Riv. It. Paleont. Strat. | v. 89 | n. 3 | pp. 377–394 | Febbraio 1984

OXYGEN AND CARBON ISOTOPE STUDY IN THE LATE EOCENE SEDIMENTS OF POSSAGNO (NORTHERN ITALY)

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Key–words: Foraminifera, Late Eocene, Northern Italy, Stratigraphy, Oxygen/Carbon isotope, Paleogeography, Paleoecology.

Abstract. Oxygen and carbon isotope data of several benthic and planktonic species of Foraminifera from a regressive sequence in northeastern Italy indicate a watermass change during the Late Eocene. In the middle of zone P 16 the Belluno Basin was temporarily cut off from the open ocean. This was probably provoked by 1) worldwide sea–level lowering during the Late Eocene and 2) tectonic activity in the relict Tethyan realm and the adjacent areas. The isolation apparently resulted in a temporary salinity increase in the relict basin.

A pronounced oxygen isotope excursion at the base of P 16 could be explained by diagenetic changes. The formation of globular cement in the chamber cavities of Foraminifera is due either to phreatic water infiltration promoted by the preceding shoaling of the sedimentary environment, or to a temporarily increased geothermal gradient resulting from the volcanic activity in the Colli Euganei.

The genera and species of the superfamily *Buliminacea* are enriched in ^{16}O relative to the taxa belonging to the superfamily *Cassidulinacea.* The $\delta^{18}O$ of *Nodosariacea* are mostly intermediate.

The oxygen isotope fractionation of benthic Foraminifera caused by biological processes (i.e. vital effect) seems to be somehow related to the wall structure (e.g. systematic classification).

Riassunto. L'analisi degli isotopi stabili dell'ossigeno e del carbonio eseguita su diverse specie di Foraminiferi bentonici e planctonici provenienti da una sequenza regressiva nell'Italia nord–orientale, indica un cambiamento nelle masse d'acqua durante l'Eocene superiore. Durante l'intervallo di tempo corrispondente alla parte media della zona P 16 il bacino di Belluno era temporaneamente isolato dall'oceano aperto. Le cause di tale isolamento sono probabilmente da attribuirsi a 1) abbassamento del livello del mare, su scala mondiale, durante l'Eocene superiore e 2) attività tettonica nell'ormai ristretto bacino della Tetide e nelle zone limitrofe. Un temporaneo aumento di salinità nel bacino residuo fu la conseguenza dell'isolamento.

Una marcata escursione nel rapporto isotopico dell'ossigeno alla base della zona P 16 può essere spiegato da alterazioni diagenetiche. La formazione di cemento globulare all'interno delle camere dei Foraminiferi è dovuta sia all'infiltrazione di acqua freatica facilitata dal precedente affondamento dell'ambiente sedimentario, sia al temporaneo aumento del gradiente geotermico, risultante dall'attività vulcanica nei Colli Euganei.

I generi e le specie della superfamiglia *Buliminacea* sono arricchiti in ^{16}O rispetto a quelli della superfamiglia *Cassidulinacea.* I valori di $\delta^{18}O$ dei *Nodosariacea* sono per la maggior parte intermedi. Il frazionamento degli isotopi dell'ossigeno nei Foraminiferi bentonici, prodotto da processi biologici (cioè "vital effect") sembra essere in qualche modo in relazione con la struttura del guscio (ossia con la classificazione sistematica).

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Introduction.

The oxygen and carbon isotope ratios of planktonic and benthic Foraminifera tests are valuable tracers of paleoclimatologic and paleoceanographic changes. In the last decade extensive isotope investigations of different Deep Sea Drilling Project sections from the Atlantic, Pacific and other areas have increased considerably the knowledge on climatic fluctuations during the Cenozoic (Shackleton & Kennett, 1975; Savin et al., 1975; Boersma & Shackleton, 1977). Douglas and Savin (1973), Shackleton and Kennett (1975), Boersma and Shackleton (1977) have shown a major cooling from the Late Eocene to the Early Oligocene. This cooling was a worldwide phenomenon which is also recognized in the paleoflora of land areas (Kemp, 1978). Investigations on Molluscs, larger Foraminifera, nannofossils and planktonic Foraminifera led Cavelier (1979) to construct a differentiated climate curve for the northern and southern part of Western Europe from early Late Eocene to early Late Oligocene time. Cavelier observed evidence for a cooling in the lower Priabonian which reached its maximum in the lowermost Oligocene. The extensive data collection from DSDP and other marine sites revealed also information on the depth–stratification of planktonic Foraminifera (Douglas & Savin, 1978) and on growth conditions of benthic Foraminifera (Shackleton, 1974; Woodruff et. al., 1980; Belanger et. al., 1981). These studies also showed that most of the Foraminifera tests, especially those of benthics, are formed under isotopic disequilibrium conditions.

In this paper oxygen and carbon isotope analyses on planktonic and benthic Foraminifera provided information on the following topics:

1) temperature history and watermass changes in a relict basin of the Tethys during the Late Eocene;

2) environmental imprint on the isotopic composition of different benthic Foraminifera, in this particular case with respect to bathymetric changes;

3) magnitude of isotopic fractionation caused by biological processes (i. e. vital effect), especially for benthic taxa with a wide depth–range.

Since the section of Possagno covers the entire Priabonian, there was an opportunity to test whether traces of such a cooling phase could be detected in this sedimentary basin as well, or whether it was compensated for by an increase in temperature promoted by the progressive shoaling of the basin.

Regional setting, paleogeography and stratigraphy.

