broad accumulations of sediment formed in parallel or semiparallel ridges oriented approximately parallel to the coastline. Often lack tidal lagoons, salt marshes, and incising tidal creeks; rather, they are connected directly to the mainland, though they may border estuaries whose creeks extend into the plain.

Beach ridge: The clastic sand and/or gravel ridges – often regressive and containing shell fragments – that are built primarily by wave processes, such as the emergence and growth of longshore bars during constructional wave activity, or the erosion of the lower beach and deposition by wave swash along the upper beach during storms. Low areas are called swales.

Foredune: A sand dune located immediately landward of the beach-backshore area and oriented parallel or near parallel to the shoreline. The first or foremost dune also known as the fore dune ridge or primary dune.

Chenier: An isolated transgressive sandy and/or shelly ridge with progradational littoral mudflat deposits both landward and seaward of the ridge.

Barrier spit: Elongated, wave-built accumulation of sand that is built laterally through longshore sediment transport and is attached on one end to a mainland coast

Glossary

Outwash plain: broad, low-relief plain composed of sediment (typically sand and fine gravel) deposited by meltwater flowing as confluent alluvial fans that emerge from multiple meltwater valleys at the terminus of a glacier.

Overwash: The process where sediment is transported by swash landward from the beach across a barrier system and is deposited in an apron-like accumulation along the backside of the barrier island or barrier spit.

Overwash usually occurs during storms when waves break through the frontal dune ridge and flow landward toward the marsh or estuary.

Washover fan: A fan-shaped body of sediment that is transported landward by marine waters flowing through or across a coastal barrier (e.g. a barrier bar or island). Such bodies are formed especially during storms, when the barriers are likely to be breached

lagoon

A lagoon (ephemeral feature in geologic time that is gradually filled in with available sediment) is a shallow body of water separated from a larger body of water by a narrow landform, such e.g. barrier islands. Lagoons are common coastal features around many parts of the world

Venice lagoon



Estuary

A semi-enclosed coastal body of water that extends landward to the effective limit of tidal influence and within which seawater enters from one or more free connections with the open sea and is diluted by freshwater derived from land drainage

Isonzo estuary



Tidal flats are intertidal platforms commonly located in sheltered areas such as bays, estuaries and lagoons, where sediments from river runoff, or inflow from tides, deposit mud or sand.

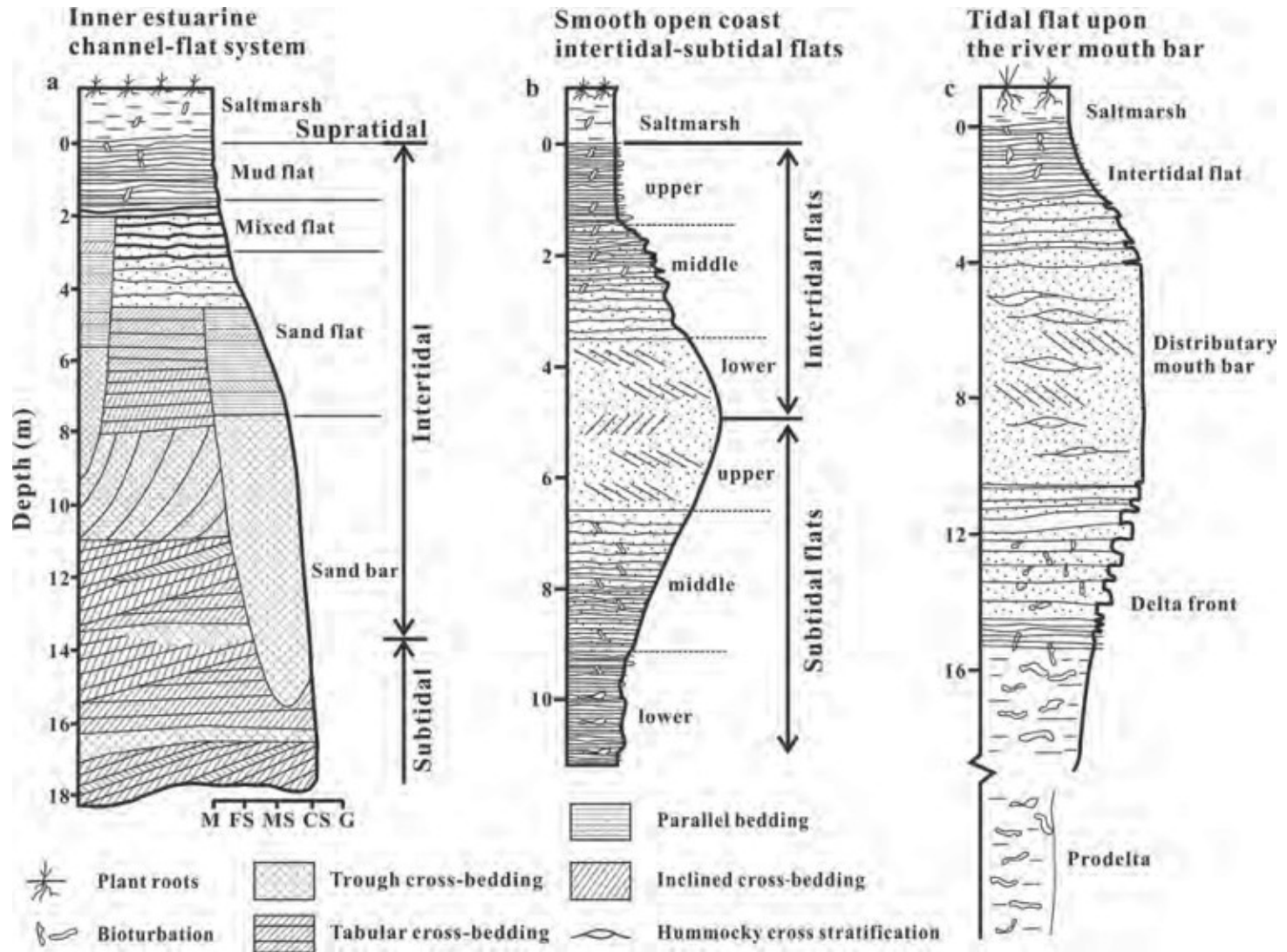
Tidal flat

Venice lagoon



tidal-flat successions

Schematic models showing the three most common progradational tidal-flat successions in the sheltered, open coast and deltaic environments



Marsh

a tract of low wet land, often treeless and periodically inundated, generally characterized by a growth of grasses, sedges, cattails, and rushes.

Isola della Cona



Delta

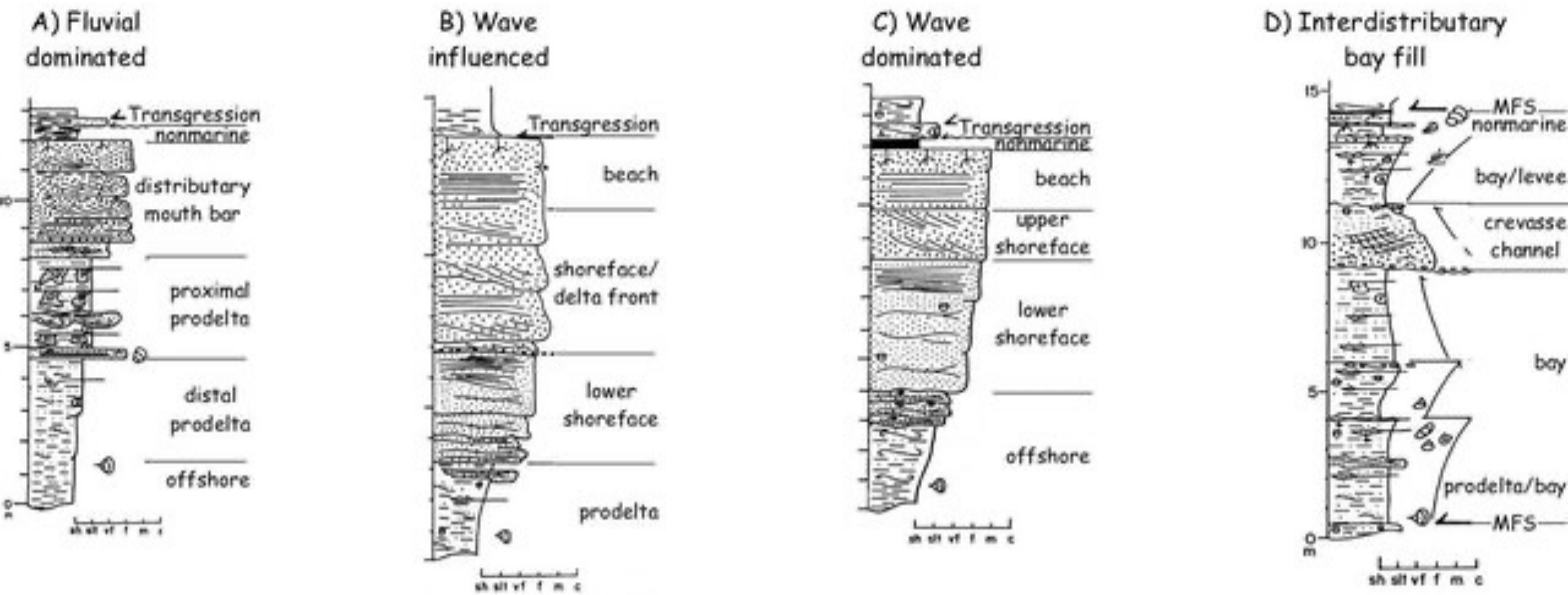
A usually triangular mass of sediment, especially silt and sand, deposited at the mouth of a river.

Po
delta

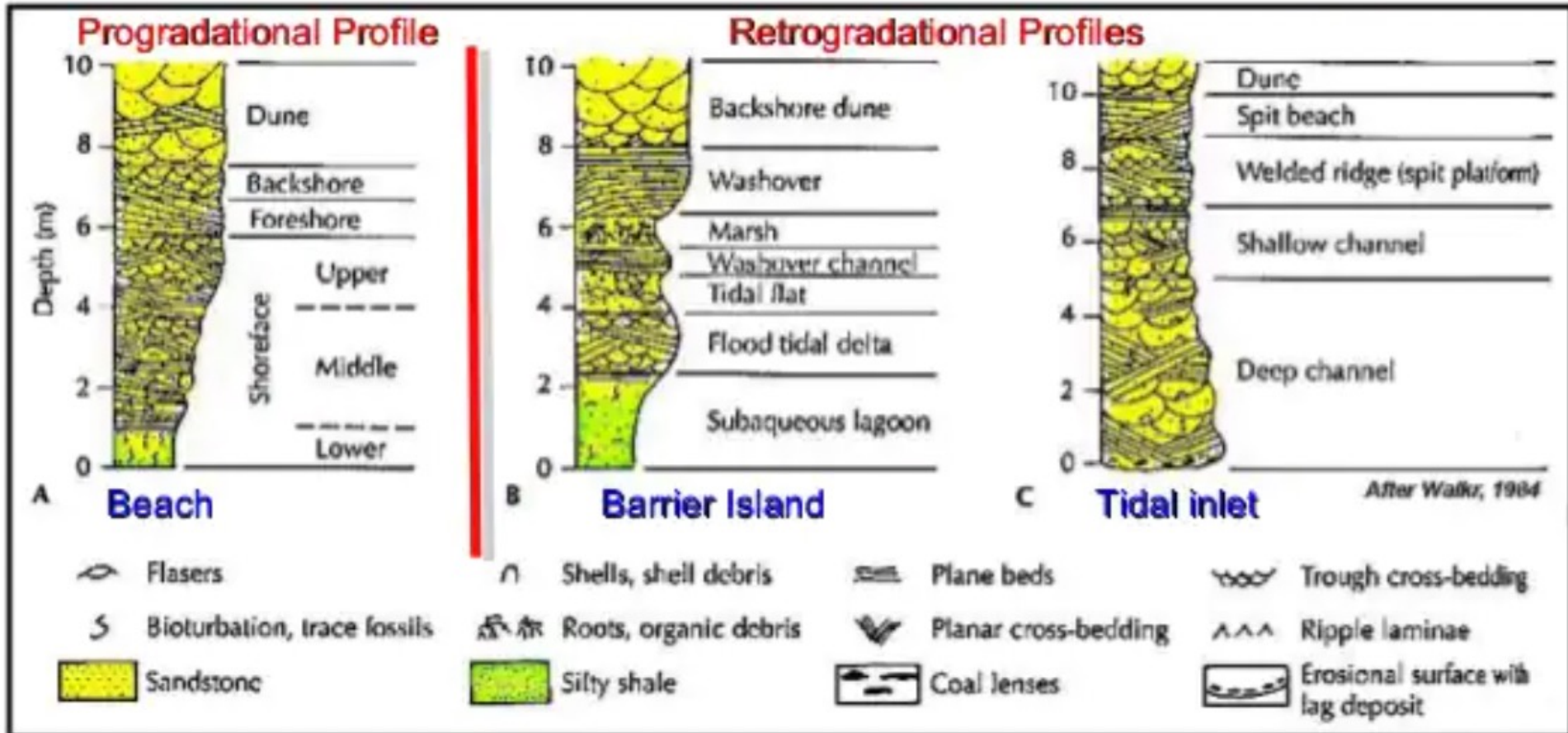


Delta sequences of deltas in the Upper-Cretaceous Funvegan Formation, Alberta (Bhattacharya and Walker, 1992).

Delta front successions for so-called A) fluvial-dominated, B) wave-influenced, and C) wave-dominated deltas; proximal prodelta is equivalent to bar front. D) Interchannel bay fill in a river-dominated delta.

