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The post-Messinian translation of the Southern Apennines-Calabrian Arc in the Bradano basin (Northern Ionian Sea)

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Reasons behind the study

The tectono-stratigraphic evolution of the collisional belt at the transition between the Calabrian Arc (CA) and Southern Apennines (SA) is still poorly constrained, and it is still not clear when the Bradano Basin (BB) was interested by collisional processes.

Few works (Ferranti et al., 2014; Filice and Seeber, 2019; Milia et al., 2017; Reitz and Seeber, 2012) define the Pliocene-Pleistocene evolution of this key area in the Central Mediterranean Sea.

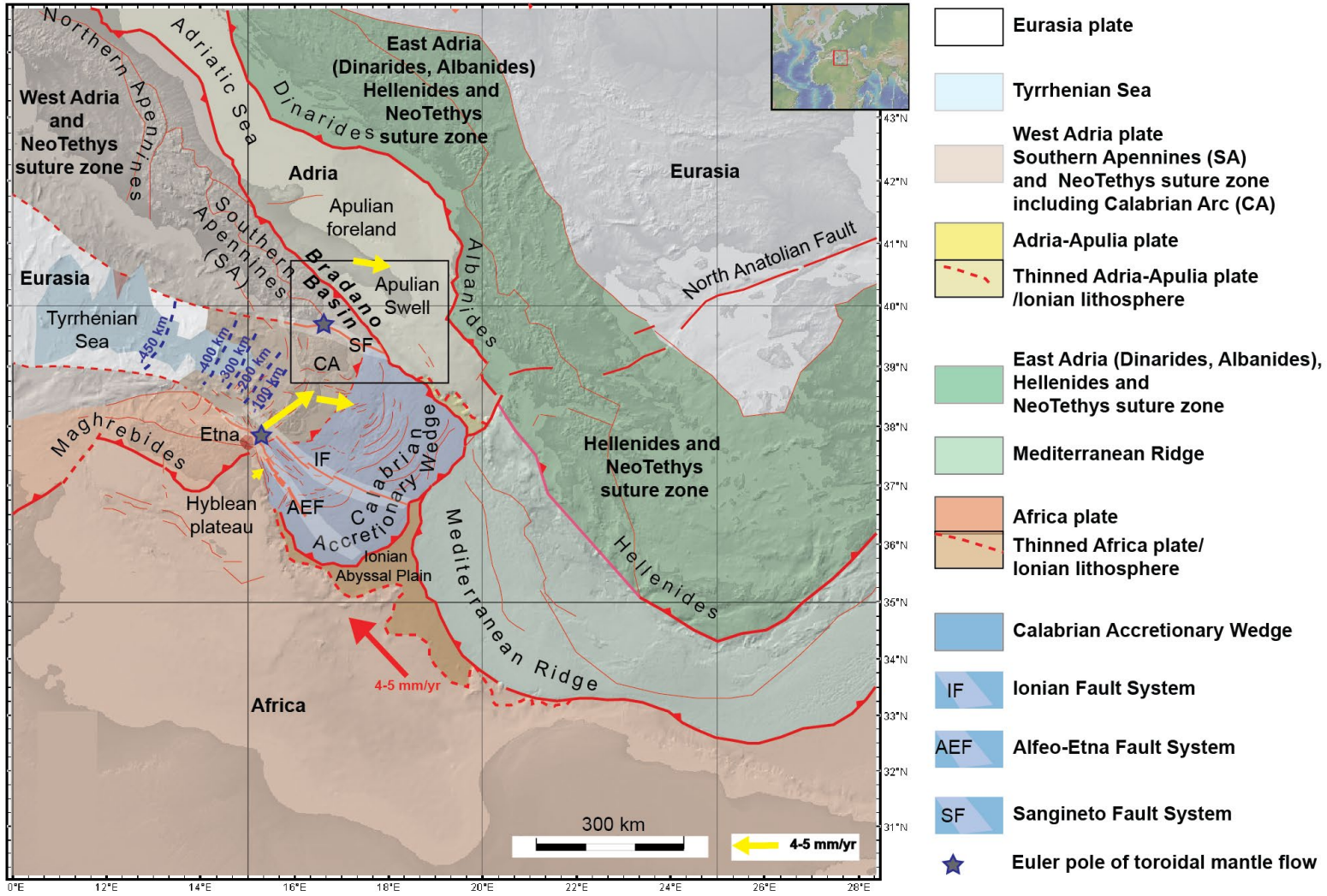
Aims of the study

Define the post-Messinian tectono-sedimentary evolution of the Bradano Basin (BB) adjacent to the Southern Apennines orogenic wedge where it bends and passes to the Calabrian Arc and Calabrian Accretionary Wedge (CAW) while they are both colliding with the subducting Apulia plate.

Define the deep geometry of the Amendolara Ridge which is one of the most prominent structure of the BB interpreted either as a thin-skinned or thick-skinned or transpressional structure.

Define the offshore prolongation of the NW-SE trending Sangineto Fault System commonly considered the boundary between Southern Apennines and Calabrian Arc.

Bradano Basin (BB) - Geodynamic framework and plates in the study area



Red arrow is the slip vector between Africa and Europe in the Europe-fix reference frame Yellow arrow are the GPS vectors in the Africa/Nubia-fix reference frame (D'Agostino et al., 2008).

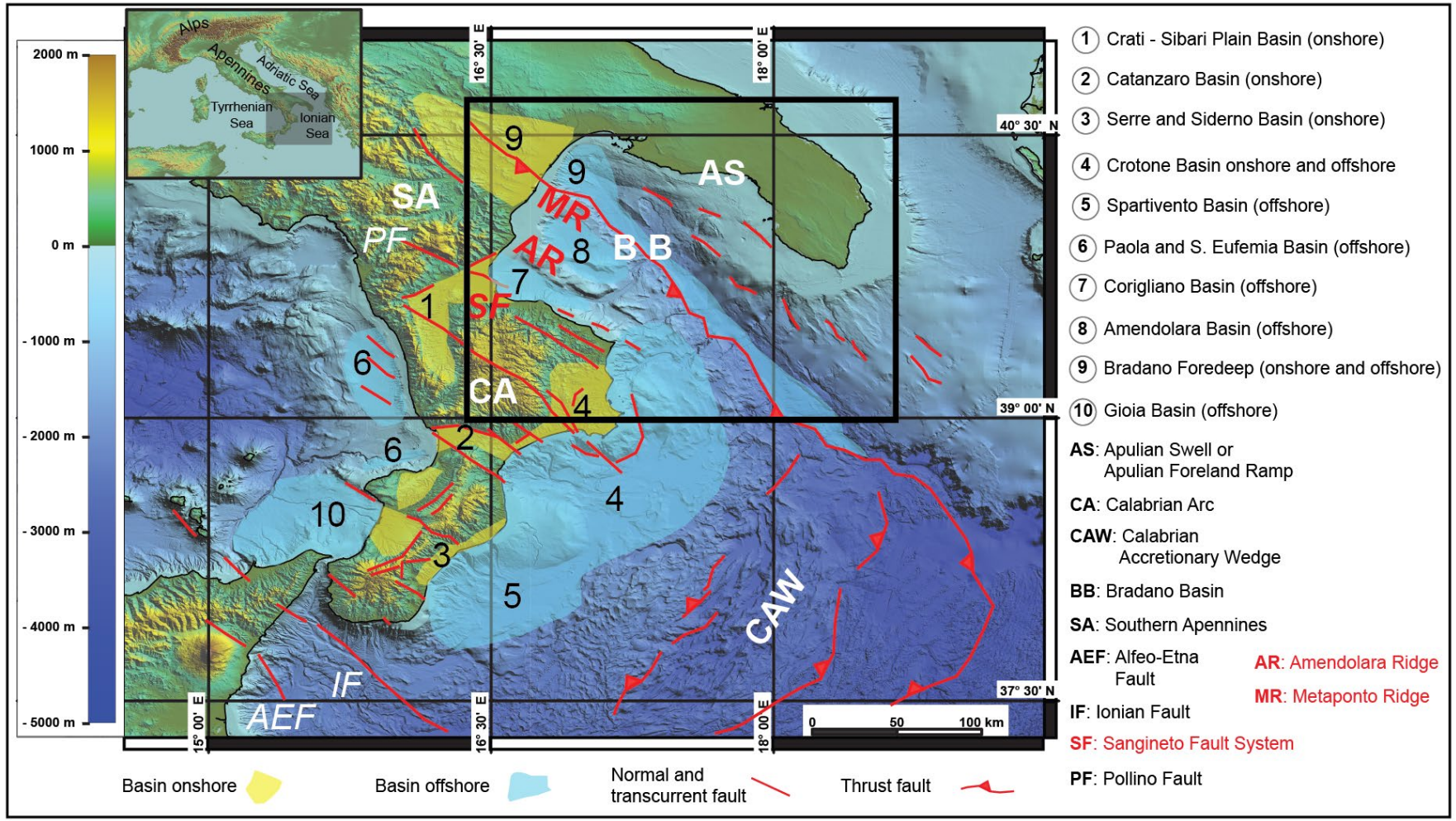
Blu dashed lines are isodepth from 100 to 450 km of the Ionian subducting slab (Selvaggi and Chiarabba, 1995).
Euler poles of toroidal mantle flow are from (Palano et al., 2017).

Major tectonic features are from various authors (Faccenna et al., 2014; Handy et al., 2010; Polonia et al., 2017, 2016, 2011).

The bathymetric and topographic basemap are from GMRT dataset available from http://www.geomapapp.org (Ryan et al., 2009).

