Available online http://amq.aiqua.it
ISSN (print): 2279-7327, ISSN (online): 2279-7335

Alpine and Mediterranean Quaternary, 29 (2), 2016, 123 -135

Work presented during the AIQUA scientific conferences
"Waiting for the Nagoya INQUA XIX Congress", held in Florence, June 18 - 19, 2015

THE MONTALBANO JONICO SECTION (SOUTH ITALY) AS A REFERENCE FOR THE EARLY/MIDDLE PLEISTOCENE BOUNDARY

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ABSTRACT: The most recent data obtained at the Montalbano Jonico succession (MJS), in the interval including the Marine Isotope Stage (MIS) 19, document the occurrence of numerous chronostratigraphic constraints and paleoenvironmental events contributing to the knowledge of a crucial time through the Lower-Middle Pleistocene transition, characterised by major modifications of the Earth's climate system. Marine and terrestrial biologic data-sets (pollen, ostracods, benthic and planktonic foraminifera, coccolithophores, teleostean fishes, mollusks) are compared with the high resolution astronomically-tuned benthic oxygen isotope curve in order to provide accurate paleoenvironmental reconstruction and acquire additional climatostratigraphic and biostratigraphic constraints within a chronostratigraphic framework which also includes the $^{40}Ar/^{39}Ar$ ages of three volcaniclastic layers. Environmental and climatic events (e.g. Termination IX, substages 19.3, 19.2, and 19.1, maximum flooding and climate optimum, maximum depth) highlight a succession of clear paleoenvironmental changes close to MIS 19, showing a remarkable correspondence between the response of marine and terrestrial proxies. Such changes have stratigraphic implication and high potential of correlation as they evidence wide scale climate changes, stressing the tight interconnection between the Mediterranean region and North Atlantic Ocean. Based on these results the MJS reveals to be an excellent candidate for the Lower-Middle Pleistocene Subseries boundary. In fact, at present the MJS fully meets the requirements indicated by Remane et al. (1996) for a GSSP selection with the sole exception that a paleomagnetic signal is missing. ^{10}Be analyses are in progress and should enhance the already rich documentation of several independent age-significant elements, contributing to the recent critical discussion on the significance of the magnetic signal at the Matuyama-Brunhes boundary as well as its role as a primary marker for the Middle Pleistocene GSSP definition.

Keywords: Montalbano Jonico section (South Italy), Early-Middle Pleistocene boundary, chronological and climatostratigraphical constraints

1. INTRODUCTION

The Montalbano Jonico section (MJS) is a candidate for the global boundary stratotype section and point (GSSP) of the Middle Pleistocene Subseries (Ciaranfi et al., 1997) due to the detailed biostratigraphic, climatostratigraphic and chronological constraints arising from multidisciplinary studies conducted over the past twenty years (Ciaranfi et al., 1994; 1996; 1997; 2001; 2010; Marino, 1996; Girone & Varola, 2001; D'Alessandro et al., 2003; Stefanelli, 2003; 2004; Maiorano et al., 2004; 2008; 2010; Stefanelli et al., 2005; Girone et al., 2013a; Sagnotti et al., 2014; Aiello et al., 2015; Bertini et al., 2015; Marino et al., 2015; Petrosino et al., 2015) and meets most of the requirements mentioned in Remane et al. (1996) for the selection of a GSSP. The primary criterion for defining the Lower-Middle Pleistocene boundary was indicated as a point to be selected in a marine succession close to the Matuyama-Brunhes boundary (MBB) (Richmond, 1996; Pillans, 2003; Head & Gibbard, 2005; Cita et al., 2006; Head et al., 2008; Head & Gibbard, 2015a). The MBB is a geomagnetic polarity reversal characterised by different age assignments (see syntheses in Channell et al., 2010; Head & Gibbard, 2015b), polarity transition lasting up to 8 kyr (Channell & Kleiven, 2000; Channell et al., 2004; Leonhardt & Fabian, 2007), associated short-lived precursor (s) (Hyodo et al., 2006, 2011; Wang et al., 2006; Yang et al., 2010; Channell et al., 2010; Sagnotti et al., 2014), and by a slightly diachronous character also depending on latitudinal and longitudinal places (Clement, 2004; Leonhardt & Fabian, 2007). Change in sedimentation rate (and related age-depth model), and the influence of burrowing may produce differences in magnetic recording efficiency and timing (magnetic lock-in depth) of remanence acquisition, possibly introducing uncertainties in the natural magnetization process in marine and continental sediments and age-assignment of the MBB (deMenocal et al., 1990; Channell et al., 2010; Suganuma et al., 2010; Roberts et al., 2013; Snowball et al., 2013; Head & Gibbard, 2015b). When correlated to marine oxygen isotope stratigraphy (MIS 19, Shackleton et al., 1990), in sedimentary successions the MBB may fall at the base, in the middle, or in the upper part of stage 19. On the other hand, climatostratigraphy during MIS 19 is revealed to be a critical means to improve