The Possagno section is situated in the southern alpine margin in north–eastern Italy, about 50 km north of Padova (Fig. 1). It is one of the standard sections of the Mediterranean Paleogene (Cita & Bolli, 1966; Cita, 1968, 1975; Bolli, 1975). This section was paleogeographically situated along the southern

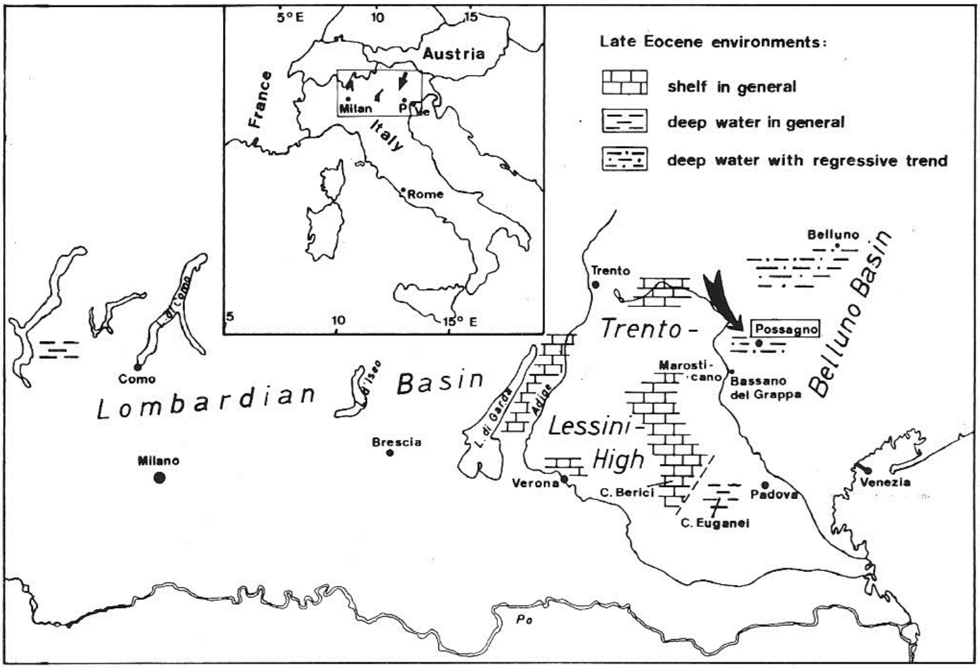

Fig. 1 — Location map of the investigated section, indicating sedimentary facies distribution.

margin of the Tethys. The closing of the Tethyan Ocean started in the Late Cretaceous and lasted till the Late Oligocene. The Campanian - Maastrichtian (76–68 m.y.) interval included the main period of tectonic evolution of the future eastern Mediterranean area (Biju–Duval et al., 1977; Biju–Duval, 1980), whereas important tectonic events in the western part took place only in the Late Eocene during the Pyrenean phase (44–40 m.y., Durand–Delga & Fontboté, 1980). Folding of the internal part of the alpine belt, related to the Eocene compressional phase, is documented from the Magrebids to their equivalents in Sardinia and Corsica and in the Penninic realm (Biju–Duval et al., 1977; Durand–Delga & Fontboté, 1980).

After that event the connection to the Central and Northern Atlantic most probably became restricted to the depositional zone south of the "Chaîne Calcaire" of Morocco (Durand–Delga & Fontboté, 1980). During the Late Eocene only a few relict sedimentary basins with open oceanic conditions, such as in the Southern Alps and in the Apennines existed in the area of the future Mediterranean. Further to the east a deep–water connection with the Indian Ocean existed from the Middle Eocene to at least the Middle Oligocene (Berggren & Hollister, 1977). Extensive paleogene volcanism (Piccoli, 1967) is known to have occurred in the areas of the Monti Lessini, the Colli Berici, the Colli Euganei and the Marosticano. The Late Eocene however, was a relatively quiet period in all these areas except the Colli Euganei.

The paleogeographic pattern of the Southern Alps during the Paleocene and Eocene was essentially inherited from the Mesozoic: basins and highs alternated along the alpine border. From west to east, we can distinguish the Lombardian Basin to the west of Lake Garda, the Trento High extending to the Lessini, the Colli Berici and into the Marosticano, the Belluno Basin and the Friuli area, where the platform sedimentation was progressively replaced by a flysch–type deposition (Fig. 1).

In the Possagno section the Paleocene and Early to Middle Eocene sediments occur in the hemipelagic Scaglia facies. This facies grades into a clay–rich sequence of about 550 meters thickness, the Possagno marls of Late Eocene age. The lower 300 meters of this marl formation consists of uniform, poorly bedded, blue–gray, clayey marls. In the middle Late Eocene sediments, intercalated sandy layers of a few centimeters thickness and enriched in biotite (up to 80%) occur (Fig. 2, stippled layers). The upper part of the section (above sample 38) is characterized by an upward increasing silt and sand content. The section is topped by shallow–water limestones (Calcari di Santa Giustina) with abundant larger Foraminifera and Coralline Algae. The $CaCO_3$ content of around 40% in the lower part decreases gradually to 15% in the upper part (Fig. 2). The sedimentation rate is estimated to be about 10 cm/1000 y. Bioturbation seems to be of minor importance, at least in the lower part of the section.

Biostratigraphic investigations of planktonic Foraminifera by Toumarkine and Bolli (1975) indicate that this section covers the interval from the *Globorotalia cerroazulensis pomeroli*/*Globorotalia cerroazulensis cerroazulensis* zone (upper part of P 14) to the *Globorotalia cerroazulensis cunialensis* zone (upper part of P 16). Data on distribution of micro– and megafossils (Bolli, 1975; Grünig, 1977) confirm the lithologic evidence for a shoaling of the basin towards the top of the section, probably as a result of the filling and closing of the Belluno Basin.

The benthic Foraminifera assemblages were used to establish a paleobathymetric zonation (Braga et al., 1975; Grünig, 1977; Grünig & Herb, 1980), consisting of the following five ecozones (from the deepest to the shallowest):

Zone 1: The assemblages are usually dominated by Nodosariids, mainly species of the genus *Lenticulina*. *Nuttallides truempyi* and *Cibicidoides parki* are restricted to this zone. Planktonic Foraminifera form 75–95% of the assemblages. The authors infer a depositional depth close to 1000 m.