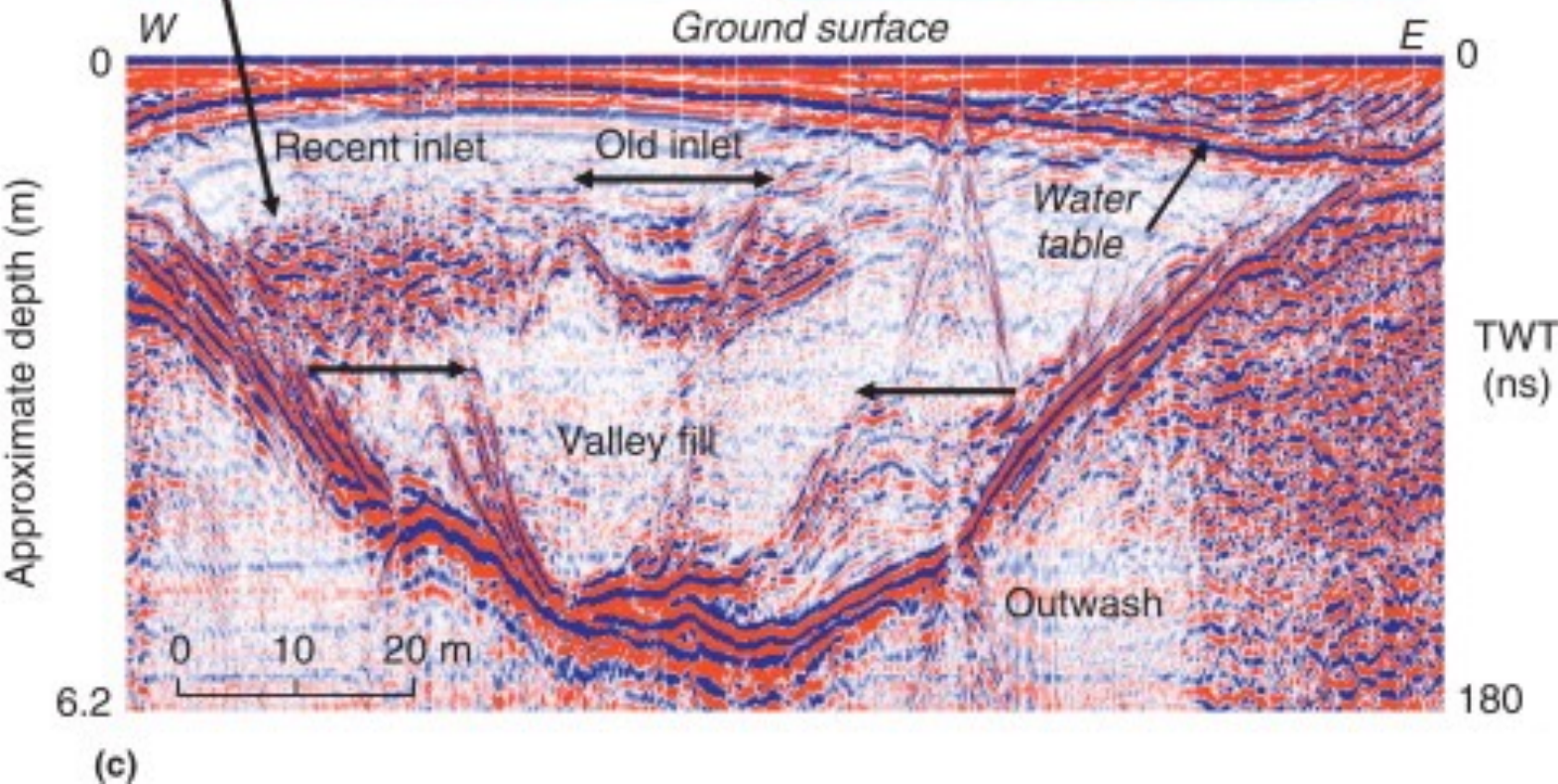
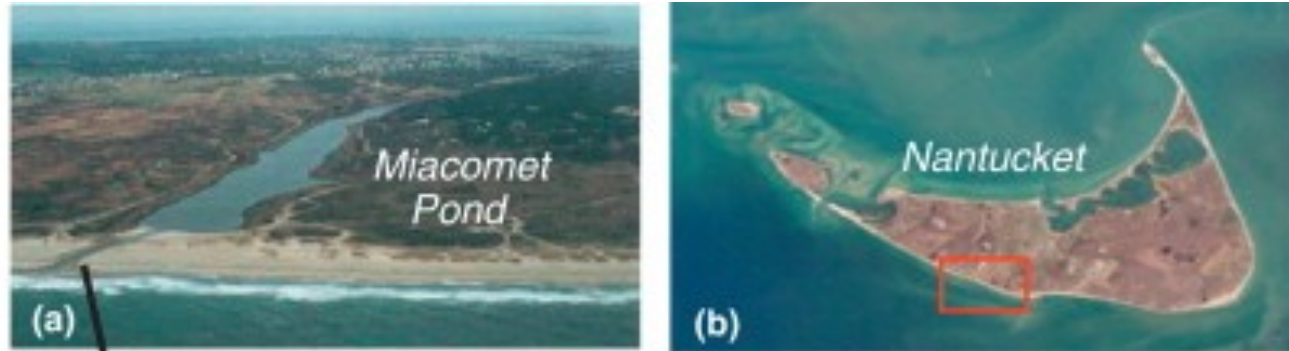


Three end-member facies models



A) a prograding barrier island, B) a transgressive barrier island and C) a channel inlet migration

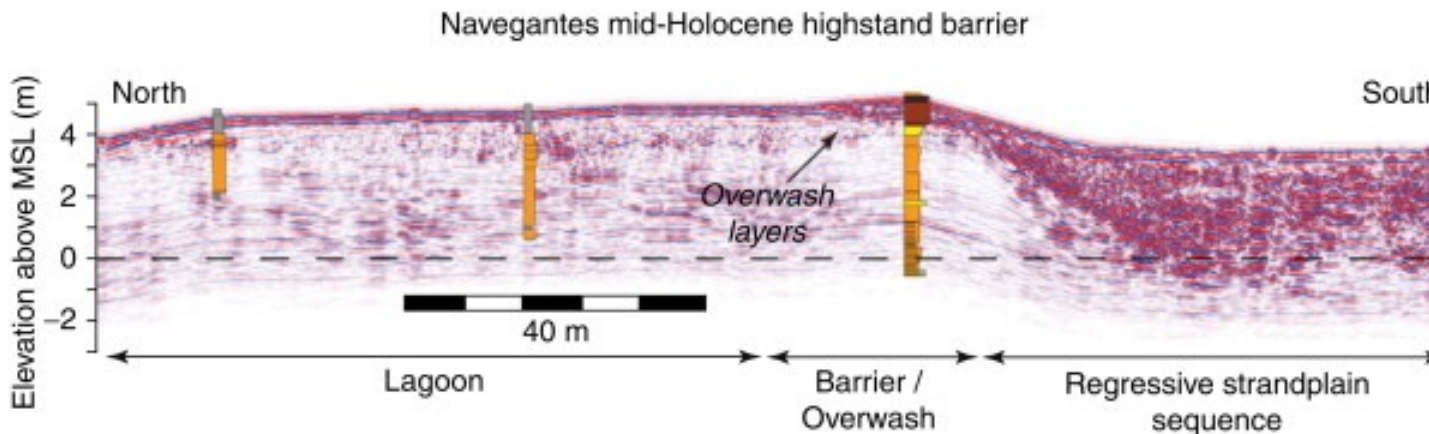
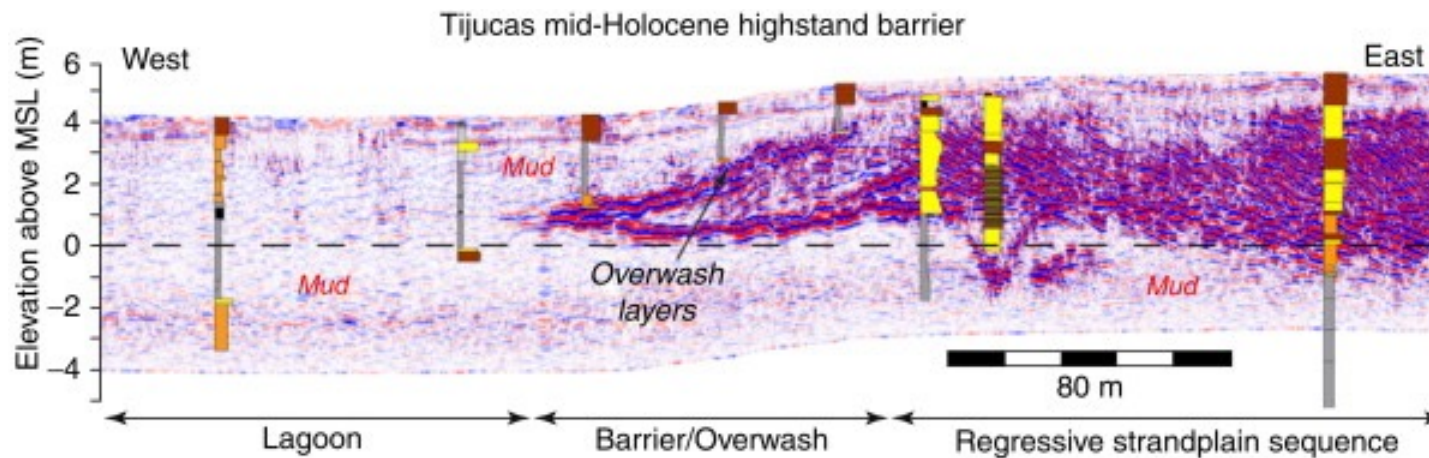
Baymouth barrier, southern shoreline of Nantucket Island



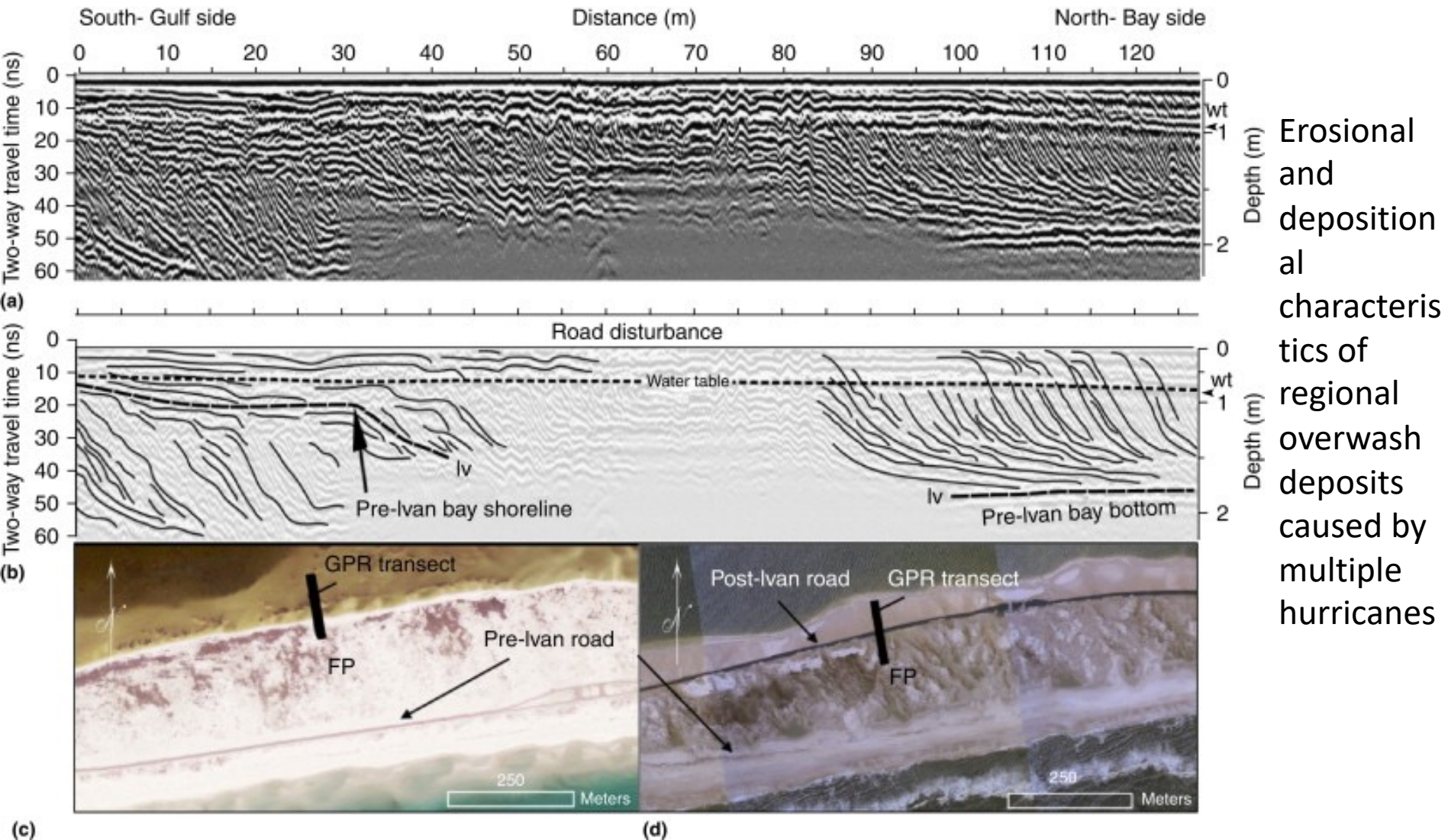
(a) Pond, outwash plain, and small inlet.
(b) Location.
(c) Shore-parallel geophysical image revealing the outline of a spring-sapping valley, the bidirectional valley fill (inward-facing arrows), as well as two shallow channel structures.

highstand barriers in Tijucas and Navegantes

Barriers are denoted by topographically high ridges and the presence of overwash layers. They are backed by lagoons (muddy in Tijucas, where the Tijucas River delivers large quantities of mud; and sandy in Navegantes, where the Itajaí River generally delivers only sand) and fronted by seaward-dipping regressive strand plain systems deposited as sea level fell

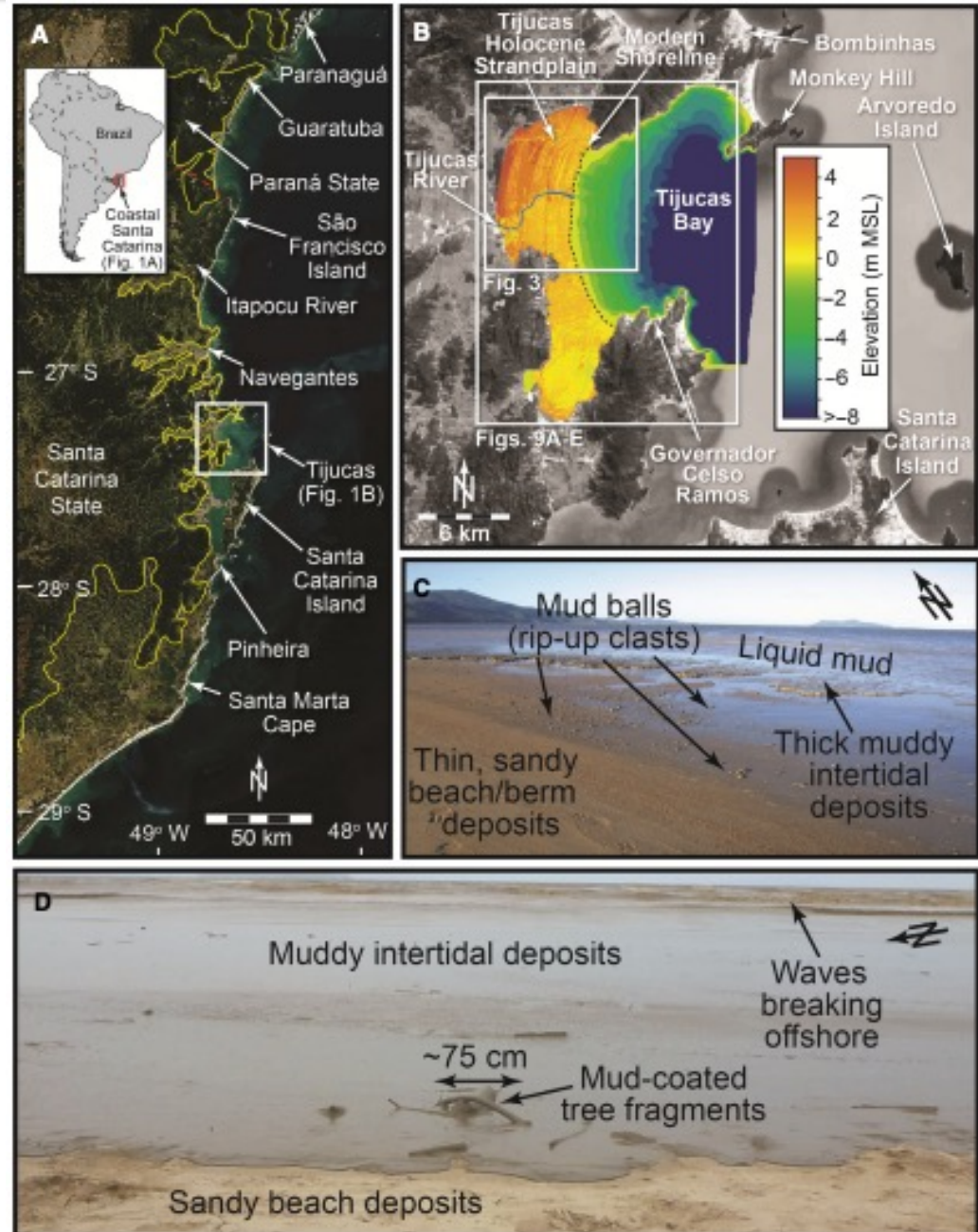


GPR transect across Santa Rosa Island and pre- (c) and post-Ivan (d) aerial photos.

