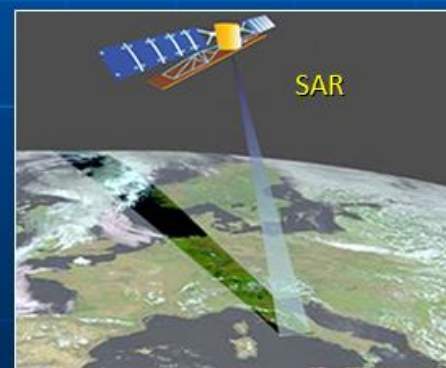
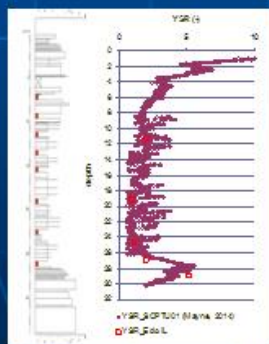
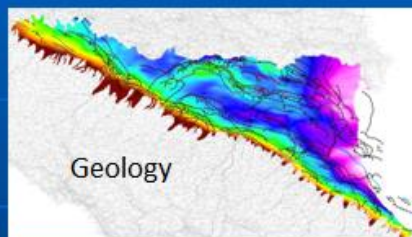
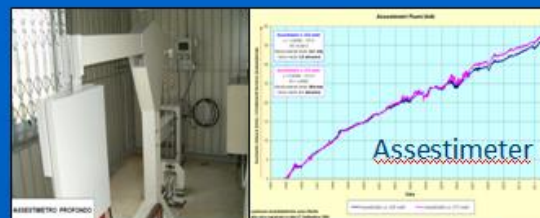


Coastal dynamic



# Integrated geological approach to the study of coastal subsidence in Emilia-Romagna

Luisa PERINI Calabrese Lorenzo, Luciani Paolo, Severi Paolo,

# Subsidence hazard of Emilia-Romagna coastal plain

*Caputo M et al., 1970*



## Subsidence components

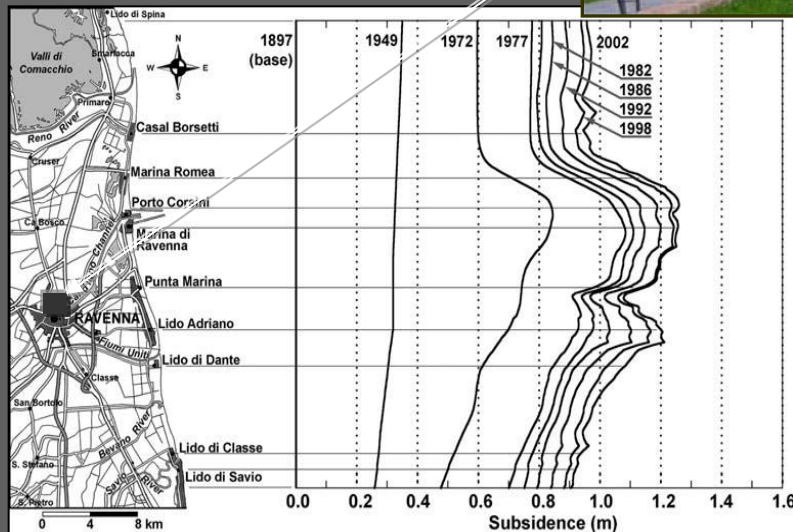
- natural: medium value 2-7 mm/y
- anthropogenic: can exceed 10-15mm/y

anthropogenic components are: groundwater & hydrocarbon pumping ; urban loading and reclamation



Urban sprawl ,in the coastal fringe of 1.5 km from the shoreline, exceeded the 400% after the II world war

*Teatini et al., 2005*



Maximum subsidence recorded values:

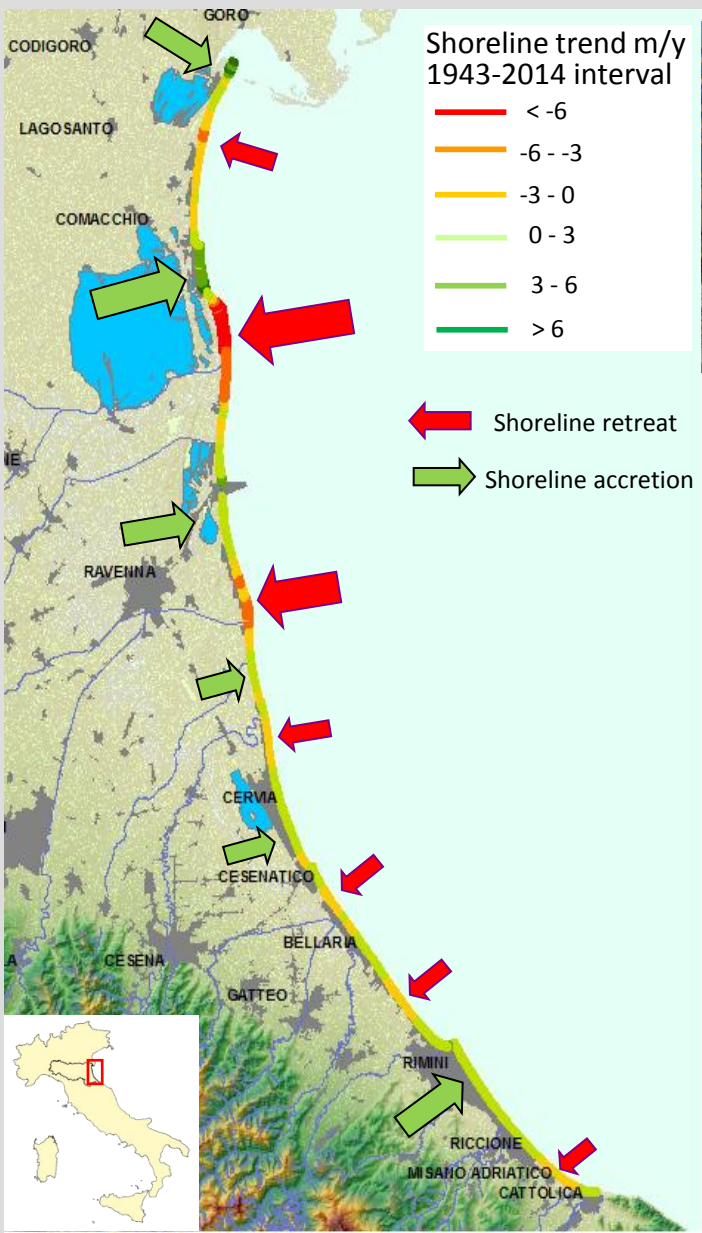
Delta Po: up to 8 cm/y from 1958 to 1967  
(from Caputo et al 1970)

Ravenna municipality: up to 7.8 cm/y from 1972 to 1977 (*from Caputo et al 1970*)

Cesenatico: up to 5 cm/y from 1984 to 1987  
(from Arpae 2002)



