



INTERGLACIAL VEGETATION PATTERNS AT THE EARLY-MIDDLE PLEISTOCENE TRANSITION: A POINT OF VIEW FROM THE MONTALBANO JONICO SECTION (SOUTHERN ITALY)

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ABSTRACT: The Montalbano Jonico succession (southern Italy) represents a rich stratigraphic archive of the Early to Middle Pleistocene environmental and climatic changes in the central Mediterranean. Pollen analyses associated to multivariate statistical methods (principal component and cluster analyses) have been carried out in the sedimentary portion including Marine Isotope Stages (MIS) 21 to 17 (~200 kyrs and ~190 m). The pollen ratio between mesotherm and steppic taxa (Pollen Temperature Index), used as a proxy of temperature, permits to precise consecutive warmer and cooler phases associated, respectively, to interglacials/interstadials and glacials/stadials (sub-stages 21.3 to 18.3 plus stage 17). Pollen data suggest major expansions of mixed oak forests during warm phases, whereas open vegetation typically marks cool to cold phases. The statistical processing puts in evidence both analogies and differences among the successive interglacials/interstadials. Mid- to high-altitude trees and Mediterranean taxa appear to expand slower than hydrophytes plus deciduous oaks and other herbs, which conversely act like pioneers. Moreover *Tsuga*, *Cedrus* plus steppic plants and Poaceae are inversely related to Mediterranean xerophytes and mesotherm deciduous taxa, possibly due to the different tolerance to temperature decreases. On this basis, three main vegetation patterns seem to occur during warm periods. The 1st pattern (including MIS 21.3, 19.3 and 17) shows a tripartite structure with a middle warm phase including higher abundances of slow-spreading taxa, sandwiched between cooler intervals (at the beginning and the end of the sub-stage) with the increase of faster-expanding taxa. The 2nd pattern (in MIS 21.1 and 19.1) shows a complex structure characterized by rapid changes in proportions between fast- and slow-spreading taxa as well as among plants with different tolerance to temperature decrease. The 3rd pattern (in two interstadials within MIS 18), is characterized by relatively high abundances of fast-spreading taxa and low abundances of warmth-demanding taxa. This work represents a first attempt for a better understanding of interglacial vegetation dynamics during the Early-Middle Pleistocene Transition; deeper investigations are in progress with the specific aim to better characterize the observed multiple patterns and possibly to define their causes.

KEYWORDS: Early-Middle Pleistocene Transition, interglacials, MIS 19, Montalbano Jonico, southern Italy, principal component analysis, pollen analysis.

1. INTRODUCTION

During the transition between Early and Middle Pleistocene (EMPT, 1.2-0.5 ka; e.g. Head & Gibbard, 2005; Maslin & Ridgwell, 2005), Earth's climate experienced a gradual change in the Glacial-Interglacial (G-I) oscillations mode. The orbital obliquity-driven 41 kyrs cyclicity, which had dominated the earlier part of the Pleistocene, was overshadowed by a high-amplitude, lower-frequency 100 kyrs-rhythm. A profound impact on terrestrial and marine biota is recorded across the EMPT as a result of changes in the intensity and duration of both glacials and interglacials (e.g. Head et al., 2008). In the Italian pollen and calcareous nannoplankton records a major shift seems to coincide with the Marine Isotope Stages (MIS) 25 to 20, at the end of the Jaramillo sub-chron, where several turnovers in the nanofossil communities and the progressive disappearance of the most thermophilous pollen taxa occurred (Bertini et al., 2010 and references therein). On the other hand, no remarkable events have been recorded at the Calabrian-Ionian transition (e.g. Head & Gibbard, 2005; Bertini et al., 2015). Quaternary European and Mediterranean pollen records display recurrent patterns of vegetation succession paralleling G-I cyclicity. In Italy, four main patterns have been summarized on the basis of latitudinal, geomorphological and local factors by Bertini (2010). Pattern 1, is expressed

by open vegetation-thermophilous forest alternations especially in Mediterranean littoral zones (e.g. Suc et al., 1995). Pattern 2, which is typical of several Northern Apennines sites, exhibits prevalent alternations between altitudinal coniferous and thermophilous forests (e.g. Bertini 2001 and references therein). Patterns 3 and 4 show the presence of thermophilous and coniferous forest, respectively, during glacials, and open vegetation and steppe, respectively, during interglacials (e.g. Bertoldi et al., 1989; Capraro et al., 2005). The interglacial structure, its duration and intensity, as well the seasonality, strongly depend on the Earth orbital geometry, which is a major factor of climate forcing (e.g. Hays et al., 1976; Berger, 1981; 1988). According to many authors, the vegetation succession of each interglacial is "unique" because of the peculiar combination of its astro-climatic variables (e.g. Watts, 1988; Bartlein & Prentice, 1989; Huntley & Webb, 1989). Moreover, even where some interglacials exhibit virtually identical orbital configurations, the occurrence of stochastic factors (e.g. relationships among taxa and/or between taxa and climate) can make the system unpredictable (e.g. Bennett et al., 1991; Tzedakis et al., 2012a). At the same time, the existence of interglacials characterized by very different climate conditions but showing similar vegetation patterns cannot be excluded (Tzedakis & Bennett, 1995); in this case, internal biotic forcings should be invoked.

One of the longest composite Quaternary pollen record, including subsequent interglacials since the base of the Gelasian, has been reconstructed by the study of both marine and continental successions of southern Italy (Fig. 1) (e.g. Combourieu-Nebout et al., 1990; Combourieu Nebout and Vergnaud Grazzini, 1991; Combourieu-Nebout, 1993; Capraro et al., 2005; Klotz et al., 2006; Joannin et al., 2008; Russo Ermolli et al., 2010a, b, 2014; Suc et al., 2010; Amato et al., 2014; Petrosino et al., 2014; Robustelli et al., 2014; Bertini et al., 2015; Marino et al., 2015). The knowledge of past interglacials is particularly significant not only because it allows the documentation of ancient paleoenvironments but also for its key role in modeling the natural course of the present interglacial (Holocene), permitting predictions about the future climate changes. For this study a selected portion of the Montalbano Jonico (MJ) section, spanning the MIS 21-16, has been submitted to detailed palynological analyses which have strongly improved those recently produced in Bertini et al. (2015), and extend the previous pollen documentation concerning MIS 37-23 (Joannin et al., 2008).

The main purpose of this paper is to recognize similarities and differences in the vegetation dynamics between subsequent warm periods (either interstadials or interglacials), assuming that each one is marked by a peculiar astronomical and vegetation signature. To achieve this aim, warmer phases have been singled out and compared using a multivariate statistical approach. The significance of the MJ pollen record is enhanced by the possibility to exclude the presence of consistent stratigraphic gaps thanks to the strong stratigraphical frame established for this marine section (e.g. Marino et al., 2015 and references therein).

2. CASE STUDY: THE MONTALBANO JONICO SECTION

2.1. Geological and stratigraphical setting

MJ composite succession is located in the Basilicata region (southern Italy), near the eponymous village, at 40°17'N 16°34'E (292 m above the sea level). Its deposition occurred within the Bradanic foredeep, a perisutural basin bounded westward by the Apennine orogenic front and eastward by the Murge highlands. The MJ succession covers more than 630 kyrs (Lower to Middle Pleistocene; Ciaranfi et al., 2010) and has been reconstructed sewing up 10 sub-sections (Ciaranfi et al., 1997; 2001). The succession is divided in two distinct portions by a stratigraphic gap (Fig. 2). The lower portion ("Interval A") consists of ~180 m thick muddy turbidites including a volcanoclastic layer (V1).

Benthic paleocommunities assign "Interval A" to an upper-slope environment involved in a prevalent shallowing upward trend (D'Alessandro et al., 2003; Stefanelli, 2004). The upper portion ("Interval B") is more than 300 m thick and includes silty sands and silty clays in which eight volcanoclastic layers (V2-V9) are embedded; repeated deepening-shallowing cycles, from outer to inner shelf environment, have been recognised (D'Alessandro et al., 2003; Stefanelli, 2004) (Fig. 2). Bathymetric changes have been firstly related to the north-eastward thrusting of the southern Apennines units (Ciaranfi et al., 1996; D'Alessandro et al., 2003), and secondly to the orbital-scale G-I cyclicity and climate-driven eustatic variations, in the frame of the progressive Plio-Pleistocene cooling (e.g. Joannin et al., 2008; Ciaranfi et al., 2010).

