Geogr. Fis. Dinam. Quat.
24 (2001),13-24, 4 figg., 3 tabb.

CARLO BARONI (*°), GIUSEPPE BRUSCHI (**), LUIGI VERONESE (***)
& GIOVANNI ZANCHETTA (*)

YOUNGER DRYAS TO EARLY HOLOCENE PALAEOENVIRONMENTAL EVOLUTION OF THE LAKE TERLAGO (SOUTHERN ALPS)

ABSTRACT: BARONI C., BRUSCHI G., VERONESE L. & ZANCHETTA G., *Younger Dryas to Early Holocene palaeoenvironmental evolution of the Lake Terlago (Southern Alps)*. (IT ISSN 0391-9838, 2001).

At Terlago lake (near Trento, 415 m a.s.l.) lake sediments were drilled to a depth of 22,2 m where the bedrock was reached. Sedimentological, malacological and stable isotope analyses of freshwater shells were carried out on the recovered core. These analyses, in conjunction with ^{14}C dating, allow the reconstruction of environmental change at Lake Terlago from the Younger Dryas to Holocene.

The oldest age, 11,890±90 yr B.P. coincides with the first appearance of *Pisidium* sp. at 1410 cm and testifies to the complete deglaciation of the area by that time, linked to the rapid glacial retreat in the Southern Alps almost completely accomplished at beginning of the Late Glacial. The mollusc assemblage of the lower part of the core indicates deep water condition. During this interval a progressive rise in $\delta^{18}O$ from 1268 to 1090 cm has been tentatively correlated with Younger Dryas/Pre-Boreal climatic transition according to ^{14}C ages and the $\delta^{18}O$ variation. The interval between 1090-930 cm, with enriched $\delta^{18}O$ values, may represent the Pre Boreal climatically favourable phase. In the following core section a progressive lowering of the water level and infilling of the lake is suggested from malacological analyses.

Another shift in the oxygen stable isotope composition occurred just before 9310±80 ^{14}C yr B.P. at 930-683 cm in concomitance with lithological and molluscan assemblage changes. $\delta^{18}O$ values progressively shift toward mean values found at the top of the core representative of a lake with isotopic composition similar to present-day precipitation. The change in lake level and temperature of calcification of the shell, hydrological factors, and the effect of meteoric precipitation probably all contribute to this isotopic drift.

KEY WORDS: Freshwater molluscs, Stable isotopes, Younger Dryas, Early Holocene, Alps.

RIASSUNTO: BARONI C., BRUSCHI G., VERONESE L. & ZANCHETTA G., *Evoluzione paleoambientale del Lago di Terlago (Alpi Meridionali) tra il Dryas recente e l'Olocene antico*. (IT ISSN 0391-9838, 2001).

Nel presente lavoro è descritto lo studio sedimentologico, malacologico ed isotopico di una carota prelevata dai sedimenti lacustri presenti a Terlago (Trento, 415 m s.l.m.). Queste analisi, insieme con alcune datazioni ottenute con il metodo del ^{14}C, hanno permesso di delineare l'evoluzione paleoambioentale del lago dal Dryas recente a parte dell'Olocene. L'età più antica ottenuta, 11.890±90 yr B.P., coincide con la prima comparsa di *Pisidium* sp. e testimonia la completa deglaciazione di quest'area. L'associazione a molluschi della parte basale della carota indica un ambiente lacustre relativamente profondo. In questo intervallo la progressiva risalita del $\delta^{18}O$ tra 1268 e 1090 cm è stata correlata alla transizione tra il Dryas recente e il Pre-Boreale. L'intervallo compreso tra 1090-930 cm, che mostra i valori di $\delta^{18}O$ più elevati di tutta la successione, rappresenta probabilmente parte del Pre-Boreale. Nell'intervallo tra 930-0 cm le associazioni a molluschi indicano un progressivo abbassamento del livello del lago, in concomitanza con la diminuzione dei valori del $\delta^{18}O$. Questa diminuzione di composizione isotopica dell'ossigeno nei molluschi può essere dovuta alle variazioni di temperatura di calcificazione delle conchiglie al diminuire della profondità del lago. Tuttavia la variazione della composizione isotopica delle acque del lago dovuta alla variazione della composizione isotopica delle piogge può aver giocato un ruolo importante.

TERMINI CHIAVE: Molluschi dulcicoli, Isotopi stabili, Younger Dryas, Olocene, Alpi.

(*) *Dipartimento di Scienze della Terra, Università di Pisa, via S. Maria 53, 56126 Pisa - Italy.*

(**) *Comune di Carrara, Settore Ambiente, p.zza 2 Giugno, 54033 Carrara - Italy.*

(***) *Servizio Geologico, Provincia Autonoma di Trento, via Vannetti 39, 38100 Trento - Italy.*

(°) *CNR, Centro di Studio per la Geologia Strutturale e Dinamica dell'Appennino, via S. Maria 53, 56126 Pisa - Italy.*

This work was carried out with financial support of MURST 40% (P.R. Federici, University of Pisa) and of the Provincia Autonoma di Trento, Geological Survey. Part of this work (stable isotopes) was supported by the EC contract n. CI1-CT90-0862 under the leadership of M.T. Alberdi, Museo Nacional de Ciencias Naturales, CSIC, Madrid, Italian leader G. Leone, Dipartimento di Scienze della Terra, University of Pisa. We are grateful to the Istituto Agrario di San Michele all'Adige (Trento) for supplying unpublished meteorological and isotopical data. We thank A. Longinelli, G. Leone and F.P. Bonadonna for helpful observations and S. Waldron for improvement to the English text. We finally thank the reviewer A.E. Fallick for the suggestions that improved the quality of the manuscript.*

INTRODUCTION

In addition to sedimentological and palaeontological studies, stable isotope analyses of lacustrine carbonate are now widely used as a standard technique in palaeolimnology, providing excellent quantitative information on climatic and environmental changes. Numerous isotopic records are now available from central and northern Europe, with considerable detail for the late Pleistocene and Holocene periods (*e.g.* Eicher & Siegenthaler, 1976; Eicher & *alii*, 1981; Lister, 1988; von Grafenstein & *alii*, 1999a). Among the sites investigated many oxygen isotope profiles show a general concordance with the Late Glacial climatic oscillations (e.g. Lotter & *alii*, 1992; von Grafenstein & *alii*, 1999a), which are closely comparable with the isotopes profiles in Greenland ice core, suggesting the same climatic control in both regions. Different behaviour of isotope profiles found in some records are explained as linked to local hydrological phenomena affecting isotopic composition of lake water (e.g. Bottger & *alii*, 1998), or due to different regional climatic control (Whittington & *alii*, 1996).

Northern Italy, with its large number of lacustrine basins developed after the last glacial retreat, represents a key area between central Europe and the Mediterranean regions, which are characterized by different climatic patterns. In the Mediterranean area climatic changes were characterized by marked arid/humid transition (*e.g.* Lamb & *alii*, 1995; Bar-Matthews & *alii*, 1999), which extensively affected hydrological balance and levels in the lacustrine systems as shown by stable isotope data from crater lake in central Italy (*e.g.* Bonadonna & Leone, 1995; Zanchetta & *alii*, 1999) and lake levels investigation (Giraudi, 1989). Moreover, the Mediterranean area has a distinctive effect of the air-sea interaction on the isotopic composition of precipitation owing to the addition of local vapour masses to cloud systems entering this area (Gat & Carmi, 1970).

With the aim to offer new data on palaeoenvironmental evolution of Northen Italy this multidisciplinary study was carried out by the Geological Survey of the Provincia Autonoma di Trento on the Terlago lake basin (Trento, North Italy, fig. 1). It gave an opportunity to investigate the interesting lacustrine sequence preserved there. In this paper we present the results of sedimentological, malacological and isotope analyses from one core recovered from near the modern shore of the lake.

