Available online http:/amq.aiqua.it
ISSN (print): 2279-7327, ISSN (online): 2279-7335

Alpine and Mediterranean Quaternary, 25 (1), 2012, 41-55

SEA LEVEL AND PALEOENVIRONMENT DURING ROMAN TIMES INFERRED FROM COASTAL ARCHAEOLOGICAL SITES IN TRIESTE (NORTHERN ITALY)

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ABSTRACT: Paleoenvironment and sea level markers have been studied from new and published data at two archaeological sites in Trieste. Results allowed to locate the Roman Age shoreline, presently buried under the city. Archaeological data clearly indicate the presence of a well-organized Roman Age seaside, which gradually moved offshore.

Imperial Roman Age structures have been found at the site located close to the Curia building. Archaeological finds indicate the subsequent widening of the seafront. During the 1st century BC, a stone wall parallel to the coast already existed at the back of a sandy beach. After the widening of the city, a large quay was built and the seafront moved offshore, covering the former Imperial Age structures. The quay was used up the 4th century AD.

Late Roman Age structures have been found at the site called Cavazzeni. The period when the site was abandoned is clearly indicated by the construction of the Medieval walls overtopping the Roman Age structures. The presence of two docks located just in front of the site are reported in several sketches, maps and historical sources dated at the 16th-17th century. Microfaunistic composition of sediments indicates that protected sectors of the harbour were built in order to allow the recovering of ships and other coastal activities.

Archaeological finds together with paleoenvironmental data suggest that vertical tectonic movements in the urban area of Trieste are significantly lower in respect of the Northern Adriatic. In fact, the presence of marine deposits with bad-preserved microfossils at elevations higher than present-day mean sea level is related to the possible occurrence of a violent storm or a tsunami event. For the latter case, radiocarbon date suggests a possible correlation to the 361 AD earthquake occurred along the Eastern Adriatic coasts.

Keywords: Urban archaeology, microfossils, sea level curves, Trieste, Italy.

1. INTRODUCTION

Archaeological sites along the Mediterranean coasts have undergone consistent environmental changes. In particular, the rapid sea level rise occurred during the Early Holocene has required continuous adaptations of human settlements to the alteration of the natural settings (Pirazzoli, 1996; Di Bella et al., 2011). To this end, several multidisciplinary proxies from archaeological and geological disciplines are generally used to define these changes (Lambeck et al., 2004a; Marriner & Morhange, 2007; Antonioli et al., 2009). Among them, the study of the coastal bioindicators (microfaunae) recorded in sediments and deposits of archaeological interest allow to reconstruct the ancient coastal paleoenvironments. The microfaunae of these environments consist of foraminifers, ostracods and mollusks (bivalves and gastropods) well known in the Mediterranean coastal areas (Pérès & Picard, 1964; Bonaduce et al., 1975; Pérès, 1982; Jorissen, 1988; Cimerman & Langer, 1991; Sgarrella & Moncharmont Zei, 1993; Montenegro et al., 1998). The coastal geoarchaeology uses these faunae to identify the paleoenvironments (rivers, swamps, marshes, lagoons, marine settings) close to human settlements, as already demonstrated in similar Mediterranean coastal archaeological sites (e.g. Reinhardt et al., 1994 and Sivan et al., 1999 in Israel; Pugliese et al., 1999 at the Aquileia harbour, for Italy; Goiran et al., 2005; Bernasconi et al., 2006; Bernasconi et al., 2007; Stanley et al., 2008 (a, b) for the coastal settings of Egypt; Marriner & Morhange, 2007, for general Mediterranean review; Amato et al., 2009 and Bernasconi et al., 2010; Di Bella et al., 2011; Mazzini et al., 2011 for Italian geoarchaeology; Ghilardi et al., 2011 for Greece). Paleoenvironmental data may integrate or improve data derived from geology and geomorphology and, in the end, they provide useful information to evaluate local sea level changes.

Sea-level change is the sum of eustatic, glacio-hydro-isostatic and tectonic movements (Lambeck et al., 2004a). While the first is global and time-dependent, the latter two varies with location, sediment load, compaction and anthropogenic factors; the tectonic factors include all movements that are not eustatic and isostatic (Lambeck et al., 2004a), the glacio-hydro-isostatic component of post-glacial sea-level rise has been recently predicted and compared with field data at several coastal sites all over the Italian coasts (Lambeck et al., 2004a; Antonioli et al., 2007, 2009; Faivre et al., 2011). The results represent an useful framework for calculating vertical tectonic movements.

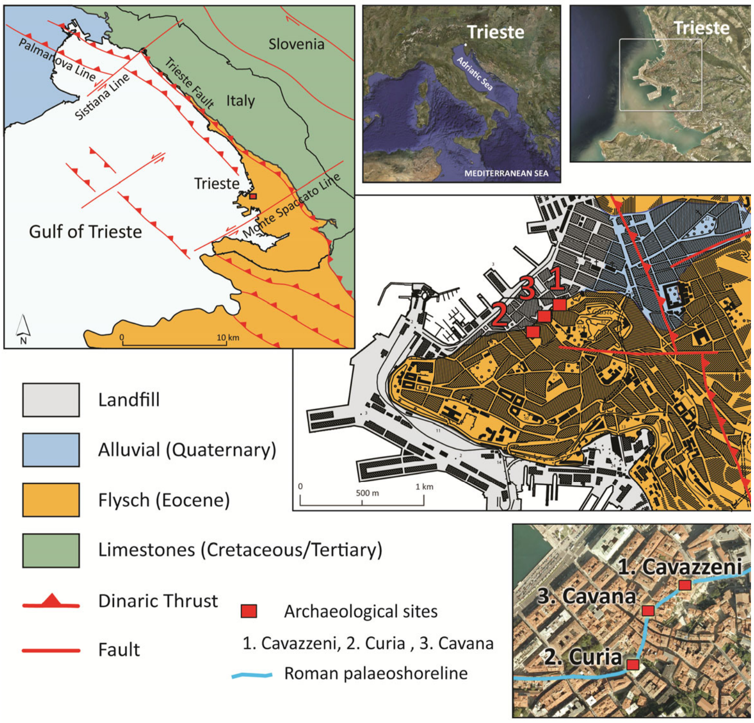

Fig. 1 - Study area. Geological map of the urban area of Trieste (modified from Tirelli et al., 2008) with the location of the archaeological sites. On the upper left-hand, a tectonic sketch of the Gulf of Trieste showing major thrusts and faults in relation to the city of Trieste is reported (modified from Busetti et al., 2008; Carulli et al., 2011; Furlani et al., 2011). Satellite images have been taken from Google Maps.

The study of the sea-level changes during the Late Holocene in the Northeastern Adriatic Sea has been studied by a number of Authors (Degrassi, 1957; D'Ambrosi, 1958; Fouache et al., 2000; Antonioli et al., 2004, 2007; Benac et al., 2004, 2008; Faivre et al., 2011; Degrassi et al., 2008; Furlani et al., 2011). Several geomorphologic, biological and archaeological markers have been used as source of information from which the relative movements between land and sea can be evaluated. Regarding this area, previous studies evidenced that Holocene submersion was largely completed about 7 ka (cal) BP and that subsequently the sea level rose slowly up to the current elevation (Antonioli et al., 2007, 2009). Moreover, marine notches or marine fossils have never been found in this sector at elevation higher than the present mean sea level, excluding a site with marine shells found by Antonioli & Furlani (2006) nearby Pola, at +0.70 m m.s.l. On the whole, recent archaeological, geomorphological and geophysical data indicate for this area a vertical tectonic signal at a rate of about -0.75 mm/yr occurring during the last two millennia. It produces a significant downward displacement of the coastline of about 1.5 m / 1.8 m since Roman Age (Antonioli et al., 2007, 2009). On the contrary, Degrassi et al. (2008) and Furlani et al. (2011) suggested that, in the same lapse of time, the urban area of Trieste should be relatively stable in respect of the Northeastern Adriatic.