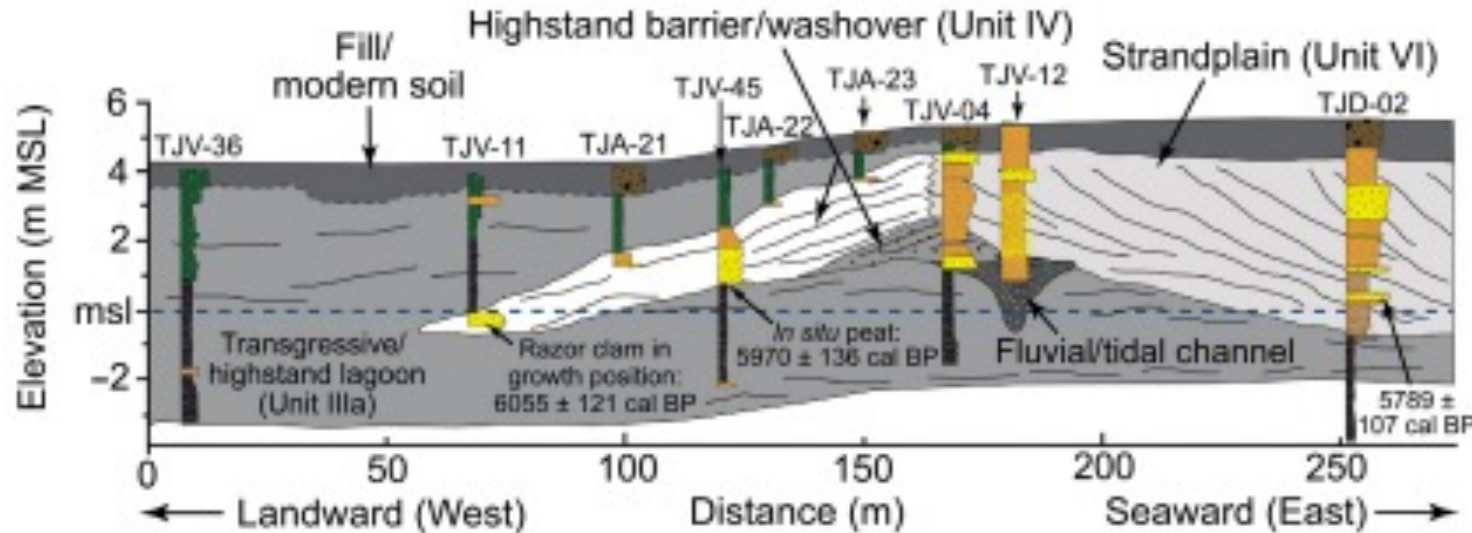
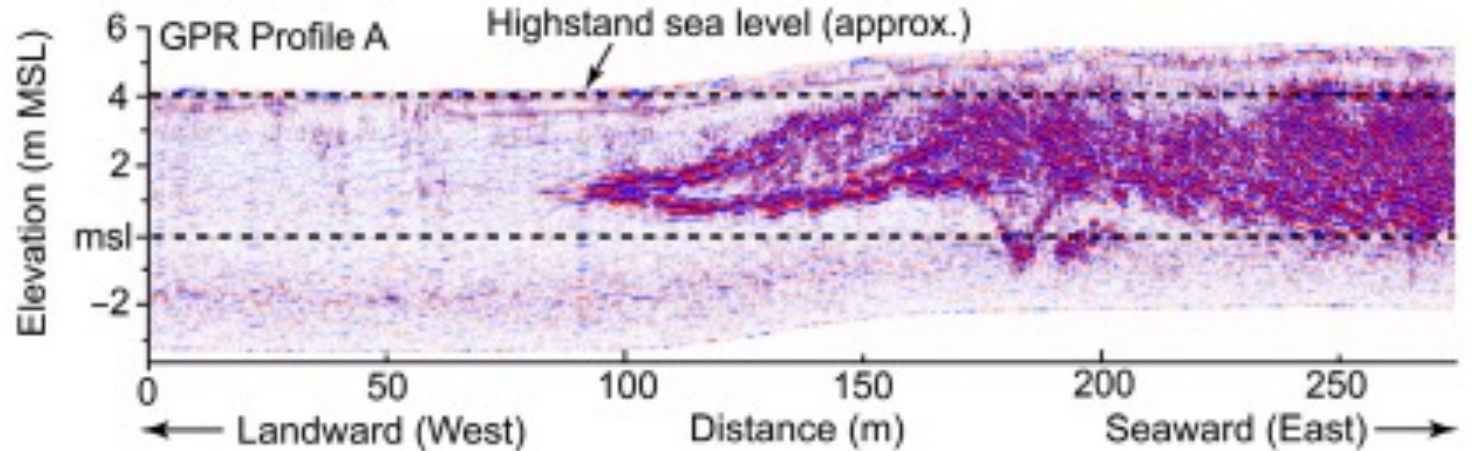


Hein et al., 2016. Sedimentology. Complex coastal change in a sub- tropical Holocene strandplain

(A) Map of the coast of Santa Catarina, Brazil. (B) Digital elevation model of Tijucas Strandplain and Tijucas Bay. (C) Tijucas Beach during calm conditions in March 2009, four months following a large flood event on the Tijucas River. (D) Image of Tijucas Beach during a moderate-energy event in November 2012. The lower beach face was coated with ca 2 cm of fine silt and clay during this event



barrier ridge in central Tjucas

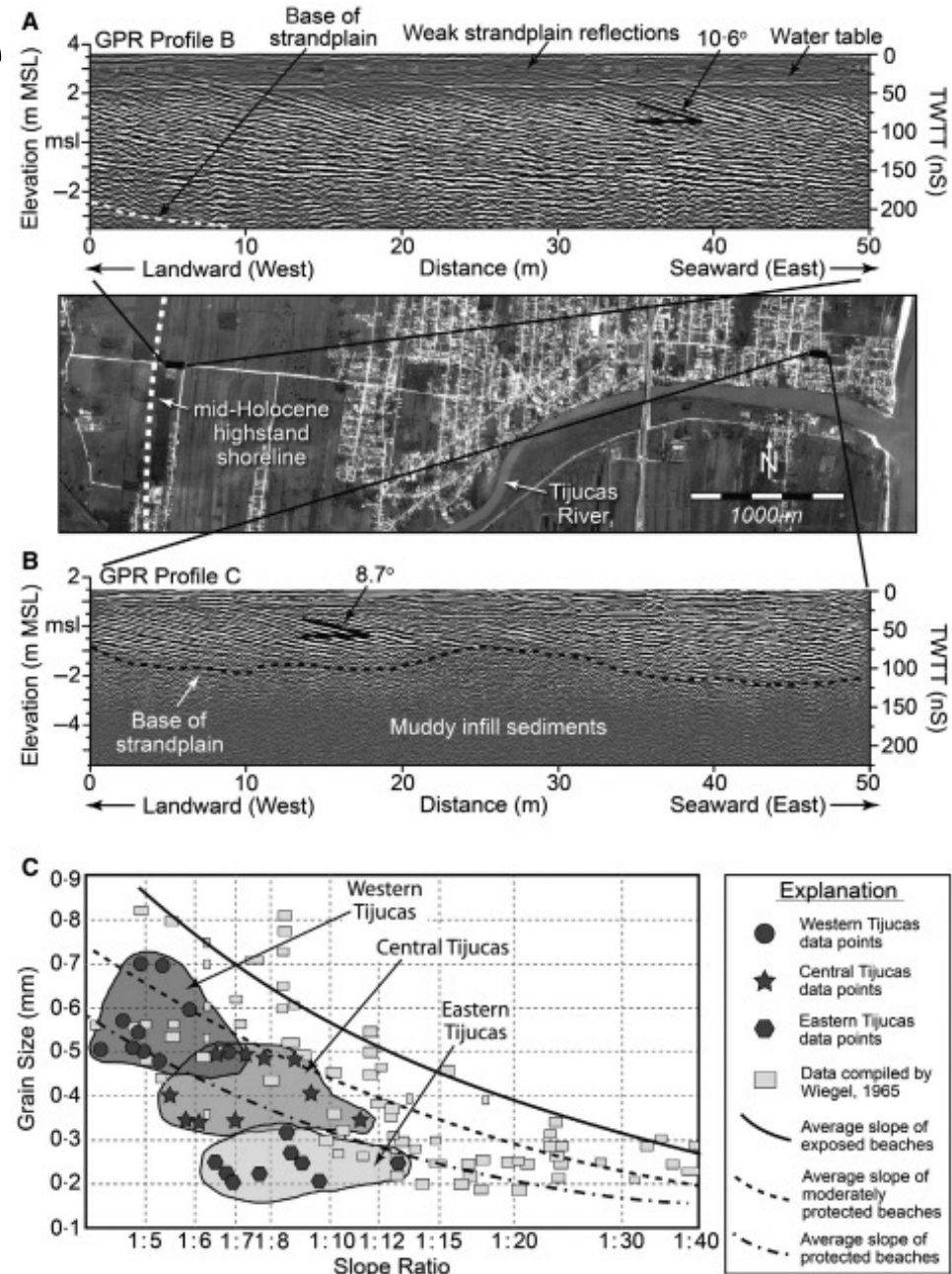


Explanation			
	Clay		Medium sand
	Mud/very fine sand		Coarse sand
	Peat/organics		Fill
			Radargram reflection traces
			GPR Vertical Exaggeration: 27.5x

Changes in beachface slope across the Tjucas Strandplain

(A) GPR Profile C, collected ca 200 m seaward (east) of the mid-Holocene highstand barrier in a sand-dominated section of the plain. (B) GPR Profile D, collected ca 650 m landward (west) of the modern shoreline in a sandy section of the mud-dominated eastern plain. Note the gentle shallowing of shoreface reflectors and the thinning of sandy strandplain units as mud-dominance increases in a seaward direction. (C) Slopes of sandy beachface (strandplain) GPR reflections and associated sediment grain sizes from across the Tjucas Strandplain

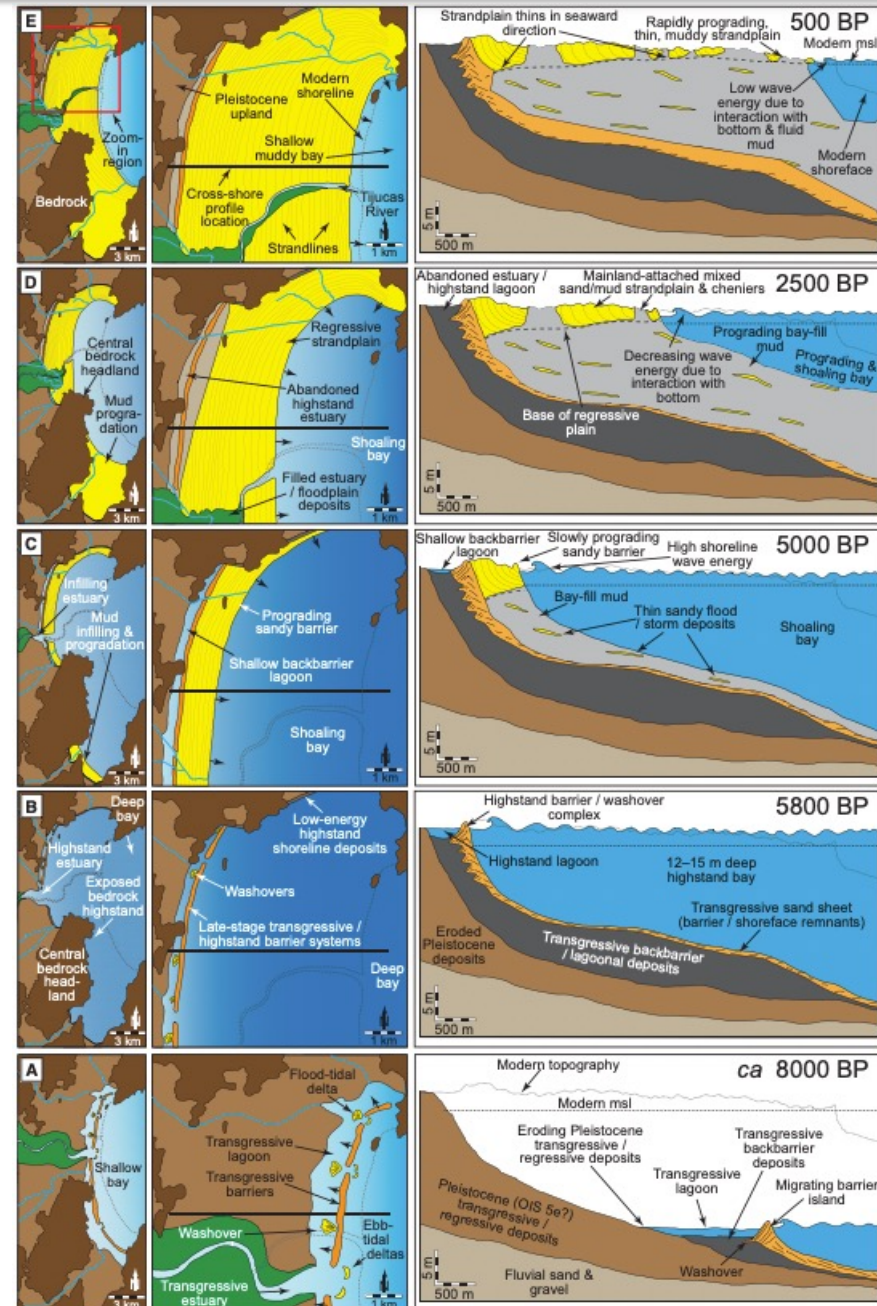
Hein et al., 2016



Holocene evolution of Tijuucas Bay and the Tijuucas Strandplain

Simplified map and cross-section views show major events and drivers [relative sea-level (RSL) change, sedimentation and bay shoaling] of coastal change in this system from ca 8 ka to present.