LAKE TERLAGO

Lake Terlago is situated at the head of Valle dei Laghi, about 6 km northwest of Trento (fig. 1). The Lake surface is about 0.3 km^2 and maximum water depth is 11 m. The lake basin is separated eastward by hills from the Val d'Adige, while to the southwest the hollow opens out towards the Valle dei Laghi. As a whole, the Terlago hollow can be defined as a «glacio-karst depression» on a tectonic synclinal structure (Cremaschi & Lanzinger, 1987). The water level is regulated by a series of watertraps flowing towards the Val d'Adige, identified by Trener & Battisti (1898) at 418 m a.s.l. The reclamation of the basin was carried out in the seventeenth century with the construction of the «Fosso Maestro» drainage channel. The lake basin is surrounded by Jurassic to Paleocene limestone and claystone (fig. 1). A series of surface deposits are present within the lake basin (Cremaschi & Lanzinger, 1987). Remains of lateral moraines are present between 520 and 540 m a.s.l. Lake deposits, fan delta deposits and loess patches have been identified. In one of the latter, a vast prehistoric settlement, attributed to Late Paleolithic to Mesolithic, was found near the northern shore of Lake Terlago, about 30 m above the present level of the lake (Bagolini & Dalmeri, 1980, 1984; Dalmeri, 1992).

Mean annual air temperature recorded in the area (S. Michele all'Adige station) for the period 1983-1992 is about 11°C. The coldest months are December and January with mean temperature of about 0° and 1°C, respectively, whereas the warmest months are July and August with mean temperature around 22°C. Mean annual rain amount is about 832 mm and mean humidity is about 72%.

Lake water temperature data are available for 1992 and 1993 (Flavio Corradini, Istituto Agrario di San Michele all'Adige, pers. com.). Registered surface temperature in July is 23 °C, decreasing to about 11 °C at 7 m. December temperature is about 4 °C along the entire profile. Thermal stratification is evident in May and July with rapidly decreasing temperature at 3-4 m (from 17 °C to 14 °C and from 23 °C to 19 °C respectively). Stratification is weak, in the first 4 m, in October and March. Lake Terlago is not monitored for stable isotope composition of the water. Mean oxygen isotope composition of the meteoric water, estimated using data from rivers (Zuppi & Bortolami, 1982; Cortecci pers. com.) and rain collection in neighbouring area (D'Amelio & *alii*, 1994), should be between –8 and –9‰. Two samples of surficial water collected on November 1999 gave $\delta^{18}O$ of –8.44 and of –9.15‰ for the lake water and inflow river, respectively. They are in agreement with $\delta^{18}O$ estimation of meteoric water even if an enrichment of ^{18}O in the surface water is presumed, especially during the summer.

MATERIALS AND METHODS

The Geological Survey of the Trento Autonomous Province carried out a continuous core borehole survey in the lake deposits of the valley bottom, at an altitude of 420 m a.s.l. (45° 05' N, 11° 03' E). The drill supplied 12 cores of 1.5 m each to the depth of 22.2 m. The argillaceous limestone of the bedrock («Scaglia Grigia» Formation, Paleocene) was reached at 22.2 below the surface. Table 1 and figure 2 supply the detailed stratigraphy.

Along the core section 79 samples were collected for malacological analyses. The mean distance between samples was approximately 15 cm. At the join of the core sections, the sampling gap was increased to a maximum of 50

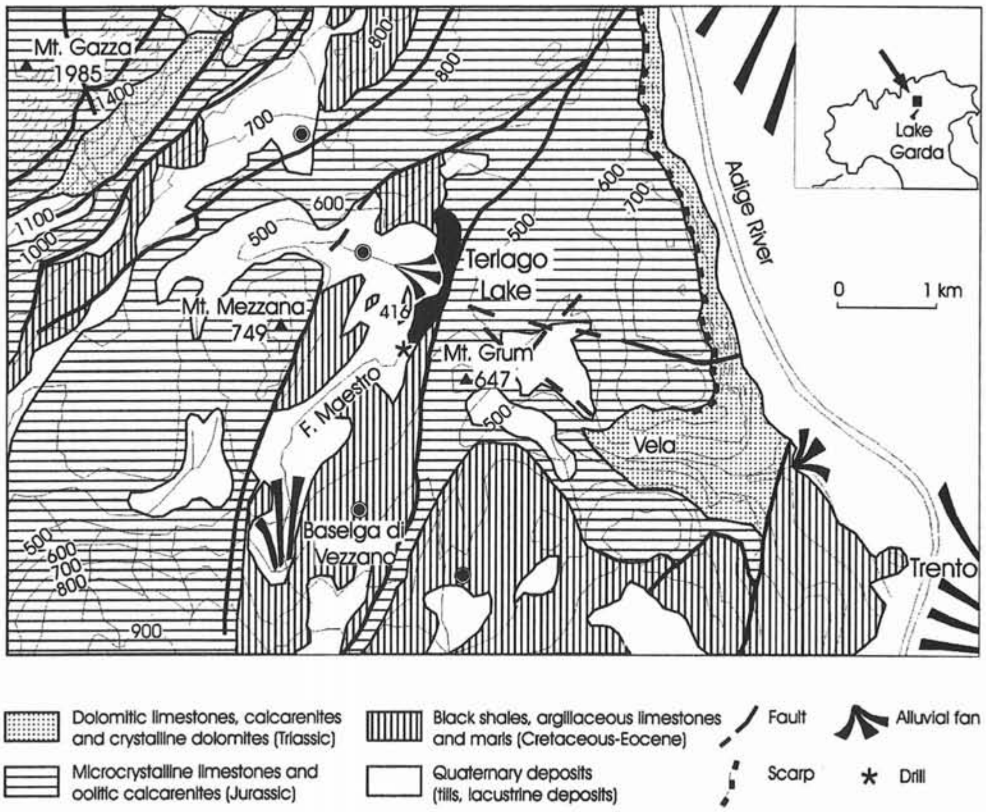


FIG. 1 - Geographical and geological setting of the studied area and location of the drill site.

TABLE 1 - Lithological description of the core

Depth (cm)	Color	Lithology	Lower Boundary
0-9	brown (10YR4/3)	silt; poorly developed medium subangular blocky	Gradual
9-57	brown to graysh brown (10YR 5/3-2)	silt to loamy silt; poorly developed subangular blocky	Gradual
57-80	grayish brown (10YR 5-6/2)	loamy silt	Clear
80-83	graysh brown (10YR 5/2)	shell bed in fine sand	Clear
83-163	dark grayish brown (2.5Y 4/2)	loamy sand with organic matter	Clear
163-165	grayish brown (2.5Y 5/2)	shell bed in fine sand	Clear
165-250	dark grayish brown (2.5Y 4-5/2)	loamy sand with organic matter d	Clear
250-270	olive brown (2.5Y 4/3)	loamy sand	Sharp
270-400	grayish brown (2.5Y 5/2)	massive silt	Gradual
400-430	grayish brown to olive brown (2.5Y 5/2-3)	loamy silt with lamine of fine sand	Sharp
430-700	grayish brown to olive brown (2.5Y 5/2-3)	massive silt	Sharp
700-900	olive gray (5Y 5/2)	loamy silt with local silty clay and fine sand lamine	Clear
900-980	olive gray (5Y 5/2)	laminated silt	Gradual
980-1070	olive gray (5Y 5/2)	laminated silty clay to silty clay loam.	Gradual
1070-1170	olive gray (5Y 5/2) to light olive gray (5Y 6/2)	coarse laminated silty clay to silty clay loam	Gradual
1170-1200	grayish brown (2.5Y 5/2)	silty loam	Gradual
1200-1250	gray (2.5Y 5/1)	gravel with sandy silt matrix	Sharp
1250-1300	olive gray (5Y 5/2) to light olive gray (5Y 6/2)	alternation of silty loam and loamy sand	Sharp
1300-1350	gray (2.5Y 5/1)	fine to medium laminated sand	Sharp
1350-1360	gray (2.5Y 5/1)	sandy gravel	Sharp
1360-1375	gray (2.5Y 5/1)	medium to fine sand	Sharp
1375-1400	gray (2.5Y 5/1)	gravel	Sharp
1400-1480	gray (2.5Y 5/1)	fine to medium laminated sand	Sharp
1480-2220	gray (2.5Y 5/1)	gravel and pebble with sand	Sharp
> 2220		Bedrock (Argillaceous Limestone)	