Zone 2: *Vulvulina lacera* is restricted to this zone. *Clavulina parisiensis*, *Heterolepa ungeriana*, and *Bolivina antegressa angulata* have their upper limit

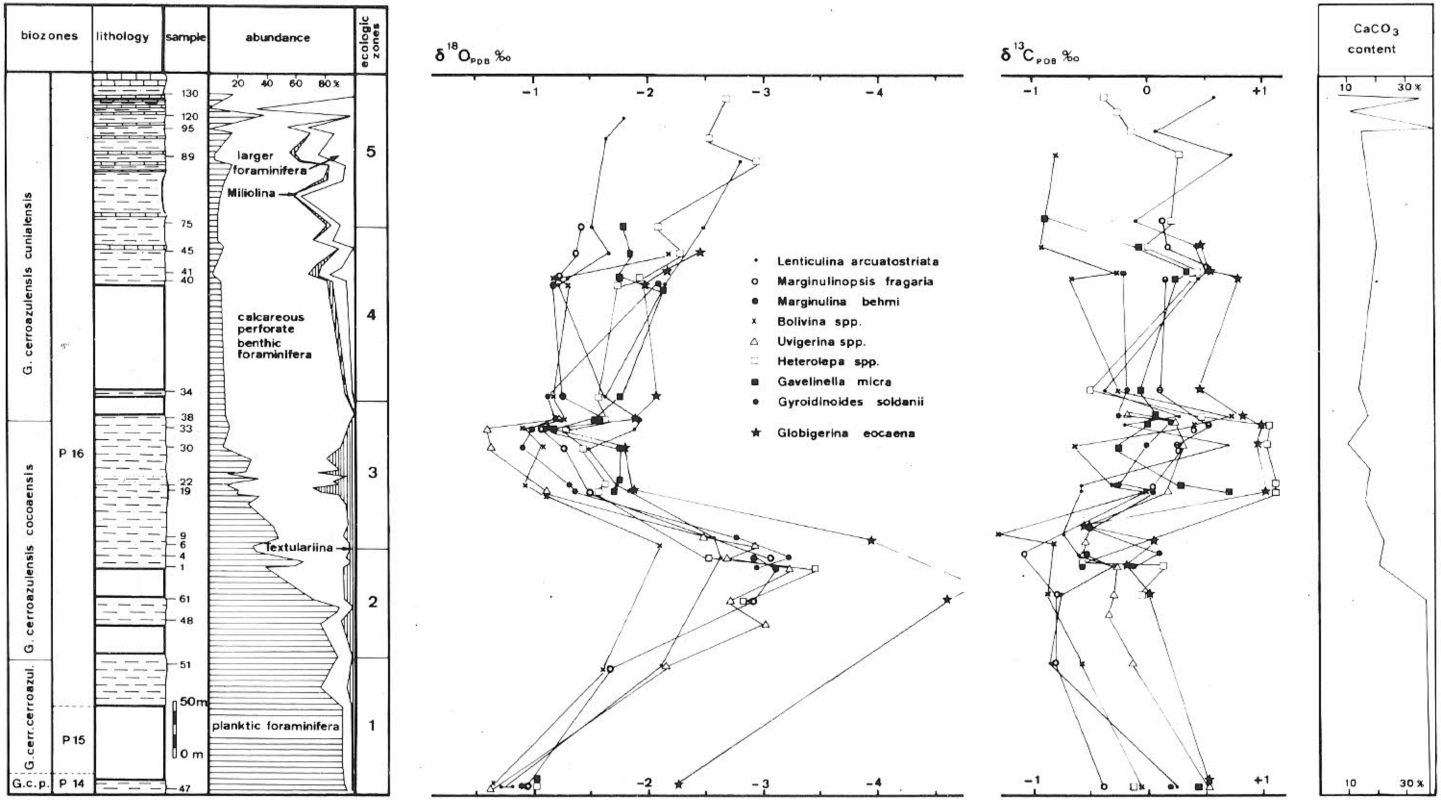

Fig. 2 – Oxygen and carbon isotope data of benthic and planktonic Foraminifera, as well as faunal abundance, ecozones and lithology of the late Middle Eocene to Late Eocene Possagno Formation.

within or slightly above this zone. Uvigerinids may occur in high percentages. Abundances of planktonic Foraminifera are 70–90% in the lower part and 30–65% in the upper part of the zone. A decreasing water depth from around 1000 m to 600 m was proposed for this zone.

Zone 3: The highest species diversity is noted within this zone. Uvigerinids may still be abundant. *Bolivina antegressa dentata* and *Cyclammina acutidorsata* are restricted to this interval. A number of species, such as *Gyroidinoides soldanii, Heterolepa reussi, Hoeglundina eocenica, Tritaxia szaboi* and all Uvigerinids have their upper depth limit at or near the top of this zone. Abundances of planktonic Foraminifera vary between 10 and 50%. A water depth from around 600 m to 150 m was inferred.

Zone 4: This zone is characterized by the occurrence of *Bulimina midwayensis* and the *Quinqueloculina juleana* groups, as well as larger Foraminifera and Molluscs. The abundance of planktonic Foraminifera is less than 10%. The assumed water depth ranges from about 150 to 30 m.

Zone 5: A restricted species diversity is typical for this zone. *Pararotalia audouini, Quinqueloculina juleana, Heterolepa dutemplei, Asterigerina, Discocyclina, Nummulites* and *Operculina* are the dominant species and genera. The high variability of planktonic Foraminifera abundance (0–40%) is partially due to reworking. The depositional depth was probably less than 30 m.

