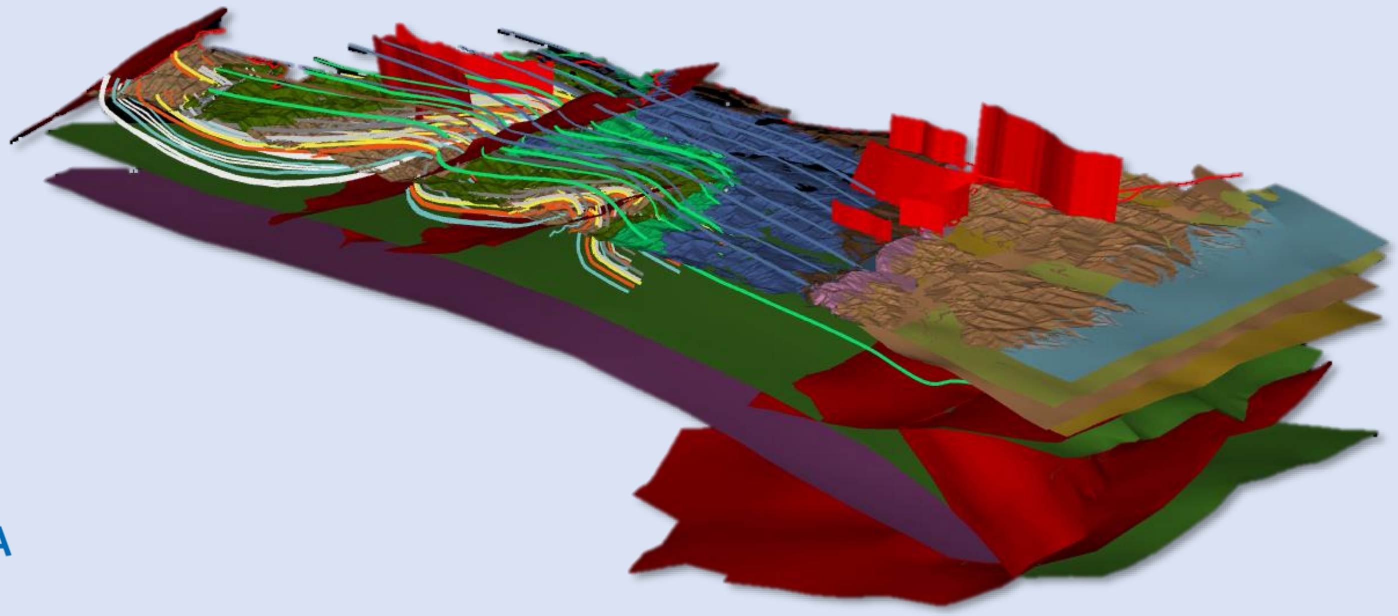
Structural analysis and 3D geological modelling of the Santerno transect in the Norhern Apennines (Italy)



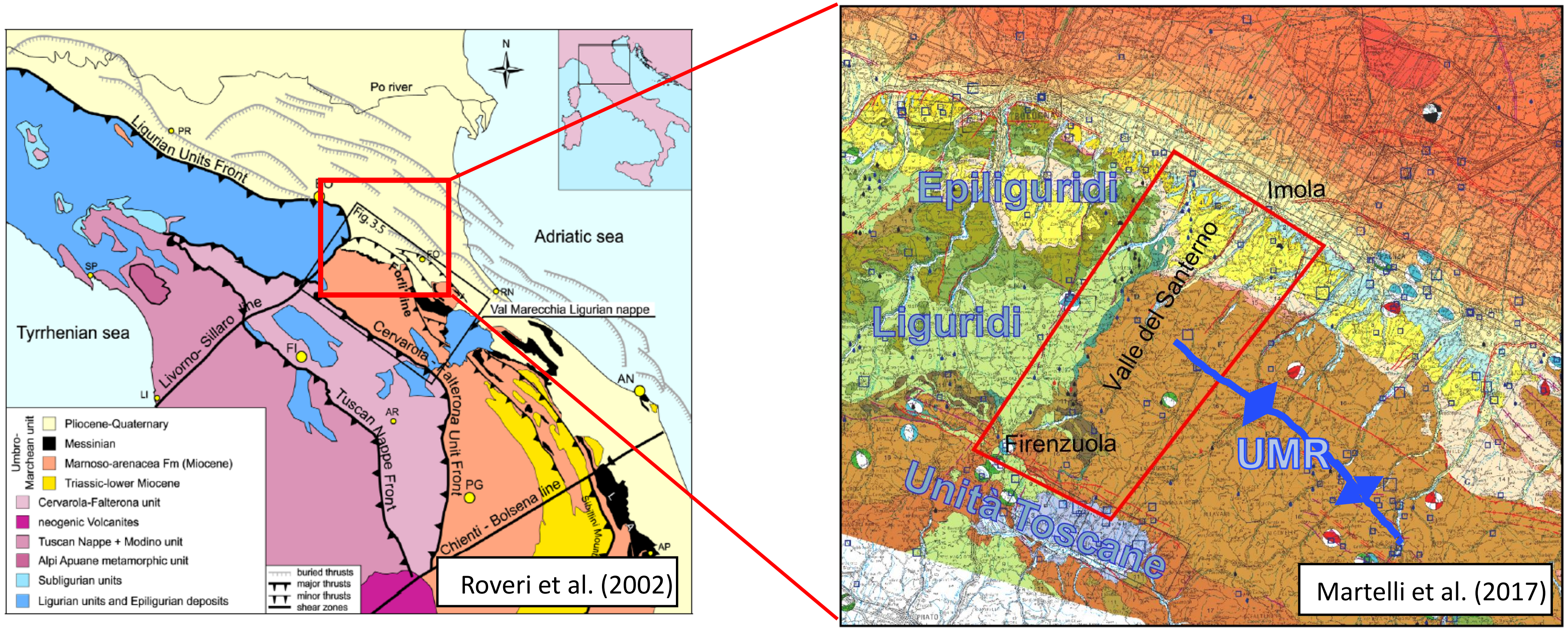
Lorenzo Griso[(1)], Andrea Bistacchi[(1)], Fabrizio Storti[(2)]

(1) *Università degli Studi di Milano-Bicocca, Dipartimento di Scienze dell'Ambiente e della Terra, Milano, Italy*
(2) *Università di Parma, Dipartimento di Scienze Chimiche, della Vita e della Sostenibilità Ambientale, Parma, Italy*

Motivation

The goal of the project is to combine surface geological and structural data with subsurface data to obtain a comprehensive 3D geological and tectonic model in this key area of the Northern Apennines.

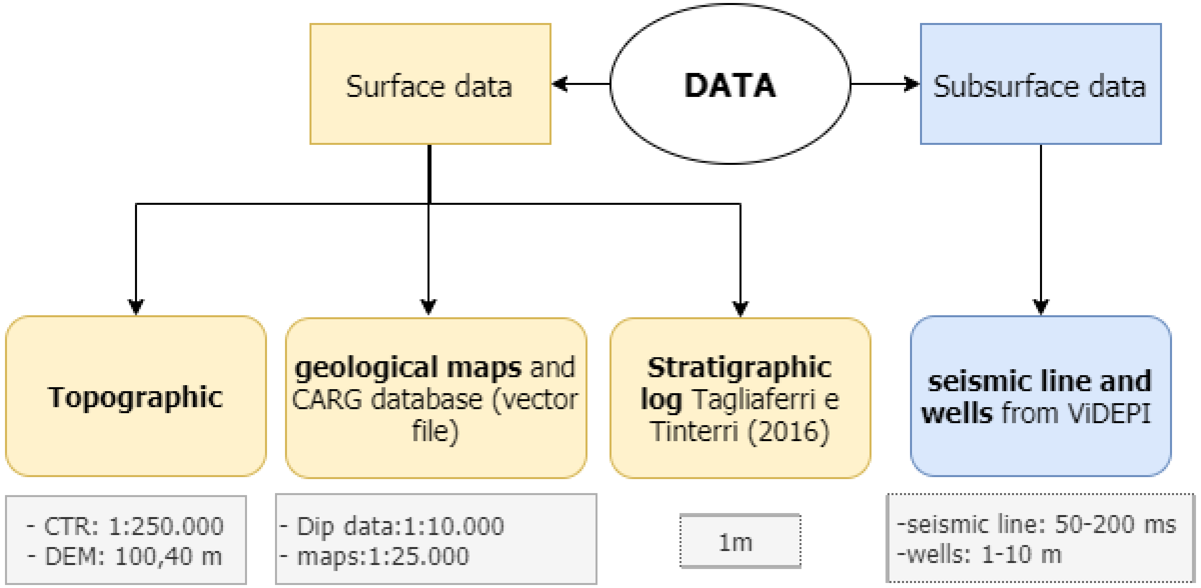
Surface data + Subsurface data = Geological section / 3D structural model

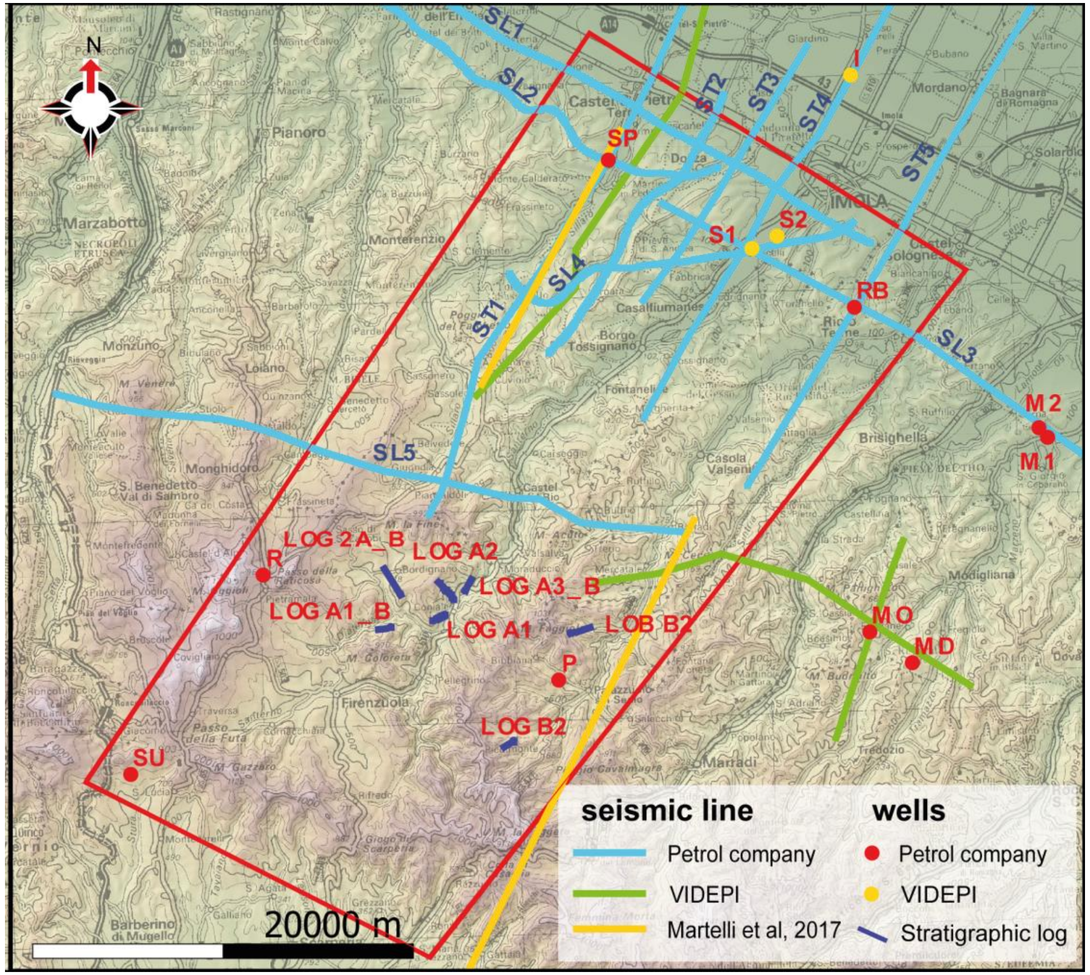


Our transect is in the NE-vergent part of Northern Apennines, in correspondence of the periclinal hinge of a regional anticline. The Marmoso-Arenacea Formation (MAF) crops out and it is overlaid by Ligurian and Epiligurian allochthonous units, to the NE, and Tuscan units, to the SW.

