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Abstract: Laminated sediments of the maar lake Lago Grande di Monticchio in southern Italy exhibit a unique sequence of numerous primary tephra events that provide both insights into the Late Quaternary eruptive history of Italian volcanoes and an archive of essential marker horizons for dating and linking palaeoclimate records throughout the Eastern Mediterranean. The acquisition of new sediment cores from this lake now extends the existing 100 ka-tephra record back to 133 ka BP, the end of the penultimate Glacial. The additional ca. 30 m of sediments host a total number of 52 tephra fallout layers that have been identified on the basis of detailed geochemical and petrographical examinations. Tephras can be assigned to hitherto poorly known Plinian to sub-Plinian eruptions of the nearby Campanian (Ischia Island, Phlegrean Fields), Roman (Sabatini volcanic district) and Aeolian-Sicilian volcanoes (Etna, Stromboli, Salina) and are dated according to the varve and sedimentation rate chronology of Monticchio sediments. The most prominent tephra layers within the interval of investigation - TM-25 and TM-27 - can be firmly correlated with Ionian Sea tephras X-5 (ca. 105 ka BP) and X-6 (ca. 108-110 ka BP). Those in addition to 25 other tephra layers correlated with radiometrically and radioisotopically dated volcanic events provide the basis for a robust revised tephrochronology of the entire Monticchio sediment sequence for the last 133 kyrs.

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Dear editor,

please find enclosed the manuscript **The 100-133 ka record of Italian explosive volcanism and revised tephrochronology of Lago Grande di Monticchio** by Sabine Wulf, Jörg Keller, Martine Paterne, Jens Mingram, Stefan Lauterbach, Stephan Opitz, Gianluca Sottili, Biagio Giaccio, Paul Albert, Chris Satow, Marco Viccaro, Achim Brauer to be submitted to the Journal "Quaternary Science Reviews". This manuscript has not has not been previously published, wholly or in part in any other scientific journal and it has not been submitted to any other journal.

This paper is an important contribution to the late Pleistocene tephrostratigraphy in the Eastern Mediterranean as provided by the high-resolution sediment record of Lago Grande di Monticchio, southern Italy.

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Thank you for your consideration of this manuscript.

On behalf of the authors,
Sincerely

Dr. Sabine Wulf (corresponding author)

Highlights

Laminated sediments of the maar lake Lago Grande di Monticchio in southern Italy exhibit a unique sequence of numerous primary tephra events that provide both insights into the Late Quaternary eruptive history of Italian volcanoes and an archive of essential marker horizons for dating and linking palaeoclimate records throughout the Eastern Mediterranean. The acquisition of new sediment cores from this lake now extends the existing 100 ka-tephra record back to 133 ka BP, the end of the penultimate Glacial. The additional ca. 30 m of sediments host a total number of 52 tephra fallout layers that have been identified on the basis of detailed geochemical and petrographical examinations. Tephras can be assigned to hitherto poorly known Plinian to sub-Plinian eruptions of the nearby Campanian (Ischia Island, Phlegrean Fields), Roman (Sabatini volcanic district) and Aeolian-Sicilian volcanoes (Etna, Stromboli, Salina) and are dated according to the varve and sedimentation rate chronology of Monticchio sediments. The most prominent tephra layers within the interval of investigation - TM-25 and TM-27 - can be firmly correlated with Ionian Sea tephras X-5 (ca. 105 ka BP) and X-6 (ca. 108-110 ka BP). Those in addition to 25 other tephra layers correlated with radiometrically and radioisotopically dated volcanic events provide the basis for a robust revised tephrochronology of the entire Monticchio sediment sequence for the last 133 kyrs.

The 100-133 ka record of Italian explosive volcanism and revised tephrochronology of Lago Grande di Monticchio

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Abstract

Laminated sediments of the maar lake Lago Grande di Monticchio in southern Italy exhibit a unique sequence of numerous primary tephra events that provide both insights into the Late Quaternary eruptive history of Italian volcanoes and an archive of essential marker horizons for dating and linking palaeoclimate records throughout the Eastern Mediterranean. The acquisition of new sediment cores from this lake now extends the existing 100 ka-tephra record back to 133 ka BP, the end of the penultimate Glacial. The additional ca. 30 m of sediments host a total number of 52 tephra fallout layers that have been identified on the basis of detailed geochemical and petrographical examinations. Tephras can be assigned to hitherto poorly known Plinian to sub-Plinian eruptions of the nearby Campanian (Ischia Island, Phlegrean Fields), Roman (Sabatini volcanic district) and Aeolian-Sicilian volcanoes (Etna, Stromboli, Salina) and are dated according to the varve and sedimentation rate chronology of Monticchio sediments. The most prominent tephra layers within the interval of investigation - TM-25 and TM-27 - can be firmly correlated with Ionian Sea tephras X-5 (ca. 105 ka BP) and X-6 (ca. 108-110 ka BP). Those in addition to 25 other tephra layers correlated with radiometrically and radioisotopically dated volcanic events provide the basis for a robust revised tephrochronology of the entire Monticchio sediment sequence for the last 133 kyrs.

Keywords: tephrochronology, Italian volcanism, Lago Grande di Monticchio, Eastern Mediterranean

1. Introduction

During the past decades, tephra studies in the Central Mediterranean facilitated the dating and linking of several medial to distal terrestrial and marine palaeoenvironmental records leading to a continuous development of detailed tephrostratigraphies of Italian explosive volcanism for at least the last 100 kyrs (e.g., Keller et al., 1978; Paterne et al., 1986; Wulf et al., 2004; Siani et al., 2004; Paterne et al., 2008; Lowe et al., 2007; Calanchi and Dinelli, 2008; Wulf et al., 2008; Sulpizio et al., 2010).

Tephrostratigraphies, in general, require a completeness of major eruptive events, a reliable dating, a clear stratigraphic order and an unambiguous identification of tephras, which in combination are difficult to derive from a single archive. Proximal (near-vent) sites, for instance, are ideal for dating tephra deposits, but may lack in complete stratigraphies due to burial and erosion processes. Medial to distal environments may record only large-magnitude eruptions and miss small-scale events, but have the potential to document the stratigraphic interfingering and super-positioning of tephras from multiple volcanic sources. However, the dating of tephras in distal sedimentary archives can be problematic due to the lack of datable material. In this respect, annually laminated lake sediments are exceptionally valuable archives since they provide both eruptive evidence from adjacent volcanic centres and robust chronologies (e.g., Brauer et al., 1999; Wulf et al., 2004). In the central Mediterranean, such an archive is given by the maar lake Lago Grande di Monticchio in southern Italy. A total of 293 visible tephra fallout layers from volcanic sources in central and southern Italy, which are located in a distance from 100-540 km, were previously identified in the Monticchio sediments providing a detailed tephrostratigraphy of the explosive volcanism in Italy for the last 100 kyrs (Newton and Dugmore, 1993; Narcisi, 1996; Wulf et al., 2004; Wulf et al., 2006; Wulf et al., 2008). Detailed studies created a large data set of chronostratigraphical and geochemical information of individual tephras that are widely used as references for the correlation and dating of other distal and proximal tephra deposits, so far (e.g., Lowe et al., 2007; Bourne et al., 2010; Smith et al., 2011; Giaccio et al., submitted).

The extended sediment record from Lago Grande di Monticchio (Brauer et al., 2007) exhibits another 52 tephra layers providing a previously undocumented record of Italian volcanism for the period 100-133 ka BP. Petrographies and geochemistries of the tephras are described and interpreted in this paper. The ages of tephra deposition are provided by a combination of new varve counting for the extended 30 m section and a partial revision of the varve and sedimentation chronology of the <100 ka profile (Brauer et al., 2007). These data contribute to the establishment of a reliable tephrostratigraphical record in the Central Mediterranean.

Please place here Figure 1.

2. The study site

Lago Grande di Monticchio (40°56’N, 15°35’E, 656 m a.s.l.) is located about 120 km east of Naples in the Monte Vulture volcanic complex in the region of Basilicata, southern Italy (Fig. 1a). It is the larger of two adjacent maar lakes that were formed during the final phreatomagmatic eruptions of Monte Vulture at 132 ± 12 ka BP (Lago Grande di Monticchio; Brocchini et al., 1994; Stoppa and Principe, 1998) and 141 ± 11 ka BP (Lago Piccolo di Monticchio; Villa and Buettner, 2009), respectively. Lago Grande di Monticchio has a total surface area of 0.4 km^2, a maximum water depth of 36 m, and has no major in-or outflows (Fig. 1b).

With a distance of 100-350 km, the site is close and in a favourable downwind position to the active volcanoes of the alkaline Roman Co-magmatic Province (RCP). The RCP is subdivided into the Campanian and Roman volcanic area. The Campanian Province includes the stratovolcanoes of Monte Vulture, Roccamonfina, Somma-Vesuvius, the Phlegrean Fields and the Islands of Ischia, Procida-Vivara and Ponza. Some of those centres were active until the recent past, for instance Vesuvius (<39 ka BP; De Vivo et al., 2001), the Phlegrean Fields (≤60 ka BP; Pappalardo et al., 1999) and Ischia (<150 ka BP; Poli et al., 1989). Activities of Procida-Vivara and Roccamonfina ceased at ca 14 ka BP (Scandone et al., 1991) and 130 ka BP (Radicati di Brozolo et al., 1988), respectively. Volcanism in the Roman Province is older than in the Campanian area. The youngest tephra producing eruptions are known from the Alban Hills (560 to 33 ka BP; Giaccio et al., 2009; Marra et al., 2011), the Sabatini Volcanic District (800 to 86 ka BP; Sottili et al., 2010) and the Vico volcanic centre (≥420 to 95 ka BP; Laurenzi and Villa, 1987; Sollevanti, 1983). Activity of both the Campanian and Roman volcanic provinces produced huge amounts of tephra fallout, mainly K-alkaline trachytic-phonolitic in composition. Lago Grande di Monticchio is furthermore located 280 to 540 km northeast of the active volcanic centres of the Aeolian Islands (280 km), Mount Etna (360 km) and the Island of Pantelleria in the Strait of Sicily (550 km). Erupted material of these volcanoes ranges in composition from calcalkaline (Aeolian Islands) to Na-pronounced alkaline to mugearitic and pantelleritic (Etna, Pantelleria). Some of these eruptions were high-explosive, and the erupted tephra material was widely dispersed in the Central Mediterranean (e.g., Keller et al., 1978; Paterne et al., 1986; Vezzoli, 1991; Paterne et al., 2008).

Please place here Figure 2.

3. Material and Chronology

Lago Grande di Monticchio is a site of intense studies for palaeoclimate reconstruction since the early 1980's. A first sediment core of 25.5 m was taken in a fen at the western margin of the lake (Watts, 1985). Three further coring campaigns were carried out within the lake basin of Lago Grande di Monticchio in the years 1990, 1994 and 2000 recovering eight overlapping sediment cores. The first sediment recovery in 1990 exhibited a sediment record of ca. 52 m total length using three parallel cores from shallow water depths of 5-6 m (cores LGM-B, LGM-D, LGM-E; Fig.1b). Counting of varved sections and calculating sedimentation rates in sections of poor varve preservation dated the base of this composite sequence at 76,344 calendar years BP (1950) (Zolitschka and Negendank, 1996). Initial tephrochronological results and ^{14}C dates of terrestrial plant material in the sediments corroborated the upper part of the varve and sedimentation rate chronology (Newton and Dugmore, 1993; Narcisi, 1996; Zolitschka and Negendank, 1996). Two new cores, LGM-L and LGM-J, from a slope at 2.3 m water depth and the deeper central part at 13.5 m water depth, respectively, were recovered during a coring campaign in 1994 (Fig. 1b). The longer core LGM-J was used to extend the existing LGM-B/D/E profile to a total length of 72.5 m. The base of the composite profile LGM-B/D/E/J has been varve dated at 101,670 calendar years BP (Brandt et al., 1999). An independently dated tephrochronology of this profile confirmed the varve and sedimentation rate chronology in overall with a mean deviation of 5%, though there were some larger deviations at the extended lower part of the profile indicating missing sediments (Wulf et al., 2004). A third field campaign was initiated in August/September 2000 providing three longer and overlapping cores, LGM-M, LGM-N and LGM-O, from sites close to core LGM-J (Fig. 1b). Core LGM-O most likely reached the base of lacustrine deposits, which is characterized by pyroclastic gravel of the final Monte Vulture volcanic activities (maar lake formation). A new composite profile, LGM-B/D/E/J/M/O, was established providing a total length of 103.1 m of sediments (Brauer et al., 2007). Varve counting of the extended >101,670 years section (core LGM-M and LGM-O) as well as a re-evaluation of varve counts in two short sections overlapping the lower part of the LGM-J core and in the upper LGM-B/D section between 11.17 m (19,280 calendar years BP) and 26.48 m composite depth yield a basal age of lake deposits of 132,900 calendar years BP (Brauer et al., 2007). As a result, time constraints of tephra deposits older than 19,280 calendar years BP published in Wulf et al. (2004) and Wulf et al. (2006) have to be revised (see Table 4).

The extended sediment section between 72.5 m (re-dated at 105,280 calendar years BP) and 103.1 m (132,900 calendar years BP; Brauer et al., 2007) contains a total of 52 visible, distal tephra layers that range in thickness between 0.2 mm and >2 m (Fig. 2). Host sediments of these ash layers are organo-clastic muds that are annually laminated for the entire section except for the lowermost part (>131 ka BP), which is characterized by the intercalation of thick turbidites (Brauer et al., 2007). Detailed studies of tephras were performed including petrographical, geochemical and grain size analyses.

Please place here Table 1.

4. Tephrochronological Methods

Tephra layers are labelled in accordance to Wulf et al. (2004) and Wulf et al. (2006) as tephra marker “TM” with the respective ascendant numbers starting from the youngest of the >100 ka tephras (TM-25) to the oldest deposit (TM-42). Tephra layers were described in respect to their mineral/lithic assemblage, maximum grain sizes and thicknesses using large-scale thin sections of in-situ sediment blocks (Brauer et al., 2000). The major-element composition of volcanic glass was analysed on polished thin sections of loose tephra material that was extracted and cleaned with a 10% hydrogen peroxide solution. Electron probe microanalyses (EPMA) were carried out at the GFZ German Research Centre of Geosciences in Potsdam using a Cameca SX-100 electron microprobe (WDS). Measurements were obtained at 15 kV (accelerating voltage) and 20 nA (beam current) with beam sizes of 15 µm or 20 µm. Peak counting times were 20 s for each element, except for Na (10 s). Between 5 and 22 glass shards were analysed per tephra layer. Instrumental calibration used interlaboratory natural mineral and glass reference materials such as the Lipari obsidian (Hunt and Hill, 1996) (supplementary table A). Tephras TM-24a, TM-24b (Wulf et al., 2004) and TM-27 were additionally analysed using a JEOL 8600 wavelength-dispersive electron microprobe in the Research Laboratory for Archaeology and the History of Art, University of Oxford, U.K. An analytical setup was chosen at 15 kV acceleration voltage, 6 nA current and 10 µm beam diameter. Element analysis times were 30 s for each element, except for P and Cl (60 s), and Na (10 s). Glass reference materials used Atho-G and StHs6/80-G (Supplementary Table B).

EPMA analyses showing totals lower than 95 wt% were excluded from either data set. Petrological classification of tephras was based on normalized data of the glass major-element composition using the Total-Alkali-Silica diagram after Le Bas et al. (1986). Tephra compositional data are summarized in Tables 1 and 2 and provided in full in the Supplementary Table A and B.

EPMA glass data of Monticchio tephras were compared with SEM-EDS glass data of marine tephras from Tyrrhenian and Ionian Sea sediment cores (Paterne, 1985; Paterne et al., 2008; this study). Here. major elements of individual glass shards of tephras were measured on a JEOL/EDS instrument (core DED 87-08; see details Paterne et al., 2008) and on a CAMEBAX/SEM equipment (cores KET 80-04 and KET 82-22; see details Paterne, 1985; Paterne et al., 1986; Paterne et al., 1988; Paterne et al., 2008) at CNRS-CEA, Gif-sur-Yvette, France.

Please place here Figure 3.

5. Results

In the following, detailed compositional and chronostratigraphical descriptions of each tephra occurring in the 100-133 ka BP section are given, starting from the youngest to the oldest deposit, and potential eruptive sources are discussed (see also Table 1). Calendar ages for tephras are provided according to the Monticchio varve and sedimentation rate chronology after Brauer et al. (2007).

TM-25 is an 11.3 cm thick and coarse-grained (max. 1.5 mm) white pumice fallout in 74.11 m composite depth. It is dated by the Monticchio varve and sedimentation rate chronology at 105,480 calendar years BP. Large phenocrysts of sanidine, zoned plagioclase, biotite, amphibole, green clinopyroxene, and olivine xenocrystals are common in this tephra (Fig. 3a). Apatite often occurs as micro-crystal inclusion in juvenile clasts. Minor amounts of volcanic lithics and altered tuffs are also visible. Pumice fragments are highly vesicular (Fig. 3a) and show a K-trachytic composition with alkali ratios of 2. The tephra layer is mixed with fine organic sedimentary material towards the top of the deposit. Based on the relatively homogenous chemical composition (Fig. 4a), the large grain sizes and the matching time constraint, we propose a correlation of TM-25 with the marine X-5 tephra. The widely distributed tephra layer X-5 (and the associated X-6) have been defined as first-order marker beds in the marine record of the Ionian Sea by Keller et al. (1978), and later confirmed by new sediment cores of the Meteor-cruise M25-4 (Keller et al., 1996; Kraml, 1997; Keller and Kraml 2004; Scheld, 1995). For X-5, a $^{40}Ar/^{39}Ar$ date of 105 ± 2 ka has been obtained by Kraml (1997) in accordance with its position directly below sapropel S-4 and with the marine oxygene isotope curve (e.g., Allen et al., 1999). The composition of X-5 points to a Campanian origin (Keller et al., 1978; Morche, 1988; Scheld, 1995, Keller and Kraml, 2004; Di Vito et al., 2008; Giaccio et al., submitted), but the proximal source of X-5 has not been defined yet. In the Tyrrhenian Sea an equivalent tephra marker, C-27, of Paterne (1985) and Paterne et al. (2008) is correlated with the X-5 tephra. The prominent layer X-5 (and the closely related X-6) have also been identified in terrestrial archives of Central and Southern Italy (Morche 1988; Lucchi et al. 2008; Marciano et al., 2008; Giaccio et al., submitted).