Throughout the section special attention has to be given to possible reworking or downslope displacement of microfossil tests. The distinct biostratigraphic and paleoecologic zonation which could be recognized in the lower 350 m, i.e. in ecozones 1–3, indicates that reworking and downslope transport were essentially absent. The isotopic data of this interval are therefore not influenced by organisms of shallower origin. In zone 5, reworked planktonic Foraminifera were recognized by Toumarkine and Bolli (1975). Wave action in nearby shallower areas may have caused some downslope transport in zones 4 and 5 and this may be the reason why the distinction of these two zones is not as clear as for zones 1 to 3.

Material and method.

The stable isotope analyses were carried out on the same sample residues used for the micropaleontologic investigations by Grünig (1977). A sample represents an average faunal assemblage over a stratigraphic interval of five or more centimeters. Considering the high sedimentation rate (in average 10–20 cm/1000 y) this sampling mode does not significantly smooth the record of environmentally caused isotopic signals. The Possagno Formation is not continuously exposed at the investigated section (Fig. 2). The available isotopic record is therefore discontinuous. There is, however, a useful record of the major time intervals of the Late Eocene. Preservation of the Foraminifera, particularly of the wall structure, was verified by SEM studies. Isotopic measurements on *Globigerina eocaena* and *Globorotalia cerroazulensis* spp. provided the $\delta^{18}O$ and $\delta^{13}C$ values for the planktonic Foraminifera. The morphology of *G. eocaena* suggests a relatively shallow habitat. Respective isotope values therefore reflect surface water conditions. The test morphology of *G. cerroazulensis* in contrast, suggests an intermediate water–depth habitat (Douglas & Savin, 1978).

The monospecific and exceptionally monogeneric Foraminifera samples were treated with 100% orthophosphoric acid at 50°C. The produced carbon dioxide was analysed with a triple–collector Micromass 903 C mass–spectrometer at the Geological Institute in Zurich. The isotopic values are reported in the δ–notation, as per mil deviations from the PDB–Standard. For oxygen and carbon isotope ratios the analytical precision is better than ± 0.1‰.

Results.

The oxygen and carbon isotope results of all benthic and planktonic Foraminifera are listed in Tables 1 and 2 respectively. In Figure 2 most of these $\delta^{18}O$ and $\delta^{13}C$ values are plotted in relation to the lithology.

The $\delta^{18}O$ plot indicates two pronounced shifts. The most striking change occurs for benthics and planktonics from the upper part of ecozone 1 to the middle part of ecozone 2. During this change the $\delta^{18}O$ signal of *G. eocaena* reaches values below −5‰, whereas benthics show $\delta^{18}O$ values between −2 and −4‰. A further marked excursion occurs in the upper part of ecozone 3. There, benthics and planktonics become depleted in ^{16}O by 0.5 to 0.75‰ and shortly later revert to the same values as before the excursion.

The $\delta^{13}C$ curve shows also two distinct events. In ecozones 1 and 2 the $\delta^{13}C$ values of planktonics and benthics decrease gradually by 0.5 to 1.0‰. This change is followed by a sharp increase of 1.0 to 1.75‰ for most of the measured species at the base of ecozone 3.

The extensive variations in the oxygen and carbon isotope ratios (Fig. 2) between species within the same sample are striking. The $\delta^{18}O$ values of benthics cover a range of 0.4‰ at the base of the section and 1.0 to 1.3‰ at the top. The same feature is noted for the $\delta^{13}C$ values of benthics, which range within the sample in average by 1.0 to 1.5‰.

Discussion.

Under equilibrium conditions the oxygen isotope ratio of foraminiferal tests reflects the oxygen isotope composition and the temperature of the water mass (Epstein et al., 1953; Craig & Gordon, 1965), whereas the δ^{13}C composition reflects the isotopic signal of the dissolved carbon dioxide in the seawater. The δ^{13}C ratio of the planktonic Foraminifera is further strongly controlled by the biological productivity in the surface water. The δ^{13}C values of both planktonics and benthics are also influenced by metabolic processes, which yet

Sample number	Uvigerina	Bulimina truncata	Bolivina	Stilostomella spp.	Lenticulina arcuatostriata	Marginulina behmi	Marginulopsis fragaria	Heterolepa	Gyroidinoides soldanii	Gavelinella micra	Melonis affinis	Hoeglundina eocaenica	Quinqueloculina	Asterigerina spp.	Operculina alpina	Nummulites ssp.	Globorotalia cerroazulensis ssp.	Globigerina eocaena
71/130								-2.64 (f)										
/120					-1.74			-1.37 (f)						-1.50				
/ 95					-1.61		-1.84	-2.48 (f)				-2.24	-2.18 (k)			-1.39		
/ 89			-1.94 (d)		-2.77			-3.68 (f)						-2.30		-2.00		
/ 75					-1.41* -2.46 -1.47	-1.39		-2.05 (f)		-1.75	-1.64		-1.89 (k)	-1.20				
/ 45			-2.14 (d)		-1.63		-1.43	-2.26 (f)		-1.90	-1.80		-1.72 (l)	-2.01				-2.42
/ 41			-1.16 (d)	-1.11	-1.26	-1.20		-1.89 (f)		-1.70	-1.39		-1.26 (k)		-0.91			-2.13
/ 40			-1.28 (d)		-2.13 -1.18	-1.17		-1.69 (f)	-2.08	-2.13			-1.04 (k) -1.69 (l)		-0.91			-1.92
/ 34			-1.15 (d)		-1.58	-1.24		-1.69 (f)	-1.23	-1.72		-1.00						-2.03
/ 38	-1.20 (a)		-1.25 (d)		-1.87	-1.64		-1.58 (f)	-1.18	-1.52		-0.95	-1.70 (l)					-1.85
/ 33	-0.58 (b)		-0.87 (e)	-0.56	-1.83	-0.91	-0.96	-1.29 (g)	-0.97	-1.16								-1.08
/ 30	-0.89 (c) -0.60 (a)	-0.91	-1.04 (e)		-1.46	-1.24	-1.40	-1.42 (g)	-0.91	-1.78			-1.38 (l)				-3.44	-1.73
/ 22			-0.91 (d)		-1.70			-1.90 (g)	-1.28	-2.03								
/ 19	-1.07 (a)	-0.94	-1.08 (d)		-1.74		-1.47	-1.53 (g)	-1.33	-1.69		-0.87						-1.80
/ 9	-2.87 (c) -2.42 (a)		-3.13 (d)	-2.51	-2.61				-2.72			-1.67					-3.93	
/ 6	-1.72 (c) -2.90 (a)		-2.08 (d)														-2.45	
/ 4	-2.49 (c) -2.65 (a)			-2.80	-2.70	-2.90	-3.04	-2.50 (g)	-3.20			-1.37						
/ 1	-3.30 (c) -3.19 (a)	-3.09		-1.83	-3.19	-3.11		-3.41 (g)	-2.93			-1.08						-5.11
/ 61	-2.70 (a)	-3.27	-3.37 (e)	-2.65	-1.71		-2.89	-2.80 (h)				-2.47						-4.36
/ 48	-2.98 (a) -3.59 (c)																	
/ 51	-2.29 (c) -2.12 (b)		-2.57 (e)		-2.17		-1.66											
/ 47	-0.61 (c) -0.75 (b)		-0.63 (e)		-0.75		-0.95	-0.99 (i)	-0.85	-1.00								-2.13

