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THE SHALLOWS PROJECT: PRELIMINARY INVESTIGATION

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Riassunto

Nell'ambito del Programma di studio "La laguna di Venezia nel quadro dei cambiamenti climatici, delle misure di mitigazione ed adattamento e dell'evoluzione degli usi del territorio", il Progetto SHALLOWS "Indagini nel sottosuolo olocenico della laguna di Venezia" è stato avviato nel contesto dell'Attività: "Analisi delle componenti a scala locale del relative *sea level rise* alla luce degli scenari globali di sviluppo futuro considerati dall'IPCC".

Questo progetto prevede l'estensione all'area lagunare centrale delle indagini del sottosuolo lagunare condotte nell'area meridionale dalla Linea di Ricerca 3.16, nel precedente programma di ricerca CORILA (2004-2006).

Le indagini verranno principalmente condotte nei bassifondi attraverso rilievi sismici ad altissima risoluzione, analisi sedimentologiche e geomorfologiche. In particolare saranno investigati in dettaglio alcuni siti chiave dove sono presenti strutture geomorfologiche sepolte, ad esempio sistemi deltizi e di argine-canale.

In questo articolo vengono presentati scopi ed obiettivi della ricerca e riportati alcuni esempi di risultati relativi alle indagini preliminare effettuate nella fase di programmazione delle campagne di rilevamento geologico.

Abstract

In the framework of the CORILA Research Programme "La laguna di Venezia nel quadro dei cambiamenti climatici, delle misure di mitigazione ed adattamento e dell'evoluzione degli usi del territorio" the SHALLOWS Project: Indagini nel sottosuolo olocenico della laguna di Venezia been activated within the Activity "Analisi delle componenti a scala locale del relative sea level rise alla luce degli scenari globali di sviluppo futuro considerati dall'IPCC".

Whit this project, the investigations of the subsoil carried out in 2004-2006 (Research Line 3.16 of the 2004-2006 CORILA Research Programme) in the southern area of the Venice Lagoon, extend to the central lagoon basin. Investigations in the subsoil down to about 20 m depth below the lagoon shallows are ongoing by Very High Resolution Seismic survey, sedimentological and geomorphological analyses. In particular, the study focused on some key sites where signs of the presence of buried geomorphological features, e.g. deltas and channel-levee systems, have been preliminary detected.

At the date, only preliminary results are available. Hence, this paper describes the aims and objectives of the research and shows a few example of the recently acquired data.

1. Introduction

The Venice Lagoon originated during the Holocene transgression of the Adriatic Sea onto the northeastern part of the Late Pleistocene Po plain and its evolution has been subjected to a complex combination of natural processes and human interventions [Gatto and Carbognin, 1981].

The activity of the Po, Adige and Brenta river systems largely influenced the evolution of the central and southern Venice Lagoon during the Holocene. At present, in the watershed NW of Venice the distal margin of the Late Pleistocene Brenta river alluvial fan is exposed [Tosi et al., 2007a; Tosi et al., 2007b]. Abandoned riverbeds recognized in the central and southern catchments mainly correspond to Late Holocene courses of the Brenta River, whereas some of the southernmost traces refer to ancient systems of the Adige and Po rivers (Fig. 1). In particular, in the coastal plain near the southern lagoon margin there is evidence of the northernmost paleoriverbed of the Po River that was probably active until the Roman Age [Tosi et al., 2007b]. Signs of paleobeach ridges, extending in NE-SW direction, were identified analyzing the digital elevation model (DEM) of the lagoon bottom (Fig. 1).

The westernmost paleobeach ridge is related to an ancient shoreline found in the coastal plain south of the Venice Lagoon and likely dating back to about 4,5 Kyr BP. In the last 4 Kyr, depositional activity of the Brenta, Bacchiglione, Adige, and Po rivers filled up the back-barrier lagoon and the surrounding swamps causing the eastward migration of the littoral, presently testified by the clear evidences of a complex system of ancient beach ridges and sand dunes [Rizzetto et al., 2003]. Very High resolution Seismic (VHRS) surveys pointed out the presence of morphological features related to these systems in the lagoon basin [Rizzetto et al., 2009; Tosi et al., 2009b; Zecchin et al., 2008; Zecchin et al., 2009] (Fig. 2).

Since Roman times the lagoon has been considered a source of security against enemies because of its peculiar environmental setting, and several hydraulic works, aimed at preserving the lagoon environment, were carried out over the centuries. First hydraulic works were carried out to divert toward the sea the course of Adige, Brenta, Bacchiglione, Sile and Piave rivers flowing into the lagoon whose continuous supply of sediment threatened the gradual silting-up of the basin and the consequent risk of the lagoon conversion into a marshland. These huge works started in 1400 A.D. and concluded in 1609 with the diversion of the Po River to the South.

