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Climatic implications of annual to decadal resolution stable isotope data from calcite varves of the Piànico interglacial lake record, Southern Alps

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ABSTRACT

Stable oxygen isotope analyses at annual, 2-, 5-, 10- and 20-varve sample resolutions were carried out on two selected varve intervals from the interglacial sediment record of the Piànico palaeolake. These sediments are particularly suitable for ultra-high-resolution isotope analyses on lacustrine endogenic calcite because of the exceptionally well-preserved varve structure. A bias through detrital contamination can be excluded because microscopically controlled sampling enabled selecting detritus-free samples. The studied sediment intervals comprise 352 and 88 continuous varve series formed during periods of rapid climate change at the onset and end of a marked millennial-scale cool interval during the Piànico Interglacial. The most intriguing result is a pronounced short-term oscillation in the bi-annually resolved isotope record superimposed on the general decreasing and increasing $\delta^{18}O$ trends at the climatic transitions that is recorded at lower sample resolution. Spectral analyses of the bi-annual time series reveal periodicities indicating solar and NAO controls on the $\delta^{18}O$ record. Multiple $\delta^{18}O$ measurements from endogenic calcite of individual varves showed variations of up to 0.6‰, thus larger than the observed inter-annual variability and most likely explained by seasonal effects.

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1. Introduction

Ultra-high-resolution palaeoclimate reconstructions have become possible through the development of new, precise sampling tools and techniques (e.g. Spötl and Mattey, 2006). Monthly to seasonal resolution palaeoclimate data can be obtained from stable isotope analyses on corals (Quinn et al., 1996; Felis and Pätzold, 2004), speleothems (Spötl et al., 2002; Mangini et al., 2005), tree rings (McCarroll and Loader, 2004; Verheyden et al., 2004), enamel of animal teeth (Grimes et al., 2008; Martin et al., 2008) and shells of mollusks (Brey and Mackensen, 1997; Dettman et al., 1999).

It has been further demonstrated that also endogenic calcite in lake sediments is a suitable carrier of stable oxygen and carbon isotope signals for reconstructing past climate and hydrological changes (Siegenthaler et al., 1984; Leng and Marshall, 2004; Jones and Roberts, 2008). However, the resolution of isotope analyses of endogenic calcite lake sediments often is limited to 0.5–1 cm sample intervals. Stable isotope analyses at annual resolution have been carried out only in few cases of sufficiently thick varves (Brauer and Casanova, 2001; Jones et al., 2006).

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The well-preserved calcite varves formed in the Piànico palaeolake provide an ideal precondition for reconstructing ultra-high (annual) resolution $\delta^{18}O$ records of endogenic calcite from an interglacial sediment archive reflecting truly natural climate variability without any human impact. In earlier studies of the Piànico sediment profile, a pronounced mid-interglacial millennial cool period (Piànico Millennial Oscillation) has been identified in various proxies including pollen, varve thickness and low-resolution stable oxygen isotopes (Moscariello et al., 2000; Mangili et al., 2007; Brauer et al., 2008). The main goal of this study is to investigate in great detail and high-resolution stable oxygen and carbon isotope responses at the beginning and at the end of the cool period, in order to learn more about the internal dynamics of rapid interglacial climate change.

2. Study site

The Piànico–Sèllere palaeolake is located on the southern slope of the Alps (Italy), and occupies the distal part of the Borlezza Valley, a tributary to the Lake Iseo (Fig. 1). The palaeolake sediments are exposed in outcrops along the bed of the Borlezza River, which cut the palaeolake deposits (Moscariello et al., 2000). A 15 500 year interglacial interval from this palaeolake sequence has been correlated to the Marine Isotope Stage 11 (ca 400 ka old) by tephrochronology (Brauer et al., 2007a). Potassium–argon dating on fine glass shards revealed an older age (ca 780 ka; Pinti et al., 2001; Roulleau et al., 2009; Scardia

