NEW VERY HIGH RESOLUTION SEISMIC SURVEYS IN SHALLOW WATER TO STUDY THE SUBSURFACE IN THE VENICE LAGOON.

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Introduction

After the Last Glacial Maximum the eustatic sea level rise caused the progressive submersion of the Adriatic paleo-plain. The sea reached the southern Gulf of Venice about 11,000 yr B.P. with the maximum ingression about 6,000 yr B.P. A long period of depositional starving (ranging from 6,000 to 10,000 yr) characterized the unconformity at the top of the Pleistocene Low System Tract (LST). This unconformity represents the boundary between the LST and the Holocene Transgressive System Tract (TST) or, mainly in the inner part of the lagoon, the High System Tract (HST), depending on the hiatus.

The upper layer of the LST is often characterized by the occurrence of a clay rich deposit, historically called "caranto" by the Venetians, that shows pedogenesis evidence due to its subaerial exposure.

Since its formation, the morphology of the Venice Lagoon underwent a rapid evolution, that became much more intensive in the last centuries, due to the impact of human activities, e.g. defences for the islands, digging of the channel, dumping of the sediments etc. (Albani et al., 1984, Albani et al., 1995).

The knowledge of the sediment dynamics, with the identification of erosional areas, the sedimentation rate and the flux of sediments, is a fundamental issue for the knowledge of the lagoon evolution and the impact assessment for engineering works. (Umgiesser et al., 2005; Amos et al., 2005).

Our knowledge of the geological settings of the upper Pleistocene and Holocene deposits of the Venice area mainly results from analyses based on cores that, even if collected in a large number, give only local information (Tosi, 1994a; Tosi 1994b). On the other hand, seismic surveys, which can offer the possibility to correlate layers between cores, were rarely carried out in the past because of poor results due to the extreme environment of the lagoon, i.e. very shallow water (McClennen et al., 1997).

In recent years, within the CARG Project, the very high-resolution (VHR) seismic technique has been updated and seismic surveys have been performed in the lagoon channels, and offshore, to a minimum water depth of 5 m. (Baradello et al., 2002; Tosi et al., 2005a and 2005b).

In order to provide new geological knowledge on the Venetian architecture subsoil, within the Co.Ri.La. Project, a VHR seismic system has been adapted for very shallow water, i.e. 1-2 m depth, and is currently under installation on a dedicated boat. Preliminary surveys have been carried out with this new technique in the lagoon, sea and Sile River. This paper reports and discusses these results and focuses on the characterization of the three main seismic units detected, which relate to the upper Pleistocene Low System Tract (LST), the Holocene Transgressive System Tract (TST) and the Holocene High System Tract (HST). In particular, the target of the investigation was the recognition within these units of features, such as filled paleo-river beds and lagoon channels, ancient littoral ridges and beach rock formations.

1 The single channel acquisition system

The quality of the high resolution seismic surveys in shallow water (less than 3 m) largely depends on the instrument specifications, the survey parameters and the boat characteristics. A seismic source should generate high frequencies, wide band and high repeatability pulses. In the frame of the CARG project in the Venice Lagoon, different sources have been tested (AAVV 2004). The best compromise between high resolution and penetration was reached by a boomer. The system was formed by an electromagnetic transducer UWAK 05 (Figure 1) and a power unit PULSAR 2002. The output power can vary between 150 and 450 Joule/shot and the frequency range is between 300 and 9000 Hz (Figure 2). The transducer is mounted on a sledge with two floats and it is maintained at a constant depth of about 50 cm.

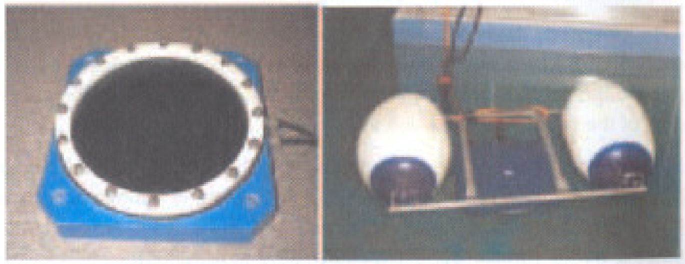


Fig.1: The seismic transducer UWAK05 (left) and the floating sledge with the transducer (right).