Based on the most recent radiometric datings

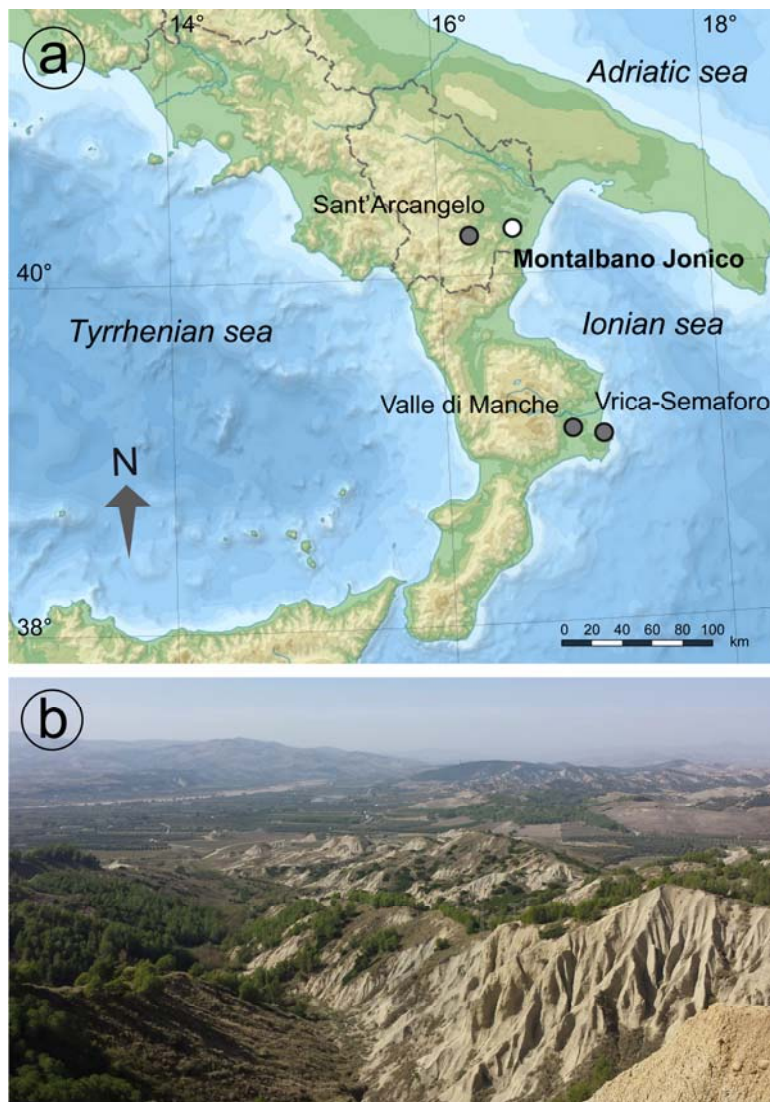


Fig. 1 - (a) Location of Montalbano Jonico and the main sites of southern Italy cited in the text. (b) View of the Montalbano Jonico succession in the "Calanchi" badlands area, with the Agri Valley in the background.

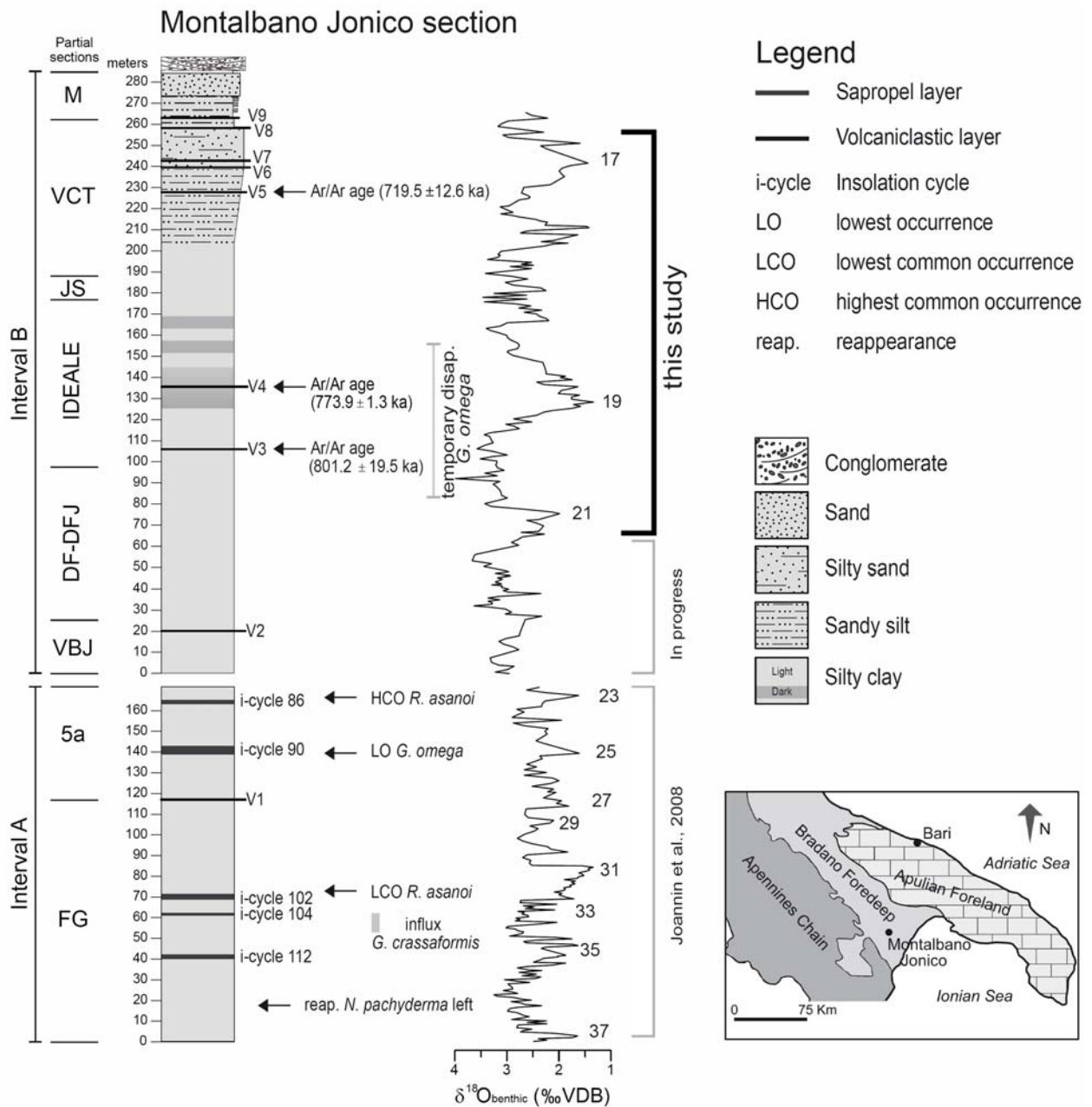


Fig. 2 - Lithostratigraphy and benthic $\delta^{18}\text{O}$ record of the Montalbano Jonico composite section (Brilli et al., 2000; Ciaranfi et al., 2010; Maiorano et al., 2010; Marino et al., 2015); the age of volcaniclastic layer V4 is after Petrosino et al. (2015); the studied portion is indicated on the right. (Modified from Bertini et al., 2015).

($^{39}\text{Ar}/^{40}\text{Ar}$) on V1-V5 tephra layers (Petrosino et al., 2015) and the constrains provided by the calcareous plankton (Maiorano et al., 2004), sapropel (Stefanelli et al., 2005) and isotopic (Brilli et al., 2000) stratigraphy, Marino et al. (2015) have proposed the age-model shown in Fig. 2, closely related to the astronomical tuning of the section by Ciaranfi et al. (2010). Correlations with LR04 benthic stack (Lisiecki and Raymo, 2005), Pacific (Mix et al., 1995a,b; Shackleton et al., 1995) and Atlantic (Bickert et al., 1997) $\delta^{18}\text{O}$ benthic records allow

the isotopic shifts related to MIS 22-16 to be outlined (Ciaranfi et al., 2010; Marino et al., 2015). According to the calcareous plankton-inferred relative chronology (Maiorano et al., 2004), "Interval B" extends from the top of *Pseudoemiliana lacunosa* Zone to the base of *Emiliana huxleyi* Zone of Rio et al. (1990) (Fig. 2). Two nannofossil events are recorded: the beginning (826.89 ka) and the end (771.04 ka) of the second temporary disappearance of *Gephyrocapsa omega* (Maiorano et al., 2004). Although no sapropels occur within the

“Interval B” (Stefanelli et al., 2005), three bands with higher organic carbon content are visible (Fig. 2): the oldest one encloses V4 tephra (773.9 ± 1.3 ka, Petrosino et al., 2015), the second and last one are located below and above the end of the second temporary disappearance of *Gephyrocapsa omega*.

The present work is based on the study of eighty-three palynological samples from the 67.7 m (858 ka, MIS 21)-257.5 m (656.05 ka, MIS 16) portion of “Interval B” (Fig. 2), this generating a mean time resolution of ~2463 years. However this result is based on highly uneven values throughout the succession, ranging from 60 years to more than 14 kyrs.

2.2. Present climate and vegetation

The MJ section lies between the Metapontine Jonian coast, to the south-east, and the Agri valley, to the north-west. The latter is part of a wider hydrographic basin including all the Apennines rivers with drainage towards the Taranto gulf (Fig. 1). The Agri valley is bordered northward by reliefs ranging from ~1700 to ~2000 m. 50 km southwest of MJ, the Pollino massif, with several peaks over 2000 m, separates Basilicata from Calabria region. The Agri valley approximates the intersection between three climatic zones: the coastal Meta-pontine area, characterized by a meso-Mediterranean regime, the eastern hinterlands, with semi-continental climatic features, and the western mountain area, with rainfalls well distributed throughout the year and strong thermal and humidity gradients depending on orography.

