

Bollettino

della

Società Paleontologica Italiana

Pubblicato sotto gli auspici
del Consiglio Nazionale delle Ricerche

Volume 43, n. 1-2, 2004

Proceeding of the
1st MEETING OF THE ITALIAN OSTRACODOLOGISTS
“IN MEMORY OF GIULIANO RUGGIERI”

Rimini, February 12-14, 2003

Editors:
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MUCCHI - MODENA

Bollettino della Società Paleontologica Italiana	43 (1-2), 2004	ISSN 0375-7633	113-122	–	Modena, Novembre 2004
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Quaternary environmental evolution of the Venice area based upon ostracod assemblages

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KEY WORDS – *Ostracoda*, *Palaeoecology*, *Biostratigraphy*, *Quaternary*, *Venice*, *Italy*.

ABSTRACT – The cores VE-1 and VE-1bis were drilled on Isola Nuova del Tronchetto (Venice). They are, in all, about 950 m long. Qualitative and quantitative analysis of ostracod assemblages from the interval depth of 917.70 to 5.10 m were carried out with the aim to study environmental and sedimentary history of this sector of the Venice lagoon. The first occurrence of *Hyalinea baltica* (Emilian Stage) at 907.98 m and of *Globorotalia truncatulinoides excelsa* (Sicilian Stage) at 768.99 m, together with ostracods species (i.e. *Palmoconcha turbida*) allowed to better specify the age of the lower interval of the core. Despite the paucity of the ostracod fauna (many samples are barren), mostly related to the widespread turbidite deposition, it was possible to reconstruct the evolution of the lagoon from the offshore marine environment (maximum inferred depth value of about 190 m) during the Lower Pleistocene to the actual lagoon.

RIASSUNTO – [Evoluzione ambientale dell'area di Venezia nel Quaternario sulle base delle associazioni ad ostracodi] - All'inizio degli anni '70 il Consiglio Nazionale delle Ricerche ha avviato un programma di ricerca volto a chiarire i fenomeni di subsidenza che hanno interessato l'area di Venezia. A questo scopo sono stati effettuati dei carotaggi e sono state prelevate due carote (VE-1 e VE-1bis) in località Isola Nuova del Tronchetto il cui studio costituisce l'oggetto di questa nota. Complessivamente le carote in questione hanno portato alla luce circa 950 m di sedimento. Le associazioni ad ostracodi relative all'intervallo compreso tra 917,70 m e 5,10 m di profondità sono state analizzate per ripercorrere la storia sedimentaria e paleoambientale di questo settore della laguna di Venezia. Il rinvenimento di *Hyalinea baltica* (Emiliano) a 907,98 m e di *Globorotalia truncatulinoides excelsa* (Siciliano) a 768,99 m insieme con specie significative di ostracodi (es. *Palmoconcha turbida*) ha consentito di precisare l'età dell'intervallo inferiore della carota. Nonostante la povertà dell'ostracofauna (molti campioni sono addirittura risultati privi di ostracodi) per lo più legata ad eventi torbidity, è stato possibile ripercorrere la storia della laguna a partire dall'ambiente di piattaforma esterna durante il Pleistocene Inferiore, fino all'attuale ambiente lagunare.

INTRODUCTION

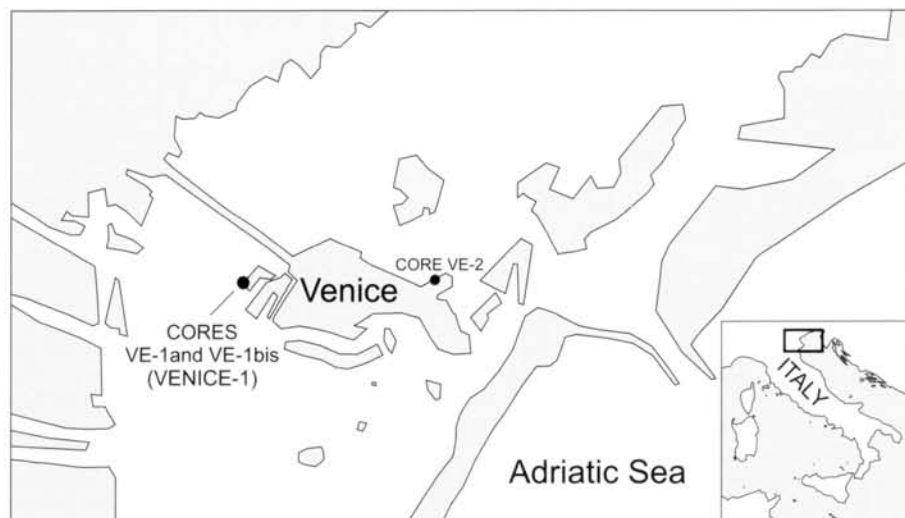
In the first years of the '70s, the Italian institute Consiglio Nazionale delle Ricerche (CNR) undertook a research program to investigate the subsidence affecting the Venice area. With this aim three bores were drilled (Text-fig. 1). The deepest well, well VE-1 was drilled from 60 to 950 m (depth of 0 m is referred to the ground elevation, that is 2 m above sea level) on the western coast of Isola Nuova del Tronchetto (Venice) in 1971. The uppermost part of this core was incomplete and was subsequently (1972) completed in a second well, well VE-1bis, located about 30 m from well VE-1 and drilled from a depth of 4.9 m to 120.3 m (depth of 0 m is referred to the drilling rotary table, that is 5.2 m above sea level). A third well, well VE-2 was drilled in 1973 on the eastern coast of Isola Nuova del Tronchetto; this well penetrated from 4.5 m to 400 m (depths are quoted as for well VE-1bis).

Wells VE-1 and VE-1bis has been the subject of several studies including lithological-sedimentological investigations, palaeontological and organic matter content analyses, which led to a series of more or less comprehensive and detailed inferences on the palaeoenvironmental and sedimentary history of the Venice area (CNR, 1971; Favero *et al.*, 1973, 1979;

Favero & Passega, 1974, 1975, 1980; Serandrei Barbero, 1975; Bellet *et al.*, 1982; Favero, 1984; Mullenders *et al.*, 1996; Kent *et al.*, 2002).

These palaeoenvironmental reconstructions took into account data mainly from foraminifers and only partly from other fossil groups such as ostracods (Favero & Passega, 1974, 1980).