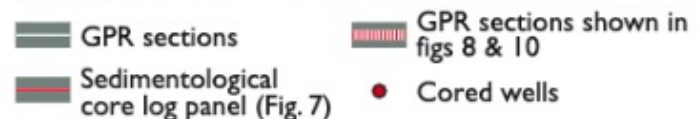
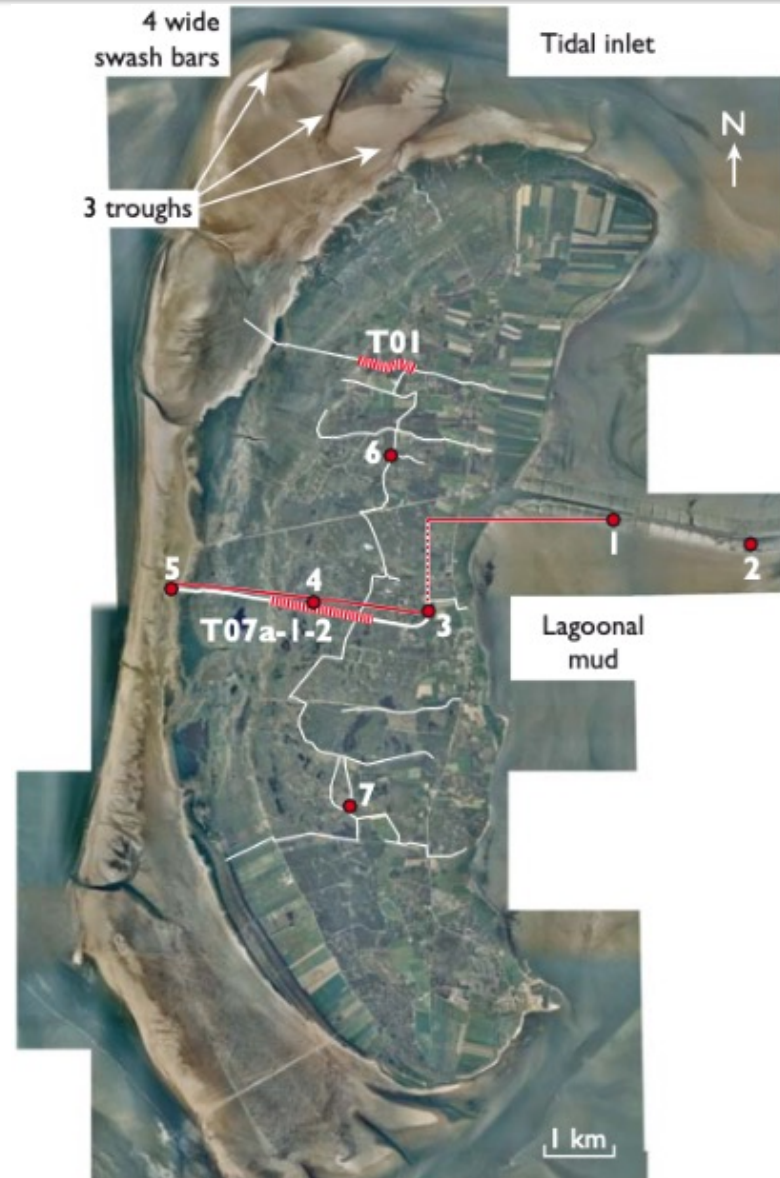
Hein et al., 2016



Architecture of an Upper Jurassic barrier island sandstone reservoir, Danish Central Graben

JOHANNESSEN 2010,
Petroleum Geology
Conference series

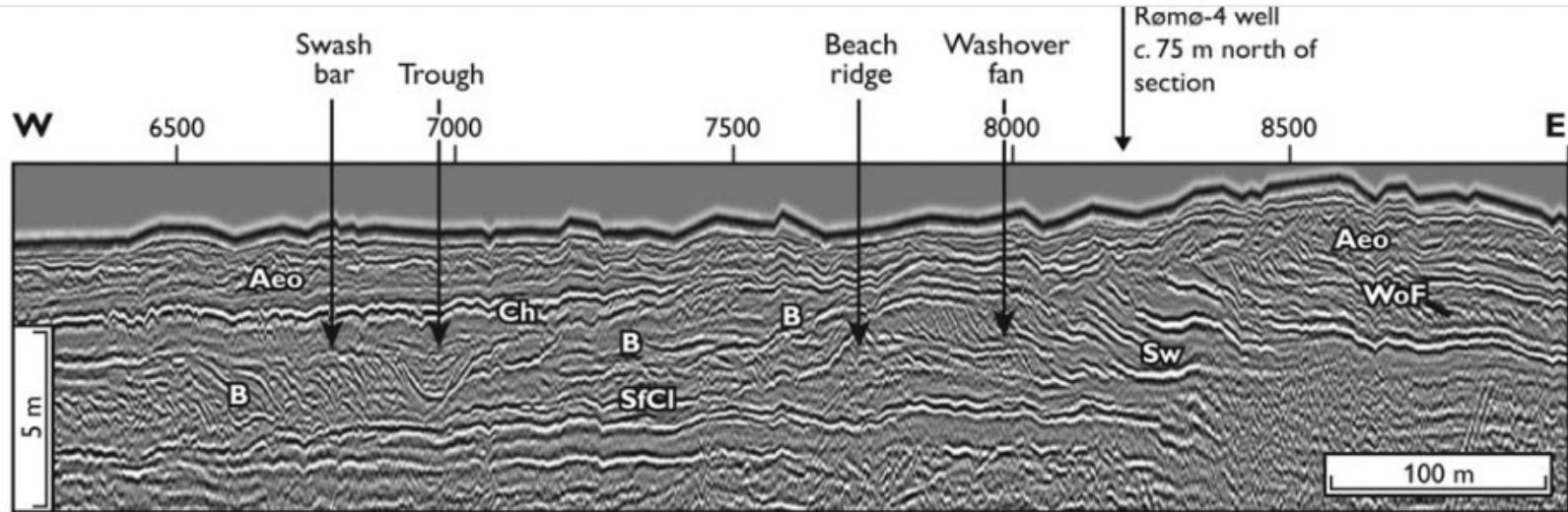
Ortho photo of the Rømø barrier island showing the distribution of GPR reflection profiles and position of the seven cored wells. Very wide tidal flat sands characterize the NW and SW end of Rømø. The island is dominated by aeolian dune sand.



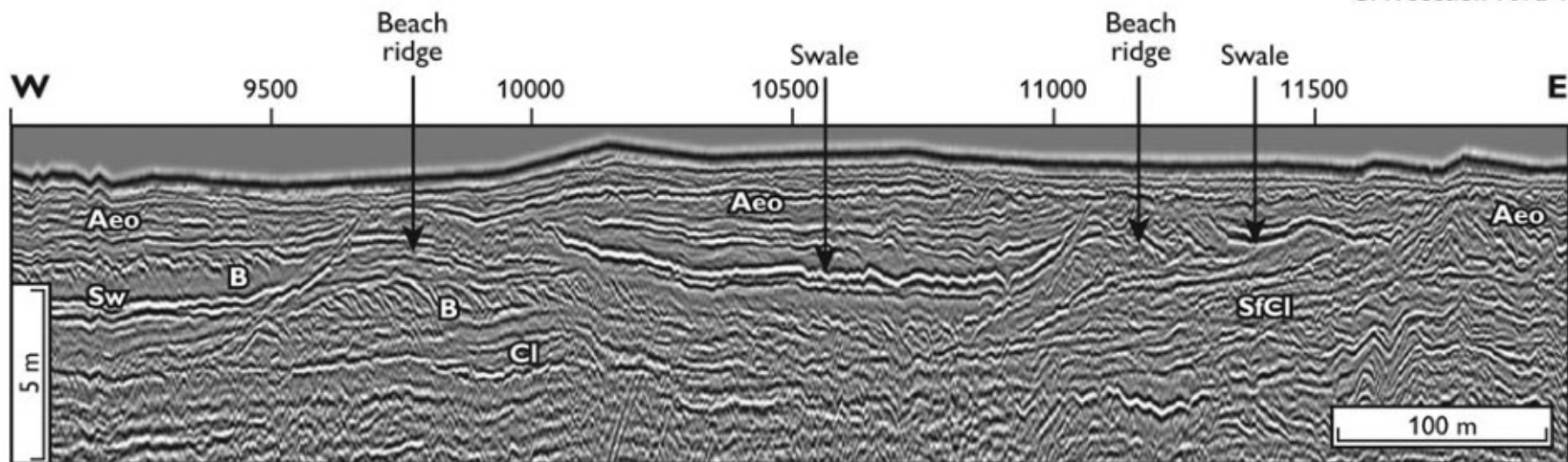


Recent development of washover fan (1990) over the Skallingen peninsula situated in the northernmost part of the Danish Wadden Sea. (a) The washover fan is 250 m long and wide and was deposited in the lagoon within a few hours during a storm flood tide. Storm surges broke through the beach ridges and aeolian sand dunes. (b) Washover fan with steep slipface terminating in the lagoon. Internally the c. 0.5 m thick washover fan is characterized by steep foresets. The washover fan was deposited several metres above mean sea-level as it formed during a storm when the storm peak sea-level was elevated by more than 4 m due to the combined effect of high tide and storm surge. Photo by Niels Nielsen.

GPR profile on Rømø barrier island. The succession of beach ridges show shoreface progradation towards the west. The upper part of the section consists of aeolian sand



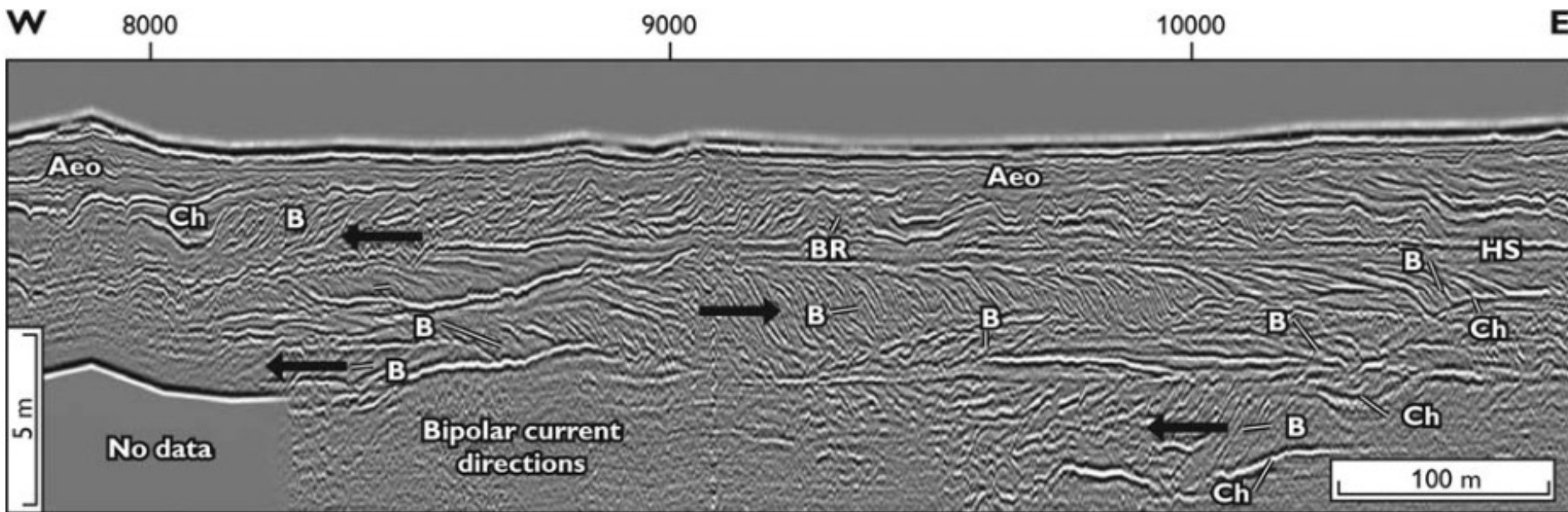
GPR section T07a-1



GPR section T07a-2

- Aeo: Aeolian
- BR: Beach ridge
- Sw: Swale
- WoF: Washover fan
- B: Bar
- HS: Horizontal strata
- Ch: Channel
- Cl: Clinoform
- SfCl: Shoreface clinoform