The expected resolution for the UWAK05 is about 10 cm. Previous surveys in the Venice area demonstrated that penetration, in good weather conditions, may reach 40 m below sea floor.

Seismic surveys are normally carried out by using a hydrophone streamer for detecting the reflected energy. Depending on the target of the survey, streamer length may vary between few meters, for single channel acquisition, to more

than a thousand meters for multichannel acquisition.

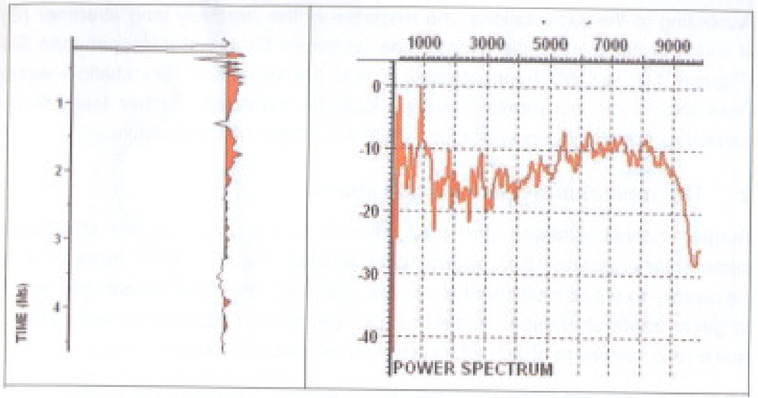
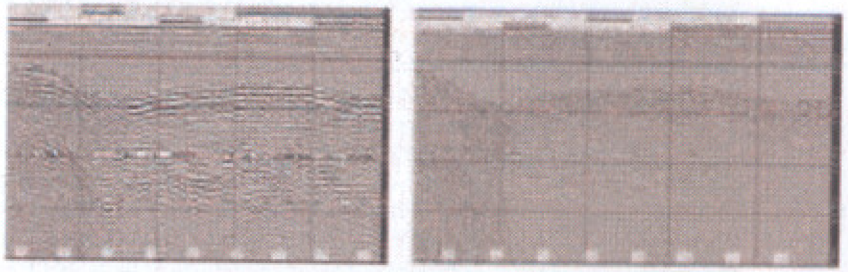


Fig. 2: Signature (left) and amplitude spectrum (right) of the seismic source UWAK05.

In previous surveys in the Venice Lagoon we operated with an EG&G (mod. 265) 320 cm streamer with 8 pre-amplified hydrophones. Multi-hydrophone streamers are useful to improve the level of the recorded energy but, for shallow water and shallow reflector arrivals, these streamers may produce a delay in the arrival time of the order of the dominant wavelet period and therefore may cause a negative interference inside the hydrophone array.



a: streamer B (60 cm length) b: streamer D (single hydrophone)

Fig. 3: Comparison between a 60 cm streamer (a) and a single hydrophone (b) for sea floor deeper than 5 m

For these reasons, the following different configurations of short to single hydrophone arrays have been tested using the CNR research boat LITUS:

Streamer A: EG&G with 8 hydrophones, active section of 270 cm, pre- amplified

Streamer B: MAE with 3 hydrophones, active section 60 cm

Streamer C: OGS with 3 hydrophones, active section 60 cm

Streamer D: MAE, single hydrophone

Streamer E: OGS, single hydrophone

According to the expectations, the response of the relatively long streamer (B) is much better than single hydrophone (streamer D) in water deeper than 5m (Figure 3). It has not been possible to test the system in very shallow water (less than 3 m), but similar results should be expected. Further test will be carried as soon as the new boat for shallow surveys will be available.