# Influence of subsidence on coastal risks: beach and dune erosion

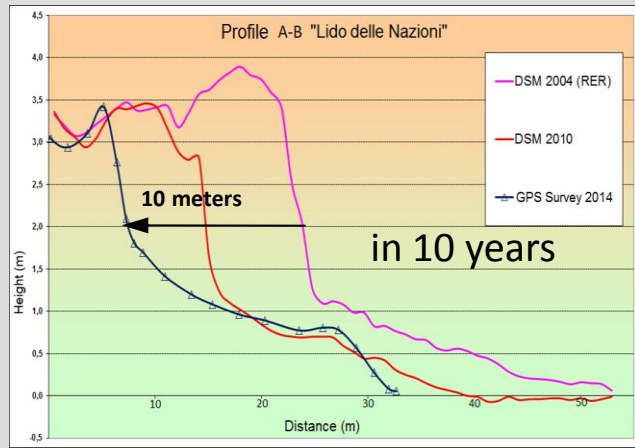


Large areas below sea level



65% of the shoreline at risk of erosion, value reduced to 30% thanks to beach nourishments

Absence &/or discontinuity of coastal dunes; less than 30% of the whole coastline



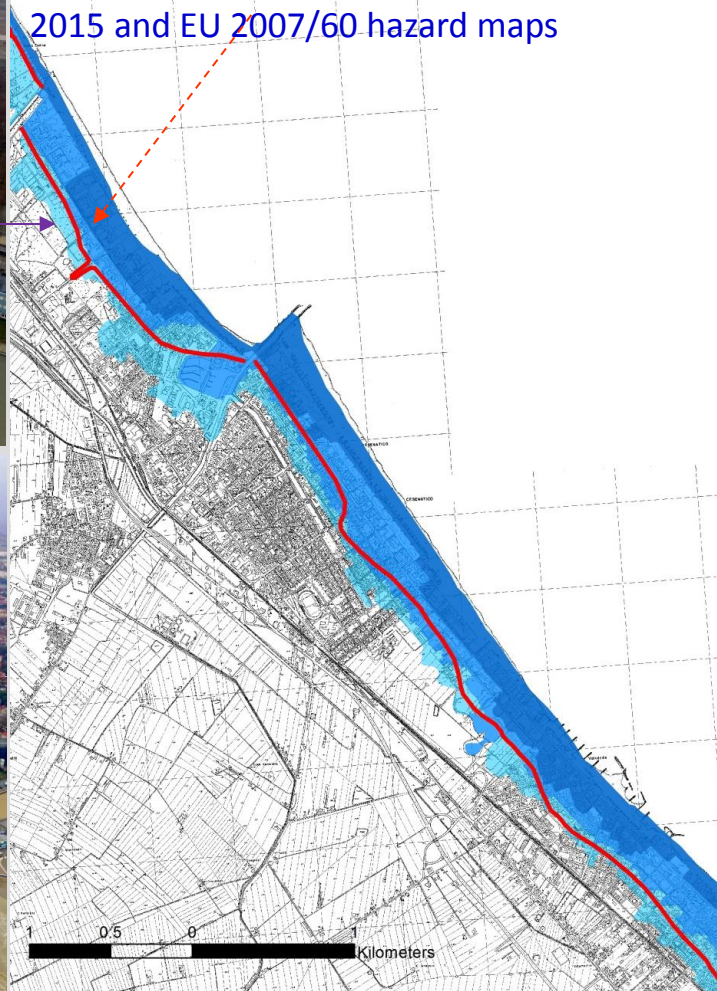


# Influence of subsidence on coastal risks: sea flooding

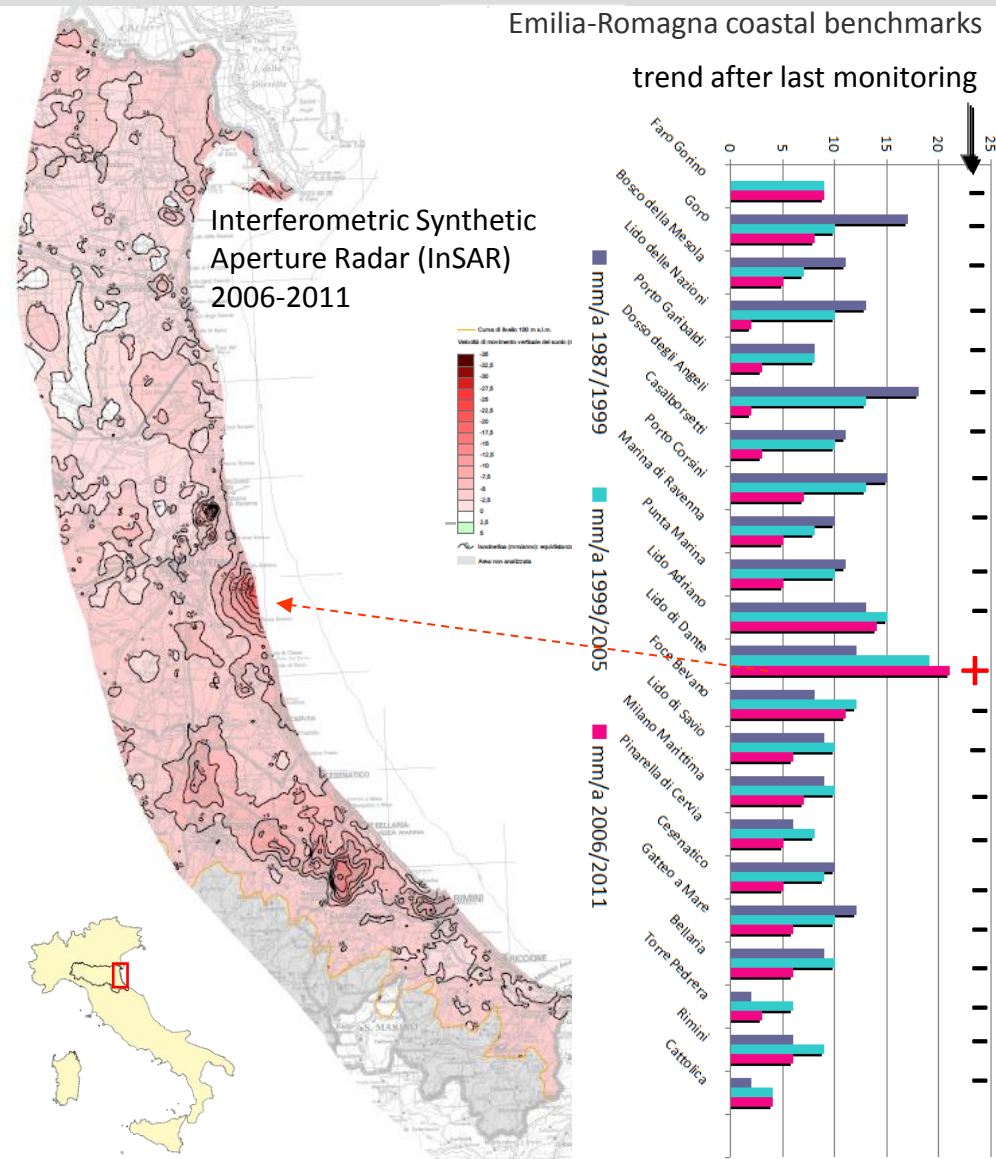
Subsidence increase risk of sea- flooding; which interest large areas of the RER coastal zone : 78.72 km<sup>2</sup>  
(according to flood directive EU dir. 2007/60) - urban areas : 22. 2 km<sup>2</sup>



Comparison between maximum flooding of  
the sea-storm occurred on 5-6 February  
2015 and EU 2007/60 hazard maps



# Coastal subsidence monitoring and measures



Regional monitoring are based on:

Levelling of coastal network : 1984 1987, 1993, 1999 & 2005.

