

Anatomy of Late Quaternary Adriatic Clinoforms: Mechanisms of Sediment Transport and Mud Accumulation on the Continental Shelf*

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Search and Discovery Article #50322 (2010)

Posted November 5, 2010

* Adapted from an oral presentation at AAPG Annual Convention and Exhibition, New Orleans, Louisiana, USA, April 11-14, 2010

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Abstract

On the land-locked Adriatic shelf (Central Mediterranean), shore-parallel muddy clinoforms develop both during highstand and falling sea-level conditions, representing the dominant building blocks of a stack of 100-kyr depositional sequences. Within each sequence, these clinoforms are tens of meters thick and rest on regional downlap surfaces traceable over hundreds of km parallel to the modern coast. The analysis of the most recent clinoform deposited during modern (highstand) conditions shows that transport is along the strike of the clinoform and the thinning of the deposit through the bottomset reflects the energetic impact of bottom water flowing along the contour. Bottom currents induce lateral advection, hinder sediment transport basinward and form elongated clinoform bodies characterized by a distinctive shore-parallel offlap break (typically in 25-30 m water depth). The modern HST Adriatic clinoform has a volume of 180 km³ with a depocenter within less than 20 km from the coast, and reaches its maximum thickness (35 m) down current with respect to the location of its deltaic entry points. Interestingly, these clinoforms register also very short-term supply fluctuations like those reflecting abrupt climate change and human impact on the catchment during the last 500 years (Little Ice Age).

Borehole PRAD1.2 allowed to point out that the bulk of Pleistocene clinoforms within 100-kyr sequences record almost exclusively interglacial stages (Stages 5, 7 and 9, in particular) suggesting that shore-parallel advection is most efficient during sea-level highstands. As sea-level fall proceeds, the semi-enclosed Adriatic basin shrinks to about 1/8th of its HST extent and circulation

becomes sluggish allowing sediment deposition beyond the shelf edge: LST deposits onlap the upper slope, are rich in organic matter, and appear characterised by thin-bedded (cm-scale) turbidity-current deposits. Also in the case of these older deposits, two main factors determine the thinning of clinoforms through the bottomset. Beside the gradual decrease of sediment received basinward, a key control is the energy impact of the West Adriatic bottom current flowing along the contour, impinging the seafloor and limiting the basinward growth of the clinoforms. In this view, bottom currents induce lateral (shore parallel) rather than basinward transport of sediment with the formation of elongated clinoform bodies characterized by a shore-parallel strike of the foreset.

References

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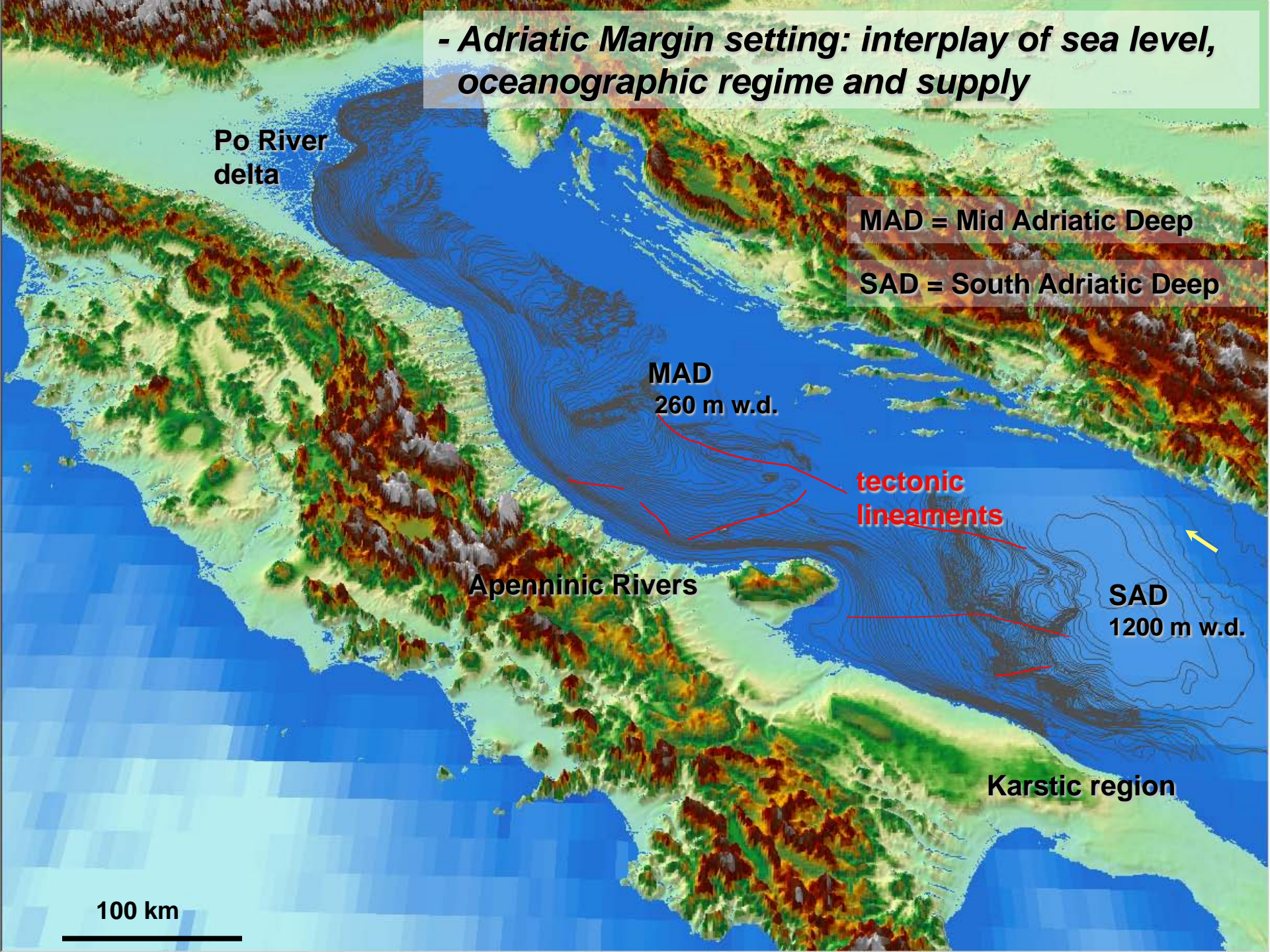
outline

- **Adriatic Margin setting: interplay of sea level, oceanographic regime and sediment dispersal**
- **clinoform pattern of progradational units**
- **internal architecture of late Pleistocene sequences based on $\delta^{18}\text{O}$ record of past ~ 400 ka from **PRAD1-2** borehole (71 m long)**
- **sequence architecture and systems tracts partitioning**
- **facies partitioning (mud vs sand) within sequences: depositional and preservation bias**
- **concluding remarks**

PRAD1-2 Borehole
185.5 m w.d.

high-resolution seismic database

- Adriatic Margin setting: interplay of sea level, oceanographic regime and supply



- Adriatic Margin setting: interplay of sea level, oceanographic regime and supply

Po River delta

MAD = Mid Adriatic Deep

SAD = South Adriatic Deep

MAD
260 m w.d.

Quaternary foredeeps acting as traps for coarser sediment

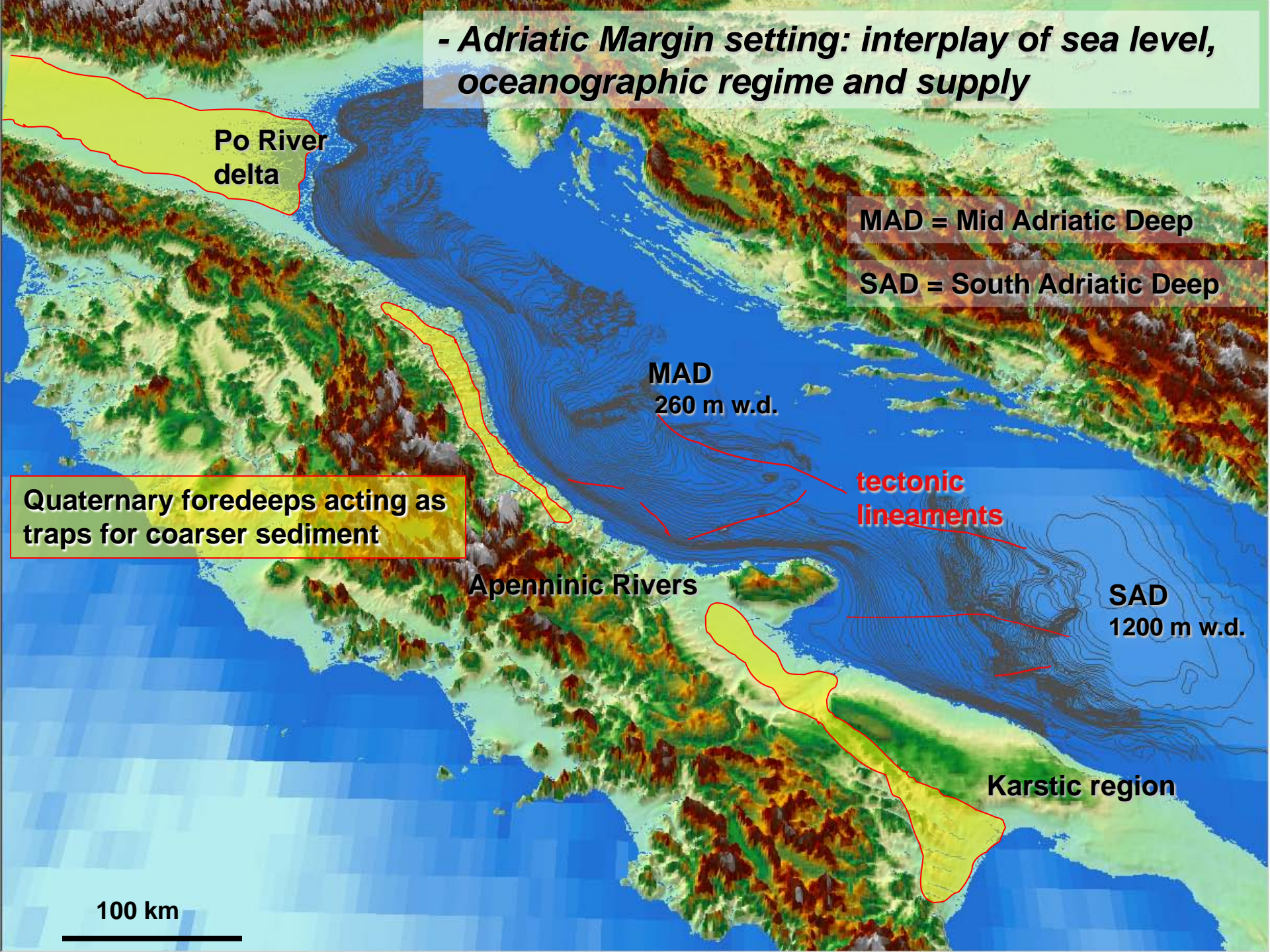
tectonic lineaments

Apenninic Rivers

SAD
1200 m w.d.

Karstic region

100 km



- Adriatic Margin setting: interplay of sea level, oceanographic regime and supply

Po River delta

MAD = Mid Adriatic Deep

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MAD
260 m w.d.

Quaternary foredeeps acting as traps for coarser sediment

tectonic lineaments

mud-dominated continental margin

Apenninic Rivers

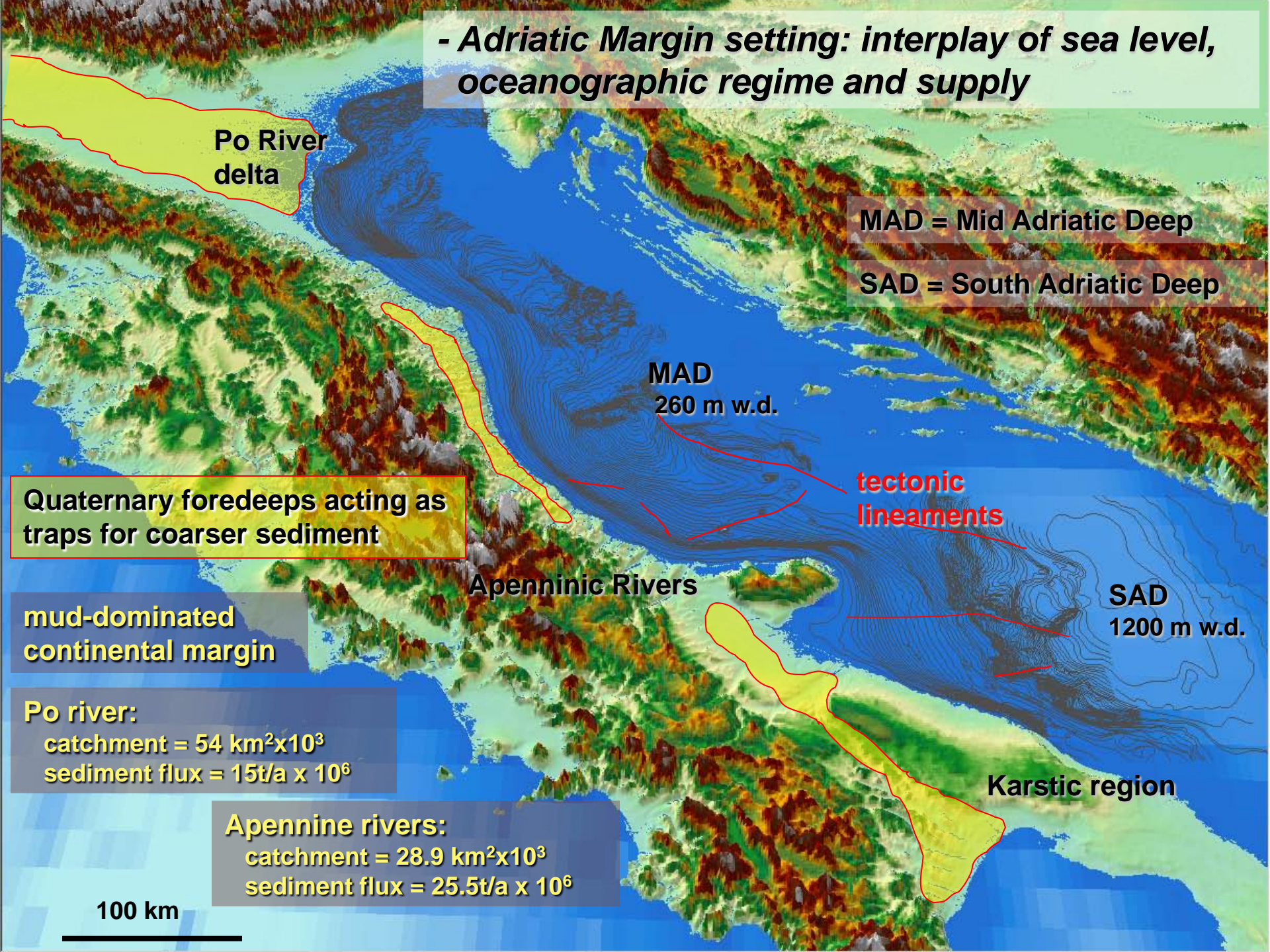
SAD
1200 m w.d.