TM-26 is a 1 mm thick, fine-grained, grey-brownish ash layer in 74.47 m composite depth that is dated at 106,300 calendar years BP. It is dominated by loose crystals of plagioclase, orthopyroxene, greenish clinopyroxene, rare sanidine, olivine, amphibole, Fe-Ti-oxides, and abundant tachylites. Glass shards are light and brown in colour, low to moderate vesicular and often rich in apatite microcrysts. The glass chemical data reflect a heterogeneous Na-pronounced trachydacitic composition showing high SiO_2 concentrations of ca. 65 wt% (normalized data). Such a glass composition is known from younger pyroclastics of Mount Etna, i.e. from the Biancavilla/Y-1 tephra (17.3 ka BP) (Fig. 4b), and therefore we propose a correlation of TM-26 with an older Plinian eruption of this volcano. Explosive behaviour of Mount Etna during the considered time period of >100 ka BP developed during activities of the Valle del Bove centres and the Timpe Phase (Coltelli et al., 2000; Branca et al., 2008; Nicotra et al., 2011), and include the units of the Ancient Alkaline Centres (220 to 100 ka BP) and Trifoglietto (100 to 60 ka BP) previously defined by Romano (1982). Based on the comparison with bulk rock geochemical data we assume a correlation of TM-26 with the proximal pyroclastics of the "Salto della Giumenta Unit" that has been assigned to activities of the "Tarderia" volcano (Nicotra et al., 2011). This correlation is further supported by a $^{40}Ar/^{39}Ar$ age of 105.8 ± 4.5 ka BP obtained from the groundmass of related lava flows of the Tarderia activities (Branca et al., 2008), which is in good agreement with the varve age of TM-26.

Please place here Figure 4a and 4b.

TM-27 positioned in 78.85 m composite depth and dated at 108,330 calendar years BP is one of the most prominent tephra deposits in the Monticchio sequence. Its base encompasses a 1.6 cm thick coarse-grained (max. 1.3 mm) pumice fallout that is overlain by ca. 2 m of finer grained, vitric ash. Due to its small grain sizes the vitric ash is interpreted as a co-ignimbrite that is mixed with lacustrine sedimentary material towards the top of the deposit. The basal fallout is composed of highly vesicular, colourless to light brownish pumice fragments, abundant phenocrysts of sanidine, biotite, plagioclase, clinopyroxene and amphibole as well as fragments of older volcanic rocks and limestones (Fig. 3c). Juvenile clasts are phonolitic to trachytic in composition and show a heterogeneous character in respect to CaO concentrations (1.6 to 2.1 wt%) and K_2O/Na_2O ratios (0.9 to 1.4). The glass composition of TM-27 matches that of the marine X-6 tephra (Fig. 4a), which forms a prominent marker horizon in the deep-sea sediments of the Ionian Sea (Keller et al., 1978; Morche, 1988). The age of X-6 is constrained by interpolation of the sapropel chronology of the Ionian Sea between sapropels S4 and S5 at ca. 108-110 ka BP (Keller et al., 1978; Kraml, 1997; Keller and Kraml, 2004) and is in good agreement with the varve age of tephra TM-27. The origin of X-6 is still under discussion. Composition, thickness and maximum grain sizes in the Monticchio record, however, strongly support the assumption of an origin of the X-6 tephra from nearby Campanian volcanoes (Keller et al., 1978; Keller and Kraml, 2004; Marciano et al., 2008; Giaccio et al., submitted). However, the exact Campanian source volcano of X-6 remains still open.

TM-28 consists of two distinct vitric ash layers of similar composition in 81.44 m (110,410 calendar years BP) and 81.53 m composite depth (110,830 calendar years BP). The upper tephra TM-28a is a 2.1 cm thick and relatively fine-grained layer. Its phenocryst content comprises sanidine, anorthoclase, biotite and orange-brown amphibole. Juvenile clasts of quenched crystals dominate the top part of this deposit. The lower tephra TM-28b is only 2 mm thick and reveals coarser grain sizes (max. 400 µm). The mineral assemblage is made up of sanidine, plagioclase, biotite, green Ti-augite and brown amphibole phenocrystals. Clasts of quenched crystals and intermediate lava rock fragments are common as well. Highly vesicular, brownish juvenile clasts characterize both tephra layers. Their trachytic to phonolitic composition resembles that of tephra TM-27/X-6 (Fig. 4a). We therefore assume a correlation of tephra layers TM-28 with a preceding undefined eruption from the same Campanian source.

Please place here Table 2.

TM-29 and TM-30 comprise a total of four eruptive sequences (TM-29-1, TM-29-2, TM-30-1 and TM-30-2) of similar composition, each made up of multiple distinct tephra fallout layers. Each sequence reflects a magma fractionation from more silicic to mafic rock composition (Fig. 4c).

The uppermost tephra succession **TM-29-1** in 81.69 m to 81.91 m composite depth is dated between 111,480 and 112,460 calendar years BP. It is made up of nine 0.2-5 mm thin, grey-brownish ash layers labelled as TM-29-1a to TM-29-1i. All tephra layers contain light-brownish, non- to low-vesicular, blocky glass shards. The glass composition is heterogeneous latitic, basaltic-andesitic, tephriphonolitic to phonotephritic for the five basal layers (TM-29-1e to TM-29-1i) and homogenous phonotephritic for the four top layers (TM-29-1a to TM-29-1d). SiO_2 values decrease from the basal to the top layer from 54.6 to 49.7 wt%. Alkali totals are low (7.9–10.8 wt%), while the K_2O/Na_2O ratios show high values of 1.7–2.7. Abundant phenocrysts of anorthoclase, pale greenish clinopyroxene, biotite as well as leucite and apatite microcrystals are present in all layers. Lithic fragments comprise lavic rocks, greenish tuffs, tachylites and clasts of quenched crystals. A remarkable decrease of lithic and phenocryst concentration is visible from the basal (TM-29-1i) to the top deposits (TM-29-1a).

The underlying tephra succession **TM-29-2** is made up of eight distinct grey-brownish tephra layers occurring between 82.06 m and 82.20 m composite depth and dated between 112,520 and 113,020 calendar years BP. The mineral and lithic assemblage is equivalent to that of tephra succession TM-29-1. Glasses are also brownish in colour, blocky and low-vesicular, but show a slightly more differentiated trachytic to basaltic trachyandesitic composition (Fig. 4c). SiO_2 values range from 60.4 to 51.6 wt% from the basal to the top layer. Within all layers, tephra components are set in a grey-brownish fine ashy matrix.

The next underlying tephra succession **TM-30-1** contains six grey to black-brownish tephra layers (TM-30-1a to TM-30-1f) between 82.26 m and 82.67 m composite depth that are dated between 113,370 and 114,000 calendar years BP. The basal layer of 12 mm thickness is the lightest and most coarse-grained (<700 µm) tephra deposit within TM-30-1. It comprises both high-vesicular, light pumice fragments and green-brownish, non- to low-vesicular, blocky glass shards with abundant apatite microcrystals (Fig. 3b). The two types of juvenile clasts reflect a bimodal chemical composition. Brown glass shards are concentrated in the younger five tephra layers TM-30-1a to TM-30-1e and expose a latitic composition. Mean SiO_2 concentrations are between 56.4 and 57.9 wt% (Fig. 4c). Light pumices, in turn, are abundant in the basal layer TM-30-1f, and are homogenous trachytic in composition with SiO_2 values of about 60 wt%. In addition, tephra particles of the uppermost tephras TM-30-1a and TM-30-1b are embedded in a dark-brownish, ashy matrix. The mineral assemblage of all layers of the succession TM-30-1 consists of large crystals of zoned plagioclase, sanidine, biotite, greenish clinopyroxene and rare olivine xenocrysts; leucite and apatite microcrystals in the juvenile phase occur as well. Lithics are abundant and encompass lavic rock fragments, tachylites, altered greenish tuffs, clasts of quenched crystals and feldspar cumulates.

Tephra succession **TM-30-2** is deposited between 82.74 and 82.78 m composite depth and date between 114,440 and 114,720 calendar years BP. TM-30-2 comprises four distinct tephra layers of which the basal tephra TM-30-2d is the most prominent and coarse-grained layer. It consists of two types of juvenile clasts characterized by a distinct chemical composition: a) light, high-vesicular pumice fragments - rich in Fe-Ti-Oxide microcrysts - showing a trachytic composition and b) rare brownish, low to moderate-vesicular glass shards of trachyandesitic composition that are more dominant in the overlying tephras TM-30-2a to TM-30-2c (Fig. 4c). Phenocrysts of all tephras of succession TM-30-2 encompass zoned plagioclase, sanidine, light-greenish clinopyroxene, biotite and apatite. Lithics are abundant and comprise older tuffs (altered pumices and tachylites with leucite inclusions), mafic to intermediate volcanic rocks and clasts of quenched crystals.

According to their chemical composition, lithology and time of deposition between ca. 111 – 115 ka BP, successions TM-29 and TM-30 can be correlated with the TAU1-b pumice fallout deposit occurring in medial-distal outcrops in the Campanian Plain and tentatively attributed to an unknown Phlegrean Field eruption (Di Vito et al., 2008). This pyroclastic unit consists of a well-sorted lapilli deposit made up of both light- and dark-coloured pumices that show a widely variable composition from latitic to trachytic, similar to those of TM-29 and TM-30 (Fig. 4c). The TAU1-b deposit is indirectly dated between the Tyrrhenian Sea high stand (125 ka BP) and the Campanian Ignimbrite (ca. 39 ka BP) (Di Vito et al., 2008).

TM-31 is a 0.5 mm thin fine-grained, white vitric ash layer in 82.79 m composite depth, which is directly underlying the basal tephra of TM-31-2. It is dated by varve counting at 114,770 calendar years BP. TM-31 comprises both colourless, high-vesicular pumice fragments of heterogeneous dacitic–trachydacitic composition (63 - 68 wt% SiO_2; K_2O/Na_2O ratios of 2.3 to 3.6; alkali totals 6.0 - 8.7 wt%) and moderate-vesicular glasses of phonotephritic to basaltic trachyandesitic composition (ca. 52 wt% SiO_2) (Fig. 4c). Only a few loose crystals of plagioclase, sanidine, biotite and clinopyroxene as well as clasts of quenched crystals occur. The mafic glass composition of TM-31 resembles that of tephra successions TM-29 and TM-30, and therefore we suggest a correlation with both the same Campanian source and the TAU1-b eruptive event.

TM-32 is a 1 mm thin, fine-grained and light-brownish ash layer in 82.85 m composite depth. It is dated at 115,250 calendar years BP. Phenocrysts are the main phase comprising K-feldspar, zoned plagioclase, light-greenish clinopyroxene, orthopyroxene and olivine. In addition, rare lithic clasts of quenched feldspar crystals and tachylites occur. The juvenile phase is made up of greyish-brownish, non- to low-vesicular volcanic glass that exhibits a rather heterogeneous calc-alkaline, trachyandesitic composition that is typical for magmas erupting from several of the Aeolian Islands. Glass shards of TM-32 show SiO_2 concentrations of ca. 60 wt%, high FeO values of about 6.5 wt%, and concentrations of CaO, Na_2O and K_2O of about 4-5 wt%, respectively. A comparison with glass data of the 85.3 ka BP Petrazza Pyroclastic Series and the equivalent distal tephra TM-21 (Wulf et al., 2004) show some similarities suggesting Stromboli volcano as a potential source, though TM-32 shows higher FeO and K_2O but lower SiO_2 concentrations (Fig. 4d). However, no Stromboli activity in the considered time period is known (Hornig-Kjarsgaard et al., 1993; Gillot and Keller, 1993), thus leaving a precise correlation of TM-32 open.

Please place here Figure 4c and Figure 4d.

TM-33 comprises two depositional units, TM-33-1 and TM-33-2, with a set of several tephra layers of similar composition. Tephra unit TM-33-1 is made up of three light-brownish, vitric ash layers up to 11 mm in thickness, deposited in 83.05 to 83.10 m composite depth. These layers are dated by the Monticchio chronology between 115,720 and 116,110 calendar years BP. Tephra unit TM-33-2 comprises two thin tephra layers in ca. 83.43 m composite depth, which are dated at 118,190 and 118,210 calendar years BP, respectively. Tephras TM-33-1 and TM-33-2 all consist of abundant light-brownish, medium- to high-vesicular pumice fragments and few large sanidine, plagioclase, biotite and rare clinopyroxene (Aegerine-augite) phenocrysts. Scarce lithics comprise clasts of quenched crystals and sedimentary rock fragments (sandstones, siltstones). Glass shards of each tephra unit show a bimodal trachytic composition (Fig. 4e). The major element chemistry within each unit differs in the concentration of SiO_2 (60.8–63.1 wt%) and CaO (1.0–2.1 wt%). The K_2O/Na_2O ratios show values of 0.8 and 1.4 for the lower and the upper tephra layers, respectively. In summary, the chemical composition of most tephras of unit TM-33 resembles that of Ischia pyroclastics (Fig. 4e). A tentative correlation can be made on the basis of the chronostratigraphical position of Monticchio tephra layers. Accordingly, units TM-33-1 and TM-33-2 most likely relate to the Punta Imperatore Formation dated at ca. 118.5 ka BP (K/Ar weighted mean age; Gillot et al., 1982; Vezzoli, 1988).

TM-34 is a distinct 0.4 mm thin tephra layer in 83.54 m composite depth that is dated at 118,810 calendar years BP. This fine-grained ash consists of blocky, non- to low-vesicular brown glass shards bearing apatite microcrystals. Phenocrysts comprise the minerals plagioclase and pale-greenish clinopyroxene with adherent glass. Few lavic lithics also occur. Volcanic glasses are heterogeneous Na-calcalkaline, trachyandesitic to basaltic trachyandesitic in composition, showing strong variations in SiO_2 (54.4–57.8 wt%) as well as high FeO (8.4–11.3 wt%), MgO (2.4–3.8 wt%) and CaO (6.2–8.2 wt%) concentrations. The comparison of published major element data of pyroclastics and lava products strongly suggest an origin of TM-34 from the Aeolian Islands (Fig. 4f). Explosive volcanism during the considered time interval is particularly known from the Islands of Salina and Lipari. On Lipari, on the one hand, the Monte San Angelo center was explosively active between 127 ± 8 ka BP and 92 ± 10 ka BP (Esperança et al., 1992), and erupted pyroclastics of the related cycles III and IV of Lipari are chemically (bulk samples) similar to TM-34 (Fig. 4f). The Fossa delle Felci stratovolcanic center on Salina, on the other hand, produced several sub-Plinian to strombolian fallout deposits within two distinct eruptive sequences of older basaltic (127 ± 5 ka BP, K/Ar; Gillot, 1987; Gertisser and Keller, 2000) and younger andesitic to dacitic volcanics (Keller, 1980; Gertisser and Keller, 2000). The latter comprise pyroclastics of the stages 5-8 showing a bulk composition that approximates most the glass composition of tephra TM-34. Volcanism of the Fossa delle Felci is supposed to have lasted no longer than a few ten thousand years (Gertisser and Keller, 2000) and therefore the age of its younger products (<127 ka BP) is well in the time frame of the deposition of TM-34 in Monticchio. The best chemical match of glass data, however, is given by a secondary glass component of a coarse-grained turbidite found in Marsili Basin core TIR2000-398 cm from the Tyrrhenian Sea (Fig. 4f) (Albert et al., 2012). These components are tentatively interpreted to represent older, so far undated activity of Salina that was incorporated during a younger collapse of the island. In summary, a reliable correlation of tephra TM-34 with a dated proximal counterpart is not possible at this moment, but the source can be most likely narrowed down to Salina Island.

Please place here Figure 4e and Figure 4f.

TM-35 comprises two tephra layers of similar composition, TM-35a (120,670 calendar years BP) and TM-35b (121,940 calendar years BP) in 84.14 m and 84.84 m composite depth, respectively. Both tephras consist of light, high-vesicular pumice fragments and large phenocrysts of sanidine, plagioclase, biotite and rare green clinopyroxene. Lithics comprise clasts of quenched crystals and altered tuffs. Geochemical data are only available for the more coarse-grained tephra TM-35a. Those reveal a homogeneous trachytic composition with CaO concentrations of about 2 wt% and K_2O/Na_2O ratios of ~1.5 (Fig. 4a). The composition suggests a general origin of tephras TM-35 from a so far unknown eruption of the Campanian Volcanic Province.