The micropaleontological and archaeological results presented in this work aim to refine previous investigations in Trieste and both to add more information on the Roman Age sea-level and the anthropogenic variation of the shoreline.

2. THE STUDY AREA

2.1. Geological and geomorphological background

The city of Trieste (Fig. 1) is located in the Eastern part of the homonymous Gulf (NE Italy). The city lies on an Eocene turbiditic succession (Flysch of Trieste), Lutetian in Age (Bensi et al., 2007, Tirelli et al., 2008).

The area is part of the External Dinarides and is affected by a series of thrusts which made the Cretaceous-Tertiary carbonate succession overlaying the Eocene turbiditic one. The compressional tectonics caused by the Dinaric orogeny (Late Jurassic-Early Oligocene) produced the development of NW-SE oriented and SW verging thrusts and the relative foredeep, with flexuring of the Mesozoic carbonate and filling by the Eocene Flysch. Late compressional phases also involved the Flysch sequence in the thrusts (Doglioni & Bosellini, 1987; Castellarin et al., 1992).

A thrust system crossing the Gulf of Trieste with Dinaric orientation, has been recently found from a multichannel seismic survey (Busetti et al., 2008, 2010). The system represents the most external Dinaric thrusts. It is characterized by intense deformation, in particular within the Eocene Flysch sequences. It is affected by tectonic activity lasting to the Plio-Quaternary. The structure deepens toward the northwest, probably due to the offset of NE-SW faults: the Monte Spaccato Fault parallel to the Northern Istrian coast (Cavallin et al., 1978; Carobene & Carulli, 1981), and a possible fault zone located in the middle of the Gulf, separating the Northern part from the Southern part (Busetti et al., 2008, 2010). According to Carulli (2011), the Monte Spaccato and Sistiana faults can be responsible for the formation of the Gulf of Trieste.

Modelling of gravity data in the gulf of Trieste and Karst area interpreted the minimum values occurring in the Northern corner of the gulf as due to the deepening toward Northwest of the limestones and to the increase of Flysch thickness (Coren et al., 2006). Northwestward tilting of the Karst area and its surroundings is confirmed also by geodetic data (Braitenberg et al., 2005).

From a geomorphological point of view, Trieste widens on a succession of ridges and valleys, the latter filled by Quaternary alluvial and marine deposits. Coastal archaeological remains are usually built at the Flysch cliff-foot. Alluvial deposits are mainly produced by small temporary streams which flow to the sea, sometimes close to the archaeological sites.

2.2. Archaeological background

Regarding the presence of Roman Age remains in Trieste, the archaeological findings discovered in the last decades during urban excavations deeply improved the knowledge of the Roman town (Maselli Scotti, 2008). Since 16th century, local historians highlighted the presence of block alignments, wooden poles and harbour structures; coastal remains have been usually reported at many sites in Trieste. Maselli Scotti (2008) suggested that the landfills between Roman Age coastal structures were built at increasing steps, using sandstone blocks for the construction of retaining walls. Imperial Age structures (late 1st century BC – early 1st century AD) are usually covered by Late Roman Age walls, the latter lying below recent buildings.

The maritime vocation of Trieste during Roman Age is proven by the existence of two harbours (Maselli Scotti, 2008). Large remains of two docks (Fig. 2A), as part of the so called "*porto esterno*", which correspond to the present-day San Marco dock basin, were clearly visible during the 18th century, as described by Ireneo della Croce (1698). They were composed by two large sea walls: the Southwestern one was arch-shaped; it connected the coast to a small island, called "*il Zucco*", now completely covered by the 17th century landfills, while the northernmost is now included in a present-day dock. The architectural project for the construction of the lazaret - project of the ÖKW, Wien, 1821- describes the presence of an ancient damaged dock which were ruined by storms (Fig. 2B). This structure emerged during low tides. The seaside of the inner harbour was found in correspondence of Cavana (Ventura et al., 2008) and Cavazzeni street. Local archaeological Superintendence found several sandstone blocks belonging to the Roman Age docks.

The existence of a small harbour was suggested from historical maps that show two semi-submerged and ruined piers. They were included in the landfill for the widening of the city and nowadays they lay below modern buildings. Archaeological remains are part of the Roman Age harbour, which presently lies below the 20th century buildings.

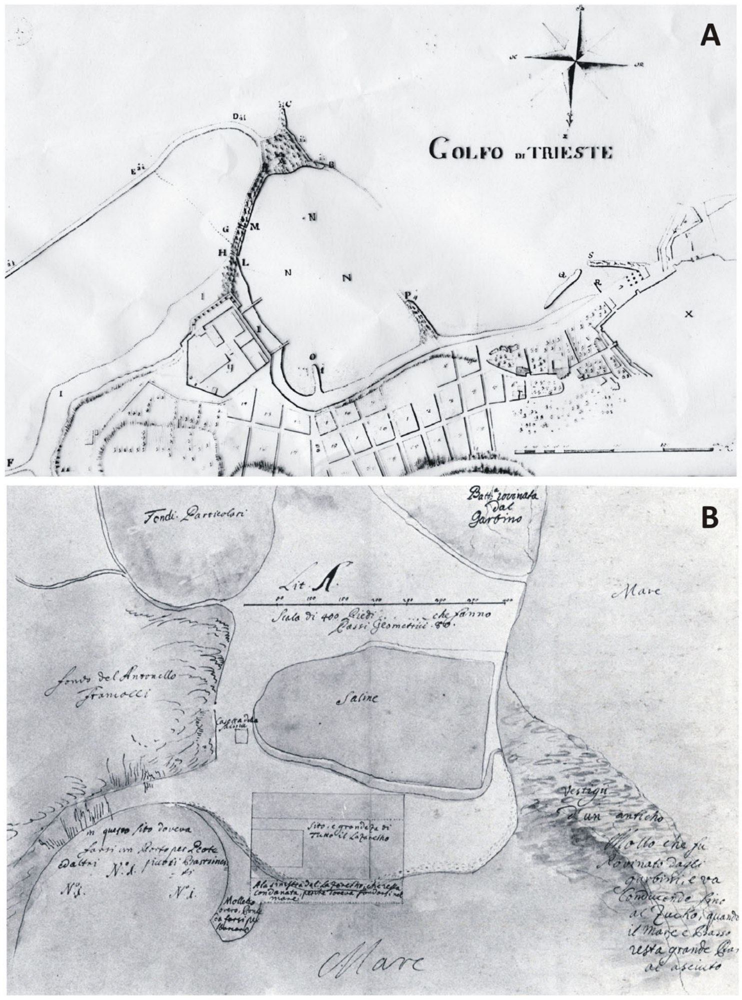

Fig. 2 - Ancient maps of Trieste. A) Unknown Author, 1745. Map from the Project for the construction of the Borgo dei Santi Martiri and the new pier "Zucco". Two piers are visible just in front of the Cavana area (Riavez, 1995); B) Unknown Author, 1821. Map from the Project for the construction of the lazaret, Wien ÖKW, with the description of an ancient pier "*vestigii d'un anticho molo che fu rovinato dagli garbini, e va conducendo fino al Zucko, quando il mare e basso resta grande parte al asciuto*".

3. METHODS

In 2008-2010, during the renovation works carried out in Trieste by the "Sovrintendenza per i Beni Archeologici del Friuli Venezia Giulia" (F. Maselli Scotti and P. Ventura excavation director), two archeological sites at "Cavazzeni" Street and in "Piazzetta S.ta Lucia", close to the "Curia" Palace (Fig. 1), were discovered. Four bulk samples of sediments, corresponding to different archaeological stratigraphic units (US) were collected at the "Cavazzeni" site, along a 1.50 m thick vertical section. Additional 10 samples were collected at the "Curia" site, along a 1.50 m thick vertical section (Fig. 3, 4).