Po river:
catchment = $54 \text{ km}^2 \times 10^3$
sediment flux = $15 \text{ t/a} \times 10^6$

Karstic region

Apennine rivers:
catchment = $28.9 \text{ km}^2 \times 10^3$
sediment flux = $25.5 \text{ t/a} \times 10^6$

100 km



- Adriatic Margin setting: interplay of sea level, oceanographic regime and supply

LGM Po delta progradation

dominant longshore currents/dispersal

MAD = Mid Adriatic Deep

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Quaternary foredeeps acting as traps for coarser sediment

mud-dominated continental margin

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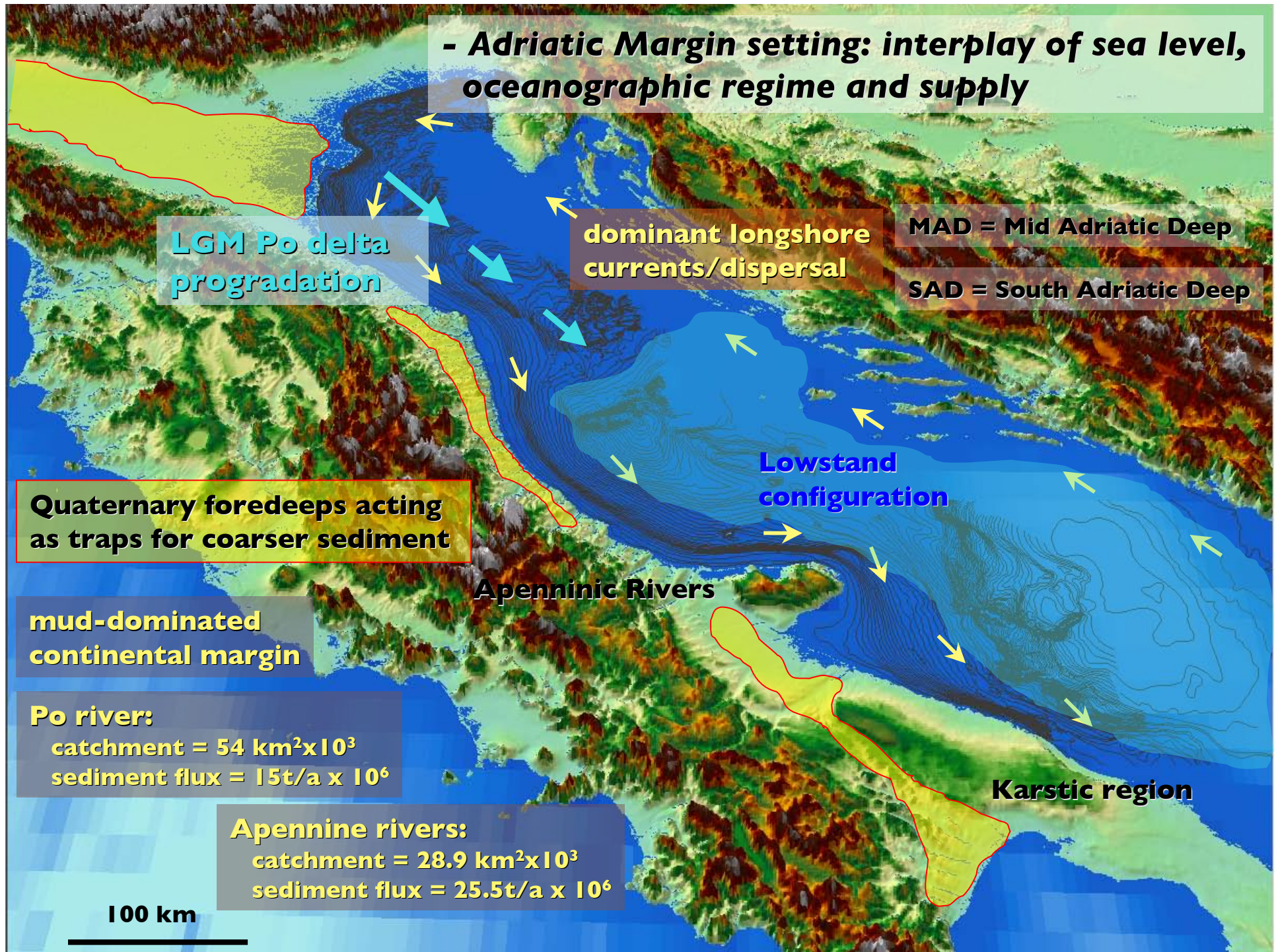
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Lowstand configuration

Apenninic Rivers

Karstic region

100 km



- Adriatic Margin setting: interplay of sea level, oceanographic regime and supply

Po River delta

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**MAD
260 m w.d.**

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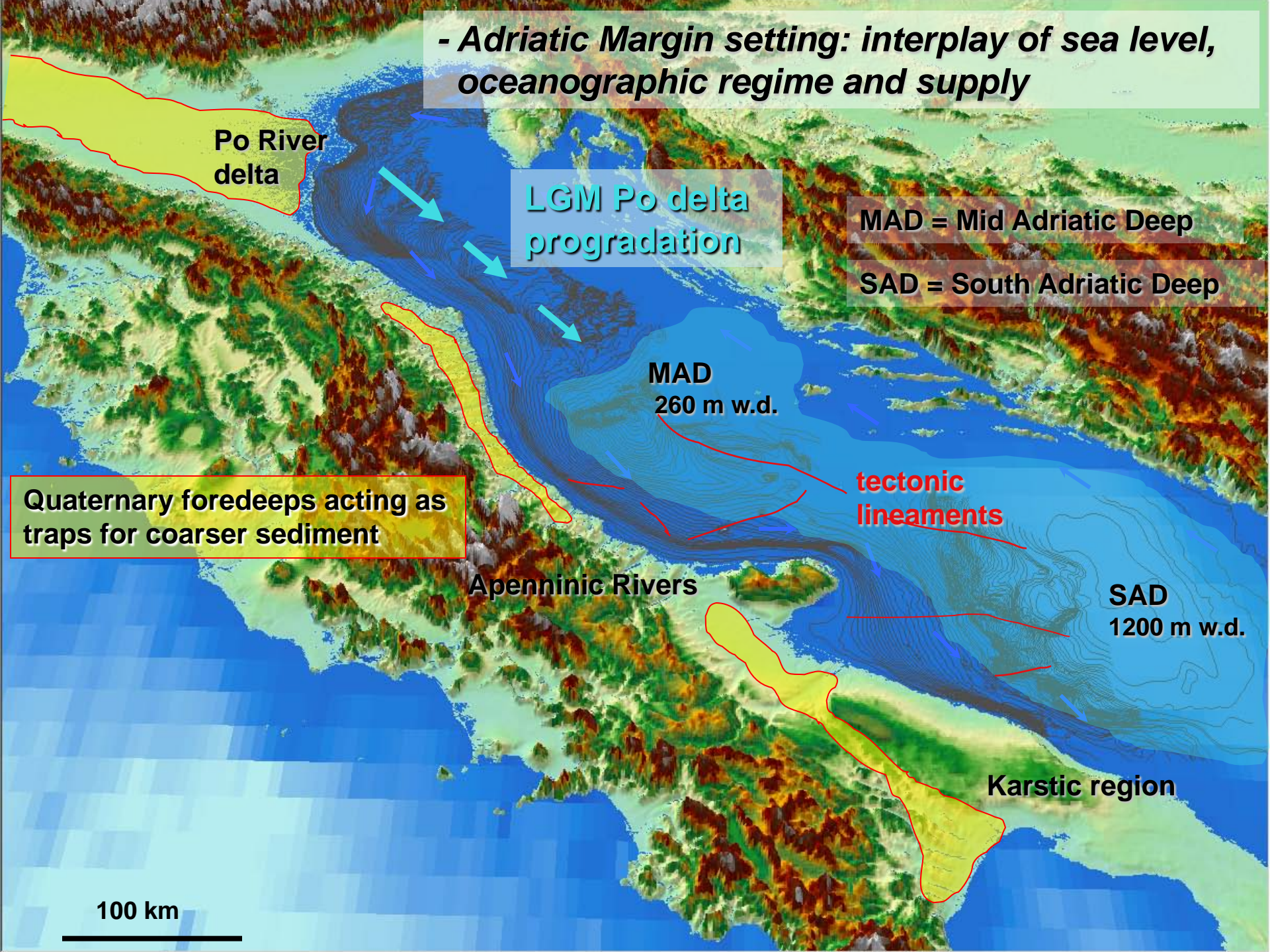
tectonic lineaments

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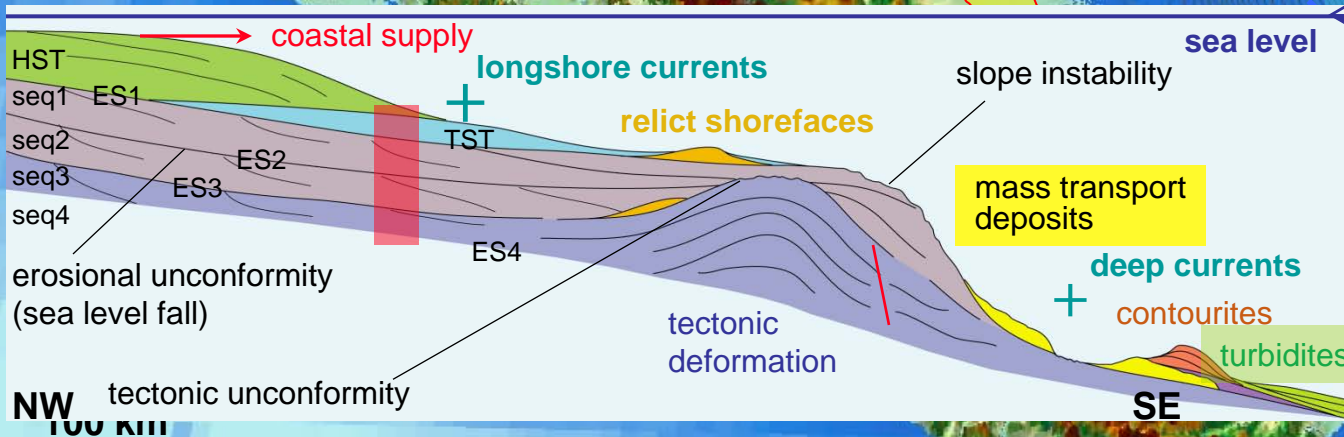
PRAD1-2
(185.5 m w.d.)

tectonic lineaments

Quaternary foredeeps acting as traps for coarser sediment

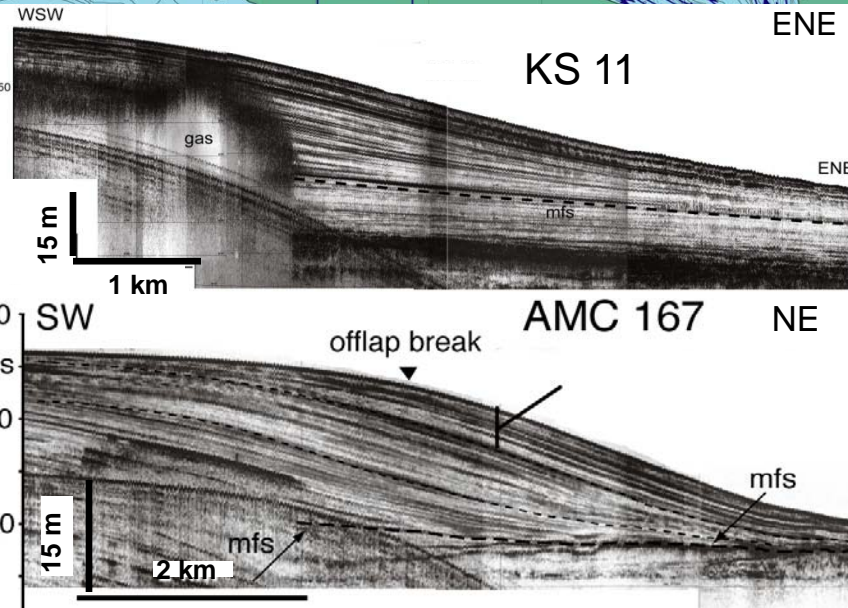
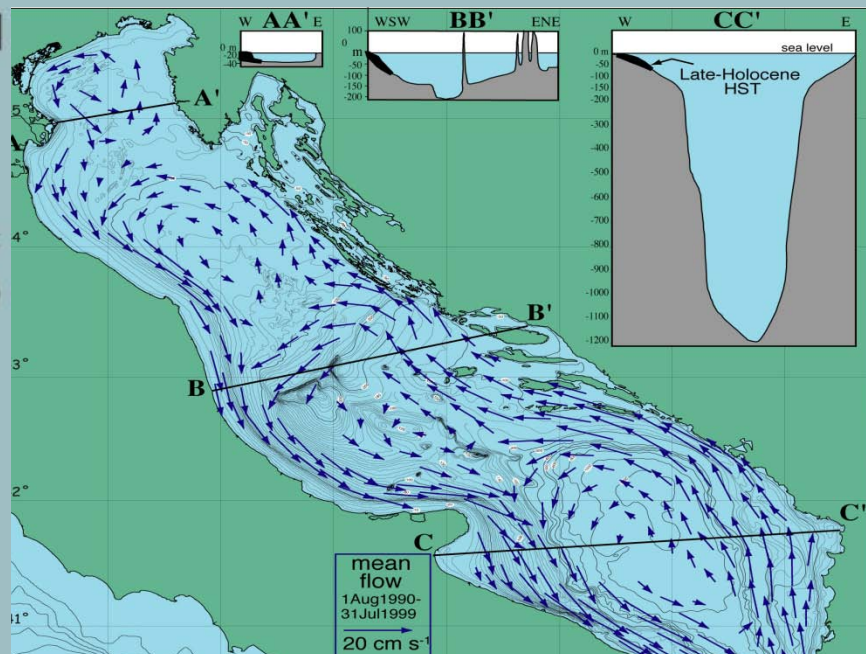
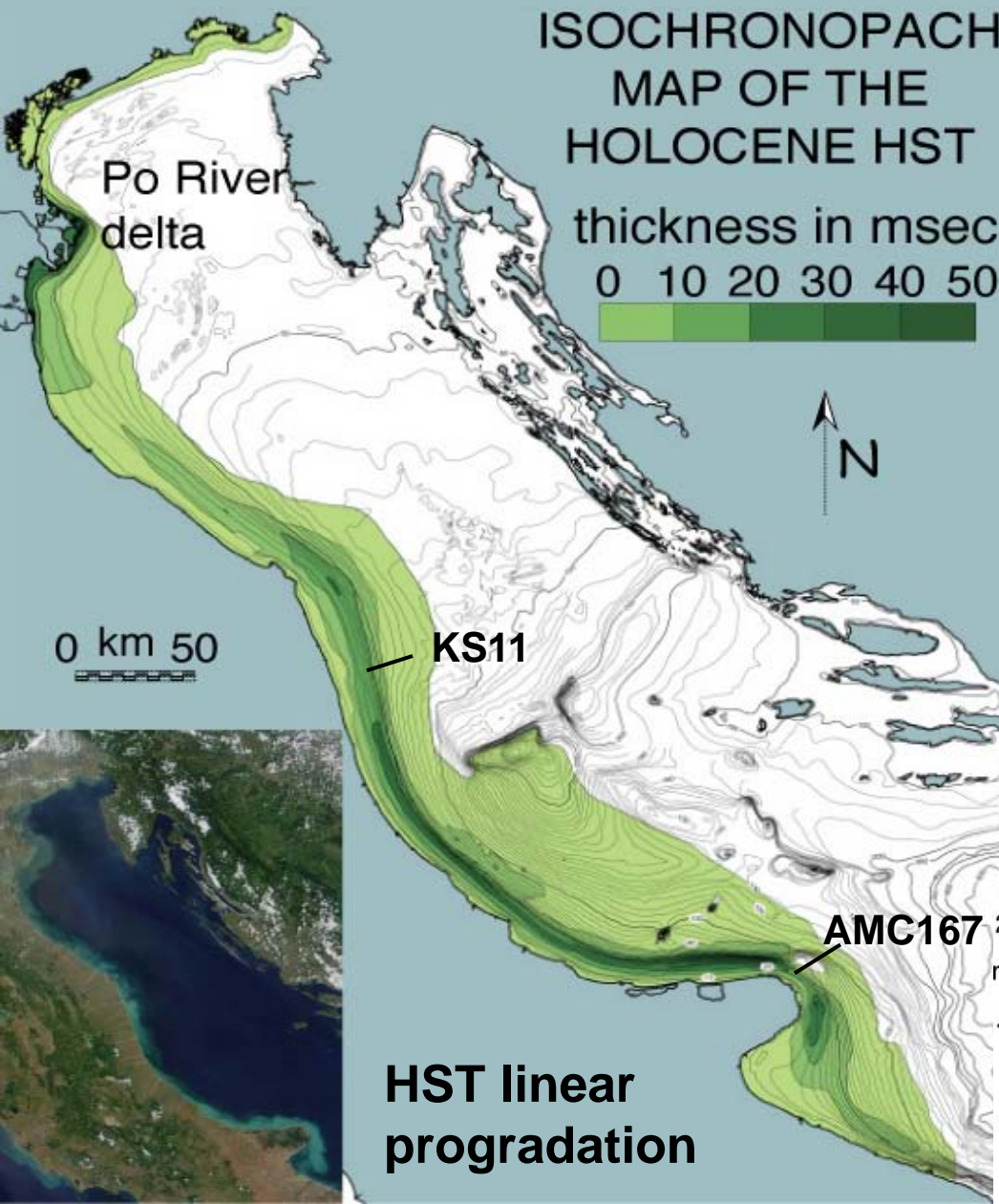
Apenninic Rivers

