



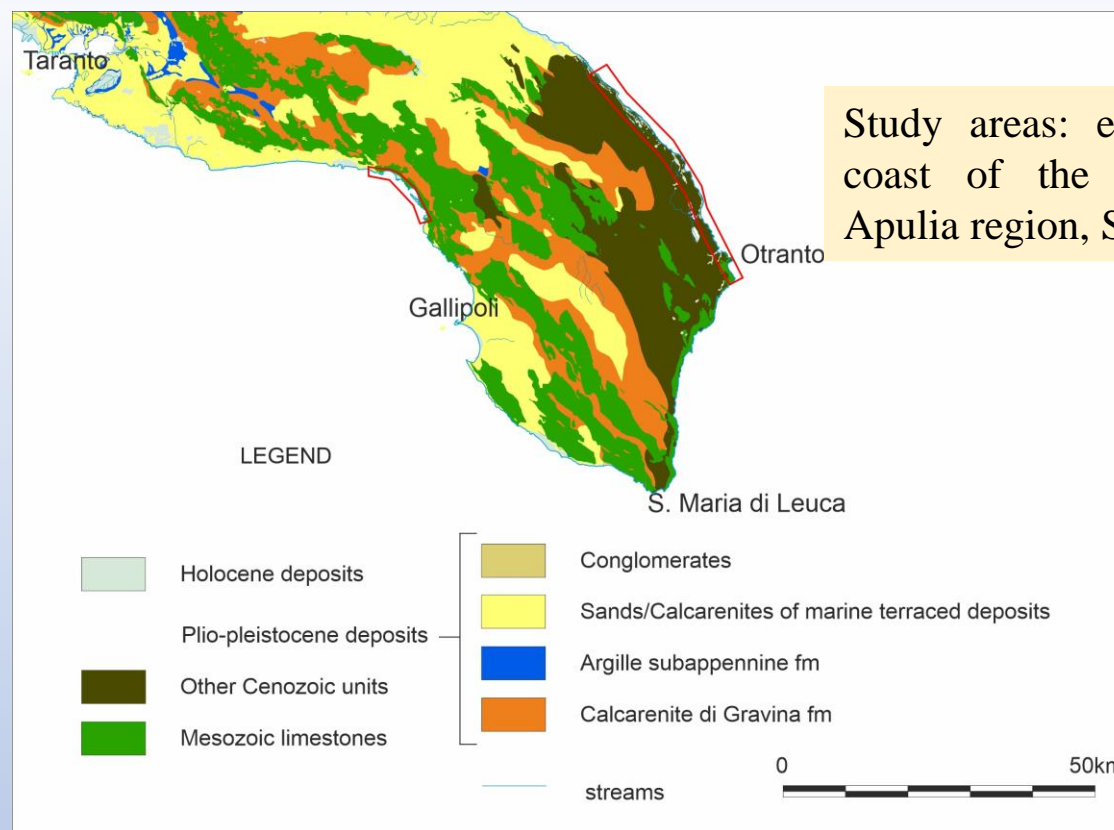
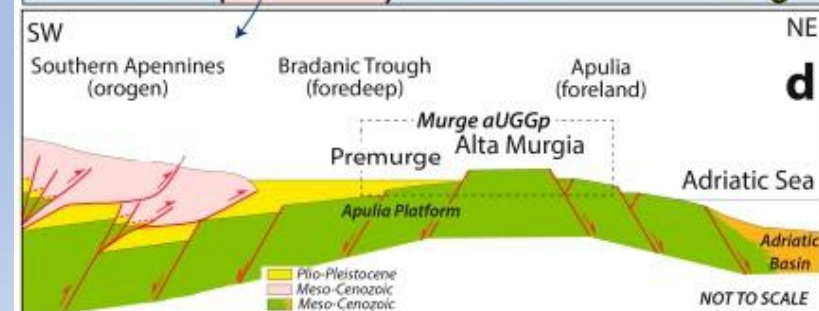
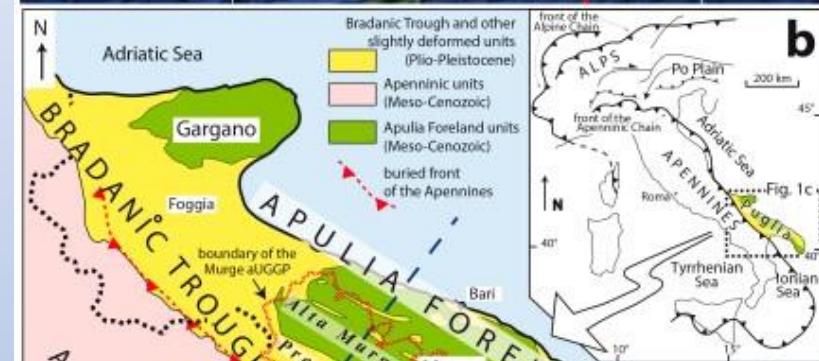
Project of Research of National Interest

PRIN PNRR 2022

*Future scenarios in **co**astal **karst**: saltwater intrusion, loss of water resources and sinkhole development as effects of climate changes*

*FU.CO.KA.*

**Geomorphological framework  
of the study areas**



Study areas: eastern and western coast of the Salento Peninsula, Apulia region, Southern Italy

Apulia region: foreland of both east verging Apennine chain and west verging Dinaric chain. Mesozoic: Adria Plate, south margin of the paleo Thethys ocean, passive subsiding margin, Apulia carbonatic platform, thick succession of carbonate sediments (Calcare di Bari and Calcare di Altamura fm).