* Saracenaria sp.

(a) Uvigerina eocaena
(b) Uvigerina spinicostata
(c) Uvigerina chirana
(d) Bolivina nobilis
– B. gracilis
(e) Bolivina antegressa
(f) Heterolepa detemplei
(g) Heterolepa reussi
(h) Heterolepa eocaena
(i) Heterolepa ungeriana
(k) Quinqueloculina juleana
(l) Quinqueloculina sp.

Table 1 – Oxygen isotope data of benthic and planktonic Foraminifera of the Possagno Formation.

are not well understood. Thus interpretations of carbon isotope ratios are still controversial.

Biological fractionation (vital effect).

Most Recent species of benthic Foraminifera form their tests in disequilibrium with respect to the oxygen and carbon isotope composition of the ambient water (Vergnaud–Grazzini, 1976; Woodruff et al., 1980; Belanger et

Sample number	Uvigerina	Bulimina truncana	Bolivina	Stilostomella ssp.	Lenticulina arcuatostriata	Marginulina behmi	Marginulopsis fragaria	Heterolepa	Gyroidinoides soldanii	Gavelinella micra	Melonis affinis	Hoeglundina eocaenica	Quinqueloculina	Asterigerina ssp.	Operculina alpina	Nummulites ssp.	Globorotalia cerroazulensis ssp.	Globigerina eocaena
71/130								-0.40 (f)										
/120					0.57			-0.26 (f)						+0.35				
/ 95					+0.08		-0.02	-0.16 (f)				-0.17	-1.49 (k)			-0.10		
/ 89			-0.80 (d)		+0.72			-0.67 (f)						-0.02		+1.44		
/ 75					-0.09* -0.25 +0.20	+0.14		0.20 (f)		-0.89	-0.43		-0.30 (k)	+0.21				
/ 45			-0.93 (d)		0.40		+0.15	0.01 (f)		-0.17	-0.65		+0.37 (l)	-0.20				+0.45
/ 41			-0.29 (d)	+0.31	0.51	+0.50		0.42 (f)		+0.32	-0.44		-0.75 (k)		+0.52			+0.48
/ 40			-0.61 (d)		0.21 0.72	+0.13		0.42 (f)	-0.20	+0.21			-1.04 (k) -0.97 (l)		+0.17			+0.77
/ 34			-0.25 (d)		-0.38	+0.09		+0.91 (f)	-0.27	-0.06		+1.09						+0.44
/ 38	-0.18 (a)		-0.72 (d)		+0.28	-0.23		+0.46 (f)	-0.26	+0.08		+1.51	-2.00 (l)					+0.83
/ 33	+0.20 (b)		+0.41 (e)	+0.58	-0.20	+0.52	+0.39	0.79 (i)	0.17	+0.02								+1.03
/ 30	+0.09 (c) +0.29 (a)	+0.02	-0.63 (e)		+0.69	+0.27	+0.30	1.04 (i)	0.00	-0.26			+0.40 (l)				+0.42	+1.00
/ 22			-0.28 (d)		-0.58			+0.81 (i)	-0.26	+0.10								+0.75
/ 19	+0.17 (a)	-0.10	0.00 (d)		-0.58		+0.06	1.10 (i)	+0.05	+0.69		+1.59						
/ 9	-0.90 (c) -0.51 (a)		-1.31 (d)	-0.51	-0.73				-0.52			+0.88					-0.61	
/ 6	-0.34 (c) -0.54 (a)		-0.82 (d)														+0.11	
/ 4	-0.64 (c) -0.57 (a)			0.52	-0.60	-0.57	-1.09	-0.61 (i)	+0.11			+1.35						
/ 1	-0.80 (c) -0.29 (a)	-0.22		+0.23	-0.29	-0.45		+0.12 (i)	-0.13			+2.54						-0.34
/ 61	-0.30 (a)	-0.47	-0.88 (e)	-0.58	-0.76		-0.77	-0.05 (h)				-0.12						-0.01
/ 48	-0.19 (a) -0.44 (c)																	
/ 51	-0.20 (c) -0.07 (b)		-0.58 (e)		-0.86		-0.82											
/ 47	-0.01 (c) -0.52 (b)		+0.05 (e)		+0.23		-0.39	+0.13 (i)	+0.23	+0.30								+0.51

*Saracenaria sp.