Data

The main source of surface geological data is represented by the **CARG national geological mapping project**, that provides a rich database with structural features, dip data, stratigraphic boundaries and key beds. We have integrated the stratigraphic dataset with **stratigraphic logs** collected from Tagliaferri and Tinterri (2016).
The subsurface data are constituted by ten **2D seismic lines**, interpreted in a dataroom session at a oil company, and **well data** and seismic lines from the ViDEPI project.



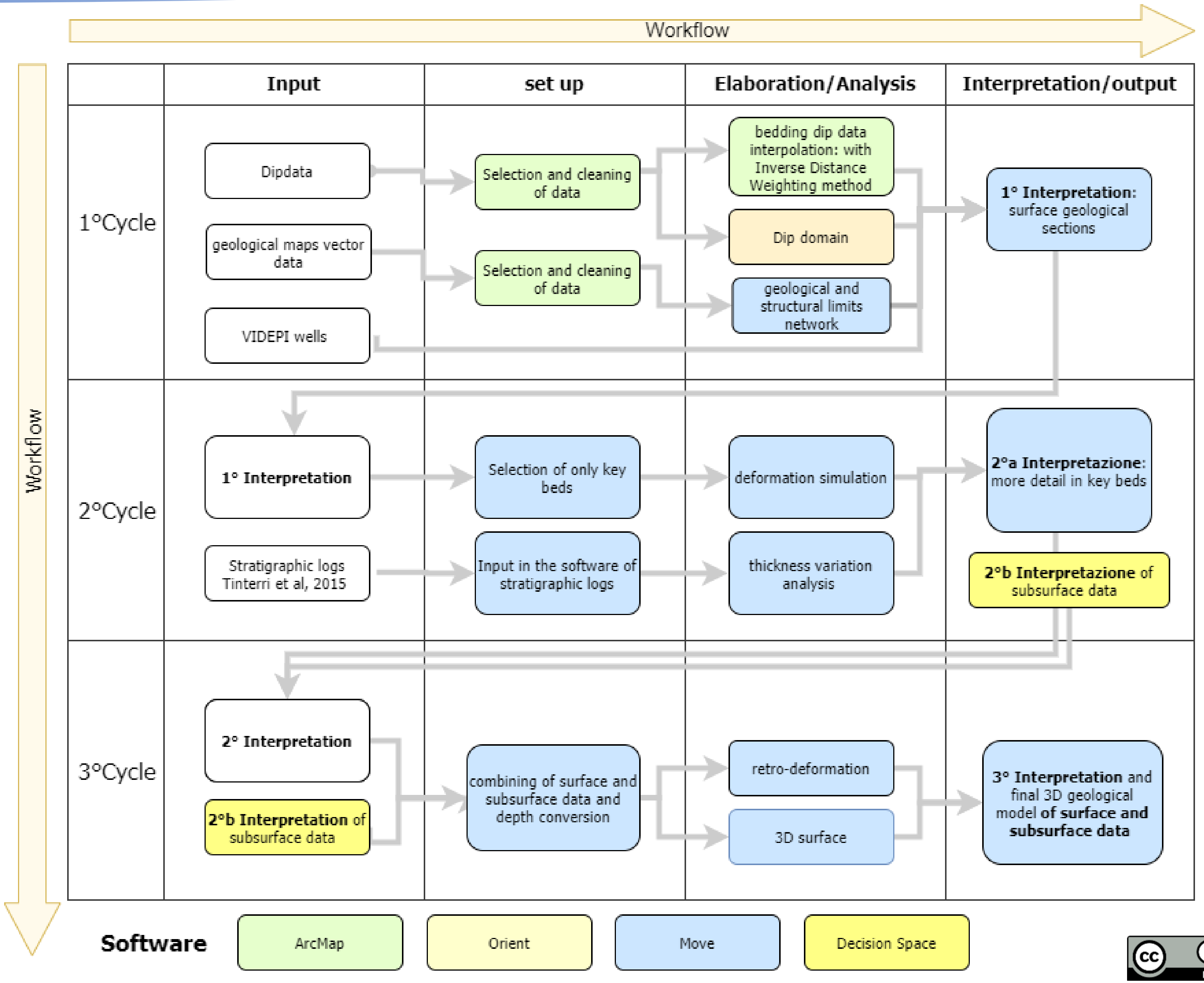


Method

The 3D geological model was reconstructed in three steps:

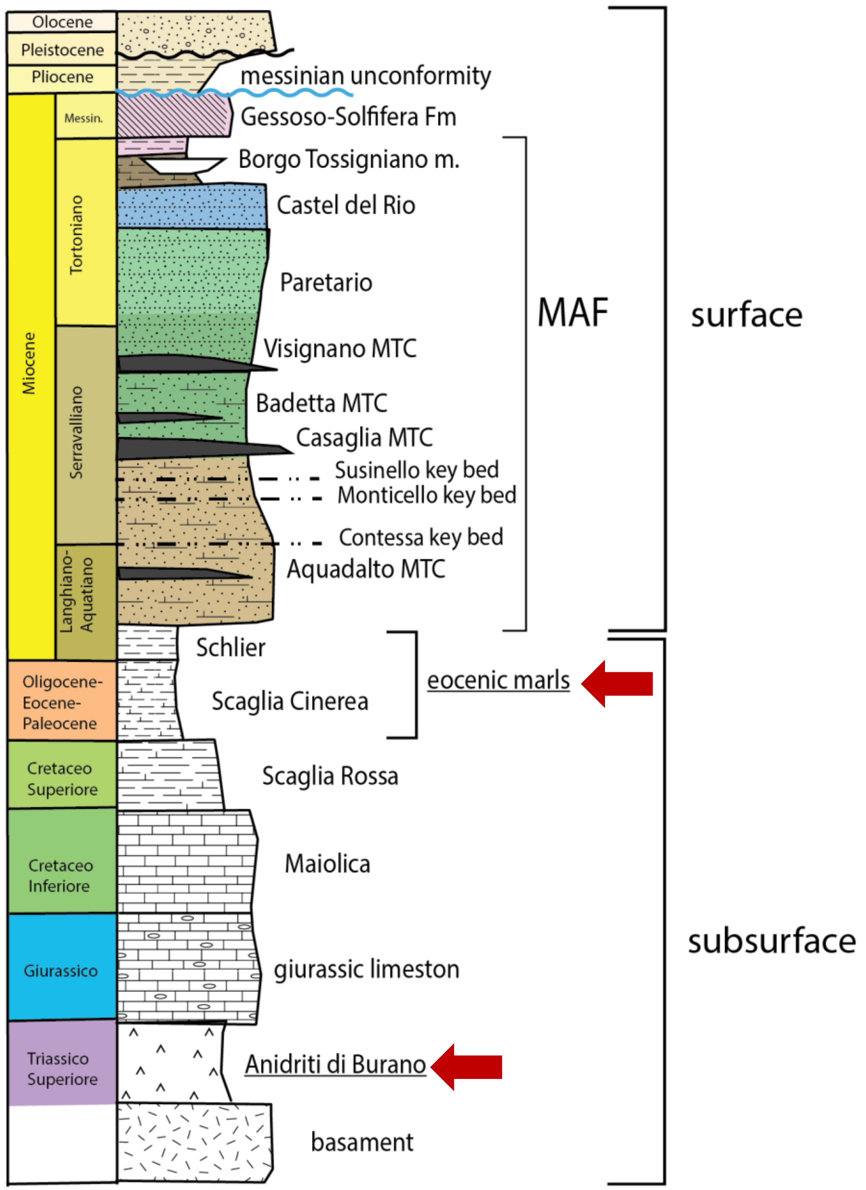
1. **data collection and quality check**;
2. **analysis and first interpretation;**
3. **detailed interpretation**.

The sequence of these three steps is replicated iteratively when new data and new observations are available, to modify or enrich the previous interpretation, eventually obtaining a more accurate final geological model.



Stratigraphy

Umbro- Marchigiano – Romagnola Succession



The stratigraphic succession is constituted by carbonates (subsurface only) from Upper Triassic to Oligocene, overlaid by siliciclastic deposits (surface) from lower Miocene to Pleistocene.

The ourcropping succession consist of three formations: the turbiditic complex of the **Marnoso Arenacea Formation (MAF),** the gypsum and clastics of the **Gessoso-Solfifera Formation** and the Pliocene and Pleistocene fine-grained clastics.