Cenozoic: closure of Thethys, emersion of the Apulia foreland, formation of a chain-foredeep-foreland system.

Foredeep: sited between the proto-Apennine chain and the Apulian Foreland, known as Bradanic Foredeep → transgressive-regressive cycle (Bradanic cycle: Calcarene di Gravina fm., Argille subappennine fm, Calcareni del Salento fm).

Quaternary: sea-level oscillations + regional uplift → series of uplifted marine terraces/paleoshorelines with related deposits.

## Coastal area between Torre Castiglione and Nardò

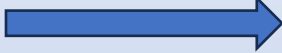



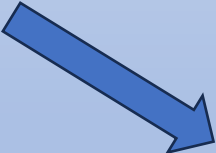
high physiographic irregularities due to the presence of promontories, bays and small islands (e.g., Isola della Malva and Isola Grande; Lapietra et al., 2022).

In rocky promontories Cretaceous limestone or Peistocene calcarenites belonging to Calcareni del Salento fm (Rossi, 1969b) crop out.

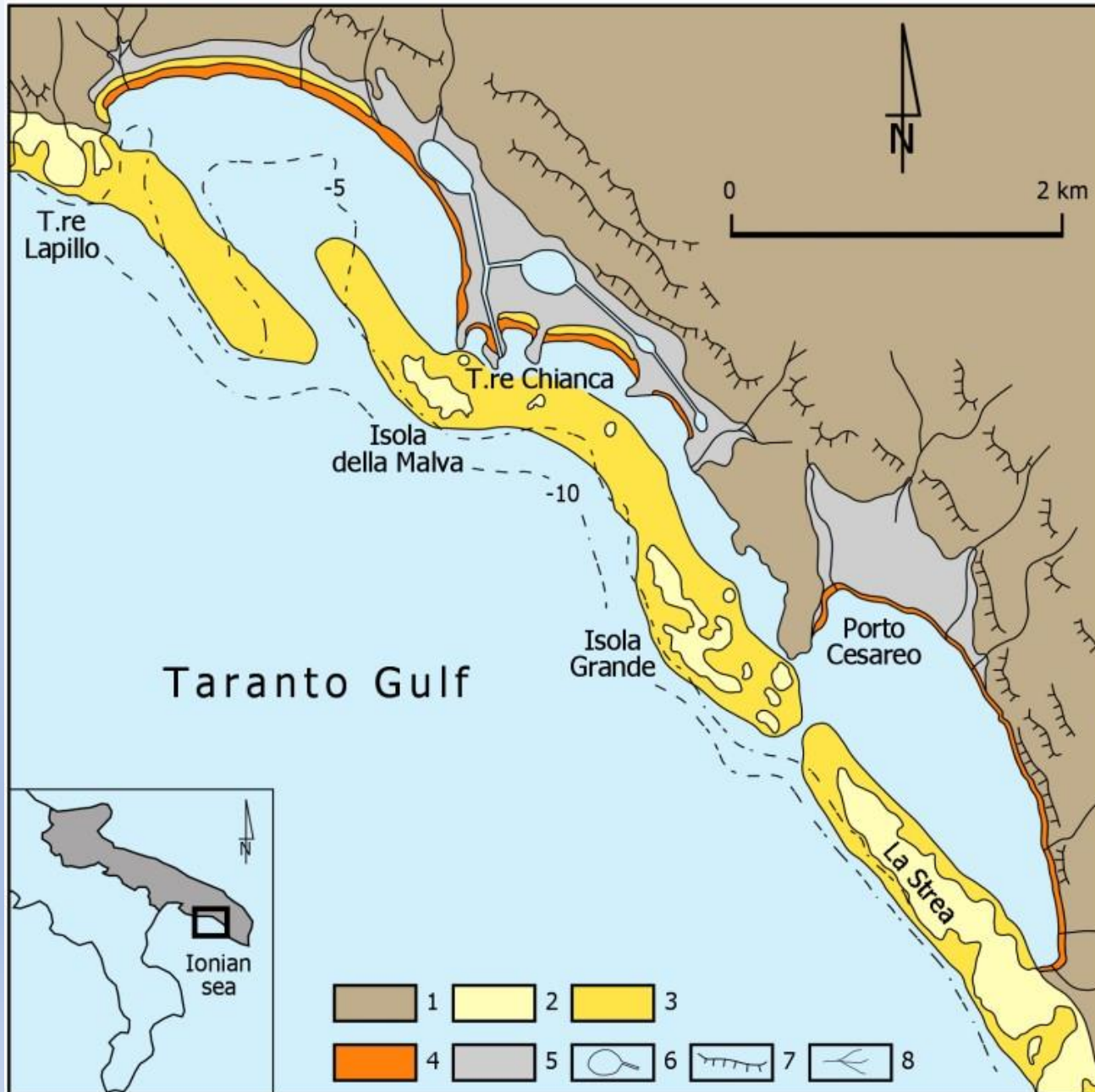
Small pocket beaches in the bays, formed by a thin layer of modern sand-sized bioclastic sediments (Ambrosano et al., 1986).

