Il Quaternario
Italian Journal of Quaternary Sciences
***12**(2), 1999, 249-256*

RELATIVE SEA-LEVEL RISE, SEDIMENT ACCUMULATION AND SUBSIDENCE IN THE CAORLE LAGOON (NORTHERN ADRIATIC SEA, ITALY) DURING THE HOLOCENE

P. Galassi & R. Marocco
Dipartimento di Scienze Geologiche, Ambientali e Marine, via E. Weiss 2, 34127 – Trieste
Marocco@univ.trieste.it

ABSTRACT - *Relative sea-level rise, sediment accumulation and subsidence in the Caorle Lagoon (northern Adriatic sea, Italy) during the Holocene.* The litho-biostratigraphic analysis and radiocarbon dating of the lagoon deposits found subsoil in the eastern Venetian plain (Portogruaro –Valle Vecchia borehole transect) has allowed the definition of the accretionary status of Caorle Lagoon and the accretion rate of deposits (AR). The knowledge of these two factors has permitted the evaluation of the relative sea level rise values of the coastal zone. For this estimation, has been used the relation which links the accretionary status of the lagoons to the accretion rate (AR) of tidal deposits and relative sea-level rise (RSL) proposed by Nichols (1989) has been used. The comparison of the various relative sea-level rise trends obtained from the deposits of Caorle and Marano Lagoons has demonstrated that significant variations exist between these lagoons, in a manner to be ascribed to different subsidence values which have affected the coastline of the Venice Gulf. Whilst proving these processes that influence the decrease of the soil level which exists in this zone, it is highlighted that the most recent contemporary deposits in Caorle lagoon show height differences, progressively increasing from the littoral zone to the hinterland deposits up to reaching maximum values of 2.8 m. Such variations correspond to the maximum absolute settling of the eastern Venetian coastal plain, recently reclaimed.

RIASSUNTO- Innalzamento relativo del livello del mare, sedimentazione e subsidenza nella laguna di Caorle (Alto Adriatico, Italia) durante l'Olocene. L'analisi lito-bio-cronostratigrafica dei depositi lagunari ubicati nel sottosuolo della pianura veneta orientale (transetto Portogruaro-Valle Vecchia) ha permesso di definire l'innalzamento relativo del livello del mare negli ultimi 8.000 anni. Per questa stima ci si è avvalsi della relazione che lega il rateo di sedimentazione lagunare e l'innalzamento relativo del livello marino allo stato di accrescimento della laguna proposta da Nichols (1989).
Il confronto dei trend d'innalzamento del livello relativo del mare dedotti dai depositi delle lagune di Caorle, di Marano e di Venezia ha dimostrato che esistono variazioni di profondità significative tra queste lagune contermini che sono da imputare a differenti valori di subsidenza che hanno interessato l'arco costiero del Golfo di Venezia. A dimostrazione dell'esistenza di questi processi di abbassamento del suolo nell'area si segnala che nella stessa laguna di Caorle i depositi coevi più recenti manifestano differenze di quota progressivamente crescenti dal cordone litorale al retroterra fino a valori massimi pari a 2.8 m. Questi dislivelli corrispondono alla massima depressione assoluta della piana costiera veneto orientale, recentemente bonificata.

Key words: relative sea level rise, lagoonal sedimentation, subsidence, Holocene, Caorle Lagoon, Italy
Parole chiave: innalzamento del livello del mare, sedimentazione lagunare, subsidenza, Olocene, laguna di Caorle, Italia.

Foreword

Lagoonal deposits in northern Adriatic Sea can be found off and on-shore; they are esentially contemporary, both dated Holocene. They are located at several depths, exactly from -35 to -40 m off Ravenna (Colantoni et al., 1990), to -26.5m on F. Dragogna plain (Piran Bay, Istria; Orogelec et al., 1981), to -10 m in the southern area of Venice Lagoon (Tosi, 1994), to –9.4 m in Caorle Lagoon (Marocco et al., 1996).

The difference of depth between these contemporary deposits demonstrates indeed the process of decrease in the ground level in the region, as appointed by many authors and lately by Gambolati (1998). This coastal and marine instability in northern Adriatic Sea, linked to tectonic and anthropogenic subsidence, makes it difficult to try the reconstruction of sea level variations during the Holocene, in accordance with Pirazzoli (1991). Nevertheless, although it is very difficult to guess the only eustatic variation of the sea level during the Holocene, the littoral deposits and especially those lagoonal, which are very frequent in this area, easily permit us to define the relative sea level rise (R.S.L.), by using suitable dating tools.

The relative sea level rise may also be defined through an indirect method, based on the consequences of this movement in lagoonal basins with a particular accretion rate (A.R.).The sea level rise on the one hand and the rate of sedimentation of the tidal deposits on the other hand consequently, cause a variation of the accretionary status of a lagoon (Nichols, 1989). In accordance with this author the terrigenous lagoons can evolve between two extreme situations:

-the accretion rate AR exceeds the RSL rise rate resulting in an accretionary "surplus";

-the RSL rise rate exceeds the accretion rate AR producing an accretionary "deficit".

An accretionary balance is atteined when sediment accumulation nearly equals RSL rise.