GPS network : 1999 & 2002.

SAR elaborations : 1992-2000, 2002-2006 & 2006-2011

Main regional measures :

- Ridracoli dam (around 1980)
- CER (Emiliano-Romagnolo Channel) (staring from 1955)
- limitation of groundwater pumping during summer

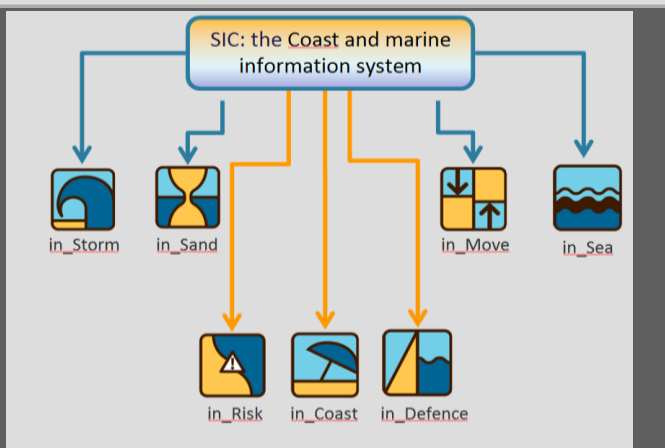
Surface monitoring now shows a general decrease in subsidence rate; it only allows to check evolution of the phenomena but not the different components

Several studies were carried out on the analysis of water pumping effects but not on geological subsidence and other anthropogenic components

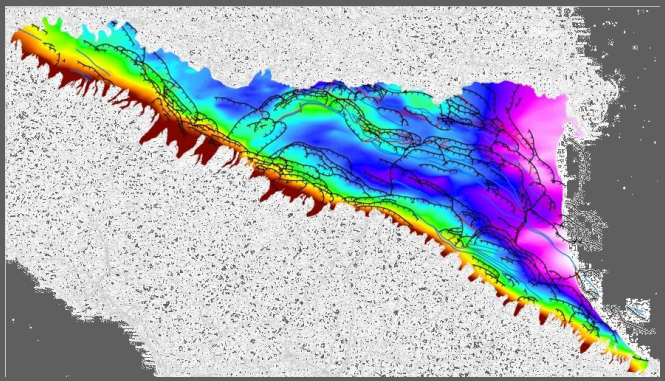




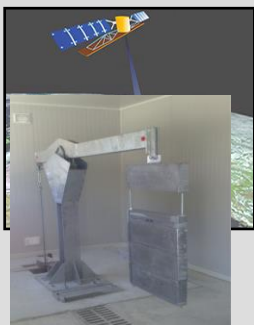
# In\_Move: a tool for the integrated analysis of land subsidence



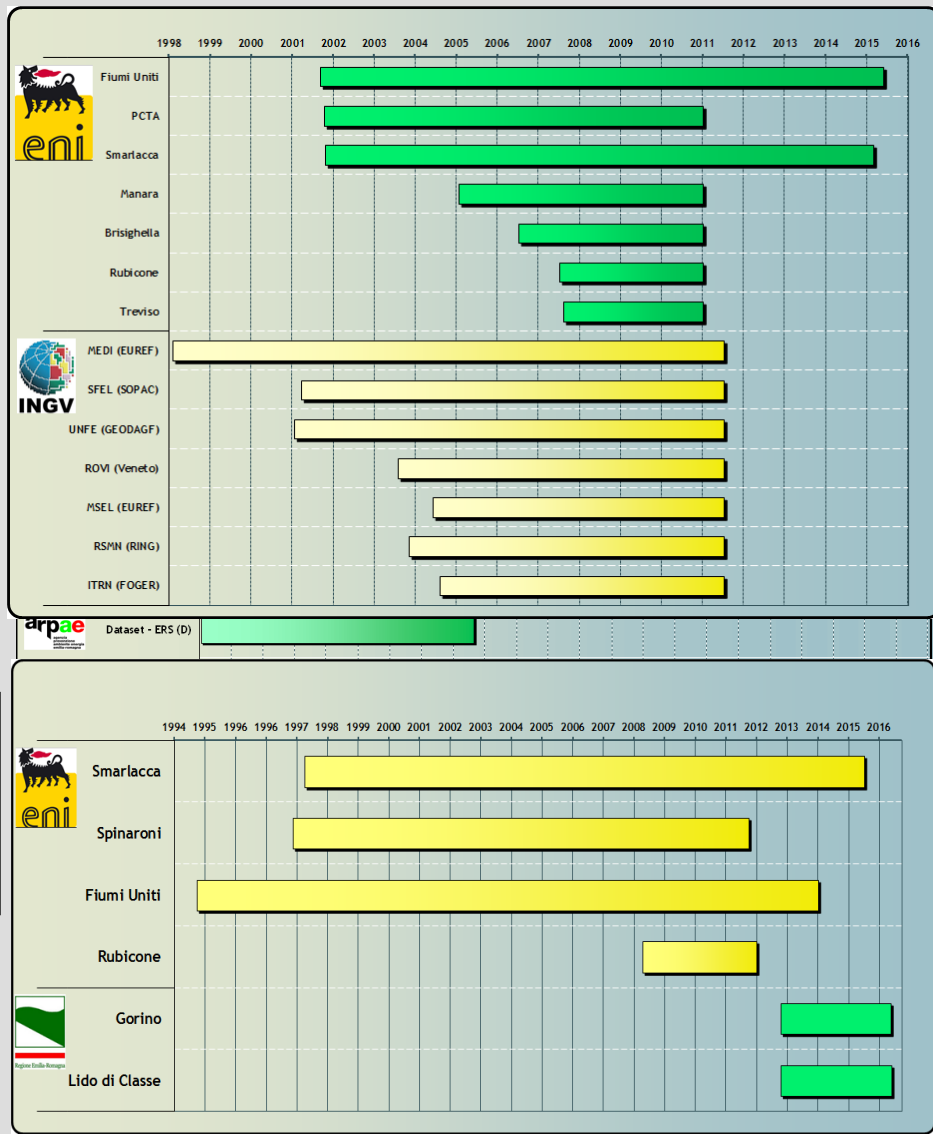
Geodatabase in\_Move integrated into the SIC and linked to the geological databases of SGSS