SAD
1200 m w.d.

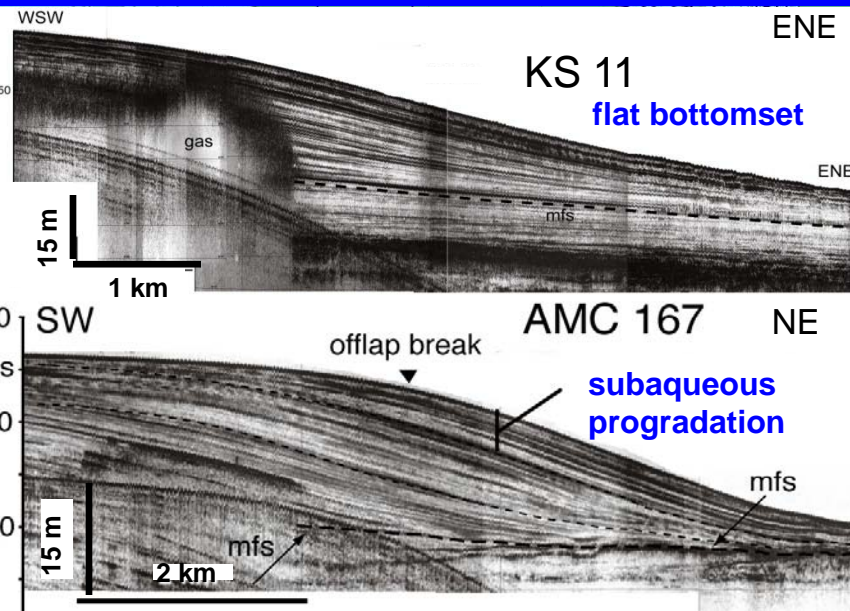
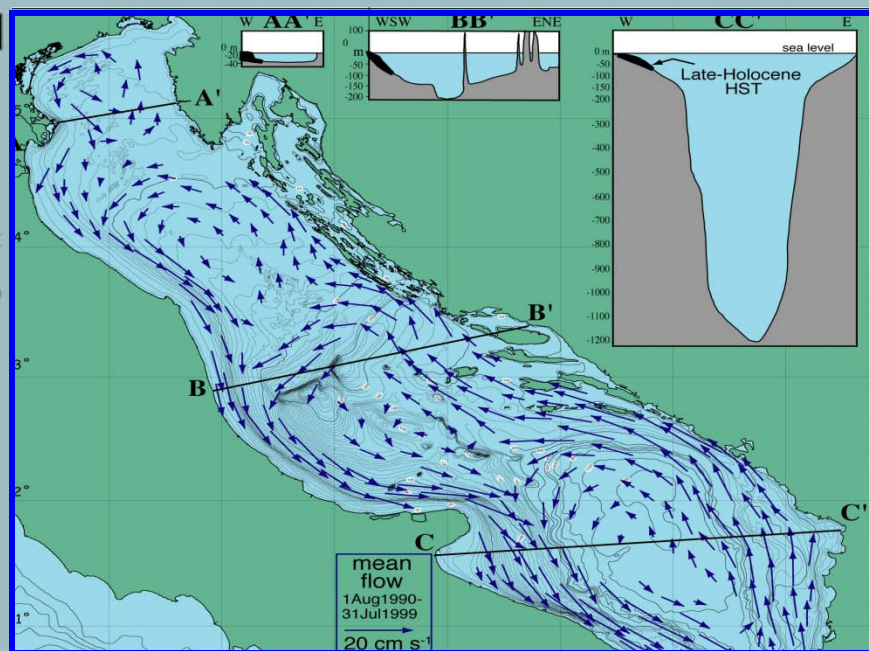
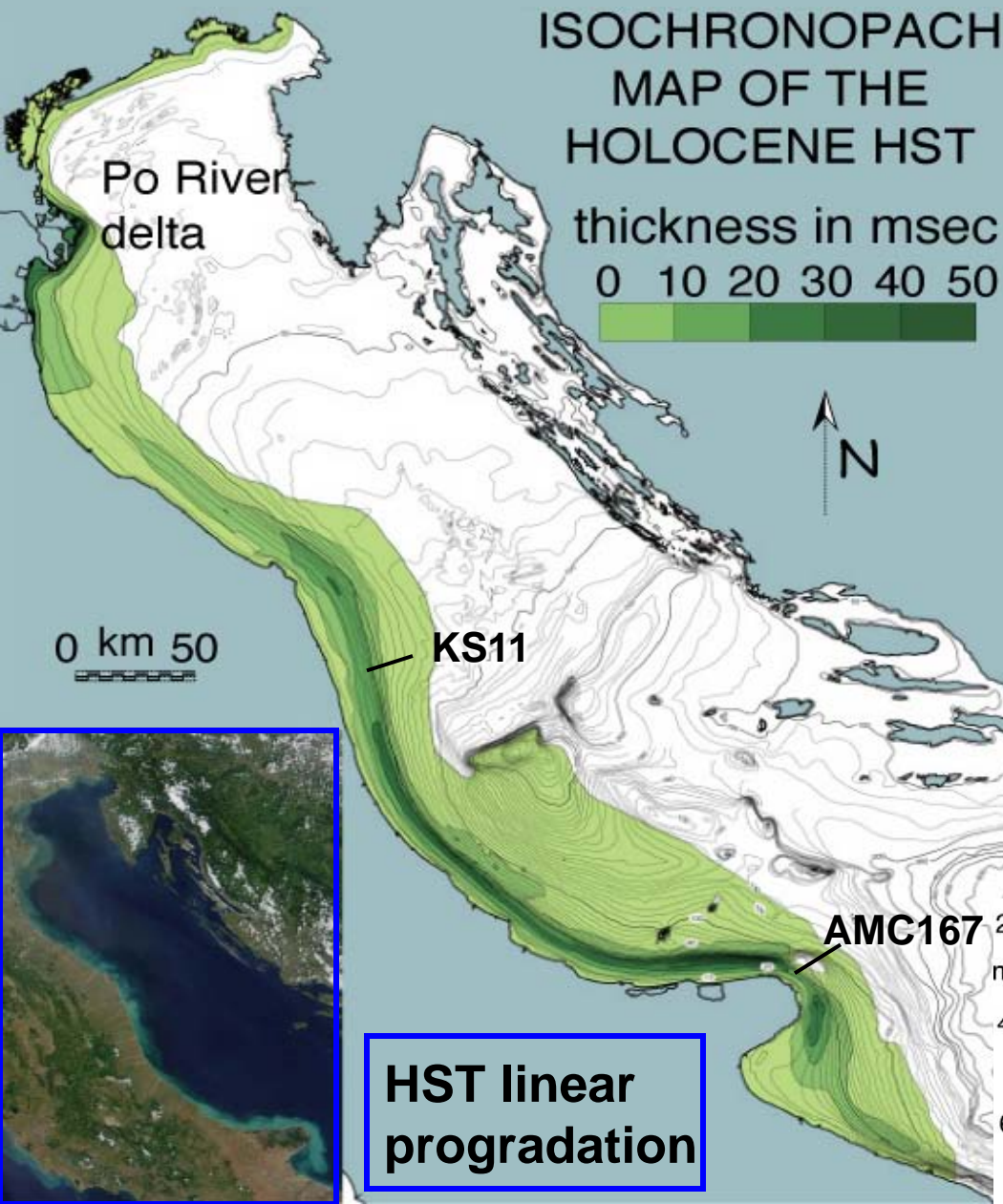


Karstic region

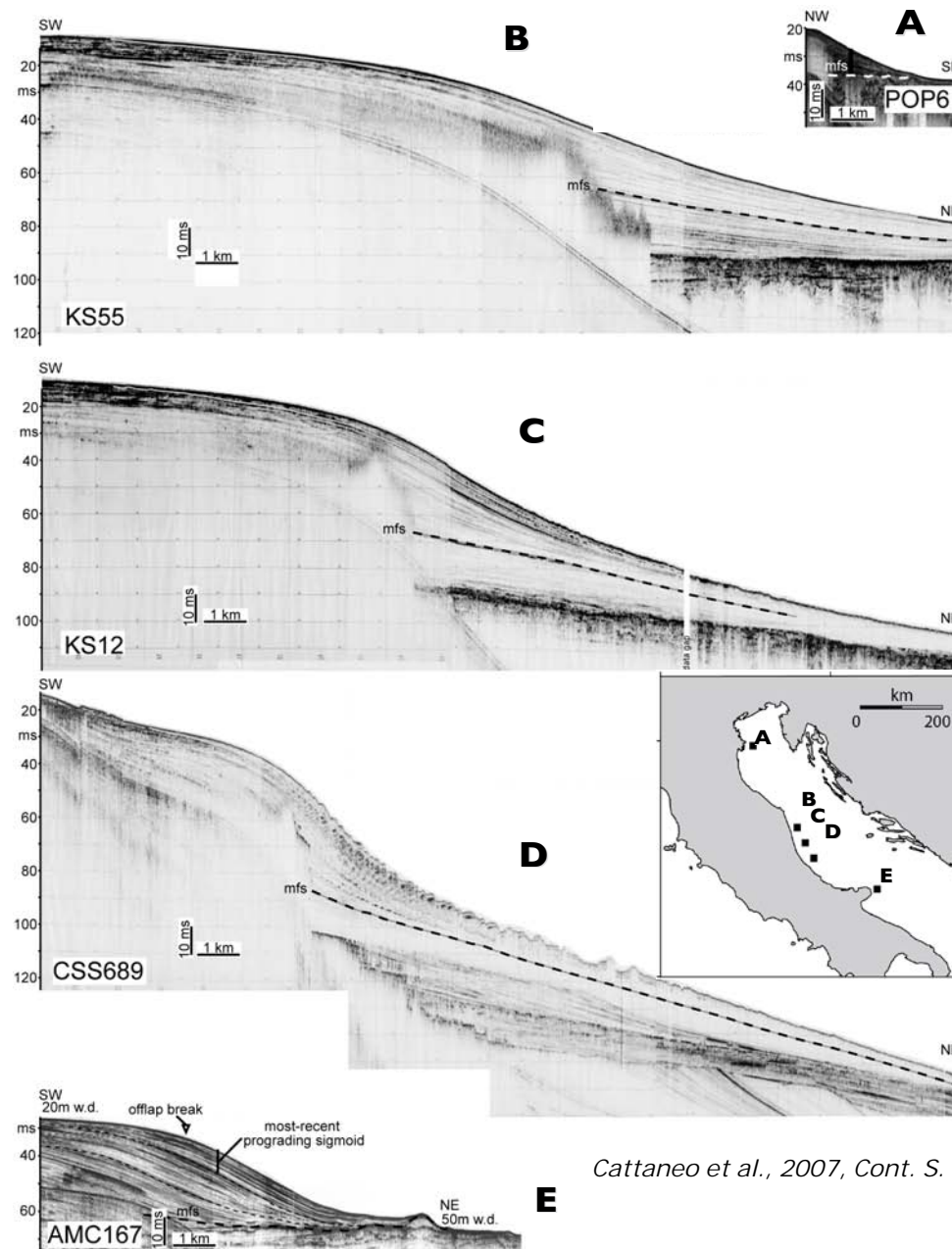
- Clinoform pattern of progradational units



- Clinoform pattern of progradational units



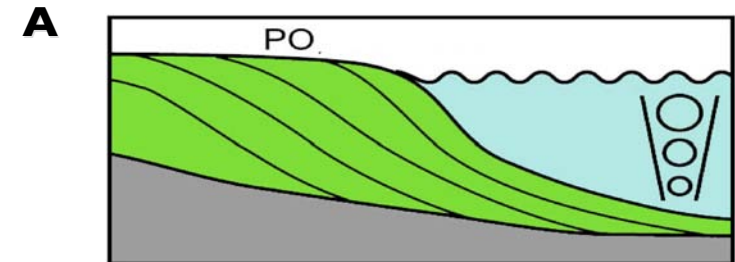
- Clinoform pattern of progradational units



Cattaneo et al., 2007, Cont. S. Res.