# SOME GEOMORPHOLOGICAL PROCESSES WHOSE TRACES ARE EVIDENT

Past geomorphological processes:  sea level oscillations

Recent geomorphological processes:  Coastal karst and sinkholes  
 beach erosion

## Past geomorphological processes: sea level oscillations

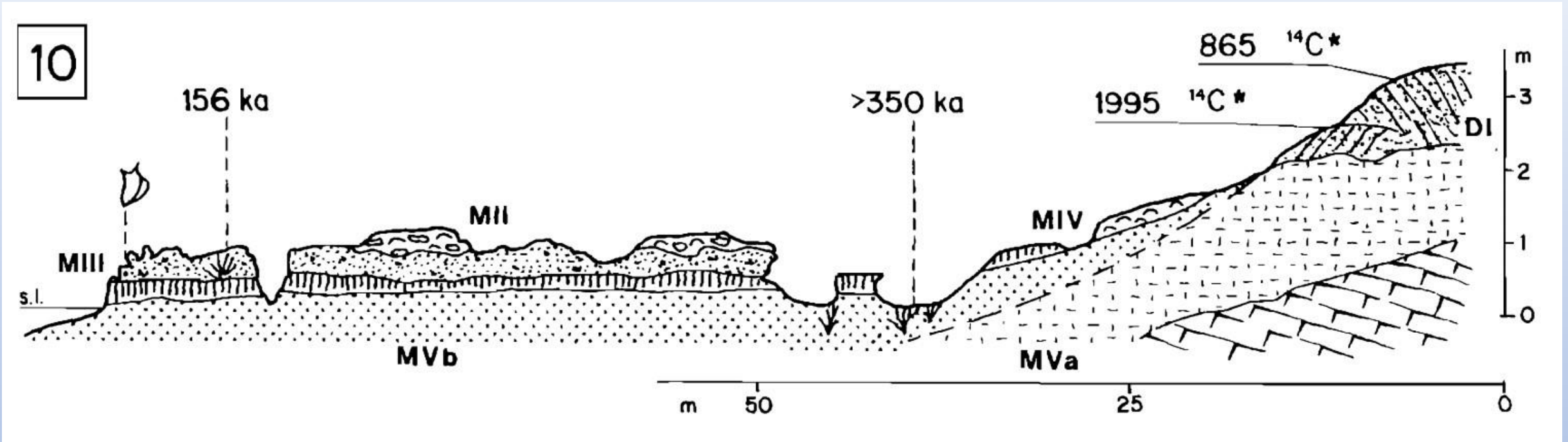


The geomorphological configuration of the coastal area between Torre Castiglione and Nardò is related to the post glacial sea-level rise (Mastronuzzi *et al.*, 1989).

In particular for the area around Porto Cesareo, according to Palmentola (1987) and Mastronuzzi *et al.* (1989), the present coastal morphology is the result of the local detachment from the mainland of a littoral barrier that has migrated further inland during the final phase of the Holocene transgression.

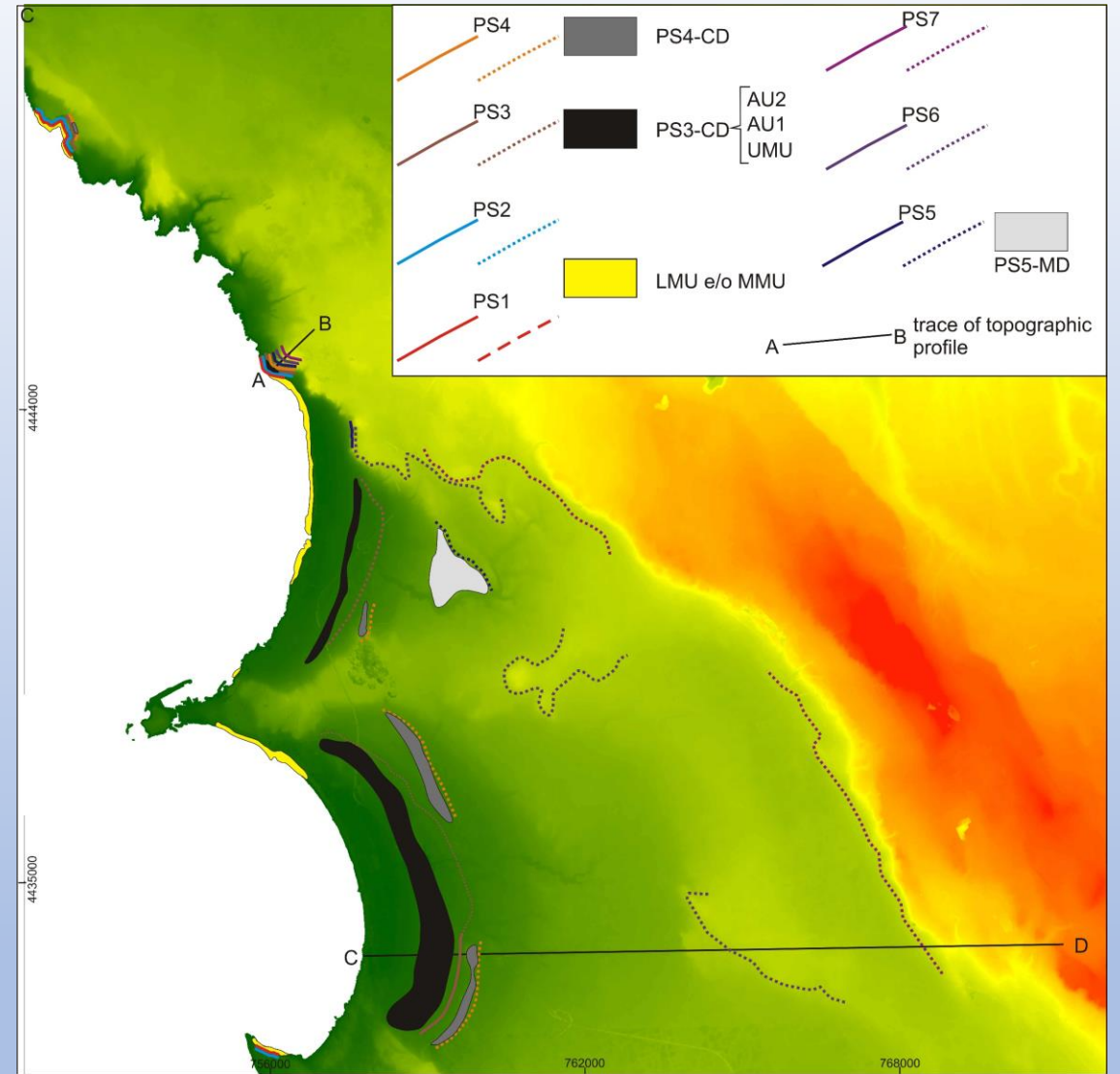
Paleogeographic reconstruction during the Late Holocene of the southern sector of the study coast. 1) pre-Holocene sediments; 2) remains of dune ridge; 3) possible configuration of the beach-dune barrier in the Late Holocene; 4) current dunes; 5) marshy deposits; 6) reclaimed areas; 7) pre-Holocene marine terraces; 8) hydrographic network (modified from Mastronuzzi *et al.*, 1989) Paleogeographic reconstruction during the Late Holocene of the southern sector of the study coast. 1) pre-Holocene sediments; 2) remains of dune ridge; 3) possible configuration of the beach-dune barrier in the Late Holocene; 4) current dunes; 5) marshy deposits; 6) reclaimed areas; 7) pre-Holocene marine terraces; 8) hydrographic network (from Milli *et al.*, 2017).