**GNSS  
Permanent Station**



**Assestimeters**



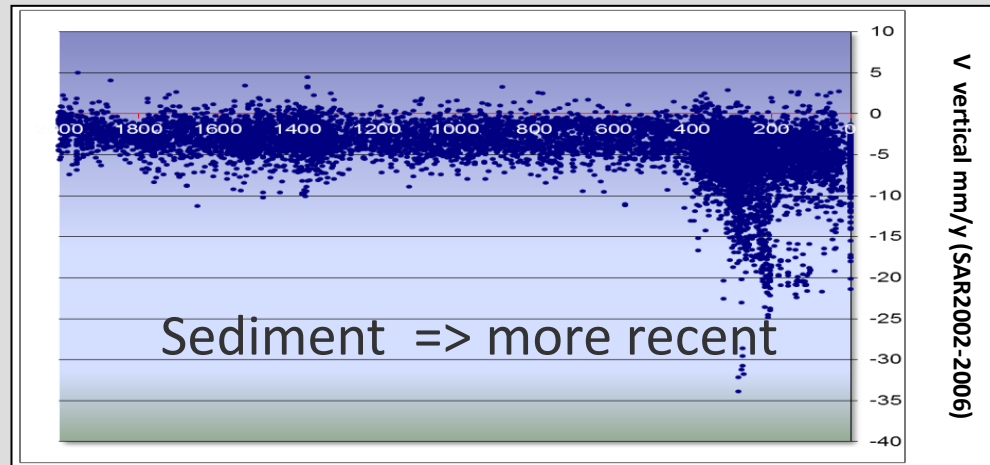
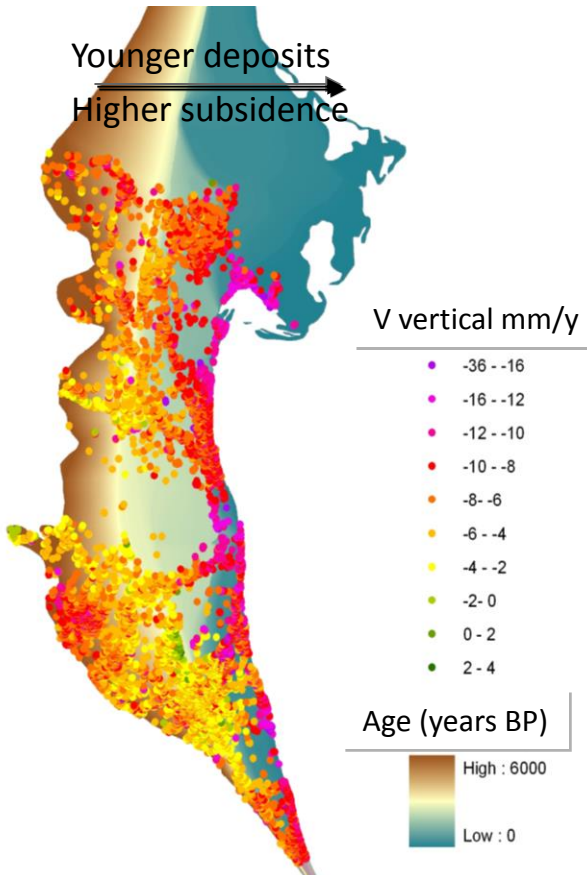
Stated studies at regional and local scale on:

- Contribution of surface geology
- anthropogenic components – urban loading and gas exploitation

# Quaternary deposits and subsidence rate

Analysed the correlation between coastal sediment age and subsidence rate - according to recent studies in the Po delta area (Teatini et al., 2011)

Subsidence rate 2006-2011  
over Holocene deposits age

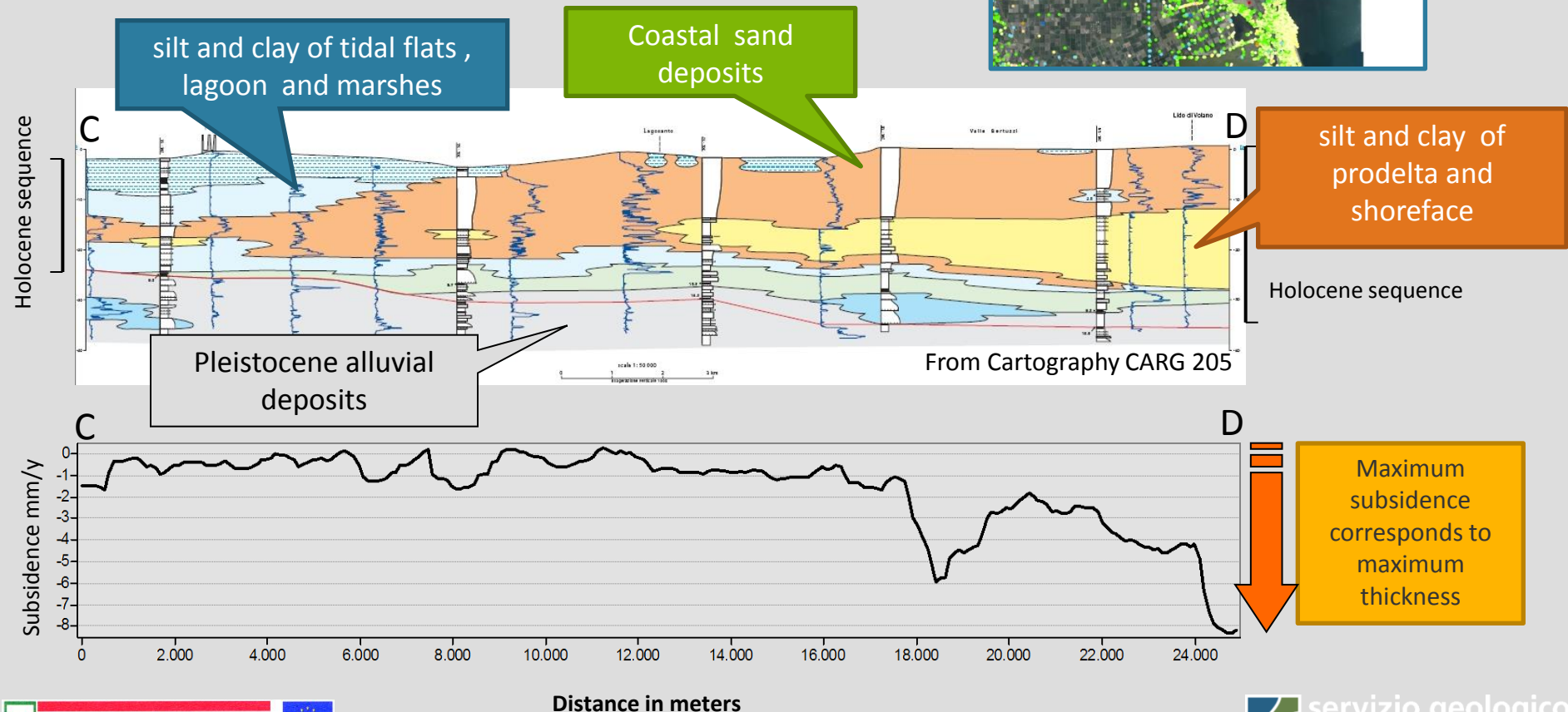


More evident where deposits age < 400 y

Towards the shoreline: more recent and unconsolidated deposits and higher thickness of fine grained deposits