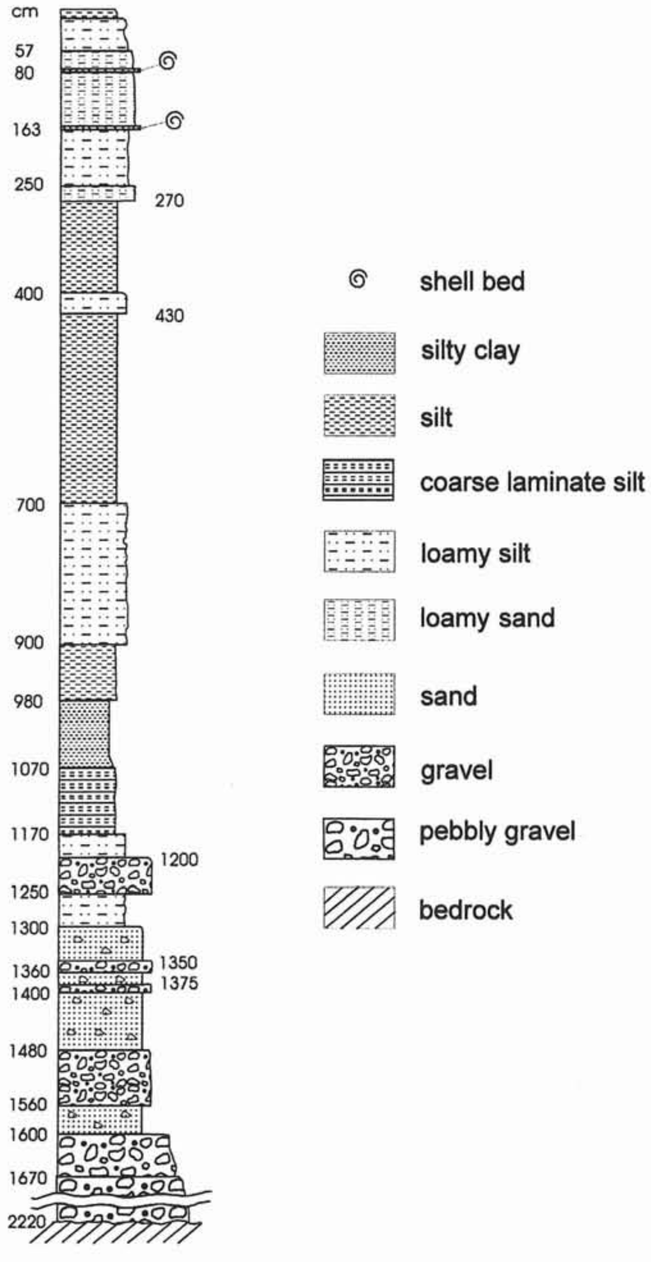


FIG. 2 - Stratigraphy of the studied core (see figure 1 for location and table 1 for description).

cm. In the zones of particular interest, e.g. those with lithological changes, the sampling gap was reduced as much as possible. Samples were about 2 cm thick, except in a few cases and where of necessity 5 cm thick samples were analysed. For the extraction of fresh water molluscs the method suggested by Lozek (1986) was followed, using 71, 325 and 500 µm mesh screens. All identifiable shells and fragments were considered (table 2). Some levels yielded a very low number of shells and they do not have statistical significance. The distribution of the molluscs is presented in figure 3 as a percentage histogram.

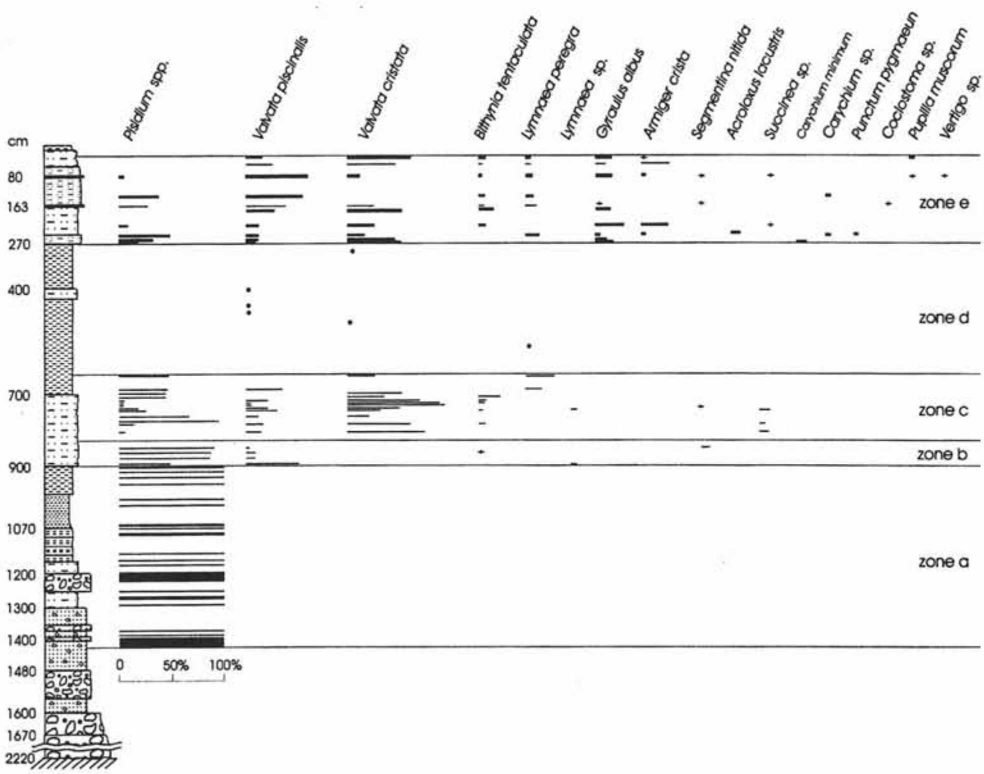
Well preserved entire shells were selected for AMS dating and isotopic analyses. Samples were treated with an additional washing in an ultra-sonic bath. The shells for AMS dating (Iso Trace Radiocarbon Laboratory, University of Toronto, Canada) were extracted from samples at depths of 1390-1400 cm, 860-862 cm (*Pisidium* sp.) and 713-715 cm (*Valvata piscinalis*). No corrections for hard water and reservoir effects were performed. The reason being that freshwater lakes and streams exhibit a wide range of reservoir effect from negligible to thousands of years. Moreover, reservoir effect is prone to significant variability, sometime even on seasonal time scales, and this is unlikely to be constant through time (Turner & *alii*, 1983). The main cause of variability is the changes in the amount of hard-water from ground water input related to dissolution of old carbonate or relative to inputs from other younger sources such as rivers. Changes in wind intesity driven exchange of CO_2 between the atmosphere and water body can also play a role.

$\delta^{18}O$ and $\delta^{13}C$ analyses (table 3 and figure 4) were carried out on shells of *Valvata piscinalis* and *Pisidium* spp., the carbonate fraction of the sediment being probably enriched by an unknown quantity of detrital calcite and dolomite. These two taxa were chosen because of their distribution along the core, which made it possible to obtain as detailed a record as possible. Stable isotope analyses were carried out at the «Centrum voor Isotopen Onderzoek» of Groningen, the Netherlands. Several shells of the same species contributed to each analysed sample. Carefully selected and cleaned shell samples were reacted, without any previous treatment, with 100% H_3PO_4 under vacuum at 25 °C to produce carbon dioxide for mass spectrometer analyses. Isotope abundances are reported using the conventional ‰ notation relative to V-PDB. Analytical error does not exceed 0.15‰ for both oxygen and carbon. Water $\delta^{18}O$ data mentioned in the text are expressed versus SMOW. Both oxygen and carbon isotopic results from two distinct samples of *Pisidium* sp. from the same level at 1063 cm show differences within the analytical error.

STABLE ISOTOPE BACKGROUND

Although oxygen isotope composition of calcium carbonate precipitated under equilibrium condition from a dilute water solution depends on the temperature and the isotopic composition of the water, with a thermodependence of about –0.2 ‰/°C (Epstein & *alii*, 1953), in the continental environment the oxygen isotope composition of the water is the main factor controlling the isotopic composition of calcium carbonate due to a large fractionation effect connected with the hydrological cycle (Gat, 1980; Rozanski & *alii*, 1993). A significant global relationship exists between mean annual air temperature and isotopic composition of rain. However, $\delta^{18}O$ composition of the precipitation depends not only on local conditions such as air temperature, but also on the source and paths of atmospheric vapour masses (Dansgaard, 1964, Siegenthaler & Oeschger, 1980; Rozanski & *alii*, 1993). In open

FIG. 3 - Mollusc diagram (percentage istogram). Circles indicate shell fragments (see figure 2 for lithostratigraphy legend).



lakes with fast water turnover the isotopic composition of lake water will reflect that of the catchment area. However, in lacustrine systems evaporation influences the isotopic composition of host water as a function of residence time of the body water, as well as the morphological features of the lake itself (Gonfiantini, 1986).