Furthermore, it is worth mentioning that biochronological inferences on the deepest part of core VE-1 are controversial. In the earlier works, the biochronostratigraphy was primarily based upon foraminiferal analysis. As discussed by Favero & Passega (1974, 1975) and Favero *et al.* (1979), the oldest sediments of well VE-1 (from 950 to 815 m) cannot be well constrained, since they are characterized by the gradual disappearance of typical Pliocene forms, e.g. *Amphistegina lessonii* Orbigny, as well as by the progressive appearance of typical Quaternary taxa, e.g. *Hyalinea baltica* (Schroeter). Anyway, Favero *et al.* (1979) placed the Plio-Pleistocene boundary at 815 m, corresponding with an important transgressive event. In the subsequent paper of Favero & Passega (1980) the top of the Pliocene was, however, assumed to be near a total depth of 900 m. The first study of calcareous nannofossil events carried out by L. Todesco (in Favero, 1984) supported such a lowering of the Plio-Pleistocene boundary. This assumption was fol-



Text-fig. 1 - Location of the composite section VENICE-1 (cores VE-1 and VE-1bis) and core VE-2.

lowed in the work of Mullenders *et al.* (1996), which offered a detailed vegetation and climate reconstruction of the Venice area based upon pollen analysis of the three cores VE-1, VE-1bis and VE-2. The more recent paper of Kent *et al.* (2002) based on new nannofossil data, palaeomagnetic stratigraphy and magnetic susceptibility, however, did not corroborate previous nannofossil analyses. According to Kent *et al.* (2002) the Plio-Pleistocene boundary should be placed at 813 m where an unconformity separates shallow water shelf facies from overlying deep water sediments, thus in good agreement with the supposition of Favero *et al.* (1979).

The present paper presents an extensive study of ostracods from wells VE-1 and VE-1bis. The main goal is to compare data emerged from the ostracod record with previously published research on other fossil groups in order to improve the palaeoenvironmental and sedimentary history of the Venice area. Although ostracod faunas are chiefly discussed from a palaeoenvironmental perspective, biostratigraphical significant data achieved by the present study, especially those concerned with the controversial location of the Plio-Pleistocene boundary, are also treated.

BACKGROUND AND METHODS

Ostracod faunas have been studied from a total of 319 samples (Tab. 1) kindly provided by Prof. D. Rio and Dr. R. Serandrei Barbero. Samples were recovered from the composite section VENICE-1 (Text-fig. 2; Kent *et al.*, 2002), which consists mostly of well VE-1 and the upper of part of well VE-1bis. Particularly samples examined from well VE-1 are from the depth interval 62.74-917.70 m, those from well VE-1bis are from the depth interval 5.10-58.80 m. The total picking of ostracods was accomplished from the washed residues for the size fraction $>125 \mu\text{m}$.

Detailed lithological and sedimentological features of the investigated section are available in CNR (1971), Favero *et al.* (1973), Favero & Passega (1974, 1980). We only report a brief note of the main lithological features and palaeoenvironmental interpretation discussed in the above-cited papers.

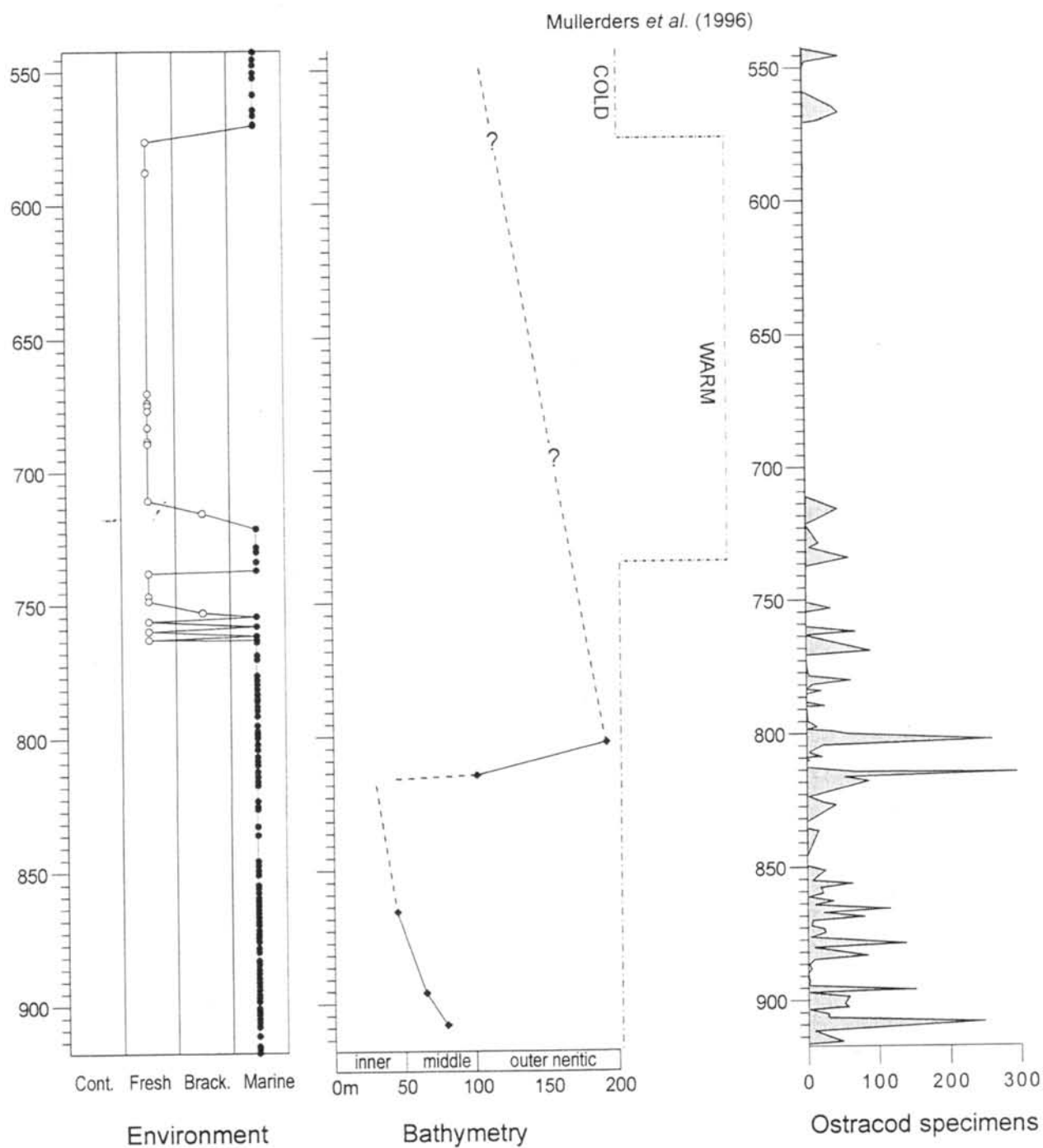
- From the bottom to 855 m the section is mostly shaly, whereas from 855 m to 815 m sediments consist of silty clay-very fine sand alternations; these sediments accumulated in an inner neritic environment.