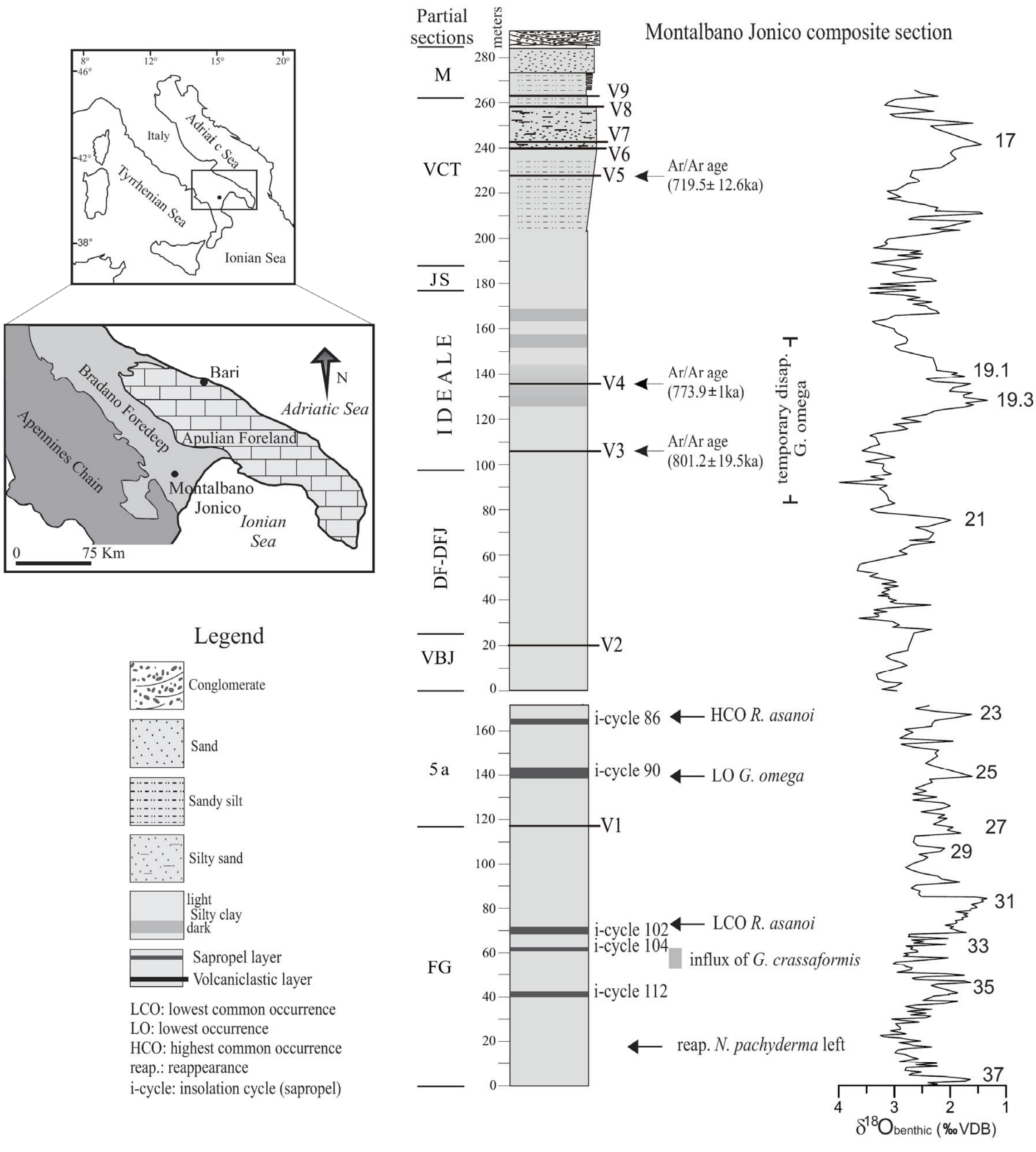


Fig. 1 - Location and stratigraphy of the Montalbano Jonico section. Main lithological features of the composite section obtained by correlating several partial sections (FG-M). Chrono-biostratigraphic constraints are shown together with benthic $\delta^{18}O$ (Brilli et al., 2000; Ciaranfi et al., 2010; Maiorano et al., 2010). Marine Isotope Stages are according to Ciaranfi et al. (2010). Ages of volcaniclastic layers are according to Ciaranfi et al. (2010), Maiorano et al. (2010), Petrosino et al. (2015).

knowledge on climate evolution during this stage and to enhance correlation between marine and terrestrial realms at the global scale. Moreover, according to some authors, paleointensity minima during MBB seem to have affected change in cosmogenic ray flux and Earth's climate (Kitaba et al., 2012; Hyodo & Kitaba, 2015). This aspect strengthens the widely accepted importance of climate in Quaternary stratigraphy, the stage boundaries being characterised by biological/physical/geochemical documentation of profound changes in the global climate. Multiple chrono/climatostratigraphic constraints are then necessary in the interval including MIS 19 and the Matuyama-Brunhes transition in order to have helpful and constructive tools aiding local/regional/global (possibly land–marine) correlation, which is a crucial feature for the selection of GSSP (Remane et al., 1996; Gradstein et al., 2003).

The aim of this paper is to provide a synthesis of recent data sets collected throughout MIS 19 at Montalbano Jonico and supply preliminary new results which improve the reliability of the numerous chronostratigraphic and climatostratigraphic markers recognized in the section close to the Early-Middle Pleistocene boundary. A synthesis of these results was presented at the "Scientific Days" (Florence, June 18-19, 2015) organized by AIQUA (Italian Association for Quaternary Study).

2. THE MONTALBANO JONICO SECTION

The Lower-Middle Pleistocene composite section of Montalbano Jonico crops out in the Lucania Basin (Balduzzi et al., 1982), a minor basin of the foredeep (Bradano Trough, in Casnedi, 1988) between the Apennines Chain and the Apulia Foreland (Fig. 1). The MJS is about 450 m thick and consists of a coarsening upward succession formed by hemipelagic silty clays and, in its upper part, by sandy clays (Ciaranfi et al., 2010) (Fig. 1). The whole section represents the regressive part of a third-order cycle with several fourth and fifth-order cycles mainly induced by climate changes (Ciaranfi et al., 1997; 2001).

