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A 10,000 yr record of high-resolution Paleosecular Variation from a flowstone of Rio Martino Cave, Northwestern Alps, Italy

Elena Zanella [a,*], Evdokia Tema [a], Luca Lanci [b], Eleonora Regattieri [c,d], Ilaria Isola [e], John C. Hellstrom [f], Emanuele Costa [a], Giovanni Zanchetta [e,g], Russell N. Drysdale [h,i], Federico Magrì [j]

[a] Dipartimento di Scienze della Terra, Via Valperga Caluso 35, 10125 Torino, Italy
[b] Dipartimento di Scienze Pure e Applicate, Piazza della Repubblica 13, 61029 Urbino, Italy
[c] Institute of Geology and Mineralogy, University of Cologne, Zülpicher Str. 49a, 50674 Cologne, Germany
[d] Istituto di Geoscienze e Georisorse IGG-CNR, via Moruzzi 1, 56100 Pisa, Italy
[e] Istituto Nazionale di Geofisica e Vulcanologia INGV, Via della Faggiola 32, 56126 Pisa, Italy
[f] School of Earth Sciences, University of Melbourne, Victoria 3010, Australia
[g] Dipartimento di Scienze della Terra, Via S. Maria 53, 56126 Pisa, Italy
[h] School of Geography, University of Melbourne, Victoria 3010, Australia
[i] EDYTEM, UMR CNRS 5204, Université de Savoie-Mont Blanc, 73376 Le Bourget du Lac cedex, France
[j] Gruppo Speleologico Valli Pinerolesi GSVP, Club Alpino Italiano, Pinerolo, Italy

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ABSTRACT

Speleothems are potentially excellent archives of the Earth's magnetic field, capable of recording its past variations. Their characteristics, such as the continuity of the record, the possibility to be easily dated, the almost instantaneous remanence acquisition and the high time-resolution make them potentially unique high-quality Paleosecular Variation (PSV) recorders. Nevertheless, speleothems are commonly characterized by low magnetic intensities, which often limits their resolution. Here we present a paleomagnetic study performed on two cores from a flowstone from the Rio Martino Cave (Western Alps, Italy). U/Th dating indicates that the flowstone's deposition covers almost the entire Holocene, spanning the period ca. 0.5–9.0 ka, while an estimation of its mean growth rate is around 1 mm per 15 years. The flowstone is composed of columnar calcite, characterized by a highly magnetic detrital content from meta-ophiolites in the cave's catchment. This favorable geological context results in an intense magnetic signal that permits the preparation and measurement of thin (∼3 mm depth equivalent) samples, each representing around 45 yr. The Characteristic Remanent Magnetization (ChRM), isolated after systematic stepwise Alternating Field demagnetization, is well defined, with Maximum Angular Deviation (MAD) generally lower than 10°. Paleomagnetic directional data allow the reconstruction of the PSV path during the Holocene for the area. Comparison of the new data with archeomagnetic data from Italian archeological and volcanic records and using the predictions of the SHA.DIF.14k and pfm9k.1a global geomagnetic field models shows that the Rio Martino flowstone represents an excellent recorder of the Earth's magnetic field during the last 9,000 years. Our high resolution paleomagnetic record, anchored by a high-quality chronology, provides promising data both for the detection of short term geomagnetic field variations and for complementing existing regional PSV curves for the prehistoric period, for which well-dated data are still scarce.

1. Introduction

To investigate geomagnetic field behavior in the past and to explore its short-term features, high-resolution records from globally distributed archives of different origin are necessary (Mandea and Olsen, 2009). For Paleosecular Variation (PSV) reconstructions, an ideal paleomagnetic record should satisfy several requirements, such as having a stable remanent magnetization, being well dated, offering a continuous record and presenting high-time resolution. Even though some Earth materials may satisfy a number of these, the characteristics of continuity and high-resolution are rarely coupled. Marine and lacustrine sediment sequences are best at ensuring continuous records and have therefore been intensively studied to obtain geomagnetic data over long

* Corresponding author.
E-mail address: elena.zanella@unito.it (E. Zanella).

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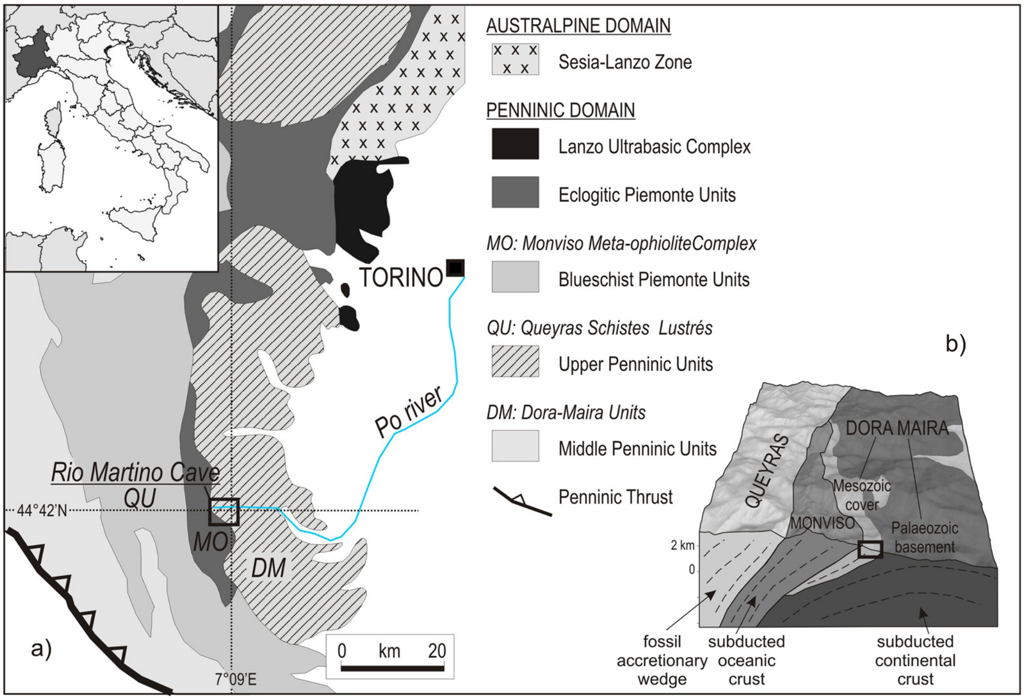