The MJ section is embedded in the evocative badlands landscape, molded by the erosion of Plio-Pleistocene marine clays. The vegetation cover is firstly influenced by edaphic factors, being the substrate the result of sediment weathering (Di Pietro et al., 2004). Halo-xerophytic components, such as *Camphorosma monspeliaca*, *Lygeum spartum* and *Mantisalca duriaei*, colonize the steepest slopes, enriched by *Sulla coronata* when slopes are weaker. Terophytes grow in more sandy and detritic soils (Fascetti et al., 2001).

Amaranthaceae (i.e. *Camphorosma*, *Atriplex*, *Suaeda*) occupy flat and more humid zones at the base of the slopes. In weakly steep areas, poorly affected by erosion processes, terophytic Fabaceae (including *Hedysarium* and *Scorpiurus*) dominate the floristic assemblage, with sporadic incursions of *Plantago afra*. On flat to sub-flat surfaces, some patchy Mediterranean maquis occurs; here *Pistacia lentiscus* dominates in association with *Rubia peregrina*, *Phillyrea latifolia*, *Juniperus oxycedrus*, *Asparagus acutifolius* and *Helictotrichon convolutum* (Biondi et al., 1992; Fascetti et al., 2001). The basal horizon of the surrounding relief, which extends from a few meters to 300-400 m, belongs to the olive tree-carob tree alliance (Mediterranean climax), also including holm oak; it is worth noting that the latter is an important component of higher (submontane) belts, forming mid-altitude (up to 800-1000 m) woodlands (Corbetta, 1974). Cypressess and Aleppo pines occur as reforestation elements. SubMediterranean to submontane horizons are marked by the presence of *Quercus pubescens*, commonly with *Fraxinus ornus* (plus *Ostrya carpinifolia*, *Carpinus betulus* and *C. orien-*

talis in moisture-rich stations), *Pyrus communis*, *Sorbus domestica*, *Crataegus oxyacantha*, *Ligustrum vulgare*, *Spartium junceum*, *Osyris alba*, and sclerophyll taxa such as *Asparagus acutifolius* and *Pistacia terebinthus*. At higher elevations *Quercus pubescens* tends to be replaced by *Q. cerris*, which, together with chestnut woods, characterizes the submontane horizon. Beechwoods and *Abies alba* relict formations punctuate mountain belts, together with *Pteridium aquilinum* brackens. The undergrowth composition varies with the altitude and includes noteworthy taxa such as *Ilex aquifolium*, *Geranium striatum*, and *Stellaria nemorum* (Corbetta, 1974).

3. METHODS

3.1. Palynological analyses

Palynological analyses have been performed on samples from the MJ section’s “Interval B” (“Ideale”, “JS” and “VCT” sub-sections: see Fig. 2) during the first year of PhD of the author; the pollen study is still in progress in order to increase the resolution in selected intervals. At present, eighty-three sediment samples have been processed using a standard palynological technique, at the Laboratory of Palynology of the Department of Earth Science of the Florence University. Samples have been first weighted before starting the physical-chemical treatment. *Lycopodium* tablets have been added to each sample to estimate palynomorph concentrations. Attacks with acid (HCl and HF), KOH and hexametaphosphate solutions have been followed by enrichments procedures (ZnCl₂ and 10µm sieving in ultrasonic bath). Residues have been mounted in slides using glycerol and finally analyzed by optical microscope (using x750 and 1250 magnifications) for quantitative pollen analyses. A mean of 284 pollen grains per sample have been counted, *Pinus* and Cupressaceae excluded. *Pinus*, which is generally over-represented in the marine sediments (Heusser, 1988; Beaudouin et al., 2005), at MJ reaches very high percentage values and for this reason has been excluded from the total pollen sum (see pollen diagram in Fig. 3); for the taphonomic and palaeo-environmental significance of *Pinus* pollen grain, see Bertini et al. (2015) and Marino et al. (2015). Cupressaceae pollen grains have been also removed from the total pollen sum as they exhibit in some levels both very high frequencies and morphologic features which do not support their unequivocal determination.

Pollen data are expressed as percentages normalized to the total pollen sum, excluding *Pinus*, Cupressaceae, indeterminate and indeterminate grains; the summary pollen diagram (Fig. 3) shows eleven selected informal pollen groups established on the basis of climate and ecological requirements of correlative modern taxa, which are: (1) *Cedrus* and *Tsuga*; (2) High-altitude taxa (*Abies* and *Picea* plus *Betula* and *Fagus*); (3) deciduous *Quercus*; (4) Broad-leaved deciduous taxa minus *Quercus*, e.g. *Carpinus*, *Ostrya*, *Alnus*, *Ulmus*, *Zelkova*, *Alnus*, *Carya*, *Pterocarya*, Ericaceae and *Hedera*; (5) Mediterranean sclerophyll taxa, e.g. *Quercus ilex* type, *Olea*, *Pistacia* and Cistaceae; (6) Asteraceae except *Artemisia*; (7) Poaceae; (8) Hydrophytes, principally Cyperaceae and *Sparganium*/*Typha angustifolia* type;

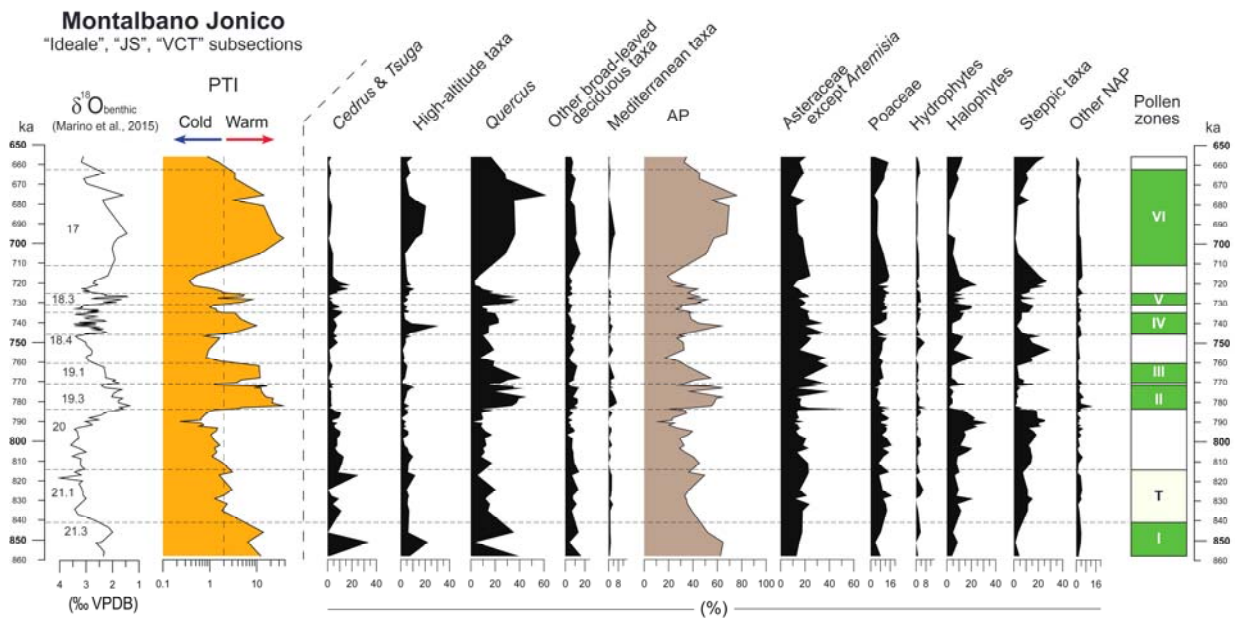


Fig. 3 - Pollen Temperature Index (PTI) and percentage values of selected pollen groups in the MIS 21-17 interval of the Montalbano Jonico section. On the left, the age-model (Marino et al., 2015) and the benthic $\delta^{18}\text{O}$ curve (Brilli et al., 2000; Ciaranfi et al., 2010). The horizontal dashed lines define informal pollen zones corresponding to the successive warm periods (i.e. Zones I-VI plus T), as specified in the column on the right. AP: Arboreal Plants.

(9) Halophytes, e.g. *Amaranthaceae*, *Caryophyllaceae* and *Plumbaginaceae*; (10) Steppic taxa, e.g. *Artemisia* and *Ephedra*; (11) Other non-arboreal plants, e.g. *Brassicaceae*, *Dipsacaceae*, *Plantago*, *Rosaceae* and *Saxifragaceae*.

Arboreal Pollen (AP) relative abundances have also been plotted (Fig. 3) as they are expected to reflect the spreading/shrinkage of the woodland in response, respectively, to the increase/decline of the atmospheric humidity. In order to discriminate warm (temperate) from cooler to cold phases, a pollen-derived palaeotemperature index (Pollen Temperature Index: PTI, Fig. 3; e.g. Joannin et al., 2008, 2011; Bertini et al., 2015) has been used. PTI, which is given by the ratio between mesothermic and steppic taxa, puts in evidence the glacial/stadial (lower values)-interglacial/interstadial (higher values) alternation in the pollen record. We have included deciduous *Quercus*, *Corylus*, *Carpinus*, *Ostrya*, *Alnus*, *Ulmus*, *Zelkova*, *Carya*, *Pterocarya*, *Tilia*, *Hedera* and *Ericaceae* (just to mention the most abundant) among mesothermic taxa and *Artemisia*, *Ephedra*, *Lygeum* and *Hippophae* among steppic taxa. A threshold-value of the PTI has been proposed at ~ 2 to divide warmer by cooler phases, so that they have distinct separations (Fig. 3). The so defined glacial/stadial (PTI $< \sim 2$) and interglacial/interstadial (PTI $> \sim 2$) phases are in good agreement - in terms of both chronologic position and time extension - with the major shifts in the $\delta^{18}\text{O}$ curve (e.g. sub-stages 21.3, 21.1, 19.3 and 19.1 after: Marino et al., 2015) of the same succession.