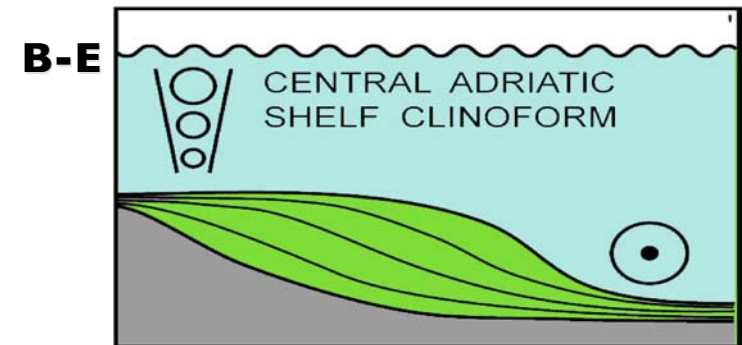
Note: scales and vertical exaggeration are the same for all profiles

Late Holocene HST mud wedge



Delta front/wave dominated
foreset:

high-angle downlap

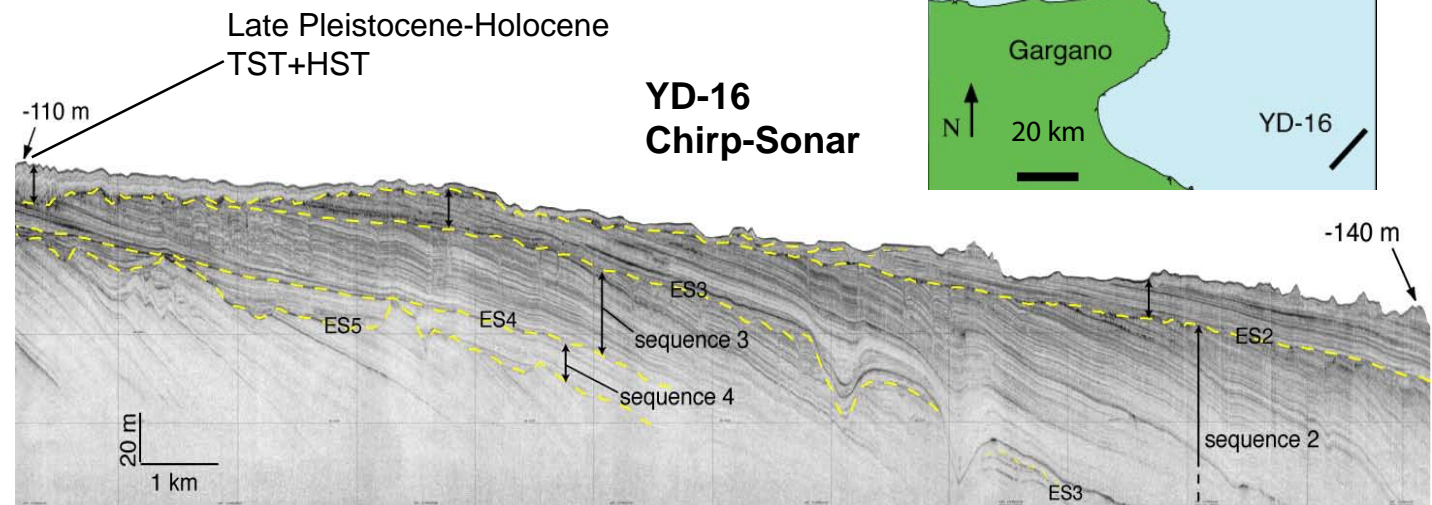
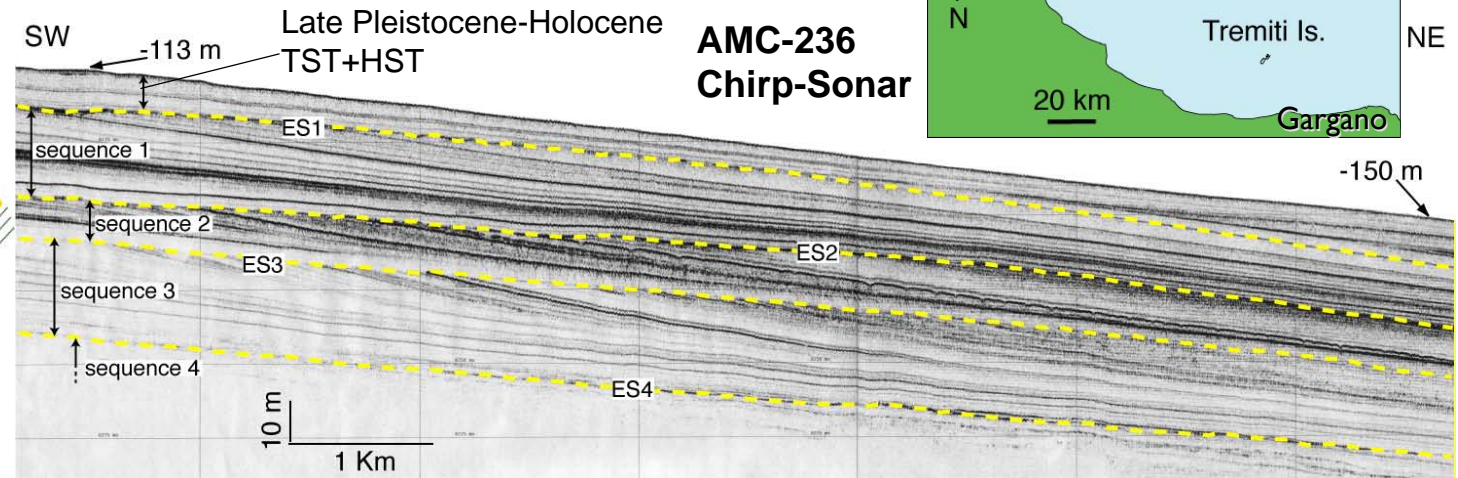
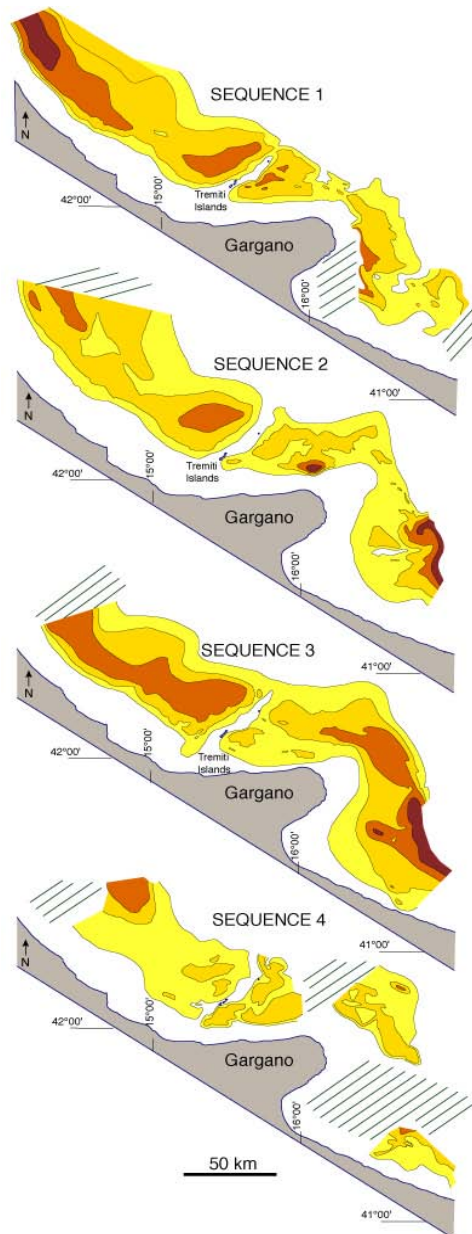


subaqueous delta progradation
and current-dominated foresets:

low angle/tangential downlap

- Clinoform pattern of progradational units

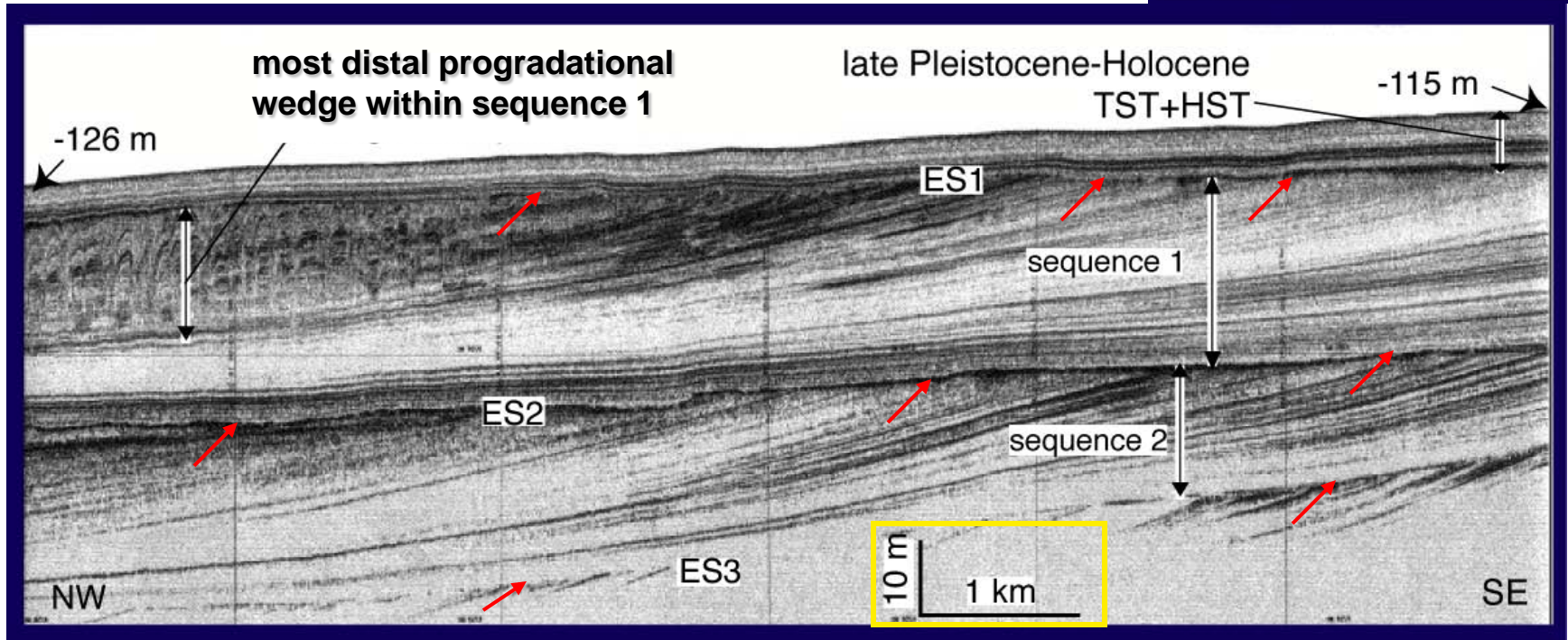
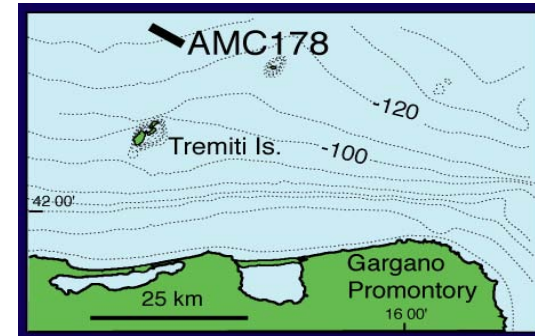
Middle-Upper Pleistocene Sequences



Ridente and Trincardi, 2002, Marine Geology

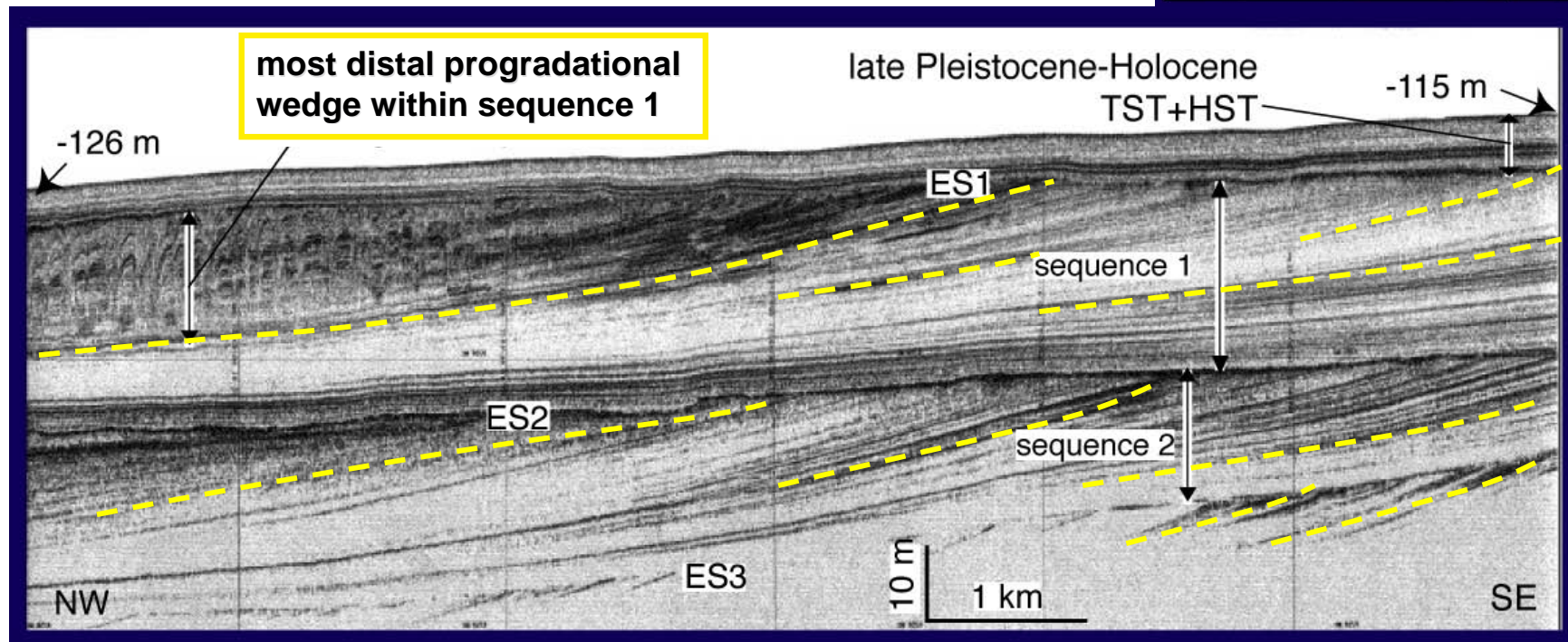
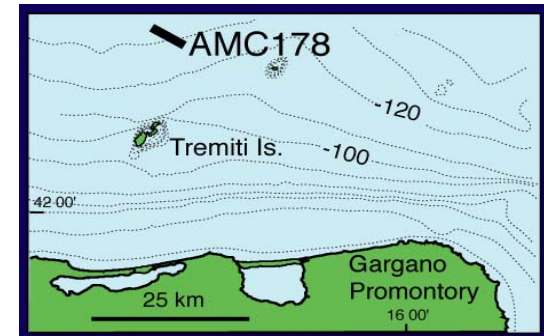
- ***Clinoform pattern of progradational units***

- Low angle progradational clinoforms compose the bulk of each sequence on the outer shelf