- From 815 m to 356 m the section consists mostly of turbidites and particularly between 815 m and 436 m fossiliferous shales are interbedded with classic sandy and silty turbidites, whereas between 436 m and 356 m sand turbidites are absent and sediments consists chiefly of turbidite siltstones and shales (slumping zones are present between 766 m and 553 m and typical deltaic deposition begins at about 540 m); on the whole foraminifers indicate a progressive transition from the outer neritic environment to the middle neritic zone; displaced faunas (fresh-brackish water ostracods and littoral foraminifers and ostracods) occur in turbidite and slumping levels.

- From 356 m to 288 m turbidite deposits are absent and sediments are mostly silts and clays with a reduced sandy fraction, this interval is closed by very fine beach sands; foraminifers are indicative of a progressive transition from the middle neritic zone to the littoral zone.

- Above 288/289 m, where the first continental sediments occur, very fine to fine sands are interbedded with silts, shales and peat beds; the environment alternates between shallow marine, brackish lagoonal and continental settings.

As discussed in the introduction, the bio-chronostratigraphy of the oldest part of the section is still controversial and our consideration on this matter will be discussed in detail later. With regards to

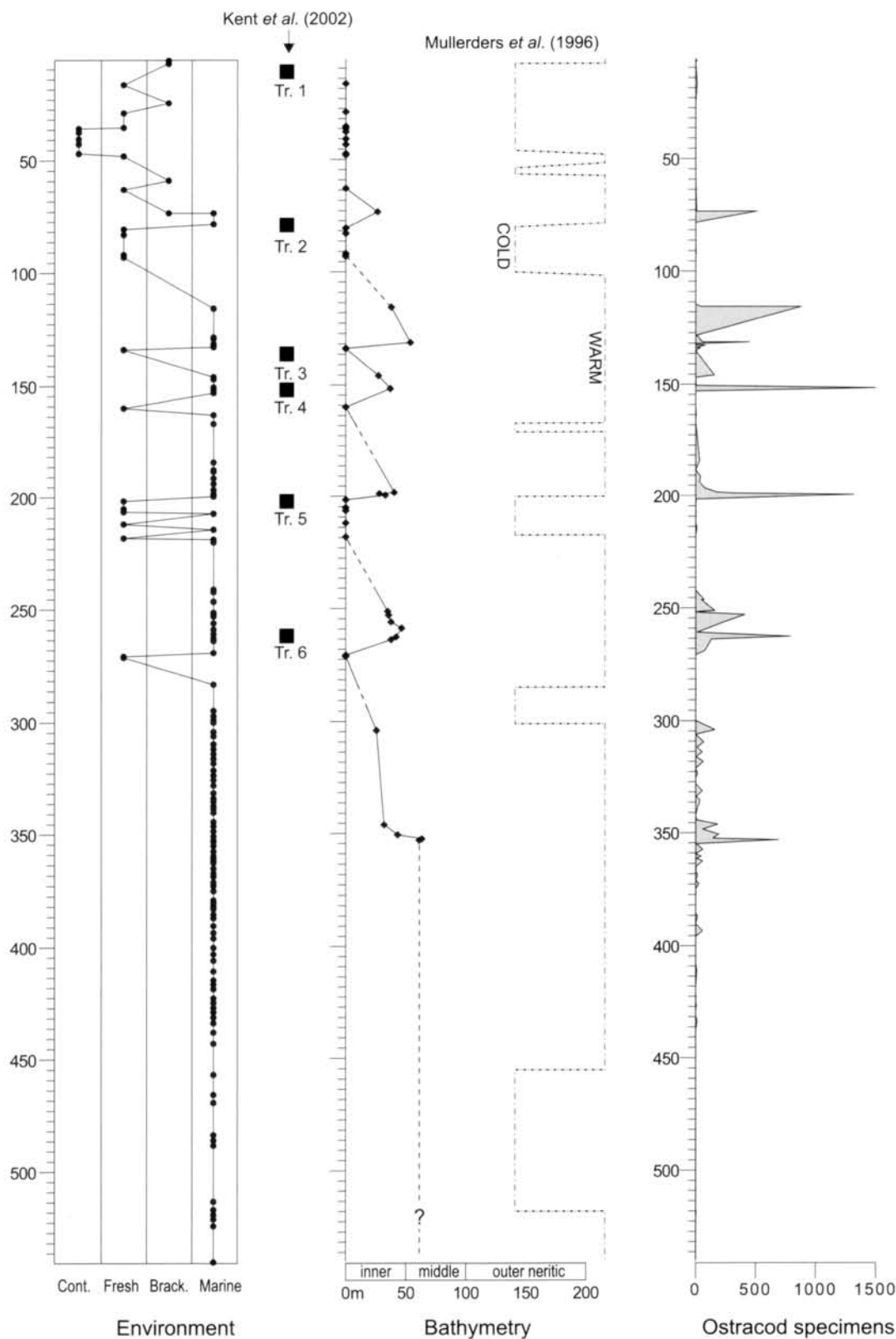


Text-fig. 2a - Lower part of the section VENICE-1: ostracod abundance, palaeoenvironment (open circles refer to displaced faunas in turbid levels) and palaeobathymetry based upon the ostracod study plotted against depth (m). The climatic evolution reconstructed by Mullenders *et al.* (1996) is reported.

the remaining section, this study refers to the work of Kent *et al.* (2002), which provides various chronostratigraphical control points.