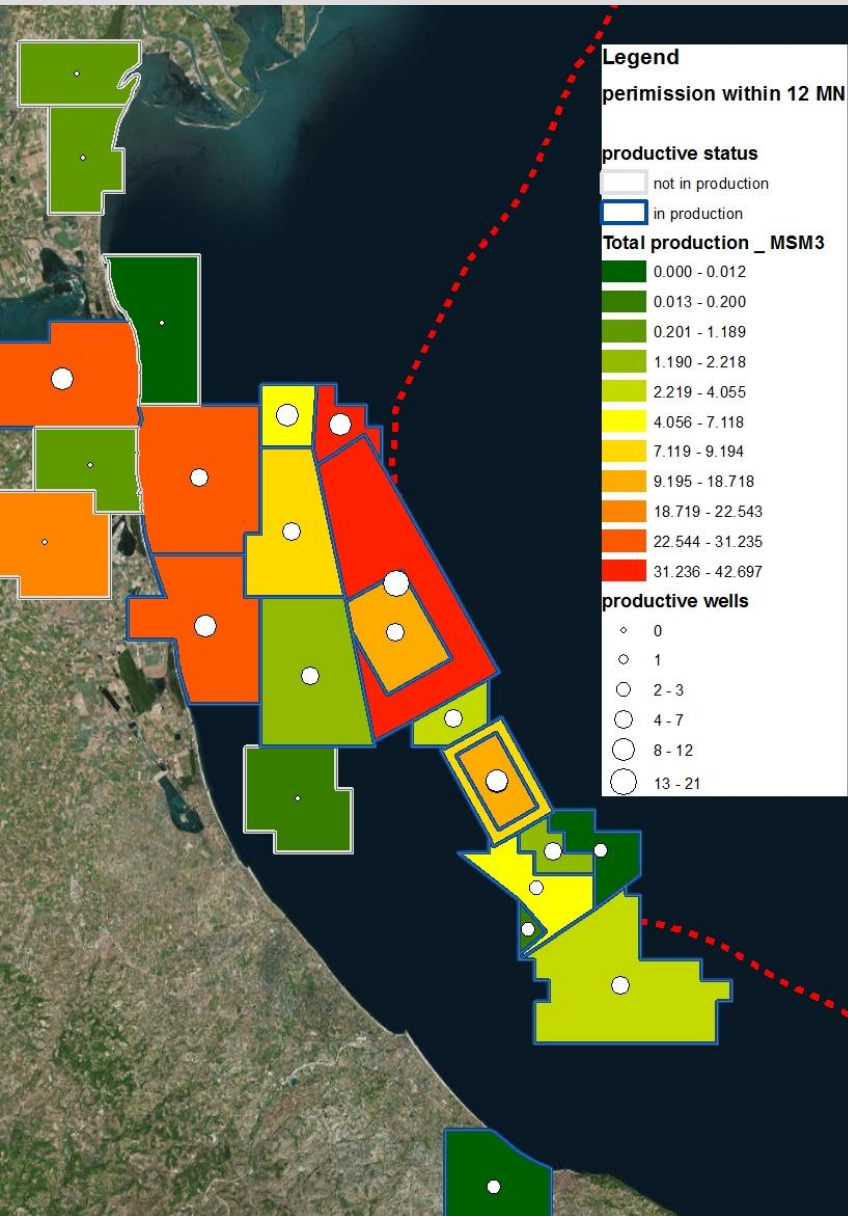
# Architecture of Holocene coastal deposits

- thickness about 20-35 m
- transgressive-regressive sequence
- sandy units including layers of fine and soft silty clay





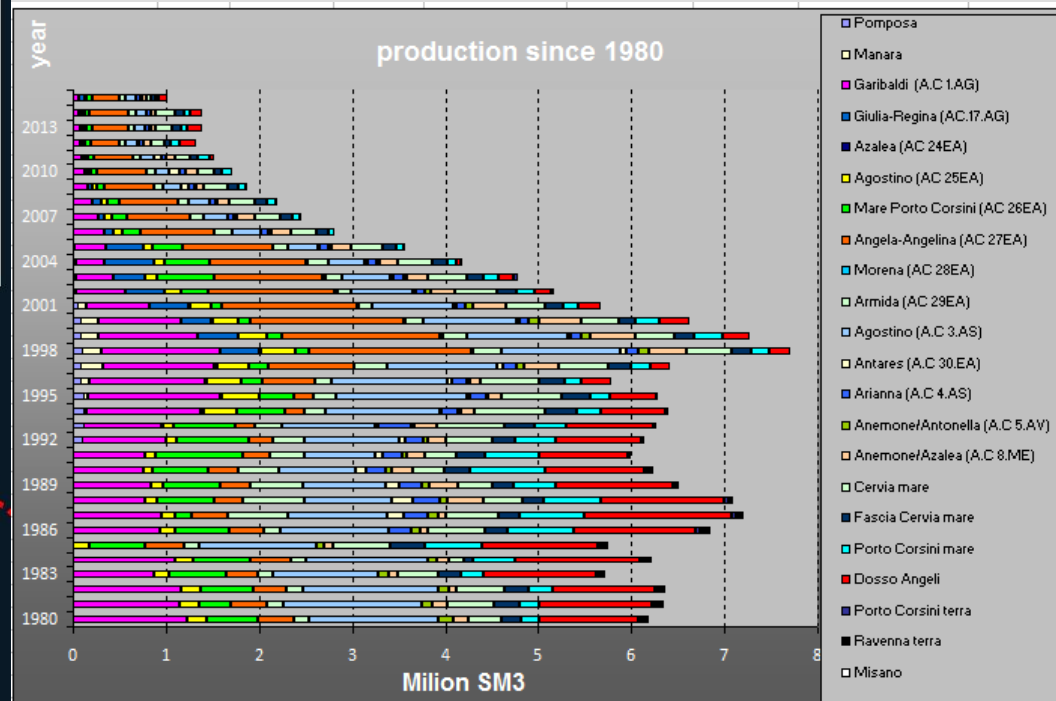
# Effect of gas exploitation



The coastal and marine area of Emilia-Romagna, within the 12 Mn (24 permissions; 113 productive wells), is interested by intensive exploitation of gas fields

Since 2010 the exploitation rapidly decreased, in fact now the production is 1/7 respect to 1998, the year of the peak in the production (7.7 million SM3)