Since equilibrium of oxygen isotopes with host water has been suggested for some bivalve and gastropod freshwater shells (Fritz & Poplawski, 1974; Burchardt & Fritz, 1980) freshwater molluscs are a useful tool for palaeoenvironmental investigation. Studies carried out on individuals of *Lymanea peregra* and *Planorbarius corneus* grown in a controlled environment (Lemeille & *alii*, 1983) show a fractionation of $\delta^{18}O$ with a temperature dependence of ~ −0.24 ‰/°C, which is good agreement with previous studies on biogenic and inorganically precipitated carbonate (e.g. McCrea, 1950; Craig, 1965). However, Lemeille & *alii*, (1983) showed an enrichment of about 1‰ with respect to calcite equilibrium. This could be explained by different isotopic fractionation factors between calcite and aragonite (about 0.6% at 25°C, Tarutani & *alii*, 1969) or offset due to vital effects. Notably, von Grafenstein & *alii*, (1994; 1999b) show that *Pisidum* spp. are enriched by 1‰ with respect to isotopic equilibrium. However, several studies have demonstrated that the isotopic composition both of aragonitic shells and authigenic calcite follow the same general trend (Stuiver, 1970; Turner & *alii*, 1983; Siegenthaler & Eicher, 1986; Bottger & *alii*, 1998). We must bear in mind that $\delta^{18}O$ data from molluscs give information on environmental conditions only during the growing season, which in temperate-cold climates, corresponds principally with summertime (Chaix & *alii*, 1982; Lemeille & *alii*, 1983). An aragonitic shell deposited during the warmer half of the year, with a mean $\delta^{18}O$ of the water about −8.5‰ and a mean temperature of the surficial water of about 20 °C will have a $\delta^{18}O$ of the carbonate of ~ −9‰.

The carbon isotopic composition of mollusc shells is controlled mainly by the $\delta^{13}C$ of dissolved inorganic carbon (DIC) in the water system where the molluscs live (Fritz and Poplaswki, 1974; Buchardt and Fritz, 1980). In lacustrine systems the $\delta^{13}C$ of the DIC is controlled by several sources namely, exchange with atmospheric CO_2 reservoir, respiratory activity of aquatic plants, mineralization of organic matter, DIC isotopic composition of the inflow water, which, in turn, depends on dissolution of available carbonate rocks and leaching of CO_2 from soils. The carbonate precipitated from solution near isotopic equilibrium with atmospheric CO_2 will have a $\delta^{13}C$ value around 0‰ whereas carbonate precipitated from DIC arising from oxidation of organic matter shows a marked ^{13}C-depletion.

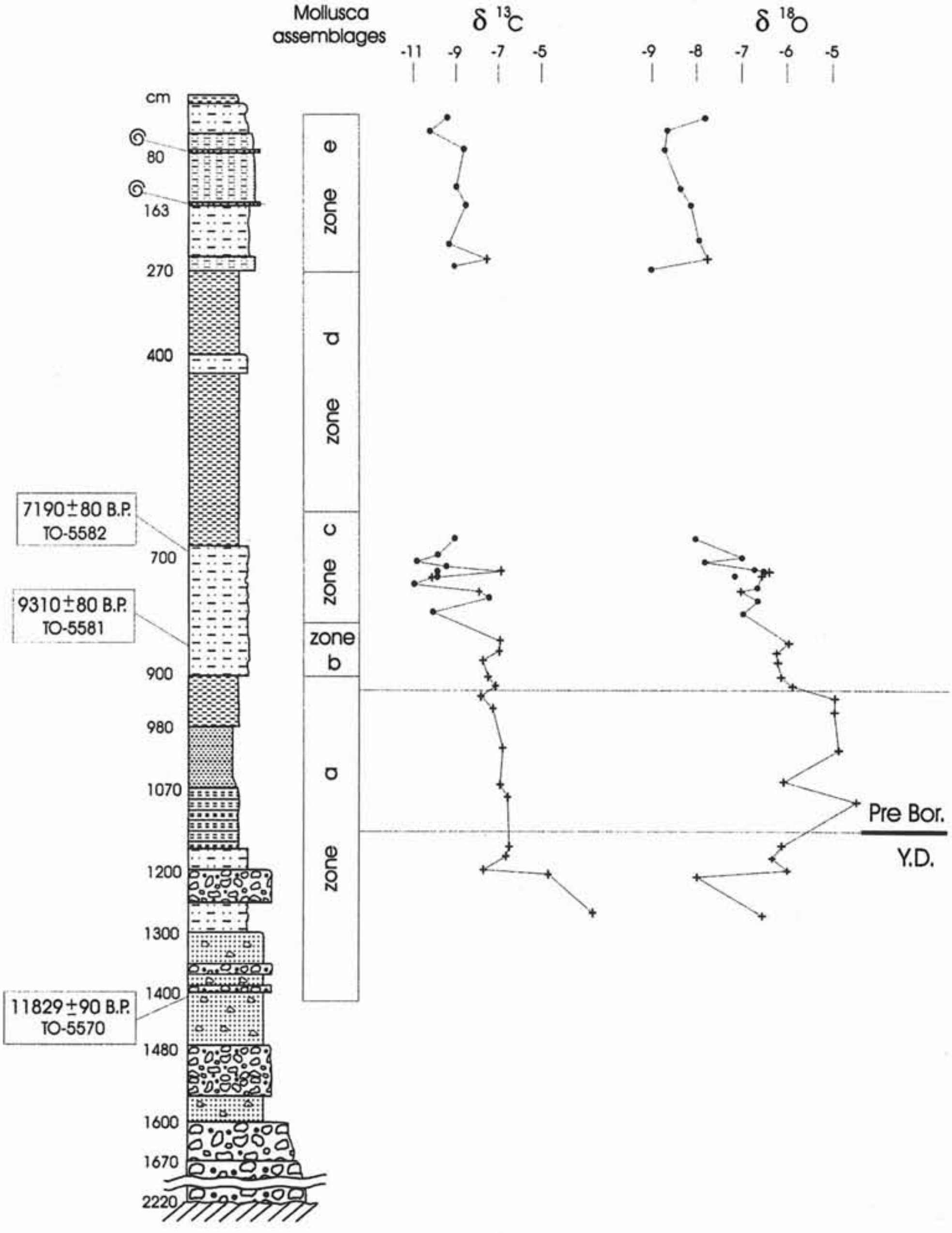
MOLLUSC ASSEMBLAGE

Molluscs are present from 1410 cm depth to the surface; the base of the core (1600-1410 cm) was devoid of shells. Two other barren sections occurred at 1307-1345

TABLE 2 - Analytical data of the mollusc collected in the core

sample (depht cm)	*Pisidium* spp.	*Valvata piscinalis*	*Valvata cristata*	*Bithinia tentaculata*	*Lymnaea peregra*	*Lymnaea* sp.	*Gyraulus albus*	*Armiger crista*	*Segmentina nitida*	*Acroloxus lacustris*	*Succinea* sp.	*Carychium minimum*	*Carychium* sp.	*Punctum pygmaeum*	*Cochlostoma* sp.	*Pupilla muscorum*	*Vertigo* sp.	total
30-35		16	55	5	2		13	1								3		95
50-52		22	31	2	4		11	27										97
80-83	20	352	45	7	13		83	10	1		1					1	1	534
138-142	17	28		1	2								1					49
163-165	103	161	73	8	8		3		2						1			359
170-175		2	3	1			1											7
220-225	3	5	8	1			10	8			1							36
250-255	30	6	7		3		2	1		3	1			1				54
260-265	3	1	7		1		1											13
265-270	2	1	6				2					1						12
270-272																		
288-290			F															
330-332																		
338-340																		
380-382																		
398-400	F																	
450-452	F																	
468-470	F																	
500-503		F																
507-510																		
530-532																		
548-550																		
560-563																		
577-580																		
600-602					F													
618-620																		
633-636																		
644-647	2		1		1													4
683-686	8	5			2													15
694-697	1		1															2
705-707	3		2		1													6
713-715	1	10	36	2														49
720-722	3	9	161	5														178
726-728	2	12	173															187
732-734	26	34	60	2		2		1										125
738-740	66	70	71	4			1											212
755-757	67	9	20															96
768-770	31																	31
780-782	25	27	89	5				8										154
798-800	8	18	126					12										164
845-847	49	1					1											51
860-862	138	9		1														148
874-876	22	1																23
888-890	3	3				1												7
900-902	20																	20
913-915	32																	32
930-932	68																	68
948-950	29																	29
990-992	50																	50
1008-1010	21																	21
1060-1065	33																	33
1070-1072	8																	8
1086-1088	3																	3
1088-1090	12																	12
1145-1147	5																	5
1163-1165	11																	11
1180-1182	27																	27
1198-1200	19																	19
1200-1220	79																	79
1250-1252	2																	2
1266-1268	1																	1
1268-1270	10																	10
1290-1292	2																	2
1307-1310																		
1330-1332																		
1344-1345																		
1365-1367	6																	6
1377-1380	2																	2
1386-1388	3																	3
1390-1397	8																	8
1397-1400	5																	5
1400-1410	1																	1