The palaeoenvironmental significance of the ostracod faunas has been investigated through the study of abundance (number of specimens) and diversity (num-

ber of species) (Tab. 1) and faunal composition (see Tab. 2, available on the web site: <http://www.dst.unipi.it/dst/bossio/VeniceOstracoda.xls>). In addition, quantitative analyses proposed by Ciampo (2003) to reconstruct palaeobathymetry have been applied to samples bearing more than 100 specimens



Text-fig. 2b - Upper part of the section VENICE-1: ostracod abundance, palaeoenvironment inferences and palaeobathymetry based upon the ostracod study plotted against depth (m). The climatic evolution reconstructed by Mullenders *et al.* (1996) and the transgressive events recognized by Kent *et al.* (2002) are reported.

and including paleobathymetrically significant ostracod taxa. This methodology was proposed studying upper Pleistocene-Holocene cores from the continental shelf of the Tyrrhenian Sea (Ciampo, 2003); herein the method is slightly modified (Ciampo, 2004, this volume).

Although the present paper focuses chiefly on ostracods, palaeontological investigations extended (especially for samples barren of ostracods, see Tab. 1) in a general perspective to the whole organic content present in the washed residues, and particularly to benthonic and planktonic foraminifers.

RESULTS

From a bio-chronostratigraphical viewpoint the following data on the distribution of significant foraminifer species have been achieved:

- the first occurrence of *Hyalinea baltica*, which marks the Santernian-Emilian boundary (Ruggieri & Sprovieri, 1978 *cum bib.*), was recorded at 907.98 m, this in agreement with Favero *et al.* (1979), who reported this species from 950 to 750 m and from 580 to 541 m;

- the first occurrence of *Globorotalia truncatulinoides* (Orbigny) *excelsa* Sprovieri, Ruggieri & Unti, which marks the Emilian/Sicilian boundary (Ruggieri & Sprovieri, 1978 *cum bib.*), was recognized at 768.99 m.

In addition, ostracod associations are characterized, although sporadically, by a certain number of biostratigraphically significant taxa. These taxa are *Loxoconcha bonaducei* Ciampo recorded from 915.30 m, *Palmoconcha turbida* (Müller) and *Cytherois uffenordei* Ruggieri recorded from 896.00 m. According to Ruggieri (1980 *cum bibl.*) and Ciampo (1998) the first appearance of the above listed taxa slightly precedes or post-dates the Pliocene-Pleistocene boundary.

Our findings would seem to restrain the biostratigraphical value of *Buntonia robusta* Ruggieri highlighted by Ruggieri (1980). The former species, which according to Ruggieri (1980) is not found after the Pliocene/Pleistocene boundary and within the Pleistocene, has been recovered at 902.40 m, thus above the *H. baltica* FO (907.98 m). However, it is worth mentioning that this finding is limited to a single specimen.

From a palaeoenvironmental viewpoint, compositional changes and fluctuations in the abundance and diversity of the ostracod faunas allowed the subdivision of the investigated succession into the following intervals (Text-figs. 2a-b):

Interval from 917.70 m to 823.50 m

Ostracod assemblages are moderately rich and diversified. Abundance and diversity show short-term high fluctuations and tend to decrease all along the

interval. Mean value of the abundance is 31, but among the 48 samples examined from this interval 4 and 6 yielded more than 100 and more than 50 specimens respectively. Diversity varies on average between 10 and 5. Faunal composition is not thoroughly homogeneous. Sketchily, from the bottom to about 865.45 m assemblages are dominated by *Aurila* spp., *Costa runcinata* (Baird), *Leptocythere* spp., *Sagmatocythere versicolor* (Müller) and subordinately *Echinocythereis pustulata* (Namias) and *Carinivalva testudo* (Namias). The calculated depths (79 m at 907.98 m, 64 m at 896.00 m and 44 m at 865.45 m) are indicative of a progressively shallower middle neritic environment. In the upper part of the interval (above 865.45 m), no sample is suitable for quantitative palaeobathymetrical analyses. However, the entrance of *Cytheretta judaea* (Brady) and *Pontocythere turbida* (Müller) together with the disappearance of *Echinocythereis pustulata* and *Carinivalva testudo* suggest a further shallowing of the sea depth.

Interval from 817.56 m to 542.64 m

A transgressive event begins at 817.56 m. Assemblages from 817.56 m to 814.12 m and from 808.53 m to 797.37 m are relatively rich and diversified (mean values of the abundance and diversity are 125 and 52 in the former interval, and 21 and 9 respectively in the latter interval). In the lowermost part of the interval major components of the fauna are *Aurila* spp., *Callistocythere vexata* Bonaduce, Ciampo & Masoli, *Cytheropteron ruggieri* Pucci, *Echinocythereis pustulata*, *Loxoconcha* spp. (including *L. subrugosa* Ruggieri). Locally also *Macrocypris* spp. and *Sagmatocythere versicolor* are well represented. This association suggests a lower middle neritic environment and, notably, the calculated depth is about 100 m at 814.12 m. In the above fossiliferous interval assemblages are dominated by *Bythocypris producta* (Seguenza), *Buntonia textilis* Bonaduce, Ciampo & Masoli and *Henryhowella sarsii* (Müller) and the cold deep species *Cytheropteron testudo* Sars occurs. Depth reaches its maximum value of about 190 m at 802.23 m.

Above this level, many samples are barren, and poor marine assemblages alternate with scarce fresh or brackish water faunas. Marine ostracod assemblages, consisting mainly of taxa typical of the outer neritic environment (*Henryhowella sarsii*, *Krithe* spp. and subordinately *Cytherella* gr. *vulgata* Ruggieri) were recovered fairly regularly from 795.37 m to 764.12 m, at 761.69 m, from 737.12 m to 728.45 m and patchily from 570.27 m to 542.64 m. Fragments or complete valves of *Candona* spp. and occasionally of *Cyprideis torosa* (Jones) and *Cytherissa lacustris* (Sars), occur mainly from 763.25 m to 670.22 m, at 587.77 m and at 576.30 m. A single sample from 752.96 m is characterized exclusively by the occurrence of *Cytheromorpha fuscata* (Brady). As pointed out in previous works, e.g. Favero & Passaga (1975, p. 74; 1980,