TM-36 is a fine-grained, brown-blackish ash layer in 85.30 m composite depth, which is dated at 123,030 calendar years BP. It contains light, high-vesicular pumice fragments, abundant large phenocrysts of sanidine, leucite, nepheline, biotite, apatite and green clinopyroxene, as well as rare altered tuffs and limestone fragments. Tephra components are set in a black (base) and brown (top) fine-grained matrix. Glass shards show a phonolitic composition with high Al_2O_3 values of 20.3 – 20.8 wt% and CaO concentrations of 4.1 – 5.3 wt%. This chemical composition is typical for products from the Sabatini Volcanic District (Roman Province) (Fig. 4g), which we consider as the source area for TM-36. The last activities of the Sabatini Volcanic District produced a cluster of dominantly hydromagmatic and subordinate magmatic eruptions of similar phonolitic composition (Sottili et al., 2010; Sottili et al., 2012). A good geochemical match, for instance, is given by the Upper Stracciacappa unit (Fig. 4g), though this unit is significantly younger (97 ± 4 ka BP; Sottili et al., 2012) than the varve age obtained for tephra TM-36. The Baccano Lower Unit, described as a leucite/analcime bearing white pumice fall deposit, erupted rather in the considered time period (131 ± 2 ka BP; Sottili et al., 2012), but has not been geochemically characterized, so far. The closest chemical and chronological match is given by the pyroclastics of the Valle dei Preti unit (VdP; Sottili et al., 2012) (Fig. 4g). The VdP unit was formerly dated at >296 ± 3 ka BP (Sottili et al., 2012). New stratigraphical data, however, indicate a much younger formation age that is closer to the considered time frame of the deposition of tephra TM-36 (i.e., younger than the Cornacchia Lava dated at 154 ± 7 ka BP; (Nappi and Mattioli, 2003). A detailed correlation, however, requires more analytical data of proximal pyroclasts, which are in progress.

Please place here Figure 4g.

TM-37 is a succession of four single tephra layers deposited between 85.68 m and 86.59 m composite depth. Layer thicknesses range between 1 mm and 1.1 cm (Table 1). The oldest tephra TM-37d (124,860 calendar years BP) is a white, fine-grained, almost pure vitric ash with high-vesicular glass components. It is overlain by pumice fallout TM-37c (124,360 calendar years BP) that is abundant in rock fragments (clasts with quenched crystal, lavic lithics, and altered green tuffs with feldspar xenocrystals) and phenocrysts of sanidine, plagioclase, biotite, green clinopyroxene and amphibole. Here, high-vesicular white pumice clasts and rare brown glass shards are common. The slightly younger tephra TM-37b (124,330 calendar years BP) is similar in composition but thicker and more coarse-grained than TM-

37c and TM-37d. The most prominent tephra layer is the youngest and thickest deposit TM-37a (124,070 calendar years BP). It is twice reversely graded and mainly composed of high-vesicular white pumice fragments. Abundant phenocrysts and lithics comparable with those in layers TM-37b and TM-37c occur at the base of the deposit. All tephra layers of succession TM-37 are homogeneous trachytic in composition showing low CaO concentrations (1.0–1.3 wt%) and K_2O/Na_2O ratios between 0.8 and 1.0. Tephras of this composition are typical for Ischia eruptions (Fig. 4e). For the proposed time of deposition between 124 and 125 ka BP, however, volcanic activity on Ischia was restricted to the formation of lava domes and minor lava flows from the Castello d'Ischia and Monte di Vezzi volcanic centres (126 ± 4 ka BP; K/Ar; Gillot et al., 1982). It is speculative whether these activities were accompanied by the eruption of larger amount of tephra material, and therefore a correlation of tephras TM-37 with proximal pyroclastic deposits remains open for now.

TM-38 (formerly labelled as TM-38a in Wulf et al., 2006) is a fine-grained, vitric ash in 87.07 m composite depth. It is composed of light-coloured glass shards of homogeneous high-K-phonolitic composition (Fig. 4a). A few loose crystals of sanidine and biotite also occur. Tephra TM-38 is dated by the Monticchio chronology at 125,550 calendar years BP and most likely originates from an unknown eruption of the Campanian Volcanic District.

TM-39 is a brownish tephra layer of 4 mm thickness at 91.98 m composite depth. It comprises brown and minor light low- to moderate-vesicular glass shards of similar homogeneous phonolitic composition that exhibit higher FeO (4.5 wt%) and CaO (3.3 wt%) concentrations and lower K_2O/Na_2O ratios (1.3–1.7) than tephra TM-38 (Fig. 4a). Phenocrysts encompass the minerals plagioclase, sanidine, green clinopyroxene, and amphibole. Leucite and apatite microcrystals occur as well as lithics of lavic rocks. TM-39 is dated at 130,530 calendar years BP. According to its chemical composition it most likely originates from a Campanian volcano.

TM-40 in 92.37 m composite depth is a white vitric ash of 5 mm thickness. It bears phenocrysts of sanidine, biotite and greenish clinopyroxene. Lithics are rare and comprise clasts of quenched crystals. The main juvenile phase is characterized by light high-vesicular and few brownish glass shards of inhomogeneous trachytic composition. The K_2O/Na_2O ratio of ~1 as well as variable CaO concentrations between 1.2 and 2.2 wt% (Fig. 4e) indicate an origin of TM-40 from a Campanian volcano with Ischia as a potential source volcano.

TM-41 (formerly labelled as TM-38b in Wulf et al., 2006) is a double layered, light brownish tephra of 6 mm thickness. It occurs at 92.77 m composite depth and is dated at 131,020 calendar years BP. Glass shards are light to brownish in colour and low-vesicular. The glass composition is heterogeneous trachytic to phonolitic, reflecting variable concentration of CaO (1.5-3.1 wt%), FeO (1.2-3.5 wt%), K_2O/Na_2O ratios (1.4-2.4) and high Al_2O_3 values (19.3–21.0 wt%) (Fig. 4e). The mineral assemblage encompasses phenocrysts of sanidine, plagioclase, biotite, clinopyroxene and apatite microcrystals. Rare volcanic rock fragments and clasts of quenched crystals also occur. The maximum grain sizes of 300 µm in combination with the composition strongly suggest an origin from a Campanian volcano.

TM-42 is a 1 mm thick light ash in 97.69 m composite depth. It is the oldest tephra layer in the Monticchio record dated at 132,110 calendar years BP. The mineral assemblage is composed of sanidine, plagioclase, biotite and minor green clinopyroxene crystals. Lithics are rare and comprise clasts of quenched crystals of intermediate composition. The juvenile phase is made up of light high-vesicular pumice fragments of homogenous trachytic character, which is typical for Ischia products (Fig. 4e). Based on its composition and age constraints we propose a tentative correlation of TM-42 with the Lower Scarrupata di Barano Formation (>123 ± 3.4 ka BP, K/Ar; Gillot et al., 1982).

Please place here Table 3.

6 Discussions

6.1 Tephra sources and distal correlation

The extended Monticchio tephra record, now reaching back to 133 ka BP, provides a total number of 345 visible and primary (non-reworked) tephra fallout layers. Out of these, 293 tephra layers were described from the upper ≤100 ka BB section (Wulf et al., 2004; Wulf et al., 2006; Wulf et al., 2008) and 52 tephras are identified in the extended sediment section between 72.5 and 103.1 m, covering the interval from 100 ka BP to 133 ka BP. Major-element glass data in combination with microscopic-petrographic results suggest sources of these older ashes within the Campanian, Roman and Sicilian-Aeolian volcanic provinces in central and southern Italy. Detailed correlations with proximal deposits, however, are quite difficult mainly due to the lack of comparable geochemical and/or chronological data of potential correlatives. Chemical comparisons are mainly based on published XRF whole rock data of pyroclastic and lava material. Whole rock analyses may significantly differ from grain-specific EPMA and SEM-EDS glass analyses, which is particularly dependent on the proportions of phenocrysts present within the tephra deposit. Such differences are known, for instance, from the younger tephra deposits of Mount Etna, the widespread Biancavilla/Y-1 tephra (17.3 ka BP), which shows a wide range in SiO_2 concentration of glass shards (60-66 wt%) compared to the respective whole rock data (~60 wt%; Coltelli et al., 2000) (Fig. 4b). A similar behaviour is expected for older Etnean tephra deposits of the AAC. In contrast, other volcanic centres such as Ischia Island exhibit only minor or none compositional differences between bulk composition and single-grain glass data. Here, the problem of a reliable correlation with distinct older proximal deposits lies in the similarity of erupted tephras. Consequently, a clear discrimination of individual layers is not possible, and tentative correlations are almost solely based on chronological and stratigraphical information. Problems in respect to reliable correlations are also given for more "exotic" tephras deriving from Roman and Aeolian Islands volcanoes. Here, the glass chemical compositions of tephras clearly refer to their respective provenances, but reliable correlations are difficult due to the lack of either one or both chemical and chronological-stratigraphical data of proximal tephra deposits.

The only strong correlations of Monticchio tephras, however, are given from other distal terrestrial or marine equivalents, which are independently dated either by K/Ar and Ar/Ar methods or by orbital tuning of oxygen isotope records of foraminifera in deep-sea sediments. Juvenile glass components are chemically characterized by either EPMA or SEM-EDS techniques. Those correlations, however, are restricted to only a few widespread marker layers in the Central Mediterranean (i.e., Keller et al., 1978; Munno and Petrosini, 2007; Marciano et al., 2008; Paterne et al., 2008).

6.1.1 Tephras from Ischia Island

During the last 133 kyrs numerous larger pyroclastic units erupted from the Island of Ischia. An example for the high intensity of explosive eruptions is given by the Y-7 / IT ("Ischia Tephra") that was recognized as a prominent and widespread marker in the land and deep-sea records of the Central Mediterranean (Keller et al., 1978; Morche, 1988; Gillot and Keller, 1993; Keller and Kraml, 2004; Lucchi et al., 2008) and dated at 56 ± 4 ka BP (Kraml, 1997; Keller and Kraml, 2004). In the time span 100-133 ka, three pyroclastic fall deposits - the Punta Imperatore, the Upper (USB) and Lower Scarrupata di Barano (LSB) Formations - are recognized in proximal sites from Ischia Island (Vezzoli, 1988). These explosive phases are accompanied by lava dome and flow activities of the Monte di Vezzi / Castello d'Ischia, Rione Bocca and Monte Cotto / La Guardiola volcanic centres (Vezzoli, 1988). A wide and overlapping range of ages is given for most of the Ischia volcanic units mainly due to the use of different dating material such as whole rock material, groundmass and sanidine crystals (Gillot et al., 1982; Poli et al., 1989; Vezzoli, 1988). The only consistent age constraint, however, is provided for the Punta Imperatore Formation (116 ± 2.6 ka BP to 123 ± 2.7 ka BP; Gillot et al., 1982). This timing in combination with geochemical evidence (Fig. 4e) provides the only reliable Ischia correlation marker for tephra successions TM-33 (ca. 118.2–115.7 ka BP) in the Monticchio record. For the older Ischia tephras TM-40 (130.9 ka BP) and TM-41 (131 ka BP), it can be only speculated whether the heterogeneity of major element glass composition is comparable with the bimodal bulk lava composition provided by different methods for the USB Formation (Fig. 4e). Consequently, the younger tephras TM-37 (ca. 124.9–124.1 ka BP) may be related to yet unrecognized pyroclastic activities between the Punta Imperatore and USB formations, that may have occurred, for instance, at the Monte di Vezzi volcanic centre (126 ± 4 ka; Gillot et al., 1982). Though the geochemical signature of TM-37 approximates the bulk composition of the Monte di Vezzi lava flow (Fig. 4e), evidence for coeval tephra emission is still missing and therefore only vague statements of a potential correlation with the Monte di Vezzi lava flow activities are possible. In respect to the oldest Ischia tephra TM-42 (ca. 132.1 ka BP), geochemical similarities occur with bulk data of pumices from the LSB Formation (Fig. 4e). The dating of the LSB, however, appears problematic. The only time constraints derive from K/Ar dates of the overlying Monte Cotto and La Guardiola lavas that propose minimum ages of the LSB between 123 ± 3.4 ka BP (Sanidine) and 147 ± 3 ka BP (groundmass) (Vezzoli, 1988). The wide age range and the lack of comparable EPMA glass data hence provide only an ambiguous correlation of tephra TM-42 with proximal deposits on Ischia Island.

Distal tephras from Ischia older than 105 ka BP are also recorded in sediment cores from the Central Tyrrhenian and Ionian Seas (Paterne et al., 2008) (Table 3). Tephra C-35 found in 485 cm sediment depth in Ionian Sea core KET 82-22 and dated at 121.5 ka BP, was tentatively assigned to the 108-110 ka marine X-6 tephra (Paterne et al., 2008). Another marine tephra, C-34, in Tyrrhenian Sea core DED 87-08 in 1260 cm and an overlaying mixed (reworked?) tephra layer in 1254 cm sediment depth dated at 116.1 ka and 115.2 ka BP, respectively, show a similar glass composition. The SEM-EDS glass composition of both C-34 and C-35 match the EPMA composition and the age of the Monticchio tephra layer sequence TM-33 (116-118 ka BP; Punta Imperatore Formation) (Table 3, Fig. 4e). Tephras

TM-40 (130.9 ka BP) and TM-41 (131 ka BP) show as well some minor affinities to tephras C-34 and C-35, but most likely derive from a different Campanian source volcano due to the high CaO concentrations of >2 wt% (Fig. 4e). In respect to Monticchio tephras TM-37 and TM-42, distal correlative have not been identified so far.

6.1.2 Tephras from unknown Campanian sources (Phlegrean Fields?)

36 tephra layers in the Monticchio record clustering around 105.8–114.7 ka and 121–131.3 ka BP show a K-phonotrachytic glass composition that is typical for more recent tephra products erupted from Campanian volcanoes, and more precisely from the Phlegrean Field caldera. The youngest tephra TM-25 of generic Campanian origin densely clusters within the chemical fields of the marine X-5 tephra. The prominent pair of X-5 and X-6 tephra layers, as defined in the Ionian Sea by Keller et al. (1978) occupies a well-defined position between the Ionian sapropels S4 and S5. The varve age of Monticchio tephra TM-25 is ca. 105.8 ka BP, which is in close agreement with the $^{40}Ar/^{39}Ar$ age of 105 ± 2 ka BP obtained on the marine X-5 tephra by Kraml (1997). TM-25 geochemically and chronologically also matches the C-27 tephra layer (103.5 ka BP) in the Tyrrhenian Sea cores DED 87-08/KET 80-04 (Paterne et al., 2008) and the POP3 layer (106.2 ± 1.3 ka BP; $^{40}Ar/^{39}Ar$) from a central Italy lacustrine succession (Popoli, Sulmona Basin; Giaccio et al., submitted) (Fig. 4a). Marine tephras X-5 and C-27 were originally assigned to the two distinct Monticchio tephras TM-24a (ca. 101.8 ka BP) and TM-24b (ca. 102.8 ka BP) in the Monticchio record based on initial major and trace element data (Wulf et al., 2004). Additional major element glass data obtained on TM-24a and TM-24b (Fig. 4a) prove a wider range in glass composition and therefore differ from the rather homogenous X-5 and TM-27 glass compositions. Also maximum grain sizes of pumices in tephras TM-24a and TM-24b are smaller than in TM-25 indicating a lower magnitude eruption for the TM-24 couplet compared to the widespread TM-25/X-5 eruption.

The thickest Monticchio tephra TM-27 (ca. 108.3 ka BP) matches the widespread marine X-6 tephra at ca. 108-110 ka BP (Keller et al., 1978; Kraml, 1997; Keller and Kraml, 2004) and therefore forms an important regional tephrochronological synchronisation marker. Furthermore, the comparison of single grain glass data shows that TM-27/X-6 can be attributed to the marine C-31 tephra (107 ka BP) that forms a thick and coarse grained marker layer in sediment cores KET 80-04, DED 87-08 and KET 82-22 in the Central Tyrrhenian and Ionian Seas (Paterne et al., 2008) (Table 3). Noteworthy, the TM-27/X-6 tephra in the Monticchio sequence is preceded by two thin and fine-grained layers, TM-28a and TM-28b, which are chemically almost identical to TM-27. These tephras are approximately 2000 and

2500 calendar years older and probably derive from the same unidentified Campanian volcanic source.

The second older cluster of Monticchio tephras deriving from not well-defined Campanian sources comprises tephra units TM-29 and TM-30 as well as tephra layers TM-31, TM-35, TM-38 and TM-39. Out of those, the compositionally highly variable tephra layers of succession TM-29, TM-30 and TM-31 (111.5-114.7 ka BP) match the glass composition of tephra OT0701-7 from a sediment sequence of Lake Ohrid, Balkans (Fig. 1a) correlated with the TAU1-b tephra deposit of the Campanian area (Sulpizio et al., 2010). In addition, one glass component occurring in a mixed tephra layer in 1254 cm sediment depth in Tyrrhenian Sea core DED 87-08 and dated at 115.2 ka BP shows a similar composition as glass shards from Monticchio tephra layer TM-29-1g (Table 3, Fig. 4c) indicating the same source.

The high-K trachytic Monticchio tephra TM-35a (ca. 120.7 ka BP), in turn, is approximating the glass composition of a distal tephra in the marine realm, the C-36 tephra layer in Tyrrhenian Sea core KET 80-04 (123.2 ka BP; Paterne et al., 2008) (Fig. 4a, Table 3). For Monticchio tephra TM-38 and TM-39 neither proximal nor distal tephra equivalents were identified, so far.