FIG. 4 - Mollusca assemblages and isotopic diagrams ($\delta^{18}O$ and $\delta^{13}C$ ‰ vs PDB). AMS dates in evidence (+ *Pisidium* sp.; • *Valvata piscinalis*).



cm and at 270-636 cm. The shell sequence from 1410 cm was subdivided into various zones on the basis of shell content, on relative proportion of the species present and their environmental significance (*e.g.* Sparks, 1961; Lozek, 1986; Walker & *alii*, 1993; figure 3). The following assemblage zones may be identified:

Zone a) 1410-900 cm. Only the genus *Pisidium* is present increasing in abundance with decreasing depth. Most of the specimens belong to *Pisidium conventus*, but *Pisidium subtruncatum* is present especially in the samples from the upper part of the zone. It is often difficult to distinguish different species of *Pisidium* on the basis of conchological characteristics. Moreover, environmental conditions have a considerable influence on the morphology of the shell of *Pisidium,* often determining the appearance local phenotypes (Castagnolo & *alii*, 1980). For these reasons we do not separate the different species of *Pisidum* in figure 3.

Pisidium is considered to be the mollusc that can live at the greatest depths. In the mountain lakes, the bottom is often occupied by *Pisidium*, which can live on rocky bottoms with a very small production of organic substance (Boycott, 1936). *Pisidium subtruncatum* tolerates a

TABLE 3 - Isotope values (δ^{13}C and δ^{18}O ‰ vs PDB) of *Valvata piscinalis* and *Pisidium* spp.

Depth (cm)	*Valvata piscinalis*		*Pisidium* spp.	
	δ^{18}O ‰ PDB	δ^{13}C ‰ PDB	δ^{18}O ‰ PDB	δ^{13}C ‰ PDB
33	– 7.83	– 9.42	—	—
50	– 8.68	– 10.14	—	—
81	– 8.73	– 8.64	—	—
139	– 8.38	– 8.98	—	—
164	– 8.14	– 8.54	—	—
223	– 7.98	– 9.36	—	—
253	—	—	– 7.77	– 7.56
260	– 9.01	– 9.17	—	—
683	– 8.02	– 9.13	—	—
713	– 6.99	– 9.94	—	—
721	– 7.81	– 10.89	—	—
727	– 6.73	– 9.51	—	—
733	– 6.51	– 9.93	– 6.38	– 6.98
739	– 7.17	– 9.95	– 6.53	– 10.18
755	– 6.67	– 11.05	—	—
768	—	—	– 7.01	– 7.95
781	– 6.66	– 7.5	—	—
800	– 7.65	– 10.15	—	—
845	—	—	– 5.89	– 6.98
861	—	—	– 6.22	– 7.08
875	—	—	– 6.19	– 7.82
900	—	—	– 6.13	– 7.84
913	—	—	– 5.88	– 7.18
930	—	—	– 4.97	– 7.89
950	—	—	– 4.96	– 7.37
1008	—	—	– 4.85	– 6.91
1063	—	—	– 6.52	– 6.99
1063	—	—	– 6.23	– 6.95
1090	—	—	– 4.44	– 6.65
1165	—	—	– 6.1	– 6.58
1180	—	—	– 6.3	– 6.78
1198	—	—	– 5.97	– 7.79
1210	—	—	– 7.95	– 4.79
1268	—	—	– 6.55	– 2.57

wide range of habitats and can be found in lakes down to a depth of 30-40 m (Castognolo & *alii*, 1980), while *Pisidium conventus* is the typical species of cold and clean lake waters (Castagnolo & *alii*, 1980; Boycott, 1936).

Zone b) 900-822 cm. Zone b is defined by the appearance of *Valvata piscinalis*, although *Pisidium* spp. remain the most frequent species. The first sample containing about 50% of *Valvata piscinalis* (888-890 cm) is not representative because of the low number of individuals. Subsequently, in the rest of this zone the number of individuals increases perceptibly and the percentages become more representative. Occasional specimens of *Bithynia tentaculata, Lymnaea* sp. and *Segmentina nitida*, with only one individual, can be considered allochthonous being typical of marginal lake environment. *Bithynia tentaculata, Lymnaea* sp. become important in the following associations. In general, *Valvata piscinalis* lives amongst submerged vegetation, generally macrophytic, in clean waters with a weak current. It prefers deeper water than most pulmonates (Kerney, 1971) and occurs in greatest numbers in a zone between about 1.5 and 2 m below the surface of the lake (Ökland, 1964).

Zone c) 822-640 cm. This association is marked by the appearance of *Valvata cristata*, a species characteristic of shallow waters rich in vegetation (Lozek, 1964). *Valvata piscinalis* increases in number compared to zone b) and *Bithynia tentaculata*, indicative of the «moving water group» (Sparks, 1961), is found in several samples. Also present are *Lymnaea peregra*, a highly tolerant species, and some specimens of *Succinea* sp., which live near the shore.

The upper limit of this association is equally clear, determined by the abrupt drop in the number of individuals, and over about 50 cm there is transition to totally barren samples.

Zone d) 640-270 cm. The rare specimens that are found are probably reworked being fragmented and considerably eroded. However a concentration of weakly fossiliferous samples was observed between 398 and 503 cm. The fragments identified belong to *Valvata piscinalis*, *Lymnaea* sp. and *Valvata cristata*. In figure 3 the fragments found in this zone are not shown as a percentage histogram, but as a symbol.

Zone e) 270-30 cm. From the barren zone below we pass abruptly to this zone in which the diversity of species increases, to include several species of land snails. A large number of individuals of *Valvata cristata* and *Valvata piscinalis* are present, associated here with *Gyraulus albus*, which becomes an important species of this association, and to *Gyraulus (Armiger) crista*. The latter two species live amongst the putrefying vegetation of ponds and marshes (Girod & *alii*, 1980; Bodon & *alii*, 1995) and, like *Lymnaea peregra*, will tolerate a wide range of habitats. *Bithynia tentaculata* and *Lymnaea peregra* are consistently present, while frequencies of *Pisidium* spp. show wide fluctuations. The absence of some species, (representative of the association, in the sample 138-142 cm, such as *Valvata cristata* and *Gyraulus albus*) and the relative increase in *Valvata piscinalis* and *Pisidium* spp. might indicate a variation in the environmental conditions within zone e). However, it did not seem appropriate to make excessive subdivisions, especially when determined by only a single sample, but rather to consider the whole upper part of the core to be in a single zone. Moreover, the taphonomic processes that characterise this zone might be responsible for phenomena of sorting. Mention should be made of the presence of terrestrial species *Carychium minimum*, loving of the moist place, *Succinea* sp., living close to water body, and of typically terrestrial species such as *Punctum pygmaeum*, *Pupilla muscorum*, and *Vertigo* sp. in this section. *Pupilla muscorum* is a species living in non-shaded habitats and screes, whereas *Punctum pygmaeum* appears prevalently in very moist and well vegetated places and marshes (Kerney & Cameron, 1979; Lozek, 1964). Overall they are part of the malacological association of the soil near the lake shore.

ISOTOPE RESULTS

The δ^{18}O values of *Pisidium* sp. range from –7.8 to –4.4‰ whereas *Valvata piscinalis* range from –9.0 to –7.2‰ (table 1 and figure 4). Differences in the δ^{18}O values between these two species are expected owing to the different style of life and any vital offset. However, when *Pisidium* and *Valvata piscinalis* were analysed from the same level (i.e. 733 and 739 cm) they showed only small differences in δ^{18}O values. Therefore, we assume that the composite δ^{18}O record obtained from the *Pisidium* and *Valvata piscinalis* does not represent an artefact due to different vital offset but mainly depends on change in temperature and isotope composition of lake water.