(a) Uvigerina eocaena
(b) Uvigerina spinicostata
(c) Uvigerina chirana

(d) Bolivina nobilis
– B. gracilis
(e) Bolivina antegressa

(f) Heterolepa detemplei
(g) Heterolepa reussi
(h) Heterolepa eocaena

(i) Heterolepa ungeriana
(k) Quinqueloculina juleana
(l) Quinqueloculina sp.

Table 2 – Carbon isotope data of benthic and planktonic Foraminifera of the Possagno Formation.

al., 1981). As Recent benthic assemblages are different from those of Eocene age, this investigation gives an opportunity to deal with fossil assemblages and their biologically controlled isotope fractionation. In the Possagno section $\delta^{18}O$ values of the benthics show some significant trends (Fig. 2). All genera and species belonging to the superfamily *Buliminacea* are enriched in ^{16}O relative to the taxa belonging to the superfamily *Cassidulinacea*. The $\delta^{18}O$ values of the *Nodosariacea* are mostly intermediate. In place this is not evident because of reworking, especially in the upper part of the section (ecozones 4 and 5).

The $\delta^{13}C$ signal of the benthics do not show such an obvious relationship to the systematic position of the particular species. Trends exist, however, on a generic level. *Bolivina, Uvigerina, Quinqueloculina* and sometimes also *Gyroidinoides* are most enriched in ^{12}C, whereas *Marginulina, Heterolepa* and sometimes also *Lenticulina* are depleted in ^{12}C. In their paper on Recent benthic Foraminifera of the Pacific Ocean, Woodruff et al. (1980) documented more or less the same trend comparing the $\delta^{13}C$ values of *Gyroidina, Oridorsalis* and *Uvigerina*.

According to our investigation it seems that the oxygen isotope fractionation of the benthics is somehow related to the wall structure (e.g. systematic classification). The wall structure itself may eventually be a functional adaptation to a specific living habitat (epi–, endobenthic etc.), and therefore reveals an environmentally imprinted specific isotope signal. Knowledge on benthic foraminiferal habitats at depths of more than several tens of meters is still insufficient. Thus the proportion of individual fractionation mechanism influenced by the environment and/or growth processes (metabolic component) cannot yet be explained in detail. But the present data strongly suggest a relationship between the wall structure, habitat, possibly the mode of test growth and the isotopic composition of the single species.

Belanger et al. (1981) have suggested that tests of benthic Foraminifera grow in equilibrium with the surrounding microenvironment. They concluded that various benthic Foraminifera inhabit various within–sediment microhabitats. According to their model, increasingly negative $\delta^{13}C$ values indicate an infaunal habitat. We believe that this is a very promising start to the unravelling of often confusing carbon–isotope patterns.

Oxygen and carbon isotope stratigraphy.

The $\delta^{18}O$ plot (Fig. 2) is dominated by a remarkably negative excursion in the lower part of the section. Within this interval (samples 51 to 9) SEM studies of planktonic and benthic Foraminifera show that the original wall structures are mostly still well preserved. Chamber cavities of planktonics and often also benthics are filled with a dense globular cement which shows casts of the inner–

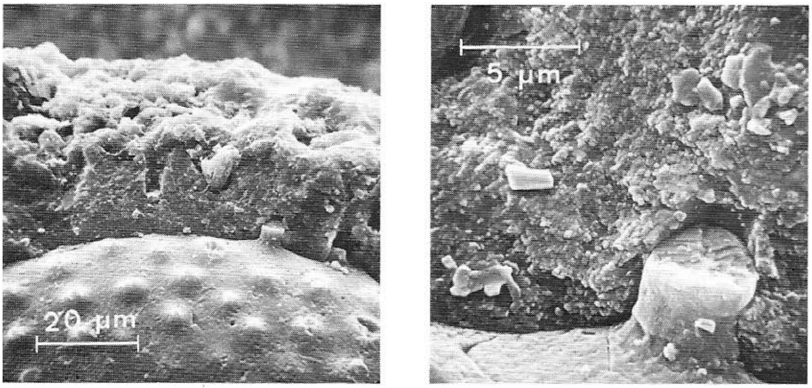

Fig. 3 – Preservation of *Globigerina eocaena* in sample 1. The chamber cavity is filled with a dense cement. The wall structure is poorly preserved.

wall surfaces (Fig. 3). The volume of the cement generally exceeds that of the test, which is pertinent for planktonics. This secondary product masks the primary isotopic information and therefore the isotope data within this interval reveals mainly imprints of the diagenetic process.

The observed diagenetic alterations could be interpreted in two ways:

1) According to the faunal investigation, the depositional environment kept shoaling from the ecozone 1 to ecozone 3, from the middle bathyal to the uppermost bathyal or even to the outermost shelf. In ecozone 3 this shoaling allowed phreatic water from a nearby shore to infiltrate the sediment. It replaced partly or completely the marine pore fluids. Such an infiltration would have changed the diagenetic potential significantly (Neugebauer, 1973; Schlanger & Douglas, 1974) and diagenetic processes may have been accelerated. The diagenesis probably occurred at shallow–burial depths the temperature being close to that of the sea floor. Thus the $\delta^{18}O$ values of the altered Foraminifera tests indicate that the $\delta^{18}O$ value of the infiltrated pore water was considerably enriched in ^{16}O.

Within this interval also the $\delta^{13}C$ values of the planktonic and benthic Foraminifera show a decrease by about 1‰. This change in the isotopic ratio also suggests a phreatic component in the pore fluid. According to Hudson (1975, 1977) the phreatic water is characterized by relatively negative $\delta^{18}O$ and slightly negative $\delta^{13}C$ values.

2) The negative oxygen and carbon isotope excursion was caused by a temporarily increased heat–flow gradient, which we would relate to the known Late Eocene volcanism in the Colli Euganei (Fig. 1). According to Scholle (1974) an increase in temperature would significantly change the diagenetic potential in the buried sediment. The pore fluid probably did not change

its $\delta^{18}O$ composition and thus revealed normal marine values (≈ 0‰ SMOW). Hence the extensive excursion of the $\delta^{18}O$ values of the altered Foraminifera would indicate a temperature change during the formation of the globular cement.