Starting from 1800, man again intensely altered the lagoon setting with large-scale intervention such as land reclamation and filling-in operation aimed at improving the agriculture and expanding the industrial and urban zones; new deep shipping canals were dug to serve the industrial harbour adequately, as well as changes to and reduction in the number of sea openings were carried out to

improve the efficiency of the port of the original eight inlets; the permanent closure of areas near the lagoon margin for use as fish farms. Furthermore, during the 1950's - 1960's the industrial water supply was provided by rash exploitation of artesian aquifers inducing a serious land subsidence, which, in turn, deepened the bottom of the basin further and contributed to an intensification of "acqua alta" events (a local idiom meaning "flooding").

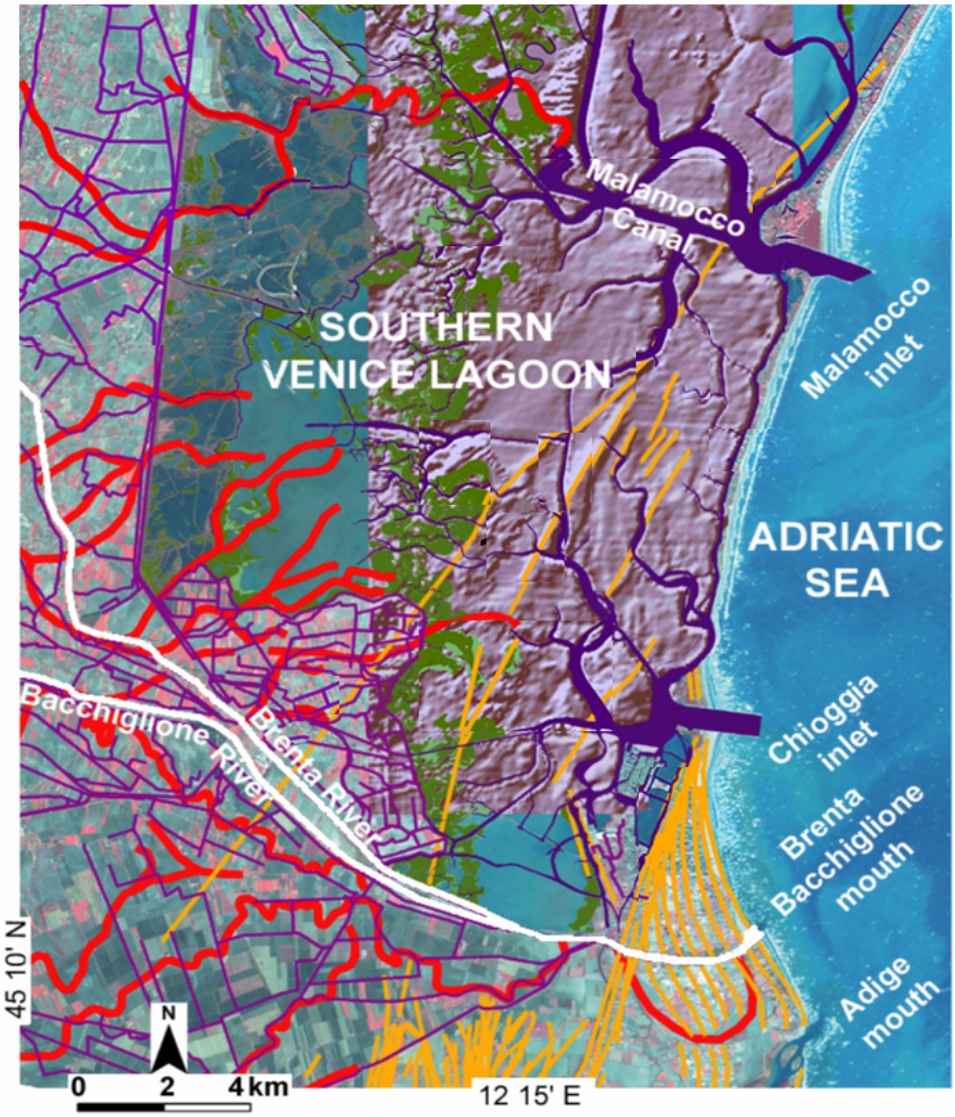

Fig 1. ASTER satellite image of the southern Venice coastland. A shaded relief map of the lagoon bottom is superimposed on the image. Red lines: paleoriverbeds; orange lines: paleobeach ridges; dark violet and light violet areas: present lagoon channels and hydrographic network, respectively; green areas: salt marshes. White lines highlight the present courses of the Brenta and Bacchiglione rivers. Modified from Tosi et al. [2009b].