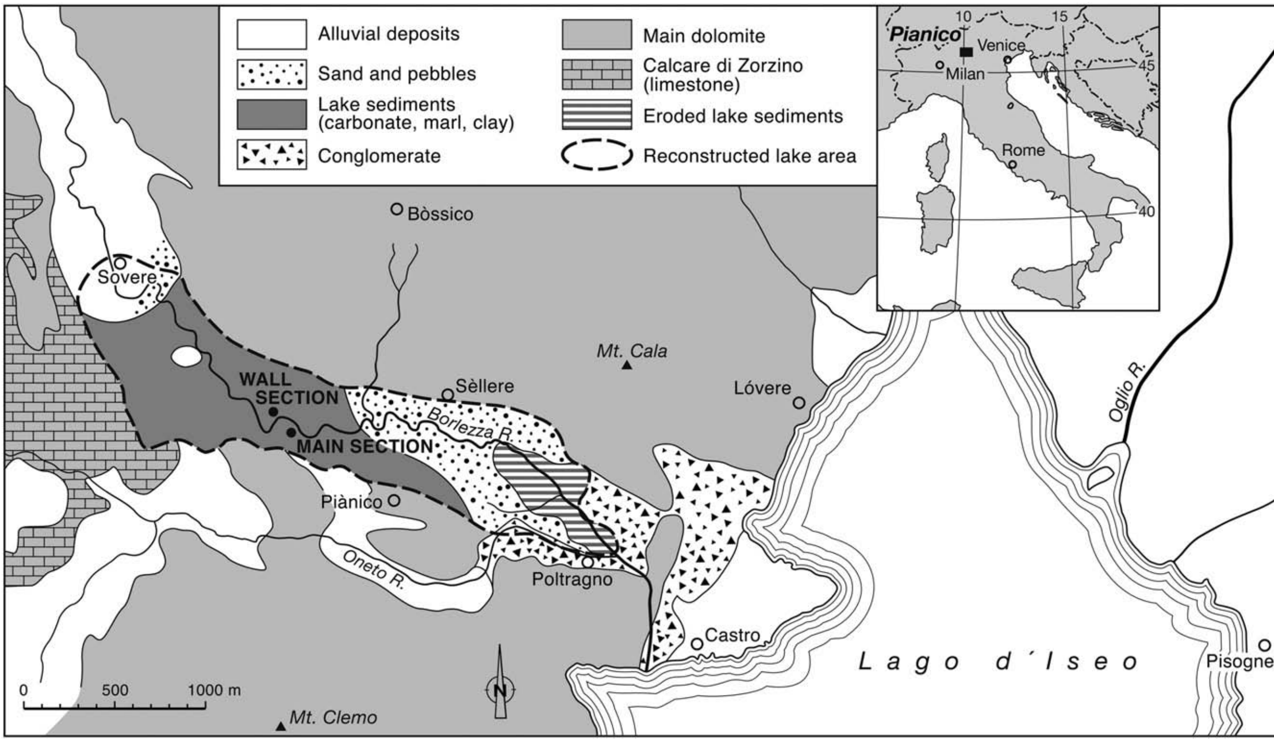

Fig. 1. Geographic location, geological setting and reconstructed extension of the Piànico palaeolake (after Casati, 1968). Distribution of the Pleistocene sediments in the basin of the Piànico palaeolake. The two main sediment outcrops, the Main and the Wall sections, are indicated by black dots. In this study samples from the Main Section were analyzed.

and Muttoni, 2009) that, however, is considered unlikely for several reasons (for detailed discussion see Brauer et al., 2007b). The interglacial unit consists of a sequence of 15 500 endogenic calcite varves (Moscariello et al., 2000; Mangili et al., 2005); these varves are 0.2 to 0.8 mm thick and formed by two layers: a light summer layer constituted by up to 96% of endogenic calcite and a dark winter layer formed by diatom frustules, organic debris and isolated detrital grains (Moscariello et al., 2000; Brauer et al., 2008). Earlier lower resolution stable isotope data of the 15 500 varve interval highlighted four centennial cool periods during the interglacial. The longest and most pronounced of these periods of climatic deterioration has been labeled as Piànico Millennial Oscillation (PMO).

3. Materials and methods

3.1. Field sampling and thin section preparation

Field sampling was performed at freshly cleaned sediment outcrops, from which 33-cm long sediment blocks were carefully carved out by means of specially designed steel boxes, thus avoiding mechanic deformation of the sediment during transport (Mangili et al., 2005). In the laboratory, the surface of these blocks was dried and then covered with Araldite 2020, impregnating the outmost 1–2 mm of the sediments and thereby stabilizing the sediment blocks for further cutting into 1–2 cm thick slices. One of these slices was used for isotope analyses and a parallel one for thin section preparation.

3.2. Sampling for isotope analyses

Stable isotope samples were selected on the base of time resolution as defined by varves instead of using depth intervals. For this purpose, detailed microfacies analyses on petrographic thin sections have been applied allowing (1) defining sample intervals comprising two, five and ten varves each and, (2) avoiding varves in which 0.03 mm to 5 mm thick detrital layers are intercalated that contain detrital carbonates originating from the lake catchment. Consequently, 46 varves were omitted from the sampling, in order to avoid a bias of the stable isotope data through detrital carbonate (Mangili et al., 2010). Thirty-three of these varves occurred in the 352 varve interval at the beginning of the PMO, and the remaining 13 in the sampled interval at the end of the PMO.

Sampling for isotope analyses was carried out on epoxy-free sediment surfaces. We sampled both study intervals at annual, 2-, 5-, and 10-varve resolution (Fig. 2). Different techniques were used for (1) annual resolution and for (2) bi- to multi-varve resolution sampling. (1) For stable isotope analyses at annual resolution, we slightly modified the sampling technique originally developed for stalagmites (Spötl and Mattey, 2006) and applied it, for the first time, to lake sediments. Microsampling at annual resolution was carried out by means of the vertical milling machine “Sherline 5410”. Due to the limited spindle diameter of 200 μm, it was only possible to sample parts of the up to 0.8 mm thick summer layers instead of the entire summer layer. The calcite drilled out of the sediment blocks was carefully transferred in vials. Ten consecutive varves were sampled at annual resolution; three to ten samples were taken from each varve at different lateral positions, each a few mm apart (Fig. 3). Due to the limited sample size of 0.01 to 0.05 mg, no duplicate measurements were possible. Stable isotope analyses were carried out using an automated carbonate extraction system (KIEL IV) interfaced with a MAT 253 IRMS (ThermoFisher Scientific). Isotopic ratios are given in the delta notation relative to the VPDB. Isotopic measurements are calibrated to NBS19 (limestone), NBS18 (carbonatite) and the internal laboratory standard C1 (marble). The isotopic precision is 0.06‰ for $\delta^{18}O$ and >0.03‰ for $\delta^{13}C$ measurements.

(2) Bi- to 20-varve resolution samples were carefully scratched from the fresh sediment surface with a scalpel under a binocular, in order to precisely separate the varves which have an average thickness of ca 0.5 mm. Sample thickness is between ca 0.1 cm (2-varve sample) and ca 1 cm (20-varve sample). A total of 237 samples including two to 20 varves were analyzed: 165 samples at bi-annual resolution, 45 5-varve samples, 17 10-varve samples, and four 20-varve samples. The number of samples was determined by the

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