Il Quaternario
Italian Journal of Quaternary Sciences
***16**(1Bis), 2003, 19-36*

EARLY TO MIDDLE PLEISTOCENE CHANGES OF THE ITALIAN FLORA AND VEGETATION IN THE LIGHT OF A CHRONOSTRATIGRAPHIC FRAMEWORK

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ABSTRACT
Palynological data from selected Pleistocene Italian sites are presented. The chronostratigraphic framework of floral and vegetational events illustrates the development of cooler climates during the Early and Middle Pleistocene. Floral and vegetational response to glacial/interglacial cycles, as well as major floristic and vegetal replacements (e.g. Taxodiaceae, *Cathaya, Tsuga*) are analysed with special attention to latitudinal and altitudinal gradients and to the different physiography of Italy. The pollen flora shows marked changes both at the beginning of the Pleistocene as well as at the time of the Mid-Pleistocene climate transition, when a major decrease in temperature, during steppe and forest phases, occurred. Alternations of *Artemisia* steppe and temperate to warm-temperate deciduous forest mark the overall glacial-interglacial vegetation changes in Italy. Glacials, however, do not correspond to dramatic drops of moisture in Northern Italy. Cycles here are characterized by the alternating spread of deciduous broad-leaved forests and altitudinal coniferous forests (mainly *Picea*) with no significant occurrence of steppe vegetation. Several sites from northern, central and southern Italy are described; reference sections permit correlations also of sites with poor time-diagnostic content. The quality of data is crucial in the application of advanced methodologies in palynology for reliable climate quantifications as well as for the elaboration of vegetation paleomaps.

RIASSUNTO
La palinologia rappresenta, potenzialmente, un importante strumento per la ricostruzione paleoambientale durante il Pleistocene. Durante questo intervallo di tempo la composizione floristica e la vegetazione sono ancora diverse da quelle presenti attualmente; un complesso melange di taxa aventi oggi una distribuzione geografica separata domina infatti le associazioni palinologiche. Numerosi taxa, ancora presenti nel nostro paese (e.g. Quercus, Picea, Abies*), sono associati ad altri aventi invece una distribuzione asiatica e/o americana (e.g. Taxodiaceae,* Cathaya, Tsuga, Carya*). Il progressivo fenomeno di raffreddamento, già cominciato durante il Pliocene, determina la progressiva scomparsa dei taxa relativamente più termofili come ad esempio Taxodiaceae,* Cathaya, Parrotia persica, Tsuga, Cedrus e Liquidambar. *Tali scomparse si verificano, nei diversi paesi europei e del litorale mediterraneo, in modo diacrono risultando fortemente influenzate da diversi gradienti climatici; la scomparsa delle Taxodiacee, avviene in modo tempo-trasgressivo all'interno della stessa penisola italiana. Tali eventi, possono, perciò, essere utilmente usati, solo se inseriti all'interno di un quadro cronostratigrafico di riferimento. La necessità di integrazione del record palinologico con altri strumenti stratigrafici è ribadita anche dal carattere spesso discontinuo di alcuni record così come dalla variabilità della vegetazionale locale. L'integrazione con elementi tempo-diagnostici quali la tefrostratigrafia o la magnetostratigrafia consente di inserire gli eventi ecobiostratigrafici in uno schema temporale; in tal modo essi diventano a loro volta elementi tempo-diagnostici in grado di migliorare la risoluzione stratigrafica; cio' rende possibile anche un loro corretto utilizzo per la definizione e la caratterizzazione di unità climatostratigrafiche e di biozone. In tal modo la palinologia diventa uno strumento efficace ed indispensabile per le ricostruzioni stratigrafiche e paleoambientali. Le diverse successioni italiane analizzate in questo lavoro di sintesi sono state selezionate sulla base della qualità del dato pollinico e della presenza di un adeguato quadro cronostratigrafico di riferimento. Ciò ha consentito di tracciare, in accordo con i cambiamenti relativi alla latitudine, altitudine e alle diverse caratteristiche fiosiografiche dei siti analizzati, la risposta della flora e della vegetazione ai cicli glaciale/interglaciale (G/I) durante il Pleistocene inferiore e medio. La palinoflora, già depauperata all'inizio del Pleistocene, subisce un progressivo ulteriore impoverimento in corrispondenza della transizione climatica del Pleistocene medio quando un'importante diminuizione della temperatura marca sia le fasi forestali che steppiche. In Italia, i cicli G/I determinano, generalmente, un'alternanza tra una vegetazione di tipo aperto prevalentemente steppica (ad* Artemisia*) sotto un clima arido da fresco a freddo ed una forestale dominata dalle latifoglie decidue sotto un clima umido e caldo-temperato. Tuttavia, nessuna importante diminuizione dell'umidità con conseguente espansione della vegetazione steppica è stata registrata durante i glaciali, nei siti dell'Italia settentrionale; qui, infatti, i cicli G/I sono caratterizzati dalla contrapposizione tra foreste di conifere di altitudine (principalmente a* Picea*) e foreste di latifoglie decidue. L'analisi floristica e vegetazionale delle diverse successioni analizzate evidenzia la buona potenzialità di alcune di loro a costituire delle sezioni di riferimento rappresentative delle diverse aree chiave della nostra penisola (nord, centro, sud). La definizione e la calibrazione dei principali eventi floristici e vegetazionali facilita le correlazioni sia a piccola - con sezioni geograficamente vicine a quelle di riferimento, non provviste di nessun altro supporto cronologico – che a grande scala. I dati selezionati potranno essere efficacemente utilizzati nell'ambito delle quantificazioni climatiche e per la ricostruzione di paleomappe di vegetazione; entrambi questi approcci sono già stati applicati con successo a siti neogenici.*