These situations determine local transgressions, regressions and aggradations of the tidal deposits or slight local variations within the lagoon, which can be found out through the normal methods of analysis of the facies and, especially, through a detailed biostratigraphic reconstruction of the sedimentary sequences (analysis of foraminifera, ostracods, gasteropods and bivalves).

To summarise, once the accretion rate of the lagoonal environment has been recognised and its sedimentation rate determined, the consequent RSL values may be estimated. These can be higher, lower or, in the most favourable cases, equal to AR. For > RSL or < AR values, it can be observed in the sedimentary sequences progradations or regressions of the tidal deposits in respect to the original position, which can be evaluated on the basis of the importance of the noticed effect. High differences between RSL and AR determine rapid, microscopic and not continuous variations of sub-lagoonal environments (tidal inlet, internal lagoon, external lagoon, lagoonal boundary). Instead, the opposite happens to the slow and progressive variations, which seem to be normal for these particular paralic environments.

The knowledge of the RSL values, with all the above mentioned conditioning, permits us to compare lagoonal environments belonging to a unique basin. This allow us to evaluate the importance of the local subsidence within the RSL, bearing in mind that the eustatic rise values are considered common *in loco*.

In the present work there is an example of definition with the proposed methodology by the relative trend of the RSL, deduced from the deposits of Caorle lagoon, recently analysed from a litho-bio-chronostratigraphic point of view (Marocco et al., 1996; Marocco et al., in press). In order to complete the research, the RSL trend of Caorle tidal deposits is compared to that of Marano lagoon (calculated with the same method, using the data of previous works; Marocco, 1989; 1991) in order to define the vertical ground variations in these two neighbouring lagoons of the northern Adriatic Sea.

1. Introduction and aims

Litho-biostratigraphical and chronological research (radiocarbon dating of lagoonal organic matter and shell- *Cerastoderma glaucum*-), carried out on the basis of four boreholes located close to the present Caorle Lagoon (Marocco, et al., in press) have allowed the detailed reconstruction of the evolution processes on the eastern Venetian coastline starting in the Holocene (Fig, 1a and 1b; Table I). As a result, it has been found that Caorle palaeolagoon existed underground in the coastal area during 8.500 years and has maintained that position since then, with very few oscillations seawards and landwards. 6.798 years ago, though, it started a rapid penetration on the backwards coastal plain, which was completed in the post-Roman period. Subsequently, a phase characterised by the withdrawal of the inner lagoon margin up reaching the present position started.

The detailed identification of the relatively steady sequences of tidal deposits and of mini transgressive-regressive sequences has allowed the definition of long term accretion rates of the lagoon according to the model proposed by Nichols (1989), namely, depending on the relation between accumulation rate (AR) and the relative sea-level rise (RSL). This was possible due to the concrete biostratigraphic and chronological information deriving from the borehole A, located behind the present barrier island (Marocco et al., 1996).

Furthermore, the stratigraphic distribution of Caorle palaeolagoon deposits (Fig. 1b) shows, after the first normal tabular aggradation, an anomalous northwards dip (in counter-slope compared to the regional slope), thus determining, for contemporary deposits, a progressive difference in depth (from 0.8 m in the borehole B- when compared to borehole A- up to 2.8 m in C, also compared to A).

The aim of this work is to find out the relations between subsidence, eustatism and sediment accumulation in Caorle Lagoon by producing a trend reporting the apparent sea-level rise. On the basis of a comparison with other tidal environments of the northern Adriatic Sea (Marano and Venice Lagoons), with different evolution, but also affected by a common value of eustatism. The subsidence values which have affected the coastal line have been evidenced.

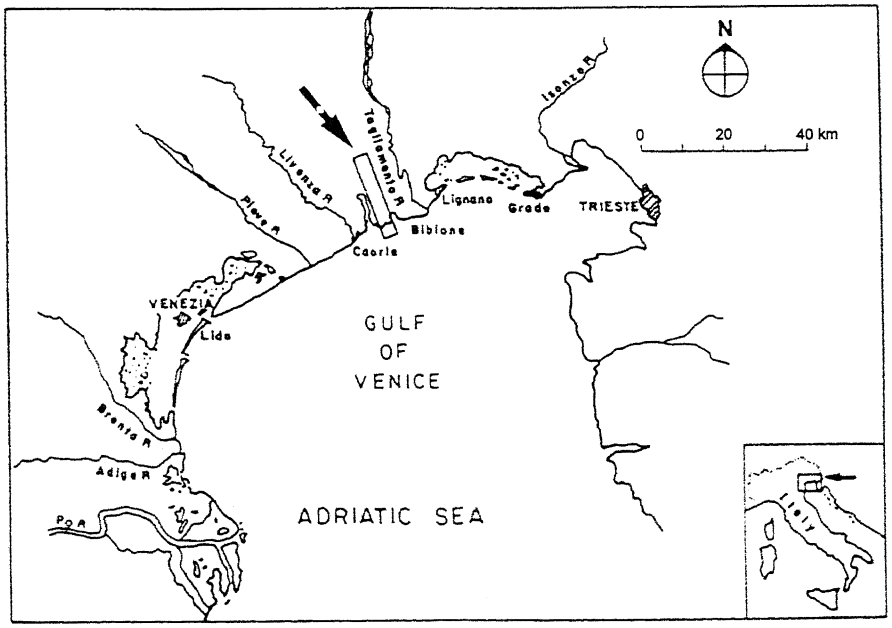

Fig. 1a – Gulf of Venice. The section highlighted marks the transect of the boreholes Portogruaro-Valle Vecchia.