The collected samples were washed using respectively 2 mm and 0.063 mm sieves, both to separate the gravelly and the sandy fraction. Finally, the sediments were dried in an oven and weighted. The foraminifers were determined in the 0.063 – 2.0 mm sieving fraction. Species counts were performed and recorded as number of specimens of each taxon, reported as percentage in Tables 1 and 2. Selected specimens were examined and photographed by a Leica Scanning Electron Microscope at the University of Trieste (Plate I). Identification of foraminifer species follows the Mediterranean systematic suggested by Le Calvez & Le Calvez (1958), Jorissen (1988), Cimerman & Langer (1991), Levy et al. (1992), Hottinger et al., (1993) and Sgarrella & Moncharmont Zei (1993). For the consultation of the original taxa description, the Ellis and Messina online catalogue on for aminifera was used (http://www.micropress. org/).

Interpretation of the paleoenvironment was established by the comparison of the foraminiferal assemblages examined here and the ecological significance of other associations from several Mediterranean coastal areas: Tyrrhenian sea (Vismara Schilling & Ferretti, 1987; Sgarrella & Moncharmont Zei, 1993; Bellotti et al., 1994), Adriatic sea (Albani & Serandrei Barbero, 1990;

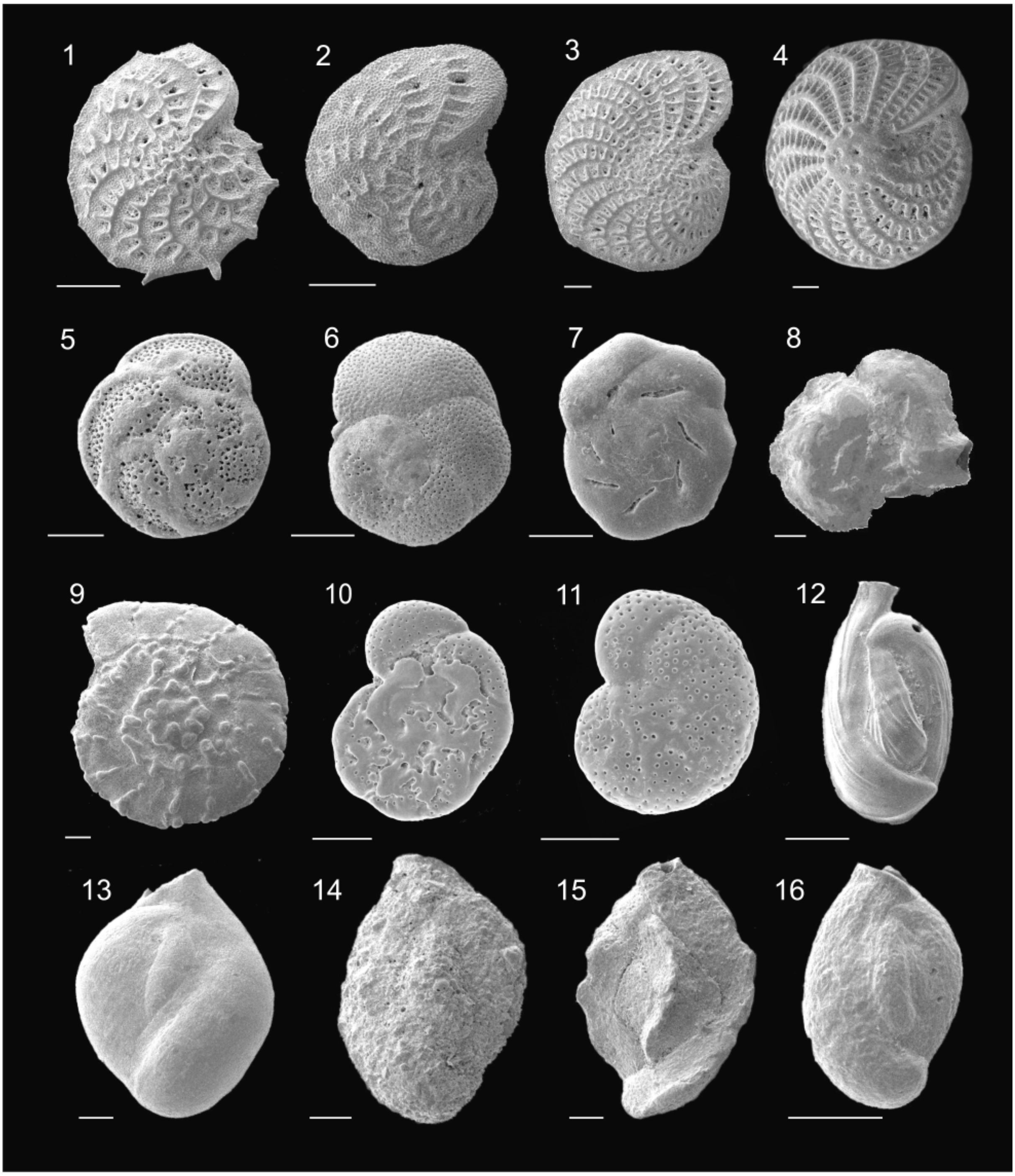

Plate I - SEM photomicrographs of some foraminifer species representative of the studied sites (magnification: bar = 100 μm): 1 - *Elphidium aculeatum*; 2 - *E. pulvereum*, side view; 3 - *E. complanatum*, side view; 4 - *E. crispum*, side view; 5 - *Rosalina bradyi*, spiral side; 6 - *R. floridana*, spiral side; 7 - *Helenina anderseni*, spiral side; 8 - *Nubecularia lucifuga*, spiral side; 9 - *Ammonia beccarii*, spiral side; 10 - *Discorbis aguayoi*, umbilical side; 11 - *D. aguayoi*, spiral side; 12 - *Adelosina carinato-striata*, chamber view; 13 - *Triloculina rotunda*, chamber side; 14 - *Siphonaperta agglutinans*, side view; 15 - *Quinqueloculina nodulosa*, side view; 16 - *Quinqueloculina parvula*, side view.

Albani et al., 1991; Jorissen, 1988; Donnici & Serandrei Barbero, 2002) and the Late Quaternary of the Po Plain near Ravenna (Fiorini & Vaiani, 2001).

Radiocarbon dates have been provided by the Poznan Rodiocarbon Laboratory, Foundation of the Adam Mickiwicz University (Poland). They were calibrated using the CALIB 5.0 program (Stuiver et al., 2005).

Ostracods were picked directly from sandy fraction and then identified (Plate II). The number of specimens