Stable oxygen isotope analyses performed throughout the entire succession on planktonic (*Globigerina bulloides*) and benthic (*Cassidulina carinata*) foraminifer tests (Brilli et al., 2000; Ciaranfi et al., 2010), combined with high resolution quantitative calcareous plankton biostratigraphy (Marino, 1996; Maiorano et al., 2004; Ciaranfi et al., 2010; Maiorano et al., 2010; Girone et al., 2013a), $^{40}Ar/^{39}Ar$ data on volcaniclastic layers V3, V4 and V5 (Ciaranfi et al., 2010; Maiorano et al., 2010; Petrosino et al., 2015), pollen data (Joannin et al., 2008), and sapropel stratigraphy (D'Alessandro et al., 2003; Stefanelli, 2004; Stefanelli et al., 2005; Maiorano et al., 2008), have provided the astronomical calibration of the MJS that covers the time interval MIS 37–16, i.e., 1.24–0.645 Ma (Ciaranfi et al., 2010; Maiorano et al., 2010). The calcareous plankton biochronology at Montalbano (Maiorano et al., 2010; Girone et al., 2013a) compares well with that in the Mediterranean Sea and Atlantic and Pacific oceans, suggesting that the section is valuable for long distance biostratigraphic correlation.

The MJS represents a unique on-land continuous succession spanning this long time interval and, together with the astronomically-tuned Vrica section, covers the entire Calabrian Stage (Maiorano et al., 2010). Furthermore, it encompasses the timing of the Matuyama-Brunhes transition. The Ideale section, is one of several comprising the Montalbano Jonico composite section, and is the key stratigraphic succession deposited continuously during MIS 20-18 (Fig. 1).

3. STRATIGRAPHIC AND PALEONVIRONMENTAL CONSTRAINTS THROUGH MIS 21-MIS 18

Recent multidisciplinary studies improved knowledge across the interval from MIS 21 to MIS 18 time (Aiello et al., 2015; Bertini et al., 2015; Marino et al., 2015; Petrosino et al., 2015), based on orbital to millennial scale marine and terrestrial biological data set (pollen, ostracod, benthic micro- and macroinvertebrates), mainly obtained by the analysis of the same samples studied for oxygen isotope stratigraphy (Fig. 2). Some of the taxa recorded from the rich and diverse micro- and macrofossil assemblages at MJS are illustrated in Plates 1 and 2. Chemical studies on juvenile vitric fragments and mineral phases from the volcaniclastic layers allowed these marker levels to be more exhaustively described in terms of their potential source and correlation to other tephra layers in both south-central Italy lacustrine successions and in marine onland and deep-sea cores within a Lower-Middle Pleistocene Mediterranean tephrostratigraphic framework.

The fine chronostratigraphic and paleoenvironmental outline obtained at the MJS makes the section an excellent candidate for the Lower-Middle Pleistocene GSSP in spite of an absent paleomagnetic signal (including the MBB) throughout the section because of remagnetization (Sagnotti et al., 2014). The several events recorded in the Ideale section have high potential for wide-scale correlation and therefore may provide multiple constraints suitable for the selection of the GSSP.

Focusing on the MIS19, it is clearly depicted between MIS 20 and MIS18 at the MJS by the planktonic and benthic $\delta^{18}O$ records (Ciaranfi et al., 2010; Maiorano et al., 2010). The interval straddling MIS 19 is very well chronologically constrained, bracketed by the $^{40}Ar/^{39}Ar$ ages of two volcaniclastic layers: V3 (801.2±19.5 ka) in MIS 20, and V4 (773.9±1.3 ka) in MIS 19. The age of V4 is very close to the age of the MBB, referred to 773 ka according to Channell et al. (2010). The beginning and end of the second temporary disappearance of the coccolithophore *Gephyrocapsa omega*, at 829 ka and 752.76 ka respectively (Fig. 2e), provide valuable bioevents for long distance correlation as they always enclose MIS 19 in Mediterranean Sea and Atlantic Ocean records (Maiorano & Marino, 2004; Maiorano et al., 2004). Additional higher resolution oxygen isotope studies across MIS 19 are in progress at the MJS and support the excellent climate signal in the section (Nomade et al., 2015).

The main climatostratigraphical constraints are shown in Figures 2 and 3 and discussed below.

3.1 The cold climate phase in the uppermost MIS 20 and Termination IX

The inception of MIS 19 is preceded by a high-amplitude shift to lighter $\delta^{18}O$ values at the MIS 20/19 deglaciation of about 2‰, between ca. 794 ka and 782 ka, marked by a change in sediment color from light gray (MIS 20) to dark gray (MIS 19) (Figs. 1, 3). Pollen data provide evidence of a strong increase of herbs (exceeding 90%) with steppe and halophyte taxa as the main components, centered at about 790 ka (Bertini et al., 2015; Marino et al., 2015). This event correlates with prominent peaks in the records of North Atlantic ice rafted debris (IRD, at the Ocean Drilling Program Site 980, Wright & Flower, 2002) and Mediterranean aeolian dust (Larrasoaña et al., 2003) (Fig. 2b-d), suggesting a phase of arid and cold climate (see lowest values in the percentage of Arboreal Plant-AP curve and in the Pollen Temperature Index-PTI at MJS) which marks the collapse of North Hemisphere ice-sheet and the end of