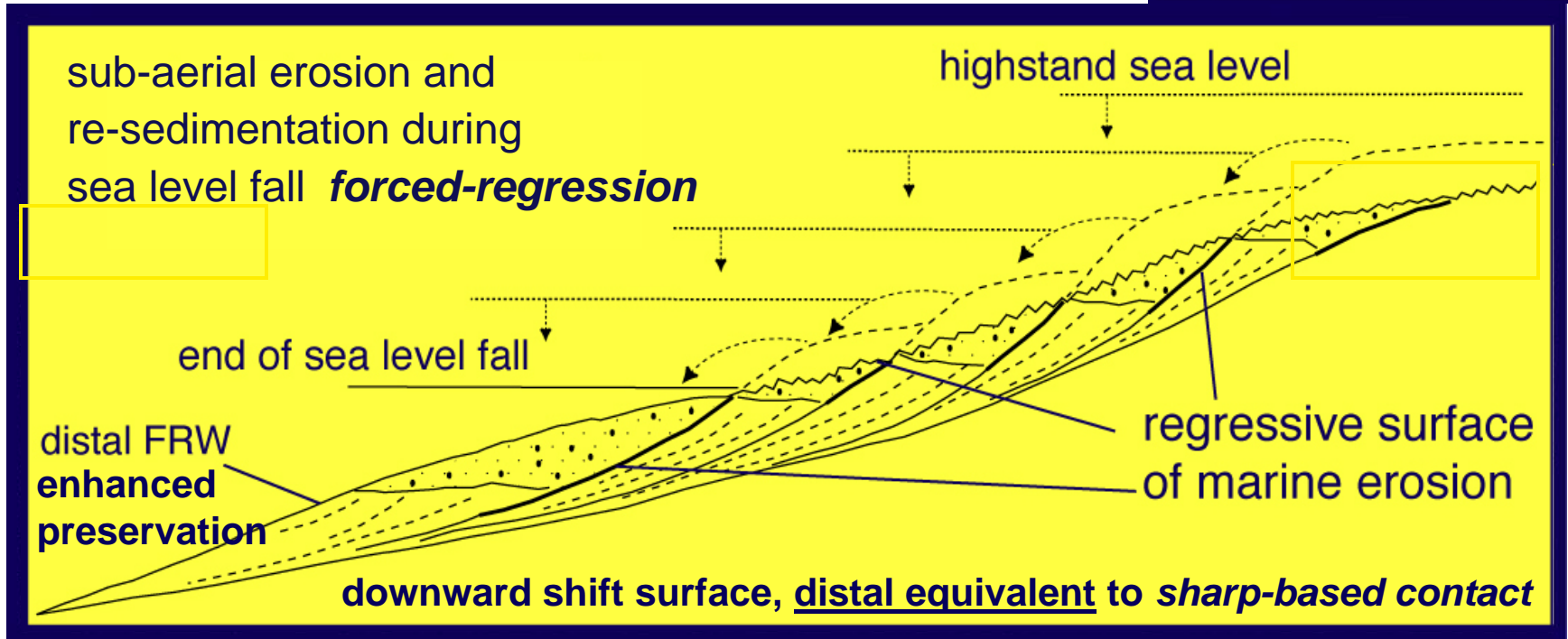
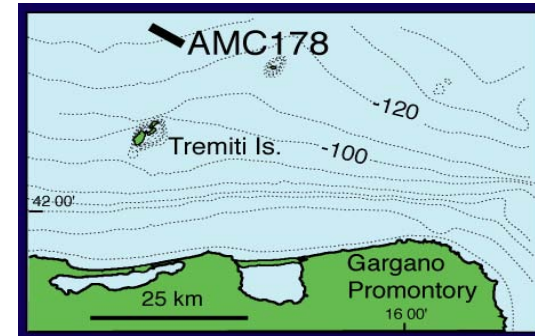
- ***Clinoform pattern of progradational units***

- **Low angle progradational clinoforms compose the bulk of each sequence on the outer shelf**
- **Variability in the seismic facies/amplitude of individual clinoforms and related basal contacts**



- *Clinoform pattern of progradational units*

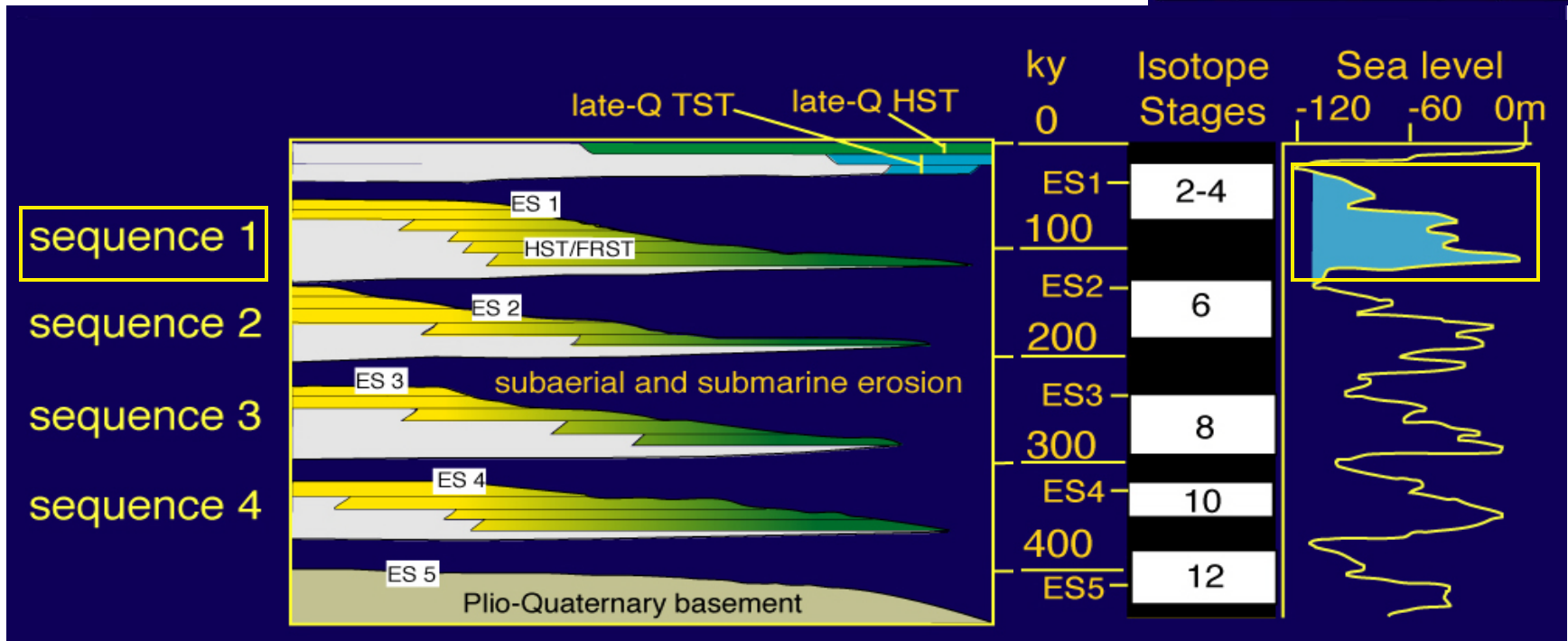
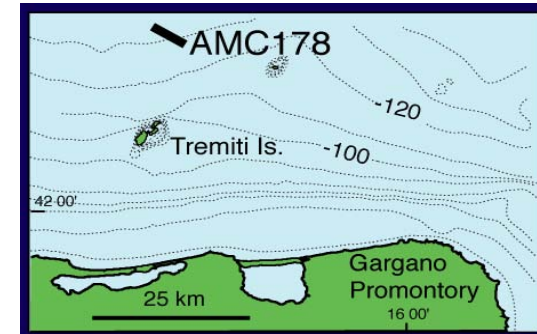
- Low angle progradational clinoforms compose the bulk of each sequence on the outer shelf
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- Is there any relationship between seismic facies/reflector variability and depositional/preservation dynamics?

- *Clinoform pattern of progradational units*

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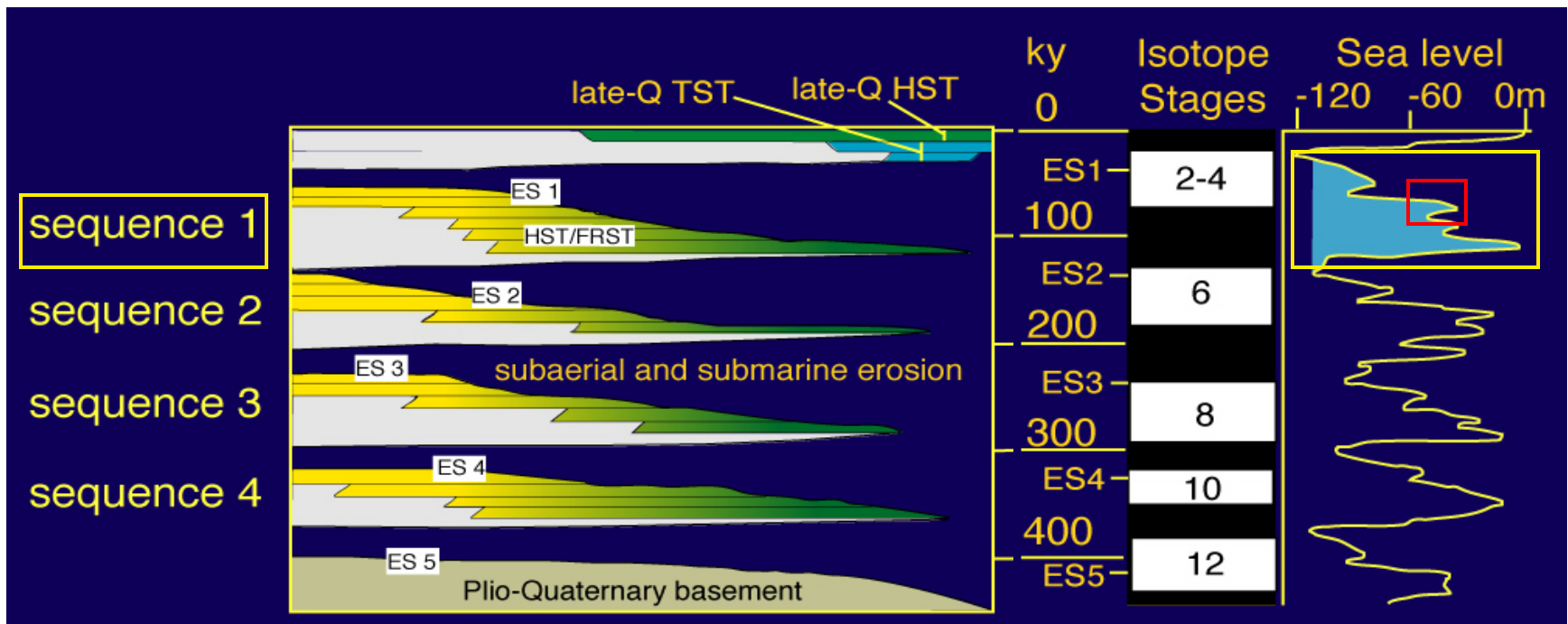


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- *Climoform pattern of progradational units*

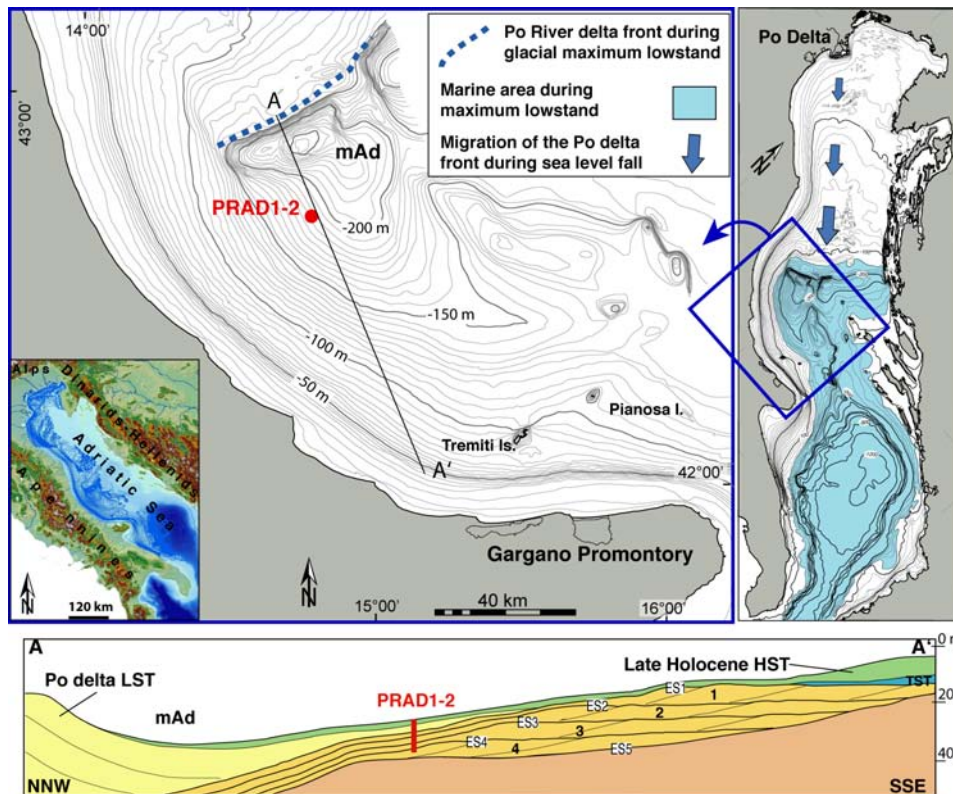
Asymmetric cyclicity:

- rapid interglacial warming (terminations) following glacial maxima
- slow and unsteady cooling after rapid interglacial warming
- 20 ka cycle punctuating 100 ka cyclicity

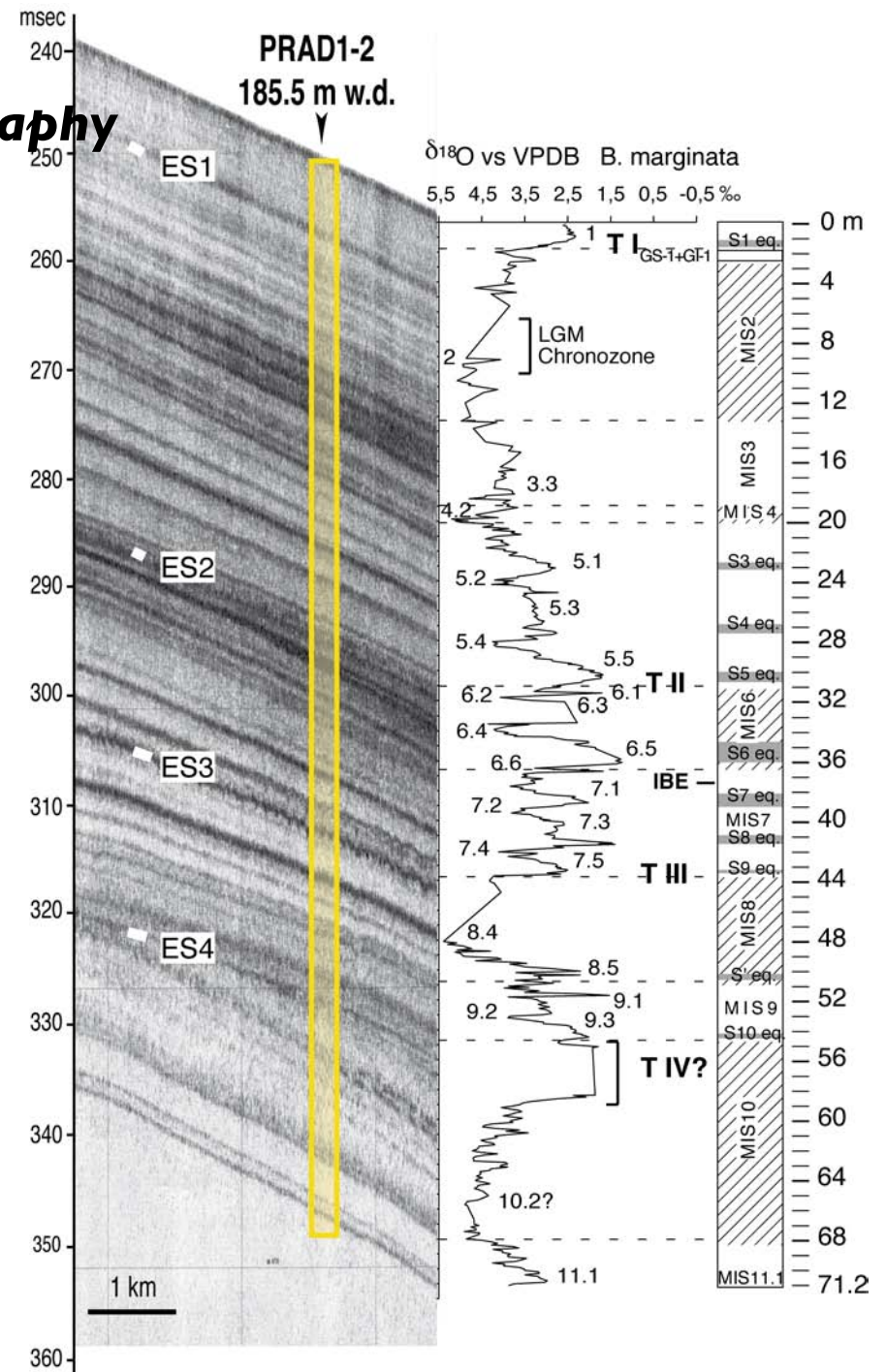


- Is the complexity of composite cyclicity recorded by progradational units and can it be resolved?