Golfo di Venezia. Ubicazione del transetto (riquadro con freccia) dei sondaggi stratigrafici eseguiti tra Portogruaro e Valle Vecchia

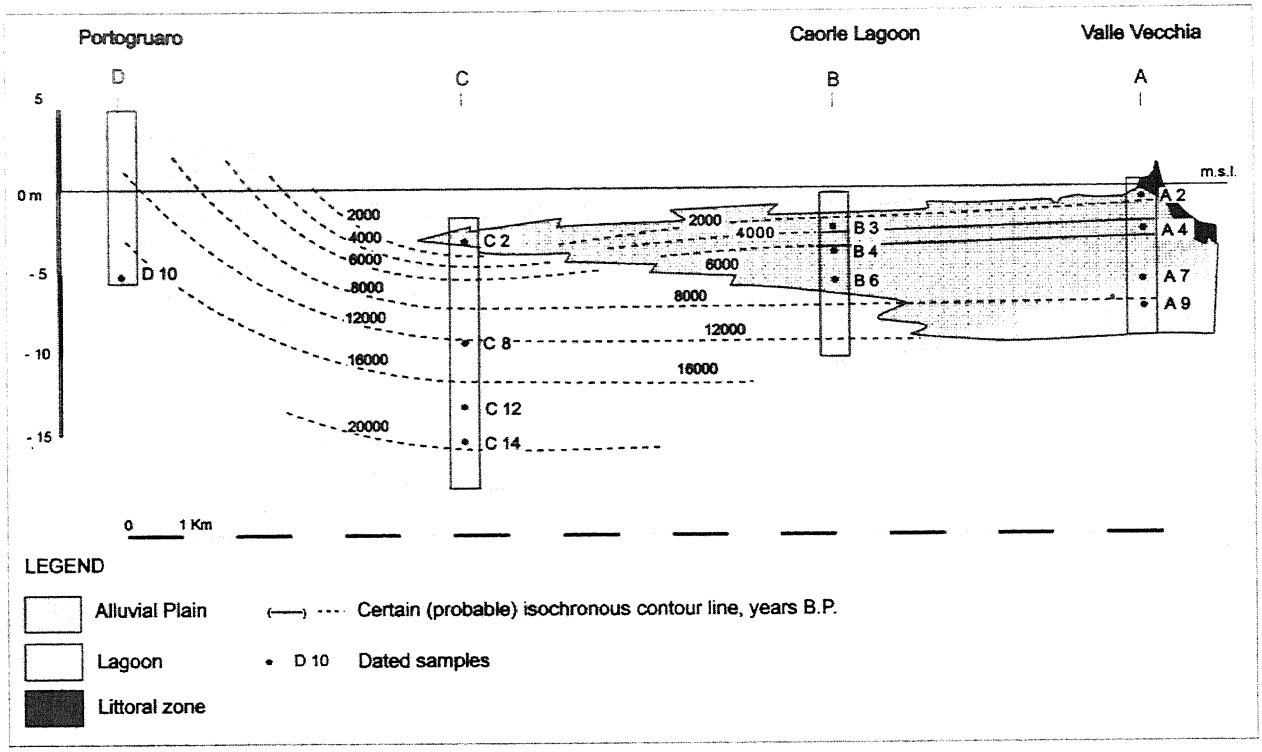

Fig. 1b – Paleogeografical and cronostratigrafic section through borehole A, B, C and D (from Marocco et al., in press).

Sezione paleogeografica e cronostratigrafica ricavata in base ai sondaggi A, B, C e D (transetto Portogruaro-Valle Vecchia; da Marocco et al., in stampa)

Borehole Core	Depth	Material	Environment	Uncalibrated age (yrs B.P.)	Calibrated age (yrs B.P.) Max	mean	min
A2	–1.16	Shell	Lagoon	2355 +/– 120	2111	(1953)	1823
A4	–3.18	Org.mat.	»	5515 +/– 270	6195	(5894)	5595
A7	–6.04	»	»	6270 +/– 515	7254	(6717)	6174
A9	–7.78	»	»	8060 +/– 655	9365	(8448)	7818
B3	–2.78	»	»	3595 +/– 245	3800	(3464)	3202
B4	–4.16	»	»	5790 +/– 480	6717	(6197)	5653
B6	–5.97	Shell	»	6355 +/– 150	6983	(6798)	6649
C2	–3.64	Peat	Alluvial plain	1236 +/– 144	1294	(1172,1157,1152)	967
C8	–9.64	»	»	10277 +/– 910	13097	(12113)	10358
C12	–13.46	»	»	18735 +/– 790		/	
C14	–15.59	»	»	20290 +/– 435		/	
D10	–5.16	»	»	14650 +/– 143	17716	(17537)	17358

Table I – Uncalibrated and calibrated (from Stuiver, Reimer; 1993) ages obtained from Radiocarbon dating performed on different samples of several cores and boreholes. Level depth, type of analysed material and relative environment are indicated. Organic matter and peat ages are corrected by old C.