Fig. 1. a) Structural sketch map of the Western Alps; b) 3D reconstruction of the Inner Western Alps in the Rio Martino zone (modified after Balestro et al., 2014). The square indicates the location of the Rio Martino Cave. Note: the region highlighted in the small inset map is not the same as the one shown in the enlargement.

time scales (e.g. Turner and Thompson, 1981; Rolph et al., 2004; Vigliotti, 2006). However, sometimes data reliability may be questionable: the remanence acquisition mechanisms, the smoothing effects of bioturbation, the inclination error and the remanence acquisition delay are just some of the problems that may affect this kind of record. On the other hand, volcanic rocks and fired archeological artifacts may preserve very reliable paleomagnetic data but they are highly discontinuous in time. The age uncertainties of the volcanic products, as well as the lack of continuity and the limited time extension of available *in situ* archeological baked clay structures, restrict their use for high-resolution record studies.

Several research groups have studied speleothems for both PSV and paleoenvironmental reconstructions (e.g. Latham et al., 1989; Lean et al., 1995; Openshaw et al., 1997; Osete et al., 2012; Xie et al., 2013; Font et al., 2014; Jaqueto et al., 2016; Lascu et al., 2016), revealing their high potential for magnetic and secular variation reconstructions (Lascu and Feinberg, 2011). Paleomagnetic time series from speleothems, although still sparse, can provide excellent temporal resolution if the speleothem has grown continuously and over a considerable age range, as, for example, in the case of the Mexican stalagmite studied in the pioneering work of Latham et al. (1986). The key features of speleothems are that they can grow continuously for 10^3–10^5 yr and can be accurately dated by the uranium-series method (e.g. Richards and Dorale, 2003). They normally show little or no secondary alteration, and are generally easy to orient and sample (though with obvious consideration of natural heritage values).

Based on magnetic properties, the remanent magnetization of speleothems can be divided into two main genetic forms, detrital (DRM) or chemical (CRM) (Lascu and Feinberg, 2011). Detrital input can originate from flood or drip water sources (Openshaw et al., 1997; Fairchild et al., 2006). Moreover, speleothems present the advantage of acquiring their magnetization rapidly after formation, meaning that the registered magnetic remanence variations reliably reflect the PSV path in the past. Nevertheless, these promising features are confounded by a speleothem's generally low concentration of magnetic minerals, and thus their low magnetic signal, which limits their use in magnetic studies. To bypass this problem, large samples have been commonly used in paleomagnetic studies, but this reduces the time-resolution of the sample. Generally, a sample of around 2 cm may average ca. 100–4000 yr (Strauss et al., 2013) and thus the obtained SV time-resolution is very low.

This paper reports the results of a paleomagnetic study performed on a flowstone sampled at Rio Martino Cave (North Western Alps, Italy). The favorable geologic context of the cave, which is mainly surrounded by meta-ophiolites, makes this flowstone very rich in detrital ferromagnetic components, and thus an ideal geomagnetic field recorder due to its high magnetic remanence properties. Although a high content of detrital material can compromise U/Th dating (Hellstrom, 2006), we have been able to produce a continuous, radiometrically-dated, directional SV record for the area during the last ∼10 kyr, at a sampling resolution averaging 45 yr. Comparison of the new data with archeomagnetic data from Italian artifacts and volcanic rocks and using predictions of global geomagnetic field models, shows that the Rio Martino flowstone represents an excellent recorder of the Earth's magnetic field in the past and demonstrates the potential of speleothems for PSV studies and for the investigation of short-term variations of the geomagnetic field.

2. Geological setting and sampling

Rio Martino Cave (44°42′ N, 7°09′ E) is located in the inner sector of the Western Alps (Northern Italy), which consists of a range of continental and oceanic tectono-metamorphic units bounded by major orogen-scale faulting (Balestro et al., 2014), and exhumed and stacked in the axial sector (Fig. 1). The cave is developed within the Mesozoic carbonate cover of the Palaeozoic Dora Maira (Balestro et al., 2013). This unit is overlain by the Monviso meta-ophiolite complex, a major eclogized remnant of the Ligurian-Piedmont oceanic lithosphere, which in turn is tectonically overlain by the Queyras Schistes Lustrés, interpreted as a fossil accretionary wedge.

The surface above the cave is overlain mainly by glacial deposits. The cave is located at 1530 m a.s.l. on the right flank of the upper Po valley. It is a spring cave, ca. 3000 m long, with 200 m