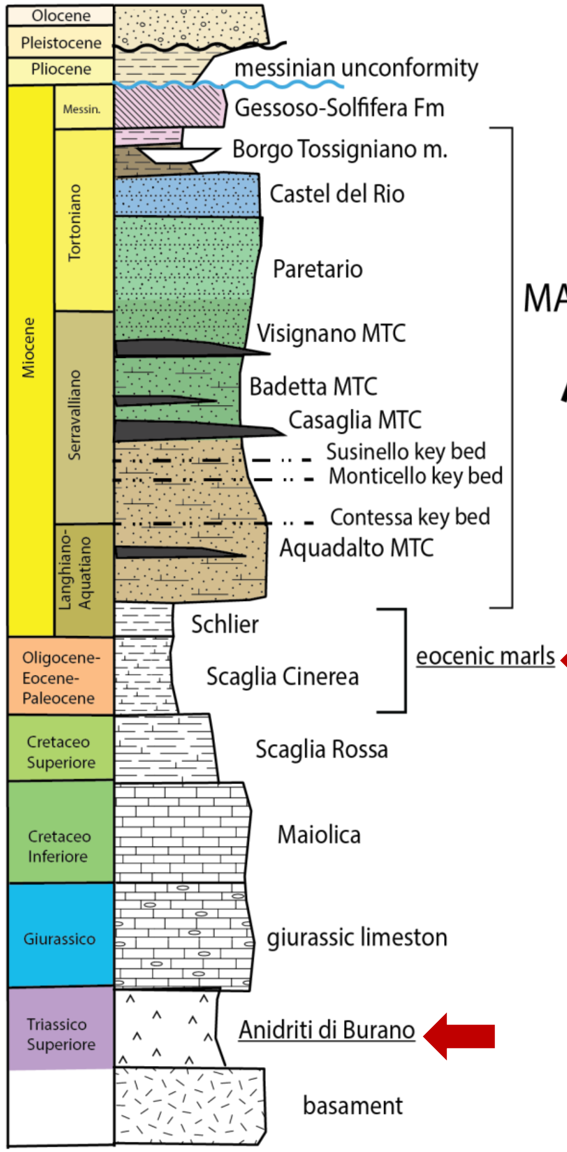
The Marmoso-Arenacea Formation is constituted by 2000 meters of siliciclastic turbidites and, to divide units among them, **key beds** and **mass transport depots (MTC)** has been used.

The subsurface succession (Fig. 2) mainly consists of **Triassic anhydrites** (Anidriti di Burano), **Lower Liassic platform carbonates**, basinal cherty limestones with intercalated pelagic marls of the middle Liassic-middle Eocene (from **Corniola to Scaglia Rossa**), and marly lithologies of the Oligocene-Miocene (**Scaglia Cinerea-Bisciaro-Schlier**).

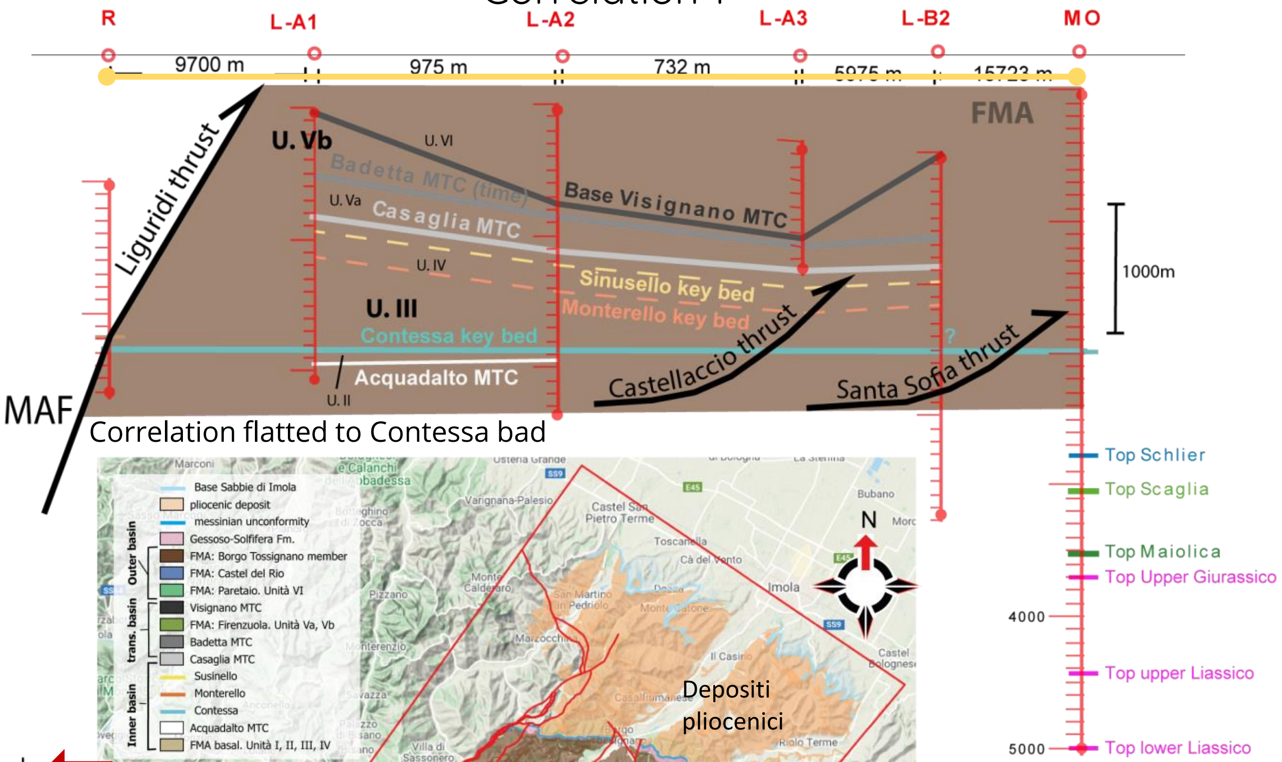
Two possible detachment surfaces are highligted: the **Triassic anhydrites** and the **eocenic marls**

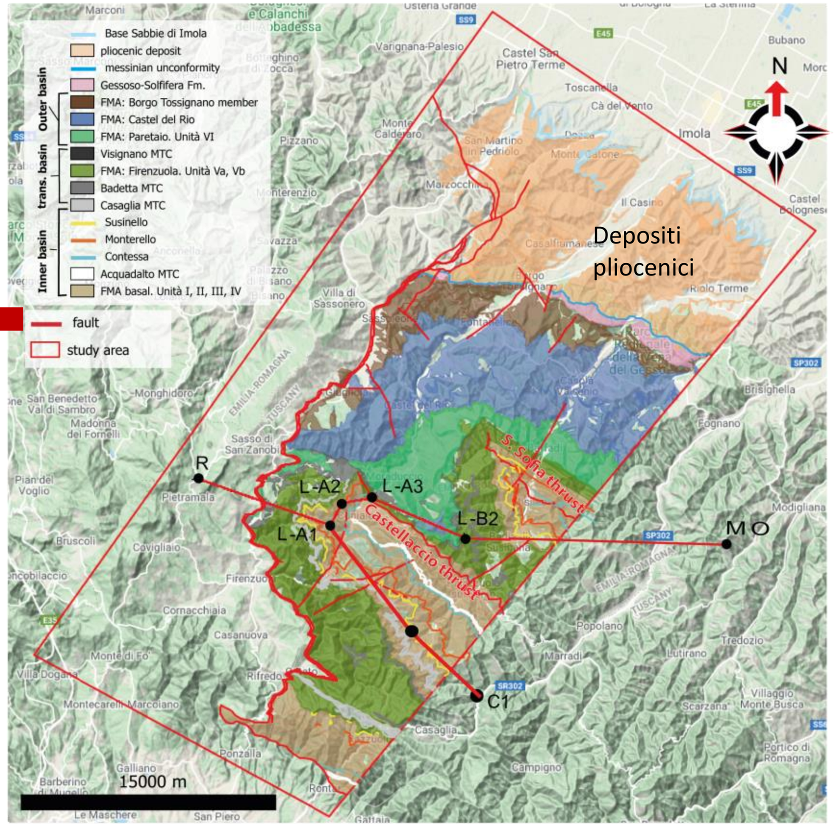
Stratigraphy – Marnoso-Arenacea Fm.

Umbro- Marchigiano – Romagnola Succession

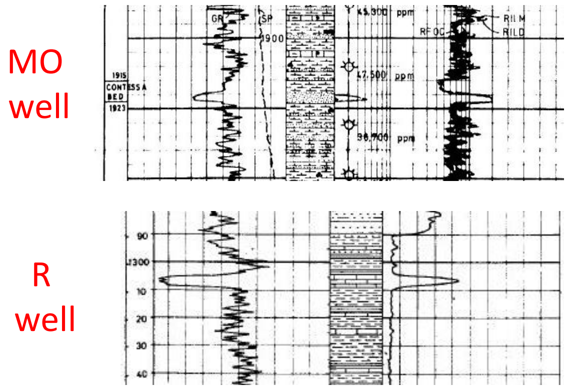


Correlation 1





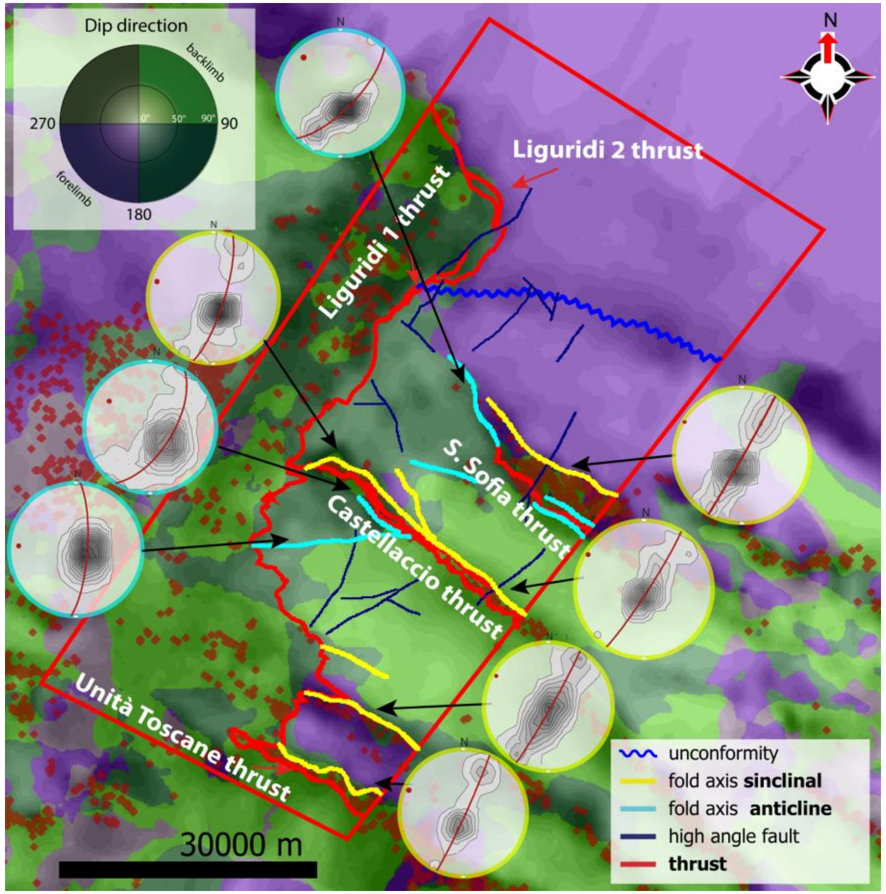
Contessa key bed



The key beds are recognized by the mainly carbonatic composition and a toward NE flow direction. The Contessa keybad is the main one and it is shown in most of the stratigraphic log and wells. On the well data the Contessa bad is marked by resistivity peak.