Età radiocarbonio calibrata (da Stuiver, Reimer, 1993) e non calibrata, profondità (riferita al l.m.m.), natura e ambiente di sedimentazione dei cambioni analizzati. Le età della sostanza organica e delle torbe sono state corrette dalla contaminazione determinata dalla presenza di C più vecchio.

3. Study area

Caorle Lagoon is a typical choked lagoon (Kjerfve, 1986) located in the middle of the Gulf of Venice, between Venice Lagoon westwards and Marano Lagoon eastwards. It is a microtidal environment (about 1 m. tidal range) at present limited and noticeably reduced (about 15 km^2) further to the reclamation work done in the last centuries (Fig.1 a). The area around the lagoon is flat, depressed, with lower depths than the lagoon beds. The soil forming is clayey, silty, very rarely sandy-silty with several types of organic matter, salt content and humidity. Recently, part of these old reclamation areas have been restored to marine-la-

Age (cal. yr B.P.)	Accretionary status	AR (mm/yr)	RSL (mm/yr)	Probable RSL value	
				min	max
8448-6900	Balance	1.0	1.0		
6900-6716	Deficit	1.0	>1.0	1.5	2.0
6716-6600	Deficit	3.5	>3.5	4.0	4.5
6600-6100	Balance	3.5	3.5		
6100-5894	Deficit	3.5	>3.5	4.0	4.5
5894-4900	Deficit	0.5	>0.5	1.0	1.5
4900-1953	Balance	0.5	0.5		
1953-0	Balance	0.5	0.5		

Table II. Sea level rise values estimated for the borehole A (Valle Vecchia)

Innalzamento del livello del mare relativo stimato in base ai dati del sondaggio A (Valle Vecchia)

goon environment, flooding them (Valle Vecchia pro-parte).

4. Relative sea level rise

On the basis of the biological zonation of the tidal flat facies in the boreholes A (Marocco et al., 1996), B and C (Marocco and Pugliese, in press), obtained through a detailed analysis of the deposits (litho- and biostratigraphic features and chronology of the sedimentary sequence of Caorle paleo-lagoon) the evolutionary state of lagoon can be inferred. This latter term implies the balance, deficit and surplus evolutionary stages, and consequently the relationship between AR and RSL following the Nichols' (1989) model.

In brief, once the accretion rate (AR) and the state of lagoon evolution are known, the relative sea-level rise (RSL) can be deduced. In the table below the latest 8.448 years of Caorle palaeolagoon have been divided in uniform intervals of time regarding the relation between accretion rate (AR) and relative sea level rise (RSL) (therefore, within an only interval, AR is equal, lower or higher than RSL).

The values not included in this interval are approximate, obtained by linear interpolation of the known data. On the basis of literature (Nichols, 1989) and of biostratigraphic indications, which usually highlight progressive and not immediate variations of the sub-environments within the lagoon, determined by minimal variations between AR and RSL, it was agreed to attribute to the RSL values higher than the AR a minimum value of AR + 0.5 mm/yr and a maximum one + 1.0 mm/yr. It is, thus, defined (arbitrarily) a «confidence» range within which RSL variations can be ascertained.

From the hereto reconstruction it is evident that the whole retrogradation of the lagoon deposits is obtained from more or less long equilibrium phases between the elements herein (sediment accumulation on the one hand and eustatism plus subsidence on the other), interrupted by brief lapses of time, when the relative sea level rise clearly prevails on the coastal progradation.

On the basis of the above mentioned data we may deduce the trend reporting RSL variations in time (Fig. 2).

The variation of RSL in the last 4.900 years is represented by a segment corresponding to a period of equilibrium between sediment accumulation on the one hand, and eustatic rise plus subsidence on the other. When the phase of the «deficit lagoon» starts, the RSL value is represented by a zone delimited by the probable minimum and maximum values. From this representation of the variation of RSL during the Holocene, the following conclusions are to be deduced:

- the whole sea level rise has been estimated in values ranging from 8.2 m to 8.9 m;
- the Holocene sea-level has never overpast the present one;
- about 5.000 years ago the sea-level rise was close to the present m.s.l. (about 2.4 m lower) and its rise trend started to reduce in respect to the past;
- research carried out in the other lagoons of the northern Adriatic (Bortolami et al., 1977; Marocco, 1991, Correggiari et al. 1996) and in other areas worldwide similar to the Adriatic zone (Pirazzoli, 1991, Kider 1995) confirms this apparently rising trend of the sea level, although the values are different.

Although the procedure used is not completely reliable, it seems at present the only possible way to evaluate at arm's length the variations of the sea and coastline in an area where a lagoon has developed. These results, quantitatively and at long term, might be compared to other analogous data obtained in similar areas of the northern Adriatic Sea. This procedure intends to separate the eustatic effect, common along this coastal stretch, from the more variable parameter, the subsidence, the isostatic adjustament or, in general, the various vertical movements of the ground surface. For example, the comparison between Caorle and Marano lagoons (Marocco, 1989;1991) indicates a very different rising trend of the latter lagoon, characterised by mainly lower and not contemporary sedimentation rates.