GPR profile on Rømø barrier island, which contains abundant tidal inlet sands



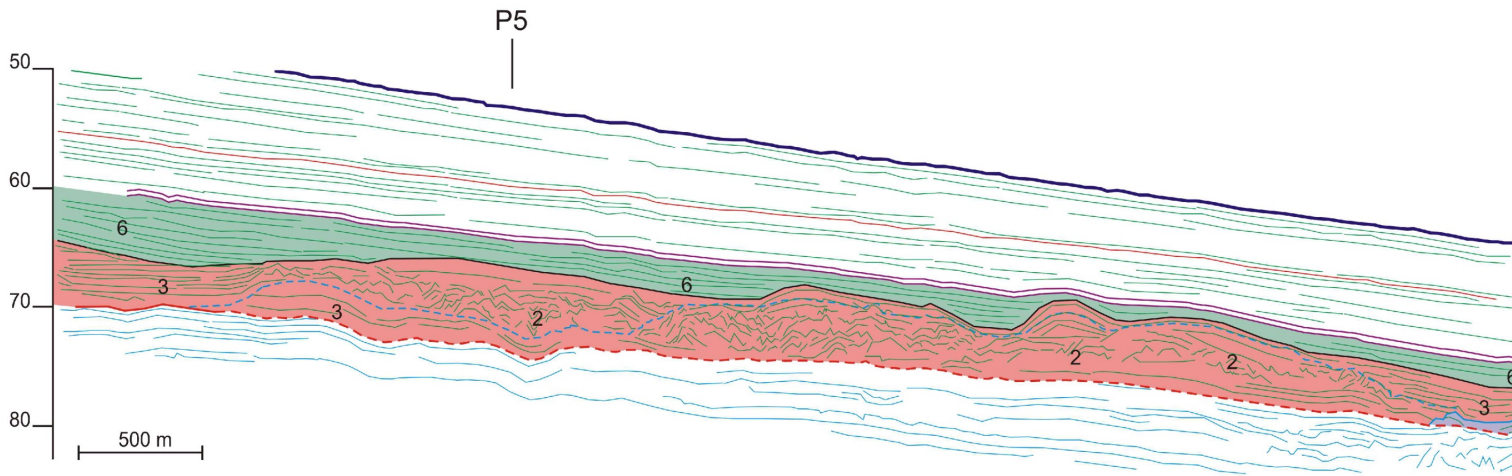
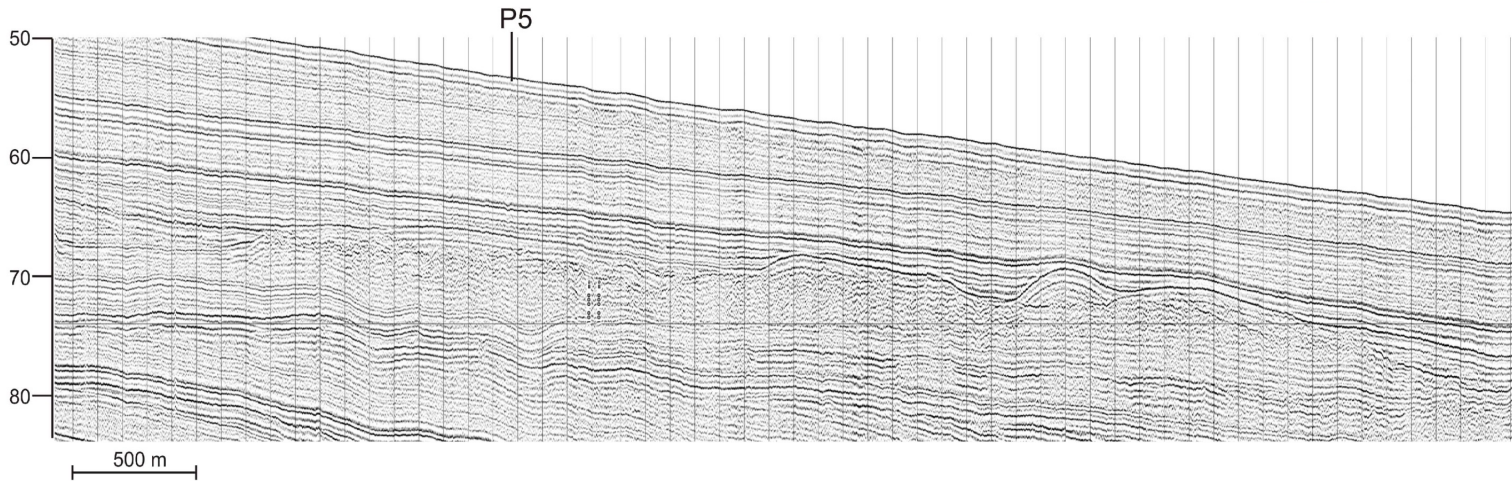
Aeo: Aeolian
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WoF: Washover fan
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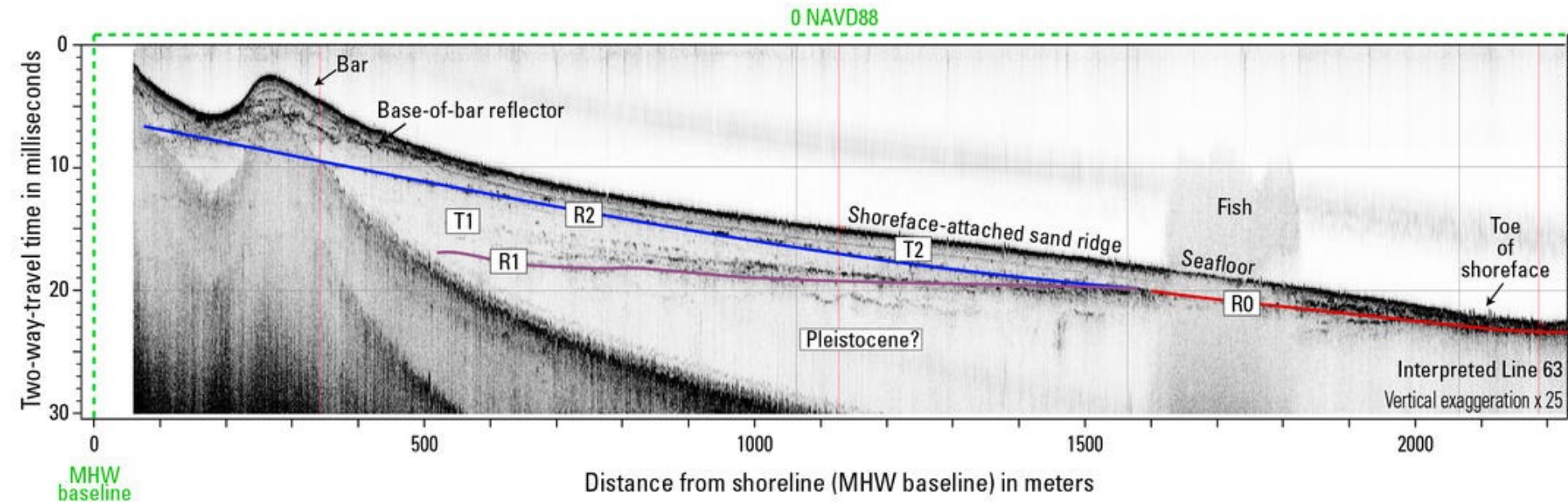
SfCl: Shoreface clinoform

Holocene transgressive architecture in the Manfredonia Gulf of the southern Adriatic Sea



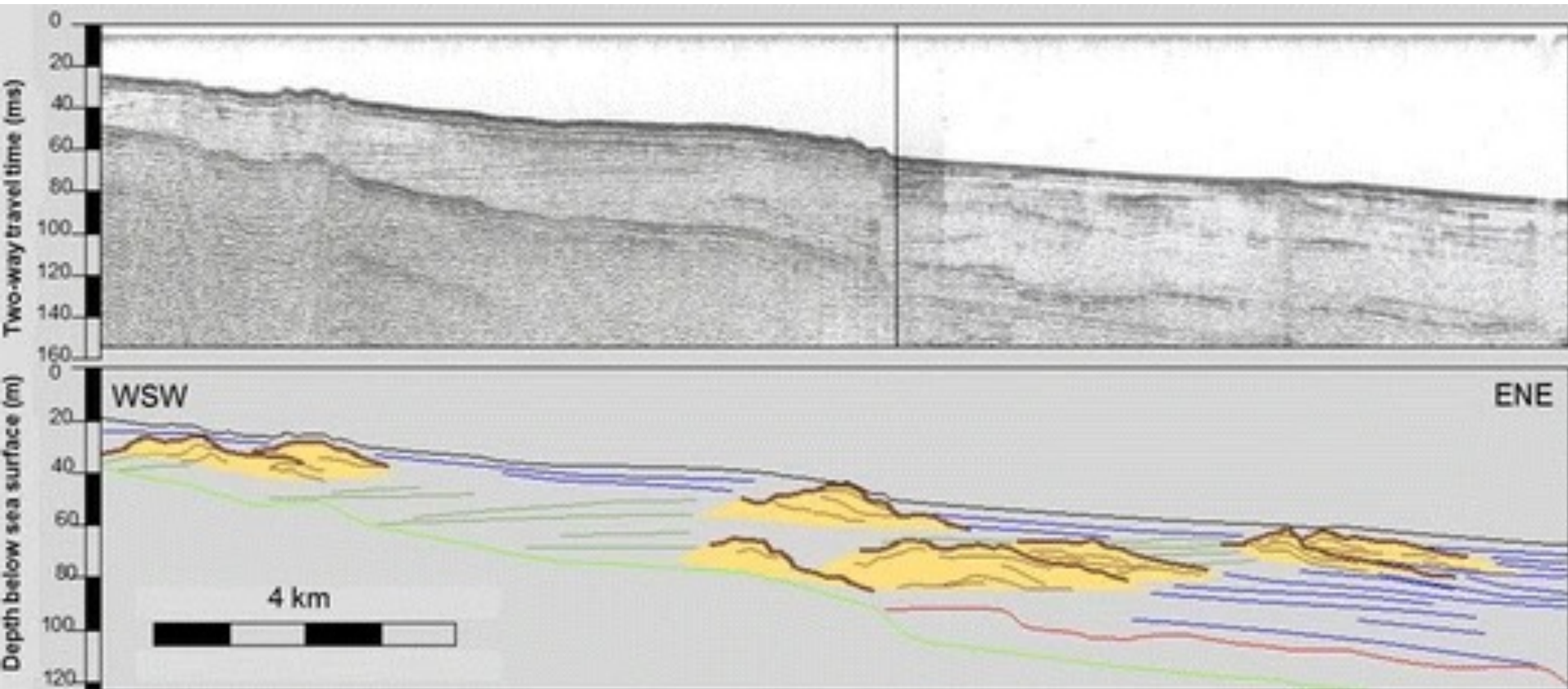
slowstand during the late Bølling-Allerød and during the Younger Dryas: formation of the coastal barrier system with a continuous landward backstepping process, due to the combination of the enhanced sediment input, low-gradient setting and slow sea-level rise

seismic profile collected from the shoreface of Fire Island, NY



The profile shows a steep shoreface, a nearshore bar, a sand ridge, and the geology beneath it all. The sediment above the blue and red lines is thought to be available for transport by waves or longshore drift.

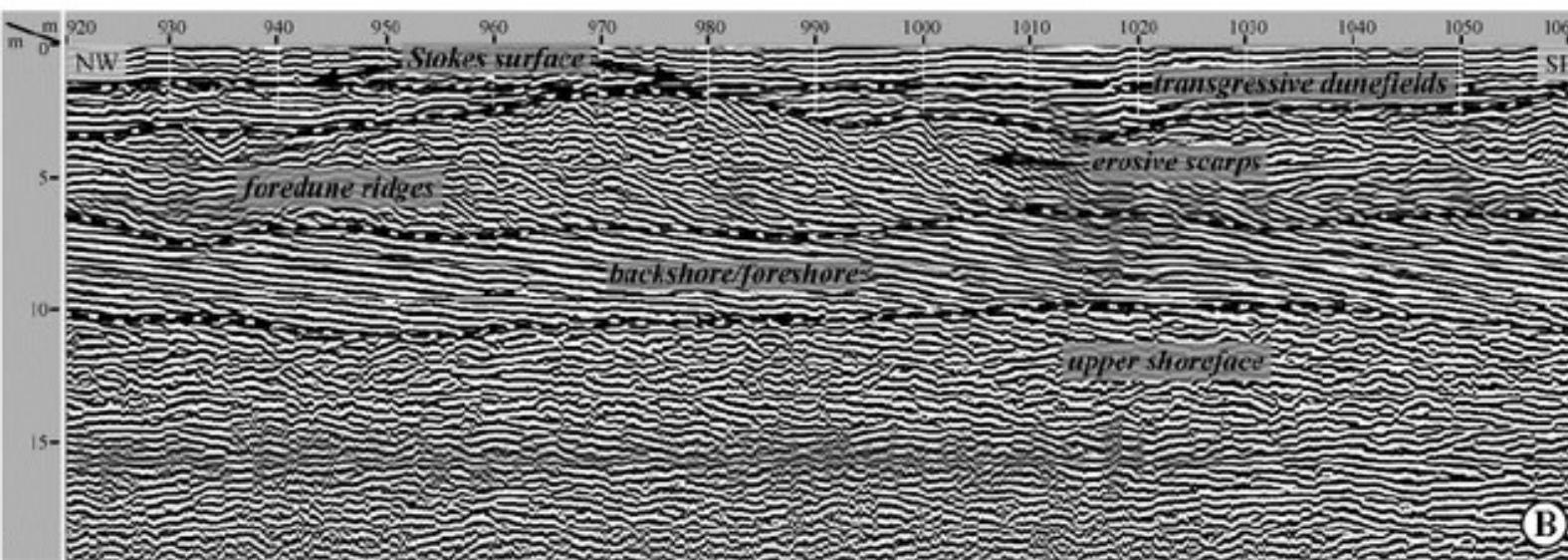
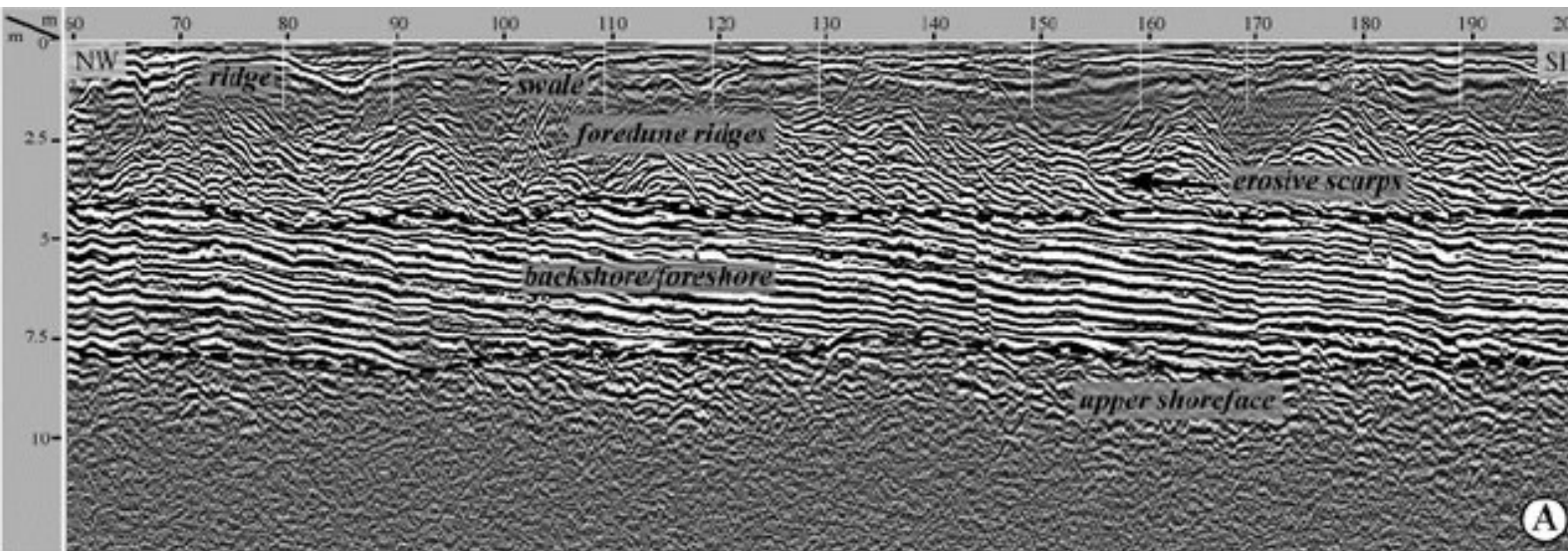
coastal sand barriers