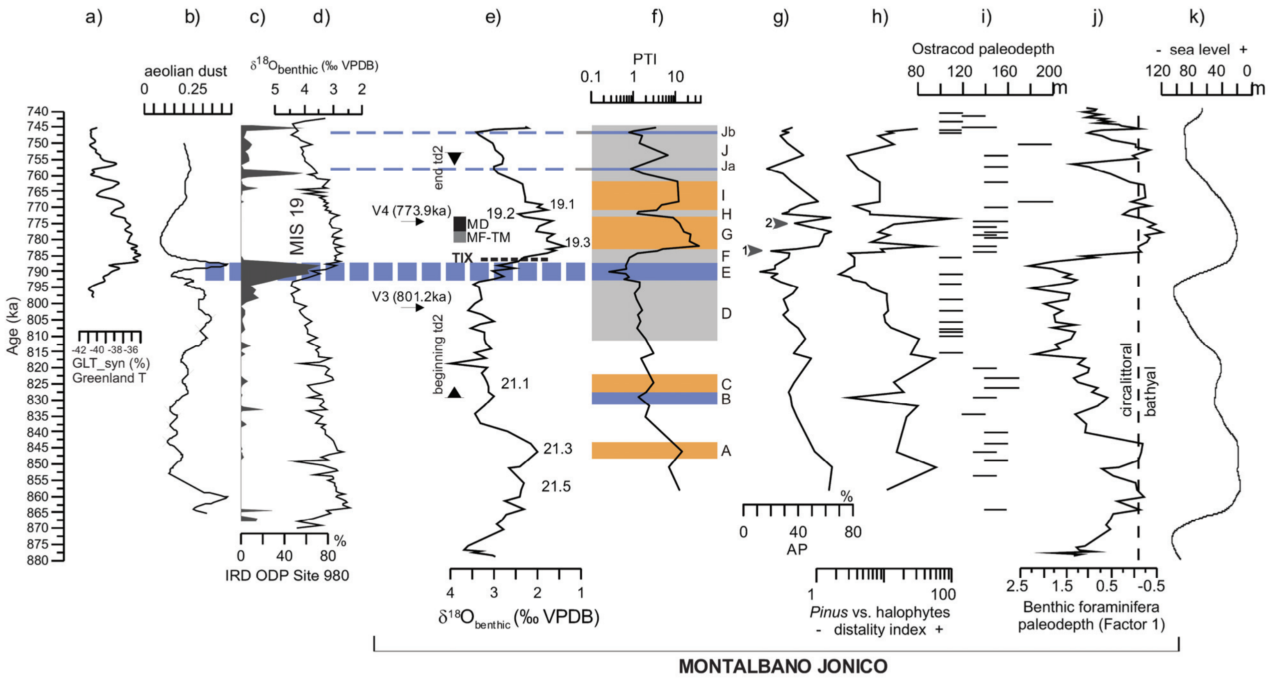


Fig. 2 - Comparison between the Montalbano Jonico succession and other reference Lower-Middle Pleistocene records (modified from Marino et al., 2015, and this work). a) Synthetic reconstruction of Greenland temperature variability (GLT_syn, Barker et al., 2011); b) East Mediterranean dust record based on hematite content derived from magnetic properties of sediments from ODP Site 967 (Larrasoaña et al., 2003); c) ice rafted detritus (IRD) curve from North Atlantic ODP Site 980 (Wright & Flower, 2002) versus age according to Lisiecki & Raymo (2005); d) benthic $\delta^{18}O$ curve from Site 980 (Wright & Flower, 2002); e) benthic $\delta^{18}O$ at the Montalbano Jonico section (MJS); f) pollen temperature index in logarithmic scale (PTI, i.e. the ratio between mesothermic arboreal taxa and steppe taxa to discriminate warm-temperate from cold phases, according to Joannin et al. (2008) and Suc et al. (2010); g) arboreal pollen, AP%; h) pollen distality index (*Pinus* vs. halophytes), in logarithmic scale; i) ostracod paleodepth curve; j) benthic foraminifera paleodepth curve (Stefanelli, 2003); k) global sea level curve (Bintanja & van de Wal, 2008). Age model of the MJS records is from Maiorano et al. (2010) slightly updated in Marino et al. (2015). Substage nomenclature is according to Bassinot et al. (1994). Bars on the PTI curve represent climate phases: warm and humid phase A, C, G, I (orange); cool phase D, F, H, J (grey); cold and arid phases B, E, Ja and Jb (blue); minor short-term climate events are indicated as 1 and 2 (cool phases) on the AP% curve. V3 and V4: volcaniclastic layers TM: Thermal Maximum (Girone & Varola, 2001); MF (Maximum Flooding) and MD (Maximum Depth) from D'Alessandro et al. (2003); td2: second temporary disappearance of *G. omega* (sensu Maiorano & Marino, 2004); TIX: Termination IX.

glacial MIS 20. Calcareous plankton data (Maiorano et al., 2016) support the prominent cold climate phase recording the higher abundance of arctic-subarctic *Coccolitus pelagicus* ssp. *pelagicus* and *Neogloboquadrina pachyderma* left-coiling, and the lowest values of the planktonic foraminifera derived Sea Surface Temperature-SST curve (M. Kucera, work in progress) in the uppermost glacial MIS 20. Similar patterns in key calcareous plankton taxa are documented in the Mediterranean Sea at the glacial-interglacial transition during the mid-Brunhes interval (Girone et al., 2013b; Maiorano et al., 2013; Capotondi et al., 2016), demonstrating that the Mediterranean signal of short-lived global climate change may be extended down to MIS 20/MIS 19 deglaciation. Such result, in agreement with the $\delta^{18}O$ pattern at the transition MIS 20/MIS 19 (Fig. 2e), could represent the Younger Dryas-like cold and dry event (Giaccio et al., 2015); however the ongoing higher resolution oxygen isotope study (Nomade et al., 2015) and calcareous plankton and pollen analyses (Maiorano et al., 2016) may give more conclusive detail on climate evolution at this time. A minimum in the benthic foraminifera paleodepth pattern (Stefanelli, 2003, 2004) is also recorded very close to the cold and arid event highlighting a prominent sea level fall (Fig. 2j). The event, combined with the high-amplitude change in benthic foraminifera and ostracod-derived paleodepth curves recorded just above, enables the identification of Termination IX (Figs. 2, 3) which is considered the most prominent marker in the $\delta^{18}O$ record before the MBB in MIS 19 (Channell et al., 2010). These results together provide the first documentation in Mediterranean onland marine sediments of Termination IX, a characteristic climate signal in global ocean records (i.e. Lisiecki & Raymo, 2005). The prominent sea level change associated with Termination IX is correlatable with the boundary between the third order cycles TB3.8-TB3.9 (Haq et al., 1987) at the major sequence boundary “Io1” (ca 0.8 Ma, Hardenbol et al., 1998; ca. 0.78 Ma, Snedden & Liu, 2010) and is recorded in the curve of global sea level of Bintanja & van de Wal (2008) (Fig. 2k). Termination IX may be also recognizable in terrestrial sediments (i.e. Florindo et al., 2007) supporting its value in climatostratigraphy.