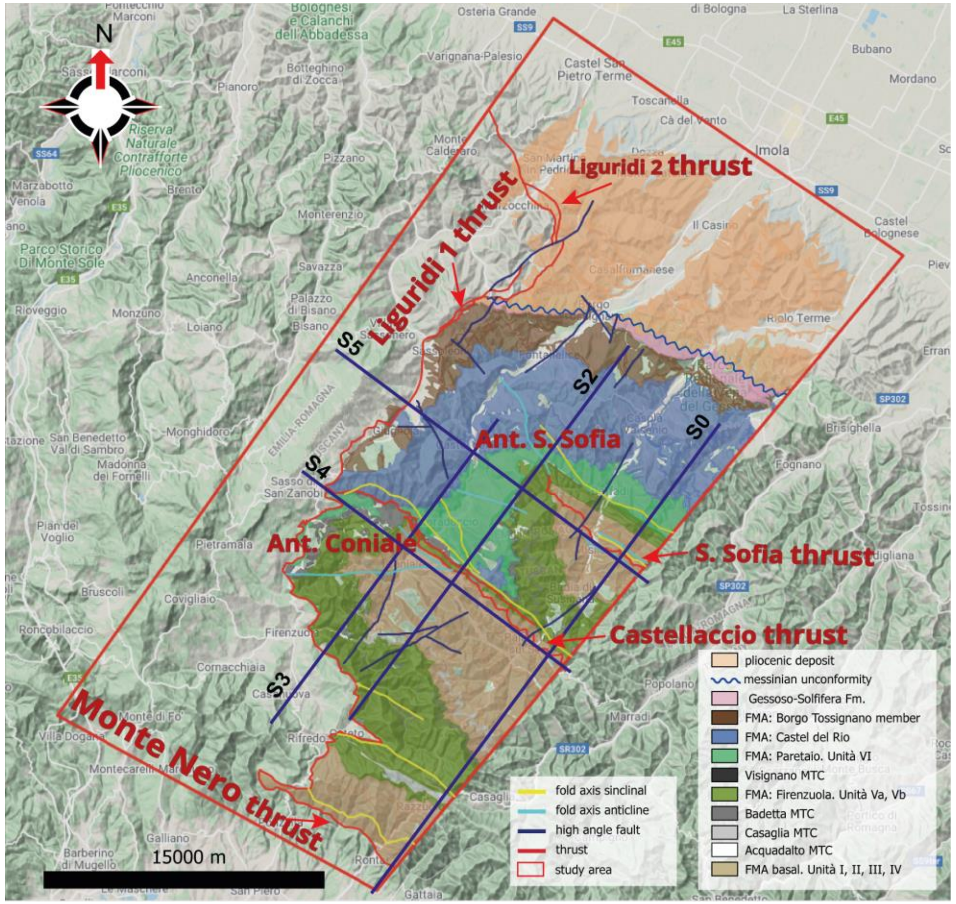
Analysing the thickness between key beds and the mass transport deposits in MAF, we observed an **important thickness variation** in the SW-NE direction, perpendicular to the main thrusts strike. The thickness **increase towards SW** and decrease towards NE, close to the Castellaccio and S. Sofia thrusts.

Surface structural analysis



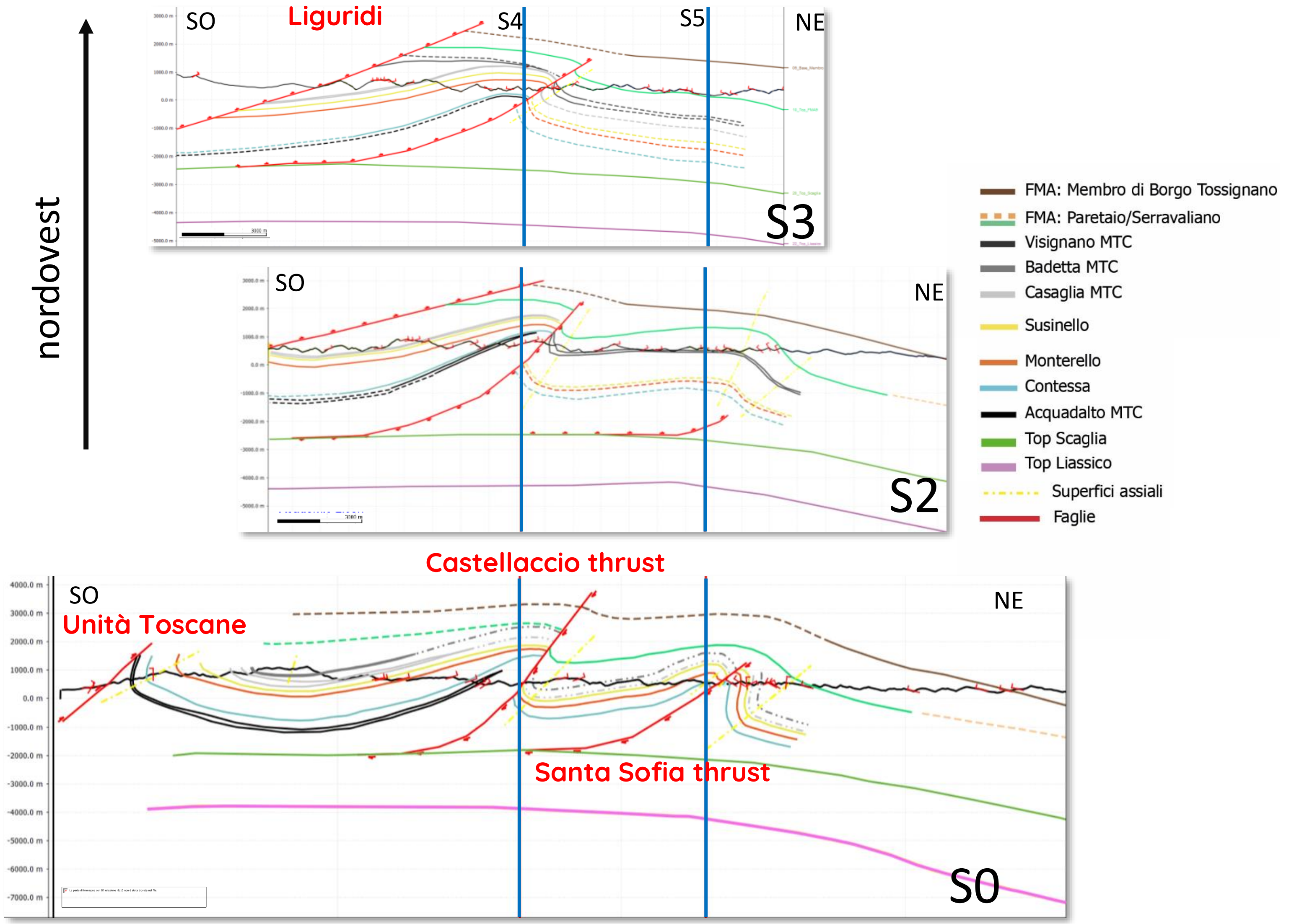
The MAF is crosscut by NE-vergent **regional-scale thrusts**, with NO-SE strike, parallel to Apennine belt direction. The main structures are the **Castellaccio** and **Santa Sophia** thrusts, both with NW-SE strike.

The footwall of these thrusts is characterized by cylindric and open folds, while the hanging wall show gentle and non-cylindric folds with a periclinal termination to the NW.

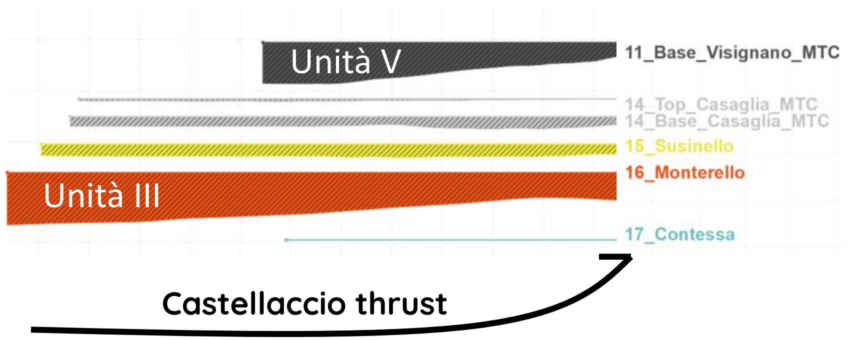


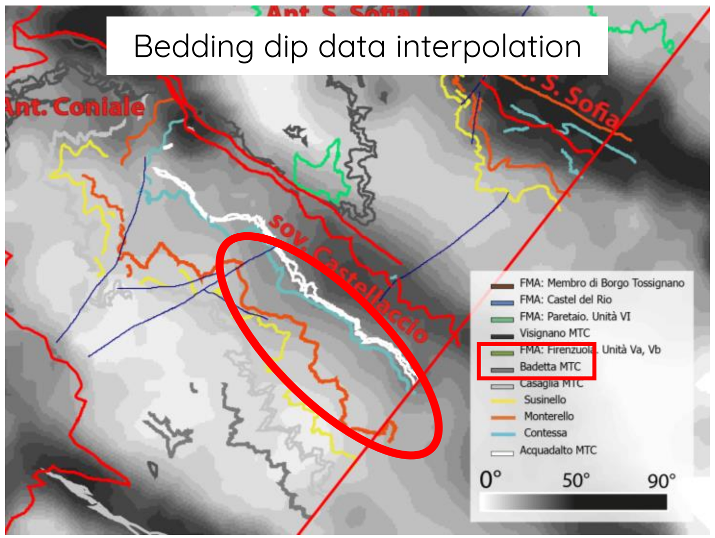
The Castellaccio thrust ends at the base of the Ligurian (s.l.) allochthonous units, offsetting the youngest units of MAF, while the Santa Sophia thrust is completely contained in the MAF units.

Geological cross-sections



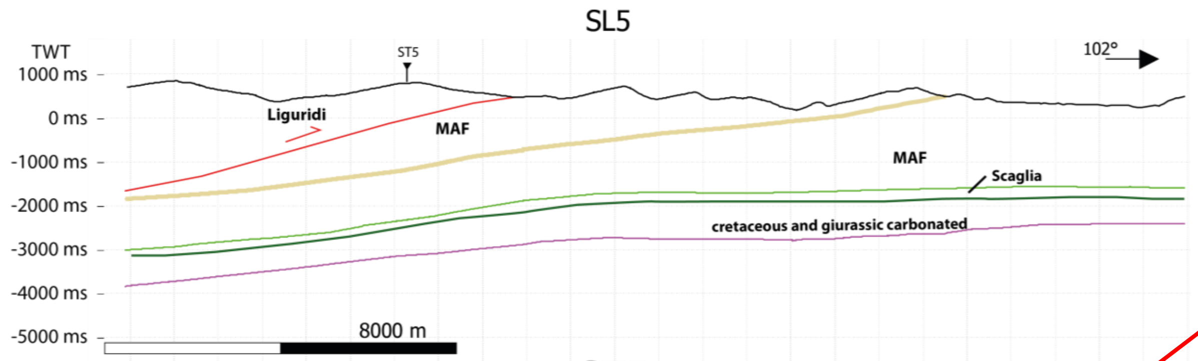
Balanced cross-sections show a relevant **along-strike variation of slip**, that is reduced towards the periclinal hinge to the NW.