Though the lack of a complete chronological and EPMA geochemical dataset hampers a precise correlation, Monticchio tephras of Campanian provenance can be most likely associated with compositionally similar pyroclastic units recognised in the Neapolitan area, dated between 125 ka and 39 ka BP (Di Vito et al., 2008). Based on field evidence these units were tentatively attributed to early, unknown explosive activities localised in the Phlegrean Fields area (Di Vito et al., 2008).

6.1.3 Tephras from Mount Etna and the Aeolian Islands

The most remarkable Monticchio tephras in terms of their geochemical composition are tephras TM-26, TM-32 and TM-34. These ashes can be related to early pyroclastic activities of Mount Etna and the Aeolian Islands. The lack of exposure and/or glass compositional data of proximal deposits and distal occurrences, however, only allows tentative correlations that are based on general geochemical signatures of products of source volcanoes described in literature. This applies in particular to tephras TM-26 (Mount Etna, ca. 106.3 ka BP) and TM-32 (Stromboli, ca. 115.2 ka BP) that show chemical affinities to younger tephras of the respective volcanoes. Apart from XRF whole rock data of proximal pyroclastics, tephra TM-26 can only be compared with SEM-EDS glass data of Etnean origin found in 1093-1095 cm and 1139-1141 cm sediment depth in Tyrrhenian Sea core KET 80-04 (Table 3). Those distal shards dated at 124.6 ka and 130.2 ka BP, respectively, are significantly older than TM-26, but are similar in composition and therefore confirm the considered correlation with older Etnean deposits. Tephra TM-32 shows strong affinities to Paleostromboli I pyroclastics, but neither entirely matches the glass composition nor fits the age of the 75.3 ka BP Petrazza pyroclastic series, the oldest pyroclastics found on Stromboli so far (Hornig-Kjarsgaard et al., 1993). Tephra TM-34 (ca. 118.8 ka BP) can be associated with Salina Island pyroclastics, and matches best the composition of glass shards found in a turbidite from a Marsili Basin core (Albert et al., 2012). Both, TM-32 and TM-34 are not documented as discrete primary tephra layers in other environments yet, and therefore a detailed correlation with independently dated events remains open.

6.1.4 Tephras from Roman volcanoes (Sabatini Volcanic District)

Out of the 52 primary tephra fallout layers, only one single tephra layer in the Monticchio sediment section, tephra TM-36 (ca. 123 ka), can be attributed to Roman volcanic activities. Tephra TM-36 shows strong affinities to late stage pyroclastics of the Sabatini Volcanic District. Those activities were characterized by the formation of maars such as the Valle dei Preti, Stracciacappa, Le Cese, Acquarella and Martignano (Sottili et al., 2012). The related proximal pyroclastic deposits are well studied (Sottili et al., 2012) and provide valuable EPMA data for the comparison of major-elements with TM-36 (Table 3). Here, the best chemical and chronological fit is given for the Valle dei Preti Units (<154 ± 7 ka BP) (Fig. 4g). Distal equivalents of tephra TM-36 were not found as distinct layers elsewhere so far. In Tyrrhenian Sea core DED 87-08, 1254 cm sediment depth, however, a mix of volcanic glass of different composition exposes also a phonolitic component that is comparable with TM-36 (Table 3, Fig. 4g). This marine tephra layer, however, is dated at 115.2 ka BP and therefore considerably younger than TM-36.

Please place here Table 5.

6.2 Revising tephrochronology

The revision of the varve and sedimentation rate chronology of the Monticchio sediments (Brauer et al., 2007) lead to changes of the timing of tephras deposited prior to the TM-13/Pomici di Base eruption (19,280 calendar years BP; Wulf et al., 2004). As a result, tephra ages became systematically older, i.e. the TM-15/Y-3 tephra now dates at 27,260 instead of 23,930 calendar years BP, whereas the timing of the TM-18/Campanian Ignimbrite tephra layer is corrected to an older age of 36,770 calendar years BP. A complete list of revised ages of main tephra markers defined in Wulf et al. (2004) is provided in Table 4. Those dates in addition to three new varve dates resulting from the extended Monticchio 100-133 ka BP section are used to re-built a tephrochronological framework, which is then compared with updated radiometric and radioisotopic ages (weighted mean ages with 2σ error range) of correlated counterparts obtained from other proximal and distal records elsewhere (Fig. 5, Table 4). The juxtaposition of both chronologies shows a general good agreement, though in some sections large and variable uncertainties are noticeable:

- **Section 1** (0–1.15 m composite depth): Sediments of the topmost 50 cm are homogenous and the lamination is not well preserved. The varve age of tephra TM-1/AD 1631 in 6 cm depth is estimated too young, most likely indicating missing sediments in the top section. Sediments in the lower section, in turn, are laminated (organic varves). Here, the calendar ages of tephras TM-2a/AD 512 and TM-2b/AD 472 Pollena agree well with a 2% uncertainty with the historical documented ages of tephra events.
- **Section 2** (1.15–10.15 m composite depth): Approximately 90% of the Monticchio sediments in this section between 1,500 and 18,000 calendar years BP are annually laminated (organic varves). The varve age of the TM-4/Avellino tephra of 4,310 calendar years BP in the upper part is within the 2σ error range of radiocarbon ages obtained in proximal and distal deposits (Table 3), but shows an older age with a difference of 9.2% compared to the weighted mean radiometric age of correlated equivalents. Varve ages of the directly overlaying tephras TM-3b/AP3 (4,020 calendar years BP) and TM-3c/AP2 (4,150 calendar years BP), in turn, are significant older than the respective ^{14}C ages of proximal correlatives (41% and 19.7% uncertainty). However, based on the good preservation of varves in the section between ca. 3,500 and 4,500 calendar years BP large varve counting errors and/or a hiatus can be excluded suggesting rather an overestimation of varves in the younger sediment section (1,500-3,500 calendar years BP). Monticchio varve ages of the TM-4/Avellino underlying tephras TM-5a/Agnano Mt. Spina, TM-7/Pomici Principali, TM-8/Neapolitan Yellow Tuff, TM-9/GM1 and TM-10d/Lagno Amendolare (4,620–15,550 calendar years BP) are in good agreement with ^{14}C and ^{39}Ar/^{40}Ar ages of correlatives with a mean uncertainty of 3.4%. The TM-6b/Mercato tephra (9,680 calendar years BP) is the only outlier, showing an older varve age in respect to the radiometric dating (8.7% uncertainty). In the lowermost section (9.5-10.15 m), the ages of the TM-11/Biancavilla tephra (16,440 calendar years BP) and the TM-12/Verdoline tephra (17,560 calendar years BP) appear too young, and a systematic

increase of deviation up to 7.2% (ca. 1360 years) between varve and radiometric ages of tephras is notable. This difference is most likely based on an underestimation of varves in this section of poor varve preservation.

- **Section 3** (10.15–18.00 m composite depth): Below the TM-12/Verdoline tephra, the annual lamination of the organic-clastic sediments is poorly preserved and therefore likely leads to an underestimation of varves. Age uncertainties increase to an average of 10% which corresponds to 2420 years for the TM-13/Pomici di Base tephra (19,280 calendar years BP) and up to ca. 4000 years for the TM-17bc/Albano unit 7 tephra (31,830 calendar years BP). Marker tephras TM-14/Solchiaro and TM-16b/Codola are re-dated to 21,260 and 31,120 calendar years BP, respectively.
- **Section 4** (18.00–27.00 m composite depth): The annual lamination of the minerogenic-calcareous sediments is exceptionally well preserved in the new cores LGM-M and LGM-O between tephras TM-17bc/Albano unit 7 and TM-18/Campanian Ignimbrite, and therefore has been re-counted (Funk, 2004). As a result, the new varve age of 36,770 calendar years BP for the TM-18/Campanian Ignimbrite tephra is now well within the 2σ error range of three radiometric and five $^{40}Ar/^{39}Ar$ dates of proximal and distal correlatives and shows an uncertainty of ca. 6% in respect to the weighted mean age (Table 4).
- **Section 5** (27.00–60.00 m composite depth): The section between 37,000 and 90,000 calendar years BP (MIS 3 to 5b) exhibits organic-minerogenic sediments that are poorly laminated with an exception between 50 and 58 m sediment depth (76,000–88,000 calendar years BP, MIS 5a). Major tephra markers occur in the lower part between 40 and 60 m and include TM-19/TVEss, TM-20/UMSA, TM-21/Petrazza and TM-22/Ignimbrite Z. The two Ischia tephra layers TM/19/TVEss and TM-20/UMSA are re-dated in the Monticchio sediments from previously 56,250 and 57,570 calendar years BP to 60,060 and 61,370 calendar years BP, respectively. The new varve ages, however, appear too old, though they are still within the 2σ error range of $^{39}Ar/^{40}Ar$ and K/Ar ages obtained on proximal and distal correlatives. This assumption is supported by the varve age of the preceding TM-21/Petrazza tephra (78,340 calendar years BP), which is 3100 years older than the K/Ar age of 75.3 ka BP (Gillot and Keller, 1993) of its proximal correlative. The varve age of tephra TM-22 (Ignimbrite Z of Pantelleria, marine tephra layer P-10) is corrected from previously 85,320 to 89,130 calendar years BP, and is now 5000 years older than the marine oxygen isotope age of the distal equivalent. In total, the mean age uncertainty is approximately 7% indicating an overestimation of varve ages in this section.

- **Section 6** (60.00–70.20 m composite depth): The section between 90,000 and 101,000 calendar years BP (MIS 5b/5c) constitutes minerogenic-organic sediments that are more or less well laminated in the upper 70% of the succession. In the lower part, varve preservation is poor. Though a total of 81 tephra fallout layers occur in this section, only one tephra could be assigned to a dated correlative. The trachytic tephra TM-23-11 was recently matched with the terrestrial POP1 tephra occurring in the Popoli section, Sulmona Basin (Latium) and dated by $^{40}Ar/^{39}Ar$ at 92.4 ± 4.6 ka BP (Giaccio et al., submitted). Here, the Monticchio varve age of 95,180 calendar years BP is well within the 2σ error range, but ca. 3000 years older than the mean radioisotopic age of its correlative indicating an overestimation of varves with an age uncertainty of ca. 3.2% in this section.
- **Section 7** (70.20–92.50 m composite depth): The newly studied section between 101,000 and 131,000 calendar years BP is well laminated, showing a variety of varve types of organic-minerogenic (MIS 5c), organic (MIS 5e) and calcareous-minerogenic (MIS 6) composition. Prominent tephra marker layers such as TM-25/X-5 and TM-27/X-6 occur in the upper part of this section providing valuable dating points at 105,480 and 108,330 calendar years BP. These are in very good agreement (0.3 and 0.5% uncertainty) with the dates obtained from the marine equivalents (Table 4). This implies an underestimation of varve ages in the poorly laminated section 6. In the lower part of section 7, the tentative correlation of the TM-33 succession (118,210 calendar years BP) with the Punta Imperatore Formation confirms the Monticchio chronology with an even lower uncertainty of ca. 0.1%.
- **Section 8** (92.50–103.10 m composite depth): The basal part of the Monticchio record is characterized by the deposition of a large number of turbidites formed during the early phase of lake development. So far, no robust time control is given for the sediments older than 131,000 calendar years BP, though an underestimation of varves of at least 10% is possible (Brauer et al., 2007).

Please place here Figure 5.

6. Conclusions

The Monticchio tephra record exhibits 345 visible tephra fallout layers that are distributed throughout the last 133 kyrs and precisely dated by the revised varve supported sedimentation rate chronology of Monticchio sediments (Brauer et al., 2007). This chronology is confirmed independently by 28 radiometric and radioisotopic ages of prominent tephra correlatives with a mean age uncertainty of 5%. Revised varve ages are provided for all Monticchio tephras >19,280 calendar years BP; i.e., the new age estimate for the Campanian Ignimbrite tephra fall (TM-18 / CI / Y-5) now has a varve age of 36,770 ± 1840 calendar years BP (2σ error), which is still too young but closer to the widely accepted $^{40}Ar/^{39}Ar$ date of 39.28 ± 0.11 ka BP obtained by De Vivo et al. (2001).

The detailed study of the 52 newly identified tephras between 100 and 133 ka BP allows defining sources in the southern and central Italian volcanic area. Most of these ashes were not described elsewhere, so far. Therefore, reliable assignments to single eruptive events were possible on a limited basis only. Those were the correlations with the prominent marine tephras X-5 (ca. 105 ka BP) and X-6 (ca. 107 ka BP) which are varve dated with an uncertainty of less than 1% (Brauer et al., 2007). Other less well constrained correlations are based either on age constraints or tentative geochemical matches. This brings up three main issues that need to be resolved by the tephra community in the future:

1. The description of tephra deposits, particularly in proximal sites, often lacks in EPMA glass data. These data, however, are essential for reliably correlating distal findings and should thus be provided for all ash layers in any type of archive.
2. Detailed chronological constraints of tephras are well derived for major eruptive events like, for example, the Avellino (4 ka BP), Neapolitan Yellow Tuff (14 ka BP) and Campanian Ignimbrite (39 ka) eruptions, and are lacking for lower-magnitude events. To overcome this issue and to achieve a most comprehensive data set of Mediterranean explosive volcanism, efforts should be made to date also tephras from small-scale eruptions in sedimentary archives.
3. The similarity of major element glass composition of tephras from the same source volcanoes (i.e., Campi Flegrei, Ischia) often prevents a reliable correlation with a specific event. This problem can be overcome by additional trace element analyses (e.g., Smith et al., 2011; Tomlinson et al., in press) and $^{87}Sr/^{86}Sr$ isotopic measurements (e.g., Di Renzo et al., 2007; Giaccio et al., 2007; Roulleau et al., 2009).

Those data in addition to the comprehensive Monticchio tephra data set will contribute to an improved Late Quaternary tephrostratigraphy in the Mediterranean.

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Table captions

Table 1: Core depths, composite depths, varve ages, thicknesses, maximum grain sizes and sources of Monticchio tephra layers deposited between 100 and 133 ka BP. CP=Campanian Province, E=Etna, PF=Phlegrean Fields, STR=Stromboli Island, IS=Ischia Island, SAL=Salina Island, SAB=Sabatini Volcanic District.

Table 2: Mean values of non-normalized EPMA glass data and 2σ standard deviation (italics) of tephra layers occurring in the Monticchio sequence between 100 and 133 ka BP. Totals are corrected for chlorine concentrations. Full analytical data of individual glass measurements are provided in Supplementary Table A.

Table 3: List of major element data of distal and proximal tephras used for correlation with Monticchio tephras (see text). Data from: * this study; (1) Paterne et al. (2008), (2) Sulpizio et al. (2010), (3) Di Vito et al., (2008), (4) Sottili et al. (2012), (5) Poli et al. (1987), (6) Fuchs (1873).

Table 4: Revised tephrochronology of Lago Grande di Monticchio for the last 133 kyrs. V = Vesuvius; PF = Campi Flegrei; E = Etna; PV = Procida-Vivara; A = Alban Hills; IS = Ischia; STR = Stromboli; PA = Pantelleria; CP = Campanian Volcanic Province; RP = Roman Province. Conventional and AMS radiocarbon dating were calibrated using CALIB 6.0.1 with the IntCal09 or Marine09 calibration curves (Stuiver and Reimer, 1993; Reimer et al., 2009). Age references for correlatives: (1) Rolandi et al. (1993), (2) Rolandi et al. (1998), (3) Vogel et al. (1990), (4) Terrasi et al. (1994), (5) Santacroce et al. (2008), (6) Andronico et al. (1995), (7) Watts et al. (1996a), (8) Pantosti et al. (1993), (9) Zanchetta et al. (2011), (10) Passariello et al. (2009), (11) Sevink et al. (2011), (12) Alessio et al. (1973), (13) Albore Livadie and D'Amore (1980), (14) Delibrias et al. (1986), (15) Marzocchella et al. (1994), (16) Rosi and Sbrana (1987), (17) de Vita et al. (1999), (18) Alessio et al. (1971), (19) Siani et al. (2004), (20) Alessio et al. (1974), (21) Di Vito et al. (1999), (22) Deino et al. (2004), (23) Pappalardo et al. (1999), (24) Andronico (1997), (25) Branca et al. (2008), (26) Kraml (1997), (27) Siani et al. (2001), (28) Delibrias et al. (1979), (29) Capaldi et al. (1985), (30) Bertagnini et al. (1998), (31) Alessio et al. (1976), (32) Sulpizio et al. (2003), (33) Buccheri et al. (2002a), (34) Buccheri et al. (2002b), (35) Giaccio et al. (2008), (36) Giaccio et al. (2009), Freda et al. (2006), (37) De Vivo et al. (2001), (38) Deino et al. (1994), (39) Ton-That et al. (2001), (40)

Fedele et al. (2002), (41) Sinitsyn (2003), (42) Gillot et al. (1982), (43) Gillot and Keller (1993), (44) Paterne et al. (1990), (45) Giaccio et al. (submitted), (46) Keller and Kraml (2004).

Figure captions

Figure 1: a) Site map of Italy showing major volcanic centres, the location of Lago Grande di Monticchio and distal correlation sites mentioned in the text. b) Bathymetric map of Lago Grande di Monticchio with coring sites.

Figure 2: Lithology and tephrostratigraphy of the composite profile LGM-B/D/E/J/M/O with focus on the 100-133 ka BP tephras.

Figure 3: Images under optical microscope of prominent tephras in the 100–133 ka BP sediment section of Lago Grande di Monticchio. **a)** TM-25; **b)** TM-30-1c; **c)** TM-26.