## Past geomorphological processes: sea level oscillations



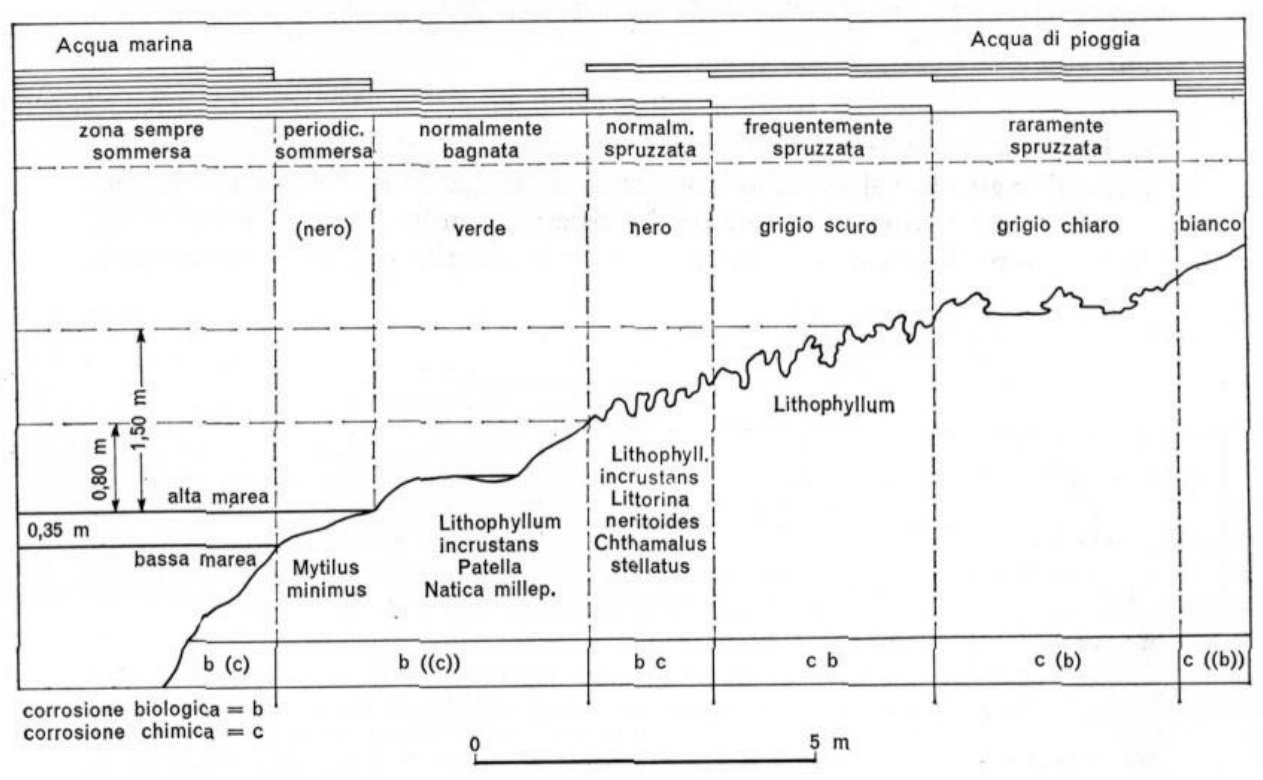
At Torre Castiglione locality, Hearty and Dai Pra (1992) recognised three marine deposits (M) lying on Mesozoic limestone, ranging from calcarenite to (bio)detrital limestone, related to middle-late Pleistocene marine oscillations: 1) MIV, correlated with aminozone F (corresponding to MIS 7); 2) MIII, characterised by the presence of *Tethystrombus latus* (Gmelin), thus dating back to MIS 5.5; 3) MII, probably belonging to a late stage of MIS 5. Above these deposits, Holocene and recent deposits lie (DI).