Since the beginning of the 1990's a vast series of safeguard measures were implemented and are currently under way, to partly restore and defend the environment. They include the creation and/or the nourishment of beaches, the restoration of sand dunes, the reconstruction and protection of the wetlands, the local defence works in the historic city and other lagoon centres, as well as a major project involving temporary closure of the three inlets to guard against exceptional floodings in the lagoon, i.e. the MOSE (MOdulo Sperimentale Elettromeccanico) project [Carbognin et al., 2000].

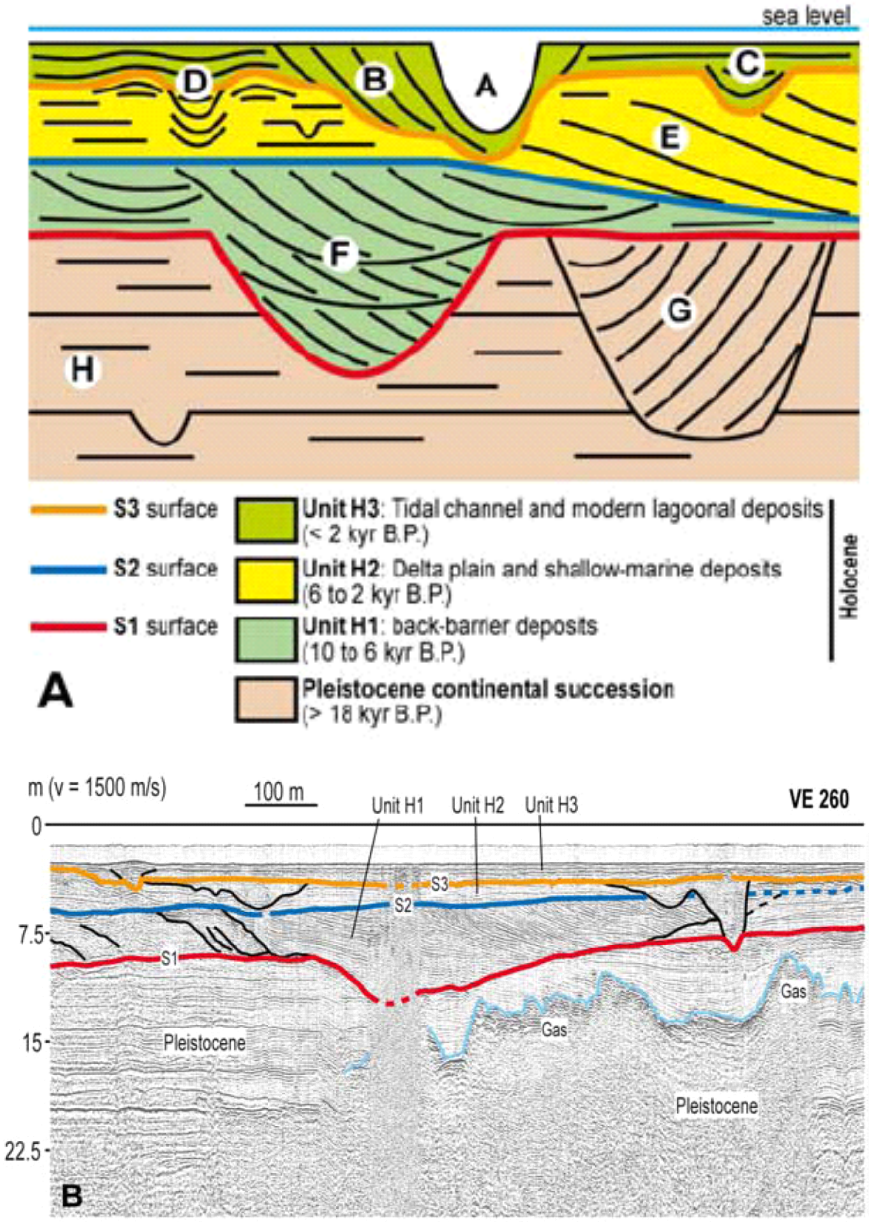

Fig 2. (a) Simplified architectural scheme of the Holocene deposits in the southern Venice Lagoon. Unit H1 represents the transgressive sequence, whereas Unit H2 is the regressive sequence. Unit H3 consists of sediments deposited during the recent human-induced transgression that followed delta abandonment. A-Active tidal channel; B-Lateral accretion; C-Buried tidal channel; D-Channel-levee system; E-Clinoforms; F-Early Holocene estuarine and fluvial channels; G-Pleistocene river; H-Pleistocene alluvial plain. (b) Late Pleistocene and Holocene complex channelized sequences. Modified from Tosi et al. [2009b].