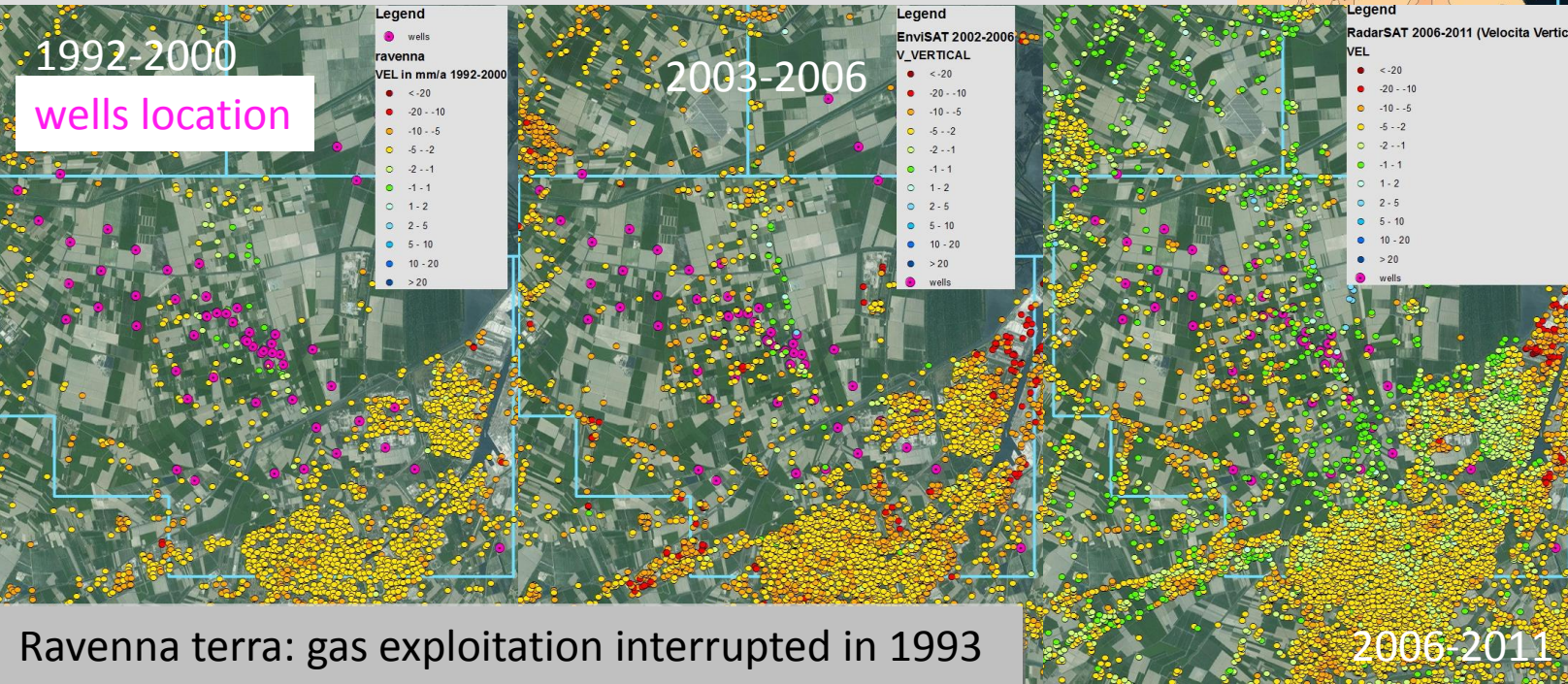
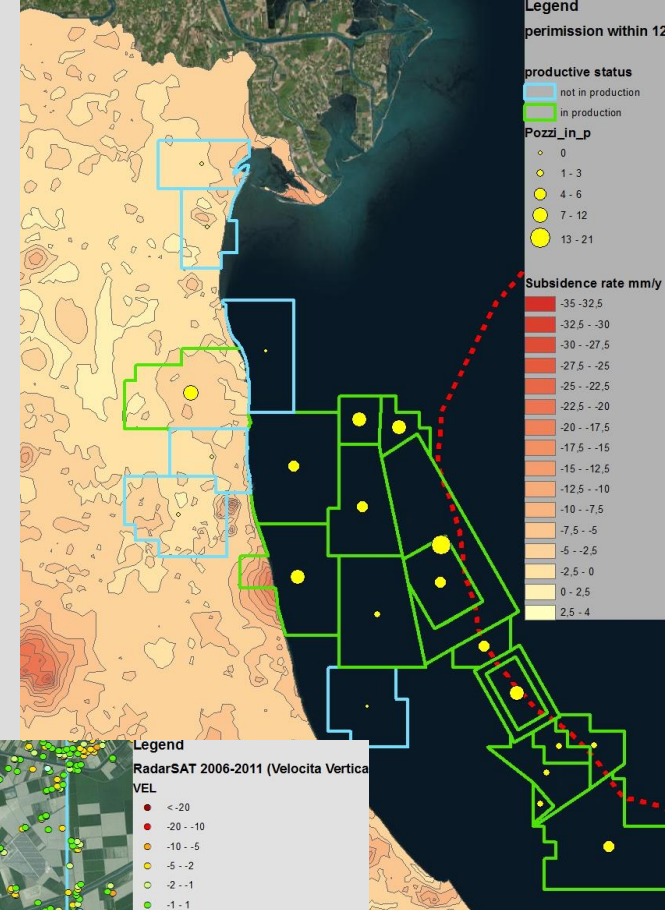
Analysis of the correlation between gas exploitation and subsidence rates is going on in collaboration with Arpae



# Effect of gas exploitation

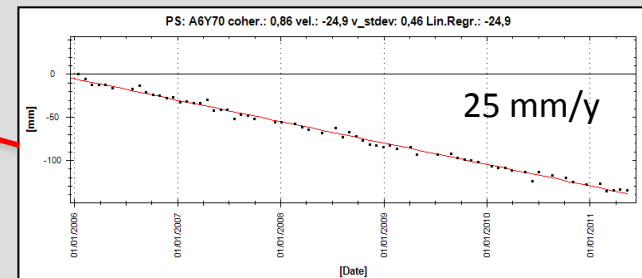
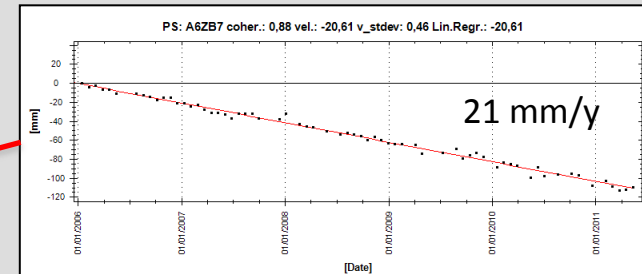
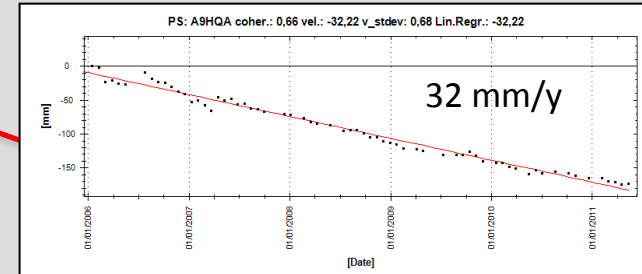
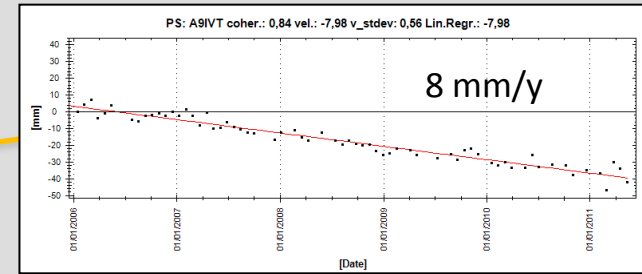
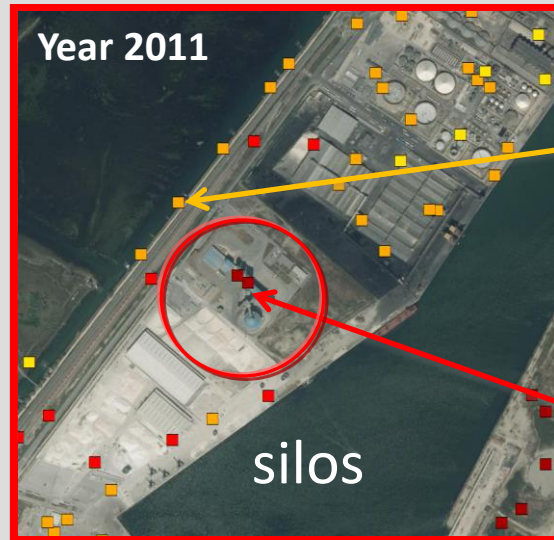
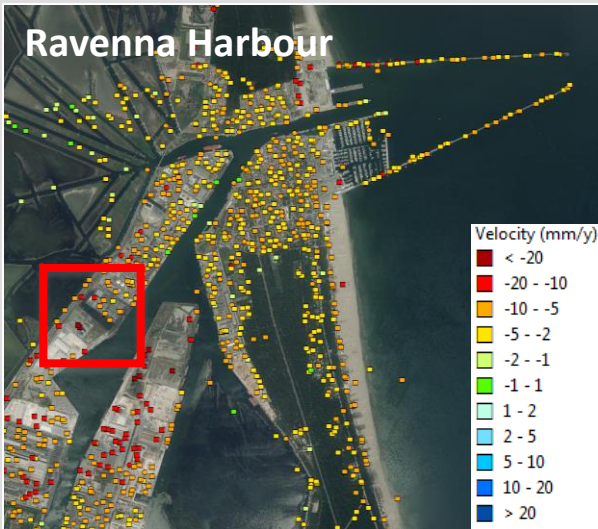
Preliminary results of the comparison between productions and subsidence of intervals 1992-2000; 2003-2006 and 2006-2011 are:

- the increase in subsidence rates during gas exploitation, is not proportional to the extracted volumes in the different permissions. An important role must be sought in the local geology
- after the stop or strong reduction of gas pumping, the subsidence decreases in a different way, probably as a consequence of a delayed behaviour of the reservoir rocks and of other causes independent from gas exploitation





# Effect of urbanization on coastal deposits compaction



Several sites show a component of subsidence rate due to the sediment consolidation under new urban or infrastructure loading

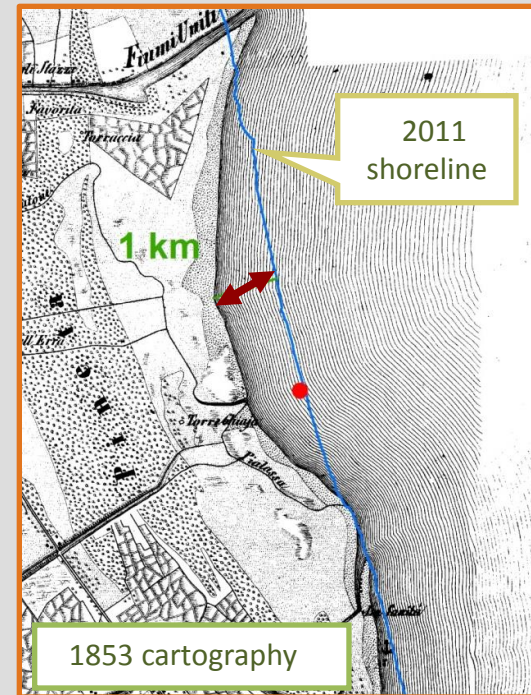
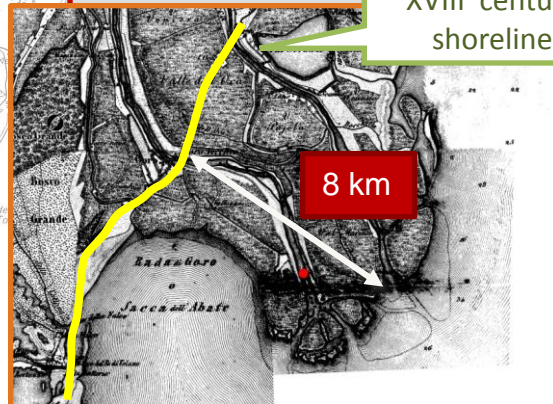


# In\_Move: study cases

2 pilot areas have been selected in order to analyse the residual compressibility of Holocene deposits, both characterized by recent accretion

## GORINO site

On the Po river deltaic lobe - rapidly increased since the XVIII century



## LIDO di CLASSE

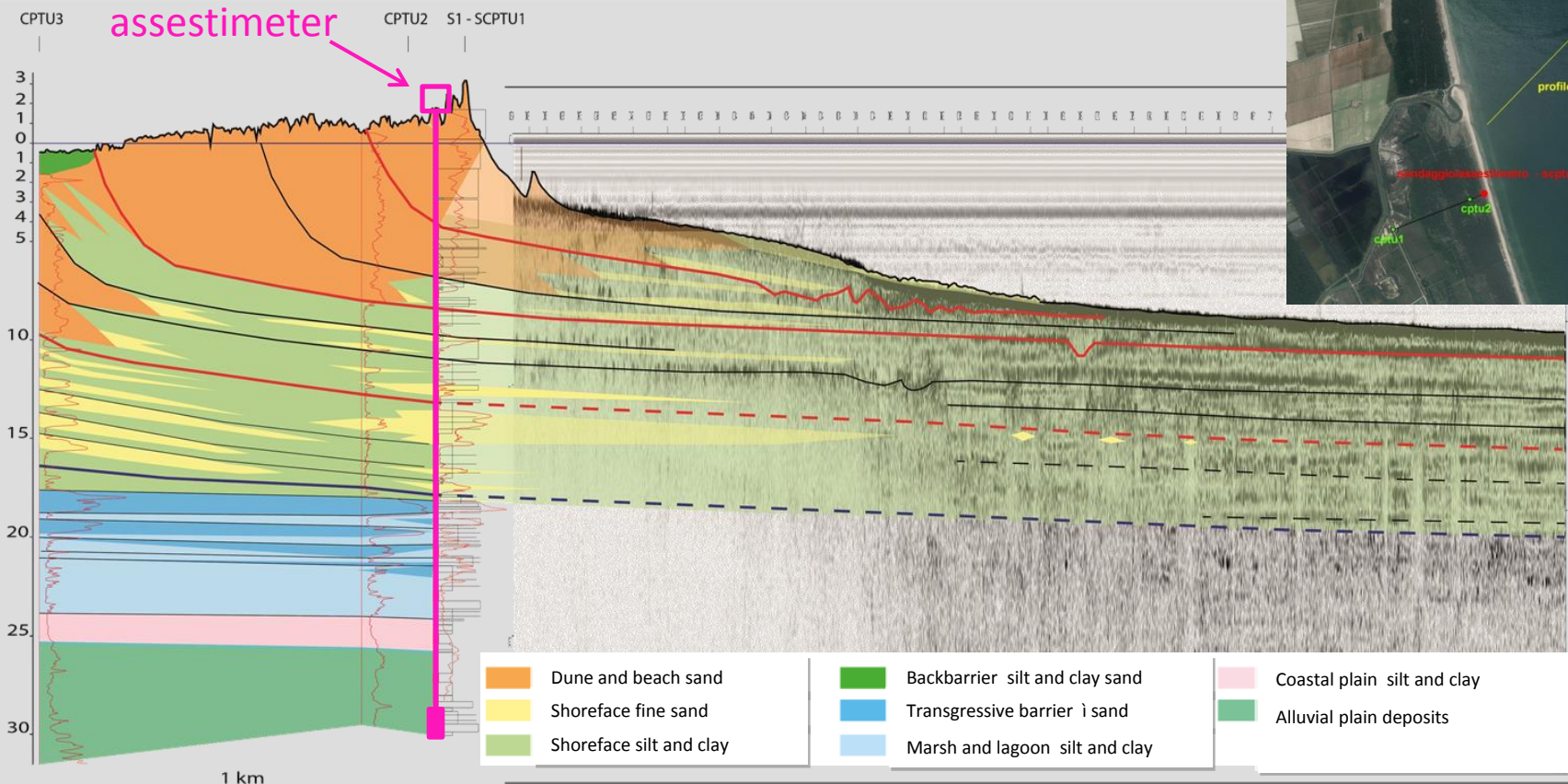
between deltaic cusps of Ronco-Montone/Fiumi Uniti rivers - increased since XVI century