The lower part of the δ^{18}O record (1268-1090 cm) is characterised by the presence of *Pisidium* with δ^{18}O as low as –7.9‰ (1210 cm) followed by an increase to –4.4‰ (1090 cm). Between 1090 and 930 cm δ^{18}O ranges from –4.4 to –5.0‰, representing the highest δ^{18}O enrichment in the isotope profile, but two samples at depth of 1063 cm show a value of about –6.3‰. From 930 to 683 cm the *Pisidium* tests are marked by a depletion of the δ^{18}O content, with an overall variation of 1.5‰. The top of the core record (260-33 cm), shows δ^{18}O values similar to those of the preceding section, even though it is separated from the previous by a long section barren in shells which corresponds to Zone d in malacological assemblages. *Valvata* δ^{18}O values swing between –9 and –7.8‰ with mean value of about –8.4‰, whereas the single sample of *Pisidium* is –7.8‰.

The δ^{13}C values of *Pisidium* sp. range from –2.6 to –10.2‰ but in general show quite constant values along the whole section studied. Between 1268 and 1090 the δ^{13}C decrease from –2.5 to –7.8‰. *Valvata piscinalis* samples have δ^{13}C values ranging between –7.5 and –11.5‰ but no clear trend is discernible. Moreover, along the isotope record, there is not statistically significant correlation of δ^{13}C with δ^{18}O.

DISCUSSION AND CONCLUSION

The presence of lake deposits between 550 and 430 m a.s.l. (up to +135 m above the present lake level, Cremaschi & Lanzinger, 1987) is evidence of a phase in which Lake Terlago extended considerably further than nowadays. According to Cremaschi & Lanzinger (1987) these deposits formed immediately after the withdrawal of Late Pleistocene glaciers.

The sequence of coarse deposits characterizing the lowest section of the core is older than 11,890±90 ^{14}C yr B.P. (TO-5570-AMS), suggesting a complete withdrawal of the glaciers from the zone before this date. Some sections at the Passo del Tonale (Adamello Group, about 50 km to the north of Terlago) also demonstrate the rapid deglaciation of the Southern Alps, during the first late-glacial phases. The glaciers were confined within the tributary valleys of the Adamello before 12,275±115 yr B.P. (GX-21040-AMS, Cavallin & *alii*, 1997).

The appearance of the genus *Pisidium* in the Terlago coincides with the first ^{14}C date of 11,890±90 yr B.P. (TO-5570-AMS). The poor malacological association observed in zone a) mainly reflects deep lake conditions. The tolerance of the species of *Pisidium* (*Pisidium subtruncatum* and *conventus*) for environments with little production of organic matter and the comparison with other cores being studied, suggest that *Pisidium* can be considered one of the first mollusc colonizers, at least of the deeper parts, of the Alpine and Pre-alpine lakes formed after the withdrawal of the glaciers (see also Chaix & *alii*, 1982). The date 11,890±90 ^{14}C yr B.P. (TO-5570-AMS) is not corrected for hard water and reservoir effect and could be older than the «true» age. However, this date may indicate that the Younger Dryas can be situated along zone a), although a part of the preceding Allerod can be included. During the Younger Dryas the depth of the lake should have been considerably less than that estimated in the early phases of deglaciation (+135 m above the present lake level), as is shown by the prehistoric finds datable to the later phases of the Epigravettian (Younger Dryas), situated only 30 m above the present level of the lake (Dalmeri, 1992).

Previous isotopic studies on European lakes (Eicher & Siegenthaler, 1976; Eicher & *alii*, 1981; Lemeille & *alii*, 1993; Lotter & Zbiden, 1989; Lotter & *alii*, 1992; Goslar & *alii*, 1993) show a clear change, with an increase of about 2-3‰, in the oxygen isotopic composition of the authigenic and biogenic carbonate during Younger Dryas and Pre-Boreal transition. The δ^{18}O trend found in the first part of zone a) in Terlago core, with the increases in ^{18}O content to the maximum observed (fig. 4), might be tentatively associated with the end of Younger Dryas and the transition to Pre-Boreal based on the ages measured and the magnitude of the isotope shift. Chronologically this part of the core is younger than 11,829±90 and older than 9,310±80 ^{14}C yr B.P. From this perspective we tentatively explain the changing δ^{18}O composition as the result of climatic improvement at the end of Younger Dryas. The lake water followed the δ^{18}O increase in the rain, related to the rising mean air temperature. The first two samples of *Pisidium* sp. have highest ^{13}C content; low biological activity is consistent with the attribution to a cold period like Younger Dryas. In the remaining part of zone a) δ^{18}O values are the highest of the record, suggesting that they represent a climatically favourable phase, maybe corresponding to Pre-Boreal. The lower δ^{18}O values at 1063 may indicate a new cooling during the early Pre-Boreal, as detected in other proxy records (e.g. Anderson & *alii,* 1997). However, chronological and isotopic resolution do not permit further interpretations.

The transition from zone a) to zone b) in which *Valvata piscinalis* appears, suggests that the lake became shallower. Moreover, the tube-like concretions and the oogonia of Characeae that are found in the sediments in this zone, should be associated, according to Magny (1992), with the platform slope (waters of a depth of about 5-15 m). This transition is slightly older than 9310±80 yr B.P. The subsequent appearance of *Valvata cristata,* index species of zone c), characteristic of shallow waters rich in vegetation associated with *Valvata piscinalis* and *Bithynia tentaculata*, suggests a further decrease in the depth of the lake. The top of zone c) is slightly younger than 7190±80 yr B.P. The decrease of $\delta^{18}O$ value of *Pisidium* roughly follows the transition from zone a) to zone b) and from zone b) to zone c).

The zone between 640 and 270 cm is barren from a malacological point of view (zone d). The absence of molluscs could occur for a variety of reasons (Lozek, 1986, Gilbertson, 1980). The activity of Holocenic alluvial fan that now divides the lake in two parts might have significantly increased the turbidity of the water and changed the lacustrine dynamics, thus inhibiting mollusc colonization in this sector.

Zone e) is characterized by a high level of species diversity. Many of the species found only in this section, such as *Gyraulus albus* and *Gyraulus (Armiger) crista*, indicate shallow and coastal water condition. This is confirmed not only by the other species found, some of which are land species, but also by the presence of two shell beds (80-83 cm and 163-165 cm), interpreted as a postmortem accumulation caused by wave-generated currents in nearshore and shoreline environments (Hanley & Flores, 1987). In this interval $\delta^{18}O$ values decrease. The *Valvata piscinalis* and *Pisidium* $\delta^{18}O$ values with a mean $\delta^{18}O$ of ~ –8.4‰, are in fair agreement with the oxygen isotope composition calculated for modern shells (~ –9‰). This may suggest that lake water had a $\delta^{18}O$ similar to today's rain, with low or negligible ^{18}O enrichment due to evaporation. As mentioned, the mean ^{18}O content of the rain is world-wide related with surface air temperature (0.58‰/°C, Rozanski & *alii*, 1993) and this relationship, when corrected for isotopic fractionation occurring during carbonate precipitation (–0.24‰/°C) can give an estimate of change in relative lake temperature (Eicher & Siegenthaler, 1976; Eicher & *alii*, 1981; Anderson & *alii*, 1997). Von Grafenstein & *alii*, (1996) suggest that in mid-Europe a $\delta^{18}O$-temperature relation for rain of about 0.6‰/°C may probably apply to the entire Holocene. This means that the difference in temperature between 1090 and 930 cm, with a mean $\delta^{18}O$ of ~ –4.7‰, and the top of the record, should be about 10 °C. Such a value is unlikely and shows, if the $\delta^{18}O$-temperature relation is appropriate for the southern Alps, that a change of the mean air temperature with the isotope signature of the rain cannot alone explain the observed shift during the Holocene. The progressive decrease in $\delta^{18}O$ from 930 to the top needs to be explained in a different way. It is interesting to note that the decrease in $\delta^{18}O$ coincides fairly well with the change in mollusc assemblages and, therefore, with the progressive shallowing of the lake. The $\delta^{18}O$ of the shell could have recorded the change in temperature only, due to the calcifying water depth change. During summer time a thermal gradient originates difference in temperature between *epilimnion* and *hypolimnion* so that $\delta^{18}O$ of shells calcified at depth and shallow water differ significantly. The overall variation of about 3‰ from 1090-930 cm to the top of the core could be explained with a difference of temperature between depth and surficial water around 15 °C. This difference appears reasonable taking into account the thermal gradient of Lake Terlago mesaured today in July. If this interpretation is correct, the consequence would be that, with respect to $\delta^{18}O$ of the lake water, no significant change is detected within Holocene and the $\delta^{18}O$ of the shells record only the lowering and the progressive filling of the lake. This would be in agreement with previous work from other side of the Alps (*e.g.* von Grafenstein & *alii*, 1999a).