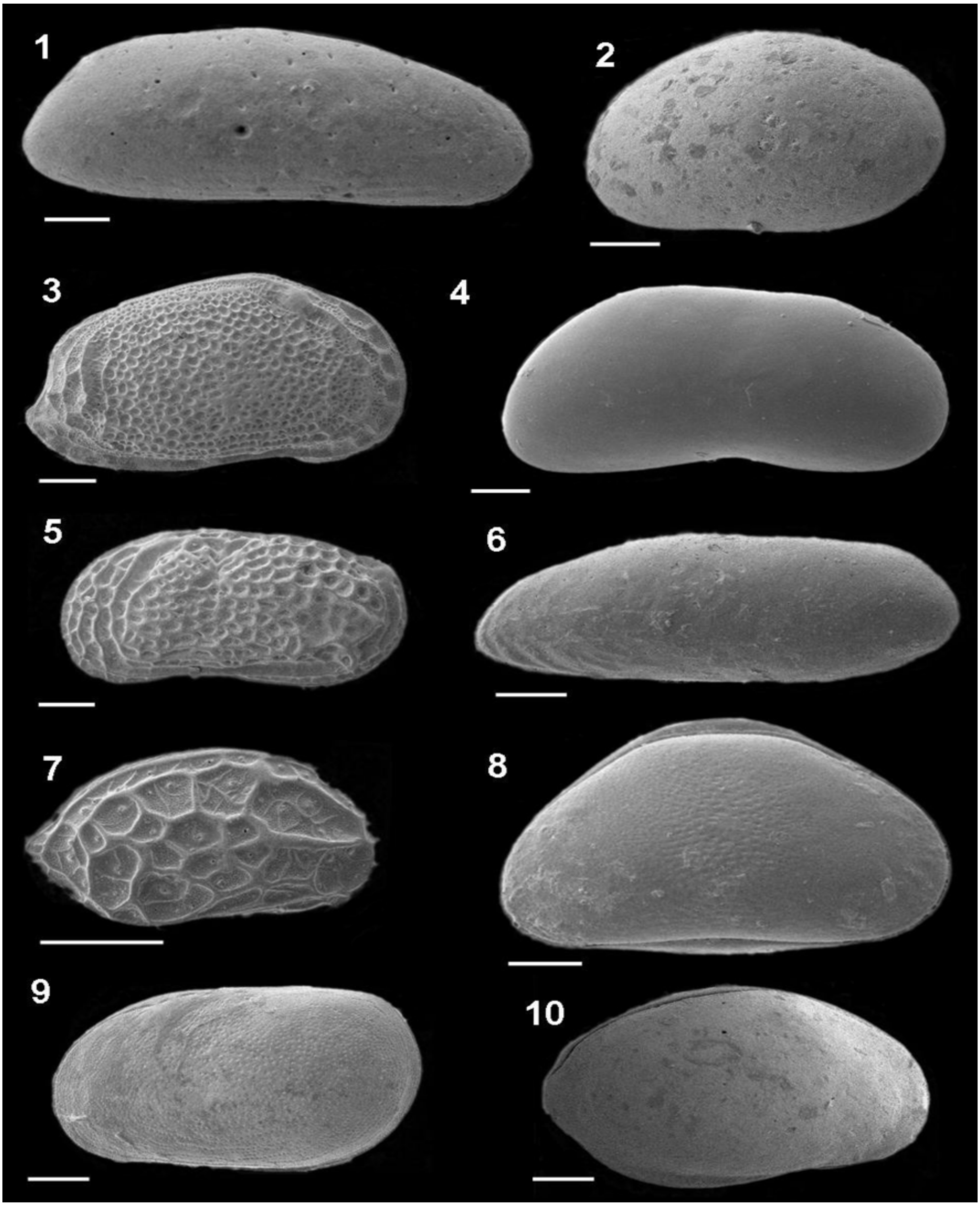

Plate II - SEM photomicrographs of some ostracod species representative of the studied sites (magnification: bar = 100 μm): 1 - *Pontocythere turbida*, right valve; 2 - *Xestoleberis communis*, complete carapace in left lateral view; 3 - *Aurila arborescens*, right valve; 4 - *Candona neglecta* (juvenile specimen), left valve; 5 - *Leptocythere lagunae*, complete carapace in left lateral view; 6 - *Neocytherideis fasciata,* left valve; 7 - *Hemicytherura videns* (juvenile specimen), right valve; 8 - *Schellencandona* sp., complete carapace in left lateral view; 9 - *Loxoconcha elliptica*, complete carapace in left lateral view; 10 - *L. stellifera*, complete carapace in right lateral view.

for each sample was reported in Tables 1 and 2; the presence of juveniles was recorded to distinguish autochthonous from allochthonous specimens. The database sources of modern and Quaternary ostracods in Mediterranean are provided by Bonaduce et al. (1975) and Breman (1975) for the northern Adriatic Sea, Mon-

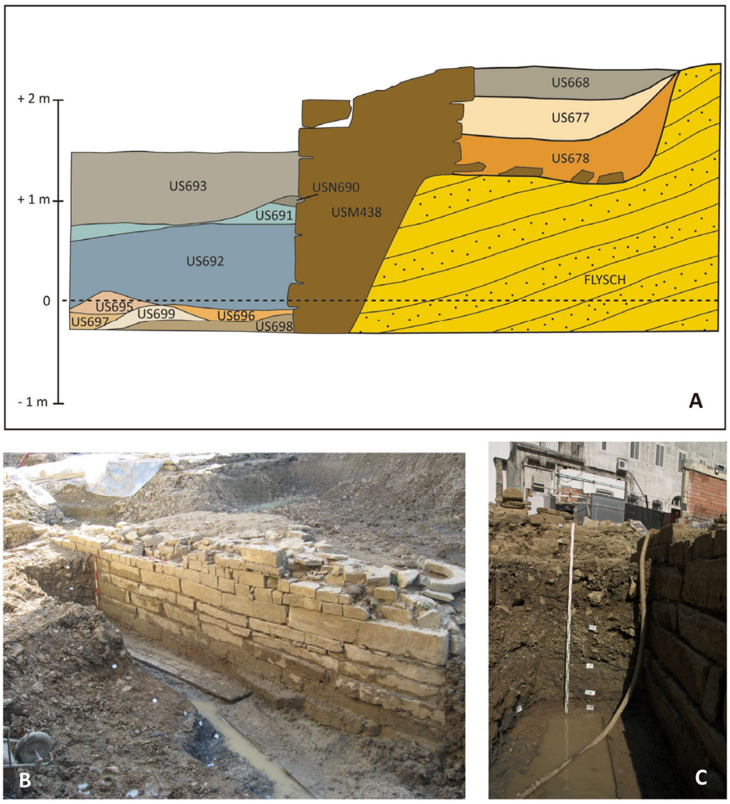

Fig. 3 - The archaeological site at Curia. A) Representative sketch of the site; B) and C) Views of the site.

tenegro et al. (1998) for Italian seas and Athersuch (1979) and Barbeito Gonzalez (1971) for Cyprus and Naxos Island, Greece. Other useful investigations include the Nile delta margin core samples that provide information on pre-modern Quaternary ostracods (Sneh et al., 1986; Pugliese & Stanley, 1991) and on Quaternary ostracods of Monastir, Tunisia (Wouters, 1973). Meisch (2000) has been used for fresh-water ostracods.

The elevation of dated sea level markers (archaeological remains and sedimentological samples) have been measured by GPS surveys. We estimated the elevations and ages of the archaeological benchmarks and evaluated their functional heights on the basis of archaeological interpretations, following Lambeck et al. (2004b), Antonioli et al. (2007) and Auriemma & Solinas (2009) advices. Elevation errors are calculated from measurements, while the uncertainty in archaeological dating is estimated from the architectural features of the structures and pottery sherds or ceramics found in the archaeological levels.

Past sea levels are evaluated considering the "functional height" of archaeological structures. It is defined as the elevation of specific architectural parts of the structure with respect to the mean sea level at the time of their construction. It depends on the structure, on its use and on the local tide amplitudes. The functional height also defines the minimum elevation of the structure above mean sea level (Antonioli et al., 2007). Data have been compared with predicted sea level curve (Lambeck et al., 2011) to define the tectonic behaviour of an area. When data are in agreement with the predicted sea level, tectonic stability is suggested. On the contrary, when the elevations of the markers are different from the predicted values, downlift or uplift is suggested.

4. RESULTS

Archaeological and paleoenvironmental data collected in correspondence of two archaeological excavations in Trieste, the "Curia" site (Fig. 3A-C) and the "Cavazzeni" site (Fig. 4A-C), are hereinafter described.

4.1. The "Curia" site

The investigations concern the discovery of a luxurious 1st century AD suburban villa overlooking a coastal road. The excavation was carried out under the pavement of the villa. It has revealed a complex stratigraphy, which highlights an impressive arrangement of the shore with a NE-SW trending (USM438). The seaward side was made up of squared blocks which gradually diminish in size upward. Excavations indicate the presence of a quay constituted of a 2 m high sea wall (Fig. 3A), dated back using ceramics between the 1st century BC and the 1st century AD. It is grounded at -0.3 m a.s.l. on the bedrock of the Roman Age shore platform (Tab. 3). At its base, a sandy beach (US698 - US699) occurs. It has been overlaid by sandy levels rich in shell fragments interbedded with plant debris elements.

The discovery of abundant ceramic in the stratigraphic sequence permits to date this area at an age ranging between the end of the 1st century BC and the early 1st century AD. Later, archaeological structures were covered with filling materials (half of the 1st century AD). In this way, a new coastal road was built on the widened shore.