		Sample n°/depth	N. specimens		N. species		Environment	Bathymetry (m)	Ostracoda		(Other fossil groups)	
Holoc.		1	5.10	2	2	b						
		2	6.25	10	1	b						
Late Pleistocene		3	6.56	0	0	b				bF-bbF		
		4	16.00	11	2	f	0					
		5	24.30	0	0	b				IG-bbF		
		6	28.80	0	0	f	0			IB		
		7	35.37	fragments	0	f	0					
		8	35.85	0	0	c	0			V		
		9	37.50	0	0	c	0			V		
		10	40.50	0	0	c	0			V		
		11	42.72	0	0	c	0			V		
		12	46.92	0	0	c	0			V		
		13	48.00	fragments	0	f	0					
		14	51.30	0	0							
		15	58.80	0	0	b				bbF		
		16	62.78	2	1	f	0					
		17	73.25	7	5	b						
		18	73.30	516	15	m	27					
		19	78.16	14	7	m						
	Middle Pleistocene		20	78.26	3	2	m					Tyrrenian
			21	78.33	0	0	m				bF	Transgression
		22	80.63	fragments	0	f	0				(Mullenders et al., 1996; Kent et al., 2002)	
		23	82.89	0	0							
		24	82.99	1	1	f	0					
		25	84.77	0	0							
		26	91.80	2	1	f	0					
		27	91.90	4	2	f	0					
		28	92.90	0	0	f	0			IG		
		29	93.53	0	0							
		30	96.63	0	0							
		31	98.57	0	0							
		32	98.65	0	0							
		33	105.45	0	0							
		34	106.00	0	0							
		35	114.00	0	0							
		36	114.76	0	0							
		37	115.70	45	13	m						
		38	115.75	885	21	m	38					
		39	128.38	3	2	m						
		40	128.95	22	7	m						
		41	131.20	55	7	m						
		42	131.26	452	25	m	54					
		43	131.95	6	5	m						
		44	132.50	3	2	m						
		45	132.60	82	14	m						
		46	133.78	2	2	f	0					
		47	133.85	39	8	f	0					
		48	135.10	0	0							
		49	145.76	157	20	m	27					
		50	146.50	1	1	m						
		51	150.45	2	1	m						
		52	151.65	1504	40	m	37					
		53	152.98	0	0	m					bF	
		54	159.82	fragments	0	f	0					
		55	162.85	4	3	m						
		56	166.76	0	0	m					bF	
		57	184.24	33	7	m						
		58	187.63	8	6	m						
		59	188.44	0	0	m					bF, E	
		60	191.35	40	4	m						
		61	193.80	31	8	m						
		62	196.55	73	12	m						
		63	198.28	174	10	m	40					
		64	198.80	311	19	m	28					
		65	199.55	1322	36	m	33					
		66	201.60	4	2	f	0					
		67	205.00	fragments	0	f	0					
		68	206.30	1	1	f	0					
		69	207.10	2	2	m						
		70	211.72	0	0	f	0				IG, IB	
		71	214.10	10	7	m						
		72	217.88	0	0	f	0				IG	
		73	218.40	0	0	m					bF	
		74	219.70	0	0	m					bF	
		75	238.30	0	0							
		76	240.25	0	0							
		77	240.91	0	0	m					p-bF	
	78	242.10	0	0	m					p-bF		
	79	246.32	70	4	m							
Middle Pleistocene		80	246.42	50	7	m						
		81	251.27	163	12	m	35					
		82	251.50	62	8	m						
		83	251.86	0	0	m					bF	
		84	252.92	411	17	m	36					
		85	256.03	251	15	m	38					
		86	258.82	118	12	m	46					
		87	260.84	12	3	m						
		88	262.76	793	32	m	42					
		89	263.95	133	16	m	38					
		90	269.33	72	18	m						
		91	270.88	0	0	f	0				IG	
		92	271.45	0	0	f	0				IG	
		93	278.10	0	0							
		94	283.35	1	1	m						
		95	294.70	0	0	m					bF	
		96	297.15	0	0	m						
		97	298.73	0	0	m					bF	
		98	299.92	0	0	m					bF	
		99	304.02	162	14	m	26					
		100	306.02	0	0	m					bF, E, B	
		101	309.51	67	16	m						
		102	311.75	11	5	m						
		103	314.00	55	18	m						
		104	316.10	2	2	m						
		105	318.21	65	15	m						
		106	321.23	0	0	m					bF	
		107	323.50	17	9	m						
		108	325.56	1	1	m						
		109	328.04	0	0	m					B	
		110	331.34	55	7	m						
		111	333.83	5	4	m						
		112	335.27	34	13	m						
		113	337.13	29	9	m						
		114	338.35	16	7	m						
		115	340.17	9	5	m						
		116	342.15	0	0							
		117	344.23	7	7	m						
		118	346.16	186	24	m	32					
		119	348.43	58	17	m						
		120	350.68	193	31	m	43					
		121	352.50	143	18	m	63					
		122	353.20	694	23	m	61					
		123	355.02	7	4	m						
		124	357.50	59	16	m						
		125	359.50	0	0	m					bF, E	
		126	360.52	46	11	m						
		127	361.50	9	7	m						
		128	362.52	57	11	m						
		129	365.00	5	2	m						
		130	367.21	2	1	m						
		131	368.52	17	6	m						
		132	371.03	3	2	m						
		133	372.53	27	11	m						
		134	374.83	1	1	m						
		135	377.04	2	2	m						
		136	378.85	0	0	m					PF, B	
		137	380.25	0	0	m					p-bF, E	
		138	381.63	0	0	m					bF	
	139	382.70	0	0	m					bF, B		
	140	385.20	0	0	m					bF		
	141	386.85	15	10	m							
	142	390.24	1	1	m							
	143	393.25	57	15	m							
	144	395.82	0	0	m					bF		
	145	400.04	0	0	m					bF, E		
	146	402.95	1	1	m							
	147	405.79	1	1	m							
	148	407.81	0	0								
	149	410.61	9	5	m							
	150	414.62	6	3	m							
	151	416.62	4	4	m							
	152	418.62	0	0	m					p-bF, E, B		
	153	420.82	0	0								
	154	422.80	3	2	m							
	155	424.82	1	1	m							
	156	427.12	6	4	m							
	157	429.03	1	1	m							
	158	431.33	0	0	m					bF		
	159	433.82	12	2	m							