Nowadays, the underground of Marano Lagoon barrier island remarks the presence of a «balance lagoon», evidenced by deposits and fauna species within the inner margin of the lagoon, probably close to the tidal inlet (N. Pugliese, personal communication, 1999). Hardly 1.400 years ago the beach deposits overlaid the lagoon deposits thus highlighting the minimum withdrawal of the lagoon system (Marocco, 1989).

On the basis of the RLS curve of Caorle and Marano Lagoons and eustatic curve by Tahiti (Bard et al., 1996), it is evident that when compared to Caorle Lagoon (Fig. 3), Marano has a more regular rising trend, but its values are very different and depend on a bigger influence of subsidence than eustatism. The medium ground surface settling values of Marano Lagoon are estimated around 0.9 mm/yr (1.500 - 2.000 years ago), which progressively increased up to a maximum of 1.8 mm/yr (4.000 - 4.500 years ago), and subsequently decreased to 1.3 mm/yr at about 4.500-5.000 years ago.

Given that the above mentioned values are relative and not absolute, the data regarding the depth variations of the lagoonal beds during the first 1500 years are in the average of the data collected up to date in the northern Adriatic (see Brunetti et al., 1998; Bondesan et al., 1995; Gambolati, 1998). Still, it is difficult to explain the rapid increasing trend and then, slightly decreasing of the difference in the two RSL curve. At the moment, there is no explanation for this phenomenon, which seems to have been imputed both, to local processes of sedimentary compaction and to anthropic subsidence associated to the recent reclaim, rather than to tectonic or isostatic reasons.

The accretion rate of Venice Lagoon (obtained from the data of the borehole 14 Venice-Lido - Bortolani et al., 1977, and from the borehole 10, Tosi, 1994), shows more analogies with Marano Lagoon than with Caorle. On the basis of this comparison, the stability of the lagoon is remarkable in the period from 0 to 3.500 years BP; the subsequent periods show values known in the Adriatic area for natural subsidence (1.3 mm/yr in Venice - Carbonin et al., 1977; 2 mm/yr at Cervia; 2.5 - 3.2 mm/yr at Porto Corsini; 3.7 mm/yr at Ravenna - Bondesan et al., 1995).

The hypothetical RSL trend calculated on the basis of lagoonal deposits at Caorle shows a course significatively different from the eustatic proposed by Bard et al. (1996) and considered valid at global scale. This difference can be assumed, on its own, as absolute value of ground lowering in the studied coastal area. In fact, some observations (reported in Antonioli, Silenzi, 1998) lead to distrust the reliability of a single RSL trend for each site. Due to this uncertainty, it seems to us more appropriate to work at regional scale with relative RSL trends, comparing them within sites not very distant from each other.

However, when the RSL rise at Caorle is compared to the eustatic curve of Bard et al. (1996), quite similar trends can be observed from 0 to 7.000 years B.P., whereas they are definitely discordant for older ages (8.5 m depth at Caorle corresponds to 35 m at Tahiti). There are no direct evidences or clues of a glacio-isostatic collapse