Figure 4a: Harker diagram SiO_2 vs. CaO for chemical discrimination of Monticchio tephras from the Campanian Province (undefined): (1) mean SEM-EDS glass data (Munno and Petrosino, 2007; Marciano et al., 2008); (2) SEM-EDS glass data (Paterne et al., 2008); (3) EPMA glass data (Scheld, 1995); (4) EPMA glass data (Wulf et al., 2004; this study); (5) EPMA glass data (Giaccio et al., submitted); (6) SEM-EDS glass data (Sulpizio et al., 2010).

Figure 4b: Harker diagram SiO_2 vs. FeO for chemical discrimination of Monticchio tephras from Mount Etna: (1) XRF whole rock data of pyroclasts (Nicotra et al., 2011); (2) SEM-EDS glass data (this study); (3) XRF whole rock data of pyroclasts (Coltelli et al., 2000); (4) EPMA glass data (Wulf et al., 2004; Wulf et al., 2008); (5) XRF whole rock data of lava (M. Viccaro, this study).

Figure 4c: Harker diagram SiO_2 vs. CaO for chemical discrimination of Monticchio tephras TM-29, TM-30 and TM-31 from the Campanian volcanic province (Phlegrean Fields?): (1) SEM-EDS glass data (Di Vito et al., 2008); (2) SEM-EDS glass data (Sulpizio et al., 2010).

Figure 4d: Harker diagram SiO_2 vs. alkali ratio for chemical discrimination of Monticchio tephras from Stromboli Island: (1) EPMA glass data (Wulf et al., 2004); (2) XRF whole rock data (Hornig-Kjarsgaard et al., 1993); (3) XRF whole rock data (Trua et al., 2002); (4) XRF whole rock data (Beccaluva et al., 1985); (5) EPMA glass data (this study, see Supplementary Table C).

Figure 4e: Harker diagram SiO_2 vs. CaO for chemical discrimination of Monticchio tephras from Ischia Island: (1) XRF whole rock data (Poli et al., 1987); (2) wet whole rock data (Rittmann, 1930); (3) wet whole rock data (Fuchs, 1873); (4) SEM-EDS glass data (Paterne et al., 2008); (5) SEM-EDS glass data (Paterne, 1985; this study).

Figure 4f: Harker diagram SiO_2 vs. CaO for chemical discrimination of Monticchio tephras from Salina Island: (1) XRF whole rock (Gertisser and Keller, 2000); (2) XRF whole rock (Esperança et al., 1992); (3) EPMA glass data (Albert et al., 2012; this study, see Supplementary Table C); (4) EPMA glass data, this study (see Supplementary Table C).

Figure 4g: Harker diagram SiO_2 vs. TiO_2 for chemical discrimination of Monticchio tephras from the Sabatini Volcanic District: (1) XRF whole rock data (Perini et al., 1997; (Perini et al., 2004); (2) EPMA glass data (Sottili et al., 2012).

Figure 5: Synthesis of revised tephrochronology and varve-supported sedimentation rate chronology of the 133 ka Monticchio sequence (upper diagram) and 2σ age uncertainties calculated by the discrepancy between mean radiometric/radioisotopic and Monticchio varve ages of tephras (lower diagram).

Table 1

Table 1

Tephra layer		Core depth (base of tephra)	Composite depth (m)	Varve age (cal. yrs BP) ± 2σ error	Thickness (mm)	Maximum grain size (μm)	Source
TM-25		M49u, 97.5 cm	74.11	105,480 ± 1050	113.0	1500	CP
TM-26		O49u, 40.4 cm	74.47	106,300 ± 1060	1.0	80	E
TM-27		O53u, 45.6 cm	78.85	108,330 ± 1080	2000.0	1300	CP
TM-28	a	M59u, 48.8 cm	81.44	110,410 ± 1100	21.0	160	CP
	b	M59u, 52.5 cm	81.53	110,830 ± 1110	2.0	400	CP
TM-29-1	a	M59u, 68.5 cm	81.69	111,480 ± 1110	0.6	280	PF ?
	b	O58u, 16.4 cm	81.86	112,180 ± 1120	1.0	100	PF ?
	c	O58u, 16.7 cm	81.87	112,210 ± 1120	1.0	180	PF ?
	d	O58u, 16.8 cm	81.87	112,230 ± 1120	0.2	100	PF ?
	e	O58u, 17.0 cm	81.87	112,230 ± 1120	0.5	190	PF ?
	f	O58u, 17.3 cm	81.87	112,250 ± 1120	2.3	300	PF ?
	g	O58u, 17.9 cm	81.88	112,310 ± 1120	0.3	100	PF ?
	h	O58u, 18.6 cm	81.88	112,330 ± 1120	5.0	400	PF ?
	i	O58u, 21.7 cm	81.91	112,460 ± 1120	4.0	260	PF ?
TM-29-2	a	M62u, 60.5 cm	82.06	112,520 ± 1130	6.0	220	PF ?
	b	M62u, 60.9 cm	82.07	112,540 ± 1130	2.5	160	PF ?
	c	M62u, 61.1 cm	82.08	112,560 ± 1130	0.5	110	PF ?
	d	M62u, 61.5 cm	82.08	112,580 ± 1130	2.5	200	PF ?
	e	M62u, 63.0 cm	82.10	112,620 ± 1130	4.0	140	PF ?
	f	M62u, 67.3 cm	82.13	112,790 ± 1130	7.0	180	PF ?
	g	M62u, 73.4 cm	82.20	112,990 ± 1130	16.0	400	PF ?
	h	M62u, 73.9 cm	82.20	113,020 ± 1130	2.5	140	PF ?
TM-30-1	a	M62u, 79.5 cm	82.26	113,370 ± 1140	2.0	100	PF ?
	b	M62u, 80.9 cm	82.28	113,490 ± 1140	3.0	280	PF ?
	c	M64u, 20.7 cm	82.55	113,660 ± 1140	18.0	300	PF ?
	d	M64u, 20.8 cm	82.55	113,670 ± 1140	0.5	100	PF ?
	e	M64u, 26.9 cm	82.61	113,880 ± 1140	1.0	90	PF ?
	f	M64u, 33.9 cm	82.67	114,000 ± 1140	12.0	700	PF ?
TM-30-2	a	M64u, 39.3 cm	82.74	114,440 ± 1140	1.5	300	PF ?
	b	M64u, 40.5 cm	82.75	114,530 ± 1150	2.0	300	PF ?
	c	M64u, 42.0 cm	82.76	114,600 ± 1150	8.0	100	PF ?
	d	M64u, 43.9 cm	82.78	114,720 ± 1150	12.0	800	PF ?
TM-31		M64u, 44.5 cm	82.79	114,770 ± 1150	0.5	180	PF ?
TM-32		M64u, 50.2 cm	82.85	115,250 ± 1150	1.0	120	STR ?
TM-33-1	a	M64u, 71.2 cm	83.05	115,720 ± 1160	10.0	320	IS
	b	M64u, 71.5 cm	83.06	115,750 ± 1160	1.0	100	IS
	c	M64u, 75.5 cm	83.10	116,110 ± 1160	4.0	240	IS
TM-33-2	a	M65u, 28.0 cm	83.43	118,190 ± 1180	0.3	110	IS
	b	M65u, 28.7 cm	83.43	118,210 ± 1180	4.0	250	IS
TM-34		M65u, 39.8 cm	83.54	118,810 ± 1190	0.4	100	SAL ?
TM-35	a	O62u, 63.0 cm	84.14	120,670 ± 1210	3.0	650	CP
	b	O63u, 59.5 cm	84.84	121,940 ± 1220	3.5	230	CP
TM-36		M70u, 22.9 cm	85.30	123,030 ± 1230	1.5	300	SAB
TM-37	a	M70u, 61.5 cm	85.68	124,080 ± 1240	11.0	200	IS
	b	M71o, 76.3 cm	86.18	124,330 ± 1240	8.0	500	IS
	c	M71o, 80.3 cm	86.22	124,360 ± 1240	1.5	150	IS
	d	M71u, 13.0 cm	86.59	124,860 ± 1250	1.0	90	IS
TM-38		M72o, 64.0 cm	87.07	125,550 ± 1260	0.4	150	CP
TM-39		O70u, 52.7 cm	91.98	130,530 ± 1310	6.0	170	CP
TM-40		O70u, 88.0 cm	92.37	130,860 ± 13,090	5.0	170	CP (IS?)
TM-41		M77u, 34.0 cm	92.77	131,020 ± 13,100	6.0	300	CP (IS?)
TM-42		O74u, 70.3 cm	97.69	132,110 ± 13,210	1.0	300	IS

Table 2

Sample	TM-25		TM-26		TM-27		TM-28a		TM-28b		TM-29-1a	
SiO_2	59.10	*1.37*	64.23	*1.57*	60.11	*0.76*	60.22	*0.65*	60.75	*0.74*	49.39	*0.53*
TiO_2	0.39	*0.05*	0.54	*0.09*	0.45	*0.03*	0.46	*0.03*	0.48	*0.02*	1.14	*0.04*
Al_2O_3	17.95	*0.39*	16.82	*1.25*	18.17	*0.26*	18.41	*0.18*	18.45	*0.19*	17.81	*0.21*
FeO	3.32	*0.34*	3.38	*0.59*	2.79	*0.15*	2.94	*0.21*	3.09	*0.08*	8.57	*0.31*
MnO	0.13	*0.02*	0.13	*0.03*	0.23	*0.06*	0.25	*0.05*	0.29	*0.03*	0.15	*0.03*
MgO	0.62	*0.13*	0.94	*0.37*	0.40	*0.08*	0.28	*0.03*	0.31	*0.02*	3.52	*0.15*
CaO	2.54	*0.30*	3.14	*0.75*	1.80	*0.10*	1.74	*0.12*	1.71	*0.11*	8.71	*0.25*
Na_2O	3.85	*0.23*	4.78	*0.34*	6.19	*0.70*	5.97	*0.52*	6.11	*0.41*	2.69	*0.16*
K_2O	8.31	*0.18*	3.79	*0.48*	7.10	*0.48*	6.30	*0.17*	6.61	*0.14*	5.58	*0.30*
P_2O_5	0.16	*0.05*	0.21	*0.04*	0.06	*0.04*	0.04	*0.02*	0.04	*0.02*	0.94	*0.06*
Cl	0.39	*0.03*	0.25	*0.04*	0.70	*0.14*	0.83	*0.14*	0.89	*0.04*	0.25	*0.02*
Total	96.67		98.14		97.86		97.25		98.63		98.70	
Analyses	n=10		n=9		n=22		n=10		n=16		n=13	

Sample	TM-29-1b		TM-29-1c		TM-29-1d		TM-29-1e		TM-29-1f		TM-29-1g	
SiO_2	49.25	*1.14*	50.21	*0.32*	50.38	*0.58*	51.67	*1.65*	50.80	*0.32*	51.69	*0.60*
TiO_2	1.10	*0.03*	1.12	*0.04*	1.10	*0.03*	1.11	*0.02*	1.10	*0.04*	1.09	*0.07*
Al_2O_3	17.67	*0.45*	18.00	*0.11*	18.17	*0.06*	17.89	*0.37*	17.96	*0.20*	17.96	*0.12*
FeO	7.90	*0.17*	8.04	*0.12*	7.85	*0.13*	7.88	*0.15*	7.91	*0.18*	7.75	*0.23*
MnO	0.14	*0.02*	0.15	*0.01*	0.15	*0.03*	0.16	*0.03*	0.13	*0.02*	0.15	*0.03*
MgO	3.29	*0.15*	3.47	*0.15*	3.49	*0.29*	3.10	*0.40*	3.33	*0.22*	2.90	*0.36*
CaO	8.13	*0.21*	8.41	*0.32*	8.44	*0.60*	7.61	*0.98*	7.83	*0.37*	7.17	*0.63*
Na_2O	2.93	*0.04*	2.91	*0.06*	2.96	*0.12*	2.95	*0.11*	2.88	*0.06*	3.00	*0.16*
K_2O	5.78	*0.14*	5.80	*0.14*	5.75	*0.36*	5.79	*0.08*	5.87	*0.28*	6.36	*0.28*
P_2O_5	0.77	*0.10*	0.70	*0.05*	0.73	*0.05*	0.68	*0.03*	0.69	*0.04*	0.72	*0.04*
Cl	0.35	*0.03*	0.34	*0.01*	0.34	*0.02*	0.33	*0.02*	0.35	*0.02*	0.40	*0.03*
Total	97.24		99.07		99.29		99.09		98.76		99.09	
Analyses	n=5		n=7		n=5		n=5		n=8		n=5	

Sample	TM-29-1h		TM-29-1i		TM-29-2a		TM-29-2b		TM-29-2c		TM-29-2d	
SiO_2	52.17	*1.27*	51.54	*1.03*	52.15	*1.24*	52.55	*0.79*	53.91	*0.52*	54.19	*0.34*
TiO_2	1.02	*0.05*	1.10	*0.06*	1.06	*0.05*	1.09	*0.04*	1.13	*0.03*	1.09	*0.03*
Al_2O_3	18.08	*0.32*	17.91	*0.23*	17.46	*0.33*	17.76	*0.35*	17.36	*0.17*	17.39	*0.17*
FeO	7.49	*0.36*	7.43	*0.22*	7.59	*0.26*	7.69	*0.27*	7.72	*0.06*	7.69	*0.22*
MnO	0.15	*0.03*	0.12	*0.02*	0.15	*0.03*	0.14	*0.02*	0.14	*0.03*	0.15	*0.04*
MgO	2.65	*0.57*	3.38	*0.36*	2.87	*0.39*	2.96	*0.38*	2.51	*0.16*	2.37	*0.11*
CaO	6.98	*0.86*	7.89	*0.72*	7.11	*0.94*	7.38	*0.63*	6.38	*0.32*	6.10	*0.21*
Na_2O	3.16	*0.35*	2.76	*0.12*	2.93	*0.21*	2.94	*0.21*	3.13	*0.09*	3.14	*0.04*
K_2O	6.01	*0.54*	5.56	*0.34*	5.54	*0.24*	5.56	*0.22*	5.85	*0.26*	5.90	*0.17*
P_2O_5	0.67	*0.07*	0.66	*0.05*	0.65	*0.09*	0.69	*0.06*	0.67	*0.04*	0.64	*0.04*
Cl	0.37	*0.05*	0.33	*0.03*	0.32	*0.02*	0.32	*0.02*	0.33	*0.01*	0.33	*0.02*
Total	98.67		98.60		97.76		99.02		99.05		98.91	
Analyses	n=15		n=16		n=9		n=14		n=5		n=14	

Sample	TM-29-2e		TM-29-2f		TM-29-2g		TM-30-1a		TM-30-1b		TM-30-1c	
SiO_2	53.15	*1.19*	54.57	*0.91*	56.91	*2.04*	53.22	*0.72*	56.43	*0.70*	55.52	*0.70*
TiO_2	1.04	*0.09*	1.13	*0.11*	0.82	*0.18*	0.75	*0.08*	0.60	*0.09*	0.80	*0.13*
Al_2O_3	17.46	*0.45*	17.85	*0.21*	18.31	*1.06*	16.73	*0.77*	18.64	*1.30*	17.59	*0.46*
FeO	7.65	*0.35*	6.78	*0.32*	5.50	*1.26*	6.20	*0.42*	5.29	*0.58*	6.66	*0.83*
MnO	0.15	*0.03*	0.14	*0.03*	0.14	*0.03*	0.14	*0.03*	0.14	*0.04*	0.14	*0.04*
MgO	2.45	*0.24*	2.59	*0.32*	1.79	*0.83*	1.97	*0.21*	1.61	*0.29*	2.04	*0.49*
CaO	6.30	*0.64*	6.14	*0.53*	4.91	*1.25*	5.69	*0.57*	5.14	*0.88*	5.49	*0.86*
Na_2O	3.15	*0.20*	3.31	*0.17*	3.69	*0.25*	2.96	*0.18*	3.49	*0.16*	3.16	*0.17*
K_2O	5.89	*0.43*	6.07	*0.24*	6.35	*0.92*	5.77	*0.24*	6.26	*0.66*	6.35	*0.75*
P_2O_5	0.65	*0.06*	0.64	*0.07*	0.38	*0.14*	0.51	*0.07*	0.37	*0.05*	0.47	*0.12*
Cl	0.33	*0.03*	0.33	*0.03*	0.37	*0.10*	0.32	*0.03*	0.28	*0.04*	0.40	*0.10*
Total	98.14		99.46		99.09		94.18		98.19		98.52	
Analyses	n=15		n=19		n=18		n=6		n=10		n=12	

Table 2 (continued)