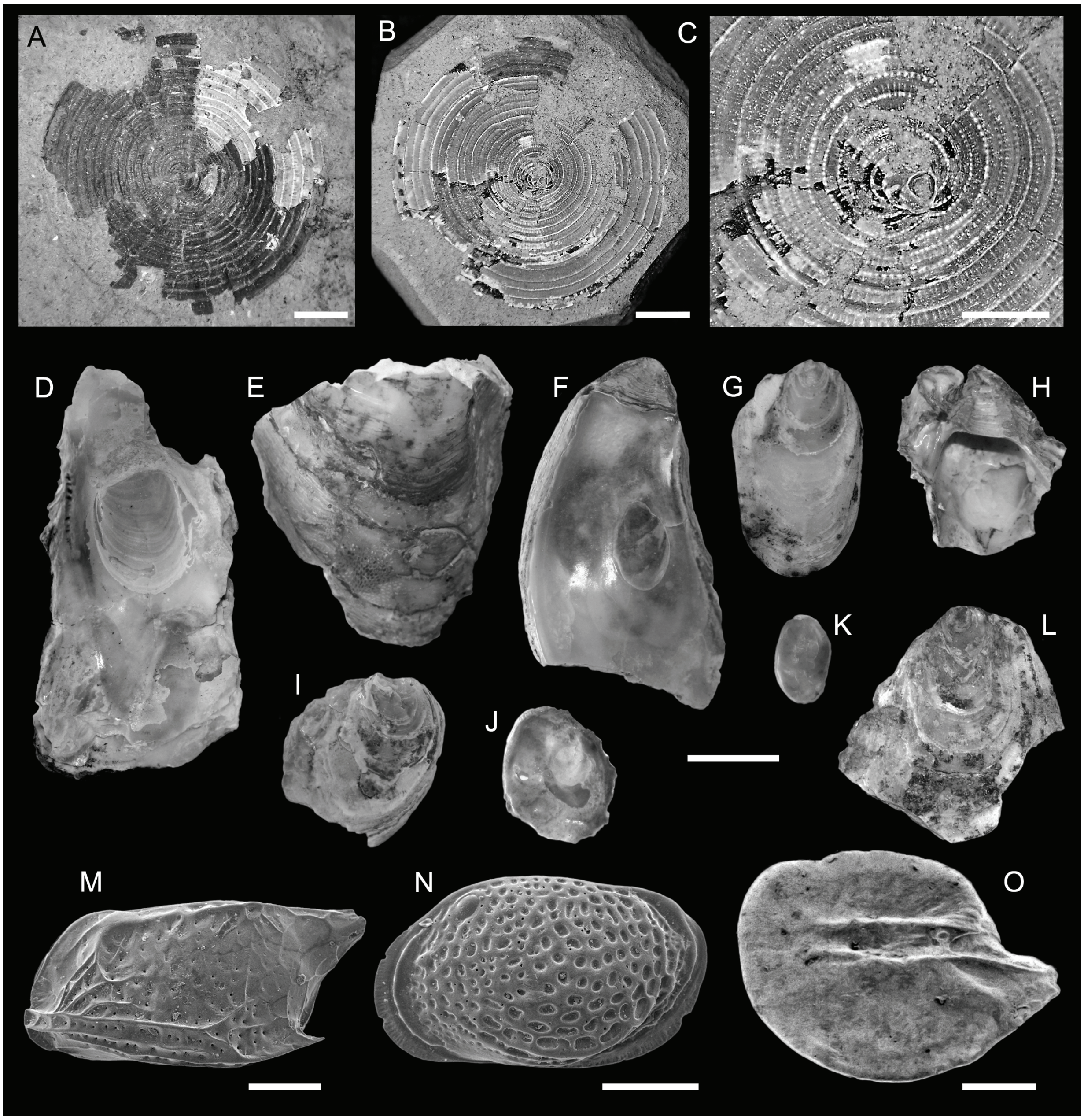
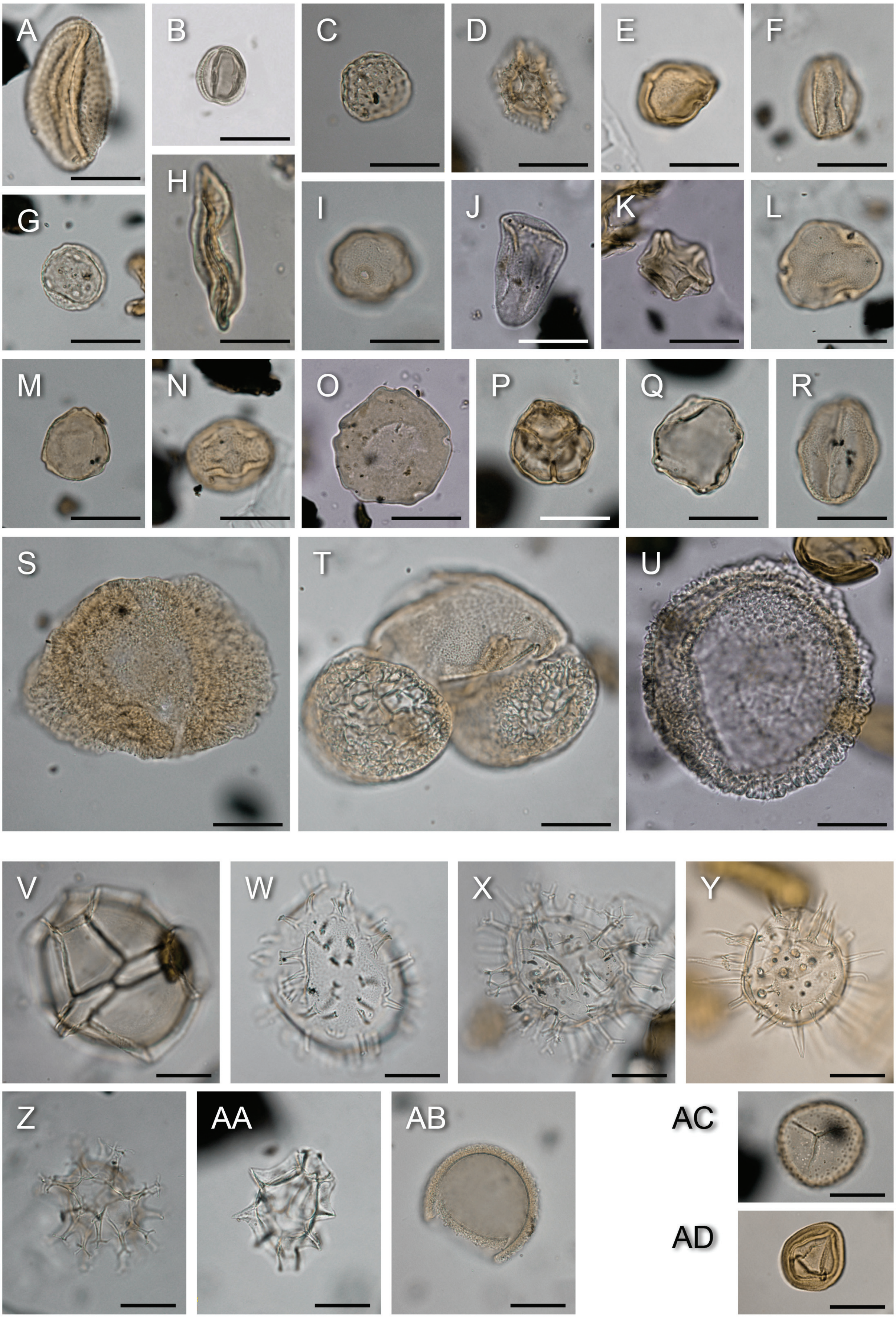