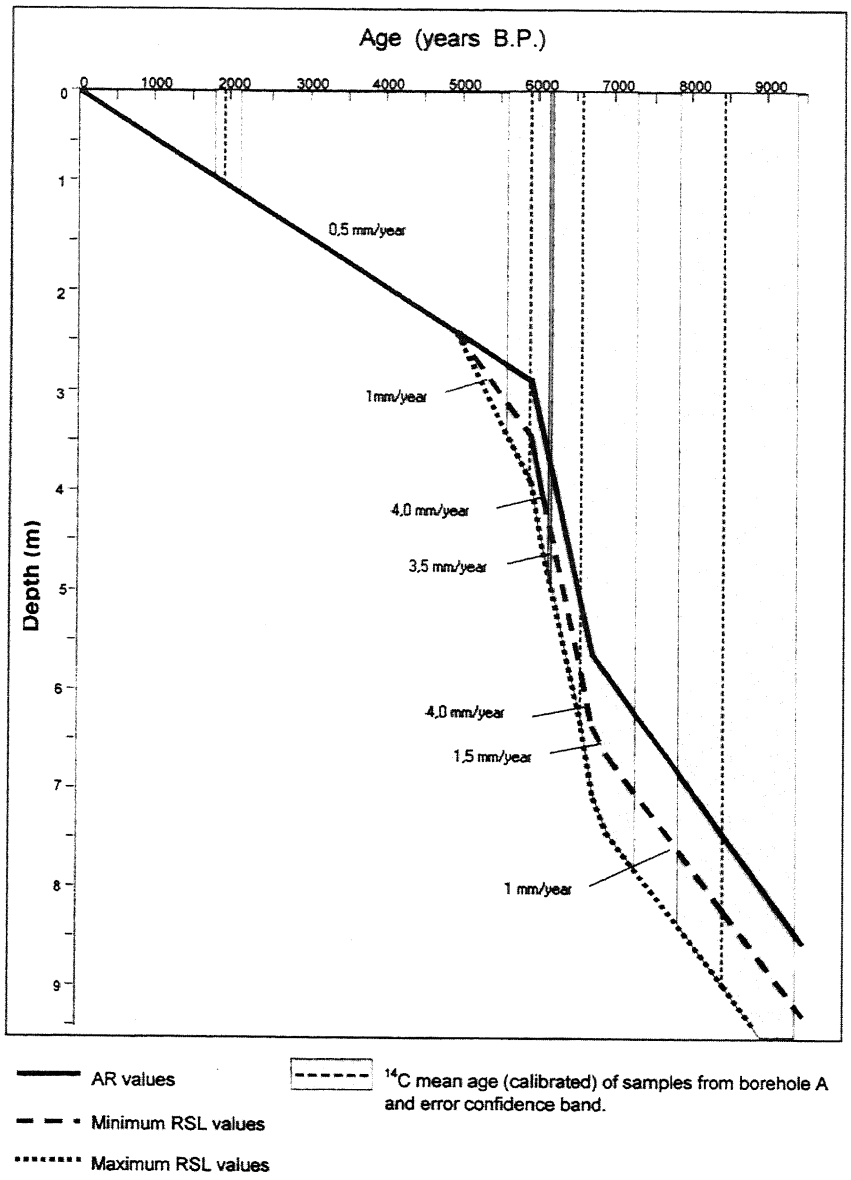

Fig. 2 – Holocene hypotetical RSL curve of Caorle Lagoon.

Ipotetica curva di risalita del livello del mare relativo (RSL) ricavata dai dati della Laguna di Caorle.

Age (cal. yr B.P.)	Accretionary status	AR (mm/yr)	RSL (mm/yr)
5540 – 3660	Balance	2.3	2.3
3660 – 1400	Balance	1.4	1.4

Table III. RSL values estimated in Marano Lagoon (re-calculated by Marocco, 1989; 1991)

Valori di innalzamento del livello del mare relativo (RSL) stimati per la Laguna di Marano (dati calcolati da Marocco, 1989; 1991)

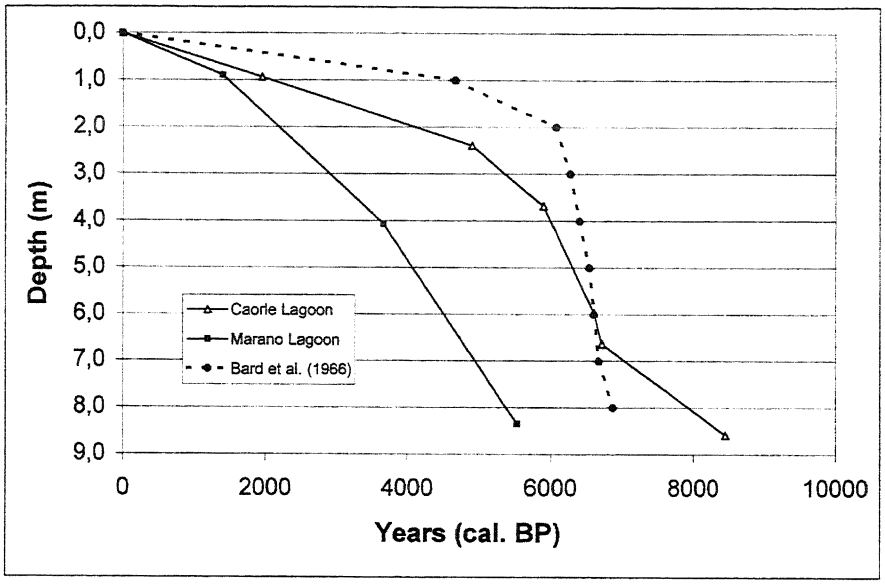

Fig. 3 – Hypothetical RSL curves of Caorle (mean) and Marano Lagoons compared to the eustatic curve proposed by Bard et al., 1996 (Tahiti, Papeete).

Ipotetiche curve di risalita del livello del mare relativo (RSL) per la Laguna di Caorle (valori medi) e di Marano confrontata con la curva eustatica proposta da Bard et al. 1996 (Tahiti, Papeete)

of the Adriatic coastal area at the moment, as it is, on the contrary, reported in the rest of the world (e.g. Tapes transgression in Norway), what would make possible such a difference. Furthermore, it must be pointed out that the Holocene transgression, recorded in the present shorelines of the northern Adriatic sea, is evident from about 8.5 m depth; only continental deposits are found at higher depths. Therefore, it is not possible to verify the sea level rise has followed a gradual trend at higher depths than those above mentioned.

This class of variations is not only found in different lagoons, located on the same coastal stretch, but might also be determined within a single lagoon. Variations in depth have been found in Caorle between contemporary sediments, between 8000-2000 years old, equivalent to subsidence values equal to 0.13 mm/yr (to 4 km from the coast) and to 0.47 mm/yr (to 8 km) in respect to the littoral area. It is remarkable that the tops of the three boreholes present significant differences of height (A= + 0.64 m; B = - 0.39 m; C = - 1.90 m) and that all the area around the lagoon is depressed, reporting a lower depth than the present lagoon bottoms.