2 The multichannel acquisition system

Single channel systems are very efficient to get data for the shallowest sedimentary section. For targets deeper than the sea floor multiple it is necessary to utilize multichannel seismic systems. The main advantages are; i) to get a drastic attenuation of the multiple reflections, ii) to improve the signal to noise ratio, and iii) to obtain information on the seismic wave velocities.

To improve our capability to obtain high resolution images of the subsurface in the lagoon area, we tested a multichannel technique. Multichannel tests were carried both in the lagoon and in the open sea area close to Chioggia. The energy source was the same Boomer that has been used for the single channel surveys. The acquisition was carried by utilising 6 channel, 2 m group interval streamers, on loan from IFREMER.

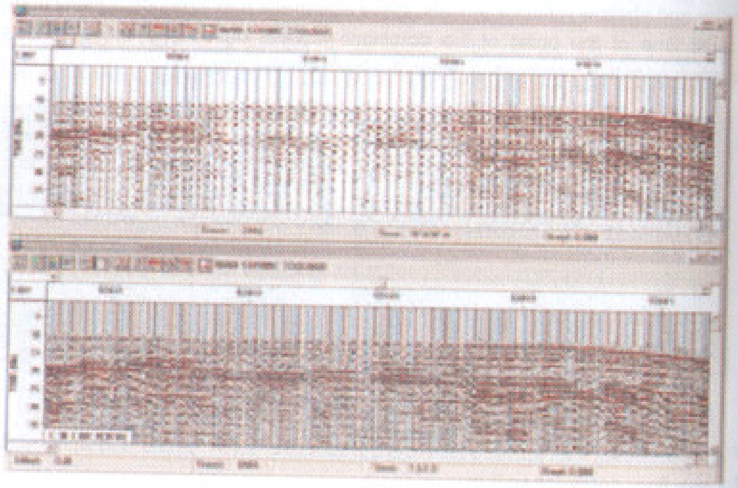


Fig. 4: Example of multichannel seismic section in the Venice Lagoon (below) and the corresponding single channel section from the same line (above). Note that the trace interval in the single channel is not constant due to variations in the boat speed.

Offshore Chioggia, a single cable was used to record a line from the coast out to the beach rocks. This line is shown in Figure 12.

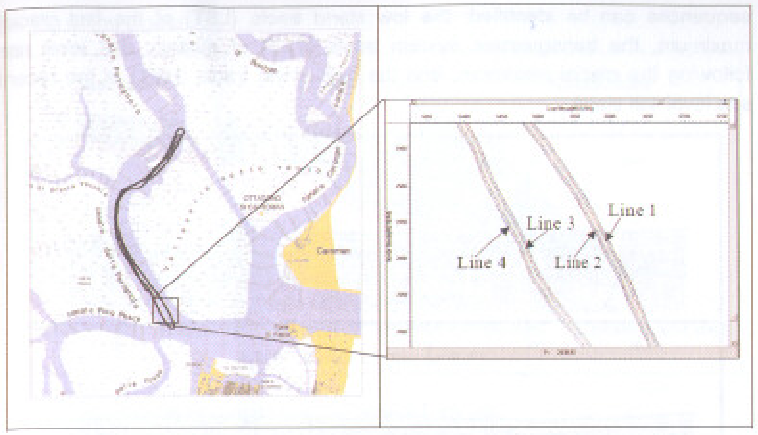


Fig. 5: The position of the 3D multi-channel seismic survey and an enlargement showing the lines displayed in Figure 6.

A comparison between multichannel and single channel data for the lagoon area is shown in Figure 4. Multichannel data produce a notable improvement in the seismic response from the deepest portion of the sedimentary section, but it is still poor in resolution for the shallowest layers. Further tests on the acquisition instruments and processing parameters will be needed to better focus the multichannel methods to the objective of the project.