In order to study the microfaunistic composition of this area, seven levels of the archaeological sequence have been selected, from the bottom to the top as follows (Fig. 3A):

US699: -0.18 m m.s.l., seaward tilted/sloping;
US698: -0.15 m m.s.l., tilted/sloping, centimeters sandy level, located only at the base of the quay;
US697T: -0.15 m m.s.l., tilted/sloping; blue-gray (alluvial?) clay with abundant rounded sandstone clasts;
US696: -0.12 m m.s.l., strongly tilted - sloping, levels rich in vegetate materials interbedded with sandy lenses. Thickness of this unit increases toward the seaside;
US695: -0.10 m m.s.l., sandy levels with centimeter thickness, interbedded with thin organic (vegetate) lenses;
US692: +0.40 m m.s.l., plano-convex lens (max thickness 0.5 m) composed by rounded lithic fragments of sandstone.

The following units, US691, 690 and 693 are considered as anthropogenic backfilling.

The foraminifers of this excavation consist of 24 species pertaining to 12 genera (Tab. 1). Among them,

Curia	**699**	**698**	**697T**	**696**	**695**	**692**
depth s.l.m. (m)	- 0.18	- 0.15	- 0.15	- 0.12	- 0.10	+ 0.40
foraminifers	%	%	%	%	%	%
Adelosina candeiana (d'Orbigny)			0,6			
Ammonia beccarii (Limneo)	71,4	70,6	60,7	62,9	61,9	85,7
Ammonia parkinsoniana (d'Orbigny)		1,7	1,7		1,8	
Ammonia tepida (Cushman)				4,3	1,4	
Aubignyna perlucida (Heron-Allen and Earland)					0,5	
Buccella granulata (Di Napoli Alliata)			0,6	1,4		
Buliminella elegantissima (d'Orbigny)	2,9					
Elphidium aculeatum (d'Orbigny)		2,3	2,3	1,4	0,9	7,1
Elphidium complanatum (d'Orbigny)	5,7	9,0	12,1	4,3	19,7	
Elphidium crispum (Linneo)	11,4	10,2	4,0	18,6	9,2	
Elphidium cuvilleri Lévy						
*Elphidium excavatum (*Terquem)						
Elphidium incertum (Williamson)		0,6				
Elphidium jenseni (Cushman)		1,7	1,2		1,4	7,1
Elphidium macellum (Fichtel & Moll)		1,7	5,2	5,7	1,4	
Elphidium pulvereum Todd	5,7	0,6	4,0		0,5	
Elphidium punctatum (Terquem)		0,6			0,9	
Nonion pauciloculum Cushman			0,6			
Polymorphina sp.		1,1	1,2		0,5	
Polymorphina mystriformis Williamson			0,0	1,4		
Quinqueloculina dimidiata Terquem			1,2			
Quinqueloculina lata Terquem			0,6			
Quinqueloculina seminulum (Linneo)			0,6			
Sinuloculina cyclostoma			1,2			
Siphonaperta aspera (d'Orbigny)			1,7			
Triloculina marioni Schlumberger	2,9		0,6			
n° of specimens	35	177	173	70	218	14
n° of species	6	11	19	8	12	3
ostracods	n°	n°	n°	n°	n°	n°
Aurila arborescens (Brady)			1			
Callistocythere sp.			x			
Candona neglecta (Sars)		x				
Candonidae	x					
Leptocythere lagunae Hartmann					1	
Loxoconcha stellifera G.W. Müller		2				
Neocytherideis fasciata (Brady & Robertson)					1	
Pontocythere turbida (G.W. Müller)	1	1x	1		1x	
Xestoleberis communis G.W. Müller	1				x	

Tab. 1 - Curia site: relative abundance of the foraminifera (above) as percentage of each species in respect to the total assemblage; ostracods (below) as number of adult specimens and presence of juveniles is reported with the "x".

Ammonia beccarii is always present and dominant (frequency from 60.69, US697T to 85.71%, US682), mainly followed by *Elphidium complanatum* and *E. crispum*, which are absent in the level US692. Other species of *Elphidium* are present, such as *E. aculeatum*, *E. jenseni*, *E. macellum* and *E. pulvereum*, without reaching

Cavazzeni	US120	US76 (bottom)	US76 (top)	US74
depth s.l.m. (m)	-0,35	-0,05	+0,25	+0.50
foraminifers	%	%	%	%
Adelosina carinato-striata Wiesner	1,7			
Adelosina sp.		0,5		
Ammonia beccarii (Limneo)		0,5	9,1	54,5
Ammonia parkinsoniana (d'Orbigny)	0,6	0,5		9,1
Ammonia tepida (Cushman)	21,2	20,9	9,1	
Aubignyna perlucida (Heron-Allen and Earland)	0,8	1,9		
Buccella granulata (Di Napoli Alliata)	0,3			
Cibicidella variabilis (d'Orbigny)	0,3			
Cibicides lobatulus (Walker & Jacob)	0,8			
Cibicides refulgens Monfort		0,5		
Cornuspira involvens (Reuss)	1,1			
Cribrononion lagunensis Albani & Serandrei Barbero		0,5		
Discorbis aguayoi Bermudez	3,9	11,2		
Elphidium aculeatum (d'Orbigny)	5,3	5,8	18,2	
Elphidium complanatum (d'Orbigny)	3,9	5,8		
Elphidium crispum (Linneo)				18,2
*Elphidium excavatum (*Terquem)	0,3			
Elphidium jenseni (Cushman)	2,5	10,2		9,1
Elphidium macellum (Fichtel & Moll)	3,1	5,8	27,3	9,1
Elphidium pulvereum Todd	28,1	4,4	9,1	
Elphidium punctatum (Terquem)	0,6			
Haynesina germanica (Ehrenberg)	0,6			
Helenina anderseni (Warren)	1,4		9,1	
Lachlanella compressa (Wiesner)	0,6			
Massilina secans (d'Orbigny)		0,5		
Miliolinella subrotunda (Montagu)	1,1	1,9		
*Nonion depressulum (*Walker & Jacob)	1,4			
Nonion pauciloculum Cushman	1,7			
Nubecularia lucifuga Defrance	2,2	1,0		
Quinqueloculina bosciana d'Orbigny	0,3	0,5		
Quinqueloculina lata Terquem	0,8	1,0		
Quinqueloculina milletti (Wiesner)	0,6			
Quinqueloculina nodulosa Wiesner	0,6	3,9		
Quinqueloculina padana Perconig		0,5		
Quinqueloculina parvula Schlumberger	3,1			
Quinqueloculina seminulum (Linneo)	2,8	1,5		
Quinqueloculina spp.	0,6	1,5		
Quinqueloculina ungeriana d'Orbigny			9,1	
Rosalina bradyi (Cushman)	0,6	0,5		
Rosalina floridana (Cushman)	0,8	14,6		
Rosalina vilardeboana d'Orbigny	1,7			
Sigmoilina costata Schlumberger	0,6			
Siphonaperta agglutinans (d'Orbigny)	0,3			
Triloculina rotunda d'Orbigny		1,9		
Trochammina inflata (Montagu)	4,2	2,4	9,1	
n° of specimens	359	206	11	11
n° of species	36	26	8	5
ostracods	n°	n°	n°	n°
Candona neglecta (Sars)			x	x
Candonidae	2x		x	x
Cytherois frequens G.W. Müller	x			
Hemicytherura videns (G.W. Müller)	2			
Heterocypris salinus (Brady)		1x		
Leptocythere lagunae Hartmann		1		
Loxoconcha affinis (Brady)		2		
Loxoconcha elliptica Brady	x	3	1x	
Loxoconcha rhomboidea (Fischer)	x		1	
Loxoconcha sp.	x	x	x	
Schellencandona sp.	x	1x	3x	x
Paradoxostoma simile G.W. Müller		1		
Xestoleberis communis G.W. Müller		2		
Xestoleberis plana G.W. Müller			x	

Tab. 2 - Cavazzeni site: relative abundance of the foraminifera (above) as percentage of each species in respect to the total assemblage; ostracods (below) as number of adult specimens and presence of juveniles is reported with the "x".

the level 697T, where the highest richness of the assemblage is reported. The preservation of the test is generally poor, above all for *A. beccarii* and *E. crispum* specimens.