4. Subsidence of Caorle Lagoon

On the basis of the litho-biostratigraphic data of the boreholes drilled in the nearby Caorle Lagoon, these seems to be no significant elements of correlation existing between accretion rate of the lagoon deposits and climatic conditions during the Holocene (variations in rain, temperature, etc.). It is, therefore, presumable that the variations of depth found in contemporary samples belonging to the same sedimentary environment are, either partially or completely ascribable to natural subsidence or caused by human activity. The attempts to discover the phenomena determining vertical movements of the ground which have provoked the present situation, have given the following results:

1. Considering the thickness of the deposits in the borehole C (4.6 m) from 8000 to 2000 years BP, and applying the 16% compaction, suggested by Gill, Lang (1977) for analogous deposits, the subsidence accumulation value found reaches at most some tens of centimetres, whereas the registered lowering is 2.8 m. This is so, although the alluvial deposits of the borehole C are on average thicker than those of the boreholes B and A. In other terms, the lithologic and textural characteristics of the deposits of the three boreholes present no differences to justify such different compaction values, and should determine an inverse situation characterised by a relative stability underground the borehole C and instability in the remaining boreholes. Therefore, this possible compaction cause of the deposits can be considered insignificant, also on the basis of the scarce thickness of the studied deposits.

2. In accordance with Bloom (1964) and other Dutch and Belgian authors (among others, Van Plassche, 1995, Denys, Baeteman, 1995) the compression of the peaty matter may determine substantial ground lowering. The diffuse presence of peaty layers in the studied boreholes and the evidence this author has found that 10 cm of peat correspond to an originary thickness of 30-40 cm, can determine a maximum ground lowering of some tens of meters.

3. The compaction processes produced in the clay by the substitution of the original interstitial waters with salty water could have been provoked after the progression of the lagoon on the alluvial plain. However, the effects of seawater intrusion are very difficult to quantify and not enough to justify the important reduction of thickness.

4. The effects of these phenomena might justify on the whole the depth variations in the contemporary deposits of boreholes A and B (0.8) m). However, they do not explain the 2.8 m level difference between contemporary deposits (2000 yr B.P.) of boreholes A and C. The data obtained up to present lead to the supposition that Caorle's situation has local interest. Among the causes that could justify these differences, the subsidence caused by fluvial diversion is to be considered. Previous studies have already remarked that Tagliamento River used to flow about 4000 years ago in an undetermined site within Caorle lagoon area and, afterwards, a deviation ea-

stwards made it move to the area previously occupied by Marano lagoon (Marocco, 1991). The most probable hypothesis is the subsidence caused by humans leading to the impressive reclamation for agricultural purposes, which started from the second half of the last century. The values of the ground lowering were already discovered in the northern Adriatic area, in Friuli plain (1.5 m maximum in 60 years – Foramitti, 1990) and in Venetian plain (about 1.5 – 2.0 cm/yr – Province of Venice, 1983).

CONCLUSIONS

The litho-biostratigraphic and chronological analysis of four boreholes drilled along a transect of the eastern Venetian plain (from Portogruaro to Valle Vecchia) has allowed the reconstruction of the relative sea-level position to the lagoon sedimentation rate and accretionary status of the lagoon on the basis of Nichols model (1989). The results were:

- the whole sea-level rise (RSL) reports values ranging between 8.2 and 8.9 m;
- the Holocene marine level has never overpast the present one:
- around 5.000 years ago, the sea-level rise was very close to the actual values (about 2.4 m) and the rise trend started to reduce when compared to the past.

The comparison between the trends of RSL estimated for Caorle and Marano lagoons show significant height variations between those almost adjoining. In detail, the sea-level rise estimated for Caorle Lagoon is basically different from Marano and Venice (pro parte), which are very similar. These variations are imputed to subsidence processes, which determine very evident lowering in depth in the northern Adriatic coastline. In Marano Lagoon, the difference of depth, when compared to Caorle, ranges from 0.9 mm/yr (1.500-2.000 yr BP) to progressively increasing values up to a maximum of 1.8 mm/yr (4.000-4.500 yr BP), which subsequently decrease up to 1.3 mm/yr (4.500-5.000 yr BP). The few data obtained for Venice lagoon when compared to Caorle show a noticeable stability of Venice lagoon system up to around 3.500 yr BP and important different values for the subsequent periods (to be verified with new data).

Depth variations between lagoon contemporary deposits are also found in Caorle Lagoon with increasing values from the barrier island located between 4 km and 8 km (-0.47 mm/yr) from the coast (-0,13 mm/yr). This causes the complete depression of the lagoon strip in respect to the present marine level, probably caused by the reclamation work executed during the second half of the last century.

Acknowledgements

With thanks to my colleagues N. Pugliese and G. Fontolan for the discussions and the helpful advice during the writing of the article. Special thanks to Dr. L. Tosi for the review of the environmental and radiometric data of Venice Lagoon and to P.A. Pirazzoli for the critical review of the preliminary version of the paper. Dr. F.Antonioli and an anonymous reviewer are fully acknowledged for their useful suggestions to improve the manuscript.

The work has been carried out in the framework of the Project «Sistema Lagunare Veneziano» (Venetian Lagoonal System), line 2.6, and of the project MURST 60% (Thematic cartography of the Friuli-Venezia Giulia Region and of the nearby areas, responsible R. Marocco).

References

Antonioli F., Silenzi S., 1998 – *Rassegna dello stato dell'arte sulle ricerche delle variazioni del livello del mare relativo e all'ultimo semiciclo climatico e sul concetto di stabilità tettonica.* Il Quaternario, 11(1), 5-18.