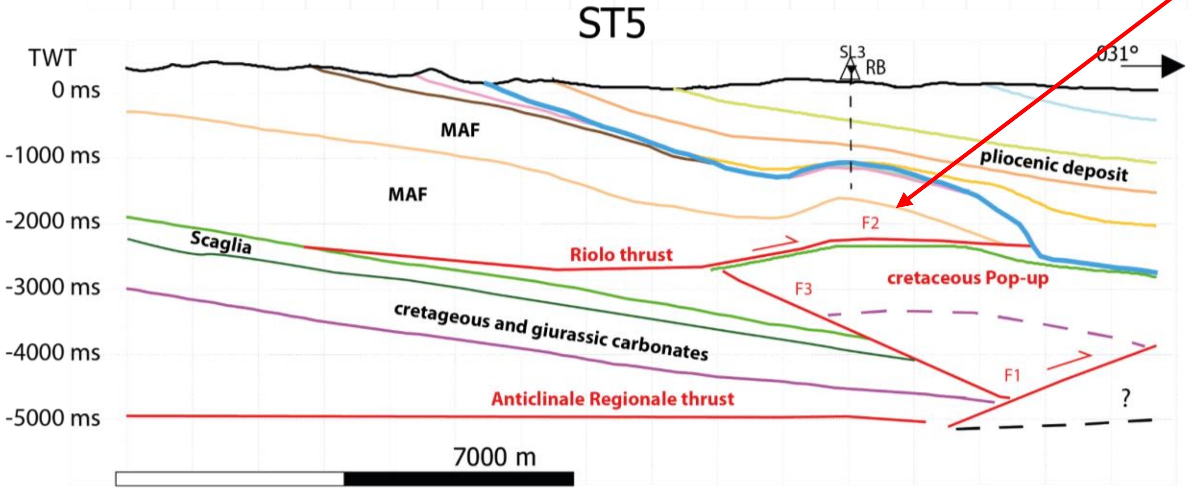


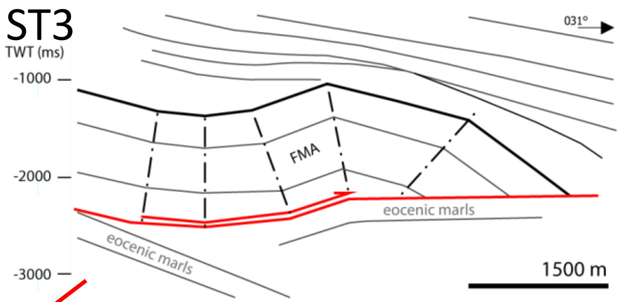


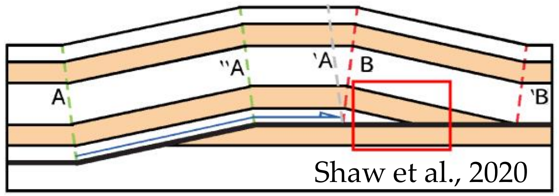
Analysing the thickness between key beds and mass transport deposits in MAF, we observed an important thickness variation across the main thrust strike. In the same units we observe a progressive decreasing in dip angle from NE to SO. This observation suggests the presence of **anticline related growth strata (i.e. syn-sedimentary tectonic activity of thrusts)**.

Seismic lines interpretation



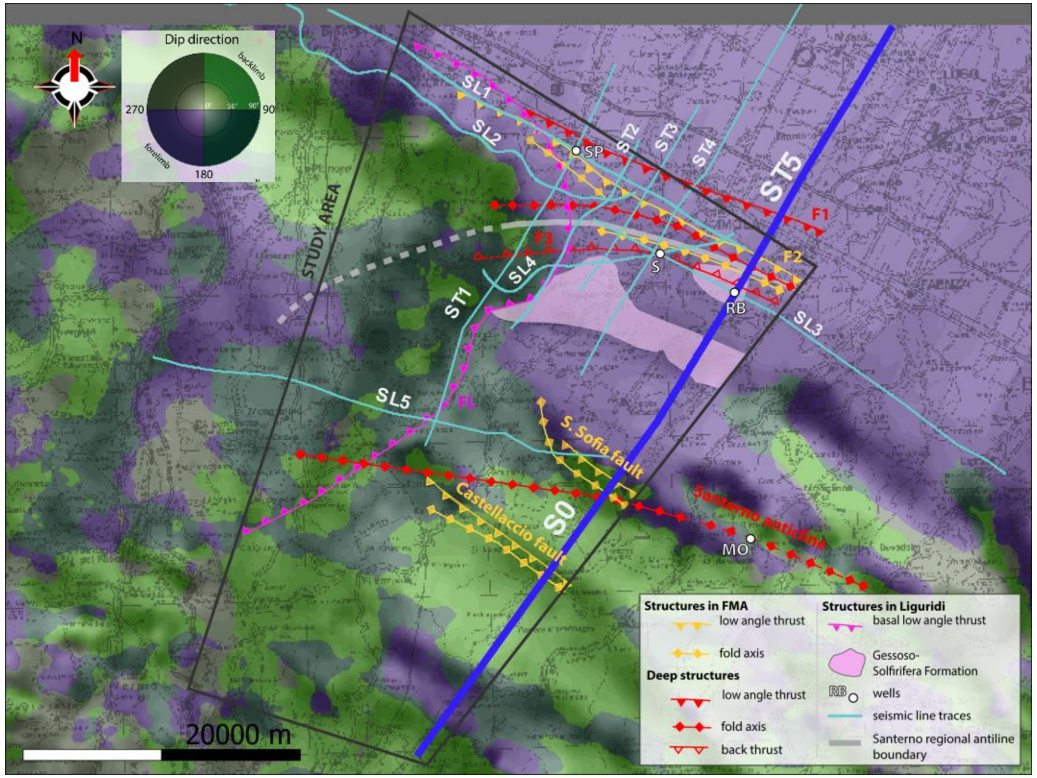






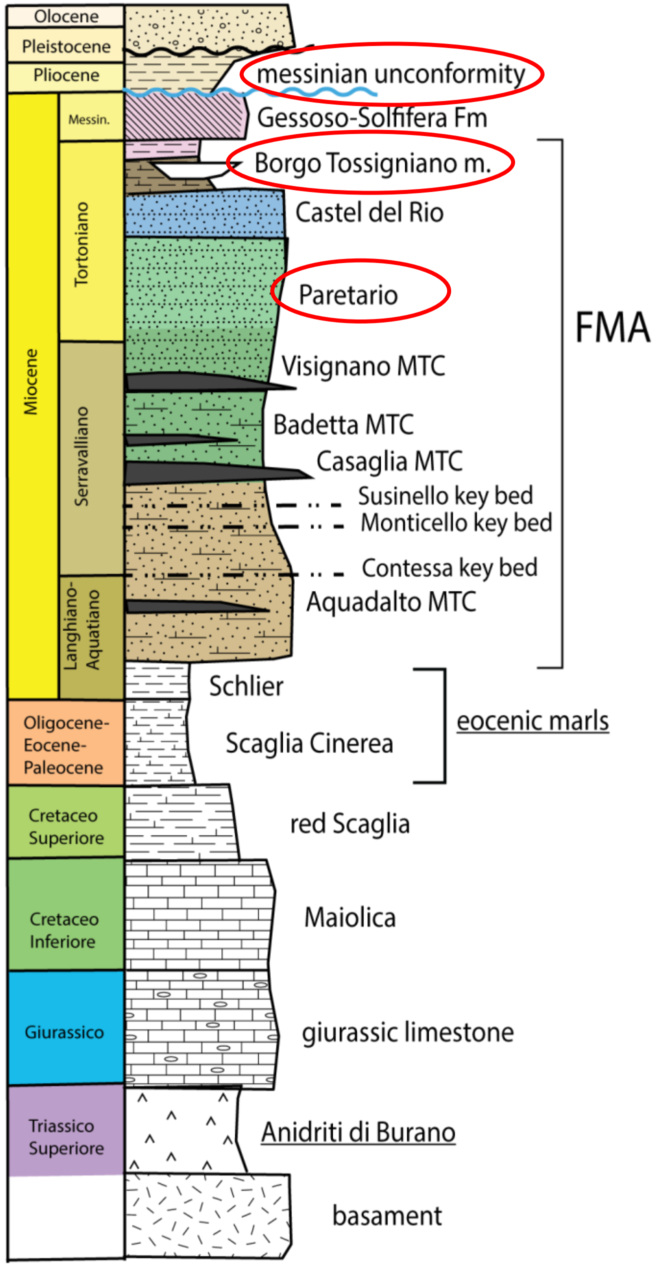
Horizon interpreted on private seismic lines consult during a data room session

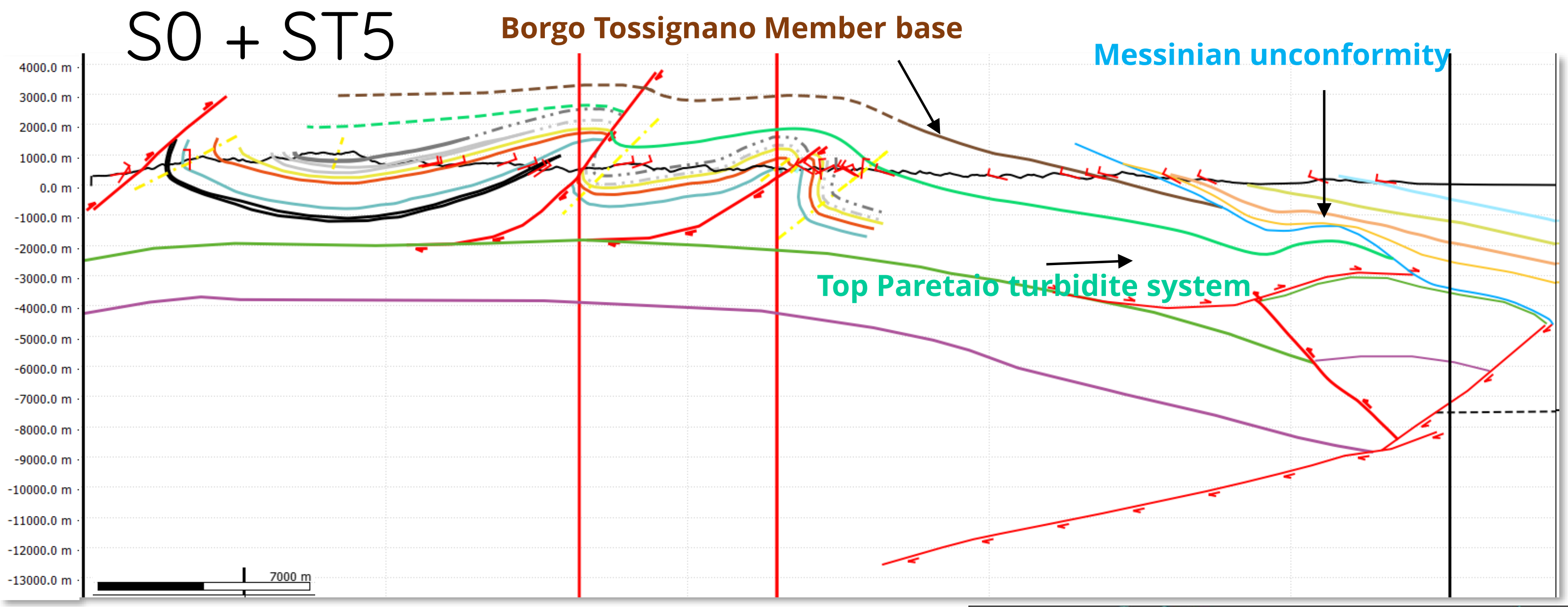
- Top Liguridi e Epliguridi
- Top middle Pleistocene
- Top upper Pliocene ?
- Top middle Pliocene?
- Top lower Pliocene
- Infra Pliocene
- messinian unconformity (Top FMA e FGS)
- Formazione Gessoso-Solfifera Base (FGS)
- Membro di Borgo Tossignano Base (FMA)
- Serravalliano?
- Top Scaglia (middle Eocene)
- Top Maiolica (Lower Cretaceo)
- Top Liassico
- uncertain horizon (fault or unconformity)