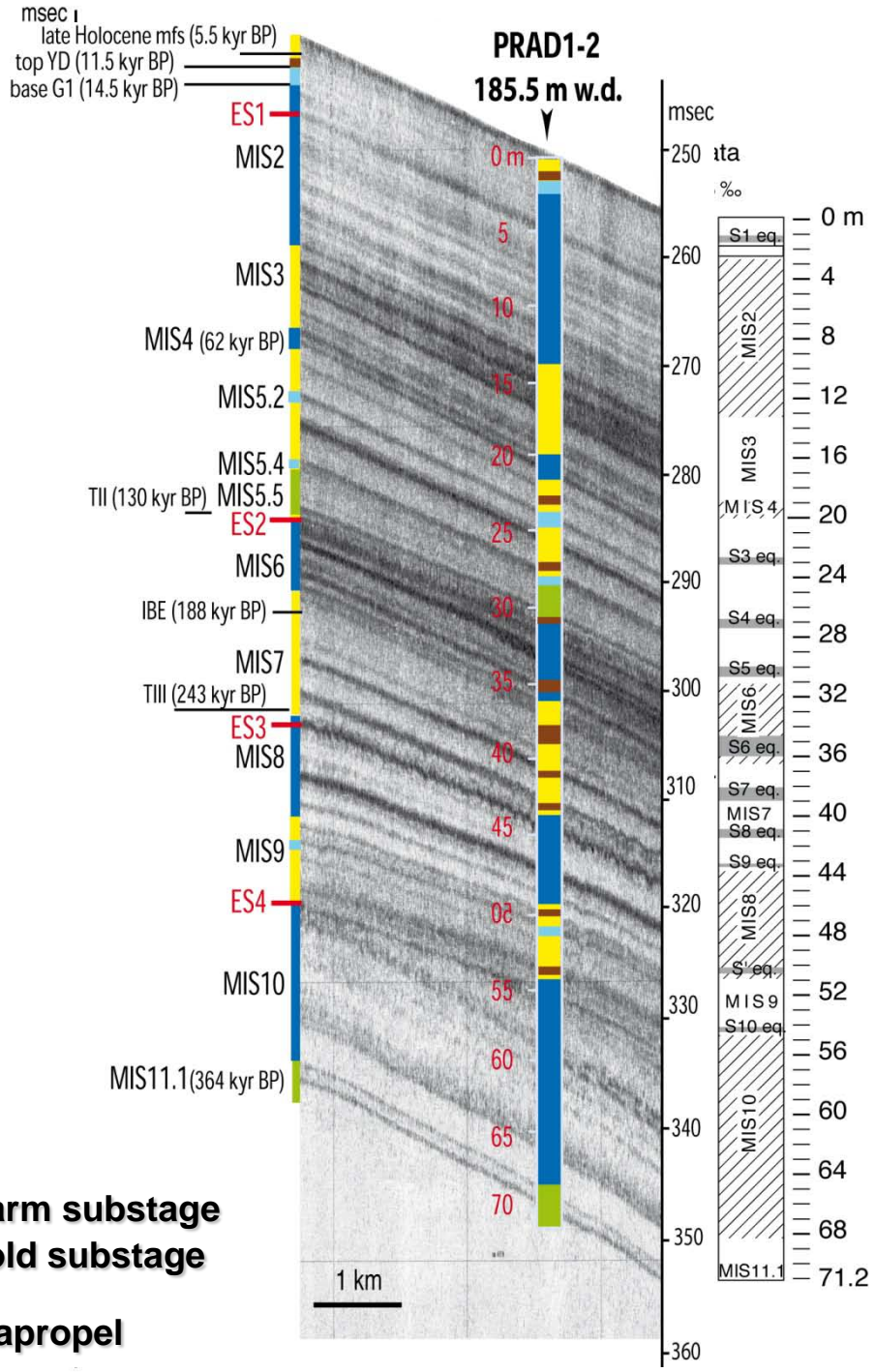
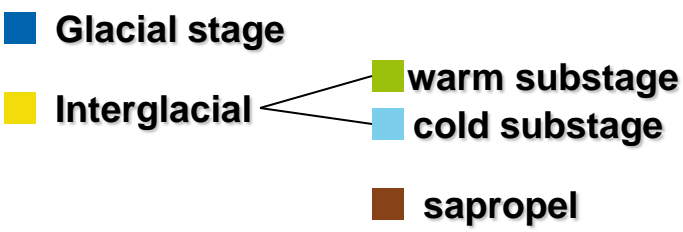
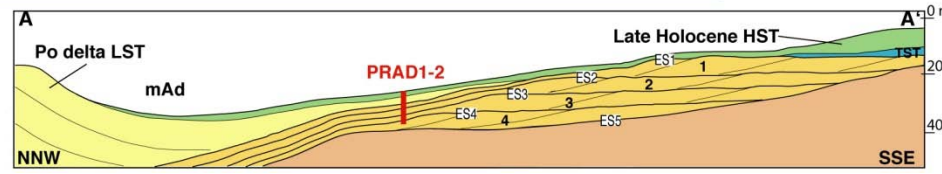
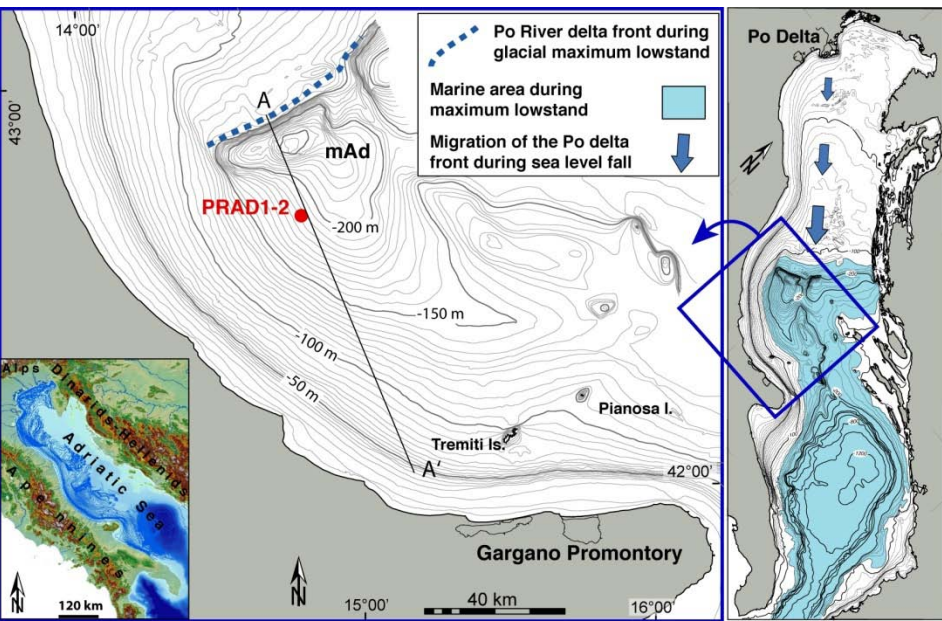
- Internal architecture of Pleistocene sequences based on PRAD1-2 stratigraphy



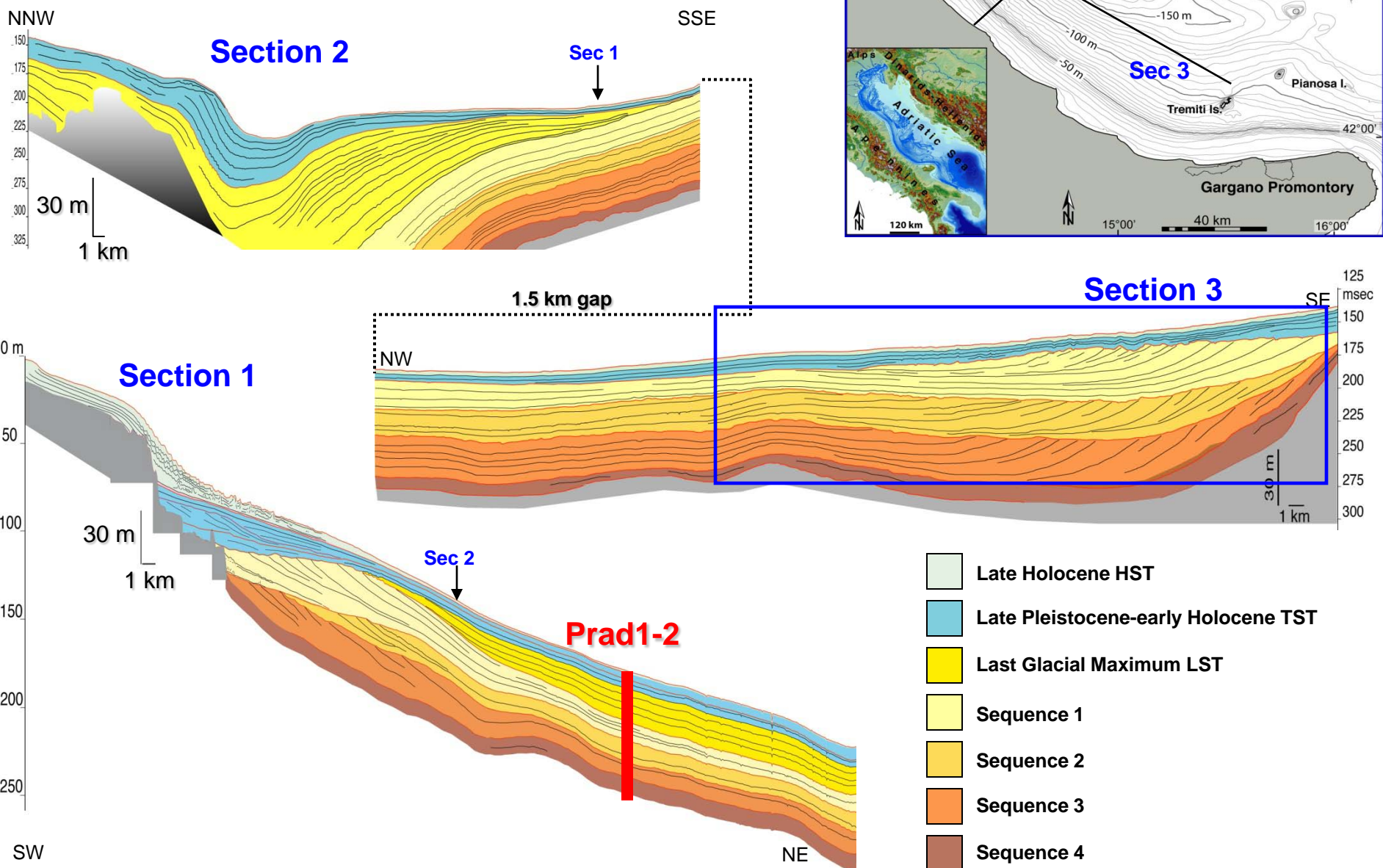
ES = correlative ES surface (sequence boundary)
IBE = Iceland Basin Excursion (188 ka BP)
TI-IV = Terminations
S eq = sapropel equivalent