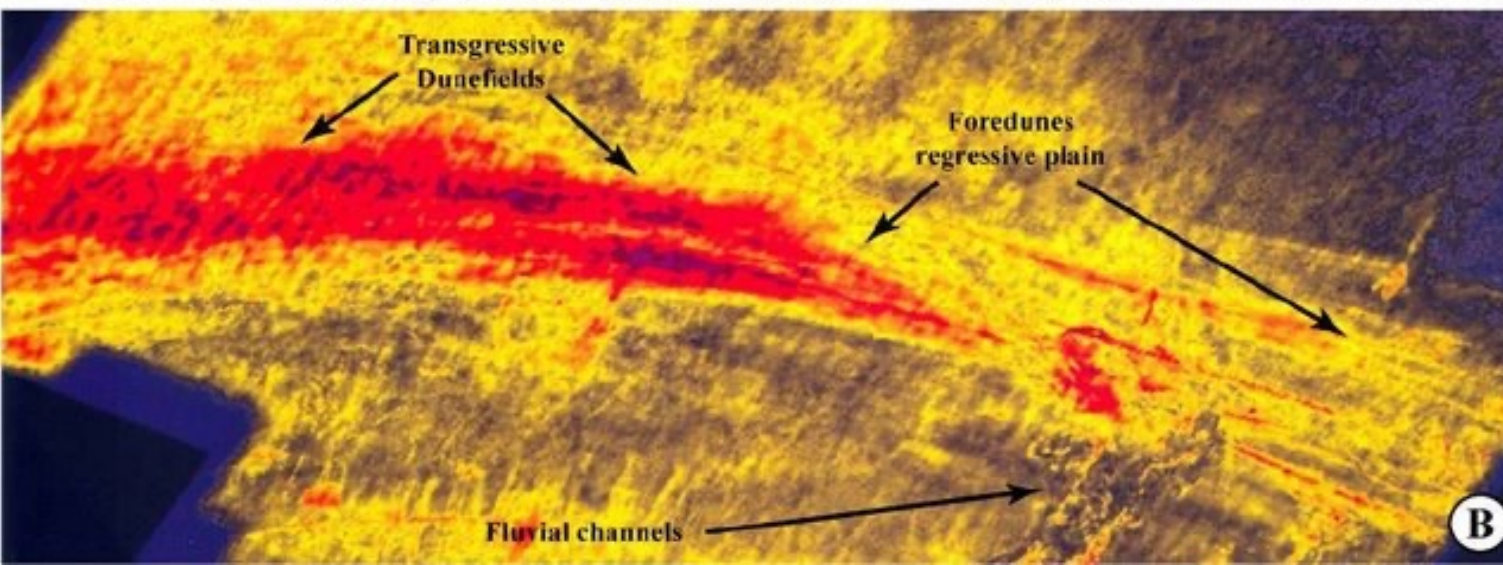
Seismic units of the southernmost seismic profile: top original migrated profile; bottom interpreted profile: light green acoustic basement, yellow coastal sand barriers, green coastal lagoon, blue continental shelf facies. *Albarracín et al. Seismic evidence for the preservation of several stacked Pleistocene coastal barrier/lagoon systems on the Gulf of Valencia continental shelf (western Mediterranean). Geo-Mar Lett 33, 217–223 (2013)*

Barboza et al., 2013. Journal of Coastal Research. Foredunes in the stratigraphic record

Progradation al sector in a coastal embayment. In both records the same progradation al pattern is observed, but in B transgressive dunes and deflations plains dominate and low angle reflectors (downlap) dip landwards.



dunes in ancient regressive systems

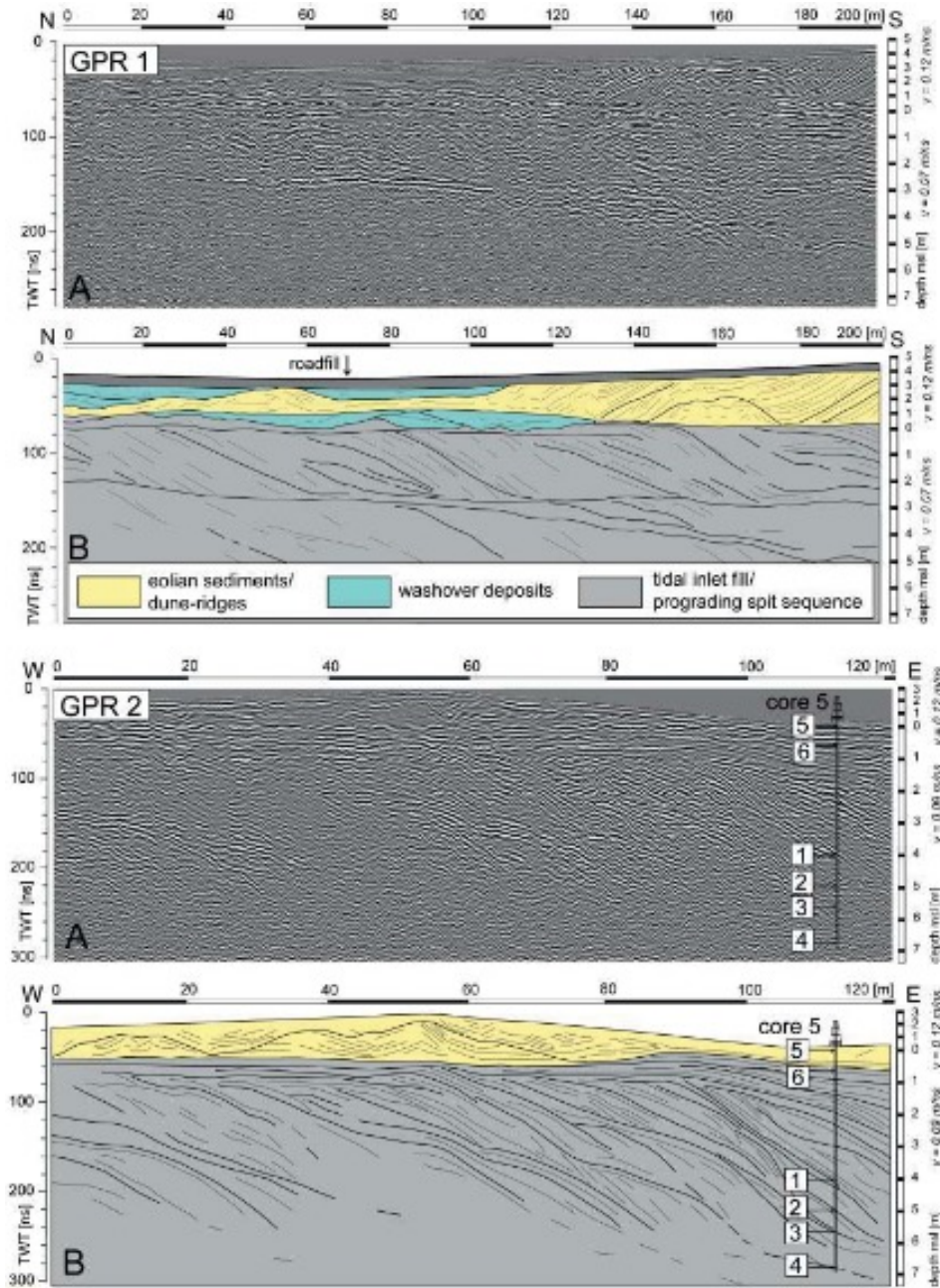


A) Foredune ridges in a context related to a Pleistocene barrier 120 ka in age. B) Time slice of the Santos Basin (southeastern Brazilian margin). At this site preservation of a sector containing regressive coastal foredune ridges and transgressive dunefields may be observed

Barrier rollover and spit accretion due to the combined action of storm surge induced washover events and progradation

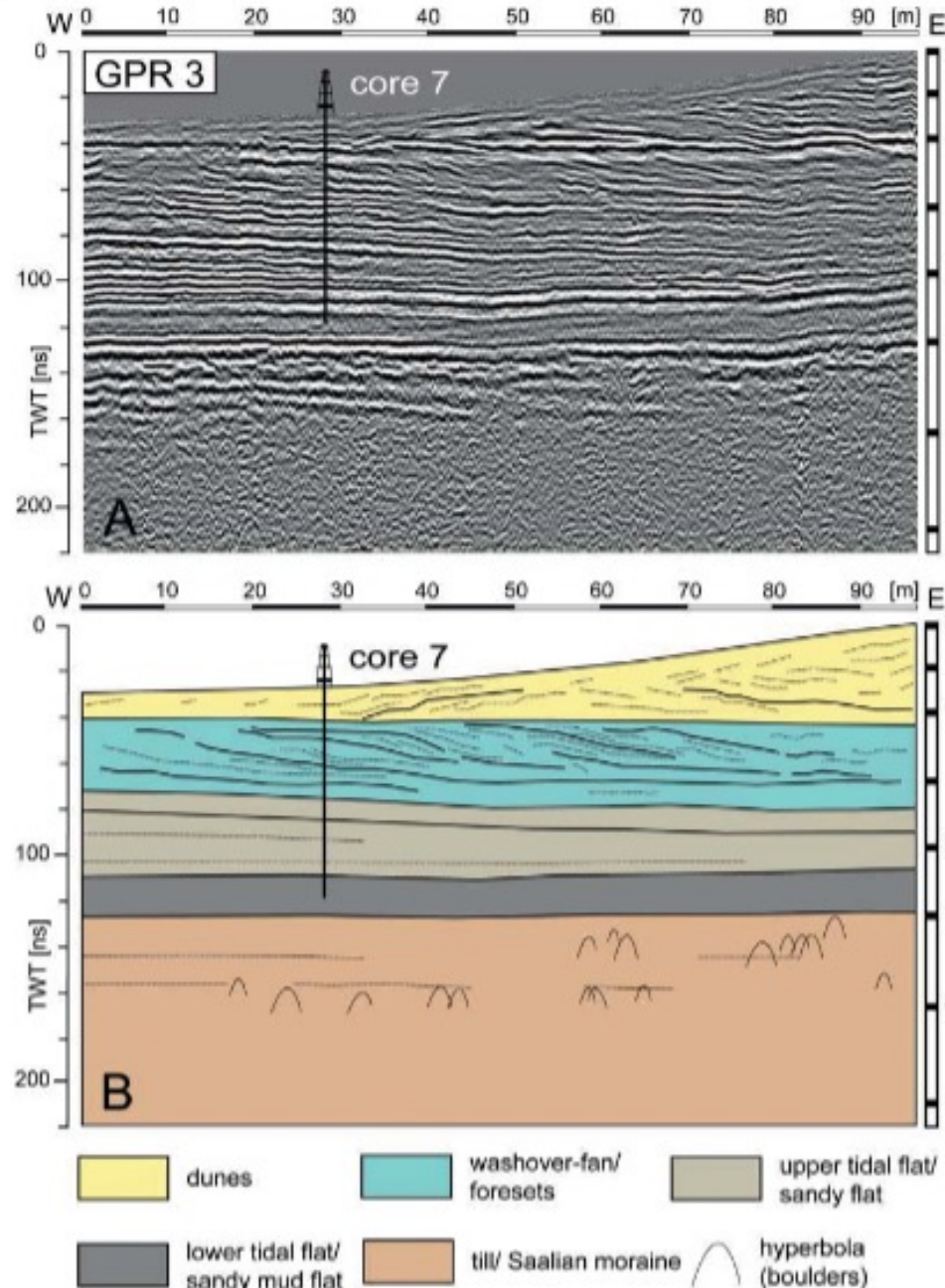
GPR line 1 and 2 represent the outer barrier island spit-end zone. The upper part of both profiles contains inclined reflections of the dune facies. This facies is interpreted as cross-bedded aeolian strata formed by migrating dunes of various dimensions. Internal bounding surface reveal two different dune generations.

Tillmann & Wunderlich (2013)
Journal of Coastal Research.

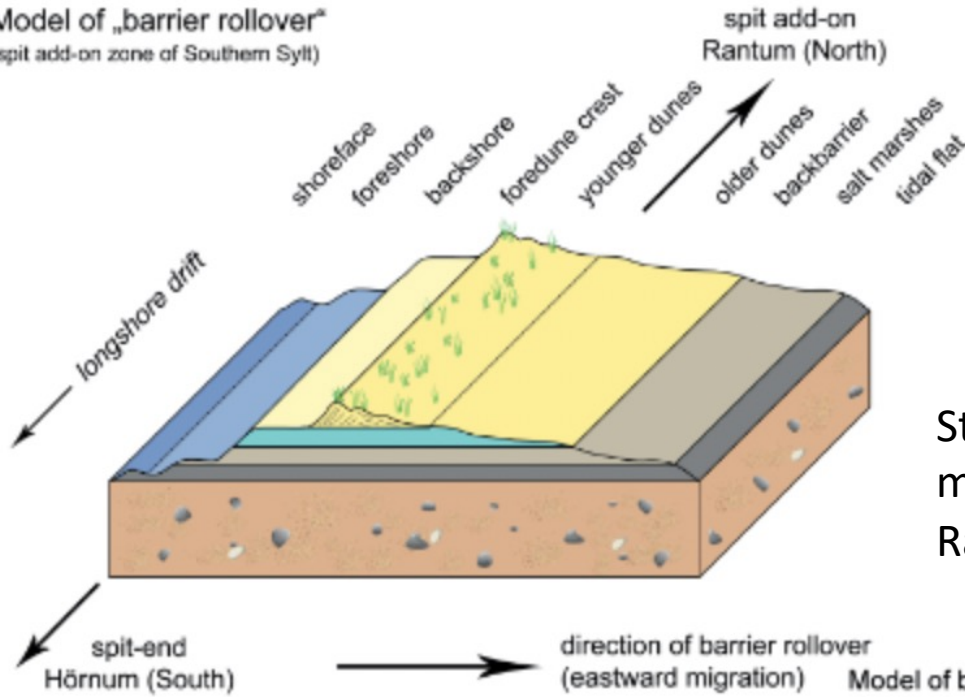


Typical radarfacies and stratigraphy order in this spit add-on region

Profile 3 can be subdivided into five main parts. The upper part of the profile which is located above the groundwater table merely contains inclined reflections of the cross-bedded aeolian dune facies. Directly beneath the groundwater table reflections occur which indicate a gentle landward dipping and are interpreted as washover foresets strata caused by flooding and inundation during several washover events. These washover foresets are parallelly orientated to the dominant washover flow direction from the west coast to the eastern part of the barrier and belong morphologically to a washover fan or a washover sheet. Post-storm aeolian modification of at least the uppermost washover layers is certain



Model of „barrier rollover”
(spit add-on zone of Southern Sylt)

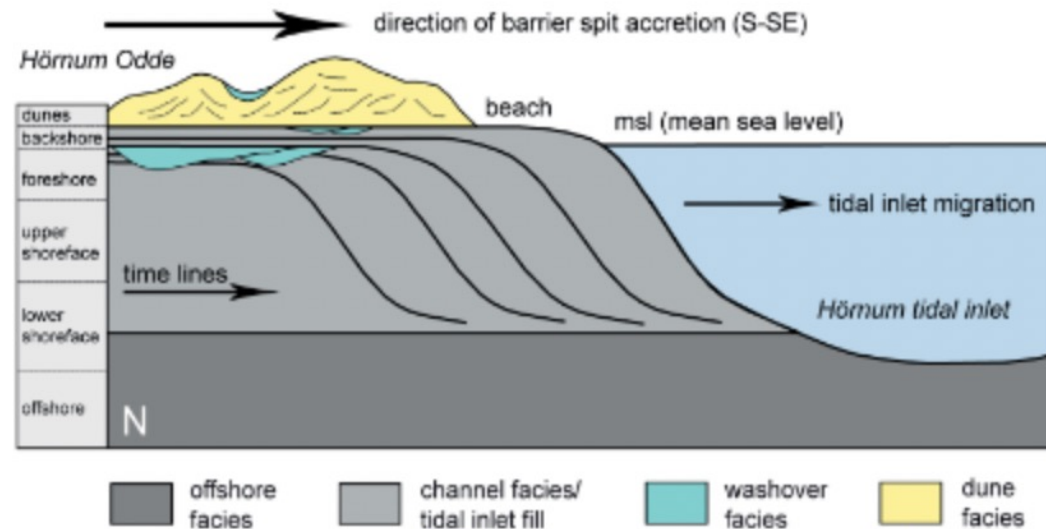


two stratigraphic models of barrier island genesis for the southern spit of Sylt.