3.2. Multivariate statistical analyses

Pollen data relative to the samples with a PTI $> \sim 2$ (assumed to belong to interglacials/interstadials, as

described in Methods), in which the variables are represented by the eleven (1-11) selected informal groups, have been examined through Principal Component Analysis (PCA) using variance-covariance matrix as data input. PCA has been adopted as a tool for transposing the original dataset variability in a lower dimension representation. In this simplified panorama, few principal components are assumed to summarize the associations among correlated variables. Centered log-ratio transformation as proposed by Aitchison (1982) have been carried out to avoid biases deriving from the compositional (constrained) nature of the data. Variability similarities between selected pollen groups have been also evaluated through hierarchical cluster analysis, that has been applied on log-centered variables by using the Euclidean distance as similarity measure and Ward's method as the subsequent linkage algorithm.

4. RESULTS

Palynological analyses point out a rich flora consisting of more than 120 taxa. They are largely herbaceous; among them *Asteraceae*, *Poaceae*, *Amaranthaceae* and *Ephedra* are dominant. *Artemisia* and *Ephedra* show subsequent phases of significant increase, reasonably linked to steppe expansion during (cold/dry) glacial periods at the expenses of forest taxa, *Amaranthaceae* usually paralleling the steppe taxa trends (Fig. 3).

Among arboreal taxa, *Pinus* pollen grains reach the highest percentage values. *Quercus* is also well represented and its increase has been associated to the expansion of the forest during warm-temperate conditions. Among the other deciduous broad-leaved taxa, *Carpinus*

betulus, *C. orientalis/Ostrya* type, *Ulmus*, *Zelkova*, etc. follow. Along with *Zelkova*, other taxa which progressively disappears in the course of the Pleistocene, such as *Carya*, *Pterocarya* and *Liquidambar*, are still found in this portion of the MJ section, where *Taxodium* type shows scattered occurrences. *Cedrus* and *Abies* are the most abundant taxa among mid- and high-altitude conifers, respectively.

As a whole the floristic composition at MJ is quite uniform as pointed out and discussed for the MIS 21 to MIS 18 interval by Bertini et al. (2015); in fact neither disappearance nor appearance events have been recorded.

4.1. Vegetation and climatic signature of interglacials and interstadials

The subsequent changes in the arboreal and non-arboreal pollen taxa throughout the MJ succession (858 to 656.05 ka) permit to recognize a clear alternation between forest and open landscapes. They are well expressed especially by the contraposition between steppe plus other non-arboreal taxa and *Quercus* plus other mesophilous taxa (Fig. 3). Based on these vegetation data, it is possible to discriminate between warmer and cooler phases. It is further possible to determine the extension of such zones through the PTI. In fact, as specified in Methods, PTI values higher than ~ 2 have been assumed to depict warm-temperate conditions associated to interglacials/interstadials whereas values lower than ~ 2 approximate glacials/stadials (Fig. 3). Forty-three samples have been thus included into seven informal "warm" zones: those labeled with roman numbers (I-VI) include samples with PTI stably above 2, whereas that labeled with T (=Transition) includes samples with PTI quickly oscillating between 1.3 and 3 (Fig. 3 and Tab. I). Each zone can be generally correlated with a stage or sub-stage of the marine isotope stratigraphy by considering the astronomical tuning after Marino et al. (2015) and the oxygen isotope stack after Bassinot et al. (1994) (Fig. 3). A short description of the informal zones is provided below.

Zone I - It is described by three pollen samples covering ~ 12 kyrs. AP percentages are constantly high, even if changes in proportions between mid- to high-altitude trees and mesophilous taxa pollen are recorded. Zone I is consistent with MIS 21.3.

Zone T - AP are in low percentages, with a main fall at 827.5 ka. Both steppic and halophytic taxa reach a peak at 824.5 ka. Short-term variations of *Cedrus* and *Tsuga* diffusely occur. This zone correlates with sub-stage 21.1.

Zone II - Mesophilous arboreal taxa show quite high percentages, decreasing only in correspondence with two short-term events (at 783.5 and 774.8 ka, Bertini et al., 2015) marked by the expansion of Asteraceae due to humidity drops. Mediterranean taxa show a significant

Pollen Zone	Age (ka)	Mean PTI	Mean AP %	Marine oxygen isotopic stratigraphy
VI	705.31 - 664.47	14.36	58.44	MIS 17
V	729.91 - 725.81	4.94	43.88	MIS 18.3
IV	745.13 - 734.95	5.65	43.77	MIS 18.4 - MIS 18.3
III	770.74 - 761.82	7.86	41.14	MIS 19.1
II	783.53 - 772.19	15.49	51.22	MIS 19.3
T	835.24 - 815.41	2.15	37.89	MIS 21.1
I	858 - 846	10.86	59.73	MIS 21.3

Tab. I - Montalbano Jonico section: pollen-based zonation for the studied interval, associated with summary vegetation indexes. Correlation with isotopic stages is also shown.

Pollen groups	PC 1	PC 2	PC 3
<i>Tsuga</i> & <i>Cedrus</i>	-0.63	0.506	0.04
High-altitude taxa	-0.407	-0.14	0.45
<i>Quercus</i>	0.29	-0.34	0.1
Deciduous broad-leaved taxa	-0.072	-0.3	0.16
Mediterranean taxa	-0.358	-0.66	-0.45
Poaceae	0.24	0.19	-0.11
Asteraceae except <i>Artemisia</i>	-0.02	0.09	-0.023
Hydrophytes	0.76	-0.09	0.13
Halophytes	0.043	0.44	-0.21
Steppic taxa	0.24	0.41	-0.11
Other NAP	-0.094	-0.1	0.03

Tab. II - Montalbano Jonico section: principal component loadings for the first three axes.

abundance at 780.56 ka, predating the acme of *Quercus* and a subsequent increase of high-altitude taxa. This zone correlates with isotopic sub-stage 19.3.

Zone III - The first portion of the interval is marked by a positive excursion of oak and Mediterranean taxa. Afterwards, the other mesophilous taxa plus the mid- to high-elevations trees slightly increase. A correlation of this zone with MIS 19.1 is consistent.

Zone IV - As a whole AP percentage values are similar to those of the previous Zone III (Tab. I). The AP curve shows a peak centered at 741.41 ka. Such an event coincides with an increase in mid- to high-altitude taxa and predates the start of *Quercus* increase at 740.12 ka. The zone extension ranges between 18.4 and 18.3 isotope sub-stages.

Zone V - AP percentages stay quite similar to those of the previous zones. *Quercus* relative abundances rapidly increase between 728.28 and 726.9 ka, with secondary superimposed oscillations well appreciable due to the high time-resolution. A correlation with the 18.3 isotope sub-stage can be proposed.

Zone VI - It corresponds to MIS 17 and represents the longest interglacial. It is also marked by the highest AP values (a huge shift is located at 675.42 ka). Between 697.31 and 677.96 ka, high-altitude taxa are considerably abundant, whereas *Cedrus* and *Tsuga* show sparse occurrences. Mediterranean taxa peak at 695 ka, while deciduous *Quercus* is involved in a gradual increase up