2. The SHALLOWS Project

Seismic surveys carried by the RL3.16 Project in the framework of the 2004-2006 CORILA Research Programmes produced new insight in the evolution of the southern Venice Lagoon through the Late Pleistocene and Holocene.

In the framework of the of the CORILA Research Programme: “La laguna di Venezia nel quadro dei cambiamenti climatici, delle misure di mitigazione ed adattamento e dell’evoluzione degli usi del territorio”, and in the context of the Activity: “Analisi delle componenti a scala locale del relative *sea level rise* alla luce degli scenari globali di sviluppo futuro considerati dall’IPCC”, the goal of Sub-activity “Investigation of the Holocene subsoil of the Venice Lagoon”, i.e. SHALLOWS Project, is to complete the investigation started in the previous RL3.16 Project by widening the study area to central lagoon basin.

SHALLOWS Project will take advantage from that experience and in particular from the Very High Resolution Seismic surveys ad hoc implemented and capable to acquire data in very shallow water (about 1 m depth).

2.1 Why it is important to perform Very High Resolution Seismic surveys in the Venice shallows?

Sediment sampling allows accurate sedimentological studies of the sedimentary successions and the precise description of depositional environments, providing the base for the lateral crono-stratigraphic and main depositional environment correlations. Recently Zecchin et al. [2008], Rizzetto et al, [2009], Tosi e et al. [2009b], Zecchin et al. [2009] providing impressive images of the southern lagoon subsoil, evidenced the high complexity of the Late Pleistocene-Holocene deposit architecture, which is characterized by a high lateral heterogeneity and the presence of numerous geomorphological structures. It is then very difficult providing a high-quality reconstruction of the deposit architecture, even with the availability of a large core number.

Fig. 3 illustrates a typical geological section across the lagoon. It is clear that the record of the recent sediments is very limited or even missed in correspondence to the major channels which are not representative of the evolution of the lagoon. The same figure also include two examples of seismic profiles both crossing a small tidal channel. It is evident that the difference in the sea floor grain size (coarser in the channel and finer in the shallows) produce a strong difference in the seismic section: in correspondence to the channel, the signal is dominated by the multiple reflections while, in the shallows, primary reflections are in a good evidence.

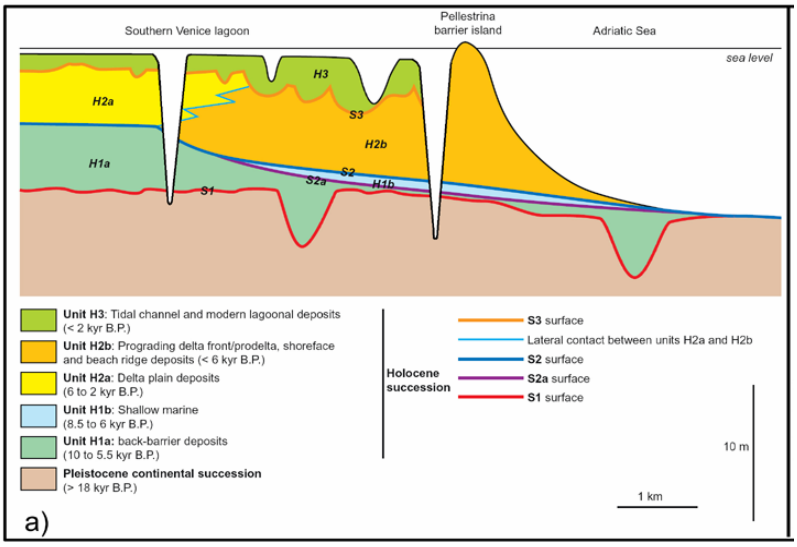

Fig 3. a) Schematic cross-section of the lagoon subsoil [modified from Zecchin et al., 2009].

Since the shallows represent the 90% of the Venice lagoon the knowledge of their geological setting is of particular relevance for many scientific and engineering issues. Only by geological and geophysical investigation in the shallows it will be possible to get a detailed tri-dimensional reconstructions of the recent evolution of the Venice lagoon and a satisfactory understanding the

rule and the interaction of the different components of the relative sea level changes.