Sample	TM-30-1d		TM-30-1e		TM-30-1f		TM-30-2b		TM-30-2c		TM-30-2d	
SiO_2	54.64	*0.91*	55.76	*0.78*	57.95	*1.89*	52.39	*0.90*	54.24	*0.73*	59.85	*0.80*
TiO_2	0.65	*0.02*	0.66	*0.07*	0.64	*0.22*	1.05	*0.12*	0.81	*0.05*	0.50	*0.03*
Al_2O_3	17.70	*0.68*	17.62	*0.61*	17.54	*0.33*	17.71	*0.64*	18.02	*0.25*	17.91	*0.44*
FeO	5.93	*0.19*	5.55	*1.15*	5.00	*1.38*	7.17	*0.69*	6.68	*0.35*	3.76	*0.29*
MnO	0.16	*0.03*	0.14	*0.04*	0.12	*0.03*	0.15	*0.03*	0.15	*0.02*	0.16	*0.03*
MgO	1.56	*0.08*	1.32	*0.35*	1.30	*0.71*	2.85	*0.44*	2.65	*0.25*	0.88	*0.15*
CaO	5.01	*0.51*	4.46	*0.78*	4.21	*1.20*	6.60	*0.74*	6.29	*0.34*	3.20	*0.34*
Na_2O	3.41	*0.30*	3.49	*0.25*	3.48	*0.33*	3.12	*0.49*	3.04	*0.11*	4.14	*0.30*
K_2O	6.55	*0.37*	6.61	*0.29*	6.91	*0.82*	5.73	*0.48*	6.13	*0.17*	6.62	*0.38*
P_2O_5	0.42	*0.04*	0.45	*0.06*	0.31	*0.20*	0.52	*0.08*	0.58	*0.07*	0.17	*0.03*
Cl	0.43	*0.05*	0.42	*0.15*	0.43	*0.08*	0.32	*0.05*	0.34	*0.02*	0.47	*0.03*
Total	96.37		96.37		97.80		97.60		98.90		97.57	
Analyses	n=5		n=6		n=13		n=10		n=11		n=10	

Sample	TM-31		TM-32		TM-33-1a		TM-33-1c		TM-33-2a		TM-33-2b	
SiO_2	61.10	*5.48*	59.73	*0.59*	59.83	*0.64*	61.64	*0.59*	61.14	*1.21*	58.57	*0.50*
TiO_2	0.73	*0.18*	0.77	*0.04*	0.46	*0.02*	0.67	*0.03*	0.62	*0.01*	0.43	*0.02*
Al_2O_3	18.43	*0.46*	16.95	*0.33*	18.66	*0.17*	18.45	*0.23*	18.01	*0.38*	18.31	*0.17*
FeO	4.18	*1.77*	6.47	*0.40*	3.03	*0.06*	2.98	*0.26*	2.77	*0.08*	2.95	*0.13*
MnO	0.24	*0.09*	0.16	*0.03*	0.25	*0.03*	0.29	*0.05*	0.28	*0.03*	0.19	*0.03*
MgO	1.12	*1.11*	1.94	*0.19*	0.41	*0.01*	0.35	*0.05*	0.31	*0.04*	0.38	*0.04*
CaO	2.86	*2.58*	4.38	*0.29*	1.86	*0.13*	1.05	*0.07*	1.00	*0.06*	1.92	*0.04*
Na_2O	2.03	*0.48*	4.17	*0.13*	5.49	*0.42*	6.96	*0.31*	6.99	*0.42*	5.27	*0.12*
K_2O	5.58	*0.64*	4.76	*0.24*	7.27	*0.07*	5.75	*0.14*	5.74	*0.18*	7.40	*0.10*
P_2O_5	0.22	*0.25*	0.45	*0.05*	0.06	*0.02*	0.05	*0.03*	0.06	*0.03*	0.07	*0.02*
Cl	0.59	*0.16*	0.37	*0.04*	0.77	*0.03*	0.69	*0.04*	0.70	*0.02*	0.65	*0.03*
Total	96.99		100.07		97.93		98.71		97.46		95.99	
Analyses	n=9		n=10		n=9		n=10		n=9		n=7	

Sample	TM-34		TM-35a		TM-36		TM-37a		TM-37b		TM-37c	
SiO_2	56.13	*1.53*	58.99	*0.58*	54.00	*0.83*	60.68	*0.60*	60.87	*0.83*	60.84	*0.67*
TiO_2	1.26	*0.10*	0.41	*0.02*	0.40	*0.02*	0.61	*0.03*	0.63	*0.03*	0.61	*0.03*
Al_2O_3	15.69	*0.74*	18.66	*0.21*	19.56	*0.26*	17.91	*0.18*	17.89	*0.41*	18.10	*0.32*
FeO	9.46	*0.83*	2.86	*0.09*	3.53	*0.41*	2.61	*0.11*	2.56	*0.03*	2.62	*0.14*
MnO	0.21	*0.03*	0.17	*0.04*	0.17	*0.01*	0.23	*0.04*	0.22	*0.03*	0.25	*0.06*
MgO	2.88	*0.37*	0.40	*0.02*	0.27	*0.04*	0.31	*0.01*	0.33	*0.01*	0.35	*0.05*
CaO	6.85	*0.61*	2.18	*0.05*	4.55	*0.33*	1.07	*0.03*	1.10	*0.02*	1.11	*0.07*
Na_2O	3.81	*0.26*	5.14	*0.16*	5.29	*0.36*	6.63	*0.35*	6.44	*0.42*	7.12	*0.58*
K_2O	2.41	*0.19*	7.94	*0.17*	7.33	*0.76*	5.90	*0.10*	5.87	*0.15*	5.99	*0.14*
P_2O_5	0.48	*0.06*	0.05	*0.02*	0.04	*0.02*	0.04	*0.02*	0.07	*0.02*	0.07	*0.02*
Cl	0.21	*0.03*	0.58	*0.03*	0.13	*0.01*	0.62	*0.03*	0.56	*0.04*	0.47	*0.07*
Total	99.35		97.26		95.24		96.46		96.41		97.44	
Analyses	n=15		n=7		n=10		n=8		n=7		n=7	

Sample	TM-37d		TM-38		TM-39		TM-40		TM-41		TM-42	
SiO_2	61.10	*0.45*	57.58	*0.60*	56.67	*0.51*	60.37	*0.84*	59.07	*1.26*	61.89	*0.53*
TiO_2	0.63	*0.02*	0.48	*0.02*	0.58	*0.02*	0.61	*0.05*	0.48	*0.06*	0.66	*0.04*
Al_2O_3	18.17	*0.16*	19.03	*0.12*	18.35	*0.23*	18.09	*0.16*	19.17	*0.56*	18.65	*0.19*
FeO	2.55	*0.11*	3.34	*0.08*	4.39	*0.25*	2.78	*0.22*	2.60	*0.75*	2.53	*0.09*
MnO	0.19	*0.03*	0.17	*0.03*	0.19	*0.02*	0.19	*0.04*	0.12	*0.04*	0.20	*0.03*
MgO	0.36	*0.02*	0.68	*0.02*	0.93	*0.07*	0.49	*0.13*	0.58	*0.18*	0.40	*0.02*
CaO	1.16	*0.06*	2.48	*0.05*	3.21	*0.09*	1.61	*0.31*	2.33	*0.45*	1.28	*0.06*
Na_2O	6.47	*0.28*	4.49	*0.26*	4.79	*0.25*	5.67	*0.31*	4.34	*0.70*	5.84	*0.56*
K_2O	6.16	*0.15*	8.42	*0.12*	7.45	*0.32*	6.27	*0.25*	7.51	*0.38*	6.36	*0.18*
P_2O_5	0.07	*0.04*	0.10	*0.04*	0.20	*0.03*	0.13	*0.04*	0.11	*0.02*	0.05	*0.03*
Cl	0.51	*0.04*	0.51	*0.03*	0.47	*0.03*	0.40	*0.07*	0.39	*0.13*	0.51	*0.02*
Total	97.25		97.28		97.13		96.50		96.61		98.25	
Analyses	n=13		n=13		n=11		n=9		n=11		n=19	

Table 3

	Distal tephra correlatives											
Sample	***C-27 KET 80-04 930-945 cm***	***C-27 KET 80-04 930-945 cm***	***C-31 KET 80-04 975-985 cm***	***TAU1-b? DED 87-08 1254 cm***	***Sabatini rew? DED 87-08 1254 cm***	***C-34 reworked? DED 87-08 1254 cm***	***C-34 DED 87-08 1260 cm***	***C-35 KET 82-22 485 cm***	***C-36 KET 80-04 1083 cm***	***C-36 KET 80-04 1083 cm***	***Etnean KET 80-04 1095 cm***	***Etnean KET 80-04 1141 cm***
SiO_2	60.46	61.87	61.80	51.10	56.11 *(0.37)*	61.20 *(0.60)*	60.92 *(0.78)*	61.97	61.42	61.22	62.38	62.55
TiO_2	0.47	0.40	0.45	1.70	0.76 *(0.05)*	0.46 *(0.12)*	0.42 *(0.10)*	0.44	0.30	0.44	0.85	0.83
Al_2O_3	18.31	18.21	18.11	17.38	19.73 *(0.08)*	18.37 *(0.19)*	18.43 *(0.25)*	18.57	19.27	18.43	17.95	17.24
FeO	3.51	3.08	3.16	8.59	4.25 *(0.20)*	3.11 *(0.28)*	3.11 *(0.15)*	3.17	2.95	3.10	5.11	5.28
MnO	0.16	0.22	0.28	0.22	0.18 *(0.05)*	0.24 *(0.12)*	0.23 *(0.10)*	0.00	0.00	0.21	-	-
MgO	0.75	0.39	0.31	3.15	1.16 *(0.10)*	0.38 *(0.21)*	0.33 *(0.12)*	0.31	0.34	0.33	1.40	1.25
CaO	2.59	1.79	1.76	7.85	3.95 *(0.09)*	1.83 *(0.47)*	1.80 *(0.19)*	1.92	2.71	1.82	4.64	4.19
Na_2O	3.69	5.82	5.64	3.30	5.38 *(0.35)*	5.61 *(1.29)*	5.91 *(0.38)*	6.58	4.47	5.63	4.38	4.92
K_2O	9.23	7.10	7.34	5.38	7.67 *(0.27)*	7.81 *(1.09)*	7.63 *(0.49)*	7.05	8.55	7.63	3.30	3.22
P_2O_5	0.01	0.00	0.02	0.77	0.15 *(0.15)*	0.00 *(0.00)*	0.01 *(0.04)*	0.00	0.00	0.00	-	-
Total	99.18	98.88	98.87	99.92	99.32	99.01	98.80	100.01	100.01	98.81	100.01	99.48
Age	*103.6 ka*	*103.6 ka*	*107 ka*	*115.2 ka*	*115.2 ka*	*115.2 ka*	*116.1 ka*	*121.5 ka*	*123.2 ka*	*125.4 ka*	*124.6 ka*	*130.2 ka*
Ref.	(1)	(1)	(1)	* N=1	* N=2	* N=18	* N=19	(1)	(1)	(1)	* N=1	* N=1

								Proximal tephra correlatives					
Sample	***C-38 DED 87-08 1370 cm***	***C-39 DED 87-08 1370 cm***	***C-39 DED 87-08 1370 cm***	***Lake Ohrid OT0701-7a***	***Lake Ohrid OT0701-7b***	***TAU1-b sc***	***TAU1-b ch***	***VDP1 Valle dei Preti Sabatini***	***Punta Imperatore Ischia***		***Monte Vezzi lavas Ischia***	***Upper Scarrupata Ischia***	***Lower Scarrupata Ischia***
SiO_2	61.22	62.61	61.95	50.86	58.30	51.99	62.13	54.28	63.56	61.05	62.85	61.74	62.63
TiO_2	0.45	0.64	0.38	1.15	0.63	1.25	0.60	0.32	0.77	0.00	0.67	0.66	0.44
Al_2O_3	18.44	18.12	18.26	18.55	19.75	19.33	18.56	19.76	19.09	18.35	18.76	17.91	18.84
Fe_2O_3	-	-	-	-	-	-	-	-	1.99	4.21	2.17	2.78	0.89
FeO	3.08	2.75	3.05	8.33	3.62	7.10	2.98	2.78	1.37	2.12	0.81	0.25	1.63
MnO	0.21	0.22	0.12	0.22	0.15	0.23	0.17	0.25	0.24	0.04	0.18	0.21	0.09
MgO	0.22	0.15	0.49	3.19	0.82	2.76	0.68	0.15	0.81	0.90	0.42	0.29	0.51
CaO	1.65	1.01	2.06	8.47	3.41	7.10	2.48	3.05	1.00	2.05	0.86	0.65	1.37
Na_2O	5.90	6.85	4.18	3.27	4.54	4.00	4.59	6.41	5.54	5.94	6.57	6.37	4.27
K_2O	7.65	6.56	8.75	5.40	8.36	6.22	7.81	7.32	5.85	5.28	5.96	6.07	6.95
P_2O_5	0.00	0.00	0.00	0.28	0.01	-	-	0.01	0.00	0.00	0.03	0.01	0.04
Total	98.82	98.91	99.24	99.99	99.99	99.98	100.00	94.36	101.37	100.26	99.27	96.92	97.67
Age	*137 ka*	*137 ka*	*137 ka*					*< 154 ka*	*118.5 ka*	*118.5 ka*	*126 ka*	*130 ka*	*≥133 ka*
Ref.	(1)	(1)	(1)	(2)	(2)	(3)	(3)	(4)	(5)	(6)	(5)	(5)	(5)

Table 4

Table 4

Monticchio Tephra	Tephra event (Source)	Monticchio varve age (calendar yrs BP)	Weighted mean age of tephra correlative (cal yr BP)	2 σ error range of ages of correlatives (cal yr BP)	Tephra dating method and (total number of dating) of correlatives	Reference (dating of correlative)
TM-1	AD 1631 (V)	90	319	319	Historical record	1
TM-2a	AD 512 (V)	1420	1,438	1438	Historical record	2
TM-2b	Pollena AD472 (V)	1440	1,478	1478	Historical record	2
TM-3b	AP3 (V)	4020	2,850	2,750 – 2,950	^{14}C (1)	2
TM-3c	AP2 (V)	4150	3,470	3,270 – 4,090	^{14}C (4)	2, 3, 4, 5
TM-4	Pomici di Avellino (V)	4310	3,950	3,480 – 4,780	^{14}C (27)	2, 3, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15
TM-5a	Agnano Mt. Spina (PF)	4620	4,740	4,090 – 5,590	^{14}C (9)	12, 16, 17, 18, 19
TM-6b	Pomici di Mercato (V)	9680	8,900	8,480 – 9,680	^{14}C (5)	5, 6, 14, 20
TM-7b	Pomici Principali (PF)	12,180	11,970	11,240 – 12,390	^{14}C (2)	19, 21
TM-8	NYT (PF)	14,120	13,570	12,580 – 15,650	^{40}Ar/^{39}Ar (1), ^{14}C (14)	12, 16, 18, 19, 22
TM-9	VM1/GM1 (PF)	14,560	14,350	13,350 – 15,750	^{40}Ar/^{39}Ar (1), ^{14}C (2)	19, 23
TM-10d	Lagno Amendolare (PF)	15,550	15,300	14,130 – 16,460	^{14}C (3)	7, 19, 24
TM-11	Biancavilla / Y-1 (E)	16,440	17,350	16,810 – 17,910	^{14}C (3)	14, 19, 26
TM-12	Pomici Verdoline (V)	17,560	18,920	17,070 – 20,330	^{14}C (7)	5, 6, 19, 27, 28
TM-13	Pomici di Base (V)	19,280	21,700	19,600 – 24,470	^{14}C (6), K/Ar (1)	5, 6, 19, 28, 29, 30
TM-14	Solchiaro (PV)	21,260	23,260	22,540 – 23,980	^{14}C (1)	31
TM-15	Y-3 (PF?)	27,260	30,600	30,180 – 31,130	^{14}C (3)	32, 33, 34
TM-16b	Codola (V/PF?)	31,120	34,270	32,530 – 36,010	^{14}C (1)	35
TM-17bc	Albano Unit 7 (A)	31,830	35,800	29,000 – 40,000	^{40}Ar/^{39}Ar (3)	36
TM-18	CI / Y-5 (PF)	36,770	39,070	33,950 – 43,150	^{40}Ar/^{39}Ar (5), ^{14}C (3)	7, 32, 37, 38, 39, 40, 41
TM-19	TVE*ss* (IS)	60,060	55,110	46,250 – 67,950	^{40}Ar/^{39}Ar (3), K/Ar (5)	7, 26, 42
TM-20	UMSA (IS)	61,370	56,000	48,000 – 64,000	^{40}Ar/^{39}Ar (1)	26
TM-21	Petrazza / Y-9 (STR)	78,340	75,300	69,300 – 81,300	K/Ar (1)	43
TM-22	Ignimbrite Z / P-10 (PA)	89,130	84,000	80,000 – 88,000	Sapropel (1)	44
TM-23-11	POP1 / C-22 (CP or RP)	95,180	92,400	87,800 – 97,000	^{40}Ar/^{39}Ar (2)	45
TM-25	X-5 / C-27 (CP)	105,480	106,090	101,000 – 109,000	^{40}Ar/^{39}Ar (2)	26, 45
TM-27	X-6 / C-31 (CP)	108,330	109,000	105,000 – 113,000	Sapropel (1)	26, 46
TM-33-2b	Punta Imperatore / C-35 (IS)	118,210	118,460	110,750 – 128,350	K/Ar (4)	42