Within the lagoon, the feasibility of a 3D-acquisition technique was tested. Normally, these tests would be conducted using four streamers, however, due to the limitations of the CNR boat LITUS and the narrowness of the channels, it was only possible to tow two streamers with safety. The streamers were towed parallel at 6m distance from each other, and with an offset of 10 m from the energy source. The distribution of the lines is shown in Figure 5 with an enlargement of part of the survey with two pairs of parallel lines. These four lines are shown, from north-east to south-west, in Figure 6 and demonstrate the lateral variability that can be seen within a cross-line distance of 100 metres. Normally, a denser grid of lines would be acquired using this configuration with similar recording intervals both in an in-line and cross-line direction that would allow a 3D reconstruction of the subsurface to be obtained.

3 Preliminary results of the seismic surveys

Following the results of the tests on the seismic instruments, three field cruises have been carried in the lagoon and open sea area by the ISMAR-CNR boat **LITUS.**

Two single channel seismic profiles have also been recorded along the Brenta and Sile rivers. Processing of the data has not been completed, nevertheless, some preliminary results can be presented and discussed.

Figure 7 illustrates a cross-section of the Venice Lagoon: three depositional sequences can be identified: the low stand tracts (LST) of the last glacial maximum, the transgressive system tracts (TST) of eustatic sea level rise following the glacial maximum, and the high stand tracts (HST) of the recent sea level still stand.

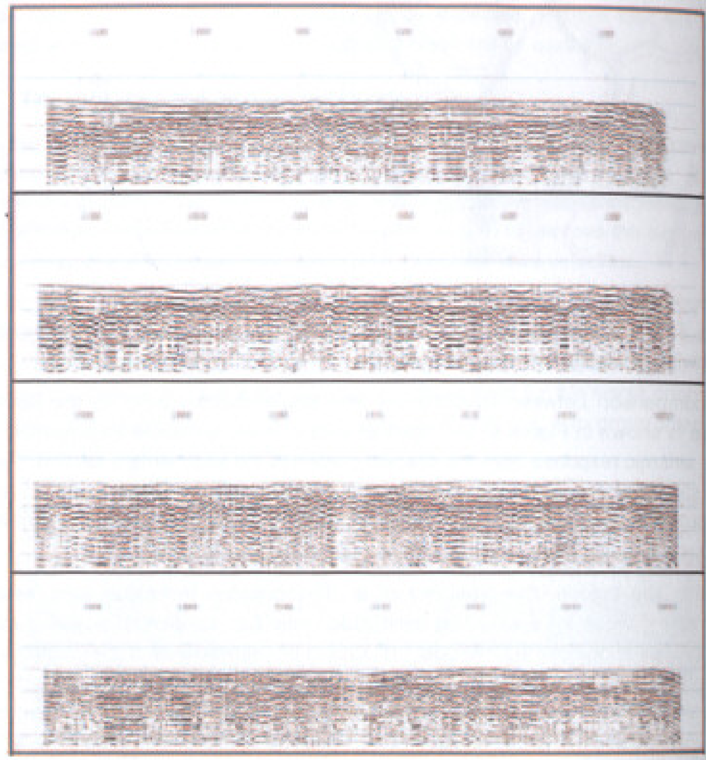


Fig. 6: Multichannel stack sections of the four parallel lines from the enlargement in Figure 5 showing the differences in the cross-line direction.

The LST belongs to the late Pleistocene, and is formed by alluvial plane deposits (generally silt, clay and sand). Locally lacustrine sediments are also present. The top of the TST, is often marked by a overconsolidated paleosoil, named "Caranto". The sequence boundary between the LST (Pleistocene) and the TST (Holocene) is a prominent unconformity, well represented in seismic sections. The Holocene sediments are composed of clay and sand, rich in organic matter, typical of the lagoon environment. The sand content increases toward the sea.

It is not always possible to detect, from seismic data, the maximum flooding surface (mfs) that separate the TST and the HST. Both sequences belong to the Holocene and, unlike the Pleistocene- Holocene transition, the mfs does not show a strong variation in acoustic properties. One of the criteria to recognize the mfs is the presence of an angular unconformity, more common in the outer

portion of the lagoon.