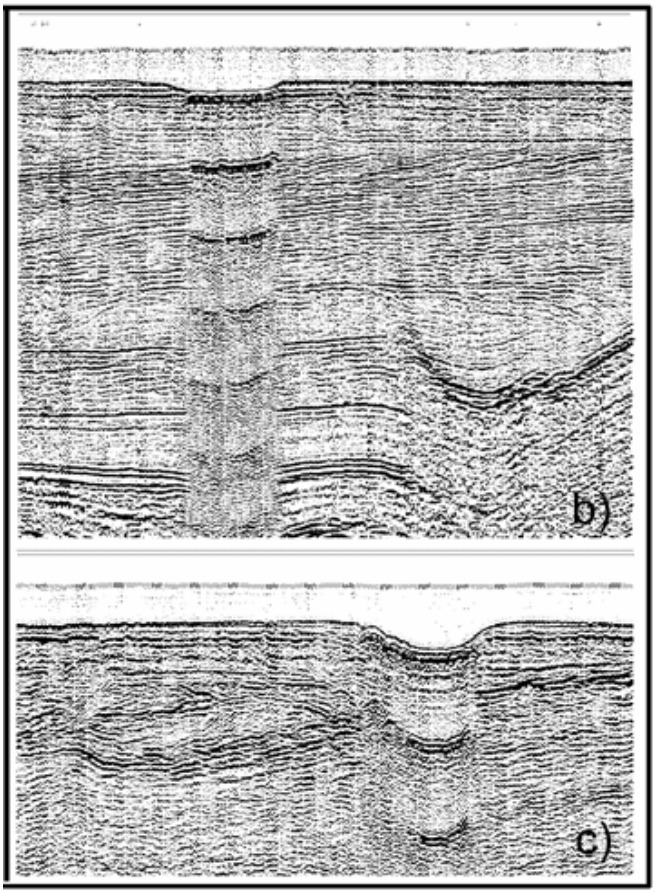

Fig. 3. b) and c) examples of VHRS profiles showing very fine detail of the subsoil below the shallows whereas bad results in correspondence of tidal channels.

2.2 Aim and objectives of the project

The aim of this study (SHALLOWS Project) is to understand the changes in the lagoon landscape over the Holocene, as well as to better distinguish natural and human-induced causes responsible for its historical evolution [e.g., Tosi et al. 2009b].

The surveys will be carried out in the shallows of southern and central parts of the Venice Lagoon. In particular, detailed investigations will be focused on some key sites where signs of the presence of buried geomorphological features, such as ancient coastlines, deltas and channel-levee systems, occur.

Specific objectives of this study are: (a) the assessment of the architecture and lateral variability of the Holocene sediments [e.g., Zecchin et al. 2009], (b) the recognition of buried fluvial channels probably related to Late Pleistocene and Holocene courses of the Brenta and Bacchiglione Rivers [e.g., Rizzetto et al. 2009, Tosi et al. 2009b], (c) the reconstruction of the evolutionary sketch of inactive and active tidal channels, aimed to understand their dynamics and their rule in the morphological evolution of the lagoon [e.g., Zecchin et al., 2009].

2.3 Materials, methods and activities

Seismic surveys, geomorphological investigations and sedimentological analyses are used in this study.

The main project activities are:

- Field acquisition and processing of a VHRS survey for approximately 100 km of sections.
- Collection, homogenization and processing of the data (sedimentological, geophysical, mapping, etc.).
- Sedimentological and micropaleontological analysis of sediment samples from available cores.
- Integration of seismic data and sedimentological data.
- Delivering of processed data and final report.

Seismic surveys are carried out by a Very High Resolution Seismic (VHRS) system optimized to operate in water depths less than 1 m [Brancolini et al., 2008]. This system consists of i) an impulsive energy source (boomer), ii) an electro-dynamic transducer mounted on a catamaran frame and iii) a pre-amplified oilfilled streamer composed of eight piezoelectric elements connected in series with a 2.8 m active array section. The boomer produces a theoretical minimum phase wavelet with an amplitude spectrum between 200 and 9000 Hz. The maximum impulse rate generally used is 8 pulses per second at 150 J and the hydrophones have a sensitivity of 63 dB/Volt/microbar and a bandwidth of 100–10,000 Hz.

After the line-drawing of the main unconformities and the geomorphological features, seismic sections are interpreted following the seismic stratigraphic models from Zecchin et al. [2009] and Tosi et al. [2009b].

Reconstruction of the seismic-morpho-stratigraphic units is generally accomplished by integrating analysis of the seismic data with both sedimentological analyses and available geological information, i.e., sedimentological, stratigraphic, geotechnical, mineralogical, textural, and bathymetric data, ^{14}C dating, satellite images, and historical maps.