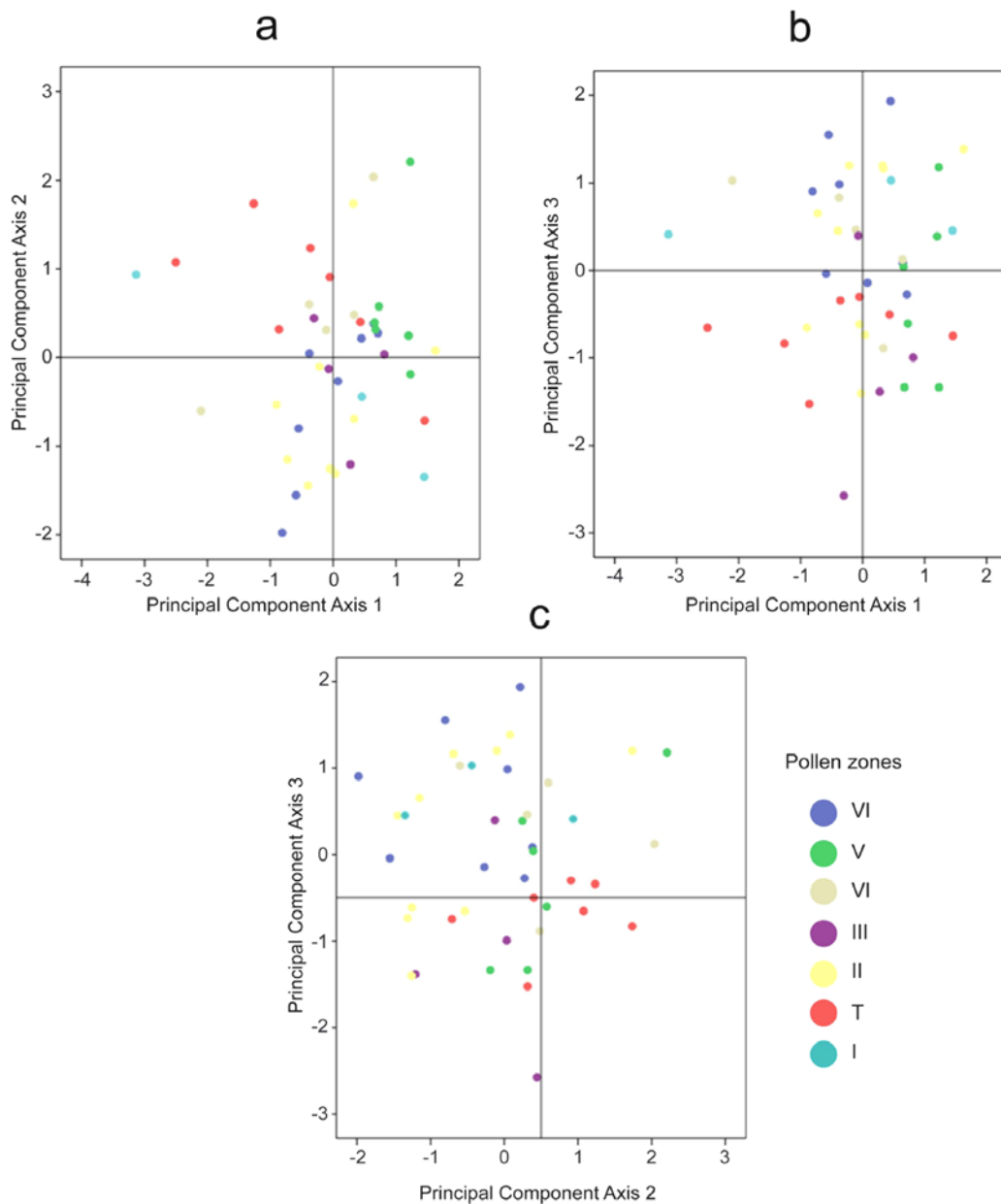


Fig. 4 - Montalbano Jonico section: plot of sample scores. (a) First vs second principal component, (b) first vs third principal component and (c) second vs third principal component. Samples colours indicate the correspondent pollen zone.

to 680.69 ka, followed by a dramatic rise 5 kyrs after, when high-altitude elements collapse.

4.2. Principal component analysis

Statistical calculations on selected pollen data allow three principal components to be extracted. They are able to take into account for about 69% of the total variance, thus providing a reasonable summary of the information contained in the dataset (Tab. II). The first principal component (PC 1) encloses 30.62% of the total variance and expresses a balance in which hydrophytes, *Quercus*, Poaceae and steppe taxa (with positive loadings) are opposed to *Tsuga* and *Cedrus*, high-

altitude taxa and Mediterranean taxa (with negative loadings). PC 1 could reflect the different timing of expansion exhibited by taxa with positive loadings (faster-expanding taxa) versus negative loadings (slower-expanding taxa). The analysis of vegetation successions in many sites of southern Europe with sufficient moisture availability confirms that non-synchronous taxa expansions occur at the onset of warm-humid periods. Deciduous *Quercus* often expands early, followed by other mesophilous trees, such as *Carpinus* and *Ostrya*, and then by *Abies*, *Fagus* and sometimes *Picea* (Tzedakis, 2007; Brauer et al., 2007). In fact, some water-demanding arboreal taxa can show delays in migration

because they require well developed soils, which do not form until several millennia from the beginning of an interglacial; conversely, deciduous oaks can grow on less organic soils (Sadori et al., 2011). Further, we may expect that hydrophytes and other herbaceous taxa react more rapidly to an increase of humidity with respect to arboreal taxa. The second principal component (PC 2) accounts for the 27.73% of the total variance, and expresses a balance between mid-altitude taxa, halophytes, stepic taxa (with positive loadings) and Mediterranean elements, *Quercus*, plus other broad-leaved thermophilous trees (with negative loadings) (Tab. II). Conceivably, this balance can be considered expression of the differential vegetation's response to cooler (with mid-altitude taxa and herbs increase) and warmer (with broad-leaved deciduous taxa and Mediterranean xerophytes increase) climate contexts. The third principal component (PC 3), contributing for the 10.89% to the total data variability, appears to be almost exclusively controlled by high-altitude taxa (with positive loadings) and Mediterranean taxa (with negative loadings). This component can reflect the different moisture requirements of Mediterranean sclerophylls (adapted to seasonal draught) and high-altitude trees (demanding more constant humidity).

Samples from the seven statistical units associated with Zones I-VI and T, plotted as scores (the coordinates of the samples in the space of the components) on the three main components (Fig. 4) show scattered distributions and overlapping domain areas. In other words, "warm" zones, regarded as groups of samples defined *a priori*, cannot be discriminated if the variance-covariance structure of taxa groups is applied.

4.3. Cluster analysis

Cluster analysis on the centered-log data has therefore been run in order to discover the presence of natural associations in the dataset. The obtained dendrogram (Fig. 5a) permits to point out the presence of two well distinct groups of samples, marked with different colors (blue cluster vs green cluster) which further help us to sight them across the seven "warm" zones (Fig. 5b). The main clusters obtained have been separated by considering that they occurred only for a high rescaled distance representing an of high dissimilarity. The two clusters have been then plotted as scores on the three main components revealed by multivariate analysis (Fig. 6). In Fig. 6a we can see that PC 1 and PC 2 are both involved in marking the separation between the two clusters. The

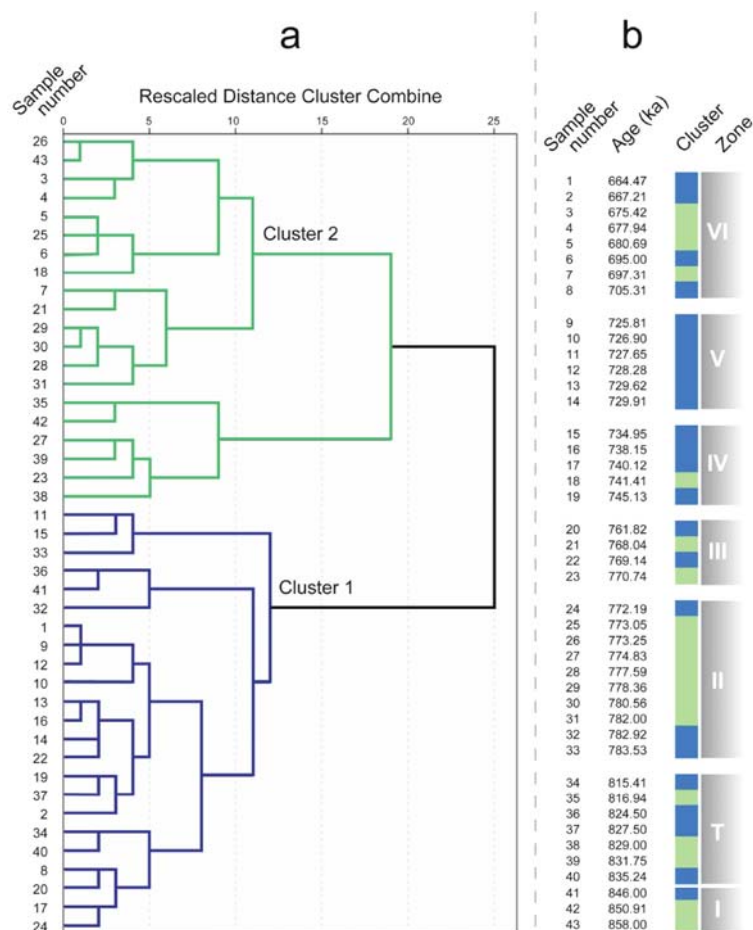


Fig. 5 - (a) Cluster analysis on the selected warm periods from the Montalbano Jonico record; dendrogram has been obtained using Ward method. (b) Clustered samples are sorted in function of the age.

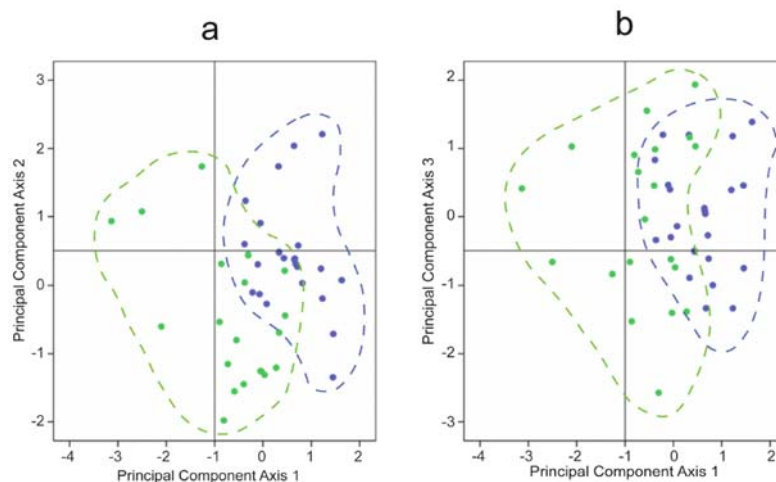


Fig. 6 - Montalbano Jonico section: plot of sample scores on the component axes already used in Fig. 4. Samples are marked with colours of natural associations revealed by the cluster analysis.

blue cluster shows higher values for both axes with respect to the green cluster. In Fig. 6b the two clusters are plotted in a PC 1 vs PC 3 diagram, and discrimination is

operated by the former. Again, the blue cluster assumes higher values than green cluster. No significant discrimination is obtained by plotting the samples in a PC 2 vs PC 3 diagram.