Key words: Pollen, flora, vegetation, climate, Early-Middle Pleistocene, Italy.

Parole chiave: Polline, flora, vegetazione, clima, Pleistocene inferiore e medio, Italia.

1. INTRODUCTION

Pollen represents, potentially, an important mean for the reconstruction of the patterns and processes of vegetation and climatic changes during the Pleistocene. At this time, the floral composition and vegetation of the Mediterranean and central European areas were still quite different from those present today; new species seldom appear and the disappearance of some thermophilous taxa (e.g. Taxodiaceae, *Parrotia persica, Cedrus, Liquidambar*) has a diachronous character (e.g. Zagwijn, 1975; Suc, 1986; Combourieu-Nebout, 1987; Fusco, 1996). The palynologic content must thus be used warily in describing biozones or climatostratigraphic units, especially when they do not make part of an established chronostratigraphic framework. Several palynostratigraphic correlations made in the past (e.g. those based on the disappearance of Taxodiaceae interpreted as an isochronous event; Lona *et al.*, 1969; Lona & Bertoldi, 1972) are incorrect (e.g. Zagwijn, 1975; Bertolani-Marchetti *et al.*, 1979; Michaux *et al.*, 1979) because based on two hazardous assumptions: the belief that the same (or similar) pollen assemblage zones in separate sections denote synchronous pollen signals; and the subsequent chronostratigraphic significance (e.g. Tiberian phase and boundary; Lona *et al.*, 1969; Lona & Bertoldi, 1972) attributed to some of these "ecobiostratigraphic" phases. This blurred the boundary between biostratigraphy and chronostratigraphy. Because of local vegetational variability and of the scantiness of many records (notably that from continental areas) palynology needs to be associated to other stratigraphic tools. In fact, the integration of time-diagnostic evidence (e.g. magnetostratigraphy and tephrostratigraphy) gives chronological value to ecobiostratigraphic events, thus enhancing stratigraphic resolution. Hence, correlation at local to regional scale between the successions lacking time-diagnostic elements is also made possible. Moreover, contrary to other fossils, palynomorphs, being contained in both marine and non-marine sediments, permit the correlation between onshore and offshore successions. All this makes palynology a very powerful tool for stratigraphic and palaeoenvironmental reconstructions.

These observations justified the selection of the Lower to Middle Pleistocene successions of Italy discussed in the paper (Figs. 1-2). The responses of the flora and vegetation to the glacial/interglacial cycles with special attention to latitudinal and altitudinal gradients are analysed, together with the major vegetation replacements.