Figure 1

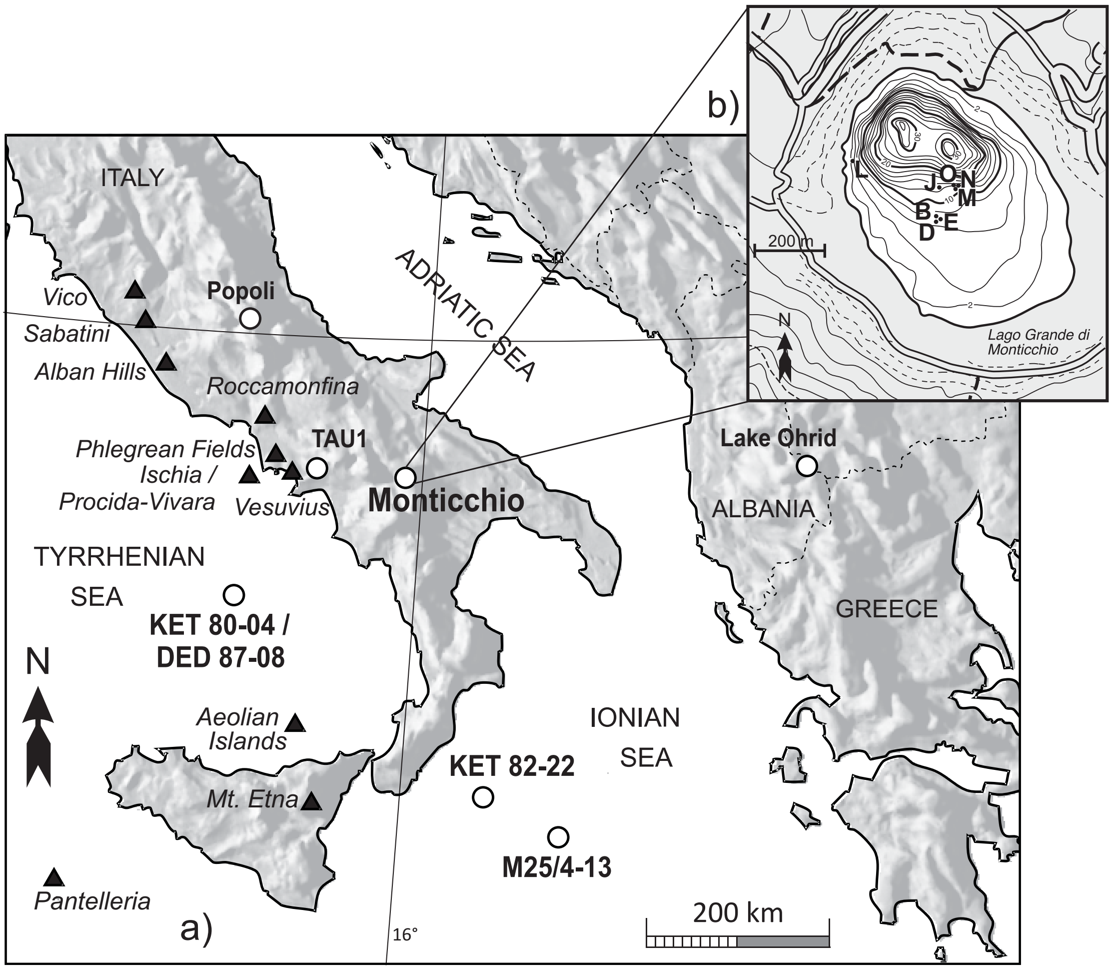

Figure 1

Figure 2

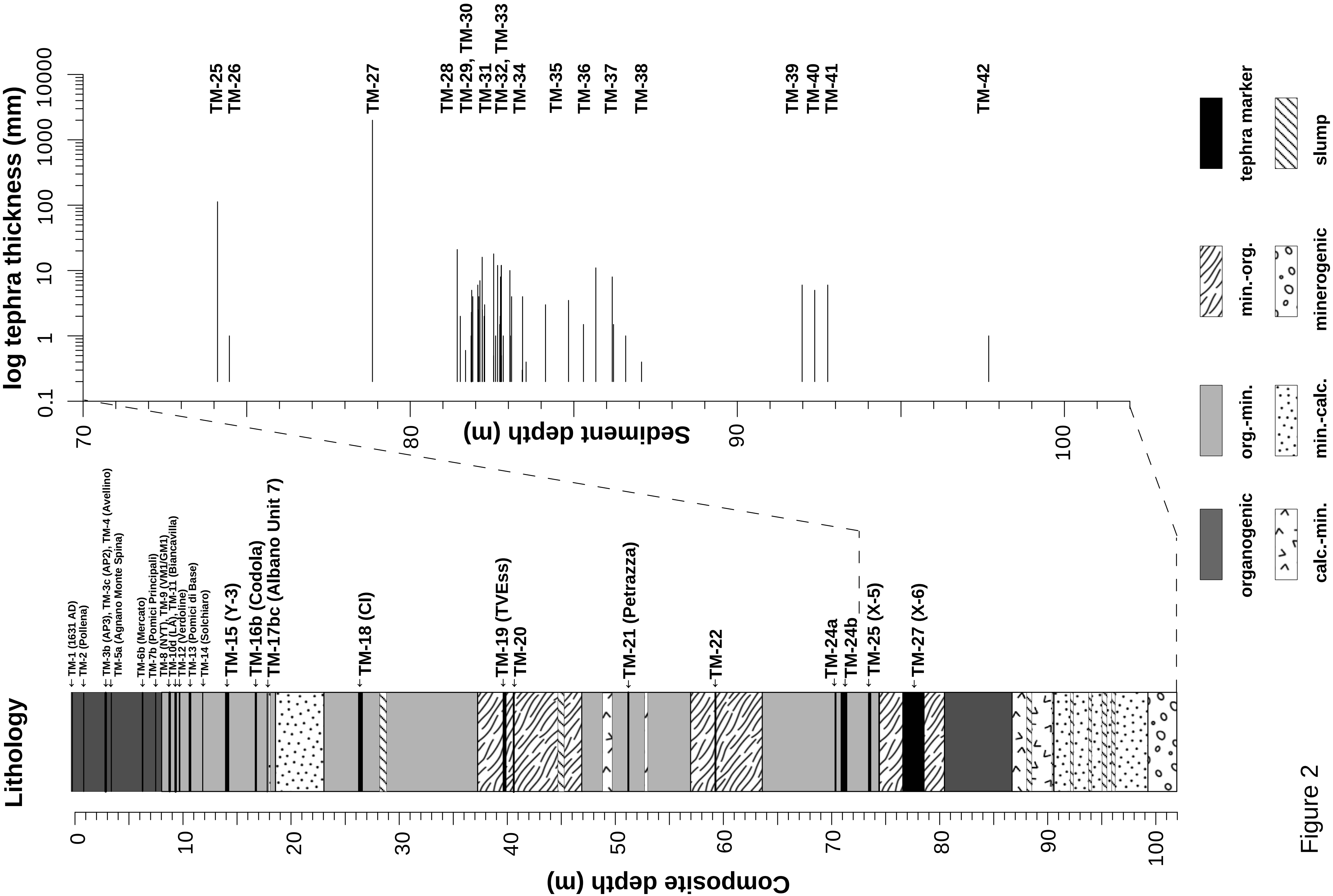

Figure 2

Figure 3

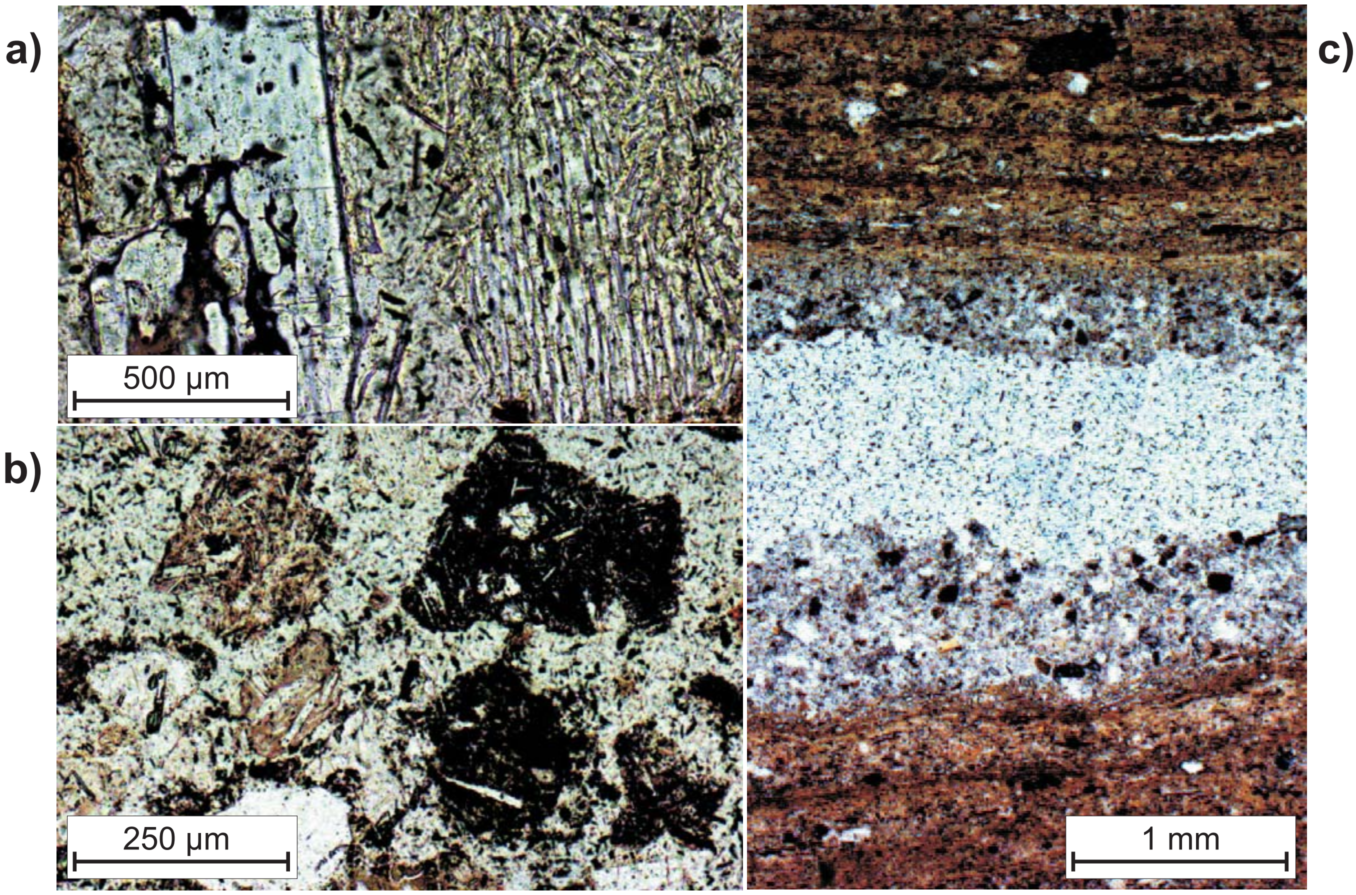

Figure 3

Figure 4a

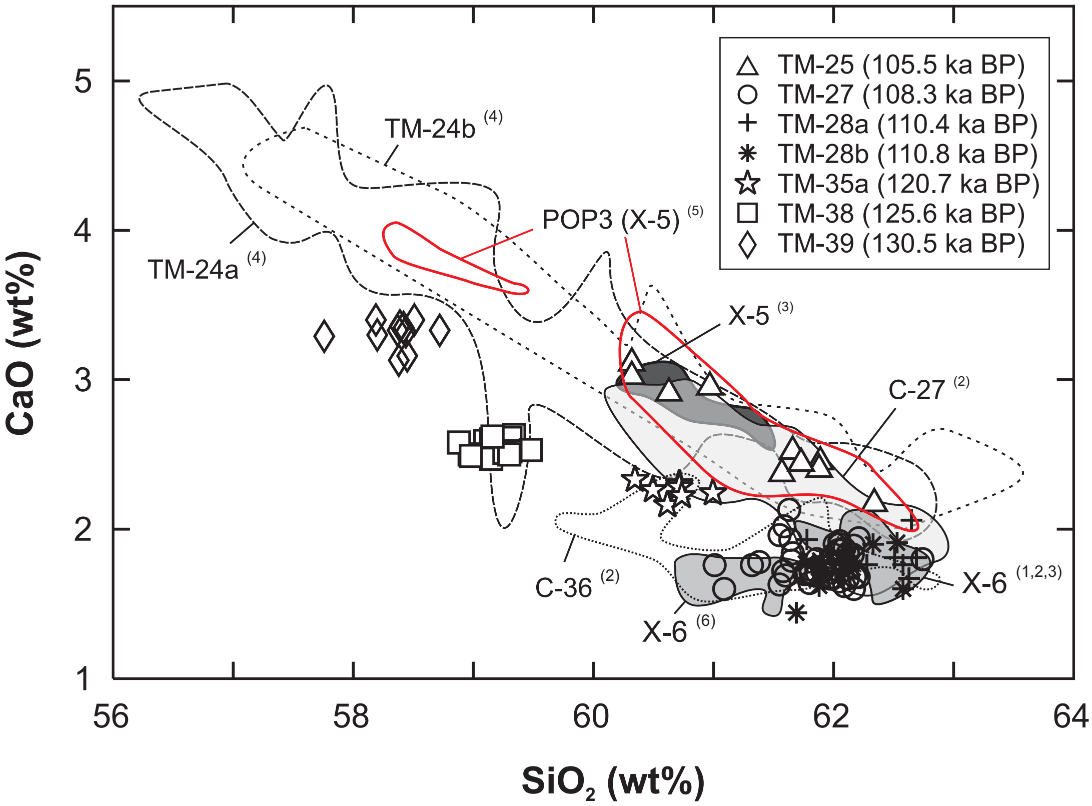

Figure 4a

Figure 4b

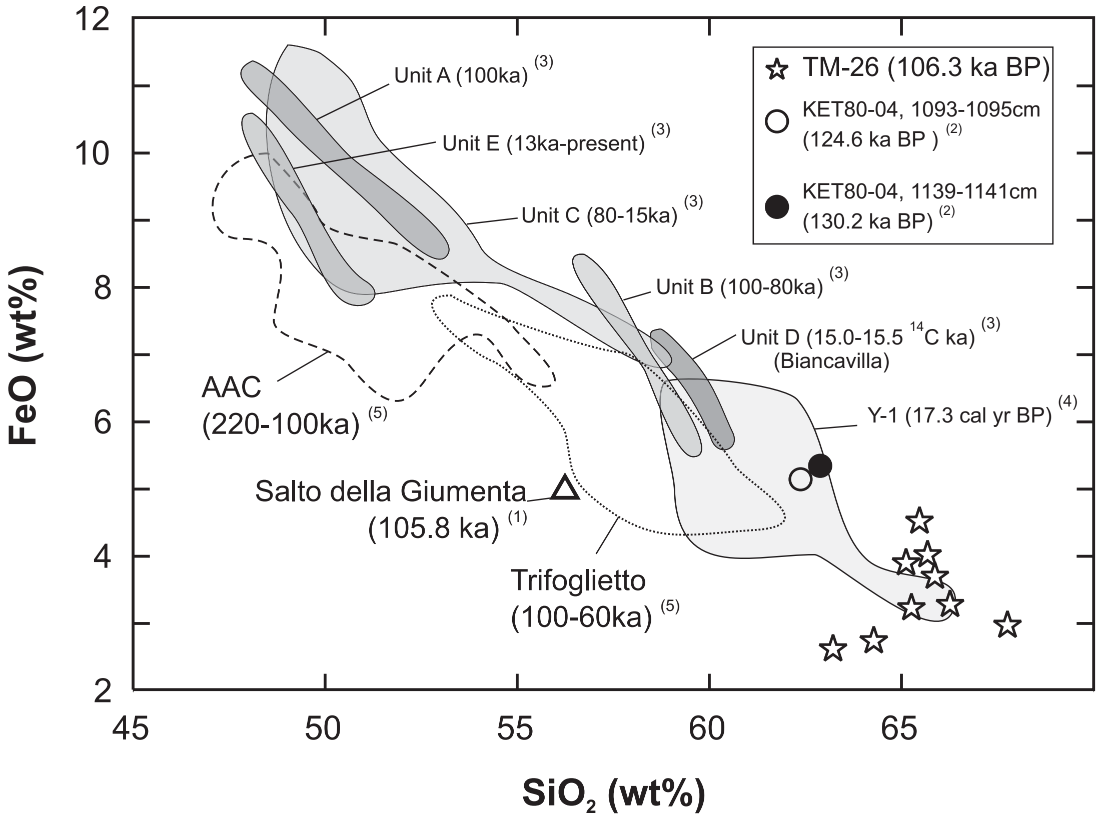

Figure 4b

Figure 4c

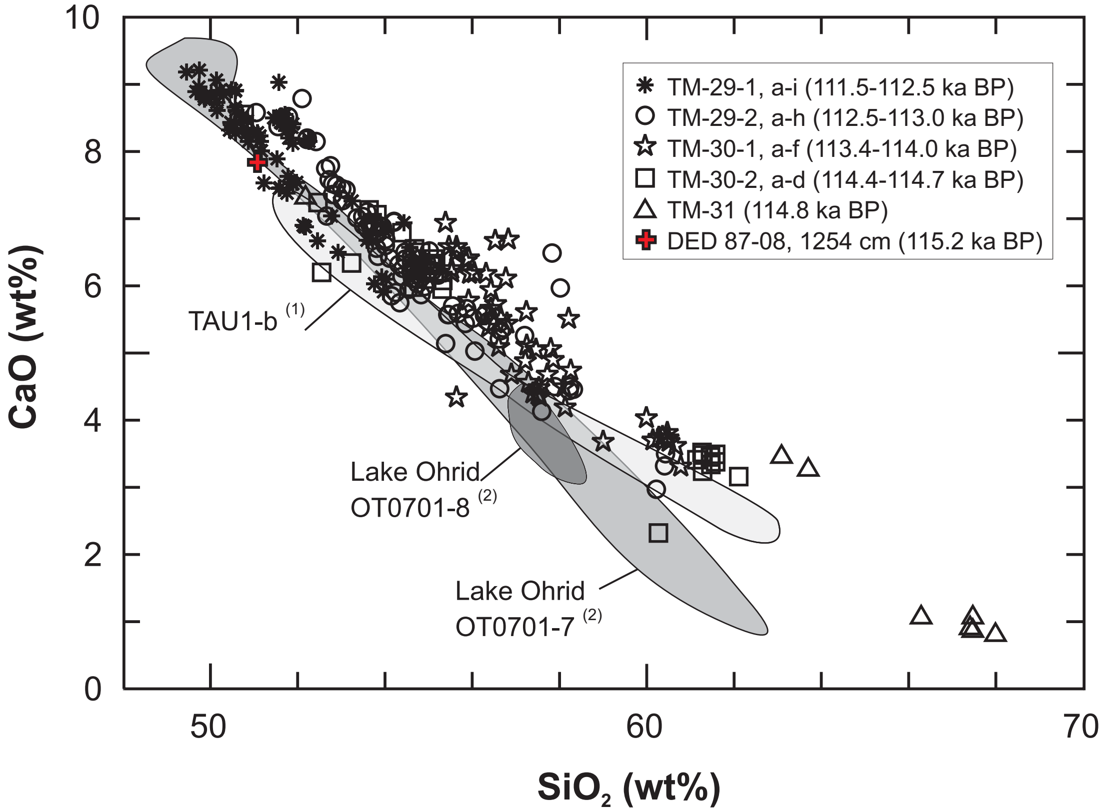

Figure 4c

Figure 4d

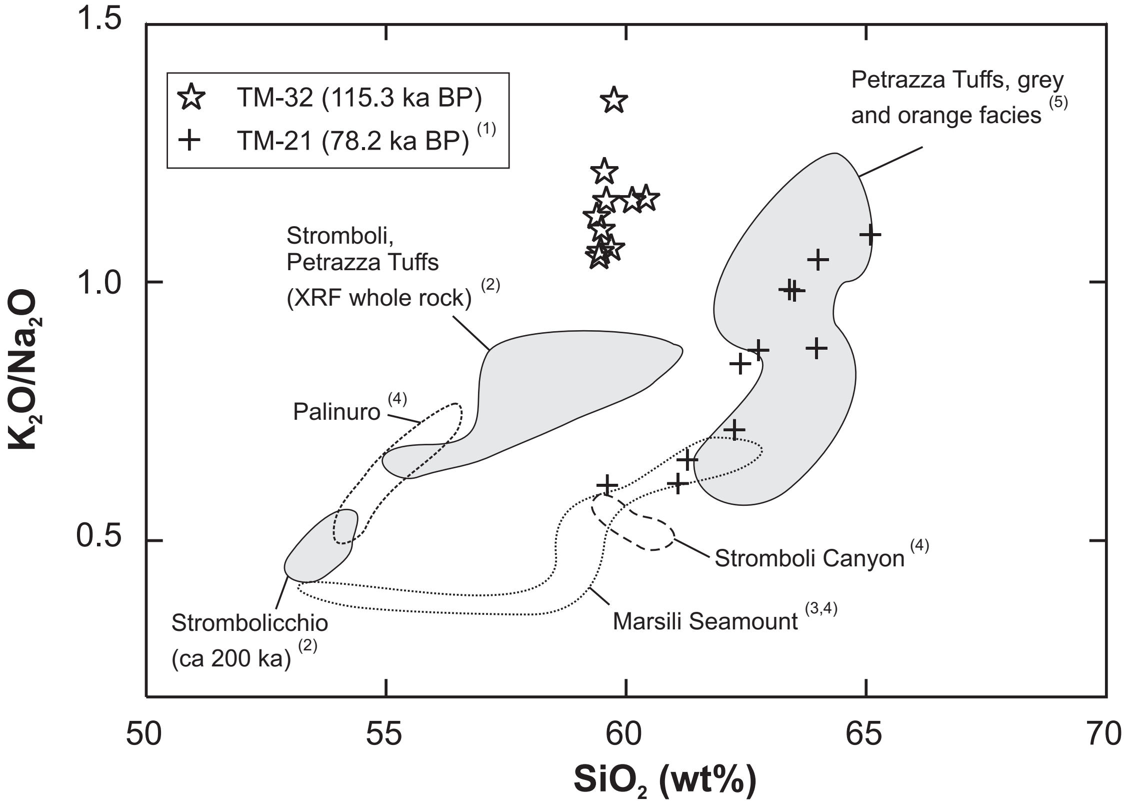

Figure 4d

Figure 4e