Modified after **Basso** et al. (2021) Marine and Petroleum Geology, 128,104999, https://doi.org/10.1016/j.marpetgeo.2021.104999

Bradano Basin (BB) – Basins setting and structures



Bradano Basin (BB) is a Foreland Basin System (sensu DeCelles and Giles, 1996) composed by

wedge-top basins [Corigliano Basin (7); Amendolara Basin (8)]

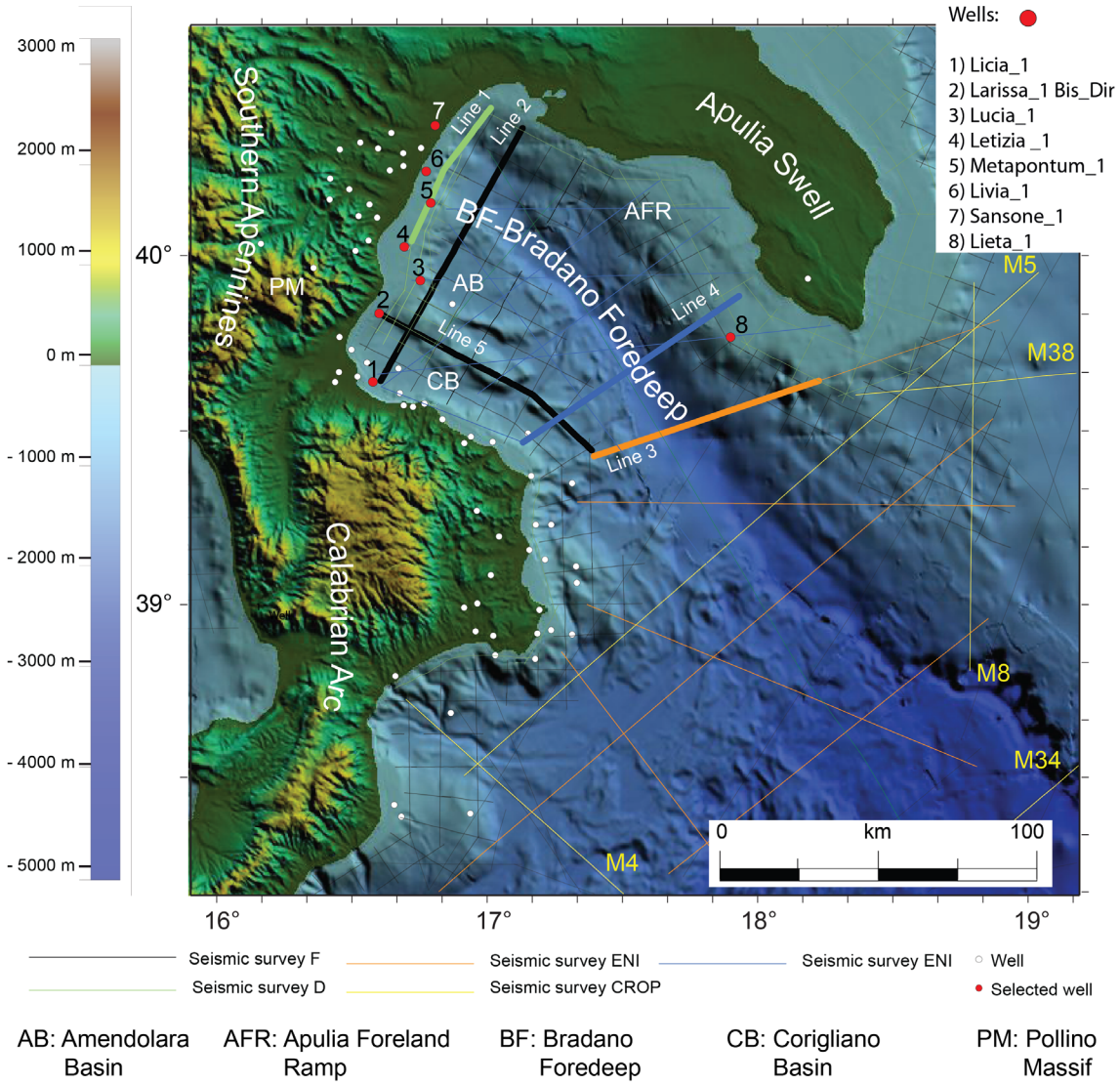
foredeep basin [Bradano foredeep (9)]

foreland ramp (Apulian Foreland Ramp or Apulian Swell –AS-)

Modified after **Basso** et al. (2021) Marine and Petroleum Geology, 128,104999, https://doi.org/10.1016/j.marpetgeo.2021.104999

Bathymetry and topography after GeoMapApp (www.geomapapp.org) / CC BY (Ryan et al., 2009), and EMODnet Digital Bathymetry (EMODnet Bathymetry Consortium, 2018), available at https://www.seadatanet.org/

Dataset and Methods



AB: Amendolara Basin | AFR: Apulia Foreland Ramp | BF: Bradano Foredeep | CB: Corigliano Basin | PM: Pollino Massif

Modified after **Basso** et al. (2021) Marine and Petroleum Geology, 128,104999, https://doi.org/10.1016/j.marpetgeo.2021.104999

Seismic reflection profiles area D and F (about 2000 km tot.) migrated with Gazmix di Seismic Unix

8 exploration wells (http://unmig.sviluppoeconomico.gov.it/videpi/)

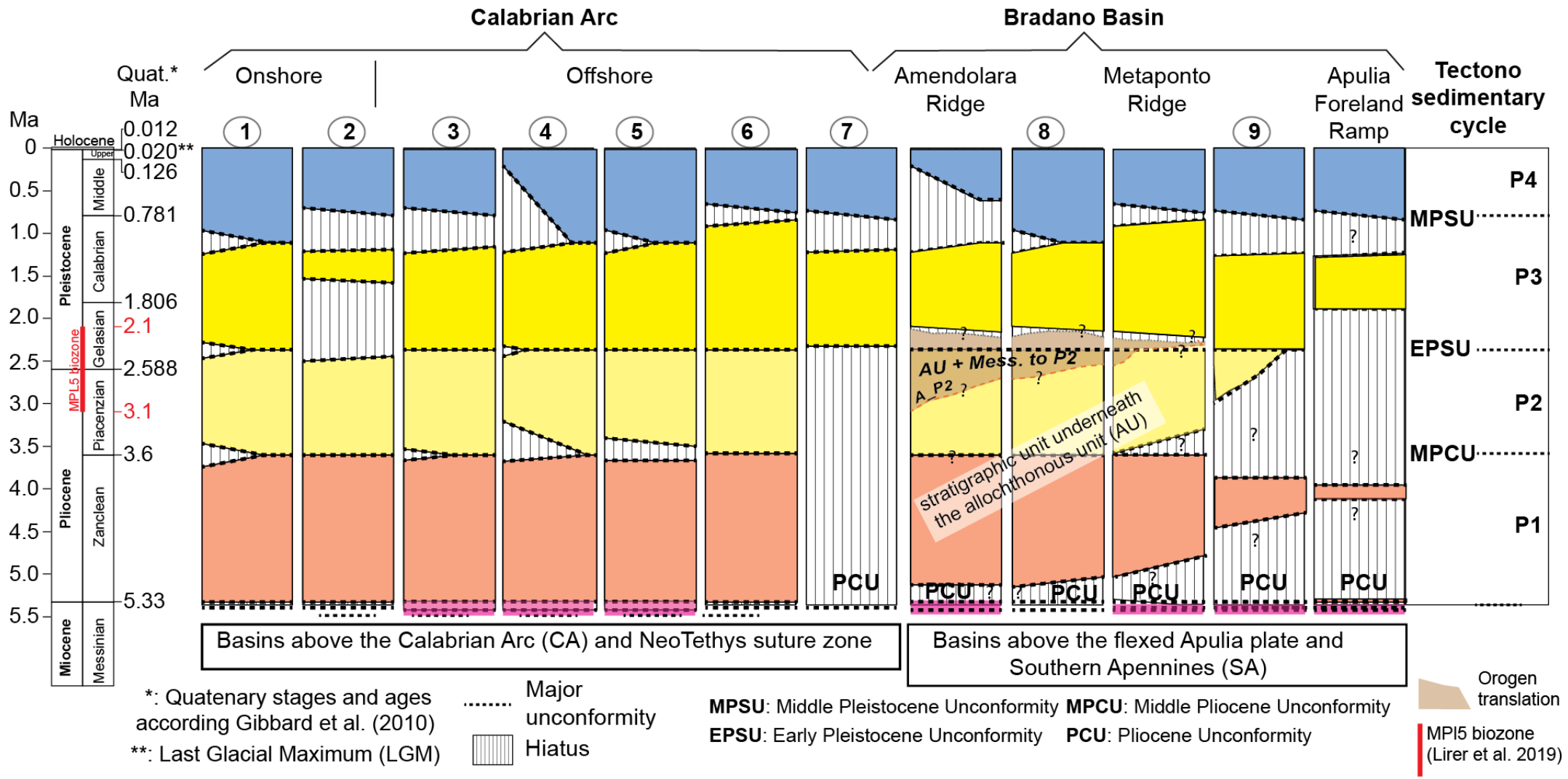
Integrated well-log and seismic stratigraphic correlations

Seismic profile interpretation with IHS-Kingdom Suite 8.0.1 – 2017

Seismic Attribute analysis with IHS_Kingdom Suite 8.15 – 2019: instantaneous amplitude, phase, frequency, Hilbert transform, envelope (reflective strength), average energy apparent polarity according to previous work (Barnes, 2001; Chopra and Marfurt, 2005)

Bathymetry and topography after GeoMapApp (www.geomapapp.org) / CC BY (Ryan et al., 2009), and EMODnet Digital Bathymetry (EMODnet Bathymetry Consortium, 2018), available at https://www.seadatanet.org/