2. STRATIGRAPHICAL SETTING

The Neogene regional and global events (e.g. Messinian salinity crisis, early Pliocene transgression, late Pliocene expansion of the Arctic ice cap and consequent start of glacial/interglacial cycles), strongly affected the successive Pleistocene history of the Mediterranean settings. From about 2.6 to 0.9 Ma, the glacial/interglacial fluctuations (G/I cycles) were dominated by orbital obliquity cycles, which have a periodicity of 41 ka; fluctuations of 100 ka, related to orbital eccentricity cycles, prevailed thereafter (Ruddiman *et al.*, 1989). This shift toward a more extended periodicity and amplitude indicates more intense glacial conditions, particularly between ca 0.9 and 0.6 Ma. In land settings, this modification in the G/I cycles produced a significant change in the vegetation and flora: steppes spread, while extreme thermophilous taxa, especially those distributed in subtropical areas today, progressively demised. The important geomorphic changes linked to the uplift of the Apennines also produced an important reorganization and restructuring of vegetation. Increased elevation led to climatic conditions similar to those found at higher latitudes; this also gave rise to dif-

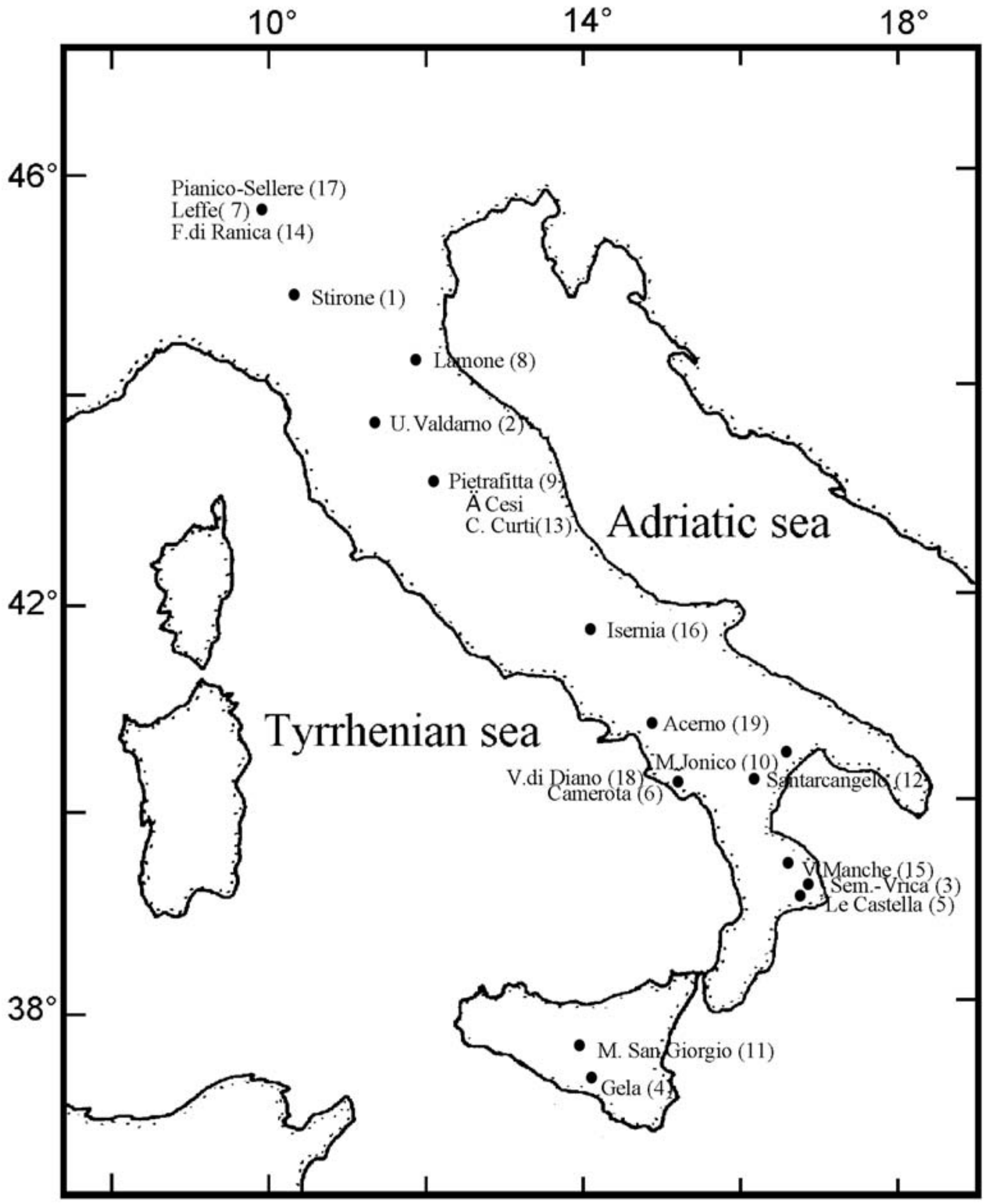

Fig. 1 - Location map of the selected sections

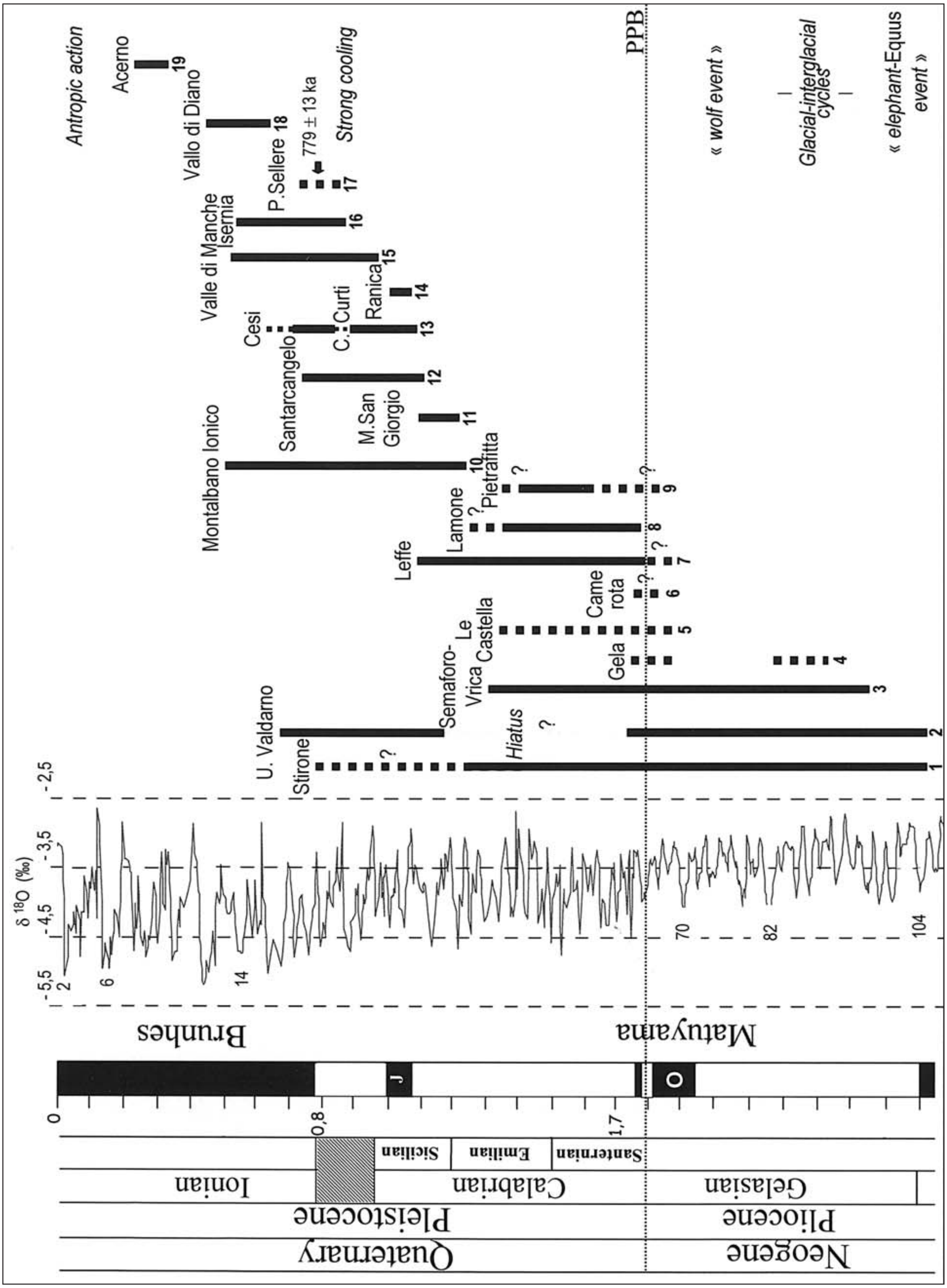

Fig. 2 - Stratigraphical location of the selected sections

ferent belts of vegetation at different altitudes.