Bard E., Hamelin B., Arnold M., Montaggioni L., Cabioch G.,Faure G. & Rougerie F., 1996 – *Deglacial sea-level record from Tahiti corals and the timing of global meltwater discharge.* Nature, **382**, 241-244.

Bloom A.L., 1964 – *Peat accumulation and compaction* In *a Connecticut coastal marsh.* Jour. Sedim. Petrol., 34, **3,** pp. 599 – 603.

Bondesan M., Castiglioni G.B., Elmi C., Gabbianelli G., Marocco R., Pirazzoli P. & Tomasin A., 1995 – *Coastal Areas at Risk from Storm Surges and Sea-level Rise in Northeastern Italy.* Jour. of Coast. Res., **11** (4), 1354 – 1379.

Bortolami G.C., Fontes J. Ch., Markgraf V. & Saliege J.F. 1977 - *Land, sea and climate in the northern adriatic region during late Pleistocene and Holocene.* Palaeogeogr. Palaeoclim. Palaeoecol., 21, 139 – 156.

Brunetti A., Denèfle M., Fontagne M., Hatté C., Pirazzoli P.A., 1998 – *Sea-level and subsidence data from a Late Holocene back-barrier lagoon (Valle Standiana, Ravenna, Italy*). Marine Geol., 150, 29-37.

Carbonin L., Gatto P., Mozzi G., Gambolati G. & Ricceri G. 1976 – *New trend in the subsidence in Venice.* In: Land Subsidence Symposium, 65 – 81, IAHS Publ. No 121.

Colantoni P, Preti M, Villani B., 1990 – *Sistema deposizionale e livelli di riva olocenica sommersi in Adriatico al largo di Ravenna.* Giorn. Geol., 52/1-2, 1-18.

Correggiari A., Roveri M. & Trincardi F. 1996 – *Late Pleistocene and Holocene evolution of the north Adriatic Sea.* Il Quaternario, **9** (2), 697 – 704.

Denys L. & Baeteman C. 1995 – *Holocene evolution of relative sea level and local mean high water sping tides in Belgium- a first assessment.* Marine Geol., 124, 1- 19.

Foramitti R., 1990 – *La bonifica idraulica ed irrigua.* In: *La Bassa Friulana:Tre Secoli di Bonifica.* Consorzio di Bonifica Bassa Friulana. Udine, pp 225 – 267.

Gambolati G., 1998 – *Coastline evolution of the upper Adriatic Sea due to sea rise and natural and anthropogenic land subsidence.* CENAS, 28, 344 pp.

Gill E.D.& Lang J.G. 1977 – *Estimation of compaction in marine geological formations from engineering data commonly available.* Marine Geol., **25,** M1-M4.

Kider P. 1995 – *Holocene relative sea-level change and crustal movement in the southwestern Netherlands.* Marine Geol., 124, 21-41.

Kjerfve B., 1986 – *Comparative oceanography of coastal lagoon.* In : D.A. Wolfe (Editor), Estuarine Variability, Academic Press, New York, 63 – 81.

Marocco R. 1989 – *Evoluzione quaternaria della Laguna di Marano (Friuli-Venezia Giulia).* Il Quaternario, **2**,(2), 125 –137.

Marocco R. 1991 – *Evoluzione tardopleistocenica – olocenica del delta del F. Tagliamento e delle lagune di Marano e Grado (Golfo di Trieste).*Il Quaternario, **4** (1b), 223 – 232.

Marocco R., Melis R., Montenegro M.E., Pugliese N., Vio E. & Lenardon G. 1996 – *Holocene evolution of the Caorle Barrier-Lagoon (northern Adriatic Sea, Italy).* Riv. It. Pal. Str., **102**, 3, 385 – 396.

Marocco R. et al., (in press) – *Alluvial plain and lagoon evolution of northeastern Venetian coast during Late Glacial and Holocene.*

Ogorelec B., Misic M., Sercelj A., Cimerman F., Faganeli J., Stegnor P. 1981- *The sediment of the salt marsh of Secovlje.* Geologija, 24, 179 – 216.

Nichols M., M. 1989 – *Sediment accumulation rates and relative Sea-level rise in lagoons.* Marine Geol., 88, 201 – 219.

Pirazzoli P.A. 1991 – *World Atlas of Holocene Sea Level Changes.* Elsevier Oceanography Series, **58.**

Provincia di Venezia 1983 – *Studio Geopedologico ed Agronomico del territorio provinciale di Venezia – Parte Nord-Orientale.* 335 pp

Stuiver M., Reimer P.J. 1993 – *Explanded ^{14} C data base and revised CALIB 3.0 ^{14}C age calibration program.* Radiocarbon, **35,** 1, 215-230.

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

Van de Plassche O., 1995 – Evolution of the intra-coastal tidal range in the Rhine-Meuse delta and Flevo Lagoon, 5700 – 300 yrs cal B.C. Marine Geol., 124, 113 – 128.

Ms. ricevuto il 1° dicembre 1999
Testo definitivo ricevuto il 28 marzo 2000

Ms. riceived: December 1, 1999
Final text received: March 28, 2000