New sedimentological and micropaleontological analyses are carried out in samples from cores provided by the Water Authority of Venice and ISMAR-CNR\Venice. In particular, sediment samples were collected along the cores at 20 cm intervals and at each lithological variation. A sub-aliquot of 50-60 g was taken from each sample for the micropaleontological and sedimentological analyses. The aliquots were dried at 50°C for 24 h, weighted and then treated with hydrogen peroxide (10 % vol) for 12 hours to remove the organic matter. They were then washed through a 63 µm mesh and dried. These fractions were weighted to determine the percentage of sand and silt remaining.

Foraminifers were studied quantitatively on a subsequent sub-sampling of at least 300 individuals, which are sufficient to identify the dominant taxa, according to Murray (1976).

The interpretation of the environmental meaning of the benthic foraminiferal

assemblages are inferred from the modern benthic communities [Serandrei Barbero et al.,1999; Donnici et al., 1997; Albani et al., 1991; Albani et al., 1998; Donnici and Serandrei Barbero, 2002, 2004; Canali et al., 2007; Zecchin el al., 2009].

2.4 The study area

The study area of the SHALLOWS Project is the central lagoon basin though some investigation are required south of the Malamocco Canal to integrate the previous survey carried out within the CORILA 3.16 subproject (**Errore. L'origine riferimento non è stata trovata.**).

3. Preliminary data

The activities related to the first six months were a test of the seismic acquisition system, sediment analysis from available a 25 m long core and the first VHRS campaign.

3.1 VHRS surveys

The seismic surveys program has been planned according to the existing data and the research objectives and a survey test carried out in the study area allowed the step-up of the VHRS system.

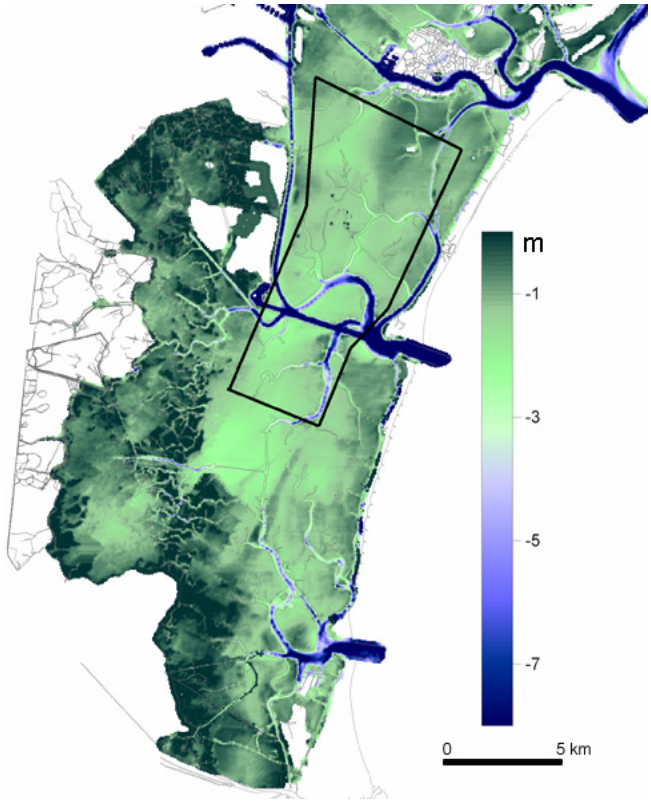

Fig 4. Bathymetric map of the southern and central basins of the Venice Lagoon showing the study area.

A test survey was performed in June 2009. Two main campaigns have been scheduled for the acquisition of seismic lines: the first one is based a coarse grid of about 80 km aimed to i) asses the architecture of the subsoil of the

central lagoon basin and to ii) identify geomorphological features of interest. The second survey follows a fine grid of about 20 km to point out the structure details of the selected active and inactive channels.

The first campaign (SHALLOWS 1) was carried out in September 2009; Fig. 5 shows the position of the seismic lines. Three examples of seismic data showing the architecture of buried channels are reported in Fig. 6, Fig. 7 and Fig.8.