All these modifications in climate and vegetation inexorably affected large mammal assemblages as well. In fact, important turnovers are detected in the Villafranchian mammal faunal communities (e.g. Torre *et al.*, 2001; Fig. 2). A strong drop in ruminant diversity, as well as the arrival of social carnivores, mark the end of the Reunion subchron and the onset of the Olduvai subchron (Azzaroli *et al.*, 1988). This is known as the “wolf-event” (Azzaroli, 1983; 1995; Rook & Torre, 1996). Another change in the Villafranchian faunal community, marked by the arrival of *Mammuthus (Archidiskodon)* and *Equus*, and known as the “Elephant-*Equus* event”, had occurred shortly before, approximately at the Gauss/Matuyama transition (Azzaroli, 1995; Torre *et al.*, 2001). The low ruminant diversity persisted until the Middle Pleistocene, when it grew again, equalling the final Pliocene levels, thanks to the arrival of new incomers.

The successions analysed in this work are mostly located in the pre-Alps and in the Apennines (Fig. 1). The schematic stratigraphic position of these sites are shown in Figure 2.

The Triassic to Paleogene marine successions exposed in the Southern Alps were involved in the final Miocene pulses of the Alpine deformation which caused the emergence of most of this area. Several valleys in the Pre-Alps, which had formed before the end of the Messinian (Bini *et al.*, 1978), were filled with Pliocene marine sediments (Bini *et al.*, 1978; Brambilla *et al.*, 1983; Brambilla & Lualdi, 1987; Violanti, 1991). During the Plio-Pleistocene, the upper Lombardy plain emerged. Fluvial sediments deposited during a successive phase of aggradation. Tributary valleys finally dammed at the end of the aggradation phase, and lacustrine basins were formed, as for example those of Leffe (Cremaschi & Ravazzi, 1995) and Fornaci di Ranica (Ravazzi *et al.*, in press). Several terraced deposits were formed during the successive middle and late Pleistocene fluvial downcut.

The Apennines started to arise in the latest Cretaceous, during the eo-alpine phase. From the late Tortonian to the early middle Pleistocene, extensional faulting affected the inner sectors of the Apennine chain, generating numerous, relatively small, eastward-progressing and younger, marine and continental basins, extended WSW of the orographic divide. Three major successions of marine to continental deposits characterize the peri-Tyrrhenian extensional areas (an outline can be found in Ghisetti & Vezzani, 1999). Martini & Sagri (1993), and Bossio *et al.* (1998) described the successions outcropping in the northern Apennines, while Cinque *et al.* (1993) the ones exposed in the southern Apennines. Compressional basins (“piggy-back” and “foredeep” basins; Ori & Friend, 1984; Ricci-Lucchi, 1986; 1990) formed on the Adriatic side of the mountain divide.

3. MATERIALS AND METHODS

The Pleistocene sections selected for this study (Figs. 1, 2) are among the most dependable from the chronological viewpoint. The main stratigraphical and geological information is summarized below, whereas the pollen records are discussed in the following paragraphs.

1. The **Stirone** succession outcrops on the banks of the Stirone River, along the Northern Apennine foothills, some 28 Km West of Parma (Northern Italy). Because of its rich stratigraphical and paleontological documentation, it is one of the best known Pliocene to Pleistocene successions of Northern Italy (e.g. Papani & Pelosio, 1963; Pelosio & Raffi, 1974; Raffi, 1982; Iaccarino & Pugliese, 1988; Capotondi, 1992; Mary *et al.*, 1993; Channel *et al.*, 1994; Monegatti & Pelosio, 1994; Iaccarino, 1996). The Stirone succession consists, from the base upwards, of about 900 m of lower to upper Pliocene marine deposits and of over 100 m of Pleistocene infralittoral sediments, with intercalations of brackish and fresh water beds. The palynological content of the Pliocene sediments was analysed by Bertini (1992; 1994a, b; 2001) and Bertini & Vannucchi (1993), whereas that of the upper Pliocene to lower Pleistocene sediments by Lona & Bertoldi (1972), Becker-Platen *et al.* (1977) and Bertolani-Marchetti *et al.* (1979).