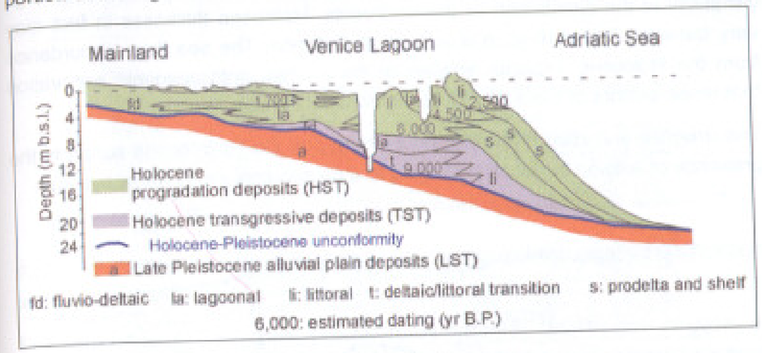


Fig. 7: Depositional sequences in the Venice Lagoon.

The seismic surveys have been carried out in the three most important environments that characterise the Venice area (Figure 8): the rivers, the lagoon and the open sea. Examples from each of them are presented and discussed.

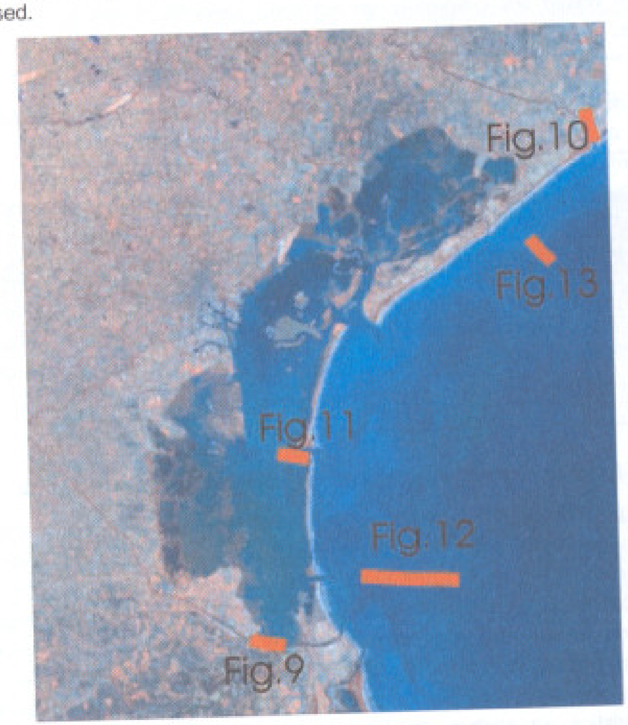


Fig. 8: Map with the trace of the sections presented in this paper

In figures 9 and 10 we present two examples from the Brenta and Sile River. In these sections the setting of the Holocene sequence is controlled by the interplay between fluvial transport and tidal effects that produced a high variability in the distribution of the sediments. Holocene thickness in fact may vary between 5 and 10 m in a very short distance. The sea floor discordance from the Holocene deposits testifies to the intense anthropogenic excavation that these sectors of the watercourse underwent in recent years.

The irregular and rough morphology of the top of the Pleistocene supports the presence of erosion surfaces belonging to a palaeo-channel channel system.

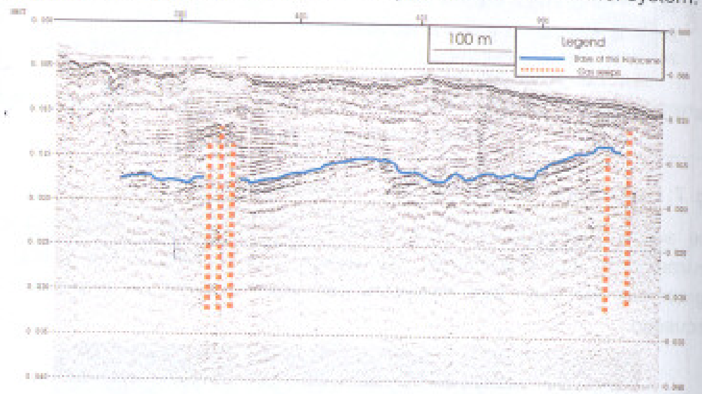


Fig. 9: Example of a single channel seismic section along the Brenta River.