# Past geomorphological processes: sea level oscillations



In the Porto Selvaggio reserve area, less outside the study area towards south, seven palaeoshorelines (PS1 to PS7, from the lower to the higher) and related marine deposits (ranging from +6 and +67 m) have been recognised (De Santis et al., 2023). These palaeoshorelines (represented by fossil tidal notches, sea caves, bands of *lithophaga* holes and so on..) and their associated deposits have been referred to sea-level highstands occurred during Middle-Late Pleistocene, specifically from Marine Isotope Stage (MIS) 15 (the higher palaeoshoreline) to MIS 5.5 (the three lower palaeoshorelines: PS1 at +6 m, PS2 at +7.5 m, and PS3 at +15 m).

# Recent geomorphological processes: coastal karst and sinkholes



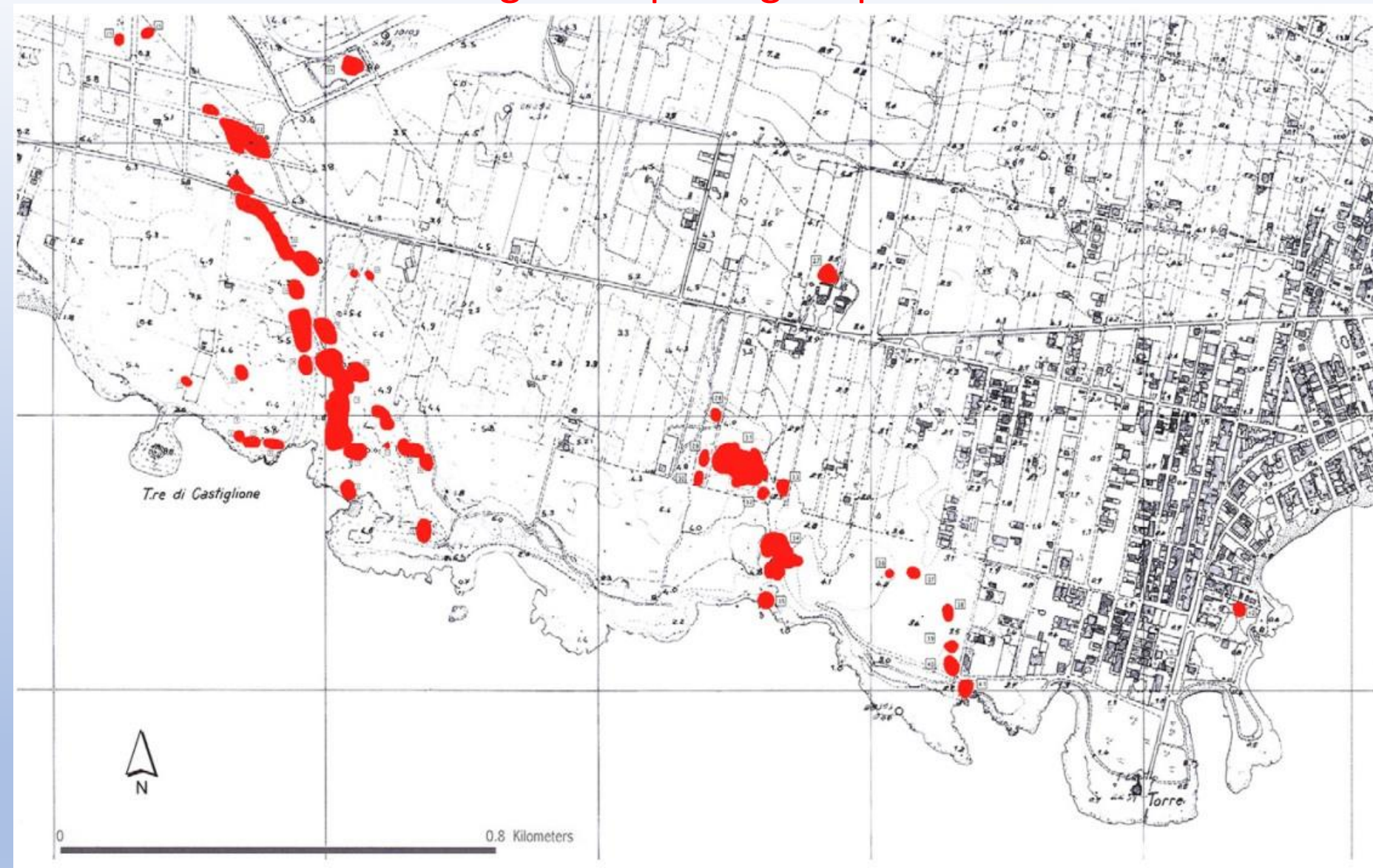
Low rocky coast → accelerated corrosion: mixing between karst processes, marine erosion, salt weathering, biological weathering..... photoles and pinnacles.

High rocky coast → sea caves, as the result of both karst processes and marine erosion





# Recent geomorphological processes: sinkholes



1. The presence of sinkholes (Bruno et al., 2008; Liso and Parise, 2023), locally named spunnulate, is widespread.
2. Many coalescent sinkholes.
3. Torre Castiglione area shows more than 60 spunnulate (Bruno et al., 2008; Fig 6).
4. Sinkholes may host ponds with typical paludal vegetation.
5. At the floor, they display a chaotic mass of big calcarenite blocks (bedrock collapse type), related to the presence of underground cavities (Bruno et al., 2008).