- Internal architecture of Pleistocene sequences based on PRAD1-2 stratigraphy

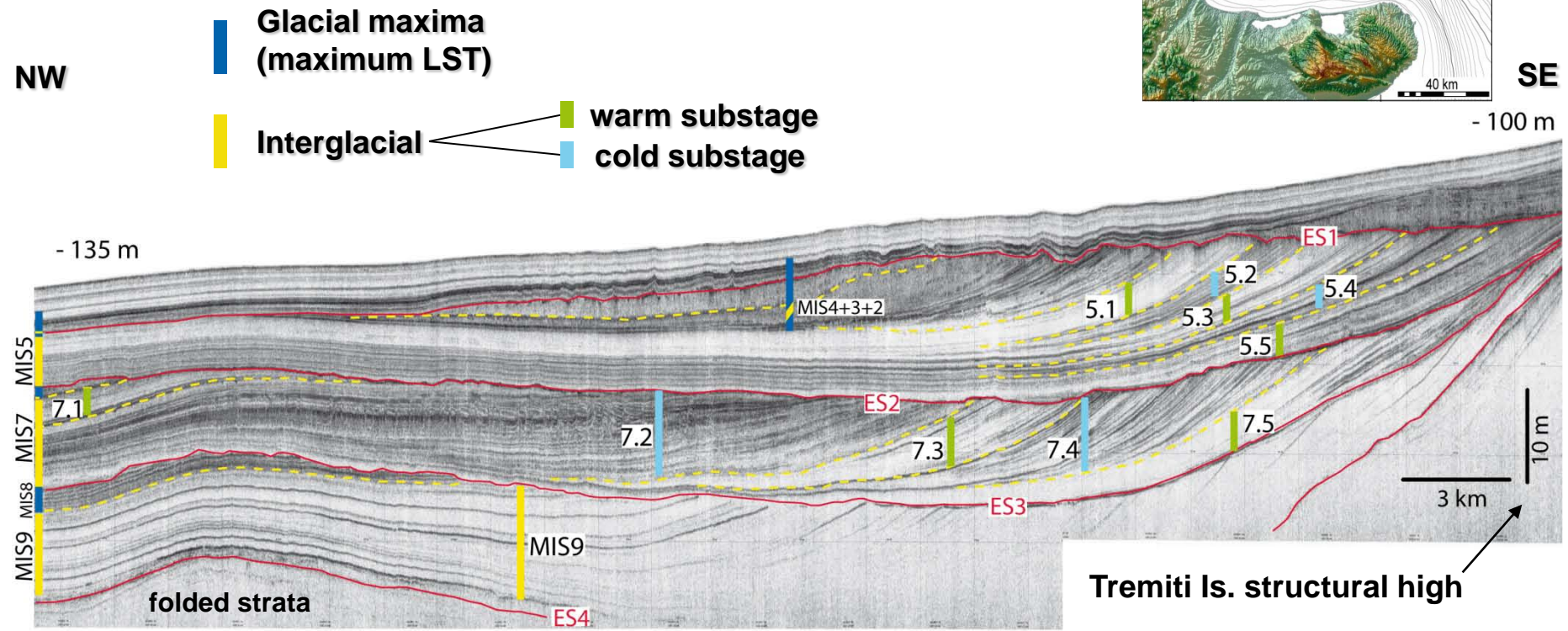


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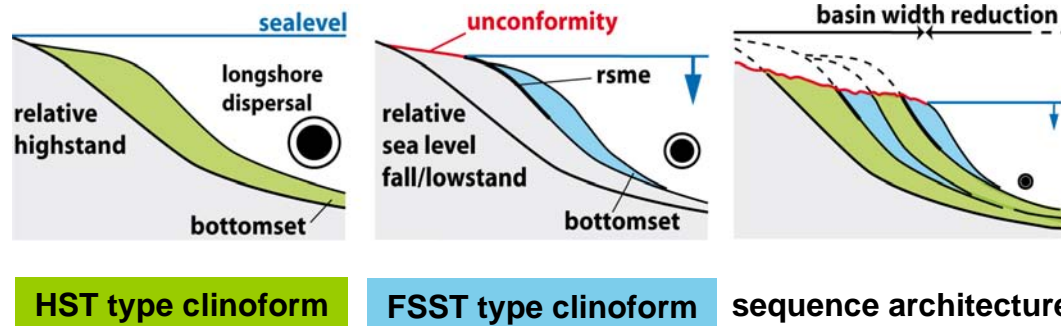
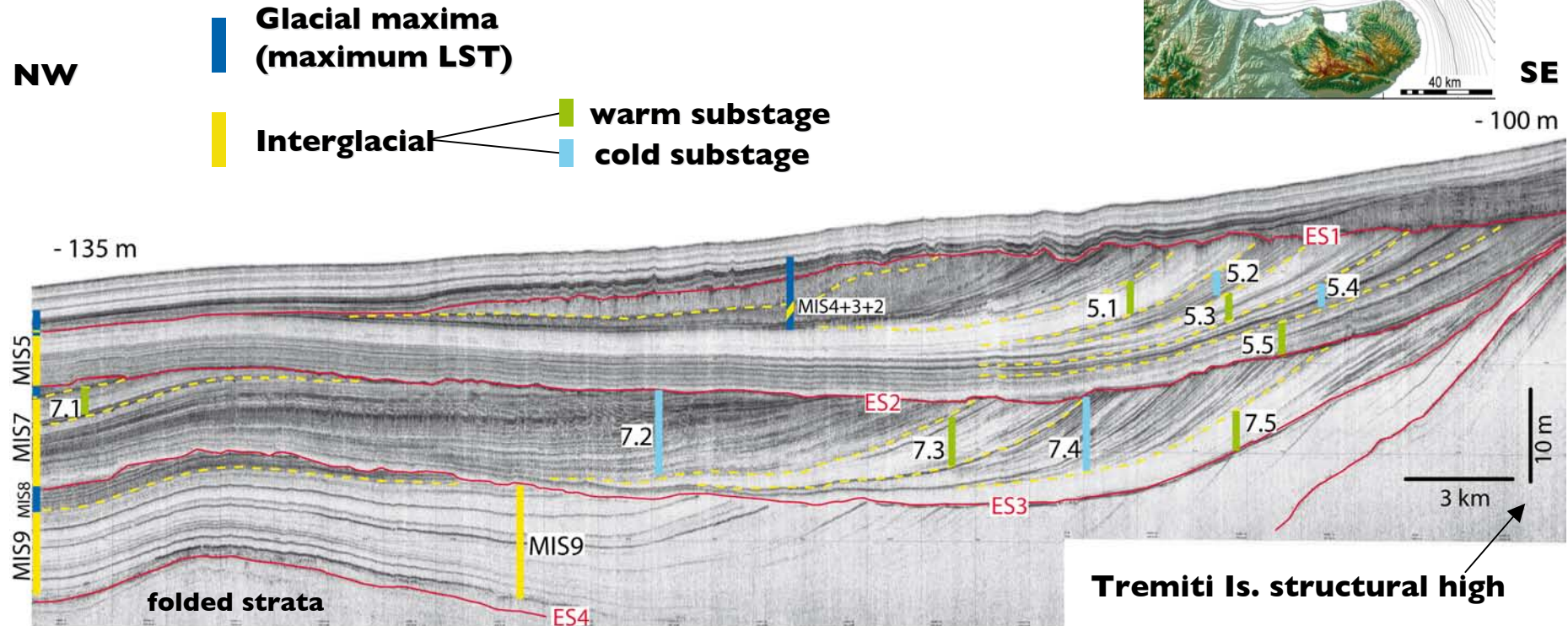
- Internal architecture of Pleistocene sequences based on PRAD1-2 results

AMC240 Chirp Sonar Profile



- Internal architecture of Pleistocene sequences based on PRADI-2 results

AMC240 Chirp Sonar Profile



- Interpretation:

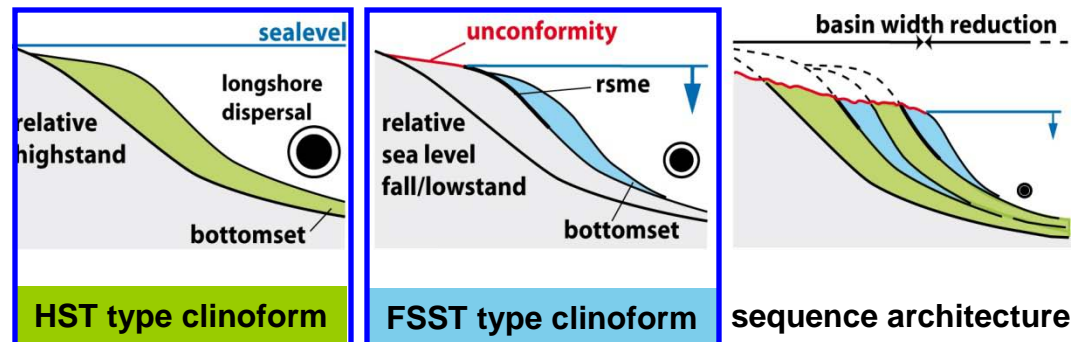
- supply/dispersal bias

dominant advection during relative highstand (warm) intervals:
enhanced distal progradation, thicker bottomsets of clinoforms

reduced advection during relative lowstand (cold) intervals:
hampered progradation, thinner bottomsets of clinoforms

- sequence architecture

100 ka unconformity-bounded sequences composed of ca. 20 ka HST and FSST progradational units with different clinoform geometry



- Interpretation:

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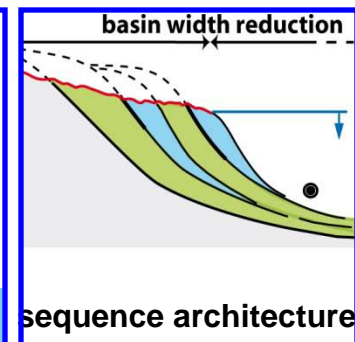
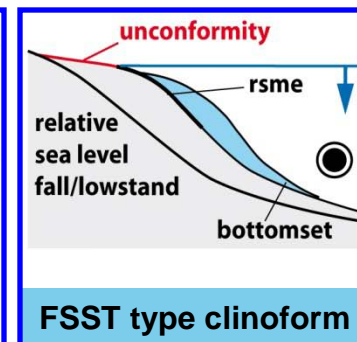
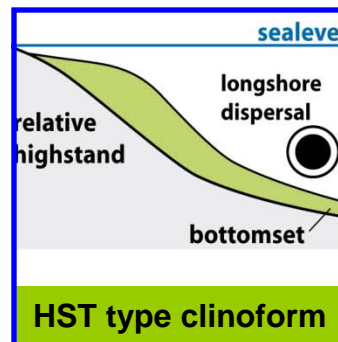
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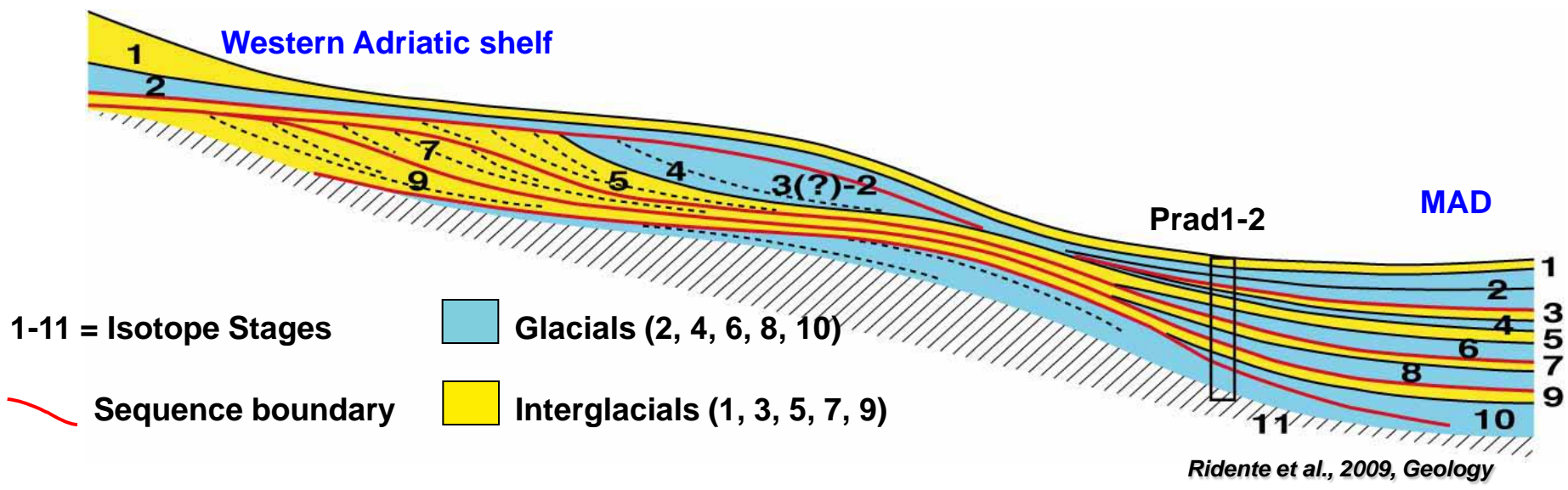
100 ka unconformity-bounded sequences composed of ca. 20 ka HST and FSST progradational units with different clinoform geometry

- LST units in 20-ka cycles?

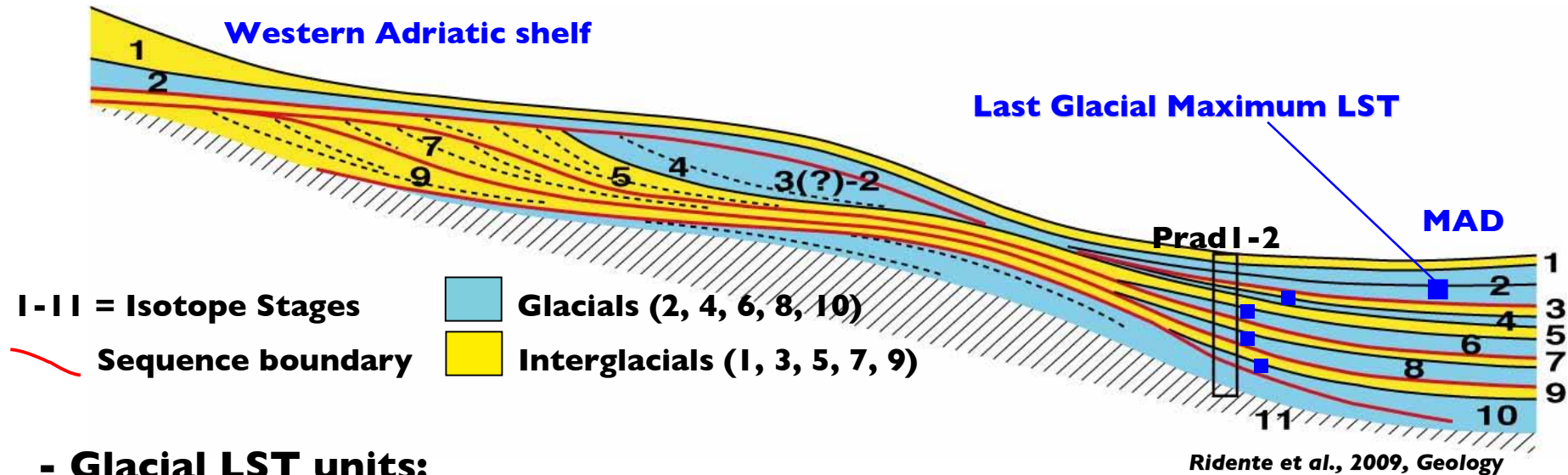
- TST units in 20-ka cycles?