Fig 5. Position of the seismic lines acquired during the first survey (SHALLOWS 1)

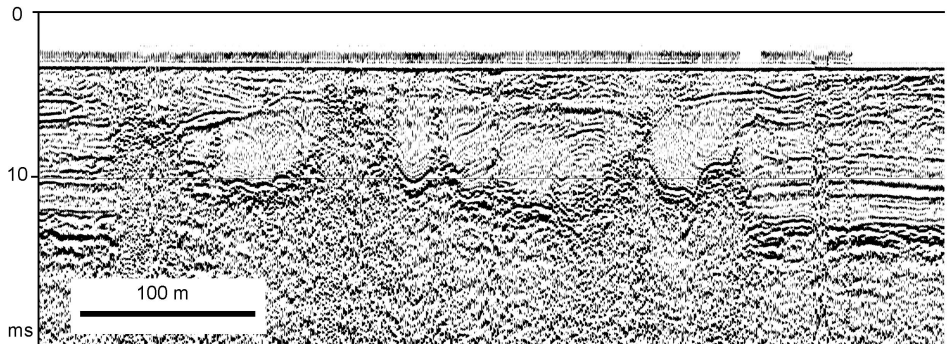

Fig 6. Example of the complexity of the subsoil architecture.

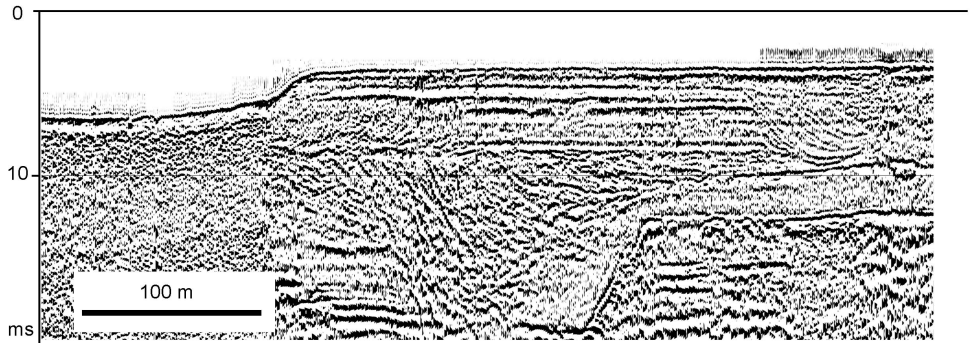

Fig 7. Example of active and buried tidal channel complex systems.

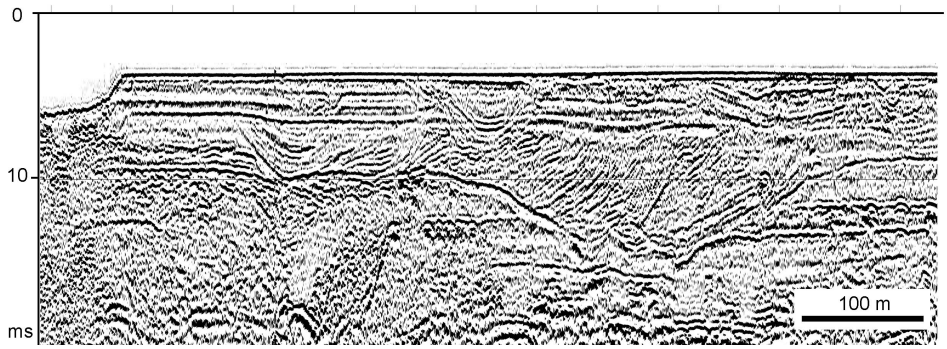

Fig 8. Example of active and buried channel complex systems.

3.2 Core analyses

Four 25 m and three 8-m long cores, available from previous researches (i.e. CARG and ECHOS projects), were sampled and analyzed.

Sedimentological analyses were carried out for the first time in the 25-m long core ISMAR-1 while an improvement of sampling and analyses were preformed in the others cores.

The preliminary stratigraphic log of the ISMAR-1 core is reported in Fig. 9. In detail, between 25 and 9,95 m depth the biogenic fraction consists of only continental gastropods, fresh-water ostracods, vegetable rests and oogons of Characeae. From 9,95 m up to the top of the core, the sediments are characterized by a organic rich fraction that is composed of benthic foraminifera, bivalves, gastropods and ostracods, typically from brackish-water.

Between the most common benthic foraminifera, individuals belonging to the species: *Ammonia beccarii*, *Haynesina paucilocula*, *Cribrononion translucens* and *Trochammina inflata* are present.

4. Conclusive considerations

After a brief overview of the main fluvial systems crossing the southern Venice area before the sea ingression, the SHALLOWS Project is introduced. Aim and objectives have been described and preliminary data have been reported. The importance to investigate the lagoon shallows representing most of the Venice lagoon basin, is emphasized.