Different stages of evolution in the development of sinkholes can be observed at Torre Castiglione. Whilst the most recent sinkholes show well-defined scarps, forming a topographic depression easily discernible in the landscape, the older sinkholes present degraded scarps as they have been strongly modelled by the combined action of erosion, further breakdown processes, and marine waves. The concentration of sinkholes in the proximity of the coastline is also due to active hyperkarst processes (Bruno et al., 2008) related to the mixing of salt water encroaching from the sea and fresh groundwater from the aquifer, that increases the aggressiveness and the dissolution capability of water

# Recent geomorphological processes: beach erosion



Photos (proceeding from west to east) along the western zone of Torre Lapillo beach.. Note the uninterrupted sequence of the houses that have replaced the original dune field and that today are very close to the shoreline

Photos collected along the eastern zone of Torre Lapillo beach. A and B) The beach near profile TL45 in April 2010 (A) and August 2016 (B). Note the disappearance of the beach in this time-interval, and the sandbags used to protect the beach resort (see red arrow) from waves. C and D) The easternmost beach portion at the two flanks of the house near to the shore (see red arrow) in April 2010 (C) and in August 2016 (D).



1) Pocket beaches dynamics is affected by: absence of sediment-delivering rivers, local production of bioclastic debris from a carbonate factory, low volume and thickness littoral prisms

2) Coastline urbanization and tourist activities have developed extensively during the last 40 years, and most of the erosional signatures have clear connections with nearby human disturbance;

3) Dune degradation related to human activities together with aeolian processes, wave action and a low sediment production from carbonate-factory source are the factors responsible for beach and dune erosion during last years. (Milli et al., 2017).

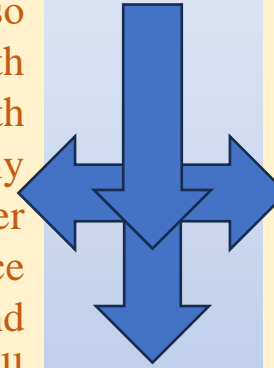
# Coastal area between Frigole and Otranto

This coastal area, from a morphological point of view, can be divided into three main sectors. Calcareniti del Salento fm (then redefined as Uggiano-La Chiesa fm (Bossio et al. 1985; Ricchetti et al. 1992) outcrops extensively, dating back to Plio-Pleistocene interval and characterised by an alternation of calcarenities and calcareous sands (Largaiolli et al., 1969; Rossi, 1969a, b).

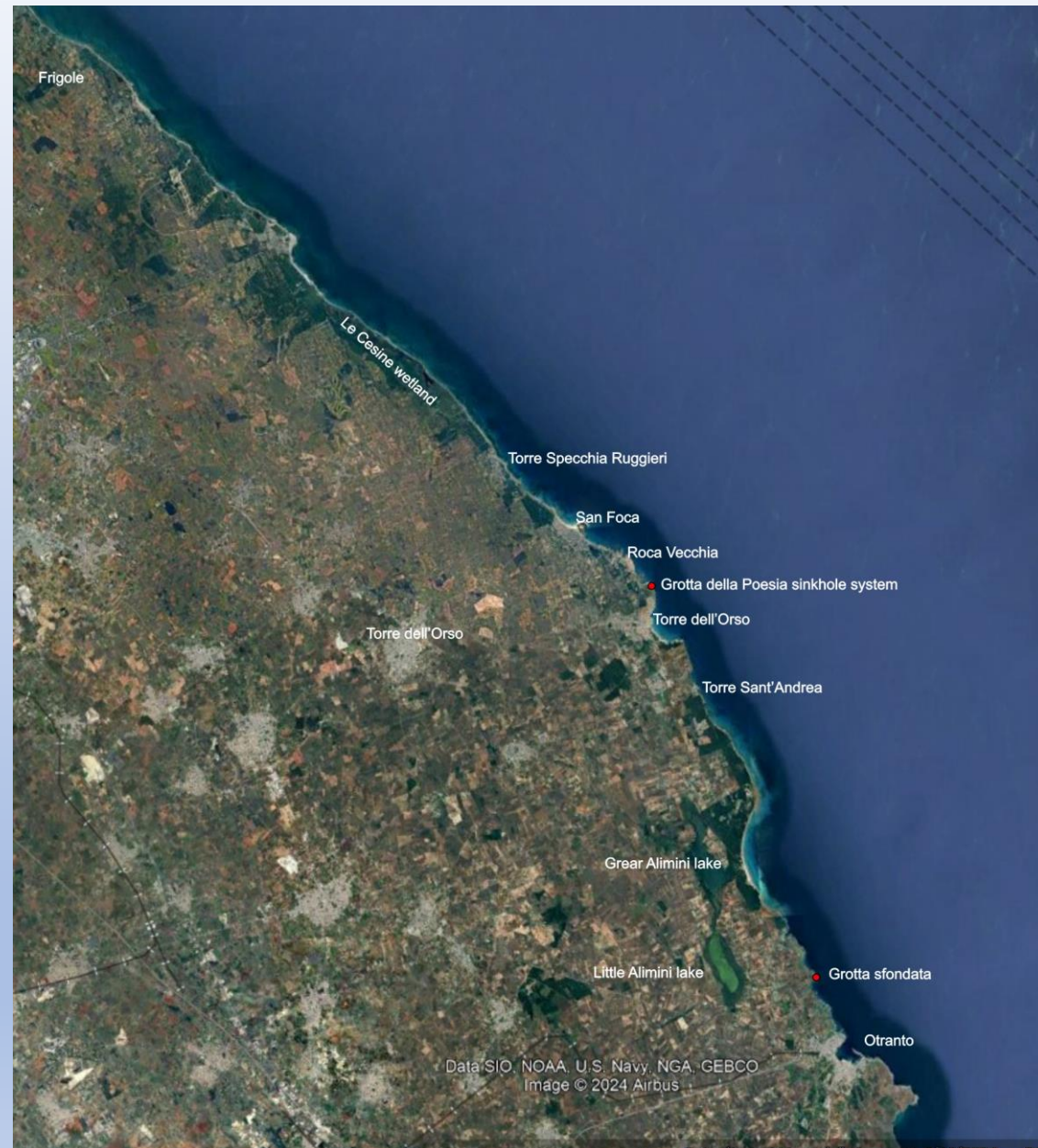
3) Between Torre dell'Orso and Otranto: some parts with cliffs and other parts with low rocky coasts gently sloping seaward, this latter characterised by alternance of small promontories and bays hosting very small pocket beaches. Both in the cliffs and in low rocky coasts, Uggiano-La Chiesa fm crops out.