However, other factor might have influenced the $\delta^{18}O$ of the lake water. For instance, McDermott & *alii*, (1999) advance a tentative climatic reconstruction based on $\delta^{18}O$ record of a speleothem from La Grotta di Ernesto (Trento). Their data support the amount effect in the rain as responsible for the $\delta^{18}O$ shift they found in the carbonate. Prior to about 7,800 cal yr B.P. Grotta di Ernesto stalagmite shows high $\delta^{18}O$ which has been interpreted as dry or dry-warm condition. From 7,800 to 6,900 cal yr BP the Grotta di Ernesto speleothem exhibits a well-defined episode of low $\delta^{18}O$ interpreted as a wet phase. A new decrease in $\delta^{18}O$ is recognised since 3,500 yr ago. These data suggest that variation in $\delta^{18}O$ of lake Terlago water probably occurred during the last 10,000 yr as response to the amount of rain.

If the amount effect explains the $\delta^{18}O$ isotopic variation of *Valvata piscinalis* at the top of the core, the variation of calcifying temperature linked to a thermal gradient with depth might combine with the previously cited amount effect to give rise to the isotopic variation between 930 and 683 cm. However, the chronological control of Lake Terlago and the unknown amount of hard-water effect on ^{14}C ages prevent any detailed correlation between the two $\delta^{18}O$ records.

On the other hand, the lake level and residence time of the water in Lake Teralgo is probably regulated by karstic watertraps whose efficiency has been suggested to change from the Late Pleistocene to Holocene (Cremaschi & Lanzinger, 1987). Karstic watertraps and the changes they introduced in the hydrological balance of the lake are unfortunately of unknown importance.

In summary, data collected in the Terlago core allows us to draw the following preliminary conclusions:

– During zone a) deep water conditions prevailed. The $\delta^{18}O$ trend between 1268 and 1090 cm has been tentatively correlated with Younger Dryas/Pre Boreal climatic transition. Interval 1090-930 cm, with the highest $\delta^{18}O$ values might represent the onset of Pre-Boreal.

– Zone b) and c) of the molluscan assemblage suggest progressive lowering of the water level. $\delta^{18}O$ moves toward the values measured at the top of the core. The difference in the $\delta^{18}O$ of *Pisidum*, between 1090 and 930 cm and the upper values can be explained by the temperature of precipitation of biogenic carbonate relating to different water depths. However, other climatic factors, as suggested by Grotta di Ernesto $\delta^{18}O$ record (i.e. amount effect) may have influenced the $\delta^{18}O$ evolution of lake water. A water lake with isotopic composition similar to present precipitation, with low or negligible evaporation, well explain isotope results at the top of the core.

Finally, our results suggest that the combined effect of hydrological and climatic changes are responsible for the isotopic and malacological evolution of the Lake Terlago.

This paper suggest that molluscan and isotope analyses can represent tools useful to reconstruct complex lake history. When other lake records are available, it will be possible to discern if hydrological factors, that make the isotope interpretation difficult, are a merely local effect or whether they have regional significance, as La Grotta di Ernesto isotope profile might suggest.

REFERENCES

Anderson W.T., Mullins H.T. & Ito E. (1997) - *Stable isotope record from Seneca Lake, New York: Evidence for a cold paleoclimate following the Younger Dryas.* Geology, 25 (2), 135-138.

Bagolini B. & Dalmeri G. (1980) - *Lago di Terlago (Trento).* Preistoria Alpina, 16, 101-103.

Bagolini B. & Dalmeri G. (1984) - *Site Paleolithique Tardif-Mésolithique dù lac de Terlago (Trento).* Preistoria Alpina, 19, 189-196.

Bar-Matthews M., Ayalon A., Kaufman A. & Wasserburg G.J. (1999) - *The Eastern Mediterranean paleoclimate as reflection of regional events: Soreq cave, Israel.* Earth Plan. Sc. Lett., 166, 85-96.

Bodon M., Favilli L., Giusti F. & Manganelli G. (1995) - *Gastropoda Pulmonata.* In: Minelli A., Ruffo S. & La Pasta S. (eds), «Cecklist delle specie della fauna italiana», 17, Calderini, Bologna.

Bonadonna F.P. & Leone G. (1995) - *Palaeoclimatological reconstruction using stable isotope data on continental molluscs from Valle di Castiglione, Rome, Italy.* The Holocene, 5, 461-469.

Bottger T., Hiller A., Junge F.W., Litt T., Mania D. & Scheele N. (1998) - *Late Glacial stable isotope record, radiocarbon stratigraphy, pollen and mollusc analyses from the Geiseltal area, Central Germany.* Boreas, 27, 88-100.

Boycott A.E. (1936) - *The habitats of fresh-water mollusca in Britain.* Journ. Anim. Ecol., 5, 116-186.

Buchardt B. & Fritz P. (1980) - *Environmental isotopes as environmental and climatological indicators.* In: Fritz P. & Fontes J.C. (eds): «Handbook of Environmental Isotope Geochemistry Elsevier», Amsterdam, 1A, 473-504.

Castagnolo L., Franchini D. & Giusti F. (1980) - *Guide per il riconoscimento delle specie animali delle acque interne italiane. Bivalvi, 10.* CNR AQ/1/49, Verona, 64 pp.

Cavallin A., Baroni C., Bini A., Carton A., Marchetti M., Orombelli G., Pelfini M. & Zanchi A. (1997) - *Geomorphology of the Central and Southern Alps.* Suppl. Geogr. Fis. Dinam. Quat., III, Tomo 2, 13-47.

Chaix L., Chassaing B. & Olive P. (1982) - *Premières données sur la composition isotopique du test de mollusques actuel de quelques plans d'eau nord-alpins.* Arch. Sc. Comp. Ren. Soc. Phys. His. Nat. Genève, 35 (1), 3-22.

Craig H. (1965) - *The measurement of oxygen isotope paleotemperatures.* In: Tongiorgi E. (ed.): «Stable isotopes in oceanographic studies and paleotemperatures». Pisa. CNR Laboratorio di Geologia Nucleare, 161-182.

Cremaschi M. & Lanzinger M. (1987) - *Studio pedostratigrafico e geomorfologico dell'area circostante il sito tardo paleolitico-mesolitico di Terlago (Trento).* St. Tren. Sc. Nat., Acta Geol., 64, 99-120.

Dalmeri G. (1992) - *Ricerche nel sito tardopaleolitico-mesolitico di Terlago (Trentino), tracce di strutture d'abitato.* Natura Bresciana, 28, 433-461.

D'Amelio L., Flora O. & Longinelli A. (1994) - *Environmental isotope data: oxygen isotope concentration in precipitation in N-E Italy (Friuli-Venezia Giulia).* Min. Petr. Acta, 37, 113-124.

Dansgaard W. (1964) - *Stable isotopes in precipitation.* Tellus, 16, 426-467.

Eicher U. & Siegenthaler U. (1976) - *Palynological and oxygen isotope investigations on Late-Glacial sediment cores fron Swiss lakes.* Boreas, 5, 109-117.

Eicher U., Siegenthaler U. & Wegmuller, S. (1981) - *Pollen and Oxygen Isotope Analyses on Late- and Post-Glacial Sediments of the Tourbière de Chirens (Dauphiné, France).* Quat. Res., 15, 160-170.

Epstein S., Buchsbaum R., Lowestam H. & Urey H.C. (1953) - *Revised carbonate-water isotopic temperature scale.* Bull. Geol. Soc. Am., 64, 315.

Fritz P. & Poplawsky S. (1974) - *^{18}O and ^{13}C in the shells of freshwater molluscs and their environments.* Earth Plan. Sc. Lett., 24, 91-98.

Gat J.R. (1980) - *The isotopes of hydrogen and oxygen in precipitation.* In: Fritz P. & Fontes J.C. (eds): «Handbook of Environmental Isotope Geochemistry». Elsevier, Amsterdam, 1A, 21-43.