The knowledge of the geological setting and the subsoil architecture is of particular relevance for many scientific issues. Expected results of this project are likely important to point out the evidence of radical changes triggered by human-induced river diversion of the lagoon tributaries, and others interventions as well as by climate and relative sea level changes. Engineering and hydrogeological studies would take advantage from the results of this project. For instance, relict sandy geomorphological features, characterized by high permeability, act as preferred pathways for groundwater flow [Carbognin and Tosi, 2003; Rizzetto et al., 2003; de Franco et al., 2009] and the architecture of the shallow subsoil play a fundamental role in the land subsidence process [Tosi et al., 2009a].

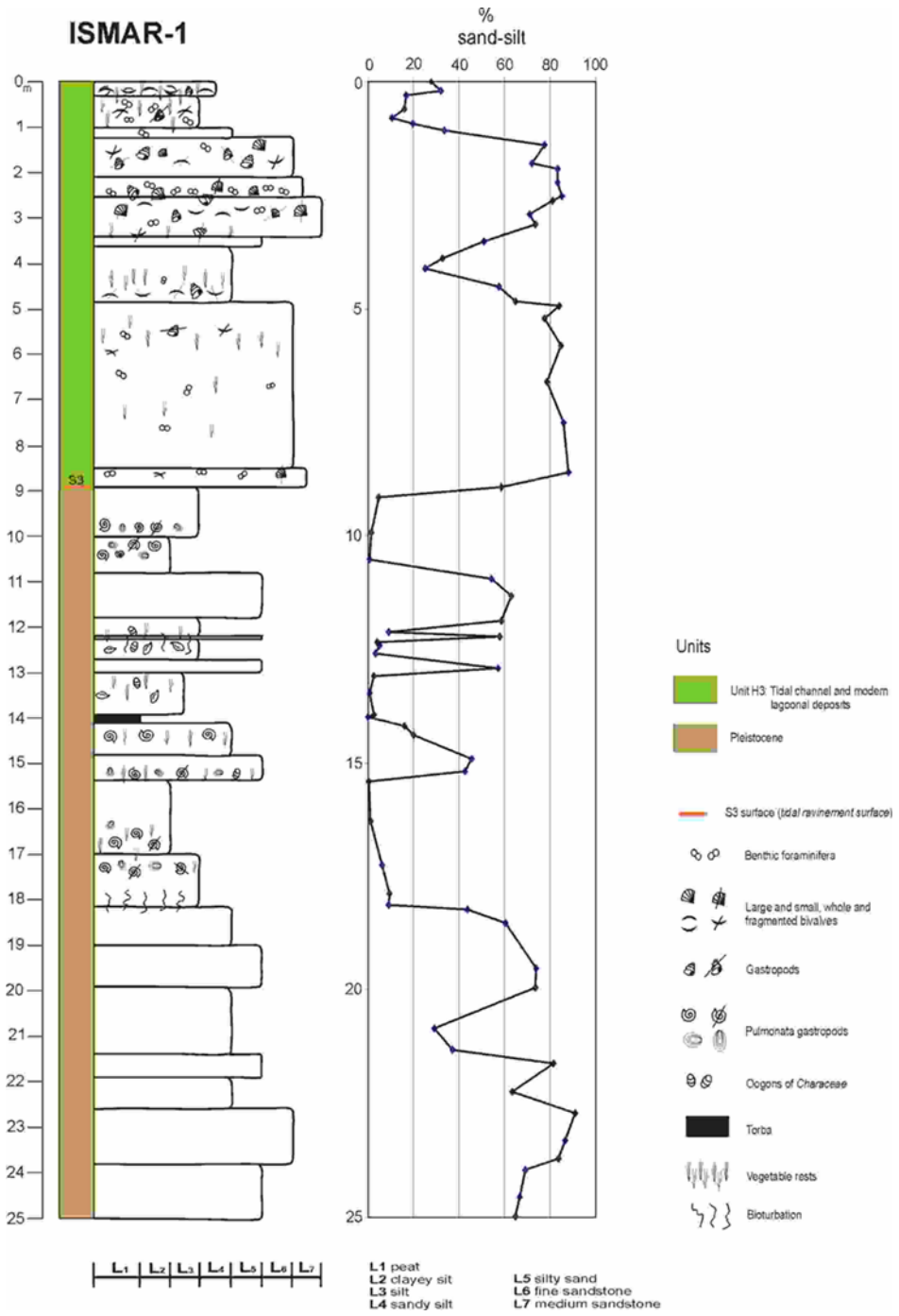

Fig. 9 - Preliminary stratigraphic log of the ISMAR-1 core

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