The different enrichment in ^{16}O for benthics and planktonics may be explained by the different wall–thickness/chamber–cavity ratio, e. g. most benthics show thicker walls and smaller chamber cavities than planktonics. Further investigations in sections with a sufficient biostratigraphic control should show why this alteration remains restricted to a well defined horizon and should hopefully bring additional evidence on the mechanism and cause of the early diagenesis.

Another significant excursion was observed in ecozone 3: the $\delta^{18}O$ and $\delta^{13}C$ values of planktonics and benthics increase and soon thereafter decrease by the same amount (Fig. 2, samples 19 to 38). The same extent is recorded for planktonic and benthic Foraminifera. But the $\delta^{18}O$ increase of benthics starts some hundred thousand years earlier (between samples 22 and 30) than for planktonics (between samples 30 and 33). The studied sedimentary environment was situated at the paleolatitude of 20 to 30° N, with a dominantly sub–tropical climate (Cavelier, 1979). It is therefore unlikely that the observed $\delta^{18}O$ variations are due to temperature changes, since the depositional environment continued to shoal. Furthermore, there is no faunal evidence which would support such drastic temperature changes by 3 to 4°C within this short time interval, either in a regional or in a larger frame (Proto Decima et al., 1975; Toumarkine & Bolli, 1975; Cavelier, 1979).

We rather consider the $\delta^{18}O$ and $\delta^{13}C$ excursion in ecozone 3 as a regional phenomenon, which may be restricted to this basin on the southern continental margin of the Tethys. We attribute the pronounced isotope variation to changes in the isotopic composition of the watermass in the relict basin. The Late Eocene folding of the internal parts of the Alps probably had its effects on the structure of the southern continental margin. Shape and bathymetry were probably modified as well. Evidence of tectonic activity shortly before the positive $\delta^{18}O$ excursion are 1) a distinct change of the depositional depth in ecozone 3, and 2) layers of sand with abundant biotite (stippled in the lithologic column in Fig. 2; see also Fig. 4). These layers are derived from a granite, which was exposed to erosion in the hinterland during tectonic activity in the internal parts of the alpine system. During Late Eocene worldwide sealevel changes occurred (Vail et al., 1977). These sea level changes combined with the shoaling trend, which is probably a regional phenomenon of the Belluno Basin as far as the limited outcrop conditions can demonstrate, could have lead to a transient isolation of the basin.

In fact stable isotope data tend to support this hypothesis. The pronounced $\delta^{18}O$ and $\delta^{13}C$ excursion in the upper part of ecozone 3 towards heavier values indicate that the water circulation to the open ocean was temporarily, partly or completely inhibited. During this time, the $\delta^{18}O$ value of the sea water in the basin became depleted in ^{16}O because of the increasing evaporation and the missing or retarded influx of normal saline ocean water. Salinity concentration probably never exceeded 38–40‰ within this interval. The faunal assemblage does not show a significant change except for *Trifarina* spp., which is very abundant in sample 33 (22%, Fig. 4).

The relatively high $\delta^{13}C$ values of benthics and planktonics (samples 19–33) could be a hint for a lowered content of respirative CO_2 (^{12}C–rich) in the restricted basin and would support the hypothesis of increased evaporation.

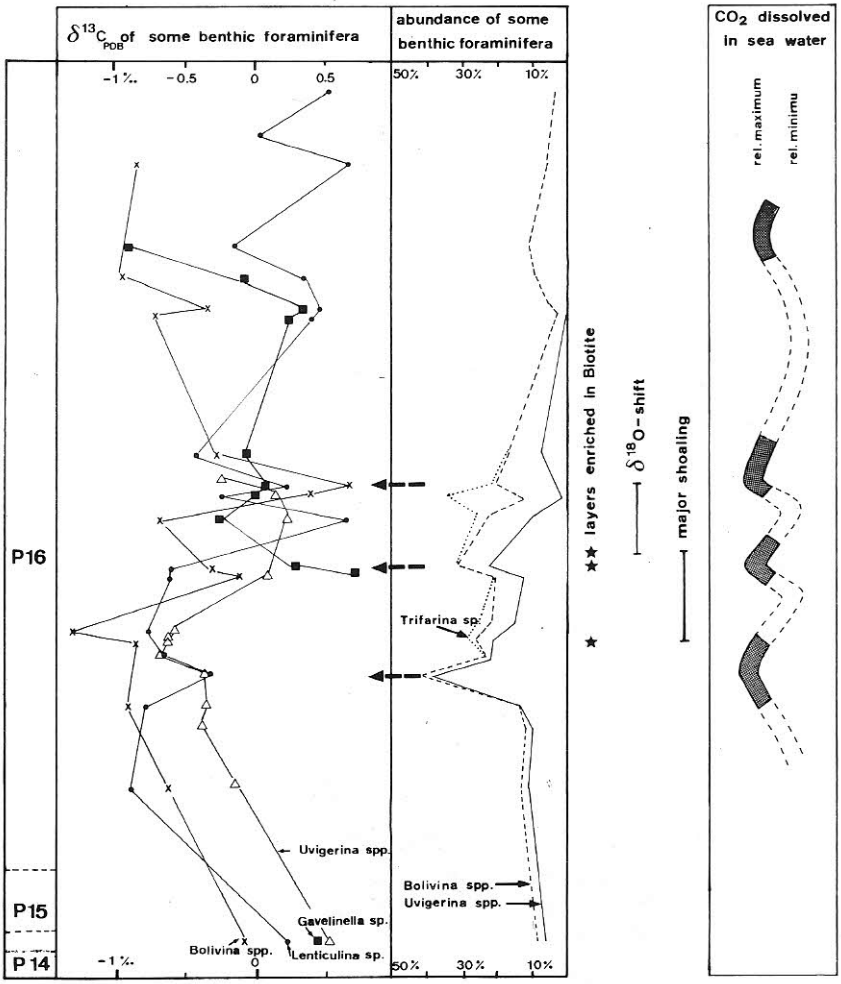

Fig. 4 – Carbon isotope plot and abundance plot of selected benthic species in relationship to a tentative curve of the dissolved CO_2.