Gat J.R. & Carmi I. (1970) - *Evolution of the isotopic composition of atmospheric waters in the Mediterranenan Sea area.* Journ. Geophys. Res., 75, 3039-3048.

Gilbertson D.D. (1980) - *The palaeoecology of Middle Pleistocene mollusca from Sugworth, Oxfordshire.* Phil. Trans. R. Soc. London, B 289, 107-118.

Giraudi C. (1989) - *Lake level and climate for the last 30,000 years in the Fucino area (Abruzzo-central Italy): A review.* Palaeogeogr., Palaeoclimatol., Palaeoecol., 70, 249-260.

Girod A., Bianchi I. & Mariani M. (1980) - *Guide per il riconoscimento delle specie animali delle acque interne italiane. Gasteropodi, 1.* CNR AQ/1/44, Verona, 86 pp.

Gonfiantini R. (1986) - *Environmental isotopes in Lake studies.* In: Fritz P. & Fontes J.C. (eds): *Handbook of Environmental Isotope Geochemistry.* Elsevier, Amsterdam, 2B, 113-168.

Goslar T., Kuc T., Ralska-Jasiewiczowa M., Rozanski K., Arnols M., Bard E., van Geel B., Pazdur M.F., Szeroczynska K., Wicik B., Wieckowski K. & Walanus A. (1993) - *High-resolution lacustrine record of the Late Glacial/Holocene transition in Central Europe.* Quat. Sc. Rev., 12, 287-294.

Hanley J.H. & Flores R.M. (1987) - *Taphonomy and Paleoecology of Nonmarine Mollusca: Indicators of Alluvial Plain Lacustrine Sedimentation, Upper Part of the Tongue River Member, Fort Union Formation (Paleocene), Northern Powder River Basin, Wyoming and Montana.* Palaios, 2, 479-496.

Kerney M.P. (1971) - *Interglacial deposits in Barnfield pit, Swanscombe, and their molluscan fauna.* Journ. Geol. Soc. London, 127, 69-93.

Kerney M.P., & Cameron R.A.D. (1979) - *A Field Guide to the Land Snails of Britan and North-West Europe.* Collins, London, 228 pp.

Lamb H.F., Gasse F., Benkaddour A., El Hamouti N., van der Kaars S., Perkins W.T., Pearce N.J. & Roberts C.N., (1995) - *Relation between century-scale Holocene arid intervals in tropical and temperate zones.* Nature, 373, 134-137.

Lemeille E., Letolle R., Meliere F. & Olive P. (1983) - *Isotopes and other physico-chemical parameters of paleolake carbonates. Tools for climatic reconstruction.* In: «Paleoclimates and Paleowaters. A collection of environmental isotopes studies». I.A.E.A., Vienna, 135-150.

Lister G.S. (1988) - *A 15,000-year isotopic record from Lake Zürich of deglaciation and climatic change in Switzerland.* Quat. Res., 29, 129-141.

Lotter A.F. & Zbiden H. (1989) - *Late-Glacial pollen analysis oxygen-isotope record and radiocarbon stratigraphy from Rotseee (Lucerne), Central Swiss Plateau.* Ecl. Geol. Helv., 82, 191-202.

Lotter A.F., Eicher U., Siegenthaler U. & Birks H.J.B. (1992) - *Late-glacial climatic oscillations as recorded in Swiss lake sediments.* Journ. Quat. Sc., 7 (3), 187-204.

Lozek V. (1964) - *Quartärmollusken der Tschechoslovaskei.* Verlag Tscheslov Akad Wiss, Praga, 374 pp.

Lozek V. (1986) - *Mollusca analysis.* In: Berglund B.E. (ed.), «Handbook of Holocene Palaeoecology and Palaeohydrology». Wiley, New York, 729-740.

Magny M. (1992) - *Holocene lake-level fluctuations in Jura and the northern subalpine ranges, France: regional pattern and climatic implications.* Boreas, 21, 219-334.

McCrea J.M. (1950) - *On the isotopic chemestry of carbonates and a paleotemperature scale.* Journ. Chem. Phys., 18, 849-857.

McDermott F., Frisia S., Huang Y., Longinelli A., Spiro B., Heaton T.H.E., Hawkesworth C.J., Borsato A., Keppens E., Fairchild I.J., Van Der Borg, K., Verheyden S. & Selmo E., (1999) - *Holocene climate variability in Europe: Evidence from $\delta^{18}O$, textural and extension-rate variations in three speleothems.* Quat. Sc. Rev., 18, 1021-1038.

Ökland J. (1964) - *The eutrophic lake Borrevan (Norway) an ecological study on shore and bottom fauna with special reference to gastropods, including a hydrographic survey.* Folia Limnol. Scand. 13, 1-337.

Rozanski K., Araguás-Araguás L. & Gonfiantini R. (1993) - *Isotopic patterns in modern global precipitation. Climatic change in continental isotopic records.* Geophys. Monograph, 78, 1-46.

Siegenthaler U. & Eicher U. (1986) - *Stable oxygen and carbon isotope analyses.* In: Berglund B.E. (ed.), *Handbook of Holocene Palaeoecology and Palaeohydrology.* Wiley, New York, 407-422.

Siegenthaler U. & Oeshger H. (1980) - *Correlation of ^{18}O in precipitation with temperature and altitude.* Nature, 285, 314-316.

Sparks B.W. (1961) - *The ecological interpretation of Quaternary nonmarine mollusca.* Proc. Linn. Soc. London, 172, 71-80.

Stuiver M. (1970) - *Oxygen and carbon isotope ratios of fresh-water carbonates as climatic indicators.* Journ. Geophys. Res., 75, 5247-5257.

Tarutani T., Clayton R.N. & Mayeda T.K. (1969) - *The effect of polymorphism and magnesium substitution on oxygen isotope fractionation between calcium carbonate and water.* Geochim. Cosmochim. Acta, 987-996.

Trener G.B. & Battisti C. (1898) - *Il lago di Terlago ed i fenomeni carsici delle Valli del Dess, della Fricca e dei Laghi.* In «Tridentum» Zippel, Trento.

Turner J.V., Fritz P., Karrow P.F. & Warner B.G. (1983) - *Isotopic and geochemical composition of marl lake waters and implications for radiocarbon dating of marl lake sediments.* Can. Journ. Earth Sc., 20, 599-615.

Von Grafenstein U., Erlernkeuser H., Brauer A., Jouzel J. & Johnsen S.J. (1999a) - *A Mid-European Decadal Isotope-Climate Record from 15,500 to 5000 Years B.P.* Science, 284, 1655-1657.

Von Grafenstein U., Erlernkeuser H. & Trimborn P. (1999b) - *Oxygen and carbon isotopes in modern fresh-water ostracod valves: assessing vital offsets and autecological effects of interest for palaeoclimate studies.* Palaeogeogr., Palaeoclimatol., Palaeoecol., 148, 133-152.

Von Grafenstein U., Erlernkeuser H., Müller J., Trimborn P. & Alefs J. (1996) - *A 200 year mid-European air temperature record preserved in lake sediments: An extension of the $\delta^{18}O_p$-air temperature relation into the past.* Geochim. Cosmochim. Acta, 60(21), 4025-4036.

Von Grafenstein U., Erlernkeuser H., Kleinmann A., Müller J. & Trimborn P. (1994) - *High-frequency climatic oscillations during the last deglaciation as revealed by oxygen-isotope records of benthic organisms (Ammersee, southern Germany).* Journ. Paleolimnol., 11, 349-357.

Walker M.J.C., Griffiths H.I., Ringwood V. & Evans J.G. (1993) - *An early-Holocene pollen, molluscs and ostracds sequence from lake marl at Llanforse Lake, South Wales. UK.* The Holocene, 3, 138-149.

Whittington G., Fallick A.E. & Edwards K.J. (1996) - *Stable oxygen isotope and pollen records from eastern Scotland and a consideration of Late-glacial and early Holocene climate change for Europe.* Journ. Quat. Sc., 11, 327-340.

Zanchetta G., Bonadonna F.P. & Leone G. (1999) - *A 37-Meter Record of Paleoclimatological Events from Stable Isotope Data on Continental Molluscs in Valle di Castiglione, near Rome, Italy.* Quat. Res., 52, 293-299.

Zuppi G.M. & Bortolami G. (1982) - *Hydrogeology: a privileged field for environmental stable isotopes applications. Some italian examples.* Rend. Soc. It. Min. Petr., 38, 1197-1212.

(ms. received 15 September 2000; accepted 1 February 2001)