	Sample n°/depth	N. specimens		N. species	Environment	Bathymetry (m)	(Other fossil groups)
		Ostracoda					
Middle Pleistocene	160	437.98	0	0	m		p-bF, E
	161	440.92	0	0			
	162	442.91	0	0	m		bF, E, B
	163	444.85	0	0			
	164	456.69	0	0	m		p-bF, B
	165	458.48	0	0			
	166	462.60	0	0			
	167	465.49	0	0	m		bF
	168	469.02	0	0	m		bF
	169	483.45	0	0	m		bF
	170	485.88	0	0	m		bF, E
	171	488.19	0	0	m		bF
	172	513.20	0	0	m		bF
	173	516.80	0	0	m		bF, B
	174	519.10	5	3			
	175	521.13	1	1			
	176	524.19	0	0	m		bF
	177	533.22	0	0			
	178	540.20	1	1	m		
	179	542.64	1	1	m		
	180	545.40	52	8	m		
	181	547.57	4	1	m		
	182	550.42	0	0	m		bF, E
	183	552.42	1	1	m		
	184	556.50	0	0			
	185	558.48	0	0			
	186	558.59	0	0	m		bF
	187	564.44	42	3	m		
	188	566.55	51	6	m		
	189	569.80	20	3	m		
	190	570.27	7	1	m		
	191	570.51	0	0			
	192	572.76	0	0			
	193	575.25	0	0			
	194	576.30	1	1	(f)		
	195	577.08	0	0			
	196	578.44	0	0			
	197	581.60	0	0			
	198	584.20	0	0			
	199	587.77	2	1	(f)		
	200	591.11	0	0			
	201	599.11	0	0			
	202	601.88	0	0			
	203	606.90	0	0			
	204	612.65	0	0			
	205	623.58	0	0			
	206	625.98	0	0			
	207	664.09	0	0			
	208	670.22	fragments	0	(f)		
	209	673.78	fragments	0	(f)		
	210	674.84	fragments	0	(f)		
	211	676.78	fragments	0	(f)		
	212	683.08	fragments	0	(f)		
	213	688.30	fragments	0	(f)		
	214	689.31	fragments	0	(f)		
	215	698.61	0	0			
	216	710.78	fragments	0	(f)		
	217	715.50	45	5	(b)		
	218	721.36	0	0	m		p-bF, E
	219	728.45	18	1	m		
	220	730.09	5	1	m		
	221	733.95	51	1	m		
	222	737.12	1	1	m		
	223	738.11	fragments	0	(f)		
	224	744.63	0	0			
	225	746.78	fragments	0	(f)		
	226	748.63	1	1	(f)		
	227	750.67	0	0			
	228	752.96	35	1	(b)		
Lower Pleistocene	229	754.42	0	0	m		p-bF
	230	756.21	fragments	0	(f)		Gephyroc. sp. 3 LO (Kent et al., 2002)
	231	758.13	0	0	m		p-bF
	232	759.87	fragments	0	(f)		
	233	761.69	70	5	m		
	234	763.05	0	0	(f)		
	235	763.25	0	0	m		p-bF, B
	236	764.12	13	2	m		
	237	768.99	91	7	m		G. exalta FO (this paper)
	238	770.55	0	0	m		p-bF, E
	239	772.00	0	0			
Lower Pleistocene	240	776.59	2	2	m		
	241	778.27	4	2	m		
	242	779.84	53	12	m		
	243	781.55	3	3	m		
	244	783.25	0	0	m		p-bF, E
	245	783.75	21	5	m		
	246	784.95	1	1	m		
	247	786.00	0	0	m		p-bF
	248	788.00	0	0	m		p-bF, E, B
	249	789.45	26	2	m		
	250	789.80	0	0			
	251	790.05	0	0			
	252	791.54	1	1	m		
	253	795.13	2	1	m		
	254	797.37	15	5	m		
	255	798.20	0	0	m		pF
	256	798.60	36	8	m		
	257	799.82	56	11	m		
	258	802.23	261	24	m	192	
	259	804.17	23	12	m		
	260	806.92	3	1	m		
	261	808.53	22	8	m		
	262	808.59	9	7	m		
	263	809.00	0	0			
	264	809.90	2	1	m		
	265	809.94	4	4	m		
	266	810.20	0	0			
	267	812.50	0	0	m		p-bF
	268	814.12	65	17	m		
	269	814.42	296	27	m	101	
	270	816.16	53	21	m		
	271	817.56	88	19	m		
	272	823.45	3	1	m		
	273	825.55	23	8	m		
	274	826.47	41	8	m		
	275	832.95	0	0	m		p-bF
	276	835.47	0	0			
	277	836.24	16	10	m		
	278	845.90	0	0	m		bF
	279	847.44	0	0	m		E, B
	280	849.40	0	0	m		bF
	281	851.07	25	10	m		
	282	854.91	7	3	m		
	283	855.95	64	20	m		
	284	857.56	19	9	m		
	285	859.60	22	5	m		
	286	861.02	1	1	m		
	287	862.48	37	5	m		
	288	864.00	10	4	m		
	289	865.45	117	16	m	44	
	290	866.90	23	7	m		
	291	868.42	81	16	m		
	292	869.85	7	5	m		
	293	871.80	5	2	m		
	294	872.91	23	4	m		
	295	874.46	25	5	m		
	296	876.05	4	4	m		
	297	878.47	139	9	m		
	298	879.97	9	3	m		
	299	883.04	85	10	m		
	300	884.56	8	5	m		
	301	886.45	2	1	m		
	302	888.05	5	1	m		
	303	889.80	0	0	m		p-bF
	304	891.27	1	1	m		
	305	892.78	3	3	m		
	306	894.37	1	1	m		
	307	896.00	152	23	m	54	
	308	897.08	2	1	m		
	309	898.52	58	15	m		
	310	901.12	51	14	m		
	311	902.42	57	13	m		
	312	903.40	2	2	m		
	313	904.97	29	4	m		
	314	906.34	29	7	m		
	315	907.98	248	31	m	79	H. batlica FO (this paper)
	316	911.40	9	4	m		
	317	915.30	49	10	m		
	318	916.30	0	0	m		p-bF
	319	917.70	0	0	m		pF

Tab. 1a-b - Stratigraphy of the section VENICE-1 with indication of the main biostratigraphical events and list of the examined samples (number and depth). Main features of the ostracod faunas (abundance and diversity), palaeoenvironmental inferences (letters in brackets refer to displaced faunas in turbid levels) and palaeobathymetrical reconstructions based upon the ostracod study are reported. Other fossil groups taken into account for palaeoenvironmental inferences in samples barren of ostracods are also indicated (pF = planktonic foraminifers, bF = benthonic foraminifers, bbF = brackish benthonic foraminifers; E = echinoids; B = bivalves, FB = fresh-water bivalves; FG = fresh-water gastropods; V = vegetal remains).

p. 160), these brackish and fresh water forms can be reasonably regarded as displaced elements introduced by turbidite currents and slumping.