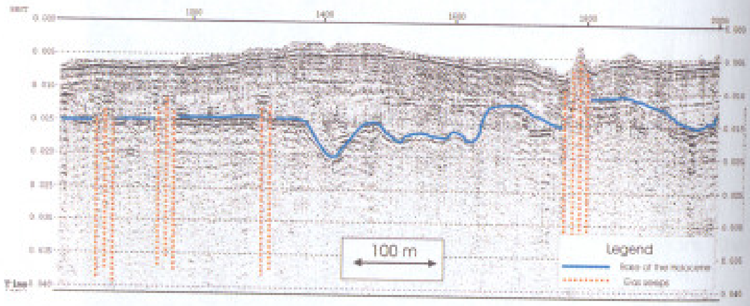


Fig. 10: Example of a single channel seismic section along the Sile River.

Two sequences have been identified inside the Holocene section in the lagoon area. The two sequences are separated by an evident unconformity (Holocene unconformity in Figure 11) and show some peculiar characteristics: the lower sequence is mostly sub-horizontal, with high continuity and low amplitude reflections, while the upper one is formed by continuous high amplitude divergent clinoforms, onlapping on the Holocene unconformity. The upper sequence is often cut by a channel levee system. Considering these characteristics, we attribute the lower sequence to the transgressive system tracts, the upper sequence to the high stand system tracts and the Holocene unconformity to the maximum flooding surface. Also, in these cases, the sea floor is highly discordant compared to the underlying sediments, and proves the

channel excavation of the channel due to human intervention.

Fig. 11: Example of a single channel seismic section in the lagoon (Malamocco) area.

The Holocene in the open sea area, in front of the Venice Lagoon, is characterized by sedimentary fans downlapping on the Pleistocene sequence boundary (Figure 12). The thickness of the marine sediments rapidly decreases and a few kilometres offshore, the Holocene is very thin (less than 15 cm) or even absent. In front of the fan, the outcrop of the Peistocene at the sea floor often coincides with a cemented formation, named "beach rocks" or "Tegnue". The pull-up in the Pleistocene unconformity underlying the beach rocks in Figure 12 testifies to the presence of a positive velocity anomaly, which could be a consequence of the high cementation degree of the formation.

The Pleistocene unconformities in Figures 12 and 13 belong to the continental sequence and are widespread in the entire marine area. There are no evident stratigraphic attributes for these unconformities. As a working hypothesis we consider them as the product of important interstadial climatic changes during the Pleistocene.

In Figure 13, the Holocene has been subdivided into two sequences. The seismic facies constituting both the sequences are not so well defined as in the section in Figure 11, nevertheless we interpret the lower unit as the Transgressive System Tracts and the upper as the High Stand System Tracts.

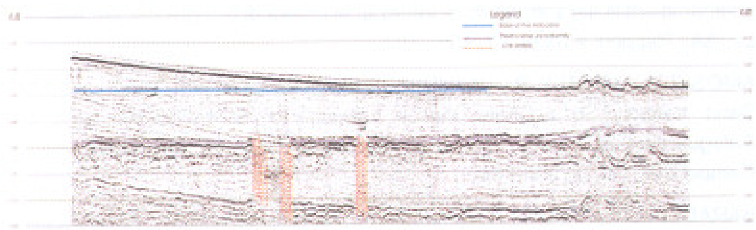


Fig. 12: Example of a multichannel seismic section in the marine area off Chioggia.