The ostracod fauna found in these samples consists of eight species pertaining to eight genera, which are listed in Table 1. Among them, *Pontocythere turbida*, *Xestoleberis communis* and *Candona neglecta* are the most common species, even if they occur with few specimens; other taxa such as *Aurila arborescens*, *Leptocythere lagunae*, *Neocytherideis fasciata* and *Loxoconcha stellifera* are occasionally present. *Callistocythere* sp. occur only as juveniles. On the whole, the species richness is very limited, up to four species in the level US695, whereas on the levels US696 and US692 the ostracods are absent. The ostracods species identified in this sequence are well-known in the modern Mediterranean as representative of freshwater, brackish and marine infralittoral settings; the occurrence of *X. communis* indicates vegetated bottoms.

4.2. The "Cavazzeni" site

The archaeological sequence is dominated by an imposing wall structure, USM4 (Structural stratigraphic unit, e.g. walls, etc.), carried out with a carefully structured double parament (and bag filling cement), which are recognized as part of the late ancient city walls. Its foundational foot, slightly overhanging, which lies at an altitude of 0.0 m m.s.l. with respect to the current sea level, overlies a large terraced structure made of large blocks of sandstone. The latter was recognized as a part of the Roman harbour pier (USM77). Due to the small size of the excavation, it is impossible to know the structural articulation of this coastal structures: only a small part of the side facing the sea was identified. It consists in minimum two steps about 0.5 m wide.

The accurate analysis of the archaeological material, allows to include the US76 in the first half of the 5th century AD. Archaeological data is confirmed by radiocarbon dating on *Bittium reticulatum* shell (1550-1580 yrs BP, Tab. 4). Similarly, some amphorae fragments recovered in the US120 have been dated at an age ranging between the end of 4th and the beginning of the 5th century AD. The radiocarbon date of a *B. reticulatum* shell found inside the sediment, has pointed out an age of 3250 yrs BP (1250 yrs BC, Tab. 4).

high percentages. *Ammonia tepida*, well preserved, are occasionally present (levels US696 and 695), while *Quinqueloculina* spp. and others miliolids occurs only in

A Site name	B Type of marker	C WGS84 coordinates	D Age (Years BP)	E Corrected measured height (m a.s.l.) and reference	F Functional height (m)	G Palaeo-sea level (m m.s.l.)	H Predicted height (Lambeck et al. 2011) (m m.s.l.)	I Vertical tectonic rates (mm/yr)
Curia	Sea wall	45.64861 13.7675	2000±50	**-0.3±0.2** This paper	**0.3**	**-0.6±0.2**	**-0.46**	**-0.07**

Tab. 3 - Dated sea level markers in Trieste. A) site name; B) type of sea level marker; C) WGS84 centesimal coordinates of the surveyed sites; D) estimated age of archaeological remains (years BP); E) corrected height of the archaeological marker and reference (if published data); F) functional height; G) paleo-sea level (measured + functional height); H) predicted sea level (from Lambeck et al., 2011); I) estimated vertical tectonic rate (mm/yr).

In order to study the microfaunistic composition of this paleoenvironments, four levels of the archaeological sequence have been selected, from the bottom to the top as follows (fig. 4A):

US120: -0.35 m m.s.l.;
US76 (bottom): -0.05 m m.s.l.;
US76 (top): +0.25 m m.s.l.;
US74: +0.50 m m.s.l.

The sedimentary sequence at the “Cavazzeni” site is characterized by muddy sands rich in gravel. The latter is more abundant toward the top of the excavation. Littoral gastropods are very abundant in the gravelly fraction, in particular well preserved specimens of *Bittium reticulatum* (Fig. 4B) and fragments of vegetation in the first three levels (US120, US76-bottom and US76-top); moreover they are enriched of carbonized wood fragments and archeological fragments toward the top (US74).

The foraminifers found in this excavation account for forty-four species comprised of twenty-three genera, listed in alphabetic order in Table 2; *Ammonia*, *Elphidium* and *Quinqueloculina* are the most frequent genera. The recovered taxa are well-known in the modern Mediterranean coastal areas, from brackish-water to infralittoral settings (see references reported in the Methods). From the bottom (older) to the top (younger) of the vertical section, the number of species strongly decreases from 36 (level US120) to 5 only (US74). In the first level (US120), *Elphidium pulvereum* and *Ammonia tepida* are the dominant species reaching the percentage of 28.13 and 21.17, respectively (Tab. 2). Other species, such as Miliolidae, *Discorbis aguayoi*, *E. aculeatum*, *E. complanatum*, *E. jenseni*, *E. macellum* and *Trochammina inflata* are well represented, even if in low percentage. In the following level, US76 (bottom), where a slightly decreasing richness is reported (26 species), the presence of *A. tepida* is nearly constant, while an increasing percentage of *D. aguayoi*, *E. jenseni* and *Rosalina floridana* is evidenced. On the contrary, *E. pulvereum* strongly decreases at a rate consistent with the previous level. In the last two levels, toward the top of the excavation, the foraminiferal assemblage is strongly reduced both in number of species and in number of tests (Tab. 2). Only few specimens of *Ammonia beccarii*, *Elphidium crispum*, *E. macellum* and *Quinqueloculina ungeriana* are reported. Moreover, these tests are often poorly preserved. It is noted that these samples contain reworked older planktonic foraminifers mixed with autochthonous forms; the reworked foraminifers mainly derive from the Eocene Flysch bedrock.

The ostracod fauna found in these samples consists of fourteen species comprised of nine genera. These are listed in alphabetical order in the Table 2. Species of *Candona*, *Schellencandona* and *Loxoconcha* are the most frequent taxa, but usually represented by juveniles. In correspondence of the level US76 (bottom), the higher number of species of ostracods is defined by the occurrence of *Loxoconcha* spp., *Xestoleberis* spp., *Heterocypris salinus* and *Leptocythere lagunae*. On the top of the excavation (US74), scattered young specimens of *Candona* spp. occur. These species of ostracods, well-known in the modern Mediterranean, are typically representative of freshwater, brackish, brackish-infralittoral and infralittoral conditions (see references reported in the Methods).

A Site name	B Sample	C WGS84 coordinates	D Elevation (m a.s.l.)	E Laboratory Number	F Age (^{14}C uncal. BP)	G Cal Age 1sigma (Years BP)
Cavazzeni (US120)	*Bittium reticulatum*	45.64861 13.7675	-0.10	Poz-15856	3250 ± 55	3074 ± 87
Cavazzeni (US76 – bottom)	*Bittium reticulatum*	45.64861 13.7675	-0.05	Poz-15854	2065 ± 30	1639 ± 48
Cavazzeni (US76 – top)	*Bittium reticulatum*	45.64861 13.7675	+0.30	Poz-15855	2020 ± 30	1576 ± 47

Tab. 4 - Radiocarbon dating. A) site name and archaeological level; B) sample; C) WGS84 centesimal coordinates of the surveyed sites; D) elevation of the sample (m m.s.l.); E) laboratory number of the sample; F) uncalibrated age (years BP); G) calibrated age 1sigma (years BP).