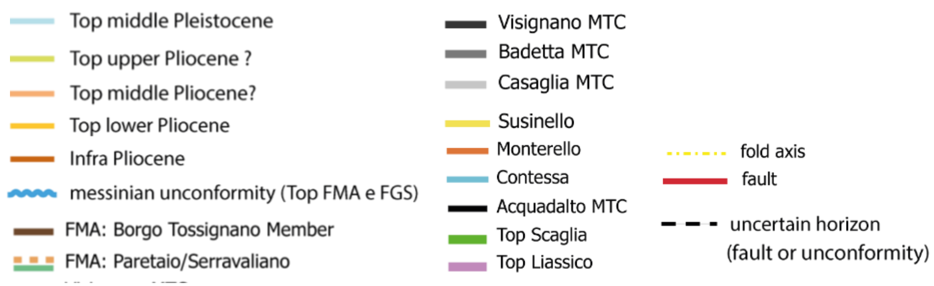


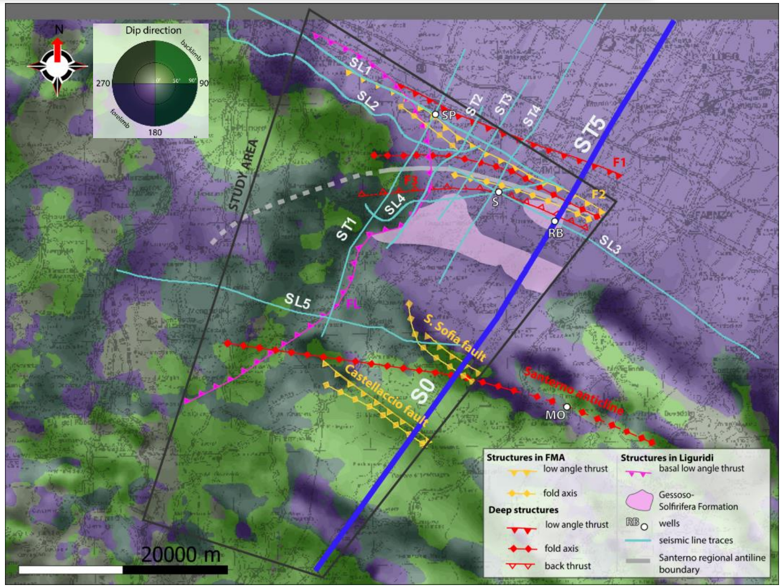
Cretaceous and Jurassic carbonates are evident in 2Dseismics, at the base of MAF. They highlight a **regional-sale gentle anticline**. The reflectors that highlight the NE limb are truncated by horizontal reflectors. This geometry can be explained with a fault-bend-fold model. This structure seems to be rooted to the SW in a very deep fault in the **Adria basement**. In the more external part of the transect, towards the lower hills and the plain around Imola, a **regional-scale pop-up**, evidenced by the late-Messinian unconformity, is the main feature also in subsurface datasets. This structure is rooted at the base of **Mesozoic carbonates.**

Combining surface and subsurface data



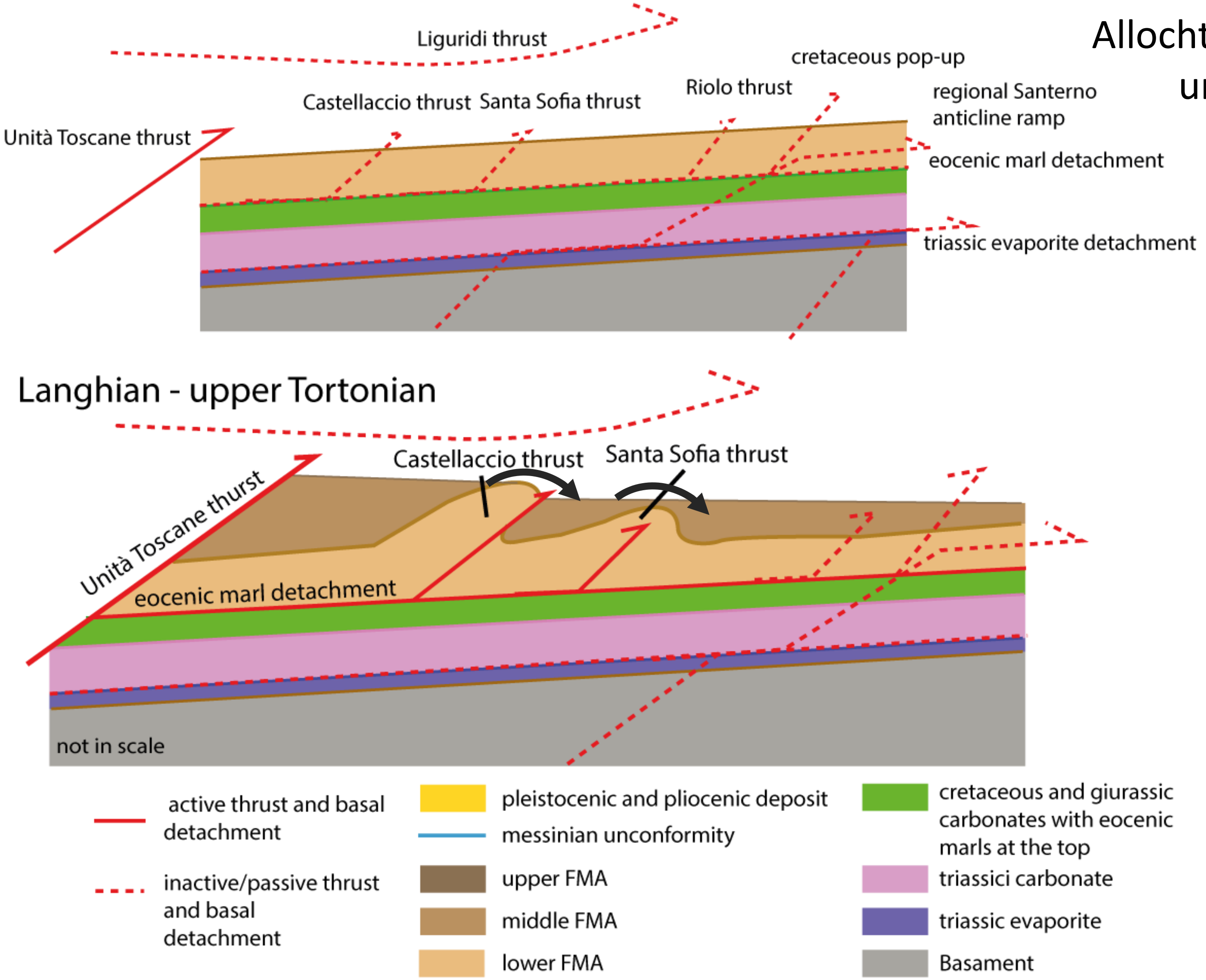


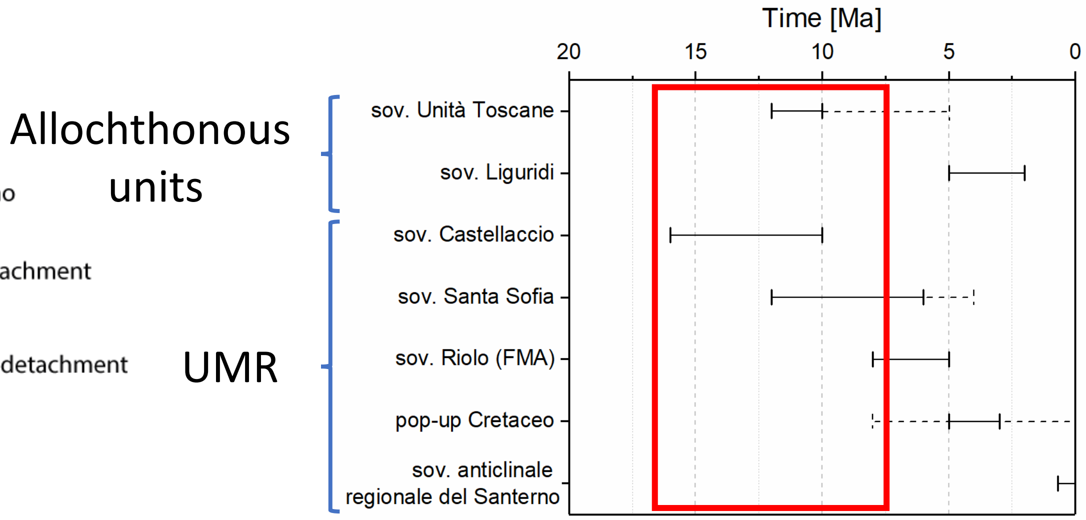




To combine surface and subsurface data, the messinian erosive unconformity, the base of Membro del Borgo Tossignano and the top of the Paretaio turbiditic system have been correlated.
Subsurface data suggest that these relatively shallow thrusts (Castelluccio and S. Sofia) are **rooted at the top of Mesozoic carbonates**, that do not crop out in the area, but are reached by wells.