Plate 1 - A-C. benthic foraminifer *Discopirina italica* (Costa, 1856) with pyrite infilling, scale bar = 2 mm (A, B), 1 mm (C).
D-L. *Neopycnodonte cochlear* (Poli, 1795), scale bar = 10 mm.Valves and valve fragments from the Maximum Flooding level in MIS 19. Note the bioeroded and bioencrusted surface of the large fragment E, suggesting exposure on the sea bottom due to low sedimentation rate.
M, N. Ostracod species commonly recorded in the Montalbano Jonico Section, typical of the circalittoral zone in the Mediterranean. M. *Semicytherura ruggieri* Pucci, 1955, left valve, scale bar = 100 µm. N. *Sagmatocythere concentrica* (Bonaduce, Ciampo & Masoli, 1976), left valve, scale bar = 100 µm.

3.2. MIS 19.3, Maximum Flooding, Climate Optimum, and Maximum Depth

The $\delta^{18}O$ pattern and all biological proxies clearly record the onset of MIS 19 (Fig. 2) which is also visible in the color sediment change at Termination IX in the Ideale section (Figs 1, 3). The deposition of darker sediments characterizes the MIS 19 interval as may be expected during an interglacial phase and high sea level, when water column stratification could have reduced oxygen levels and thereby increased organic matter preservation on the sea floor. Moreover, the $\delta^{18}O$ pattern distinctively describes substages 19.3, 19.2, and 19.1 (Figs. 1, 3). All biological data from both marine (i.e. Marino et al., 2015) and terrestrial (Bertini et al., 2015; Toti, 2015) realms support the substage subdivision indicating 19.3 as the warmest, based on the elevated values in PTI and AP curves. Increases in the warm-water calcareous plankton taxa confirm the peculiar climate behavior of substage 19.3. In detail, calcareous plankton records the highest abundance of warm water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1 Cold and arid climate phase (uppermost MIS 20)

2 Maximum flooding, climate optimum

3 Maximum depth

4 end td2 *G. omega*

V3, V4: volcaniclastic layers

18-20: Marine Isotope Stage/substage

Fig. 3 - Main chronological and paleoenvironmental constraints drawn on the outcrop of the Ideale section.

taxa in the lower portion of substage 19.3 (Maiorano et al., 2016) in correspondence with the lowest δ^{18}O value (ca. 782 ka), suggesting a climate optimum in the sea surface waters. During the 780.56-777.31 kyr interval, the presence of tropical-subtropical mesopelagic teleostean fish *Bonapartia pedaliota* (Girone & Varola, 2001) (Plate 1, O) suggests warmer conditions deeper in the water column; the highest percentages of *Quercus* (here included among the AP, see Bertini et al., 2015 for detail) and PTI, are recorded contemporaneously (Fig. 2f). Concomitantly, the maximum flooding is indicated by the occurrence of a *Neopycnodonte cochlear* community (D'Alessandro et al., 2003) (Figs. 2e, 3, Plate 1, D-L). It is a deep-water oyster forming encrusting clusters, most probably thriving under conditions of low sedimentation rate, as suggested by the ecological data on a congener species (Wisshak et al., 2009; Gofas et al., 2010). Such environmental conditions are possibly related to the rapid sea level rise after deglaciation.