- Sequence architecture and systems tracts partitioning



- Sequence architecture and systems tracts partitioning



- Glacial LST units:

- confined in the MAD during glacial maxima
- form FSST on the shelf during glacial-substages

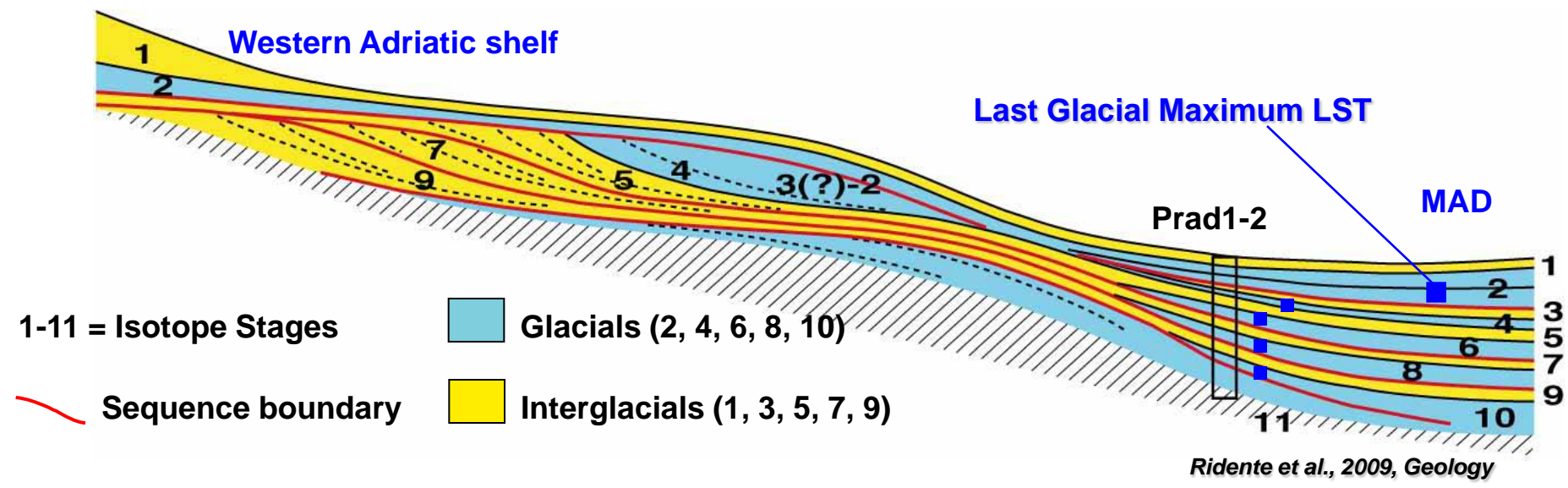
- TST units:

- thin “unresolved” parts of HST during minor sea level rises punctuating the overall 100 ka falls
- patchy depocentres during major terminations (i.e. major sea level rise) following glacial maxima

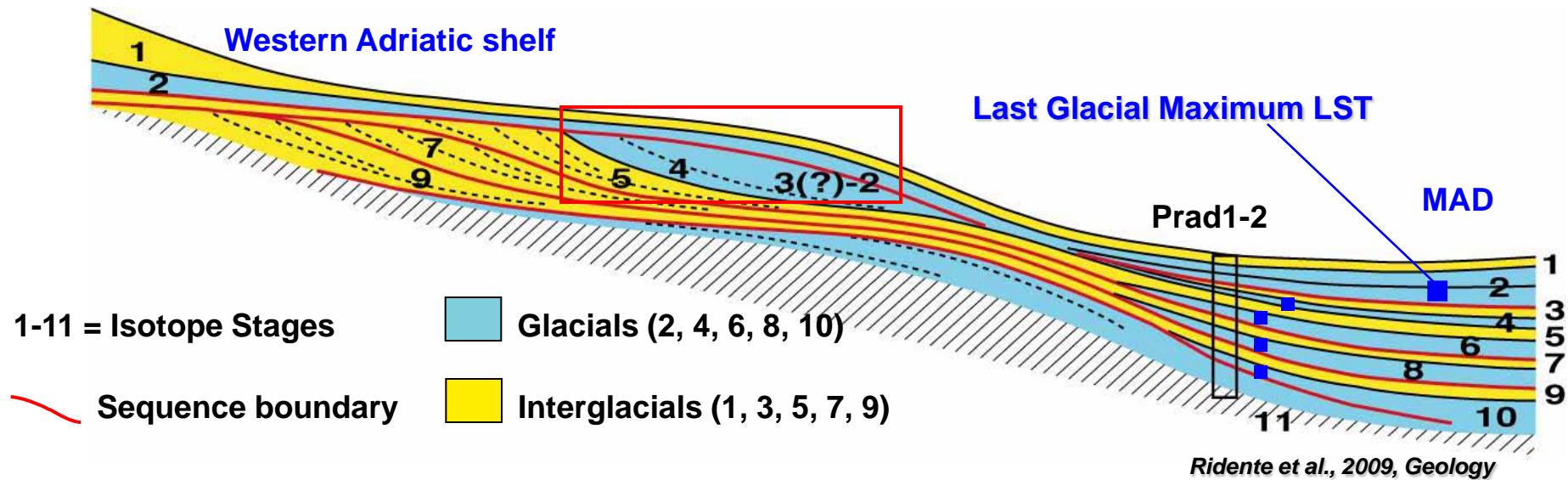
- Sand deposits form as:

- turbiditic layers in the MAD during glacial lowstand maxima
- sharp-based nearshore deposits on the shelf during sea level fall

- Facies partitioning (mud vs sand) within sequences



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- depositional bias:

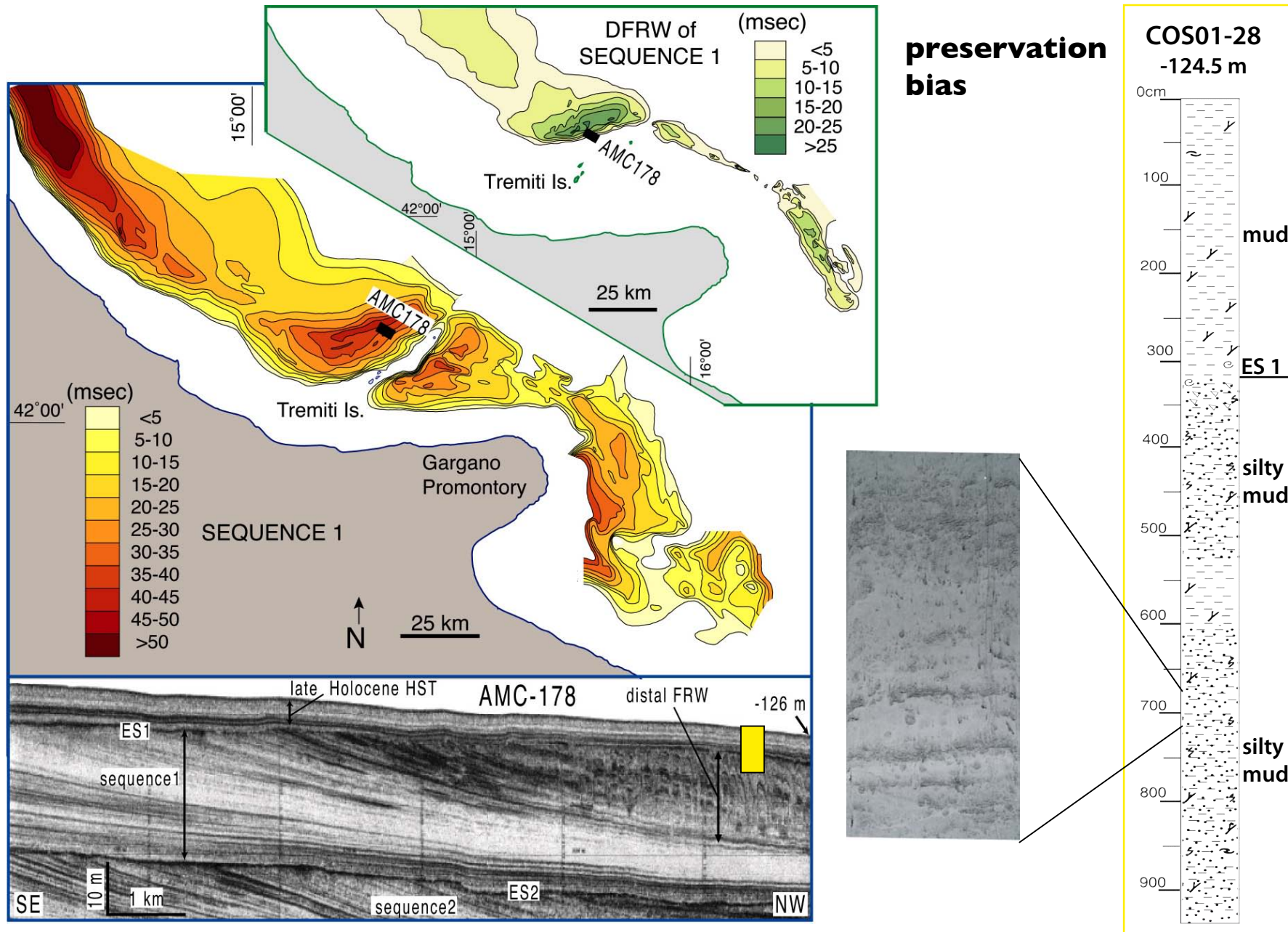
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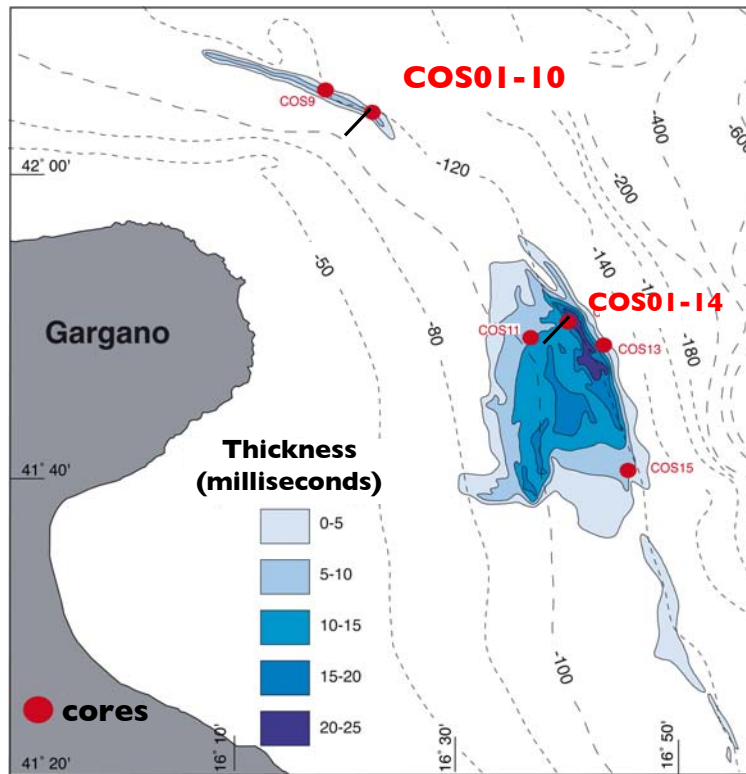
- preservation bias:

- preservation of sharp-based forced-regressive nearshore deposits only at the end (glacial maxima) of the 100 ka sea level fall

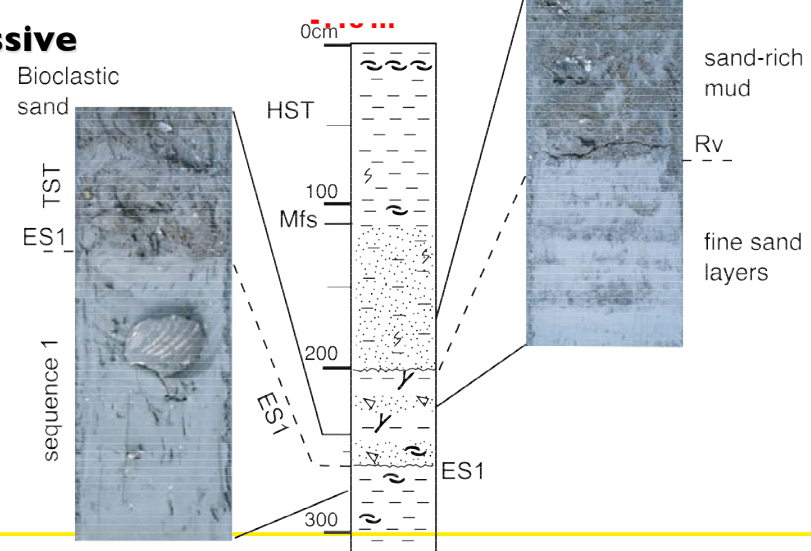
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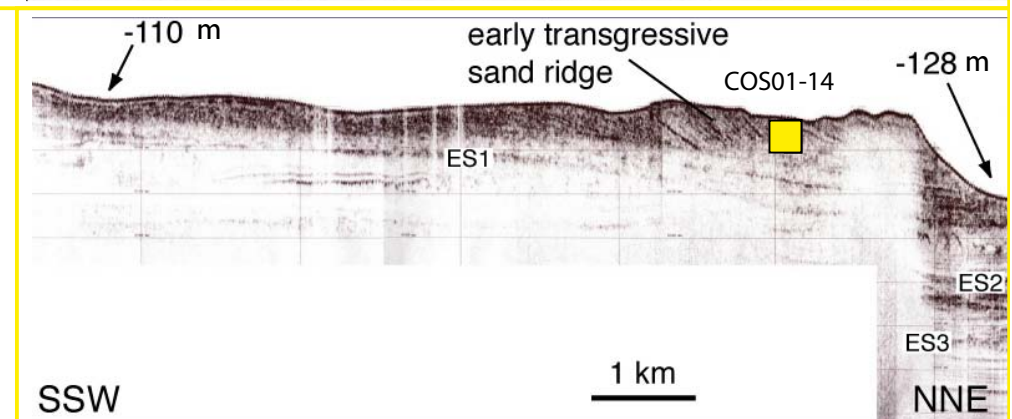
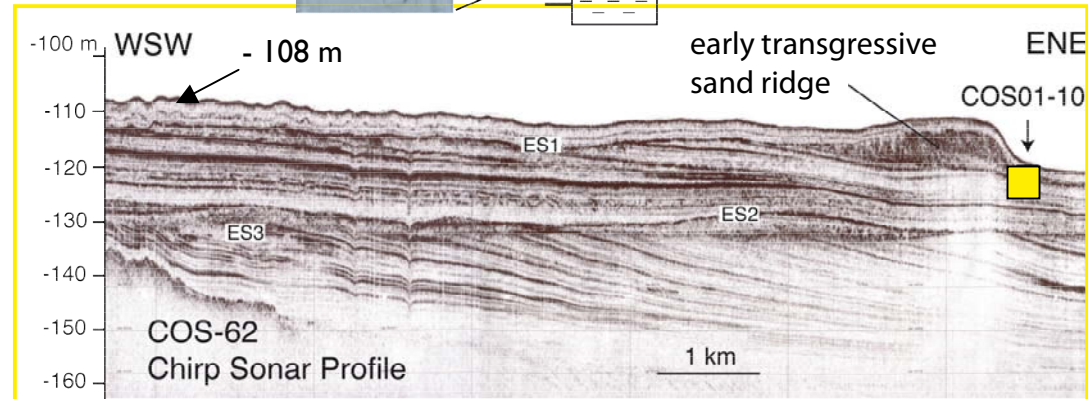
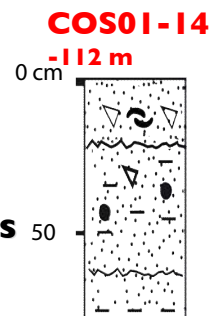


Early transgressive unit Isopach Map



transgressive “sand ridges”

- coarse bioclastic sand and pebbles
- high-angle (3-7°) progradational foresets
- sharp-based contact over muddy forced regression deposits



- Summary and concluding remarks

- The Adriatic is an example of a mud-dominated setting where progradation of shelf units is accomplished by offshore mud transport and accumulation under the control of longshore currents**
- Changing sea level during Quaternary climate-driven cycles alternatively switched-off longshore currents and sediment transport, generating a distinct signature in clinoform geometry**
- This signature in clinoform geometry has been used to unravel sequence architecture resulting from composite 100 and 20 ka Milankovitch cyclicity**
- Shelf stratigraphy is largely composed by interglacial muddy progradational units made of thicker HST that alternate with thinner FSST that lack coarser-grained sediment**
- Lowstand units during glacial intervals are confined to the slope and so are coarser sandy deposits, with the exception of patchy, “transgressive sand ridge” deposits that escape post-glacial transgressive erosion and reworking**
- In contrast with many pre-Quaternary settings, forced-regressions form *continuous-muddy* rather than *patchy-sandy* shelf deposits**

- *More general remarks*

On many late Quaternary continental margins, the high-amplitude, high-frequency and multiple climate-driven sea level cycles generate sequence-stratigraphic patterns that are not accounted for in classical sequence stratigraphy

This is essentially because classical models of sequence stratigraphy:

- are largely based on ancient (pre-quaternary) settings;**
- poorly consider the importance of supply fluctuations, particularly in the along-strike direction (2-D models)**
- conceive only the “accommodation space” in terms of “physical limitation”, whereas oceanographic processes and supply dynamics may equally act as constraints relative to depositional geometry**

Thank you for attention