5. DISCUSSION

Palynological analyses point out, in agreement with the isotopic record (Marino et al., 2015), the succession of climatic oscillations between MIS 21 and MIS 16. In particular interglacials and interstadials are well expressed by major increases in deciduous *Quercus* and other mesophilous taxa and by PTI values higher than ~ 2 . On the other hand, glacials and stadials are characterized by the large expansion of steppe and halophytic taxa as well as by PTI values lower than ~ 2 .

Cluster analysis on the pollen samples from the “warm” zones (I-VI plus T) indicates that the variability in taxa percentages is expressed by two main associations of samples (i.e. blue and green clusters), showing well sorted distributions on the PCA plots (Fig. 6a and b). Each studied interval (Zones I-VI and T) includes samples associated to both blue and green cluster, except for the Zone V, which is exclusively represented by blue cluster’s samples (Fig. 7). A first observation is that a similar “blue-green-blue” arrangement unites Zone II and Zone VI (MIS 19.3 and 17, respectively) (Fig. 7). (Zone I represents the last ~ 12 kyrs of MIS 21.3 and shows a pattern very close to those better expressed in both Zone II and Zone VI). Analogies can also be recognised between Zone IV and Zone V (MIS 18.3-18.4 interval and MIS 18.3, respectively), since they both show the predominance (up to totality) of “blue” samples (Fig. 7). Instead Zone T and Zone III (MIS 21.1 and 19.1, respectively) show a thickly alternate blue-green pattern.

Key remarks arise when samples are plotted into the PC 1 vs PC 2 diagram (Fig. 6a). Increasing values of the PC 1 highlight major differences on the rapidity of plant community changes: hydrophytes and deciduous *Quercus* as well as other herbaceous taxa (with positive loadings), are expected to react more quickly to palaeoenvironmental changes than mid- to high-altitude forest taxa and Mediterranean sclerophylls (with negative loadings) (Tab. II). On the other hand, the PC 2 can be thought to reflect the duality among plants with different tolerance to cold: *Tsuga*, *Cedrus*, halophytes and steppe taxa - with positive loadings -, though diffused in very different environments, can tolerate decrease in temperature; conversely, Mediterranean taxa and deciduous broad-leaved elements - with negative loadings - have a lower tolerance to temperature decreases. Blue cluster’s samples are marked by higher values for both principal component axes than green cluster’s samples (Fig. 6a). Hence, the former reflect periods marked by (a) not very high temperatures (higher values on PC 2) and (b) the increase of fast-spreading taxa (higher values on PC 1); vice versa, the latter suggest contexts with (c) higher temperatures (lower values on PC 2) and (d) lower abundances of pioneer taxa (lower values on PC 1).

This allow some considerations to be made, in the light of the three pattern previously described:

- Vegetation succession during MIS 19.3 and 17 (and possibly 21.3) is characterized by a warm mid-phase with a relatively high percentage of slow-spreading taxa, rimmed by cooler intervals with higher abundance of fast-expanding plants (*sandwich* pattern).
- The vegetation landscape within MIS 21.1 and 19.1 constantly changes from warmer states, with the increase of slow-spreading taxa, to cooler states, in which higher frequencies of fast-spreading taxa are recorded.
- Interstadial between MIS 18.4 and MIS 18.3, as well as MIS 18.3, show a rather monotonous vegetation pattern, marked by the constant relatively low presence of both slow-spreading and warmth-demanding taxa. This is probably due to the shortness of the warm phase that prevent those plants to settle.

Selected warm periods at MJ section, “Interval B” are different under many points of view, being their duration, time-scale position, intensity and orbital configurations widely varying. Nevertheless, cluster analysis shows that the most of the variability is described by only two main classes of samples, which generally coexist within each interval. At one level, warm periods globally show more similarities than initially predicted. As hinted by Tzedakis & Bennet (1995), internal biotic factor such as inter- and intra-specific competition can be invoked to justify these analogies. At the same time, it is worth nothing that each period is characterized by a specific vegetation dynamics (see the presence of three patterns), which induce to stress the role of the forcing by external factors.

6. CONCLUSIONS AND PERSPECTIVES

MJ section represents an important stratigraphic archive for the reconstruction of the Early-Middle Pleistocene G-I cycles in the central Mediterranean basin. In-depth studies on flora and vegetation changes have been previously carried out by Joannin et al. (2008) and Bertini et al. (2015), for the MIS 37-23 and MIS 21-18 intervals, respectively.

Here, high resolution palynological analyses and statistical processing of pollen data have been performed for the interval MIS 21 to 16. Such an approach has permitted to characterize and compare successive warm periods in terms of duration, intensity and vegetation dynamics. The PCA carried out on PTI-based statistical groups has not permitted to discriminate the different warm periods. On the other hand, cluster analyses underline the presence of two natural association of samples, which bear vegetational signatures when they are plotted on principal component axes. Such a double type of samples is not randomly arranged across the succession and points out three main pattern in the warm periods.

Since the age-model of the MJ section allows correlations with the orbital geometry predicted for each period (e.g. after Laskar et al., 2004), it would be possible to verify if astronomical forcing can be (at least partially) responsible for the different structure of warm periods. The chronologic model suggests a major role especially of the 100 kyrs-period oscillations. In particular, (absolute or relative) eccentricity maxima correlate

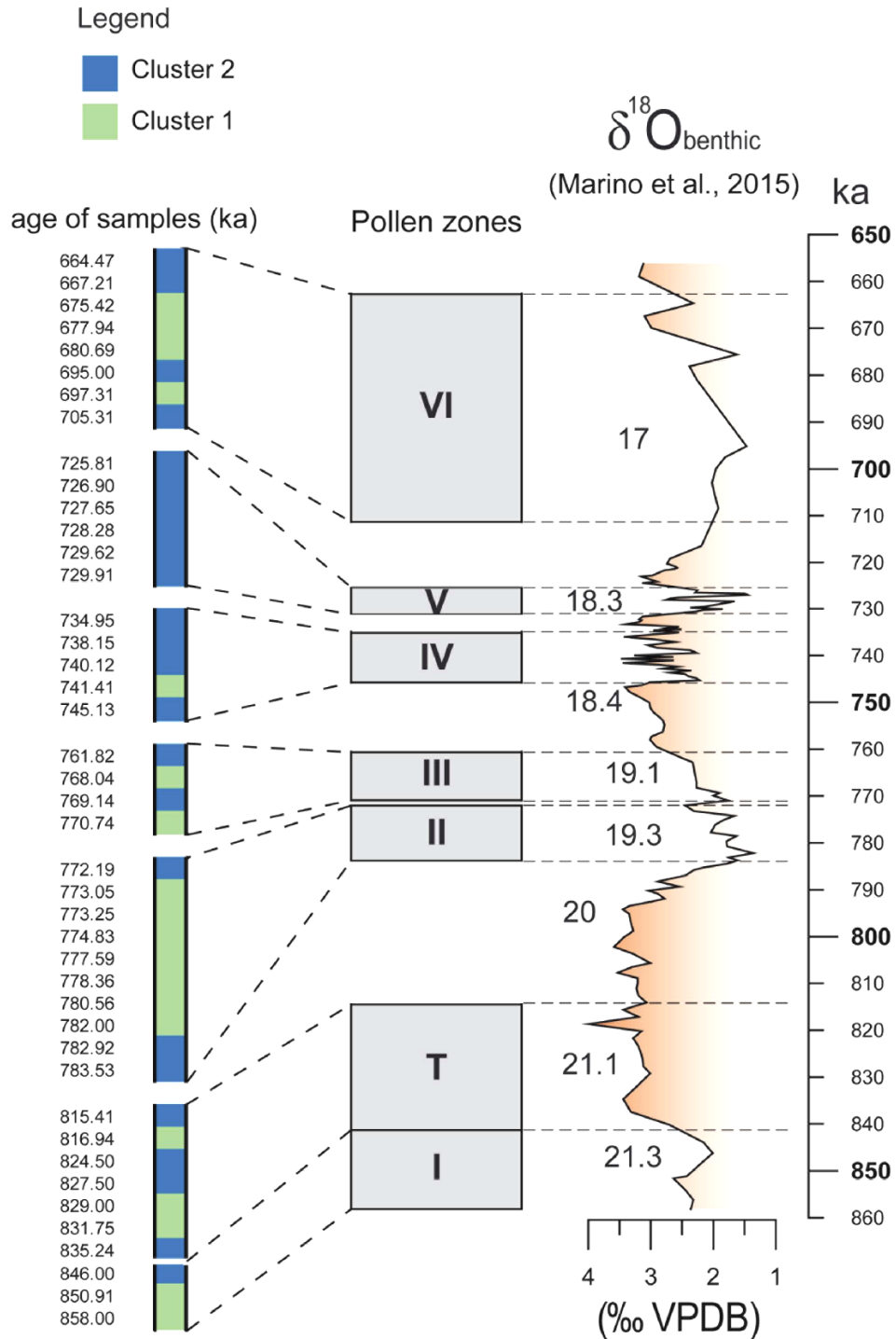


Fig. 7 - Selected samples of the warm periods of the Montalbano Jonico pollen record - marked with colours from the cluster analysis -, "warm" pollen zones and oxygen isotopic curve (Brilli et al., 2000; Ciaranfi et al., 2010; Marino et al., 2015).

well with the first (*sandwich*) structure. An in-depth statistical approach would permit to test relationships between orbital and vegetation phenomena but also to better understand how astronomical factors modulate vegetation changes during interglacials and warm

phases (Tzedakis, 2012a, b).