The maximum depth follows the maximum flooding (ca. 777.3 ka-ca. 773.2 ka), and it is highlighted by the benthic invertebrate communities (D'Alessandro et al., 2003) which record dispersed macrobenthic fauna and the occurrence of bathyal taxa such as *Discospirina italica* (Plate 1, A-C), a large miliolid foraminifer from deep waters (Gooday et al., 2013), the mollusks *Dentalium agile, Cadulus ovulum, Neilonella pusio* and *Delectopecten vitreus,* typical of Pleistocene bathyal assemblages (Di Geronimo and La Perna, 1997); this phase probably reflects higher sedimentation rate and deeper waters which prevented the development of the *Neopycnodonte* (*N. cochlear*) community. The occurrence of the bathyal ostracod *Krithe compressa* is consistent with deeper environment. Therefore, this paleocommunity indicates a transition to a slope setting ("*Discospirina*, *Nassarius*" communities in D'Alessandro

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Plate 2 - Micrographs of representative pollen grains (A-U), organic-walled dinocysts (V-AB) and other palynomorphs (AB, AC) from the MIS 20-18 interval of the MJS. A. *Centaurea* (equatorial view). B. *Artemisia* (equatorial view). C. Amaranthaceae. D. Asteraceae, Cichorioideae. E. *Hippophaë* (equatorial view). F. Deciduous *Quercus* (equatorial view). G. *Plantago lanceolata* type. H. *Ephedra distachia* type (equatorial view). I. Poaceae (distal view). J. Cyperaceae (equatorial view). K. *Alnus* (polar view). L. *Tilia* (polar view). M. *Corylus* (polar view). N. Fabaceae (equatorial view). O. *Pterocarya* (polar view). P. Ericaceae (tetrad in polar view). Q. *Carpinus betulus* (polar view). R. *Calligonum* (equatorial view). S. *Cedrus* (proximal view). T. *Pinus* (equatorial view). U. *Tsuga diversifolia* type (proximal view). V. *Impagidinium patulum* (lateral view). W. *Polysphaeridium zoharyi* (apical view). X. *Spiniferites hyperacanthus* type (ventral view). Y. *Lingulodinium machaerophorum* (lateral view). Z. *Spiniferites ramosus* (lateral view). AA. *Impagidinium aculeatum* (cross section). AB. *Tectatodinium pellitum* (cross section). AC. *Ophioglossum* type (proximal view). AD. *Classopollis* (polar view, reworked). All scale bars are 20 μm.

et al., 2003) during a sea-level high stand, in good agreement with the major deepening during MIS 19 suggested by benthic foraminifera (Stefanelli, 2003) and ostracod assemblages (Aiello et al., 2015) from ca. 779 ka to 773 ka (Marino et al., 2015), close to the increase in the values of pollen distality index (Bertini et al., 2015) (Fig. 2h).

3.3. End of full interglacial, MIS 19.2-19.1 towards MIS 18

The end of substage 19.3 is marked by the increase of steppe and halophyte elements associated with the slightly higher values in the $\delta^{18}O$ record, during substage 19.2, at about 771.8 ka, just above the V4 layer (Fig. 2e-g). The signal of a decrease in sea-surface temperature is also recorded in the calcareous plankton assemblage (Maiorano et al., 2016), since a distinct drop occurs in the abundance of the warm water taxa. A contemporaneous decrease in the pattern of a synthetic (modeled) reconstruction of Greenland temperature (Barker et al., 2011) is evident (Fig. 2a). Upwards, in MIS 19.1, again warm and humid conditions are inferred by pollen data (increase in arboreal mesothermic taxa, Fig. 2g) (Bertini et al., 2015), according to lighter values in $\delta^{18}O$ (Fig. 2e). An upward decreasing trend in mesothermic arboreal taxa parallels the increase of open vegetation taxa concomitant with heavier $\delta^{18}O$ values, thus marking the beginning of the climate deterioration associated with MIS 18. Distinct fluctuations in isotope curve and biological proxies, and in sediment color as well (Figs. 1-3), are also recorded in MJS during this glacial inception. They are in good agreement with the IRD and oxygen patterns at the North Atlantic Site 980 (Fig. 2c-d), and with the synthetic reconstruction of Greenland temperature variability (Fig. 2a), evidencing global features of suborbital climate variation widely documented in oceanic and lacustrine (i.e. Wright & Flower, 2002; Kleiven et al., 2011; Giaccio et al., 2015), and ice core (i.e. Jouzel et al., 2007; Pol et al., 2010; Barker et al., 2011) records. A better understanding of climate evolution at the end of the full interglacial MIS 19, considered the best analogous of the Holocene (Tzedakis et al., 2012; Yin & Berger, 2012), is crucial for evaluating the temporal extent of the current interglacial and for future climate prediction.

4. CONCLUSIONS

The MJS sedimentary succession provides an exceptional data-set to trace the main palaeoenvironmental and climatic changes through MIS 37-MIS 16 in the central Mediterranean, a historical key area for the study of Quaternary stratigraphy and climate. The timing and mode of such changes are examined closely in the interval MIS 20-MIS 18, and correlated with climate fluctuation from globally-distributed records. The integrations of continental (pollen) and marine (ostracods, benthic and planktonic foraminifera, coccolithophores, teleostean fishes, mollusks) proxies allows us to document, up to millennial scale, the nearly contemporaneous response to paleoenvironmental events in the two biological domains, providing an invaluable tool for marine-terrestrial correlation. Multiple chrono- and climatostratigraphic constraints are recorded and the most important are synthesised in Fig. 3:

a) coldest phase in the uppermost MIS 20;
b) Termination IX;
c) substages 19.3, 19.2, 19.1;
d) events of maximum flooding, climate optimum, and maximum depth;
e) end of the second temporary disappearance of *Gephyrocapsa omega*;
f) radiometric age of volcaniclastic layers V3 and V4 bracketing MIS 19.