Tectonic evolution – 1° stage

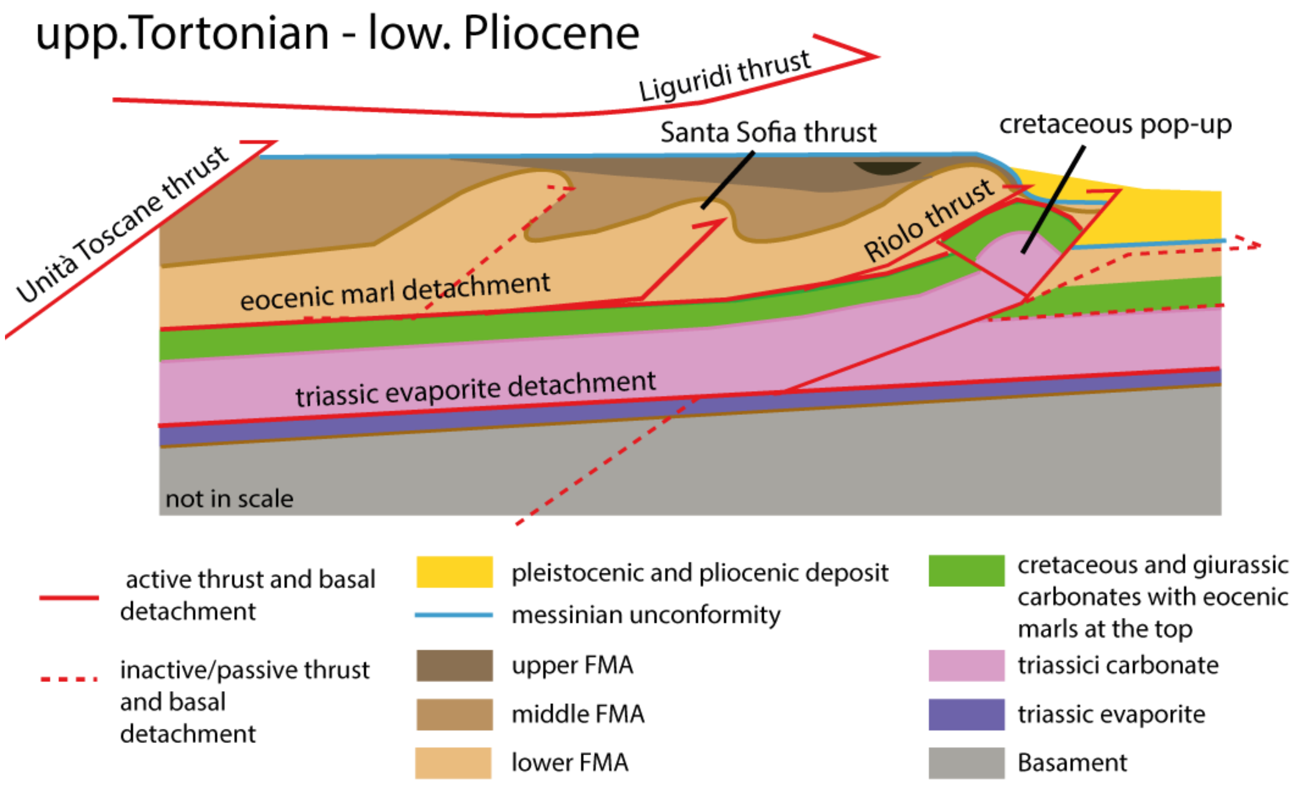


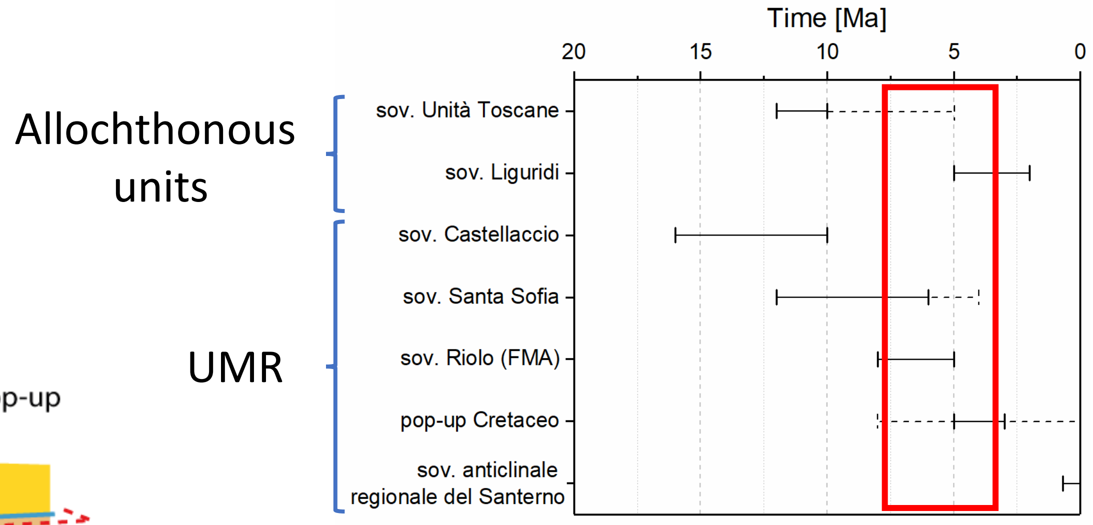


The first stage shows the activation, in the Langhian, of the shallow thrusts rooted at the Eocene marls detachment, during MAF sedimentation in the Appennine foredeep basin.

The sedimentary evolution is characterized by an early inner basin confined to the north by the Castellaccio thrust (from Langhian to Serravallian), and by a later outer basin, located to the north of the Castellaccio thrust, recording a **shift of the depocenter towards the foreland**.

Tectonic evolution – 2° stage



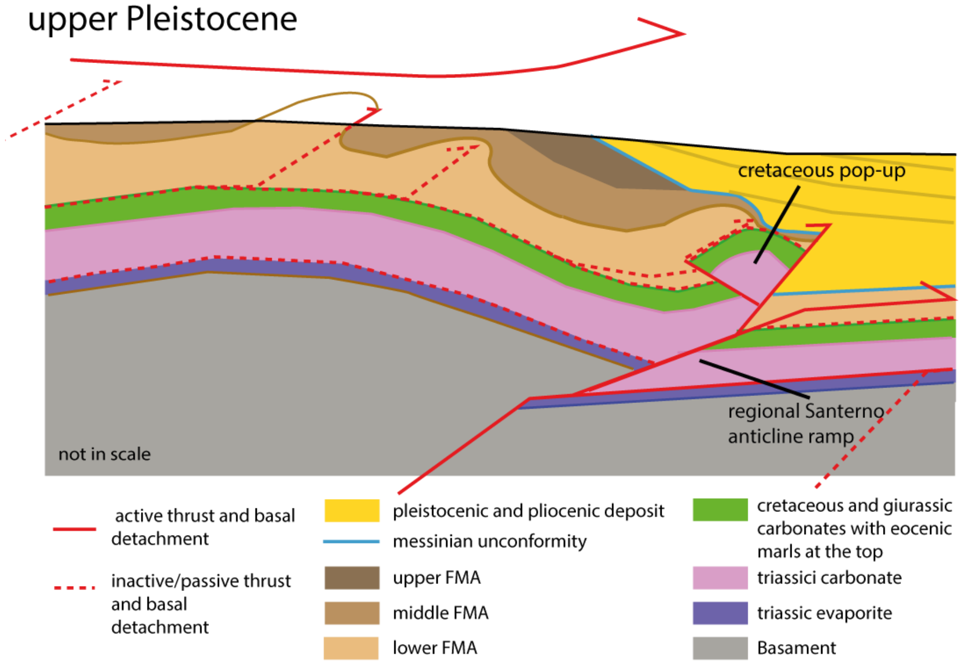


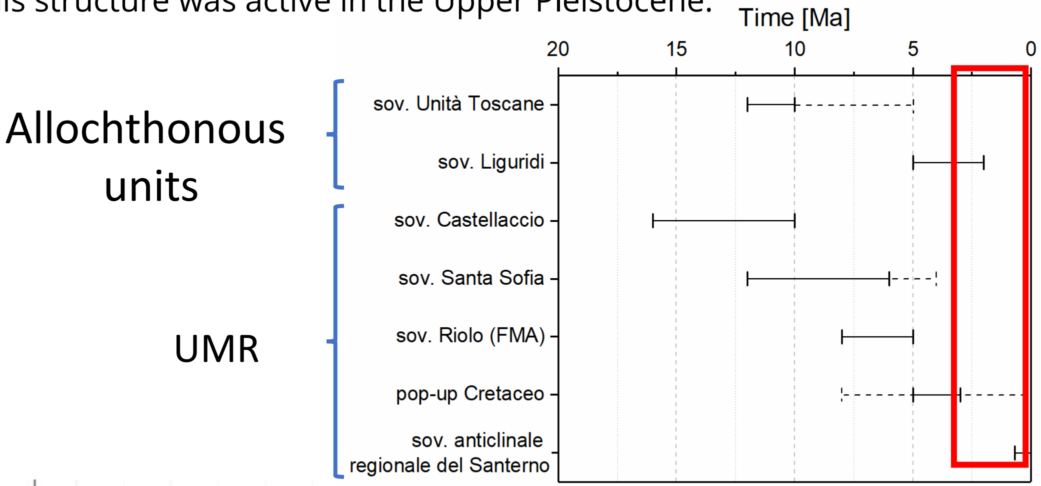
From the Tortonian, the Lower Triassic evaporite detachment was activated, resulting in a **pop-up cored with Cretaceous units**, also creating the northern boundary of foredeep basin of the MAF. The growing cretaceous pop-up successively localized **a ramp for the Riolo thrust**. From tectonics-sedimentation relationships, these structures were active at the time of the Messinian unconformity.