The $\delta^{13}C$ values of benthics and planktonics decrease as soon as the basin was reopened to the ocean circulation. This excursion towards higher $\delta^{13}C$ values is evident for *Globigerina eocaena* and *Heterolepa* spp., less pronounced also for *Uvigerina* spp. The $\delta^{13}C$ values of other benthic species (*Gavelinella micra, Gyroidinoides soldanii, Lenticulina arcuatostriata* and *Bolivina* spp.) show a «saw–tooth» like pattern (Fig. 2 and 4).

In Fig. 4 the $\delta^{13}C$ values of these benthic taxa are plotted together with the abundance of *Bolivina, Uvigerina* and *Trifarina* spp. The *Buliminacea*, or at least some of the taxa are very good tracers for a specific environment. Schnitker (1974), Lohmann (1978), Streeter and Shackleton (1979) and Poag (pers. com., 1981) showed that *Uvigerina* and *Bolivina* spp. abundances increase in proportion to the dissolved CO_2 in the bottom water. In Fig. 4 the abundance of these species is interpreted in that way and results in a CO_2 curve indicating relative minimum and maximum stages in the bottom water of the investigated environment. Comparing the abundance of *Uvigerina* and *Bolivina* spp. with the $\delta^{13}C$ values of these benthics in the respective level we find striking relationships. While the *Buliminacea* taxa show a maximum in their occurrence, the $\delta^{13}C$ values of *Lenticulina arcuatostriata, Gavelinella micra, Bolivina* spp. and sometimes also of *Uvigerina* spp. are heavier than within those intervals with lower prosperity of the *Buliminacea* species. Paleontological investigations showed no evidence for changes of the fertility rate nor dissolution or significant reworking below sample 40 (Toumarkine & Bolli, 1975; Grünig, 1977; Grünig & Herb, 1980), hence these factors may not have significantly contributed to the $\delta^{13}C$ changes.

According to Deuser and Hunt (1969) the carbon isotope composition of the dissolved CO_2, which derives from the oxidation of the organic matter is lighter because the organic matter is preferentially enriched in ^{12}C. We favour the following interpretation to explain the oscillating $\delta^{13}C$ values in ecozone 3. During the shoaling of the basin, periodical overturn of the waterbody gained importance. By this overturn "old", less oxygenated bottom water was regularly replaced by "young", well oxygenated surface water. The increased oxygen content of the water favoured the oxidation of the organic matter and thus the bottom water CO_2 became enriched in ^{12}C, and the $\delta^{13}C$ of Foraminifera decreased. The reoccurring overturn may have been caused by salinity changes due to temporary isolation of the basin and to the shoaling.

The generally slightly decreasing $\delta^{18}O$ values of benthic and planktonic Foraminifera in ecozones 4 and 5 (Fig. 2) may be interpreted as temperature increases due to the progressive shoaling. At some levels the oxygen and carbon isotope values for benthic taxa vary over a wide range, especially in the uppermost part of ecozones 4 and 5. In this interval a certain degree of faunal displacement and photosynthetic activities by symbionts (Duplessy et al., 1970; Wefer et al., 1981) may account for this fact.

The isotopic record of the Late Eocene samples from the studied Tethyan basin could not be linked with those found in DSDP cores. We did not recognize the changes in the oxygen isotope record at the Middle to Late Eocene transition, which are well known from Pacific Ocean DSDP sites (Douglas & Savin, 1973). This may simply be due to diagenetic alterations and environmental changes (e.g. progressive shoaling), which we noted in the Zones *Globorotalia cerroazulensis cerroazulensis* and *Globorotalia cerroazulensis cocoaensis*. We believe therefore that the observed stable isotope pattern reflects mainly local environmental changes.

Conclusions.

The following uncertainties and changes impeded the interpretation of the isotopic record and concealed the temperature history of the Belluno Basin during Late Eocene.

– The paleogeographic configuration of the relict Tethys is not very well known.

– During the investigated interval major bathymetric changes occurred in the sedimentary environment.

– Alpine tectonic movements influenced the bathymetric setting and may have been a contributing factor to the development of the open–sea connections between the remnant basins of the Tethyan realm and the Indopacific and Atlantic Oceans.

The oxygen and carbon isotope analyses combined with sedimentological, paleontological and tectonic information led to the following interpretation:

1) The abrupt increase and subsequent abrupt decrease of the $\delta^{18}O$ and $\delta^{13}C$ values of benthics and planktonics in the upper part of ecozone 3 is a regional phenomenon and documents a transient isolation of the sedimentary basin from the open ocean circulation. We interpret the oxygen isotope signal as a temporary salinity increase due to the isolation, which may have been caused by worldwide Late Eocene sea–level lowering and by tectonic modification of the basin morphology.

2) The prominent $\delta^{18}O$ signals in ecozone 2 are linked with advanced diagenetic alterations due either to phreatic water infiltration because of the preceding shoaling, or to an increased heat–flow because of the volcanic activity in the Colli Euganei. Further study is required to know more about the mechanism.

Acknowledgements.

We would like to thank H. Weissert and J. McKenzie for fruitful discussions. The paper benefited from W. Deuser's (Woods Hole) and H.R. Thiersteins's (Scripps Inst.) comments on an early draft. G. Lister corrected the English. Mr. Zweili was very helpful. He prepared and processed the SEM photographs. The work was supported by the Swiss National Science Foundation (project Nr. 2.125.0.74).

The paper was reviewed by M. B. Cita.

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