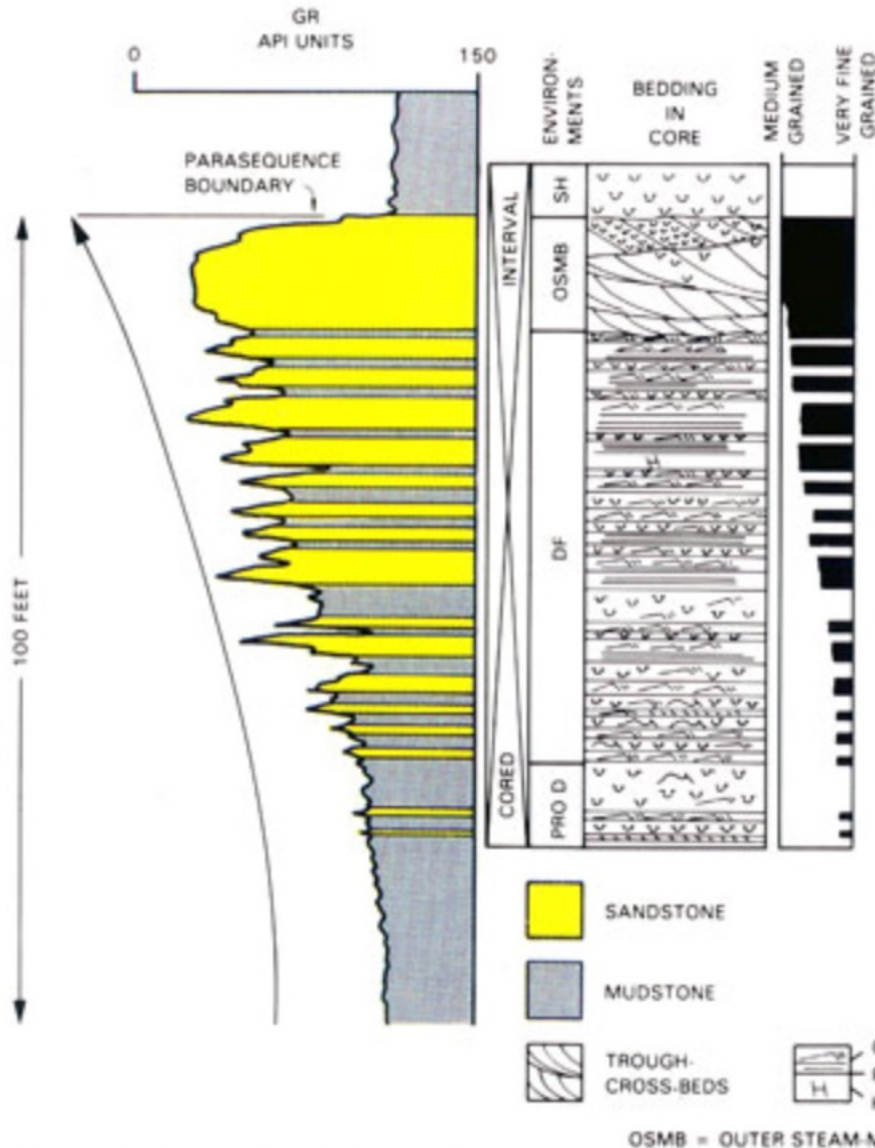
Stratigraphy of the eastward migrating barrier add-on zone of Rantum affected by “barrier rollover”

	low tide		upper tidal flat/ sandy flat
	high tide		lower tidal flat/ sandy mud flat
	beach		till/ Saalian moraine
	dune		boulders
	washover-layers/ washover-fan		dune grass (<i>Ammophila arenaria</i>)

Model of barrier spit accretion
(spit-end of Southern Sylt)



Model of barrier spit accretion concerning the spit-end of Southern Sylt based on GPR and sedimentological data



WITHIN EACH PARASEQUENCE:

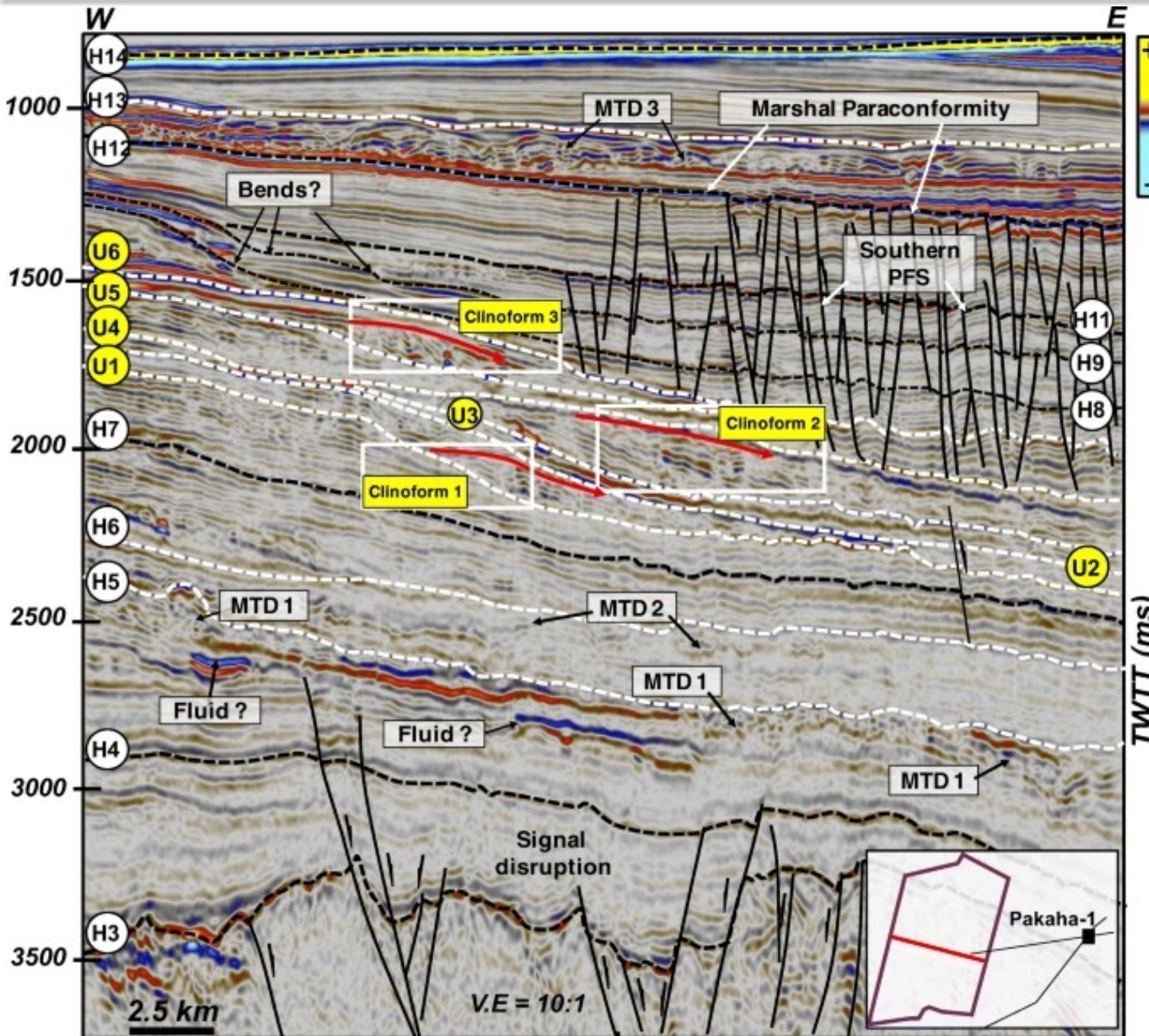
- SANDSTONE BEDS OR BEDSETS THICKEN UPWARD
- SANDSTONE/MUDSTONE RATIO INCREASES UPWARD
- GRAIN SIZE INCREASES UPWARD
- LAMINAE GEOMETRY BECOME STEEPER UPWARD
- BIOTURBATION INCREASES UPWARD TO THE PARASEQUENCE BOUNDARY
- FACIES WITHIN THE PARASEQUENCE SHOAL UPWARD

PARASEQUENCE BOUNDARY MARKED BY:

- ABRUPT CHANGE IN LITHOLOGY FROM SANDSTONE BELOW TO MUDSTONE ABOVE
- ABRUPT DECREASE IN BED THICKNESS
- POSSIBLE SLIGHT TRUNCATION OF UNDERLYING LAMINAE
- HORIZON OF BIOTURBATION; BURROWING INTENSITY DECREASES DOWNWARD
- GLAUCONITE, SHELL HASH, PHOSPHORITE, OR ORGANIC-RICH SHALE
- ABRUPT DEEPENING IN DEPOSITIONAL ENVIRONMENT ACROSS THE BOUNDARY

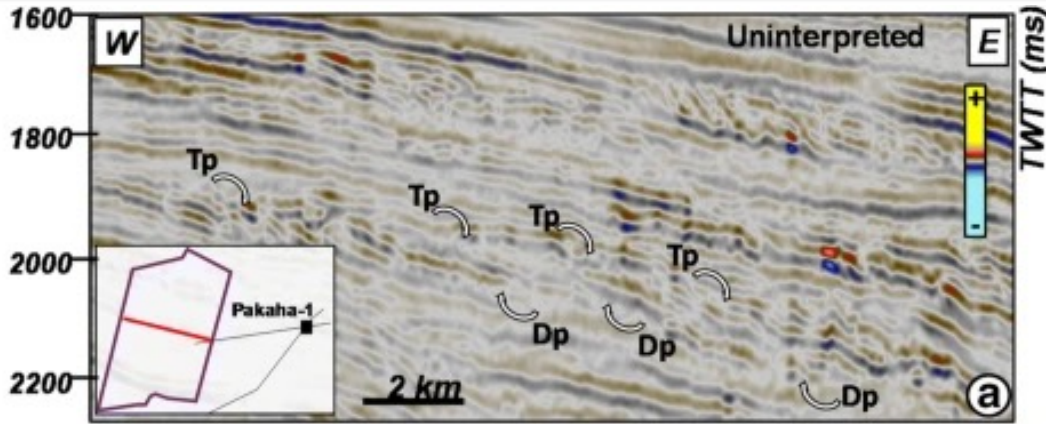
OSMB = OUTER STEAM-MOUTH BAR, DF = DELTA FRONT, PRO D = PRO DELTA, SH = SHELF

Stratal characteristics of an upward-coarsening parasequence. This type of parasequence is interpreted to form in a deltaic setting on a sandy, fluvial-wave dominated shoreline (after Van Wagoner et al, 1990).



Seismic geomorphology of Cenozoic slope deposits and deltaic clinoforms, Great South Basin, New Zealand
 Omosanya & Harishidayat (2019). Geo-Mar Lett 39, 77–99

Sigmoidal to oblique Clinoforms 1–3 are here interpreted as deltaic clinoforms because they are less than 100 m in vertical relief and greater than 50 km in length



Tp - Toplap Dp - Downlap

Uninterpreted (a) and interpreted (b) seismic sections showing **sigmoidal** clinoforms and clinotherms within Clinoform 1. Note the changing vertical position between the clinoforms tops. Red arrows = direction of progradatio. (c) Flattening along the inferred maximum flooding surface shows that the clinoforms have a general 'ascending-descending-ascending' trajectory. (d) main shoreline trajectory classes

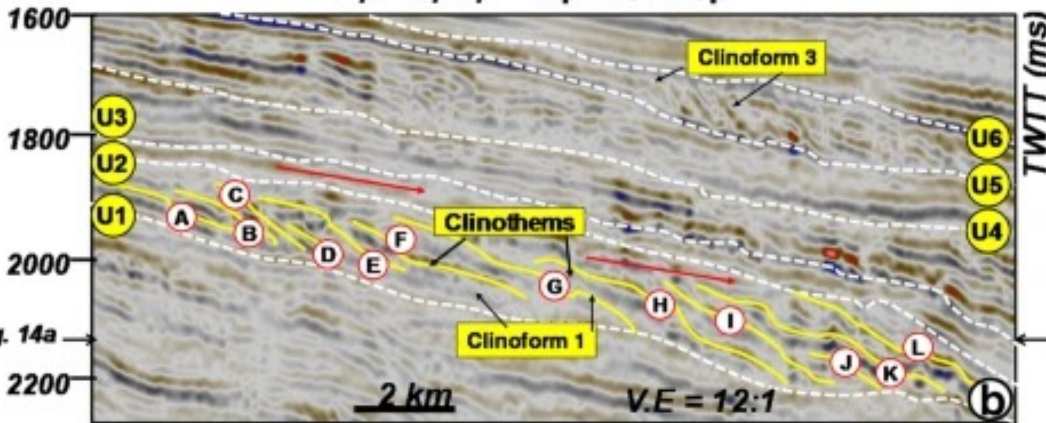
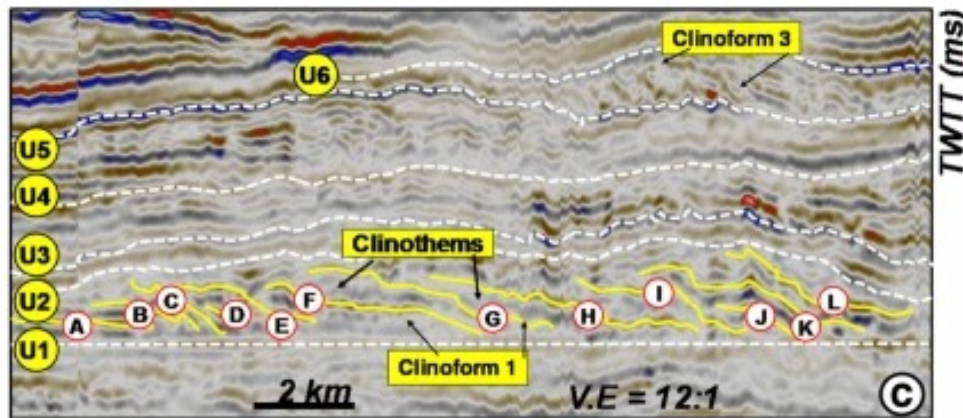
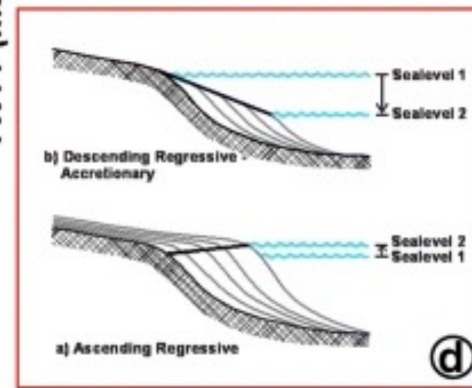