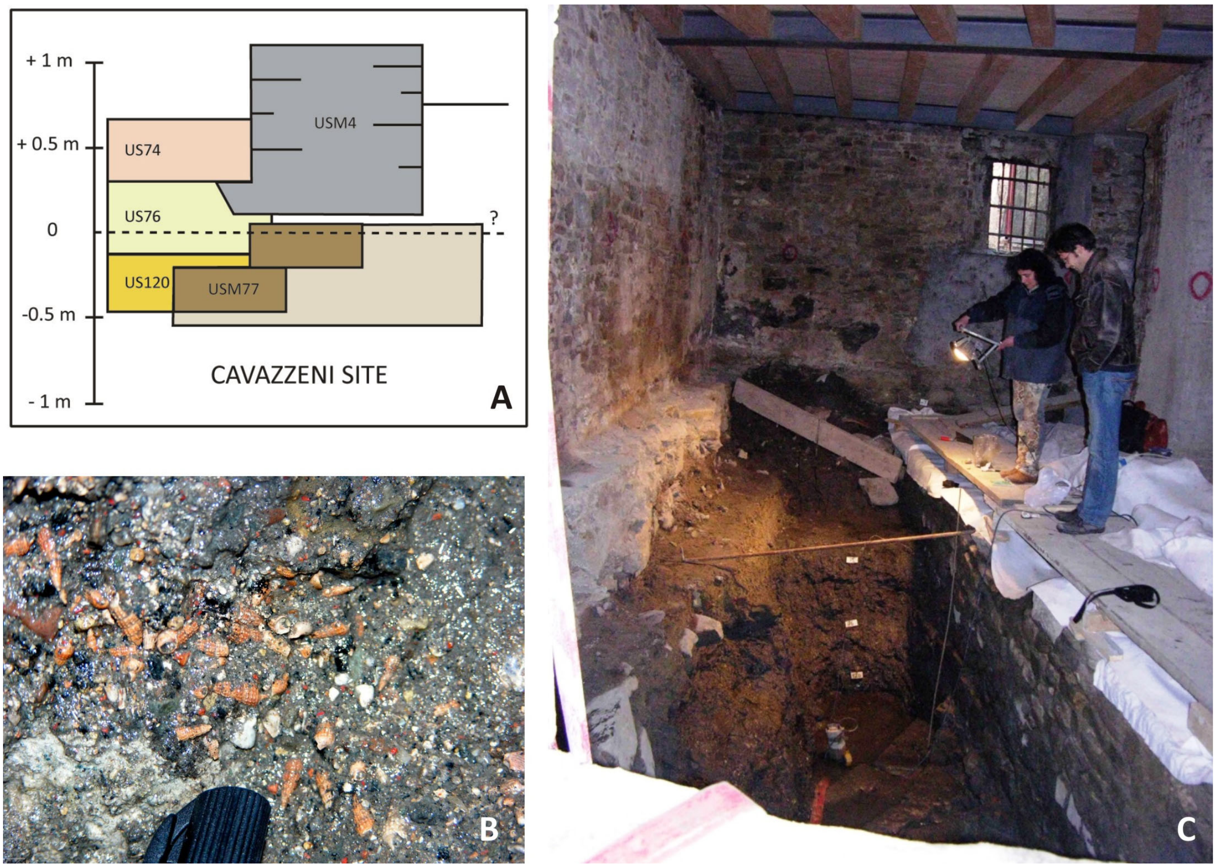

Fig. 4 - The archaeological site at Cavazzeni. A) Representative sketch of the site; B) Particular of the level US120 with abundant gastropods and C) View of the site.

5. DISCUSSION

Holocene paleoenvironments of coastal areas are closely related to sea level and its variations. In particular favorable conditions, as in urban environments, the archaeological structures can preserve sedimentological markers which were deposited during their construction or during the employment of coastal artifacts. From a geomorphological point of view, all the coastal structures found out in Trieste were roughly located at the Flysch cliff foot, which nowadays is completely covered by buildings of the 18th century. The present-day shoreline is, in fact, shifted offshore with respect to the Roman Age one (Fig. 1).

Two coastal archaeological sites recently found out allowed to reconstruct the Roman Age sea level and its related environment. Moreover, the comparison of surveyed and published data (Ventura et al., 2008) concerning the site of Cavana provides the *trait d'union* to support our thesis concerning Roman Age sea level. Moreover, the comparison of their present elevations with predicted sea level curves (e.g. Lambeck et al., 2011) allowed to define the tectonic behaviour of the area.

The detailed study of archaeological structures and the relative stratigraphic sequences found out at the studied sites highlighted the occurrence of marine deposits at an altitude ranging from -0.35 to +0.50 m m.s.l. Since no other marine deposits at altitudes higher than present-day have been found along the whole Eastern Adriatic coasts, the studied sites are very significant. These marine fossils lay above mean sea level, but they are not directly related to past mean sea levels as they were probably deposited during a storm event or tsunami. Even if written historical sources of a tsunami in the Gulf of Trieste have never been found, marine shells dated in the archaeological level US76 - top suggest that they can be related to the 361 AD earthquake occurred in the Qvarner area (Croatia). A number of Authors (Pirazzoli, 1980; Benac et al., 2004, 2008), in fact, explained the submerged position of the notch along the Eastern Adriatic coast indicating the co-seismic movement related to this earthquake.

Archaeological survey in Trieste highlights a complex Roman Age coastal architecture made up of sea walls, docks and piers connected by a coastal road and functional to a wide urban texture. The construction of the waterfront was probably the result of a wide project, gradually started since the 1st-2nd century AD (Maselli Scotti, 2008) and subsequently modified time after time up to the 5th century AD. The archaeological setting of the Curia site highlights that significant land reclamation have been carried out during Imperial Age too. From a geomorphological point of view, Roman Age coastal structures have been surveyed in correspondence of the cliff-platform junction. The natural morphology of the shoreline was probably still visible during Imperial Age, but it was subsequently modified by the following landfills.

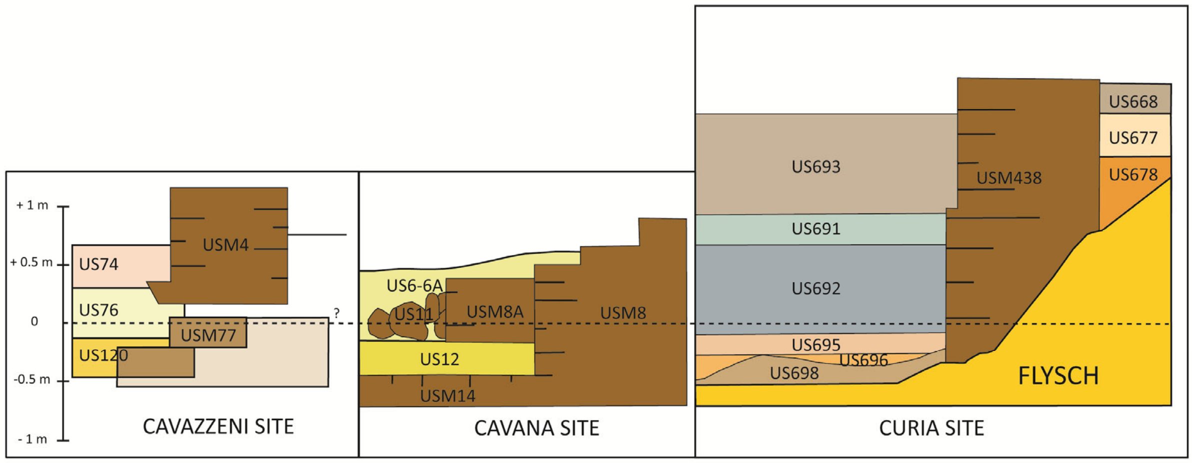

Fig. 5 - Representative sketch of the relations among the archaeological sites at Cavazzeni, Cavana and Curia.

The composition of the foraminiferal assemblage of marine deposits at the base of the wall suggests a high energy shallow marine environment, as highlighted by the dominance of *A. beccarii* and *E. crispum*, whom specimens are both well and poorly preserved. The association with some epiphytic forms, such as *E. aculeatum* and *E. pulvereum*, indicates some vegetation cover. The stratigraphical sequence seems to indicate the presence of a sandy bar (US699) which separates an inner environment (US696) and an outer one (US697). Only level US697T (-0.15 m.s.l.) is indicative of an open marine setting. Scattered occurrence of brackish taxa such as *A. tepida*, *E. excavatum*, *N. pauciloculum* suggests a slight influence of freshwater input. The ostracods, which are generally scarce or absent, confirm this paleoenvironmental interpretation.