The plethora of data for the MIS 20 to MIS 18 interval collected in the continuous succession (Ideale section) makes it possible to consider the MJS highly suitable for hosting the GSSP of the Middle Pleistocene Subseries and its associated stage. In fact, it meets most of the requirements cited in Remane et al. (1996) for a GSSP:

i) geological, i.e. *exposure over an adequate thickness, continuous sedimentation, high sedimentation rate, absence of synsedimentary and tectonic disturbances, absence of metamorphism and strong diagenetic alteration* (see Ciaranfi et al., 2010; Maiorano et al., 2010);
ii) biostratigraphic, i.e. *abundance and diversity of well preserved fossils, absence of vertical facies changes, favourable facies and numerous biovents for long-range biostratigraphic correlations* (see Marino, 1996; Girone & Varola, 2001; D'Alessandro et al., 2003; Stefanelli, 2003, 2004; Maiorano & Marino, 2004; Maiorano et al., 2004; Joannin et al., 2008; Maiorano et al., 2008; Girone et al., 2013a; Aiello et al., 2015; Bertini et al., 2015; Marino et al., 2015);
iii) chemostratigraphic and astrochronology (see Brilli et al., 2000; Ciaranfi et al., 2010; Maiorano et al., 2010);
iv) radioisotopic dating (see Ciaranfi et al., 2010; Maiorano et al., 2010; Petrosino et al., 2015);
v) sapropel stratigraphy (see D'Alessandro et al., 2003; Stefanelli, 2003; Stefanelli et al., 2005; Maiorano et al., 2008).

Finally, accessibility, free access, permanent protection of the MJS site are guaranteed by a regional law (L.R. January 27-2011, n.3) by the Basilicata regional administration that established the ***Special Nature Reserve of the Montalbano Jonico badlands***.

Panoramic views of the badlands and some details of the Ideale section are visible at the link: https://youtu.be/PD8AEisZI4M.

The section has been visited by people from many countries during several scientific fieldtrips, the most recent held in Bari (Italy, *Field-workshop on the Lower-Middle Pleistocene transition in Italy*, October 11 -13, 2014) (Fig. 4) organised by the Dipartimento di Scienze della Terra e Geoambientali (University of Bari), and supported by the Italian Association for Quaternary Study (AIQUA) and International Commission on Stratigraphy (ICS) (Ciaranfi et al., 2015).

Fig. 4 - Participants at the Field Workshop on the Lower-Middle Pleistocene transition in Italy (Bari 11-13 October, 2014; Ciaranfi et al., 2015). The Ideale section is visible in the background. 1 P. Lombardi; 2 G. Miraglia; 3 M. Tropeano; 4 F. Toti; 5 P. Maiorano; 6 C. Lin; 7 P. Ferretti; 8 H. Nirei; 9 A. Negri; 10 R. La Perna; 11 A. Fusco; 12 N. Ciaranfi; 13 D. Scarponi ; 141 V. De Vincenzis (Mayor of Montalbano Jonico, 2014); 15 L. Capraro; 16 S. Gallicchio; 17 O. Kazaoka; 18 Y. Suganuma; 19 C. Turner; 20 M. Marino; 21 S. Nomade; 22 L. Sabato; 23 N. Combourieu Nebout; 24 A. Girone; 25 F. Lirer; 26 M. Okada; 27 A. Sposato; 28 A. Bertini; 29 P. Petrosino; 30 M. Head; 31 M. Coltorti; 32 V. Rosito. Photo by G. Vai.

The MJS is the focus of new investigations even now; supplementary higher temporal resolution analyses on calcareous plankton and pollen, and on mineralogic features of sediments across MIS 19 have been recently performed (Maiorano et al., 2016). Planktonic and benthic oxygen isotope stratigraphy up to the centennial scale is advancing close to MIS 19 in the Ideale section (Nomade et al., 2015) and will provide the best $\delta^{18}O$ record from an onland marine succession known so far. Analyses on the cosmogenic radionuclide ^{10}Be are in progress; the latter has a distinctive pattern (^{10}Be flux anomaly) during the MB transition as documented in the sediments (e.g., Frank et al., 1997; Christl et al., 2003; Suganuma et al., 2010) and ice cores (e.g., Wagner et al., 2000; Raisbeck et al., 2006; Dreyfus et al., 2008). Results of these analyses are promising and will likely be compared with other worldwide records, with the aim to provide reliable information on the timing of the paleomagnetic reversal, avoiding the possible effect of post-depositional remanent magnetization lock-in of the geomagnetic signal (Suganuma et al., 2011; Roberts et al., 2013).

ACKNOWLEDGEMENTS

Valuable comments and suggestions by an anonymous reviewer and by Martin J. Head significantly improved the manuscript. This research was financially supported by the Università degli Studi di Bari Aldo Moro: Fondi di Ateneo R. La Perna 2010, and M. Marino 2012. Financial support was also provided by Università degli Studi di Firenze (Fondi di Ateneo A. Bertini 2011 and 2012, and a Ph.D. fellowship to F. Toti). Special tanks to the Montalbano Jonico administration and communities which helped our research. The microscope laboratory at the Dipartimento di Scienze della Terra and Geoambientali, Università degli Studi di Bari Aldo Moro, used for pictures of Plate 1, was funded by Potenziamento Strutturale PONa3_00369 "Laboratorio per lo Sviluppo Integrato delle Scienze e delle Tecnologie dei Materiali Avanzati e per dispositivi innovativi (SISTEMA)".

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Ms. received: December 18, 2015
Final text received: April 13, 2016