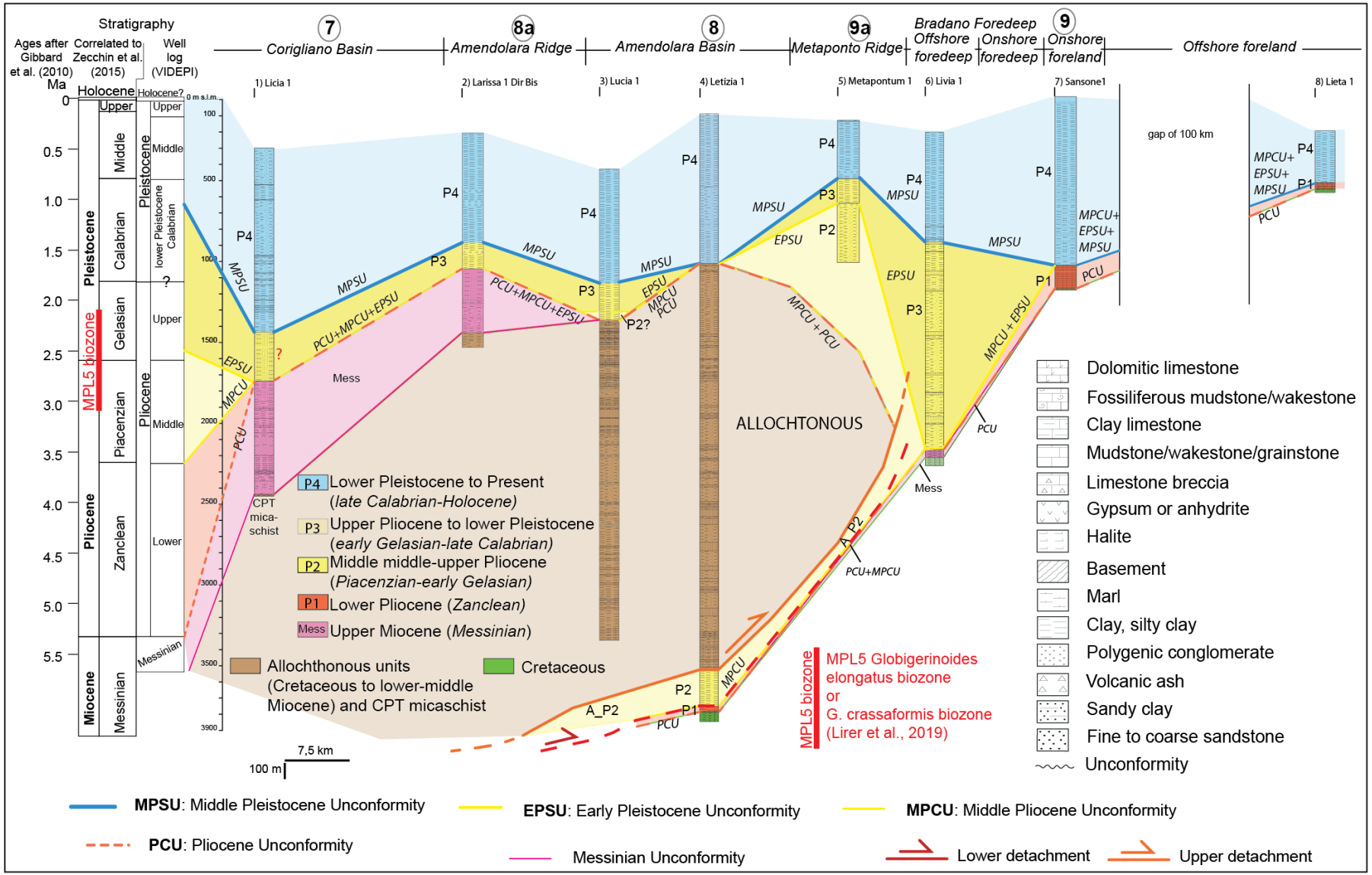
Result I – Stratigraphic scheme from Calabrian Arc to Bradano Basin



Modified after **Basso** et al. (2021) Marine and Petroleum Geology, 128,104999, https://doi.org/10.1016/j.marpetgeo.2021.104999

Stratigraphic scheme extending the tectonostratigraphic units of Zecchin et al. (2015) (1-7) to the BB [Amendolara Ridge, Amendolara Basin (8), Metaponto Ridge, Bradano Foredeep (9) and Apulian Foreland ramp] based on well log stratigraphy and seismostratigraphy analysis

Result II – Well log correlation in the whole BB



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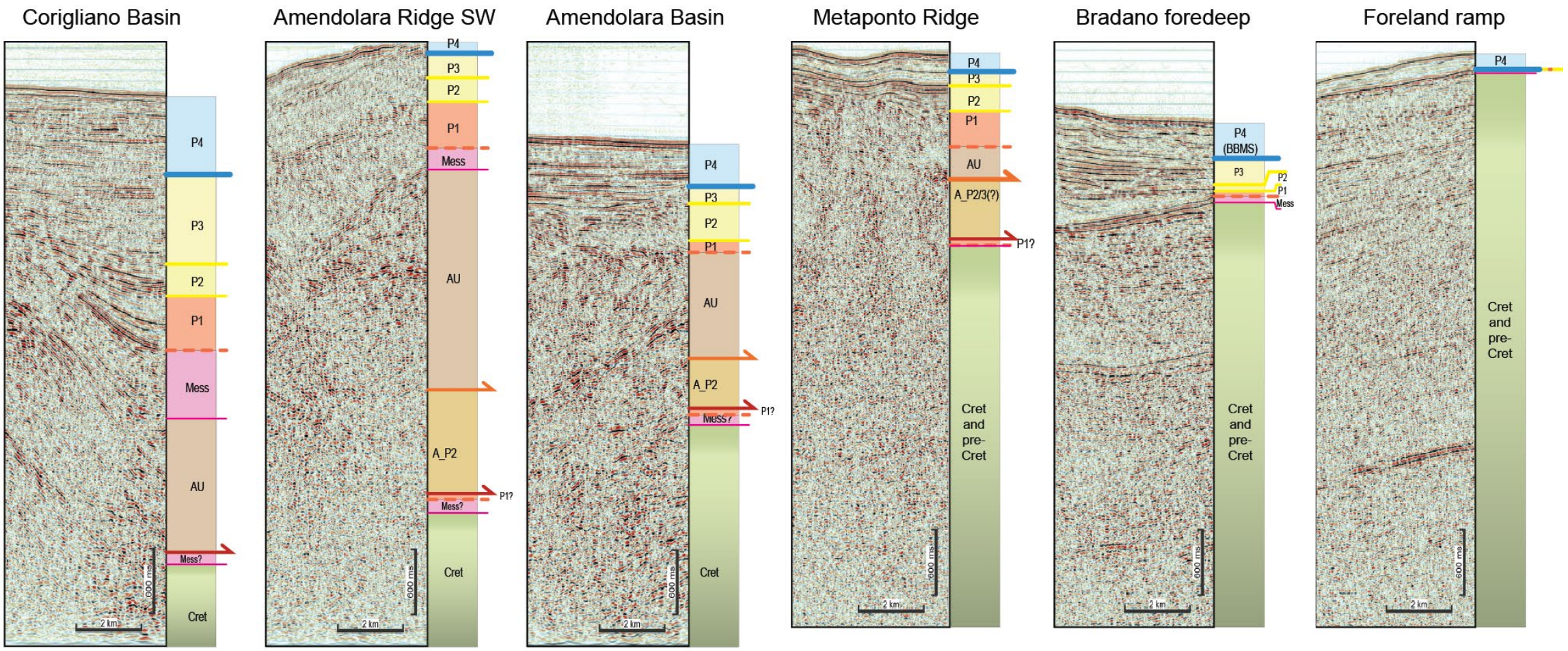
ViDEPI well logs and more recent stratigraphic schemes are reported in the stratigraphy at the left and in the legend.

The MPL5 biozone or MPL5 Globigerinoides elongatus biozone (Lirer et al., 2019) corresponds to the G. crassaformis biozone, spans from middle Piacenzian to middle Gelasian (between ~3.1 Ma and ~2.1 Ma), covers the upper part of the P2 cycle and lower part of P3 cycle, contains the intra-Gelasian EPSU unconformity (~2.5 Ma) (Zecchin et al., 2015), the Pliocene-Pleistocene boundary at 2.588 Ma (Gibbard et al., 2010) confirms that the P2 cycle can be dated Piacenzian-early Gelasian.

Result III – Example of seismic facies in the different settings of BB



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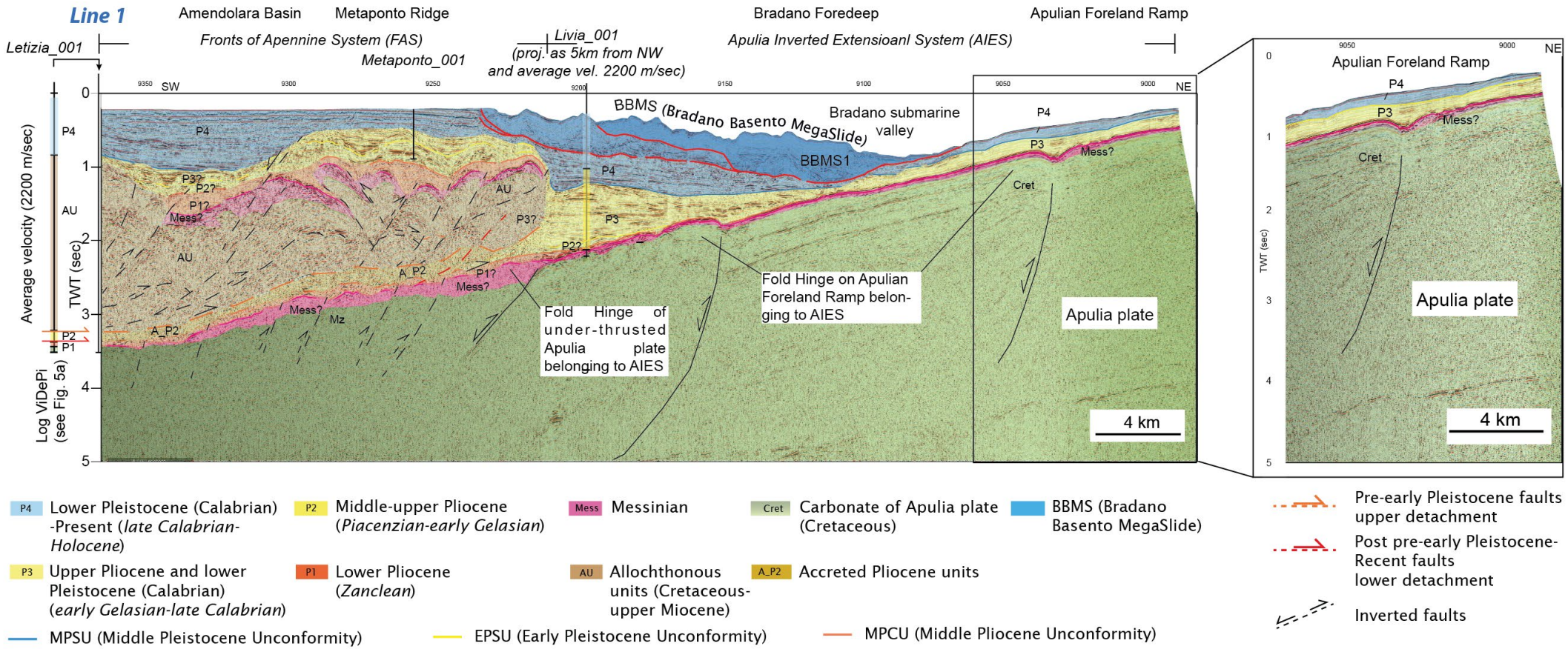
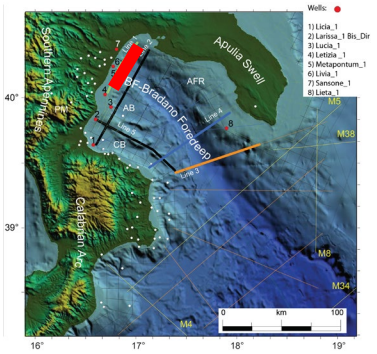
Result IV – Interpretation of seismic reflection line 1

Modified after **Basso** et al. (2021) Marine and Petroleum Geology, 128,104999, https://doi.org/10.1016/j.marpetgeo.2021.104999





Bathymetry and topography after GeoMapApp (www.geomapapp.org) / CC BY (Ryan et al., 2009), and EMODnet Digital Bathymetry (EMODnet Bathymetry Consortium, 2018), available at https://www.seadatanet.org/

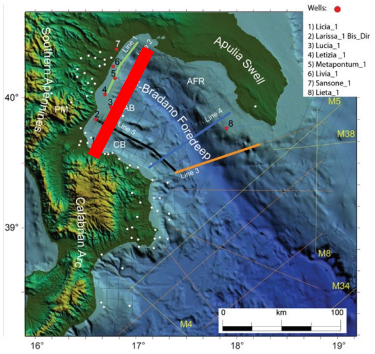
Letizia_1 well constrains the emplacement of the allochthonous units (AU) to the upper part of the P2 cycle (**latest Pliocene/early Pleistocene**) and pre- upper part of P3 cycle (**early Pleistocene/pre-Calabrian**)

Evidences of inversion structures (fold hinges) in the subducting Apulia plate and sealed by P3 cycle (pre-EPSU unconformity).