Afterward, the Imperial Age harbour system suffered a widespread crisis during the Late Roman Age (Ventura et al., 2008) so important as to remain out of the 5th century defensive system of the city. Later, archaeological and micropaleontological data indicate the prograding of the coastline created through the accumulation of filling material (from US692 upward).

Late Roman Age coastal structures which overlay an Imperial Age pier have been discovered at Cavazzeni (Fig. 4, Maselli Scotti, 2008; Degrassi et al., 2008). The pier could be similar to fluvial dock structures found out at Altino (Venice, Italy, Tirelli, 2001), where the fluvial port was terraced, as in Trieste, and couplet with wood poles, used for docking and protection of the dock itself (Tirelli, 2001). Even if the portuality and the harbour environment of Trieste was necessarily different, Roman Age oak poles have been found near the Cavazzeni site (Ventura, 1996).

Regarding the Cavazzeni site, the microfaunae composition of the levels US120 and US76 (bottom), which are located from –0.35 to –0.05 m m.s.l., represents a shallow-marine infralittoral paleoenvironment, as testified by several species of miliolids and other marine hyaline taxa among the foraminifers, and by species of *Loxoconcha* spp., *Xestoleberis* spp. and *Hemicytherura videns* among the ostracods. The occurrence of epiphytic species such as *Elphidium* spp., *Rosalina* spp. and *Discorbis aguayoi*, indicates the highly vegetate conditions of the bottom, whom remains are abundant in the studied sediments. In particular, *D. aguayoi* has been frequently found on *Zoostera noltii* leaves (Hohenegger et al., 1989). This marine paleoenvironment is influenced by salinity variability, as indicated by the occurrence of *A. tepida* (> 20% of frequency), *A. perlucida*, *Haynesina* spp. and *T. inflata*, which are species of brackish-water affinity characteristic of lagoon, estuarine, or river-mouth environments. The fresh water input is testified also by the presence of ostracods such as *Candona* spp., which is exclusive of lake settings. Probably in this shallow coastal environment, highly vegetated, fresh water may also accumulate from small streams or from human harbour activities. Considering the good preservation of the microfossils and the abundance of vegetation, it is possible to assume that it was a partially protected environment, maybe a small harbour. In fact, the high occurrence in all the studied levels, but one (US74), of *B. reticulatum*, which is a marine infralittoral gastropod, could

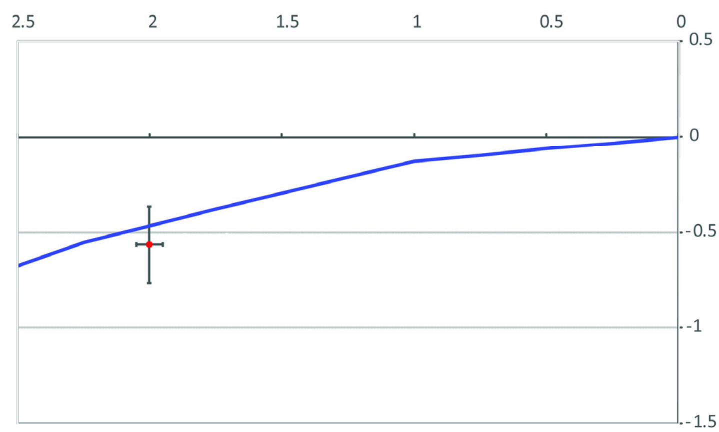

Fig. 6 - Predicted sea level curve (Lambeck et al., 2011) compared with the elevation of the sea level markers quoted in Table 3.

indicate a limited confinement of this area. The accumulation of these shells could be due to the backwash action. 17th century maps (Fig. 2) highlight the presence of piers and breakwaters which created sheltered areas behind them along almost the waterfront. Dating of pottery sherds and ceramics found out at the studied sites agree with the radiocarbon age on marine shells found out in the same deposits. In the upper part of the sequence (US76 - top and US74, from +0.25 to +0.50 m m.s.l.), very few foraminifers always badly preserved are recovered; they are represented by coastal marine taxa of high hydrodynamics such as *A. beccarii*, *A. parkinsoniana* and *E. crispum*, *E. macellum*, probably transported by violent storm episodes and accumulated in this confined basin or representing a non-protected coastline. Ostracods are very scarce and are represented only by juveniles of freshwater species. Archaeological materials indicate that the level US74 probably represents a landfill.

The archaeological setting of the two sites and the comparison with data collected at Cavana (Fig. 1, 5; Ventura et al., 2008; Degrassi et al., 2008) suggests the presence of marine deposits in all the studied sites. Thanks to the presence of coastal deposits and the joint analysis of both archaeological remains, micropaleontological data and radiocarbon dating of marine shells, sea level change in the study area was evaluated. Regarding the Curia site, even if the archaeological structure is poor of information, the presence of a beach deposit located at the base of the coastal wall reduces the errors related to the Roman Age sea level height. In particular, we compared the archaeological structure to current retaining sea walls scattered along the shoreline Northward from Trieste. Their base is located averagely 0.3 m above mean sea level. According to the hypothetical similarity between present-day and ancient sea walls, we suggest that Roman Age functionality of the studied sea wall was about 0.3 m (Tab. 3). Considering an elevation uncertainty of +0.2 m, Roman sea level was therefore at about -0.6±0.2 m m.s.l. Afterwards, these structures and the related coastal deposits were covered by filling materials, in order to create a new waterfront, moved off-shore (Fig. 2). On the contrary, due to the small size of the excavation, it is more difficult to evaluate the role and consequently the functionality of Imperial Age structures at Cavazzeni. Therefore it is impossible to evaluate the sea level change which occurred since the time of their construction.

Degrassi et al. (2008) suggested two hypothesis concerning sea level change in the area. The first hypothesis assumes the tectonic stability, while the latter assumes the vertical downdrop, in agreement with the whole Eastern Adriatic coast. Thank to the availability of new archaeological and micropaleontological data at Curia site, we support the first hypothesis. In fact, the comparison of surveyed data and predicted curves (Antonioli et al. 2007; Lambeck et al., 2011) suggests that limited relative sea level variations occurred since Roman Age (Fig. 6), despite the significant tectonic subsidence of the Eastern and Northern Adriatic coast (Antonioli et al., 2007; Faivre et al., 2011). Data here discussed confirm the tectonic peculiarity of the Trieste area suggested by Furlani et al. (2011) with respect to the surrounding area.

6. CONCLUSIONS

A detailed analysis of published and new data on archaeological remains and sedimentological deposits at two archaeological sites in Trieste allowed to reconstruct the paleoenvironment and the sea level during Roman Age. At that time, the shoreline was already strongly affected by human activities, as testified by the presence of well-developed coastal structures. Afterwards, these structures were covered by 17th century reclamation works. Archaeological and micropaleontological data indicate that Roman Age sea level was -0.6±0.2 m lower than nowadays. Therefore the comparison between past sea level and the predicted sea level curve (Lambeck et al., 2011) suggests that this sector of the Gulf of Trieste has been affected by a vertical tectonic downlift of about -0.2 mm/yr since Roman Age. These data disagree with the higher tectonic subsidence observed along the remaining part of the Northern Adriatic Sea (Antonioli et al., 2007).

The presence of marine deposits with bad-preserved microfossils at elevations higher than current mean sea level suggests the possible occurrence of a violent storm or a tsunami event. Radiocarbon dating suggests a correlation with the 361 AD earthquake occurred along the Eastern Adriatic coasts. This earthquake was considered as the driving factor in the origin of the submerged notch in the same area by Pirazzoli (1980) and Benac et al. (2004, 2008).

Acknowledgements

We are kindly grateful to Prof. Nevio Pugliese, Department of Mathematics and Geosciences, University of Trieste, for micropaleontological advices. Moreover we thank two anonymous reviewers for the useful advices.

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Ms. received: January 23, 2012
Final text received: March 8, 2012