Although fairly poor, autochthonous ostracod faunas are still indicative of an outer neritic environment, perhaps slightly shallower than in the previous interval. The scarcity of the ostracod fauna, the abundance, among benthonic foraminifers, of *Bolivina* spp. and *Bulimina* spp. and finally the widespread presence of pyrite suggest bottom oxygen depleted conditions.

Interval from 540.22 m to 270.88 m

At the base of this interval (from 540.22 m to 519.10 m) ostracods are extremely rare and include a few species, i.e. *Krithe praetexta* (Sars), *Leptocythere rara* (Müller), *Loxoconcha rubritincta* Ruggieri, and *Pontocythere turbida*. These forms would be indicative of a rapid decrease of the sea depth, however the scarcity of the fauna and the possibility that the ostracods are displaced do not allow conclusive inferences on the basin depth.

After an interval barren of ostracods (from 516.80 to 437.98 m), the fauna progressively became more abundant and diversified. Particularly, the highest values of the abundance occur between 353.20 m and 346.16 m (mean values of abundance and diversity are about 254 and 23 respectively). The development of conditions favourable to bottom life is most likely related to the end of the turbidite deposition.

Within this long interval, assemblages do not show significant compositional changes, but only modifications of the relative abundance of single species. Major components of the fauna are *Aurila* spp., *Callistocythere* spp., *Carinocythereis antiquata* (Baird), *Cistacythereis (Hiltermannicythere) turbida* (Müller), *Leptocythere* spp., *Loxoconcha* spp., *Pontocythere turbida*, *Sagmatocythere* spp., *Semicytherura* spp. and subordinatedly also *Cytheridea neapolitana* Kollmann. Palaeobathymetries inferred from quantitative analyses (61 m at 353.20 m, 63 m at 352.50 m, 43 m at 350.68, 32 m at 346.16 m, 26 m at 304.02 m) indicate a gradual shallowing of the basin from the upper part of the middle neritic zone to the inner neritic zone.

This interval is closed by a set of samples barren of ostracods (from 299.92 to 270.88 m). Lower samples are characterized by rare benthonic foraminifers suggesting the permanence of a shallow marine environment up to 283.35 m, whereas the topmost samples (at 271.45 m and 270.88 m) contain fresh water molluscs and indicate the first transition to a fresh water setting.

Interval from 269.33 m to 218.40 m

In the lower part of this interval (from 269.33 m to 246.32 m) environmental conditions become again favourable to the development of ostracod communi-

ties. Abundance and to lesser extent diversity, show high values (mean value of abundance is about 170 and mean value of diversity is about 12).

Assemblages are dominated by *Callistocythere* spp., *Carinocythereis antiquata*, *Cistacythereis (Hiltermannicythere) turbida*, *Cytheridea neapolitana*, *Leptocythere bacescoi* (Rome), *Palmoconcha turbida* and locally also by *Pontocythere turbida*, *Pterygocythereis jonesi* (Baird) and *Semicytherura* spp. The calculated bathymetries (38 m at 263.95 m, 42 m at 262.76 m, 46 m at 258.82 m, 38 m at 256.03 m, 36 m at 252.92 m and 35 m at 251.27 m) are characteristic of the deepest part of the inner neritic zone.

The upper part of this interval (from 242.10 m to 218.40 m) is barren of ostracods, but it is still referable to a prevalently marine environment (local presence of rare marine benthonic foraminifers).

Interval from 217.88 m to the top of the section

From here to the top of the section, ostracods are patchily present, but associations can be locally very rich. This interval is complex and shallow marine and fresh water environments alternate.

Particularly, from 217.88 m to 201.60 m ostracods are extremely rare. Most of the samples contain fresh water ostracods (fragments or complete valves of *Candona* spp.) and fresh-water molluscs. Only two samples are characterized by benthonic marine forms, among ostracods *Callistocythere* spp., *Carinocythereis antiquata*, *Cytheridea neapolitana*, *Leptocythere ramosa* (Rome), *Loxoconcha ovulata* (Costa), *Pontocythere turbida*, *Sagmatocythere napoliana* (Puri) and *Semicytherura incongruens* (Müller) were recovered.

From 199.55 m to 162.85 m, microfaunas are indicative of a marine environment. Ostracod faunas are particularly rich in the lower samples (values of abundance range from 40 to 1322), but become rather poor to completely absent upwards. Major components of the assemblages are *Callistocythere* spp., *Carinocythereis antiquata*, *Cytheridea neapolitana*, *Cistacythereis (Hiltermannicythere) turbida*, *Leptocythere* spp., *Loxoconcha* spp., *Pontocythere turbida*, and *Semicytherura* spp. The calculated depths are typical of the inner neritic zone (33 m at 199.55, 28 m at 198.80 m and 40 m at 198.28 m).

A single sample at 159.82 m containing some fragments of *Candona* spp. indicates a brief transition to a fresh water environment.

Above, from 152.98 m to 115.70 m the return to marine conditions is documented by fairly rich associations (maximum peaks of abundance reach 445, 885, 1504 number of specimens per sample). The marine environment is testified by associations typical of the inner neritic zone, including mainly *Callistocythere* spp., *Carinocythereis* spp., *Costa edwardsii* (Roemer), *Cytheretta juadea*, *Cytheridea neapolitana*, *Cistacythereis (Hiltermannicythere) turbida*, *Leptocythere* spp., *Loxoconcha* spp., *Pontocythere turbida* and

Semicytherura spp. Quantitative analyses provided the following palaeobathymetries: 37 m at 151.65 m, 27 m at 145.76 m, 54 m at 131.26 m, 38 m at 115.75 m. This long marine interval is, however, interrupted by a brief fresh episode at 133.85 and at 133.78 m, where scarce fresh-brackish water forms are mixed with reworked marine elements.

After a completely barren interval (from 114.76 m to 93.53 m), a fresh water episode (from 92.90 m to 80.63 m) is documented by the occurrences of *Candona* aff. *parallela* Müller, *Candona* spp. and *Ilyocypris gibba* (Ramdohr).