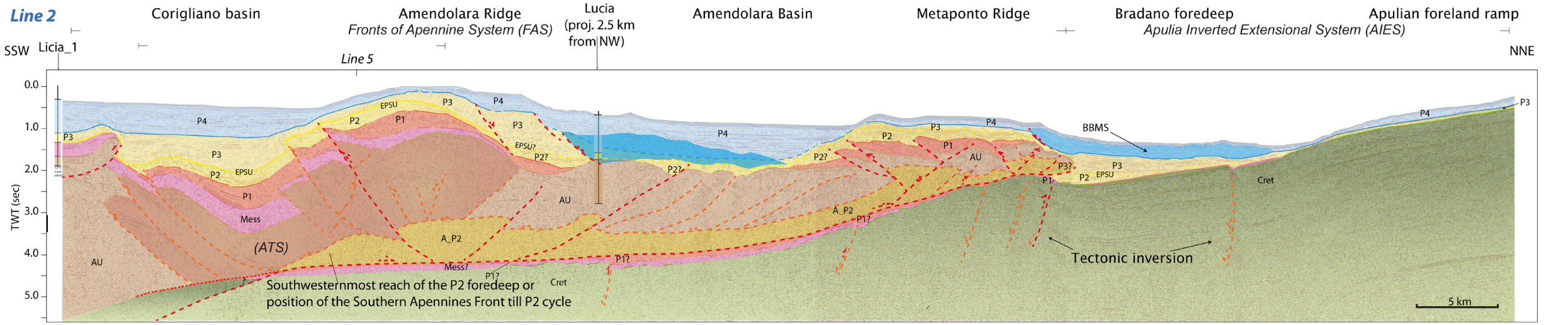
This compression in foreland ramp is **pre-early Pleistocene**.

Result IV – Interpretation of seismic reflection line 2

Modified after **Basso** et al. (2021) Marine and Petroleum Geology, 128,104999, https://doi.org/10.1016/j.marpetgeo.2021.104999



Bathymetry and topography after GeoMapApp (www.geomapapp.org) / CC BY (Ryan et al., 2009), and EMODnet Digital Bathymetry (EMODnet Bathymetry Consortium, 2018), available at https://www.seadatanet.org/



P4 Lower Pleistocene (Calabrian) -Present (late *Calabrian-Holocene*)

P3 Upper Pliocene and lower Pleistocene (Calabrian) (*early Gelasian-late Calabrian*)

P2 Middle-upper Pliocene (*Piacenzian-early Gelasian*)

P1 Lower Pliocene (*Zanclean*)

Mess Messinian

AU Allochthonous units (Cretaceous-upper Miocene)

Cret Carbonate of Apulia plate (Cretaceous)

A_P2 Accreted Pliocene units

Remobilized and deformed body with LST (Pleistocene)

BBMS (Bradano Basento MegaSlide)

MPSU (Middle Pleistocene Unconformity)

EPSU (Early Pleistocene Unconformity)

MPCU (Middle Pliocene Unconformity)

(ATS)

Amendolara Traspressive System (ATS)

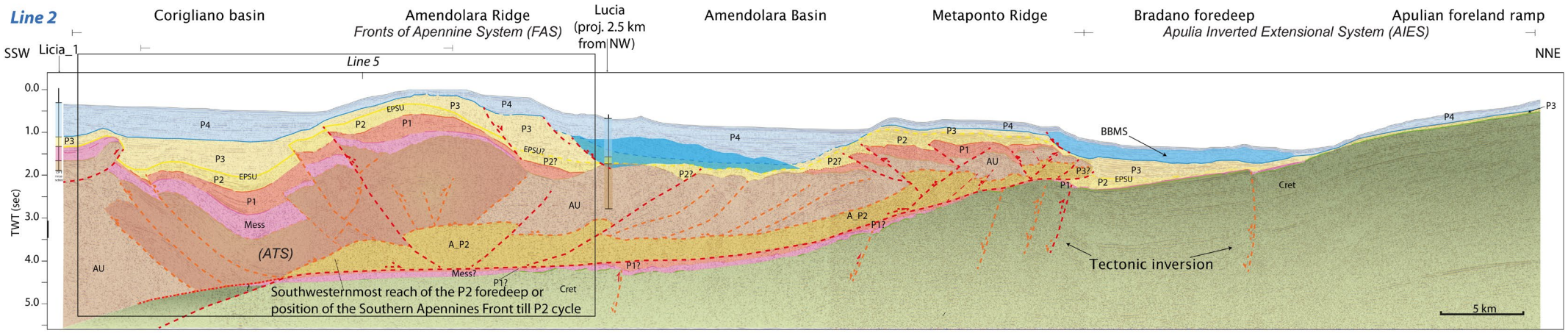
Pre-early Pleistocene faults upper detachment

Post pre-early Pleistocene-Recent faults lower detachment

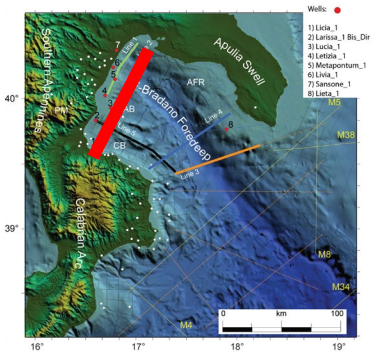
Inverted faults

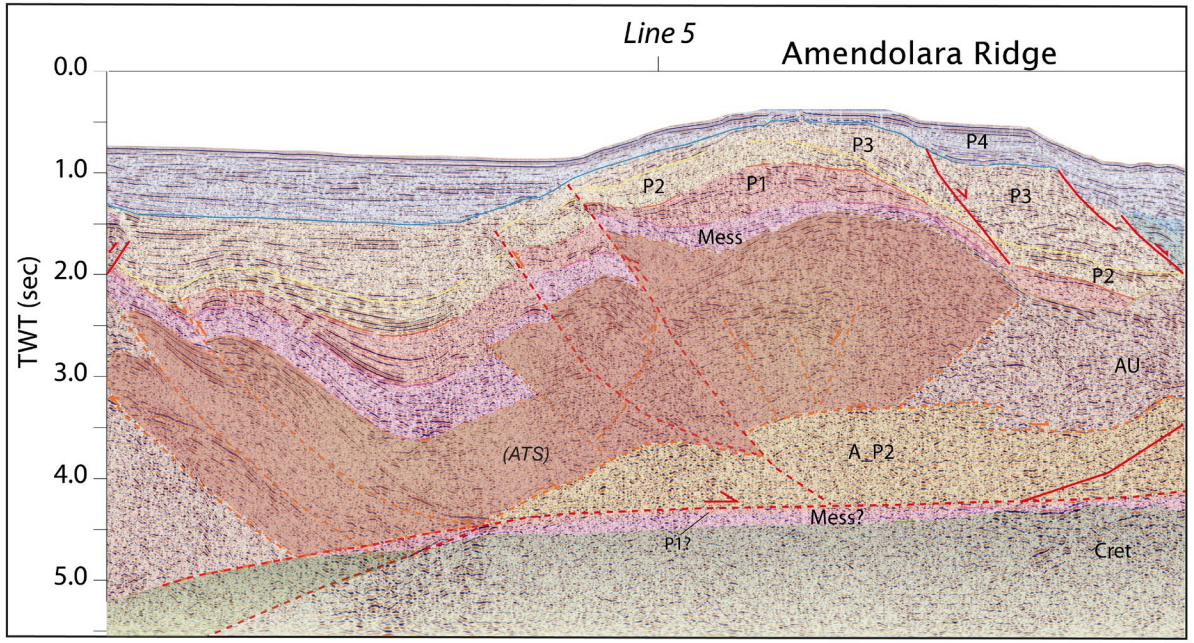
Two detachment levels shape the allochthonous units (AU): upper detachment (orange dashed) and lower detachment (red dashed). The AU contain other thrust faults and the **Amendolara Transpressive System (ATS)**.

Result IV – Interpretation of seismic reflection line 2



Bathymetry and topography after GeoMapApp (www.geomapapp.org) / CC BY (Ryan et al., 2009), and EMODnet Digital Bathymetry (EMODnet Bathymetry Consortium, 2018), available at https://www.seadatanet.org/





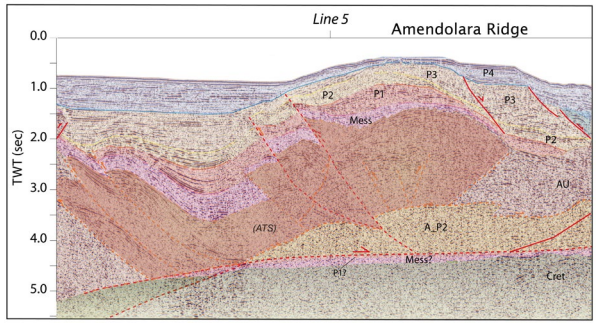
Details of the **Amendolara Ridge**

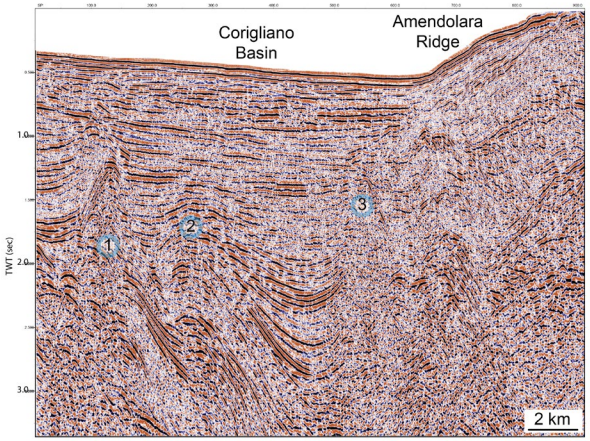
As shown by seismic attribute analysis (see next page), there are no evidences of subvertical structures underneath the Amendolara Ridge.