Only in the sector north and south of Alimini lakes mouth, a continuous sandy beach is present, bordered inland by a dune ridge.

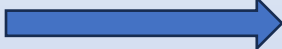
1) Between Frigole and Torre Specchia Ruggieri: low profile and narrow sandy beaches which, in some cases, coincide with the outer margins of sandy barrier which separate coastal lakes and ponds from the open sea. In other cases, the narrow beaches are contiguous to the mainland

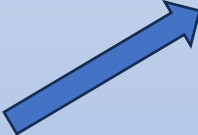
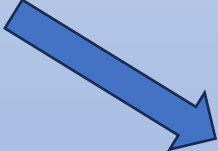


2) Between Torre Specchia Ruggieri and Torre dell'Orso: higher physiographic irregularities due to the presence of promontories, bays and small islands. The bays host often pocket beaches bounded landward by aeolian dunes. These pocket beaches are separated by promontories characterised both by low rocky coast and cliffs. In these promontories, Calcareniti del Salento fm crops out (Largaiolli et al., 1969).



# SOME GEOMORPHOLOGICAL PROCESSES WHOSE TRACES ARE EVIDENT

Past geomorphological processes:  sea level oscillations

Recent geomorphological processes:  Coastal karst and sinkholes  
 coastal cliff retreat

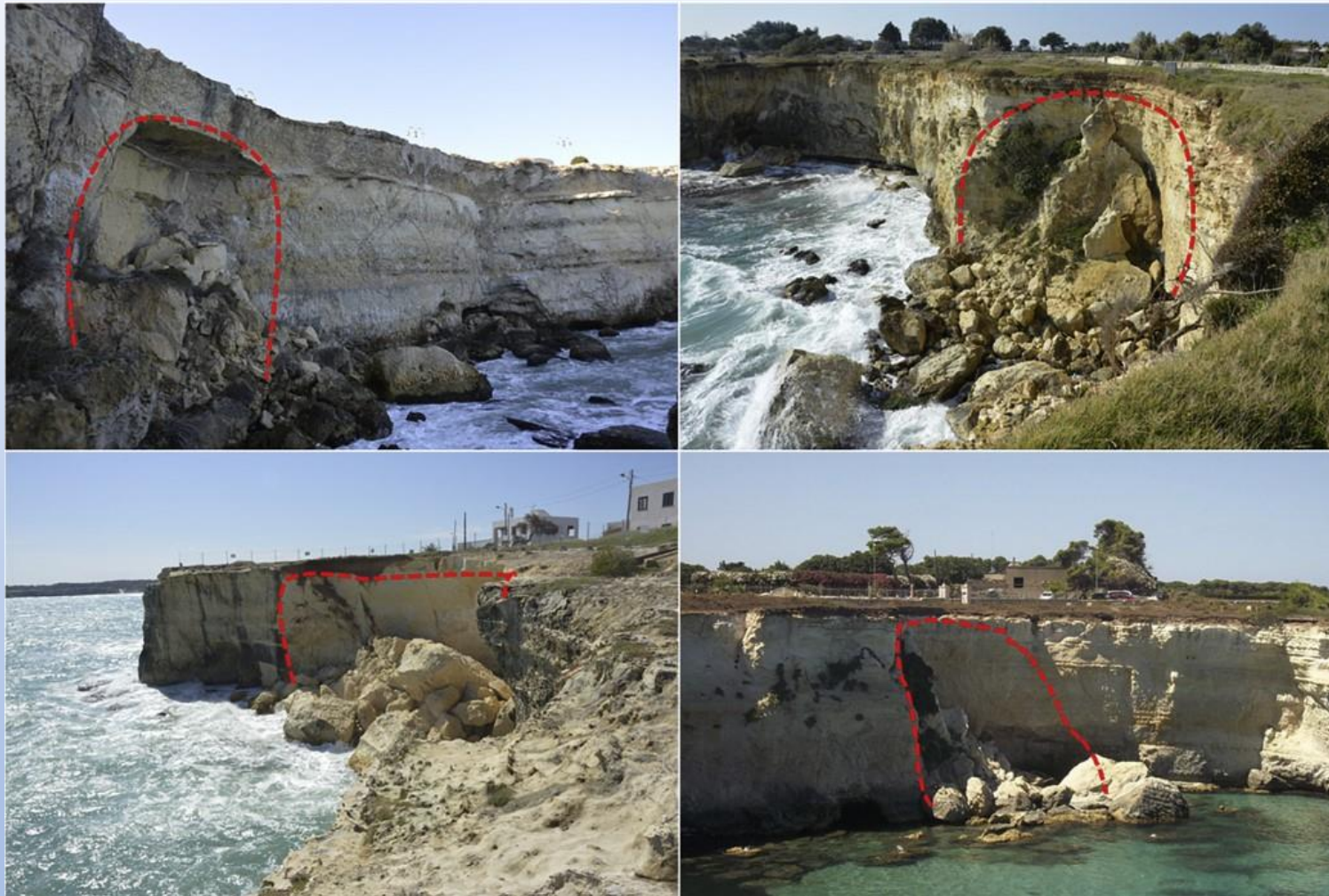
## Past geomorphological processes: sea level oscillations



1. Between Torre dell'Orso and Otranto, traces of Pleistocene sea-level oscillations are present.
2. Six main orders of marine terraces/relict wave-cut platforms placed between +103 m and few metres above the present sea level (Mastronuzzi and Sansò, 2003)
3. Two wide wave-cut platforms are present between +1 and +2.2 m, and between +2.8 and 3 m (Mastronuzzi and Sansò, 2003), immediately south of Torre dell'Orso.