The present study also fits the issue concerning the extent of the impact of the EMPT on terrestrial ecosystems. Finally the high-resolution record of one of the investigated interglacials, i.e. MIS 19, represents a par-

ticularly appreciable datum as it is now considered one of the "best analogues" of the present interglacial (Berger et al., 2012; Tzedakis et al., 2012a).

ACKNOWLEDGEMENTS

This research has been financially supported by the Università degli Studi di Firenze (*Fondi di Ateneo, A. Bertini 2011-2013*) and a PhD fellowship. The author is deeply grateful to Adele Bertini and Antonella Buccianti (Università degli Studi di Firenze) for the many constructive advices. The author wish to thank Luigi Forte, Neri Ciaranfi, Angela Girone, Patrizia Maiorano and Maria Marino (Università degli Studi di Bari, Aldo Moro). A thanks goes to Elda Russo Ermolli and an anonymous reviewer for the thoughtful comments on the previous version of the manuscript.

REFERENCES

- Aitchison J. (1982) - The statistical analysis of compositional data (with discussion). *Journal of the Royal Statistical Society, Series B (Statistical Methodology)*, 44(2), 139-177.
- Amato V., Aucelli P., Cesarano M., Jicha B., Lebreton V., Orain R., Pappone G., Petrosino P., Russo Ermolli E. (2014) - Quaternary evolution of the largest intermontane basin of the Molise Apennine (central-southern Italy). *Rendiconti Lincei*, <http://dx.doi.org/10.1007/s12210-014-0324-y>
- Bartlein P.J., Prentice I.C. (1989) - Orbital variations, climate and paleoecology. *Trends in Ecology and Evolution*, 4, 195-199.
- Bassinot F.C., Labeyrie L.D., Vincent F., Quidelleur X., Shackleton N.J., Lancelot Y. (1994) - The astronomical theory of climate and the age of the Brunhes-Matuyama magnetic reversal. *Earth and Planetary Science Letters*, 126, 91-108.
- Beaudouin C., Suc J.P., Cambon F., Touzani A., Girresse P., Pont D., Aloïsi, J.C. Marsset T., Cochonat P., Duzer D., Ferrier J. (2005) - Present-day rhythmic deposition in the Grand Rhône prodelta (NW Mediterranean) according to high-resolution pollen analyses. *Journal of Coastal Research*, 21, 292-306.
- Bennett K.D., Tzedakis P.C., Willis K.J. (1991) - Quaternary refugia of north European trees. *Journal of Biogeography*, 18(1), 103-115.
- Berger A.L. (1981) - The astronomical theory of paleoclimates. In: Berger A.L. (eds), *Climatic Variations and Variability: Facts and Theories*. Reidel, Dordrecht, 501-525.
- Berger A. (1988) - Milankovitch theory and climate. *Reviews of Geophysics*, 26, 624-657.
- Berger A., Yin Q.Z., Herold N. (2012) - MIS-11 and MIS-19 analogues of our Interglacial. 3rd International Conference on Earth System Modelling, September 17-21, 2012, Hamburg, Germany.
- Bertini A. (2001) - Pliocene climatic cycles and altitudinal forest development from 2.7 Ma in the northern Apennines (Italy): evidences from the pollen record of the Stirone section (~5.1 to ~2.2 Ma). *Geobios*, 34, 253-265.
- Bertini A. (2010) - Pliocene to Pleistocene palynoflora and vegetation in Italy: state of the art. *Quaternary International*, 225(1), 5-24.
- Bertini A., Ciaranfi N., Marino M., Palombo M.R. (2010) - Proposal for Pliocene and Pleistocene land-sea correlation in the Italian area. *Quaternary International*, 219, 95-108.
- Bertini A., Toti F., Marino M., Ciaranfi N. (2015) - Vegetation and climate across the Early-Middle Pleistocene transition at the Montalbano Jonico section (southern Italy). *Quaternary International*, <http://dx.doi.org/10.1016/j.quaint.2015.01.003>.
- Bertoldi R., Rio D., Thunell R. (1989) - Pliocene-Pleistocene vegetational and climatic evolution of the south-central Mediterranean. *Palaeogeography, Palaeoclimatology, Palaeoecology*, 72, 263-275.
- Bickert T., Curry W.B., Wefer G. (1997) - Late Pliocene to Holocene (2.6-0 Ma) western equatorial Atlantic deep-water circulation: inferences from benthic stable isotope. In: Shackleton N.J., Curry, W.B., Richter C., Bralower T.J. (eds), *Proceedings of the Ocean Drilling Program. Scientific Results 154*, College Station (TX), 239-253
- Biondi E., Ballelli S., Taffetani F. (1992) - La vegetazione di alcuni territori calanchivi in Basilicata (Italia meridionale). *Documents Phytosociologiques, N.S.*, 14, 489-498.
- Brauer A., Allen J.R.M., Mingram J., Dulski P., Wulff S., Huntley B. (2007) - Evidence for Last Interglacial chronology and environmental change from southern Europe. *Proceedings of the National Academy of Sciences*, 104, 450-454.
- Brilli M., Lerche J., Ciaranfi N., Turi B. (2000) - Evidence of precession and obliquity orbital forcing in Oxygen 18 isotope composition of Montalbano Jonico section (Basilicata, southern Italy). *Applied Radiation and Isotope*, 52, 957-964.
- Capraro L., Asioli A., Backman J., Bertoldi R., Channell J.E.T., Massari F., Rio D. (2005) - Climatic patterns revealed by pollen and oxygen isotope records across the Matuyama-Brunhes Boundary in the central Mediterranean (southern Italy). In: Head M.J., Gibbard P.L. (eds), *Early-Middle Pleistocene Transitions: the Land-Ocean Evidence*, Geological Society London, Special Publications, 247, 159-182.
- Ciaranfi N., Marino M., Sabato L., D'Alessandro A., De Rosa R. (1996) - Studio geologico-stratigrafico di una successione infra e mesopleistocenica nella parte sud-occidentale della Fossa bradanica (Montalbano Jonico, Basilicata). *Bollettino Società Geologica Italiana*, 115, 379-391.
- Ciaranfi N., D'Alessandro A., Marino M. (1997) - A candidate section for the lower-middle Pleistocene boundary (Apennine foredeep, South Italy). In: Naiwen, W., Remane, J. (eds), *Proceedings 30th International Geological Congress*, 11, 201-211.
- Ciaranfi N., D'Alessandro A., Girone A., Maiorano P., Marino M., Soldani D., Stefanelli S. (2001) - Pleistocene sections in the Montalbano Jonico area and the potential GSSP for Early-Middle Pleistocene in the Lucania Basin (southern Italy). *Memorie di Scienze Geologiche*, 53, 67-83.