The Amendolara Ridge results to be formed by the out-of-sequence activity of the lower detachment (red dashed line) which deforms the allochthonous units (AU) translated above the upper detachment (orange dashed line).

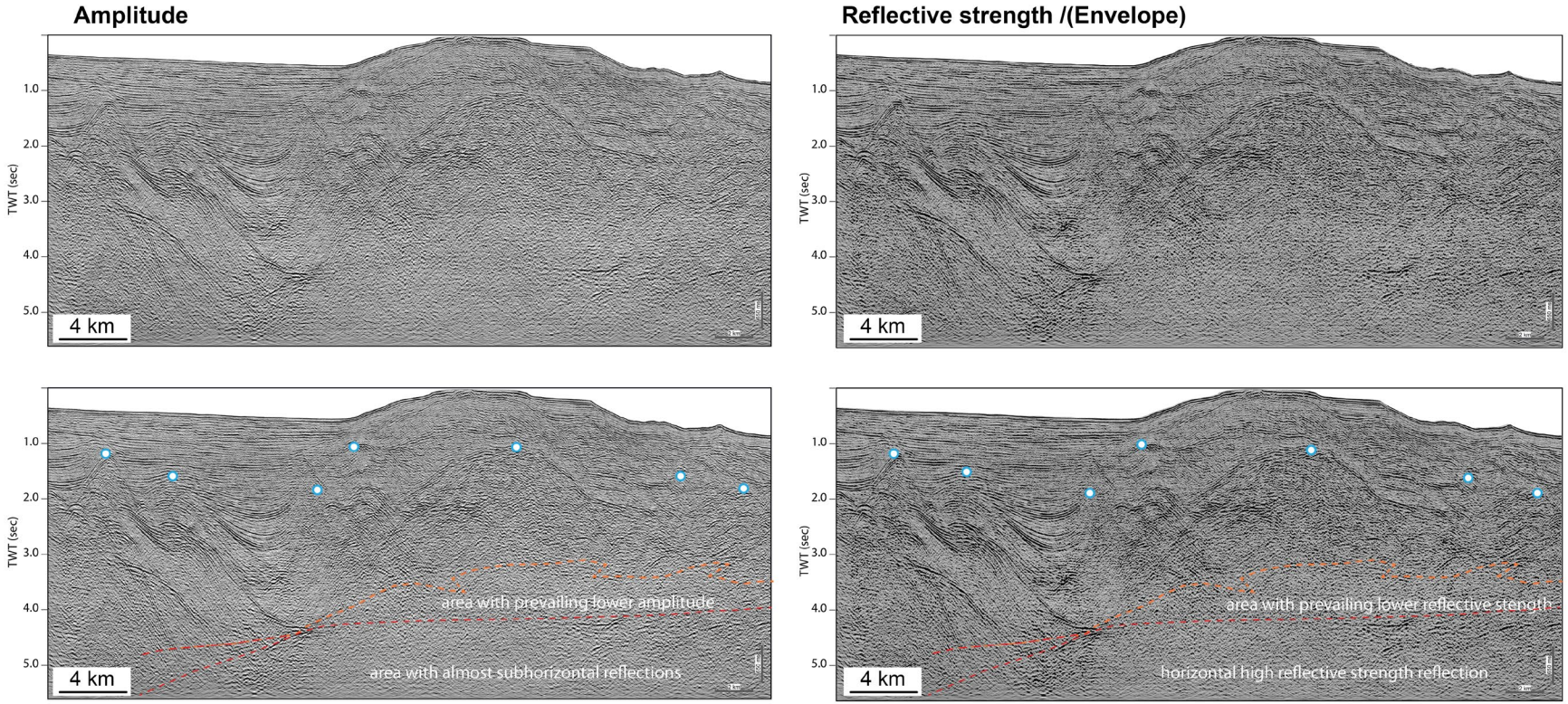
Modified after **Basso** et al. (2021) Marine and Petroleum Geology, 128,104999, https://doi.org/10.1016/j.marpetgeo.2021.104999

Result V – Deep structure of the Amendolara Ridge based on seismic attribute analysis along seismic reflection line 2





1 Sealed anticline hinge of the Messinian(?)-Pliocene ATS (Amendolara Transpressive System)



upper detachment (pre-early Pleistocene)

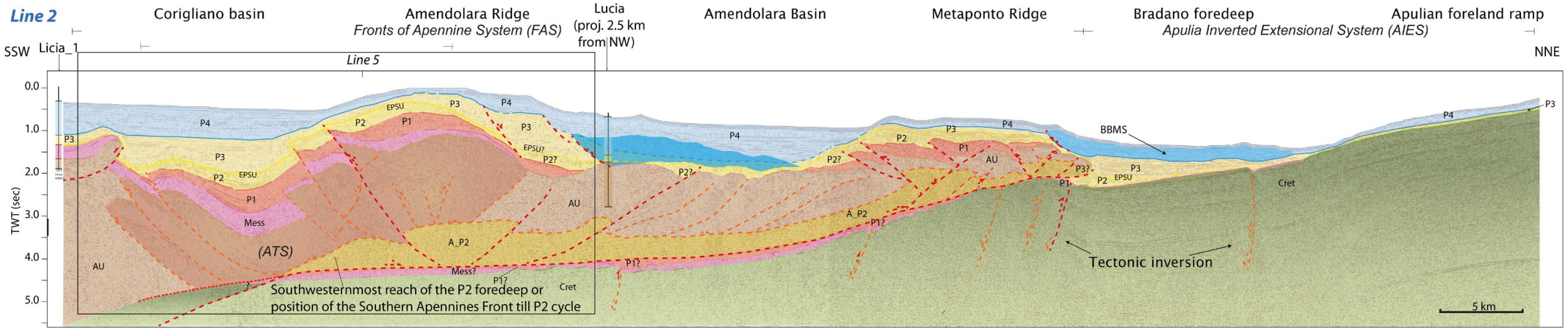
lower detachment (post-early Pleistocene)

hinge and hinge zone unrelated to seafloor fold (Amendolara Ridge)

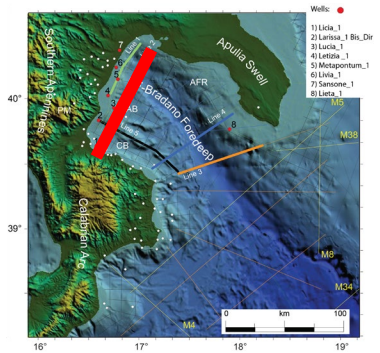
Modified after **Basso** et al. (2021) Marine and Petroleum Geology, 128, 104999, https://doi.org/10.1016/j.marpetgeo.2021.104999

The Amendolara Ridge reveals to contain pre-early Pleistocene thrust-related anticline's hinges (blue circles) sealed by P3 Cycle and cutted by the upper detachment (orange dashed line). The upper detachment is the basal detachment of the allochthonous units (AU) and it coincides to the irregular top boundary of the area characterized by lower amplitude-lower reflective strength seismic attributes. The upper detachment is deformed by thrusts detaching on the lower detachment (red dashed line) that prosecutes SW to form a ramp-flat geometry. There is no evidences of subvertical structures cutting through the flat portion of the lower detachment. The lower detachment is **post-early Pleistocene**.

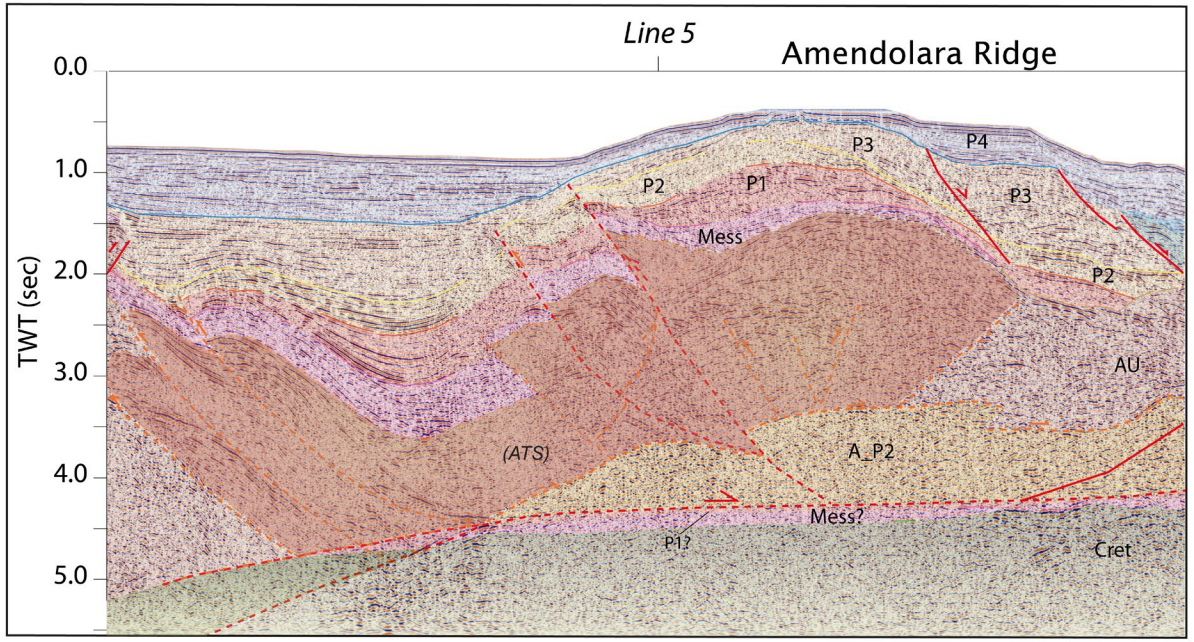
Result VI – Interpretation of seismic reflection line 2



Bathymetry and topography after GeoMapApp (www.geomapapp.org) / CC BY (Ryan et al., 2009), and EMODnet Digital Bathymetry (EMODnet Bathymetry Consortium, 2018), available at https://www.seadatanet.org/