From 78.33 m to 73.30 m, recovered microfaunas are again indicative of a marine environment, although most likely influenced by fresh water inputs. The ostracod fauna is abundant only at 73.30 m, where about 500 specimens were recovered and the calculated depth is 27 m. Ostracods are represented mainly by *Cyprideis torosa*, *Cistacythereis* (*Hiltermannicythere*) *turbida*, *Leptocythere macella* Ruggieri, *Palmoconcha turbida*, *Neocythereideis fasciata* (Brady & Robertson), *Pontocythere turbida*, *Semicytherura incongruens*, *Xestoleberis communis* Müller and *X. dispar* Müller.

From 73.25 m to 16.00 m most samples are completely barren and are referable to a continental environment; a few samples yield fresh water ostracods (mainly *Candona* spp.) and molluscs or brackish microfaunas.

In the uppermost samples (from 6.25 m to 5.10 m) ostracods are represented exclusively by *Cyprideis torosa* and are indicative of a transition to brackish conditions.

DISCUSSION

As previously discussed, results of the integrated study by Kent *et al.* (2002) provided a detailed chronostratigraphy of the middle-upper part of the composite section VENICE-1, but they are not exhaustive with respect to the oldest sediments. Particularly, calcareous nannofossil bioevents recognized by Kent *et al.* (2002) are not consistent with those by L. Todesco (in Favero, 1984) and, this discrepancy has not yet been discussed. Furthermore, although in most of the previous works palaeoenvironmental inferences were based primarily upon foraminifers, their biostratigraphical meaning has never been taken fully into account.

Data from the present study have provided new insights about this matter. The *H. baltica* FO recognized at 907.98 m allowed to ascribe the oldest sediments of VENICE-1 herein investigated to the Lower Pleistocene (Emilian). The occurrence at more or less the same depth of some typical Quaternary ostracod species (*Loxoconcha bonaducei*, *Palmoconcha turbida*, *Cytherois uffernordei*) confirms this hypothesis. This is in good agreement with the conclusion of Favero & Passegga (1980), Favero (1984) and Mullenders *et al.* (1996). However, we want to stress that our data are

insufficient to placing the Plio-Pleistocene boundary at about 900 m and that the first Pleistocene sediments we investigated are reasonably Emilian in age.

From a general point of view, palaeoenvironmental reconstruction based on the ostracod study agrees fairly well with previous inferences from other fossil groups and facies analysis (Text-figs. 2a-b).

Most of the works published on the cores VE-1, VE-1bis and VE-2 report palaeobathymetrical curves, which show similar long-term trends, but can differ locally for short-term fluctuations. These small discrepancies, which can derive also from differences in sampling resolution, make it difficult to undertake meticulous and constructive comparisons. For example, ostracod faunas from the oldest part of the composite section VENICE-1 (from 917.70 m to 823.50 m) are indicative of a progressively shallower middle neritic environment. This is in good agreement with the general trend reconstructed in most of the previous works based upon foraminifers. However, we have not been able to document the brief deepening event reported by Kent *et al.* (2002) between ca. 920 and 900 m, as well as that reported by Bellet *et al.* (1982), Favero (1984; see also Mullenders *et al.*, 1996) and Kent *et al.* (2002) between ca. 890 and 880 m.

The significant transgressive event at about 818 m has been recognized in all the previous researches. Data based upon quantitative analyses of ostracod assemblages suggest a very rapid deepening of the sea (at least up to -190 m) and match quite well with the palaeobathymetrical reconstruction by Favero & Passegga (1980; see also Mullenders *et al.*, 1996) and Favero (1984), less so with that by Bellet *et al.* (1982) and Kent *et al.* (2002).

Above this transgressive event up to 542.64 m, sediments are dominated by turbidites and ostracods are rare. Autochthonous faunas are not suitable for providing precise palaeobathymetrical data, but, in agreement with foraminifers, they are still indicative of an outer neritic environment.

Displaced ostracods in turbidite levels consist of fragments or complete valves of fresh and brackish water species. The presence at 752.96 m of a fairly abundant, displaced fauna consisting of the single brackish species *Cytheromorpha fuscata* supports the hypothesis of Favero & Passegga (1980) that in this interval sediments from rivers did not experience mixing with coastal shelf deposits and were readily "transported as a whole" by turbidite currents.

Sedimentological and foraminiferal analyses of the interval between 540 m and 356 m indicate that turbidite deposition persisted, although it underwent significant changes, mostly related to a decreasing sea depth and slope gradient, which allowed a sandy coastal shelf to be built (Favero & Passegga, 1980). These authors report the presence in this interval of a mixed fauna consisting of displaced littoral forms (related to turbidite deposition) and autochthonous middle neritic taxa. In the lower part of this interval ostracod

faunas are very poor or completely absent, but becomes progressively more abundant and diversified from about 438 m. No quantitative analyses have been carried out on these ostracod faunas, but they can be considered characteristic of a middle neritic environment. Contrary to observations based on foraminiferal faunas, we did not find clear evidence of elements displaced from the littoral environment by turbidite currents, apart from the very scarce and sporadic occurrence of the euryhaline species *Cyprideis torosa*. However, it is worth noting that the strong increase in ostracod abundance from about 353 m seems to be strictly related to the end of the turbidite deposition, which according to Favero & Passegga (1980) occurs at about 356 m.

After the closing of the turbidite deposition, ostracod analyses are consistent with previous researches and indicate a progressive decrease of the basin depth. As discussed by Kent *et al.* (2002) this shallowing trend is primarily related to the basin filling, which led to the deposition of the first continental sediments at 289 m. With respect to this first continental event, our data do not seem to match well with those so far published. Particularly, we found evidence of the existence of a marine setting up to 283.35 m, where fairly common benthonic and rare planktonic foraminifers, remains of echinoids and a single valve of *Leptocythere bacescoi* occur. However, it should be noted that sampling used for this interval was not closely spaced and, notably, no sample between 283.35 m and 294.70 m has been examined.

For the remaining part of the section, in which the environment alternates between shallow marine, brackish lagoonal and continental settings, comparison between our results and those previously published do not show significant discrepancies.

On the whole, palaeoenvironmental reconstruction based upon ostracods shows a good correlation with the six transgressive events recognized by Kent *et al.* (2002).

ACKNOWLEDGEMENTS

The authors wish to thank Prof. D. Rio and Dr. R. Serandrei Barbero for provision of the entire samples-set of the composite section VENICE-1. We thank Prof. M. Keen and an anonymous referee for their constructive comments on the manuscript.

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(manuscript received October 23, 2003
accepted March 19, 2004)

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