Fig. 14a

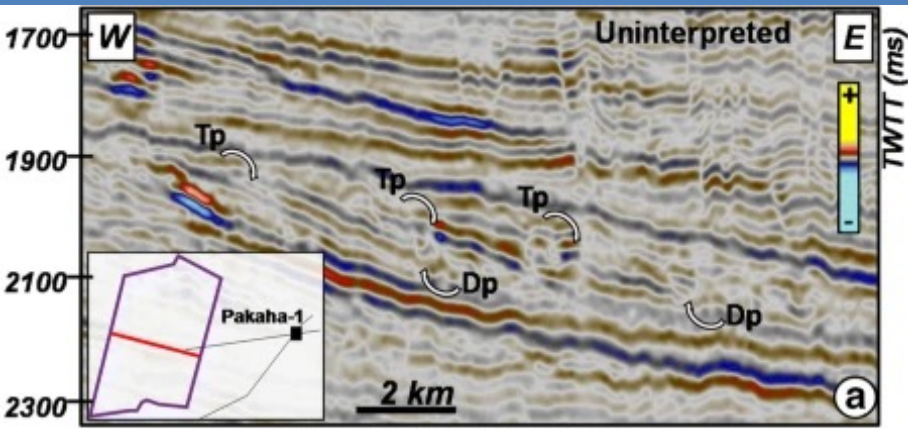
Fig. 14a



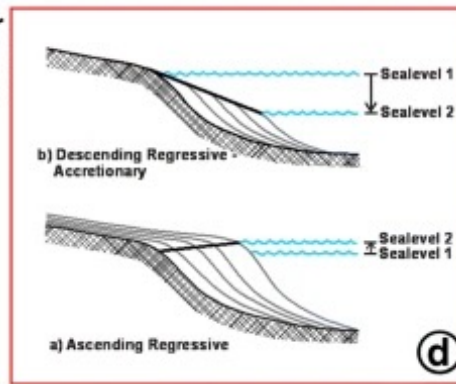
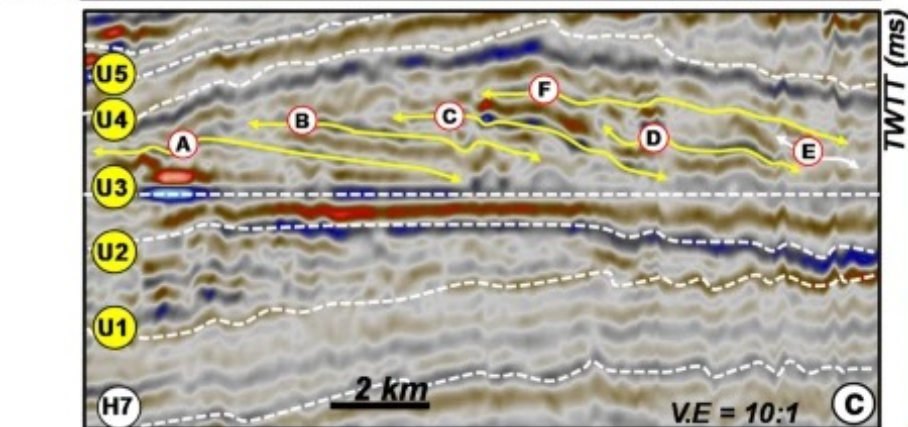
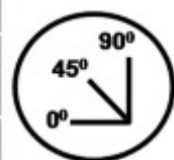
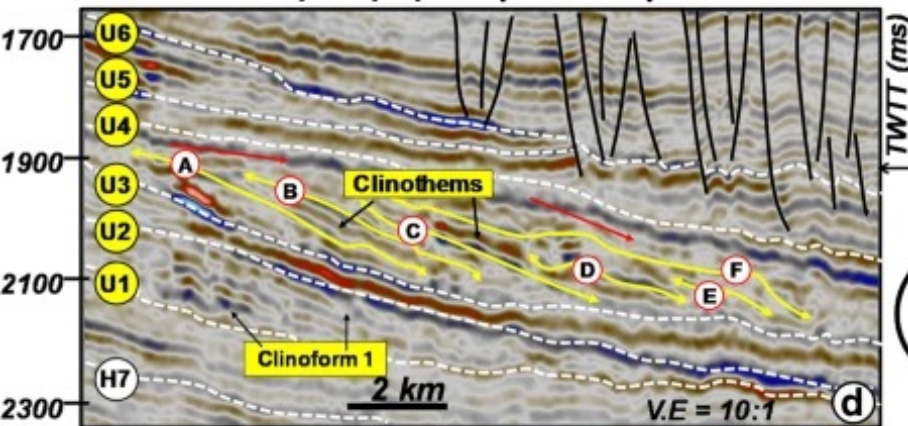
(c)

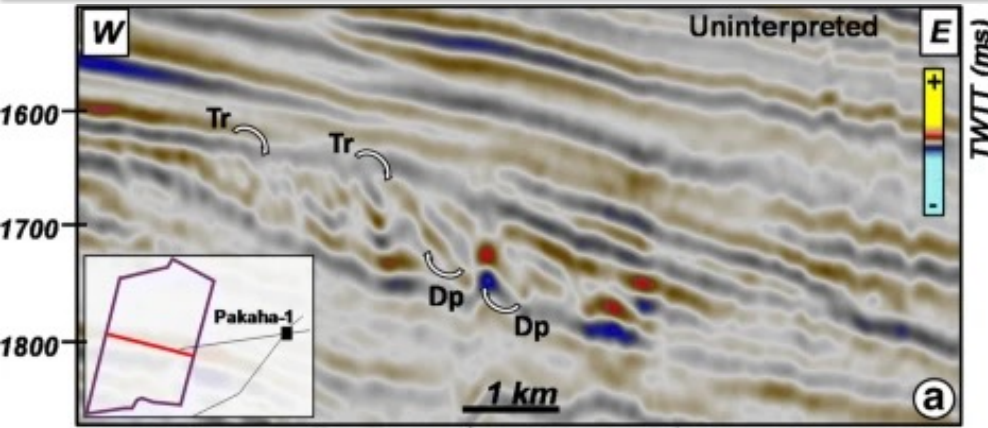


(d)

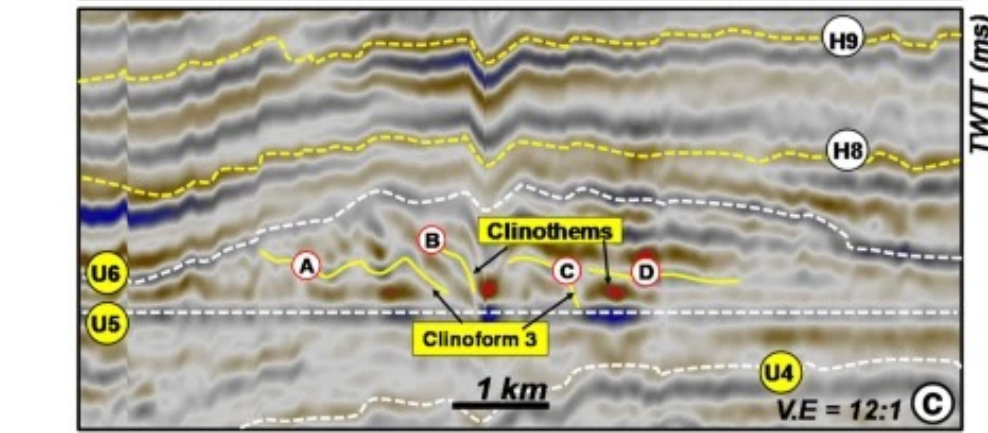
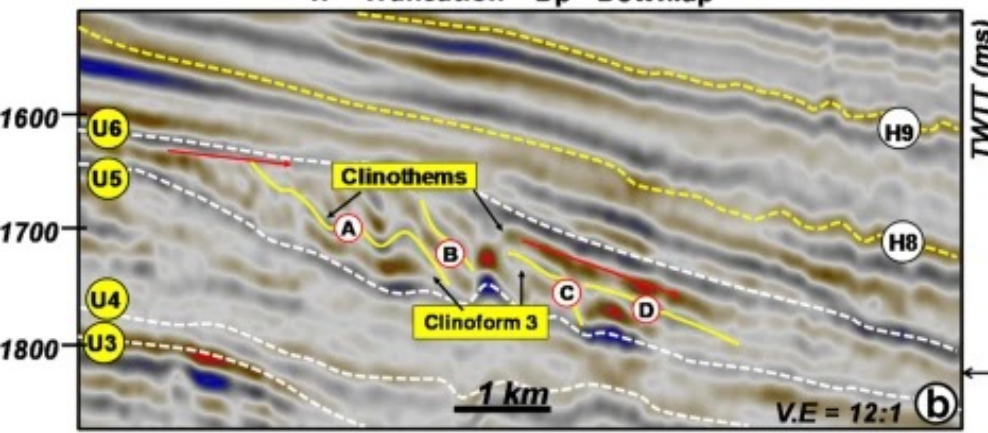


Uninterpreted (a) and interpreted (b) seismic sections showing **complex sigmoid to oblique** clinoforms and clinothem within Clinoform 2. Note the changing vertical position between the clinoform tops. Red arrows = direction of progradation. (c) The flattening of U3 shows that clinoforms have a descending-ascending trajectory. (d) main shoreline trajectory classes

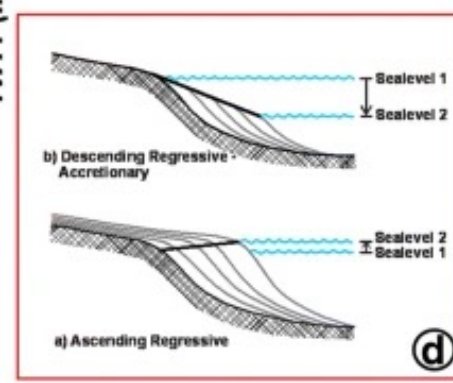




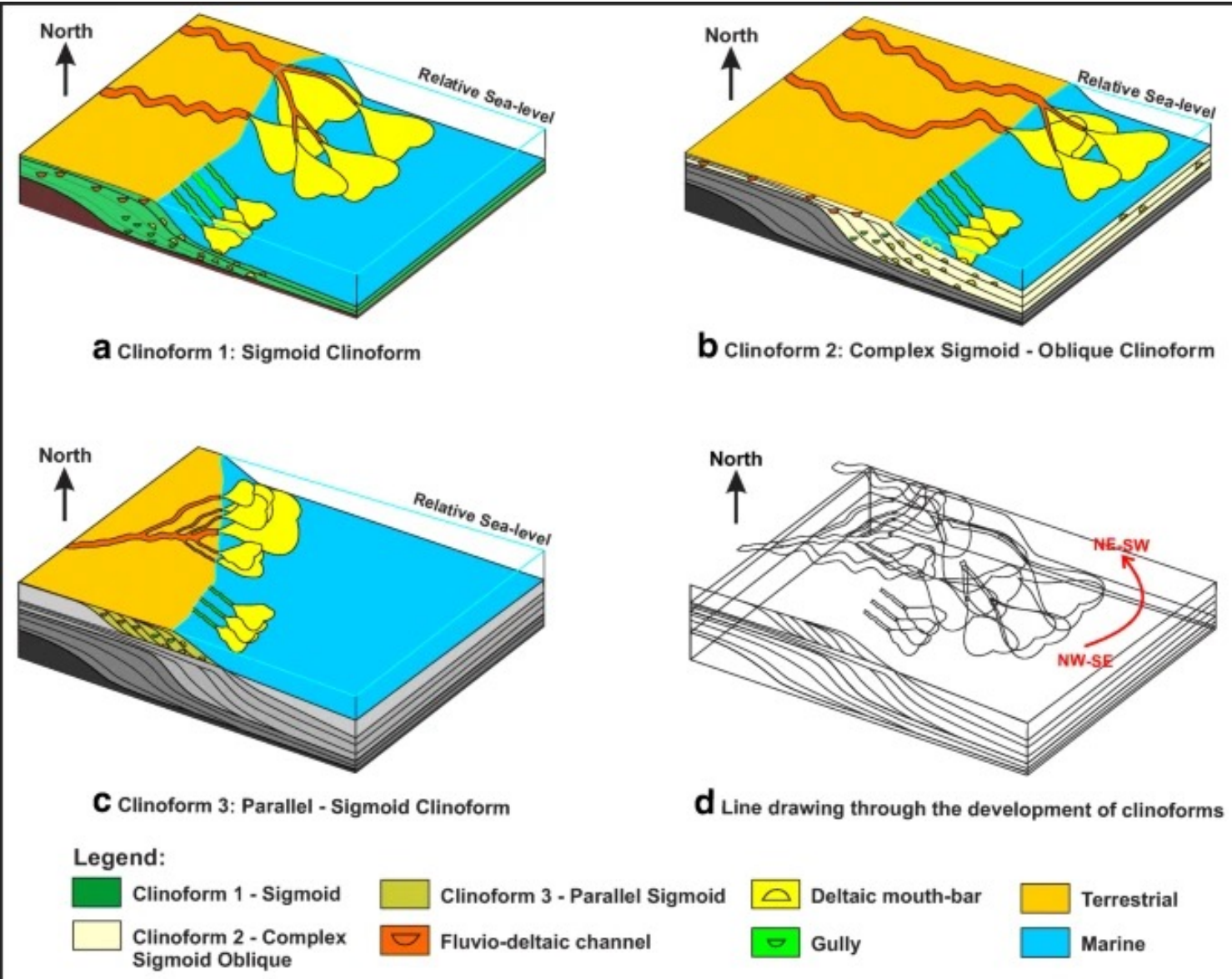
Tr - Truncation Dp - Downlap



Uninterpreted (a) and interpreted (b) seismic sections showing **parallel-sigmoid** clinoforms and clinothems within Clinoform 3. Note the changing vertical position between the clinoforms tops. Red arrows = direction of progradation. (c) The clinoforms have an ascending to descending trajectory. (d) main shoreline trajectory classes



Evolution of deltaic clinoforms in Clinoform 1 to Clinoform 3



The block diagrams show that these river dominated deltas were fed by fluvial channels, prograded over the shelf and are transported to the SE and NE parts from the Early Eocene to Mid Eocene. The dynamics and orientation of the channels and their lobes may be controlled by regional tectonics during the Eocene or nearshore currents

Interpretation criteria for deltaic clinoforms

The deltaic systems are characterised by internal reflection terminations such as toplap and downlap, and configurations as mounded reflections. The shoreline trajectory describes the cross-sectional path of the shoreline as it migrates, as a function of bathymetry, sediment supply, eustatic sea-level changes, loading subsidence and compaction. Clinoform shoreline trajectory may include very low angle-ascending trajectory, a high angle-ascending trajectory, a flat trajectory and a descending trajectory. Ascending shoreline trajectories will result in a sigmoidal seismic pattern and long-term rise in the relative base level. Flat and descending trajectories will produce an oblique progradational seismic pattern. A flat trajectory suggests a stable, relative base level through time, usually formed by an optimal sediment supply. A descending trajectory may signify a large sediment supply influenced by relative sea-level fall and strong fluvial input

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