Modified after **Basso** et al. (2021) Marine and Petroleum Geology, 128.104999. https://doi.org/10.1016/j.marpetgeo.2021.104999

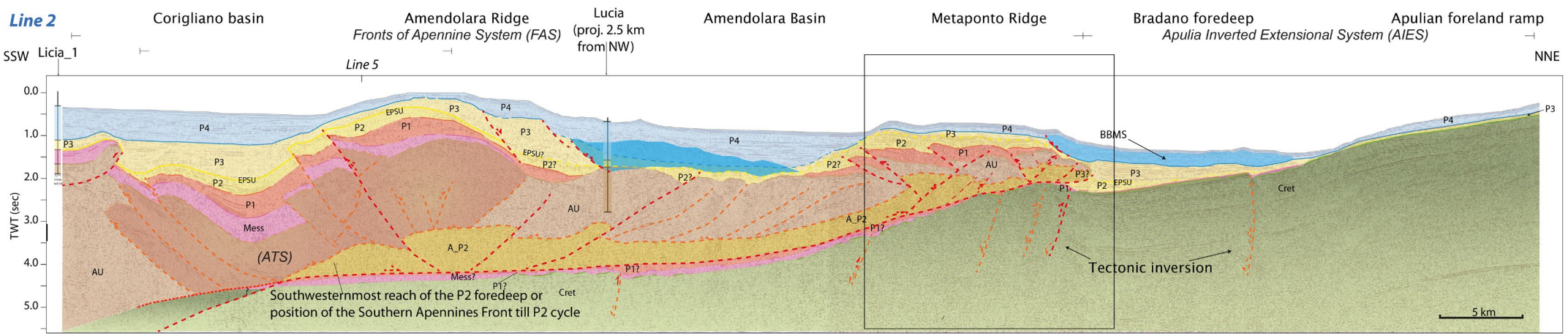


The **Amendolara Transpressive System (ATS)** is a structure ~20-30 km wide, 10 to 30 km long and it is made of arcuate thrusts forming left-lateral NW-SE restraining bends (see also page 16); the thrusts verge both toward the NE and the SW as in positive flower structure.

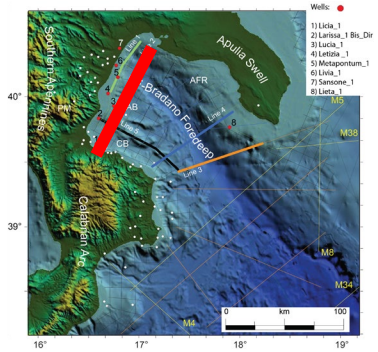
The upper detachment, the thrust faults and the **ATS** inside the AU are sealed by the P3-P4 cycles and thus they are **pre-early Pleistocene**.

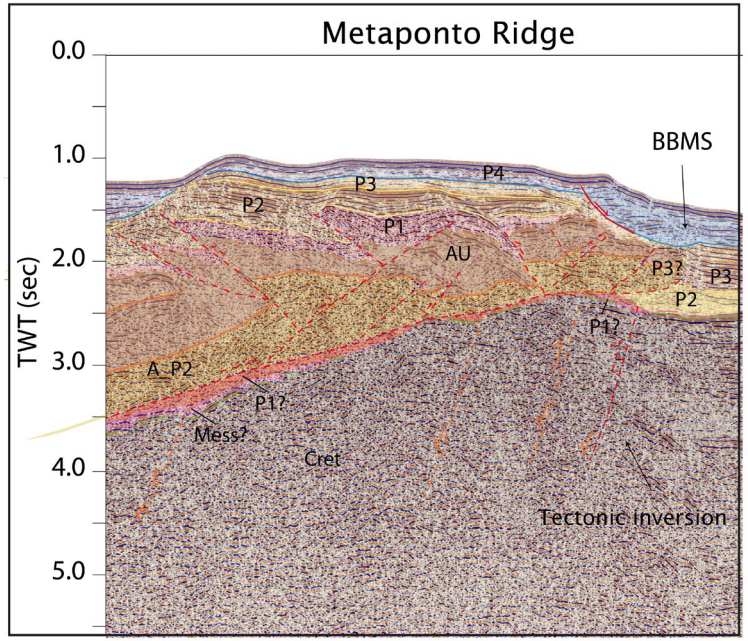
Details of the **Amendolara Transpressive System (ATS)** inside the Amendolara Ridge

Result VII – Interpretation of seismic reflection line 2



Bathymetry and topography after GeoMapApp (www.geomapapp.org) / CC BY (Ryan et al., 2009), and EMODnet Digital Bathymetry (EMODnet Bathymetry Consortium, 2018), available at https://www.seadatanet.org/





Details of the **Metaponto Ridge**

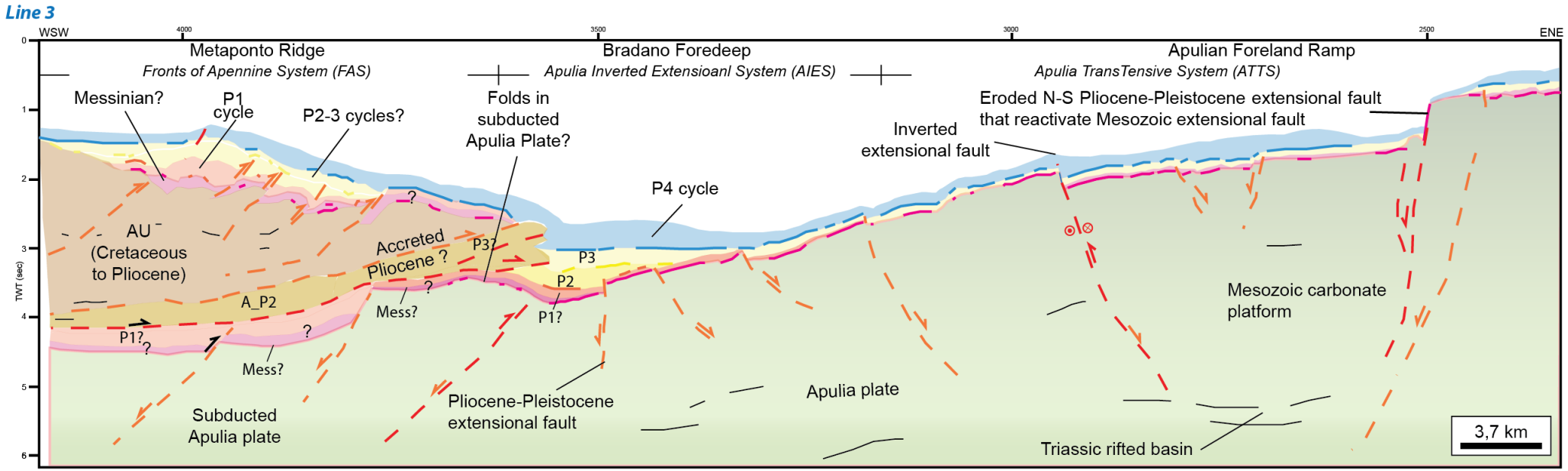
There is still evidences of inversion structures in the subducting Apulia plate or time pull-up(?).

There is also clear evidence of Recent deformation deforming the seafloor and related to lower detachment (red dashed line).

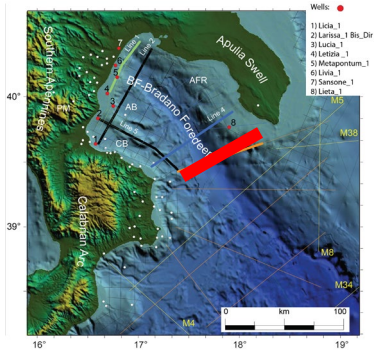
This compression **post-early Pleistocene**.

Modified after **Basso** et al. (2021) Marine and Petroleum Geology, 128,104999, https://doi.org/10.1016/j.marpetgeo.2021.104999

Result VIII – Interpretation of seismic reflection line 3



Bathymetry and topography after GeoMapApp (www.geomapapp.org) / CC BY (Ryan et al., 2009), and EMODnet Digital Bathymetry (EMODnet Bathymetry Consortium, 2018), available at https://www.seadatanet.org/



P4 Lower Pleistocene (Calabrian) -Present (late *Calabrian-Holocene*)

P2 Middle-upper Pliocene (*Piacenzian-early Gelasian*)

Mess Messinian

Cret Carbonate of Apulia plate (Cretaceous)

Pre-early Pleistocene faults upper detachment

Post early-Pleistocene-Recent faults lower detachment

Inverted faults

P3 Upper Pliocene and lower Pleistocene (Calabrian) (*early Gelasian-late Calabrian*)

P1 Lower Pliocene (*Zanclean*)

AU Allochthonous units (Cretaceous-upper Miocene)

A_P2 Accreted Pliocene units

MPSU (Middle Pleistocene Unconformity)

EPSU (Early Pleistocene Unconformity)

MPCU (Middle Pliocene Unconformity)