- Assestimeters anchored below the Holocene deposits – installed in November 2013



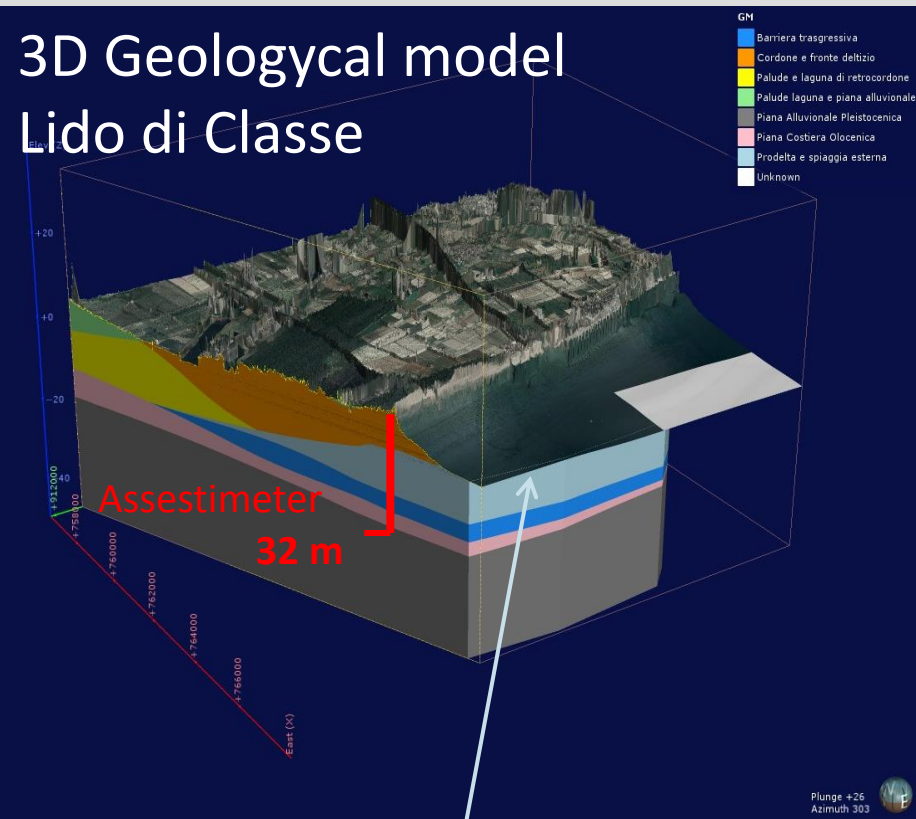
# Study cases

both sites have been investigated through geological, geotechnical and geophysical survey (activity in joint with CNR-ISMR) ring - cone penetration tests (CPTU) – sediment classification and oedometer tests



Detailed stratigraphic correlation at lido di classe

# Study cases

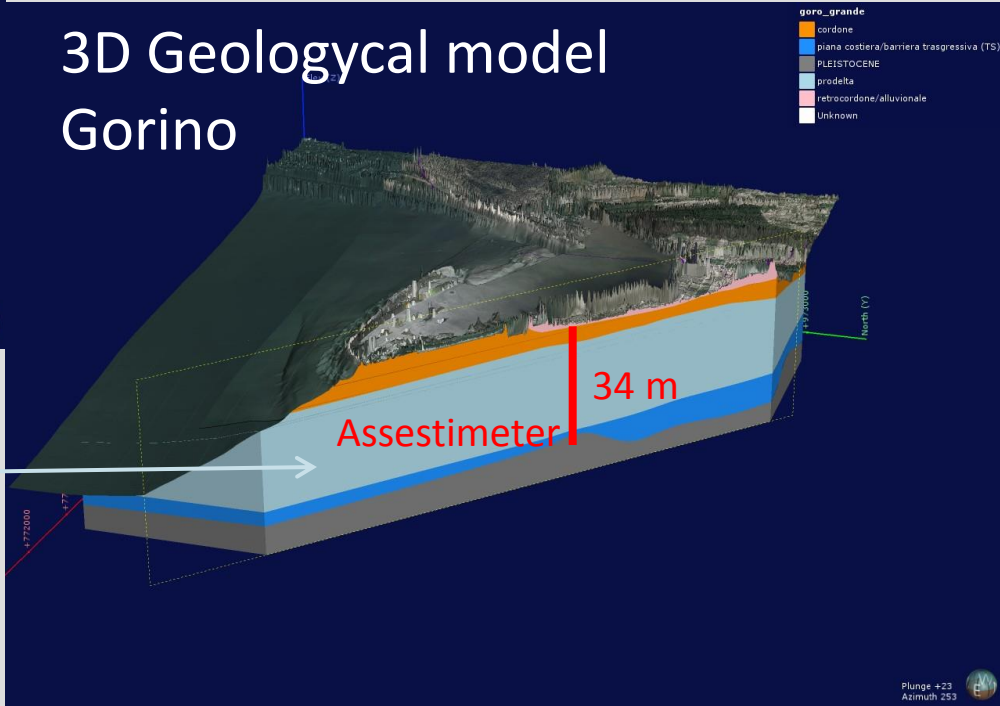


Silt and clay layers where maximum consolidation is expected (thickness 15 m at Lido di Classe and 15-20 m at Gorino site)

First results of the laboratory tests (carried out by Unife-ISMGeo -analysed following Burland 1990 approach) show that some intervals, corresponding to the prodelta and shoreface silty clay deposits are characterised by high void ratio and low strength, here more compressibility is expected

Assestimeter analysis are still insufficient, a longer series is needed :

- they generally show a compressibility of few mm/y
- especially in Gorino site high variability due oscillation of water table





# Final remarks

A new approach to the subsidence phenomena evaluation has been started in SGSS -RER

It's based on an integrated approach using multiple data sets which give a wider view of the phenomena in the area of interest; different survey techniques increase quality of interpretation

different methodologies in data acquisition allow a different scale analysis: SAR for general overview; GPS and assestimeters for local analysis; we need to improve the integrated analysis of the different systems

the analysis of geological components (such as residual compressibility of Holocene deposits) and of anthropogenic components (urban loading) provided interesting scenery for a better comprehension of the phenomena along the coastline