Coastal stretch between Torre dell'Orso and Otranto, with a wave-cut platform whose inner margin is at + 3m

## Recent geomorphological processes: coastal cliff retreat



Rock blocks detached from the sea cliff, caps, inlets, arches and stacks in the area of Sant'Andrea (From Fazio et al., 2019).

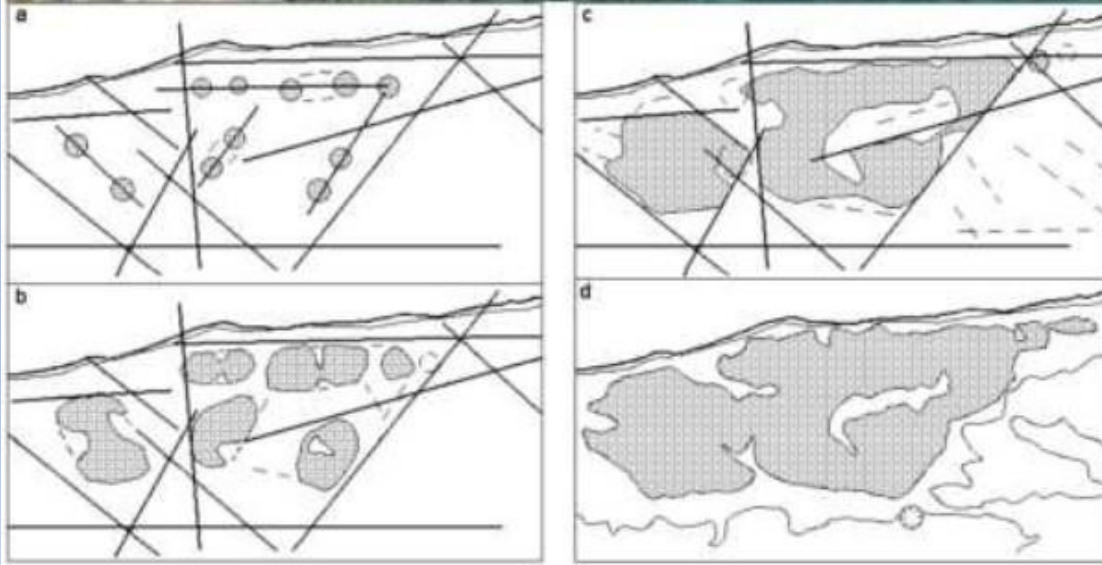
As regards the cliff retreat processes, one of the best examples is represented by the Sant'Andrea cliff, within the municipality of Melendugno, south of Torre dell'Orso locality. The area is characterized by the presence of a steep plunging cliff, with a vertical and, in places, overhanging face.

Selective erosive phenomena and landsliding along the coastline are widespread. Cliff retreat is essentially an episodic and localized process closely associated with storm waves. Slides, falls and topples characterize this coastal cliff stretch.

The cliff ranges from 12 to 18 m in height, and ends in subhorizontal surfaces at the top, whereas the cliff foot is below the sea level at 1–2 m depth (Fazio et al., 2019).

The cliff develops in well-stratified fossiliferous yellowish marly calcisiltites and yellowish to light grey calcarenites dating back to the Middle-Upper Pliocene.

## Recent geomorphological processes: coastal karst and sinkholes



1. Cesine wetlands is a WWF protected zone, since it hosts a variety of fauna species and botanical ecosystem. They can be described as an advanced evolution stage of collapse sinkholes (Delle Rose and Parise, 2002).
2. Starting from individual sinkholes, through coalescence and merging, the evolution processes is so advanced that the identification of the single initial sinkholes is no longer possible.
3. This type of situation represents the final stage in the evolution of sinkhole-prone areas in low coasts (Liso and Parise, 2023).

The Cesine wetland. Above: bird's eye view. Below: sketch showing the evolution stages in wetland formation, from single sinkholes (a) to current setting (d). From Liso and Parise, 2023.

## Recent geomorphological processes: sinkholes

The coastal stretch north of Torre dell'Orso locality, within the municipality of Melendugno (Liso et al., 2023) is in an area of tourist and archaeological importance, where the Grotta della Poesia sinkhole system is present (Delle Rose and Parise, 2005; Liso and Parise, 2023). It is characterized by two main collapse sinkholes, developed in a high cliff made of calcarenites of Plio-Pleistocene age. Poesia Grande and Poesia Piccola are connected to the sea.

Along the coast surrounding Roca Vecchia, other sinkholes are also present, some of which are very recent.



Finally, it deserves mention the *Grotta Sfondata*, literally meaning “broken cave”, at the northern rim of the town of Otranto, which is a classic collapse sinkhole, originated by the sea wave action, that produced upward falls from the roof of a marine cave



**Thank you for your attention**