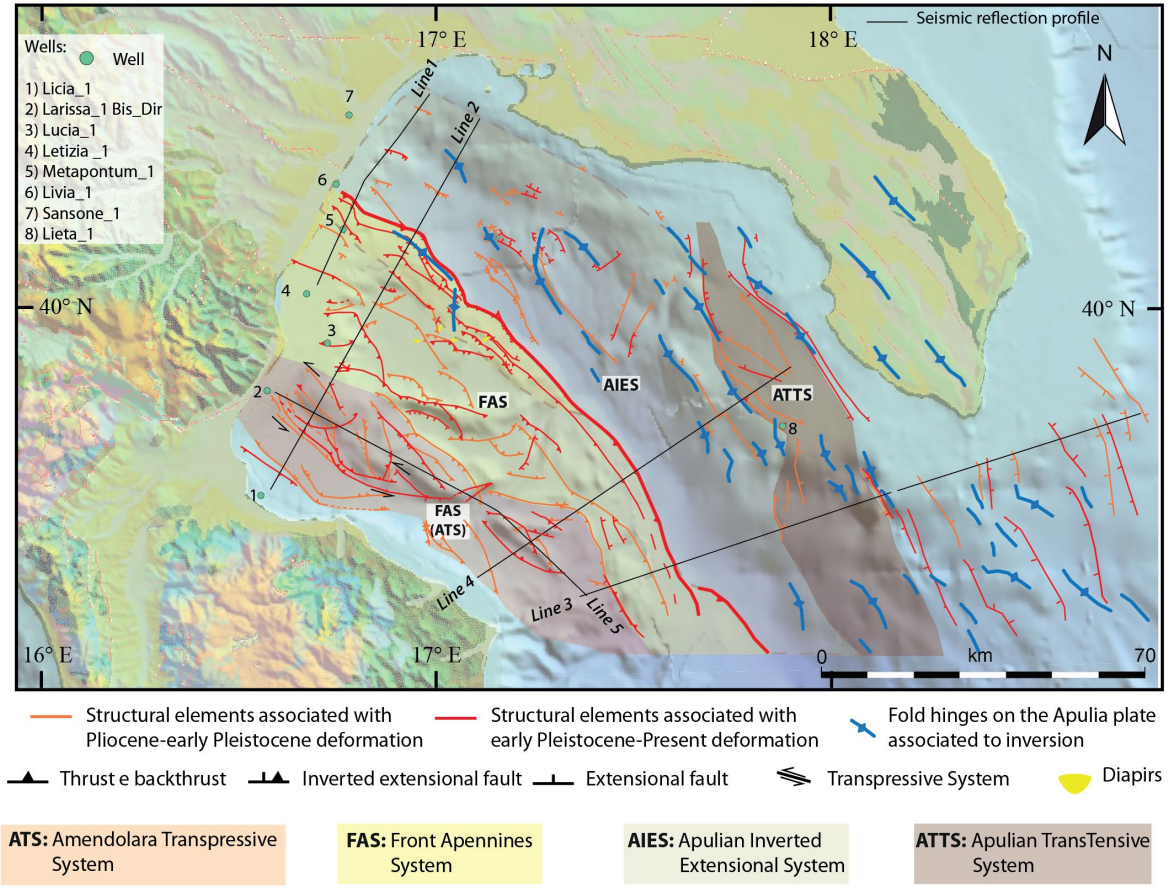
Modified after **Basso** et al. (2021) Marine and Petroleum Geology, 128, 104999, https://doi.org/10.1016/j.marpetgeo.2021.104999

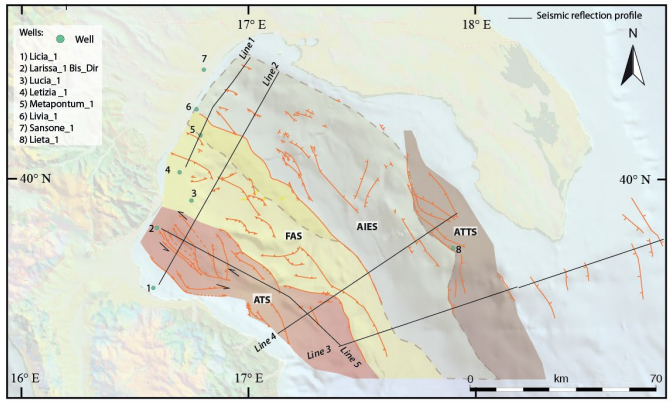
- Possible advancement of the allochthonous units (AU) accreting P3 cycle at the leading egde of the orogenic wedge.
- Preserved pre-P3 cycle exensional fault in the subducting Apulia plate.
- Inverted extensional faults and reactivated Mesozoic extensional faults deforming the seafloor of the subducting Apulia plate; they are Recent deforming features (post- P4 cycle).

See also **Chizzini, N.,** Artoni, A., Torelli, L., Polonia, A., Basso, J., and Gasperini, L.: The interaction between the Apula plate and the Calabrian Accretionary Wedge in the Northern Ionian Sea: tectonic-stratigraphic evolution and implications for subduction processes., EGU General Assembly 2021, online, 19–30 Apr 2021, EGU21-8874, https://doi.org/10.5194/egusphere-egu21-8874 , 2021.

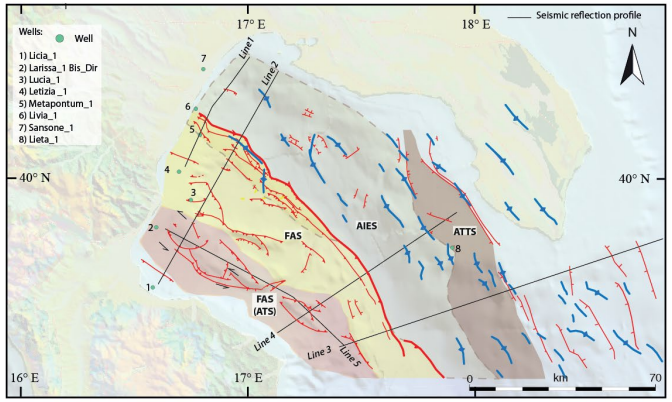
Result IX – Structural maps pre- and post-early Pleistocene

Modified after **Basso** et al. (2021) Marine and Petroleum Geology, 128, 104999, https://doi.org/10.1016/j.marpetgeo.2021.104999





Pliocene-early Pleistocene (Zanclean-early Gelasian)



early Pleistocene-Present (early Gelasian-Holocene)

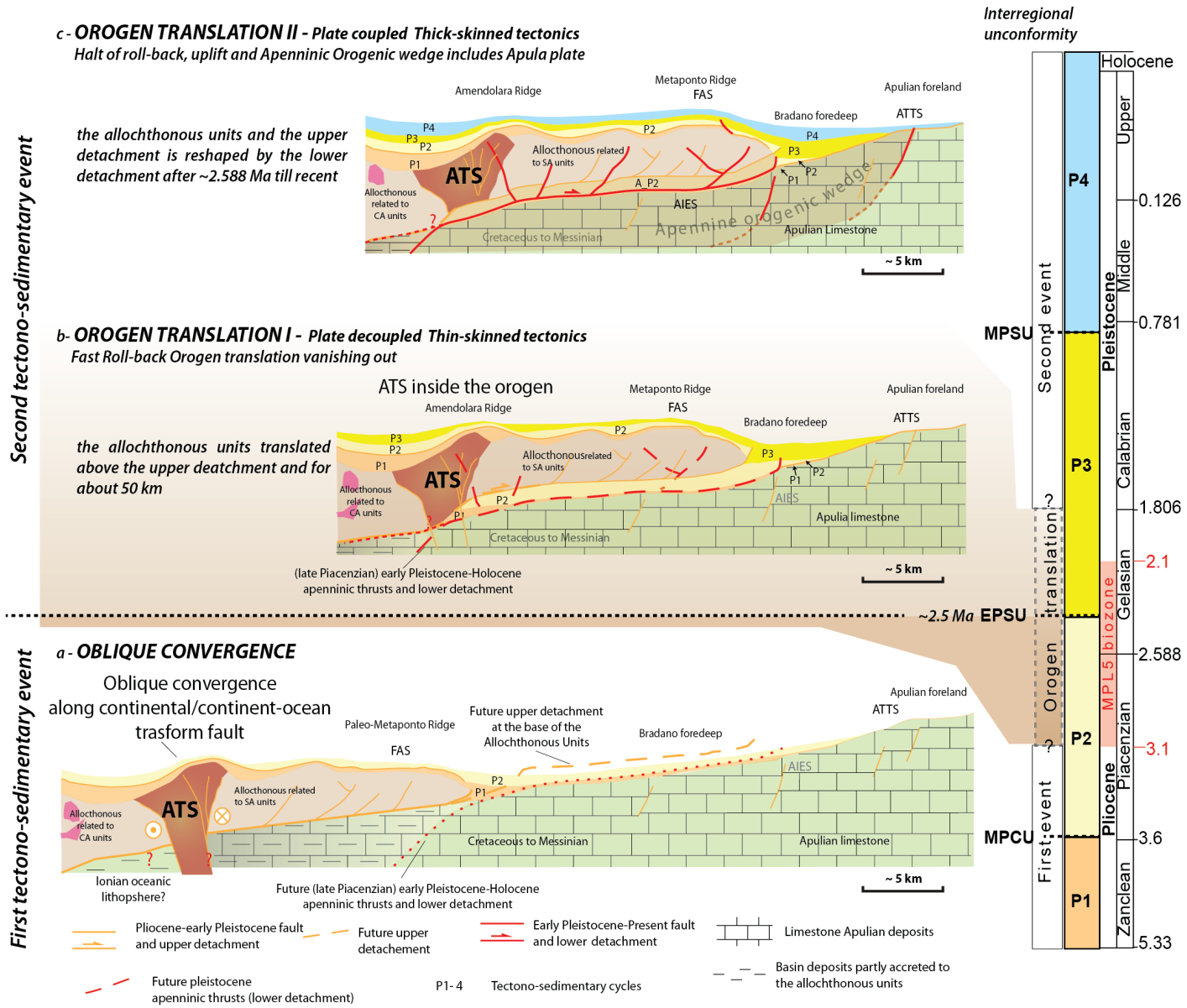
Bathymetry and topography after GeoMapApp (www.geomapapp.org) / CC BY (Ryan et al., 2009), and EMODnet Digital Bathymetry (EMODnet Bathymetry Consortium, 2018), available at https://www.seadatanet.org/ Geology after ISPRA (http://www.isprambiente.gov.it/it/banche-dati/suolo-e-territorio) e Geoportale Nazionale (www.pcn.minambiente.it/)

The structures affecting and controlling the Pliocene-Pleistocene BB are grouped in four polyphased systems (ATS, FAS, AIES, ATTS) according to their ages of activity which are essentially pre-early Pleistocene and post-early Pleistocene.

In **pre-early Pleistocene** (*Pliocene-early Pleistocene*) the ATS was partitioning the strain with the earlier Appenninic fronts FAS (earlier, sealed thrust within the allochthonous units) and earlier inversion (AEIS) as well as transtension (ATTS) was affecting the subducting Apulia plate.

In **post-early Pleistocene** (*early Pleistocene-present*) Apenninic Front FAS and inverted/reactivated AIES and ATTS are part of the Apenninic orogenic wedge .

Conclusions I – Post-Messinian tectono-stratigraphic evolution of the Bradano Basin



After Messinian times, two main tectono-sedimentary events deeply modified the Bradano Basin.