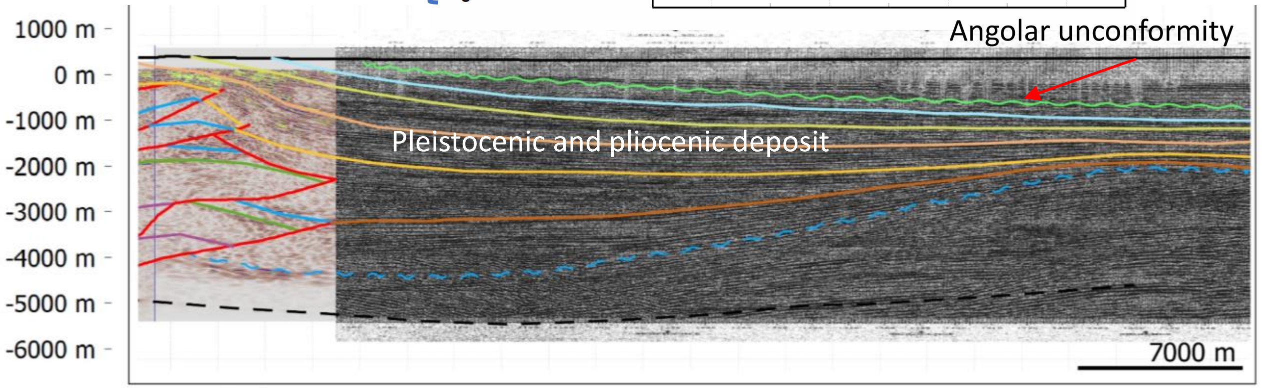
Tectonic evolution – 3° stage

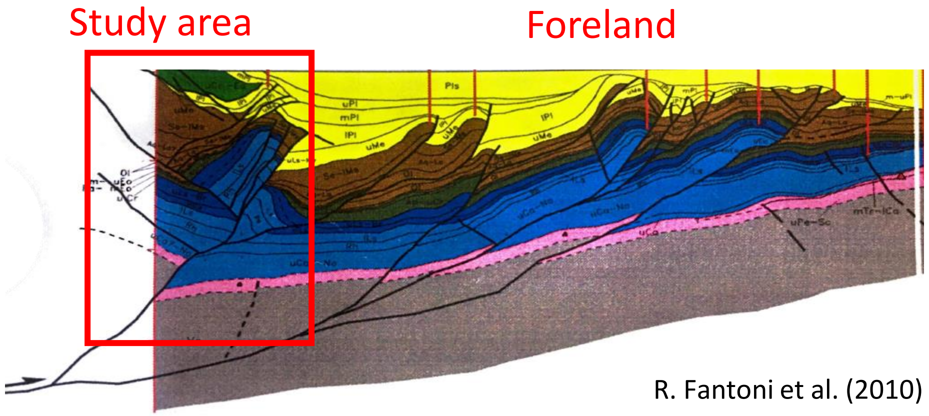
The last stage shows the activation of **very deep structures** rooted in the basement. A new ramp develops and is connected to the cretaceous pop-up, then, propagating further to the north, results new structures in the foreland. This deep structures forms the Santerno regional anticline, as a regional-scale fault-bend-fold ramp anticline.

The geometry of the reflectors in Pliocene deposits in the foredeep suggests that this structure was active in the Upper Pleistocene.





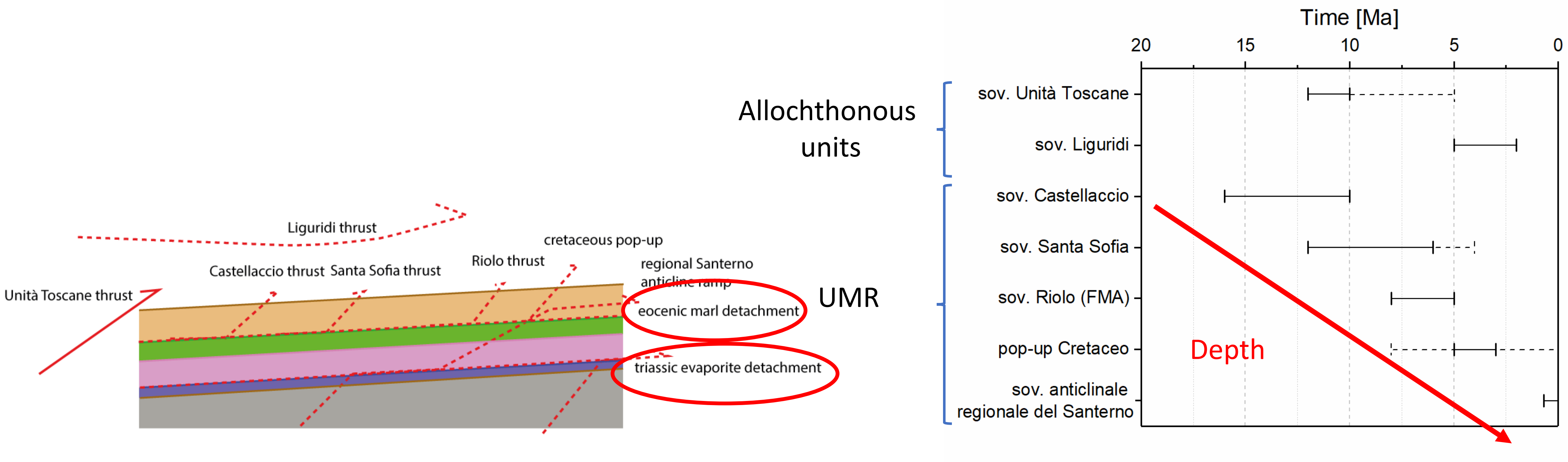




R. Fantoni et al. (2010)

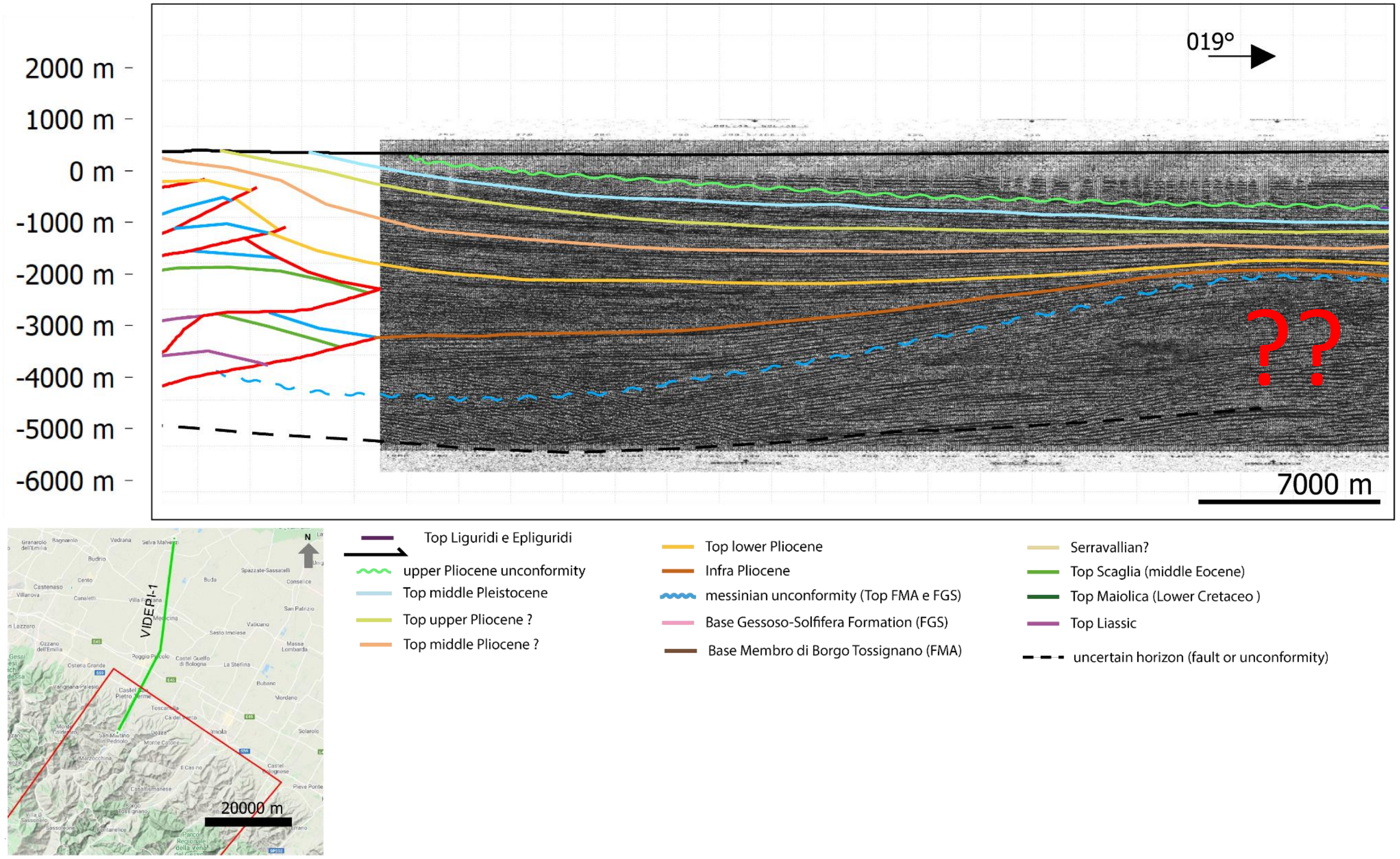
Conclusion 1/2

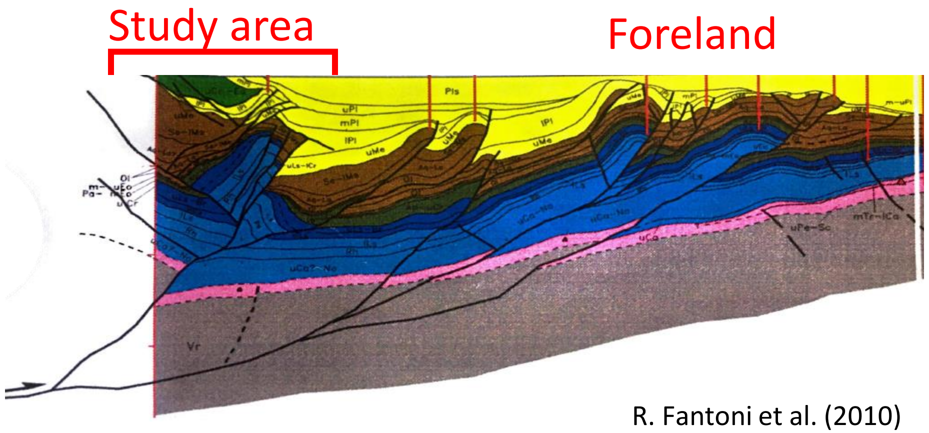
We identified two detachment surfaces: (i) eocenic marls at the top of the carbonate succession, and (ii) triassic evaporites. The Santerno regional ramp anticline suggests the presence of a deeper and younger thrust, rooted in the basement, which could be the source of recent seismic activity in the area. Crosscutting and tectonics-sedimentation relationships show that deeper and more external structures are younger than shallower and more internal ones.



Conclusion 2/2

To better understand the deeper structures and to obtain a proper retro-deformation, it will be necessary to study the subsurface data in the foreland.





R. Fantoni et al. (2010)

Reference

- Mutti, E., Ricci Lucchi, F., & Roveri, M. (2002, May). Revisiting turbidites of the Marnoso-arenacea Formation and their basin-margin equivalents: problems with classic models. In *Excursion guidebook of the turbidite workshop, Parma, Italy* (pp. 21-22).
- Anon. n.d. "Martelli, Ercolessi , Molinari, Calabrese, Severi , 2017 . Note Illustrative Della Carta Sismotettonica Della Regione Emilia Romagna Ed Aree Limitrofe . Regione Emilia Romagna, Servizio Geologico Sismico e Dei Suoli."
- Shaw, John H., Christopher Connors, and John Suppe. 2020. Seismic Interpretation of Contractional Fault-Related Folds.
- Fantoni, R. and R. Franciosi. 2010. "Tectono-Sedimentary Setting of the Po Plain and Adriatic Foreland." Rendiconti Lincei 21(SUPPL. 1):197–209.