- Ciaranfi N., Lirer F., Lirer L., Louren, L.J., Maioran, P., Marino M., Petrosino P., Sprovieri M., Stefanelli S., Brilli M., Girone A., Joannin S., Pelosi N., Vallefucio M. (2010) - Integrated stratigraphy and astronomical tuning of the Lower-Middle Pleistocene Montalbano Jonico land section (southern Italy). *Quaternary International*, 210, 109-120.
- Combourieu-Nebout N. (1993) - Vegetation response to Upper Pliocene glacial/Interglacial cyclicity in the central Mediterranean. *Quaternary Research* 40, 228-236.
- Combourieu-Nebout N., Semah F., Djubiantono T. (1990) - La limite Pliocène-Pléistocène: précisions magnétostratigraphiques par l'étude sériée de la coupe-type de Vrica (Crotone, Italie). *Comptes Rendus de l'Académie de Sciences, Paris (ser. II)*, 311, 851-857.
- Combourieu Nebout N., Vergnaud Grazzini C. (1991) - Late Pliocene northern hemisphere glaciations: the continental and marine responses in the central Mediterranean. *Quaternary Science Reviews*, 10, 319-334.
- Corbetta F. (1974) - Lineamenti della vegetazione lucana. *Giornale Botanico Italiano* 108(5), 211-234.
- D'Alessandro A., La Perna R., Ciaranfi N. (2003) - Response of macrobenthos to changes in paleoenvironment in the Lower-Middle Pleistocene (Lucania Basin, Southern Italy). *Il Quaternario*, 16, 167-182.
- Di Pietro R., Fascetti S., Pompili M. (2004) - Vegetation soil relationship in Basilicata badlands (southern Italy). *Symposium of the Federation Internationale de Phytosociologie, Tenerife*.
- Fascetti S., Di Pietro R., Pompili M. (2001) - Aspetti sinecologici della vegetazione dei rilievi argillosi della Basilicata. *Atti Congresso Società Italiana Fitosociologia. La Vegetazione Sinantropica, Lipari, 2001*.
- Hays J.D., Imbrie J., Shackleton N.J. (1976) - Variations in the Earth's orbit: pacemaker of the ice ages. *Science*, 194, 1121-1132.
- Head M.J., Gibbard, P.L. (2005) - Early-Middle Pleistocene transitions: an overview and recommendation for the defining boundary. In: Head M.J., Gibbard P.L. (eds), *Early-Middle Pleistocene transitions: the land-ocean evidence: Geological Society of London, Special Publication*, 247, 1-18.
- Head M.J., Pillans B., Farquhar A. (2008) - The Early Middle Pleistocene transition: characterization and proposed guide for the defining boundary. *Episodes*, 31, 255-259.
- Huntley B., Webb T. III (1989) - Migration: species' response to climatic variations caused by changes in the earth's orbit. *Journal of Biogeography*, 16, 5-19.
- Heusser L.E. (1988) - Pollen distribution in marine sediments on the continental margin off northern California. *Marine Geology*, 80, 131-147.
- Klotz S., Fauquette S., Combourieu Nebout N., Uhl D., Suc J.P., Mosbrugger V. (2006) - Seasonality intensification and long-term winter cooling as a part of the Late Pliocene climate development. *Earth and Planetary Science Letters*, 241, 174-187.
- Joannin S., Ciaranfi N., Stefanelli S. (2008) - Vegetation changes during the late Early Pleistocene at Montalbano Jonico (Province of Matera, Southern Italy) based on pollen analysis. *Palaeogeography, Palaeoclimatology, Palaeoecology*, 270, 92-101.
- Joannin S., Bassinot F., Combourieu Nebout N., Peyron O., Beaudouin C. (2011) - Vegetation response to obliquity and precession forcing during the Mid-Pleistocene Transition in Western Mediterranean region (ODP site 976). *Quaternary Science Reviews*, 30, 280-297.
- Laskar J., Robutel P., Joutel F., Gastineau M., Correia A.C.M., Levrard B. (2004) - A long term numerical solution for the insolation quantities of the Earth, *Astronomy and Astrophysics*, 428, 261-286.
- Lisieki L.E., Raymo M.E. (2005) - A Pliocene-Pleistocene stack of 57 globally distributed benthic $\delta^{18}\text{O}$ records. *Paleoceanography*, 20, PA1003.
- Maiorano P., Marino M., Di Stefano E., Ciaranfi N. (2004) - Calcareous nannofossil events in the lower-middle Pleistocene transition at the Montalbano Jonico section and ODP Site 964: calibration with isotope and sapropel stratigraphy. *Rivista Italiana di Paleontologia e Stratigrafia*, 110, 547-557.
- Marino M., Bertini A., Ciaranfi N., Aiello G., Barra D., Gallicchio S., Girone A., La Perna R., Lirer F., Maiorano P., Petrosino P., Toti F. (2015) - Paleoenvironmental and climatostratigraphic insights for Marine Isotope Stage 19 (Pleistocene) at the Montalbano Jonico section, South Italy. *Quaternary International*, <http://dx.doi.org/10.1016/j.quaint.2015.01.043>
- Maslin M.A., Ridgwell A.J. (2005) - Mid-Pleistocene revolution and the 'eccentricity myth'. In: M.J. Head and P.L. Gibbard (eds), *Early-Middle Pleistocene transitions: the land-ocean evidence: Geological Society of London, Special Publication*, 247, 19-34.
- Mix A.C., Le J., Shackleton N.J. (1995a) - Benthic foraminifer stable isotope stratigraphy of Site 846: 0-1.8 Ma. In: Pisias N.G., Mayer L., Janecek T., Palmer-Julson A., van Andel T.H. (eds), *Proceedings of the Ocean Drilling Program. Scientific Results*, 138, College Station (TX), 839-856.
- Mix A.C., Pisias N.G., Rugh W., Wilson J., Morey A., Hagelberg T. (1995b) - Benthic foraminifer stable isotope record from Site 849: 0-5 Ma. In: Pisias N.G., Mayer L., Janecek T., Palmer-Julson A., van Andel T.H. (eds), *Proceedings of the Ocean Drilling Program. Scientific Results* 138, College Station (TX), 371-412.
- Petrosino P., Jicha B., Mazzeo F.C., Russo Ermolli E. (2014) - A high resolution tephrochronological record of MIS 14-12 in the Southern Apennines (Acerno basin, Italy). *Journal of Volcanology and Geothermal Research*, 274, 34-50.
- Petrosino P., Jicha B.R., Mazzeo F.C., Ciaranfi N., Girone A., Maiorano P., Marino M. (2015) - The Montalbano Jonico marine succession: An archive for distal tephra layers at the Early-Middle Pleistocene boundary in southern Italy. *Quaternary International*, <http://dx.doi.org/10.1016/j.quaint.2014>.

- 10.049
- Robustelli G., Russo Ermolli E., Petrosino P., Jicha B., Sardella R., Donato P. (2014) - Tectonic and climatic controls on geomorphological and sedimentary evolution of the Mercure basin, Southern Apennines, Italy. *Geomorphology*, 214, 423-435.
- Russo Ermolli E., Aucelli P., Di Rollo A., Mattei M., Petrosino P., Porreca M., Roskopf C. (2010a) - An integrated stratigraphical approach to the late Middle Pleistocene succession of the Sessano lacustrine basin (Molise, Italy). *Quaternary International*, 225, 114-127.
- Russo Ermolli E., Sardella R., Di Maio G., Petronio C., Santangelo N. (2010b) - The late Early Pleistocene record of Saticula (Sant'Agata de' Goti, Benevento, Italy). *Quaternary International*, 225, 128-137.
- Russo Ermolli E., Di Donato V., Martin-Fernandez J., Orain R., Lebreton V., Piovesan G. (2014) - Vegetation patterns in the Southern Apennines (Italy) during MIS 13: deciphering pollen variability along a NW-SE transect. *Review of Palaeobotany and Palynology*, <http://dx.doi.org/10.1016/j.revpalbo.2014.11.004>
- Sadori L., Jahns S., Peyron O. (2011) - Mid-Holocene vegetation history of the central Mediterranean. *The Holocene*, 21(1) 117-129.
- Shackleton N.J., Hall M.A., Pate D. (1995) - Pliocene stable isotope stratigraphy of Site 846. In: Pias N.G., Mayer L.A., Janecek T.R., Palmer-Julson A., van Andel T.H. (eds), Leg 138. *Proceedings of the Ocean Drilling Program, Scientific Results*, 138, 337-355.
- Stefanelli S. (2004) - Cyclic stages in oxygenation based on foraminiferal microhabitats: early-middle Pleistocene, Lucania basin, southern Italy. *Journal of Micropaleontology*, 23, 81-95.
- Stefanelli S., Capotondi L., Ciaranfi N. (2005) - Foraminiferal record and environmental changes during the deposition of early-middle Pleistocene sapropels in southern Italy. *Palaeogeography, Palaeoclimatology, Palaeoecology*, 216, 27-52.
- Suc J.-P., Bertini A., Combourieu-Nebout N., Diniz F., Leroy S., Russo-Ermolli E., Zheng Z., Bessais E., Ferrier J. (1995) - Structure of West Mediterranean vegetation and climate since 5.3 Ma. *Acta Zoologica Cracoviense*, 38(1), 3-16.
- Suc J.P., Combourieu Nebout N., Seret G., Popescu S.A., Klotz S., Gautier F., Clauzon G., Westgate J., Insinga D., Sandhu A.S. (2010) - The Croton series: a synthesis and new data. *Quaternary International*, 219, 121-133.
- Tzedakis P.C., Bennett K.D. (1995) - Interglacial vegetation succession: a view from southern Europe. *Quaternary Science Reviews*, 14, 967-982.
- Tzedakis P.C. (2007) - Seven ambiguities in the Mediterranean palaeoenvironmental narrative. *Quaternary Science Reviews*, 26, 2042-2066
- Tzedakis P.C., Wolff E.W., Skinner L.C., Brovkin V., Hodell D.A., McManus J.F., Raynaud D. (2012a) - Can we predict the duration of an Interglacial? *Climate of the Past*, 8, 1473-1485.
- Tzedakis P.C., Channell J.E.T., Hodell D.A., Kleiven H.F., Skinner L.C. (2012b) - Determining the natural length of the current interglacial. *Nature Geoscience*, 5, 138-141.
- Watts, W.A. (1988) - Europe. In: Huntley B., Webb III T. (eds), *Handbook of Vegetation Science 7. Vegetation History*. Kluwer, Dordrecht, pp. 155-192.

Ms. received: May 18, 2015
Final text received: July 10, 2015