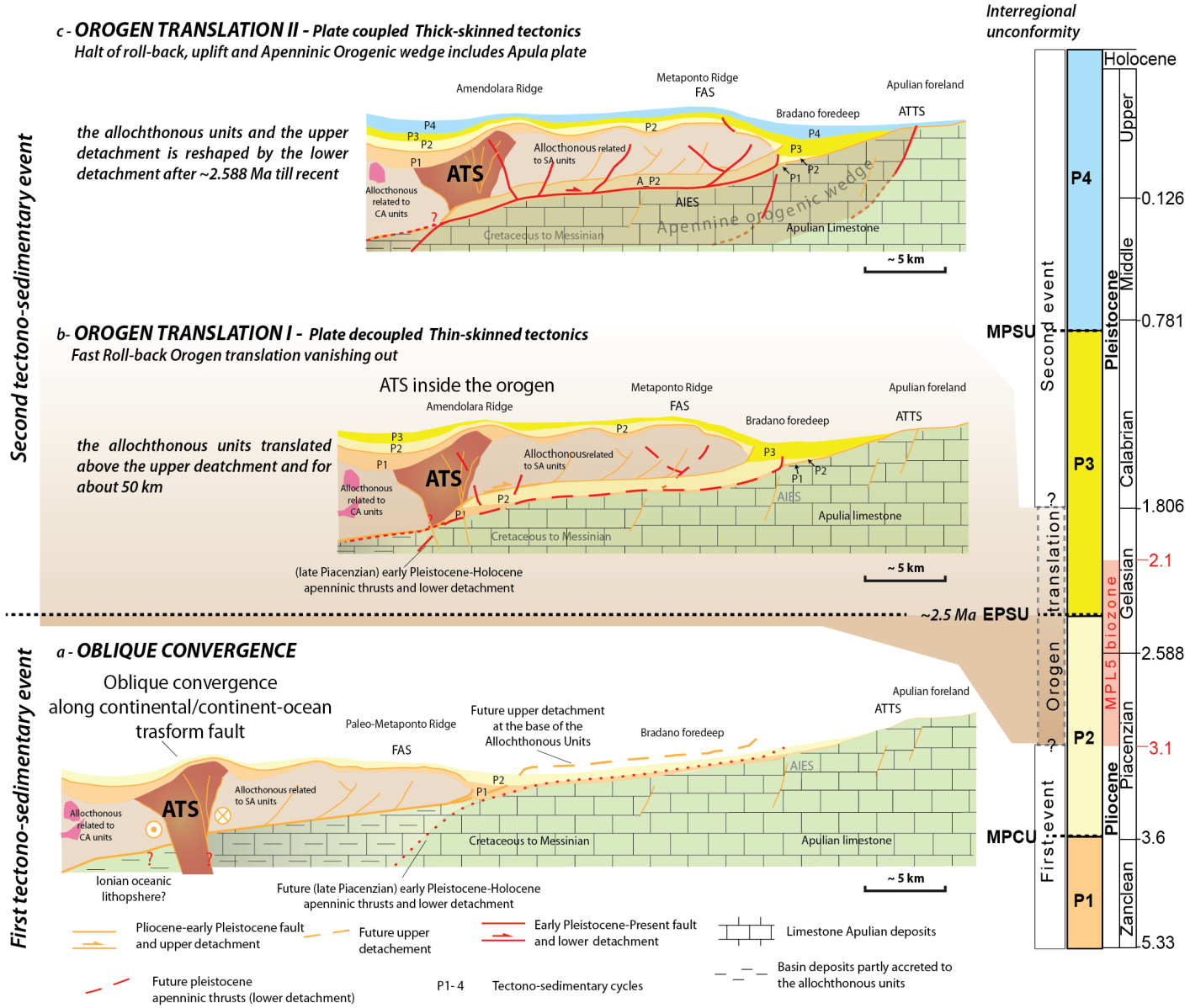
During the ***first tectono-sedimentary event*** (early Pliocene-early Pleistocene), a left-lateral transpressive system (ATS) was part of an oblique convergent margin along which the Southern Apennines and the Calabrian Arc collided; remnants of this transpressive system are now buried under the western portion of the Bradano Basin near the Calabrian margin.
Shelf to deep marine turbiditic deposits were prevailing during this first event.

Around the Pliocene-Pleistocene boundary (~2.58 Ma), a sudden and widespread basin rearrangement occurred.

During the ***second tectono-stratigraphic event*** (early Pleistocene-Present) the orogenic front of the Southern Apennines (FAS) and the earlier transcurrent systems (ATS) were suddenly translated to the NE of about 50 km and the left-lateral transpressive boundary between the Southern Apennines and Calabrian Arc became part of the orogenic wedge. Both upper and lower converging plates were shortened together along multiple detachments levels and out-of-sequence thrusts (lower detachment deformed the upper detachment).
During this second event, prograding deltaic and shelfal deposits seal the earlier transpressive system (ATS) and Apenninic thrust (FAS) and pass to deep marine deposits in the Bradano Foredeep.

Modified after **Basso** et al. (2021) Marine and Petroleum Geology, 128, 104999, https://doi.org/10.1016/j.marpetgeo.2021.104999

Conclusions II – The Amendolara Ridge and the Sangineto Lineament



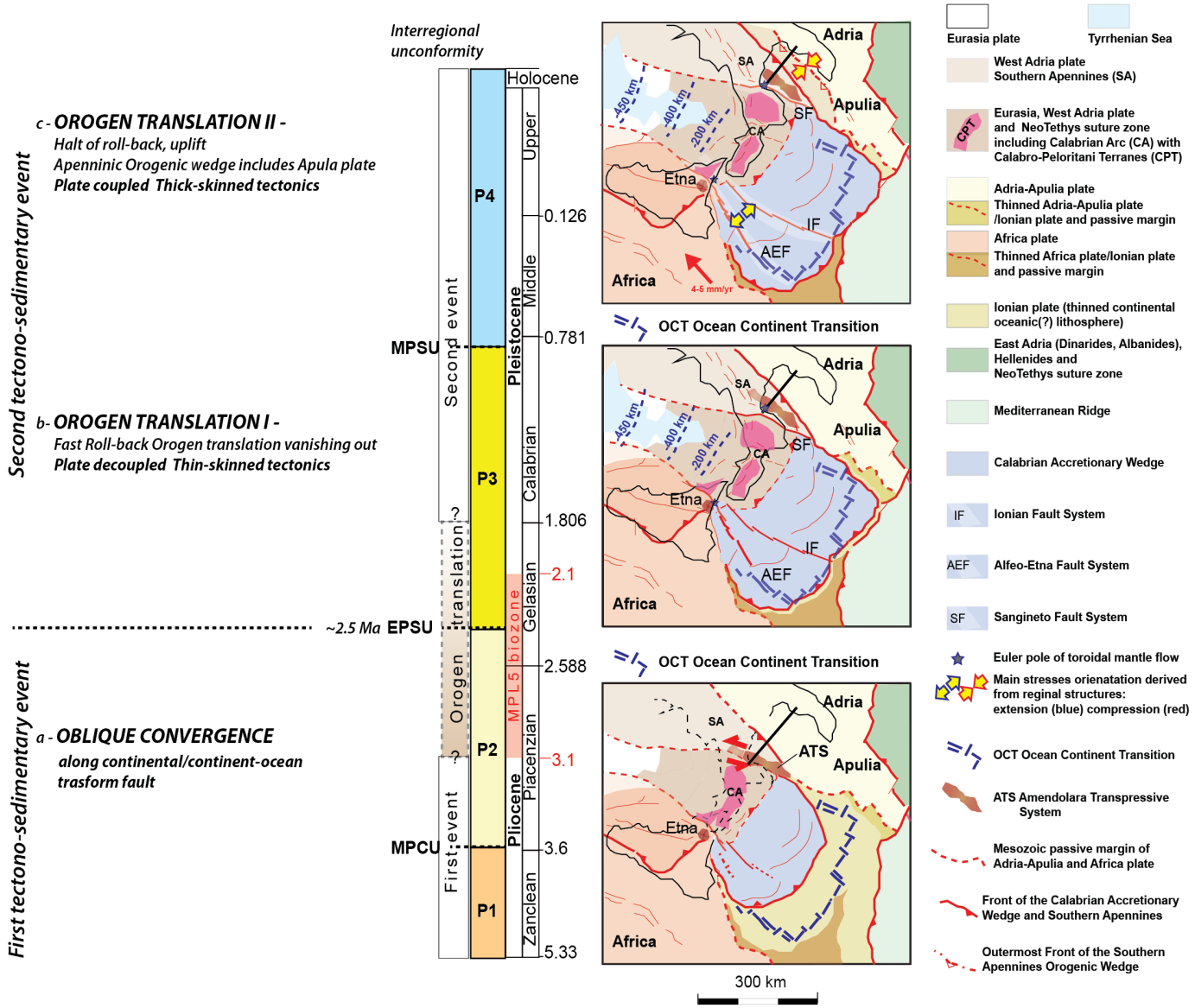
The Amendolara Ridge is a thin-skinned structure; it is an anticline detached along the Messinian-early Pliocene foredeep on top of the subducting Apulia plate.
It is a post-early Pleistocene anticline and it affects the seafloor and post Last Glacial Maximum (Ferranti et al. 2014).

The eastern boundary between Southern Apennines and Calabrian Arc is a wide deformation belt including the Sangineto Lineament which is now deforming the Calabrian Arc onshore.

The Messinian-Pliocene transpressive system (ATS) can be considered a paleo-Sangineto Lineament (or boundary between Southern Apennines and Calabrian Arc) now buried and translating inside the Apenninic thrusts toward the NE since Early Pleistocene.

Modified after **Basso** et al. (2021) Marine and Petroleum Geology, 128, 104999, https://doi.org/10.1016/j.marpetgeo.2021.104999

Conclusions III – Geodynamic implications



The ***first tectono-sedimentary event*** (early Pliocene-early Pleistocene) is controlled by oblique continental/continent-ocean transform fault and thus continental collision was already active.

The ***second tectono-stratigraphic event*** (early Pleistocene-Present) is controlled by:

- At first, fast roll-back and orogen translation;
  - upper plate (Southern Apennines, Calabrian Arc and Calabrian Accretionary Wedge) and lower plate (Apulia) were decoupled;
  - thin-skinned tectonics prevail;
- Later, roll-back halts/slows down;
  - upper plate (Southern Apennines, Calabrian Arc and Calabrian Accretionary Wedge) and lower plate (Apulia) were coupled;
  - thick-skinned tectonics prevail;

The two tectono-sedimentary events are persistently controlled by inherited structures that are envisaged to be Ocean Continent Transition (OCT) zone of the Mesozoic eastern passive margin of the Ligure-Piemontese ocean.

The Mesozoic Ligure-Piemotese ocean was already completely subducted/accreted in Pliocene time; a narrow stretch of this ocean might be preserved in the lower plate underneath the Calabrian Arc and in the subducting slab underneath the thinned Tyrrhenian Sea.

Modified after **Basso** et al. (2021) Marine and Petroleum Geology, 128, 104999, https://doi.org/10.1016/j.marpetgeo.2021.104999

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THANKS A LOT FOR READING AND FEED-BACKS ARE WELCOME!!

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Corigliano basin, the Sibari plain and Pollino Massif from the Ionian Sea

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