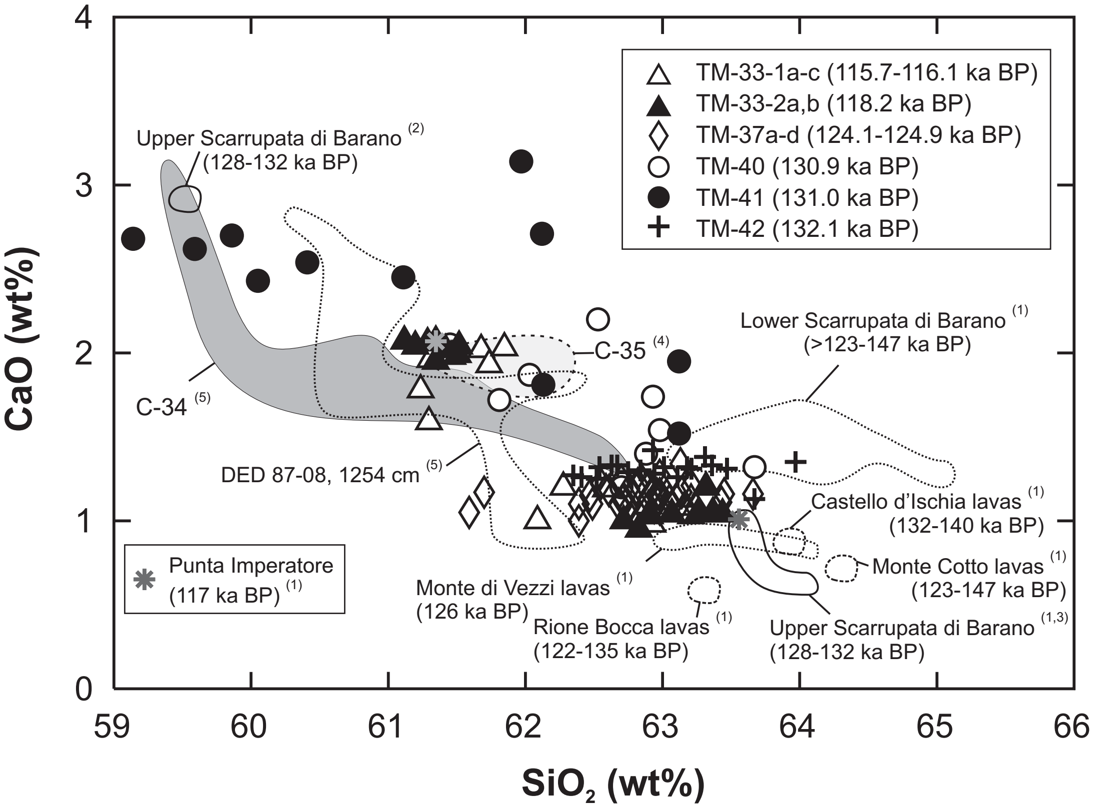

Figure 4e

Figure 4f

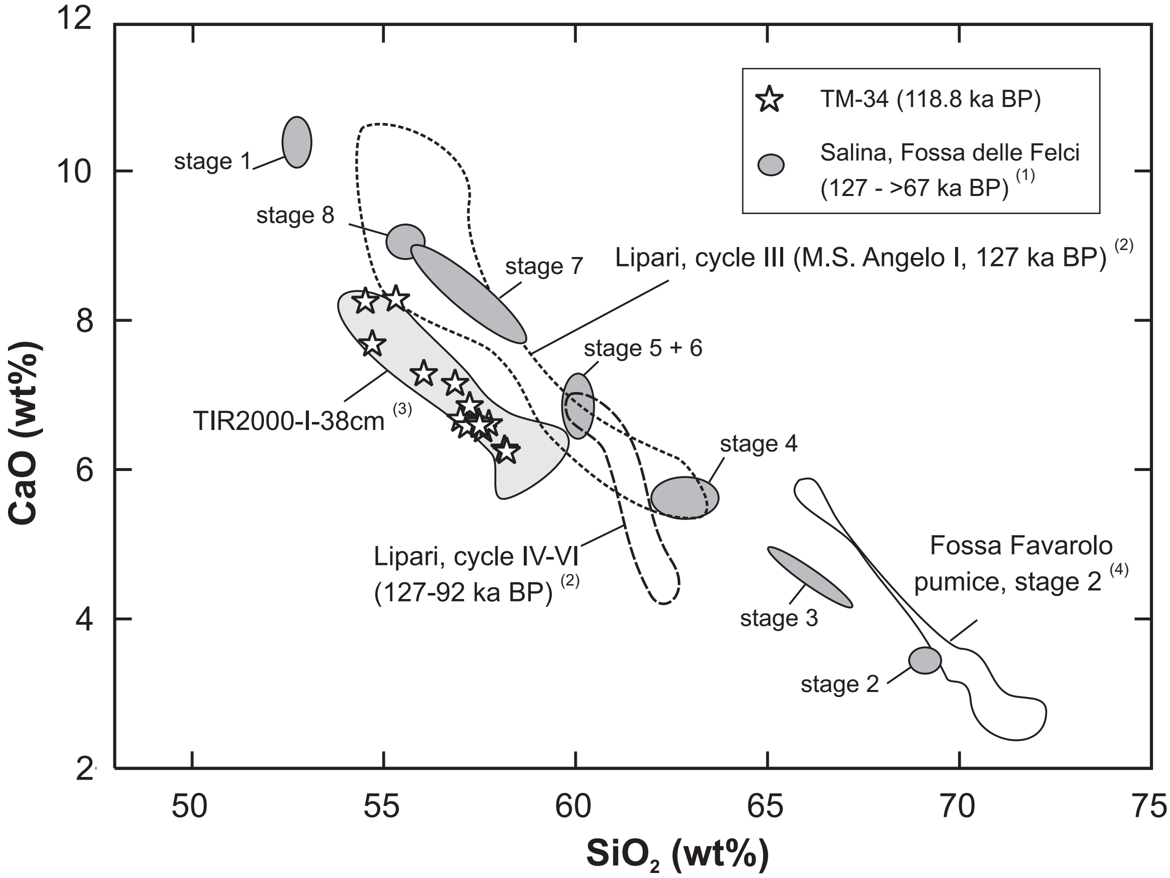

Figure 4f

Figure 4g

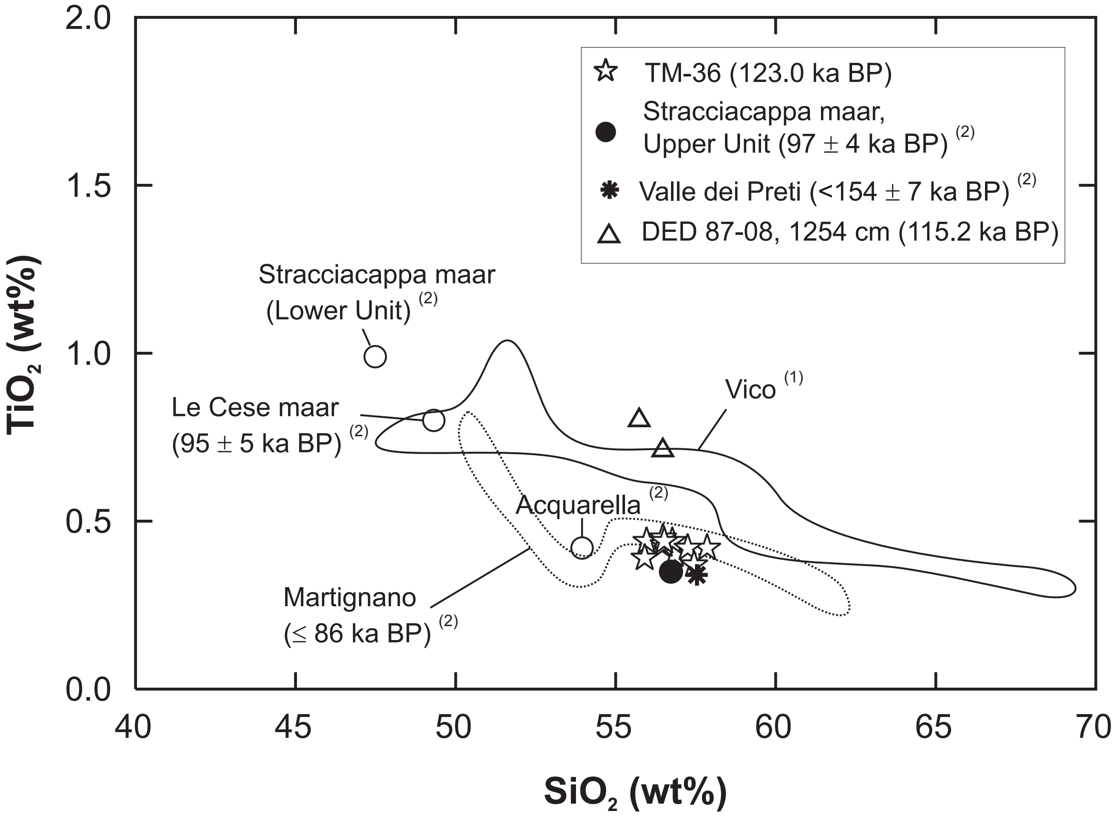

Figure 4g

Figure 5

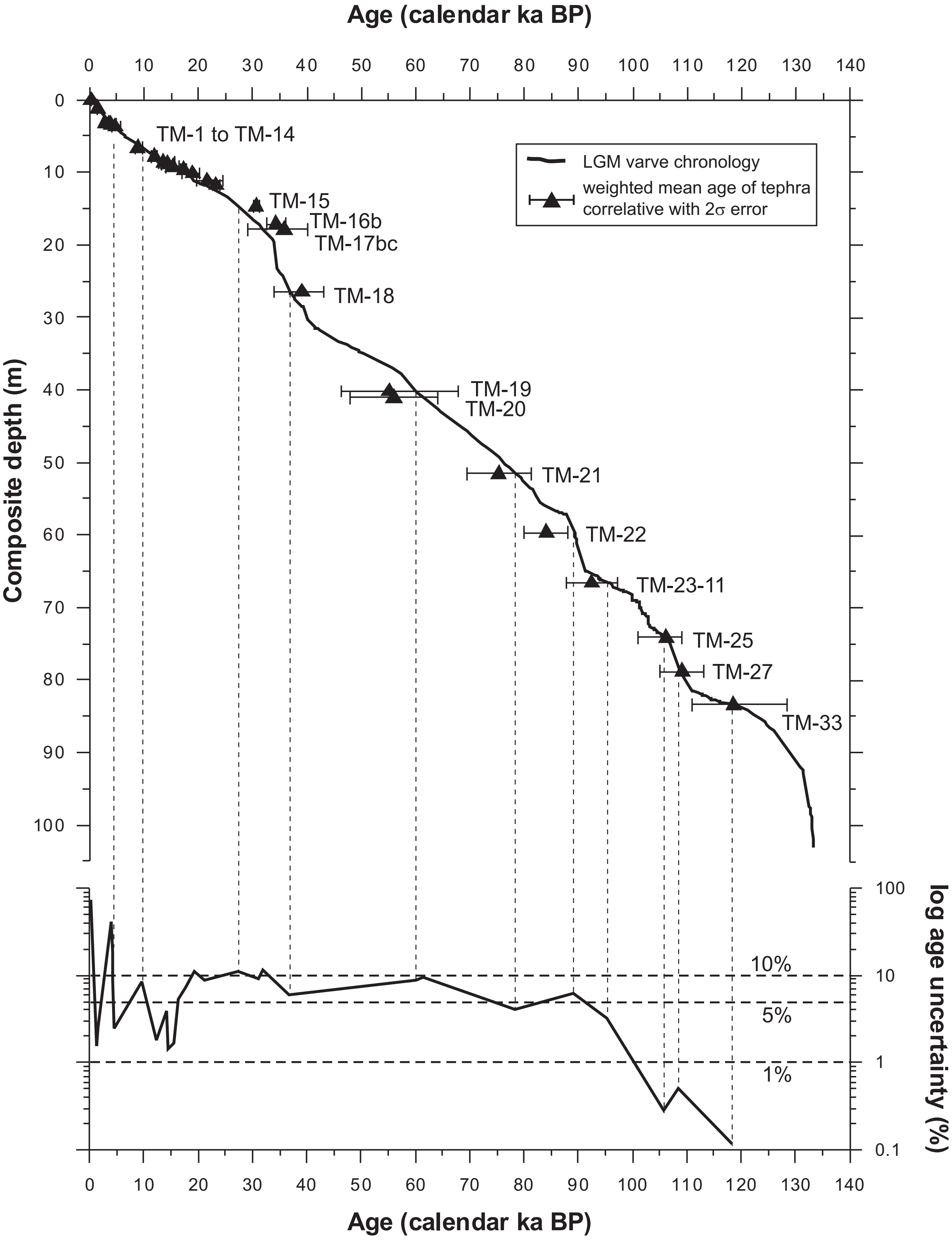

Figure 5

Supplementary Table A

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Supplementary Table B

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Supplementary Table C

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