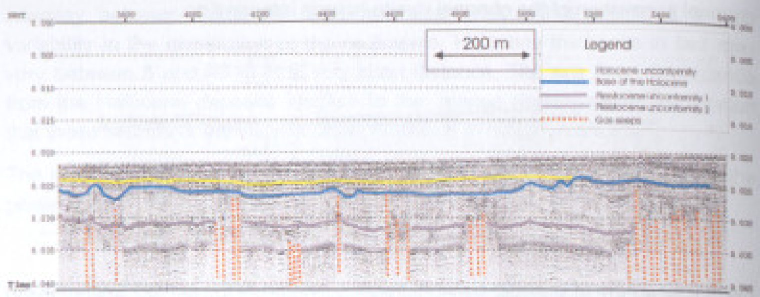


Fig.13: Example of a single channel seismic section in the marine area off Jesolo.

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References

AA VV. 2004: Rilievo Sismico nella Laguna Veneta, Convenzione 11294, Progetto CARG, Rapporto Finale. Istituto Nazionale di Oceanografia e di Geofisica Sperimentale, Dipartimento di Geofisica della Litosfera 4/2004 OGS,

ALBANI A., FAVERO V. & SERANDREI BARBERO R. (1984) - Apparati intertidali ai margini di canali lagunari. Studio morfologico, micropaleontologico e sedimentologico. Ist. Ven. SS. LL. AA., Rapporti e Studi, 9, 137 - 162.

ALBANI A., FAVERO V. & SERANDREI BARBERO R. (1995) - Condizioni paleoambientali nel sottosuolo di Venezia: la chiesa di S. Lorenzo. Ist. Ven. SS. LL. AA., Rapporti e Studi, 12, 155 - 182.

AMOS C. L., HELSBY R., UMGIESSER G., MAZZOLDI A., TOSI L. (2005) - Sand transport in northern Venice Lagoon. In: Scientific Research and Safeguarding of Venice. Co.Ri.La. Research Program 2001-2003. Ed. P. Campostrini, Vol. III, 369-383.

BARADELLO L., FANZUTTI F., RIZZETTO F., TOSI L., (2002) - Rilievo sismico ad altissima risoluzione nel settore meridionale della Laguna di Venezia. Proceedings of the 21th Convegno Nazionale del Gruppo Nazionale di Geofisica della Terra Solida (Rome, Italy), 293-294.

MC CLENNEN C., AMMERMANN A. & SCHOCK S. (1997) - Framework stratigraphy for the Lagoon of Venice, Italy: revealed new seismic-reflection profiles and cores. Journal of Coastal Research, 13 (3), 745-759.

TOSI L. (1994a) - L'evoluzione paleoambientale tardo-quaternaria del litorale veneziano nelle attuali conoscenze. Il Quaternario, 7(2): 589-596.

TOSI L. (1994b) - I sedimenti tardo-quaternari dell'area litorale veneziana: analisi delle caratteristiche fisico-meccaniche. Geologia Tecnica ed Ambientale, 2, 47-60.

TOSI L., RIZZETTO F., BONARDI M., DONNICI S., SERANDREI BARBERO R. & TOFFOLETTO F. (2005a) - Note illustrative della Carta Geologica d'Italia alla scala 1:50.000. Foglio 128 – Venezia (in press).

TOSI L., RIZZETTO F., BONARDI M., DONNICI S., SERANDREI BARBERO R. & TOFFOLETTO F. (2005b) - Note illustrative della Carta Geologica d'Italia alla scala 1:50.000. Foglio 148-149 –Chioggia-Malamocco (in press).

UMGIESSER G., AMOS C., BERGAMASCO A., BONARDI M., BREDA A., BONSEMBIANTE N., CARNIEL S., CORACI E., CUCCO A., DE PASCALIS F., DONNICI S., FERRARIN C., FRIEND P. L., HELSBY R., RIZZETTO F., SCLAVO M., SERANDREI BARBERO R., STROZZI T., TEATINI P., TOSI L., WEGMÜLLER U., (2005) - Hydrodinamics and Morphology CORILA 3.2. In: Scientific Research and Safeguarding of Venice. Co.Ri.La. Research Program 2001-2003. Ed. P. Campostrini, Vol. III, 111-130.