2. The **Upper Valdarno** (central Italy) is one of the most extensive Plio-Pleistocene intermontane basins of the Northern Apennines. It is located 35 km SE of Florence between the Chianti Mountains and the Pratomagno Ridge. It is filled with some 550 m of fluvio-lacustrine deposits which can be divided into three main sedimentary successions (e.g. Merla & Abbate, 1967; Azzaroli & Lazzeri, 1977; Abbate, 1983; Magi & Sagri, 1994) of middle Pliocene to Pleistocene age on the basis of bio- and magnetochronological evidence (Torre *et al.*, 1993, 1996; Albianelli *et al.*, 1997; Napoleone *et al.*, this volume). Pollen analyses were carried out by Bertini (1994b; in press), Bertini & Roiron (1997) and Mazza *et al.* (submitted).

3. The **Semaforo-Vrica** composite section outcrops 4 km south of Crotone (Calabria, southern Italy). It consists of about 451 m of Pliocene and Pleistocene marine blue grey silty-marly claystones with sapropelic laminite and cineritic intercalations. At Vrica, the base of the marine claystones, which conformably overlies the sapropelic Marker Bed "e", marks the onset of the Pleistocene Series (Aguirre & Pasini, 1985; Basset, 1985; van Couvering, 1997). Palynological analyses were carried out by Bertolani-Marchetti (in Selli *et al.*, 1977), Nakagawa *et al.* (1980; 1997), Combourieu-Nebout & Vergnaud-Grazzini (1991), and Combourieu-Nebout (e.g. 1993; 1995).

4. The marine Plio-Pleistocene section of **Gela**, in Sicily (Agrigento, southern Italy), is well known in literature thanks to the studies of Rio *et al.* (1984) and Sprovieri *et al.* (1986). Palynological studies there were carried out by Bertoldi *et al.* (1989).

5. Le Castella is a marine section located on the Ionian side of northern Calabria (Crotone basin). It was first described by Emiliani *et al.* (1961). Calcareous nannofossil biostratigraphy (Raffi & Rio, 1980) revealed a fairly long hiatus at the sandy “marker bed” of Emiliani *et al.* (1961). Pollen records are available from the upper part of the Late Pliocene, as well as from the middle part of Early Pleistocene (Bertoldi, 1977; Bertoldi *et al.*, 1989).

6. The **Camerota** basin, in the Cilento promontory, is a structural depression formed during the Late Pliocene extensional tectonics that disrupted the eastern margin of the southern Tyrrhenian basin (Borrelli *et al.*, 1988). Here palynological research was performed in sediments of an about 40-50 m thick lacustrine succession of clays and marls with recurrent tephra and peat beds in the upper portion (Baggioni *et al.*, 1981; Brenac, 1984; Russo-Ermolli, 1999). Unfortunately, these deposits are void of significant time-diagnostic elements. The only sure stratigraphical reference are Santernian marine deposits which unconformably cap the sequence.

7. The **Leffe** section, in the Lombardian Pre-Alps, consists of a Plio-Pleistocene continental succession of clays, brown-coals, peats, gyttja, and biogenic calcareous laminites. More precisely, the succession extends between the top of the Olduvai (Muttoni, in progress, and Ravazzi, pers. com. 2002, claim that it possibly reaches the base of the Olduvai) and the base of the Jaramillo (which however was never located). The palynologic content of this sequence was studied by Lona (1950), Lona & Follieri (1957), Lona & Bertoldi (1972), Ravazzi (1993: see for geological and stratigraphical references), Ravazzi & Rossignol-Strick (1994; 1995), Ravazzi & Moscariello (1998) and Pini & Ravazzi (2002).

8. The **Lamone** succession, in the north-eastern Apennines, consists of marine grey-blue clays of the Argille Azzurre Fm. This succession is Santernian to Emilian in age, on the basis of its foraminiferal content (Vaiani, 1996). Palynological studies have been carried out in two separate sections (Fusco, 1996). The first one contains the Santernian/Emilian boundary, marked by the appearance of the benthonic foraminifer *Hyalinea baltica* (Pasini & Colalongo, 1994). This same taxon is distributed throughout the whole second section, which therefore is dated to the Emilian.

9. The **Pietrafitta** lacustrine succession outcrops in the Tavernelle Basin, which forms the upper valley of the Nestore river (Umbria, central Italy). The succession consists of clays, peaty clays and lignite beds. The latter have yielded numerous fossil remains of vertebrates, invertebrates, and macroflora. The mammal remains have been referred to the Farneto Faunal Unit (Late Villafranchian Mammal Age; Gliozzi *et al.*, 1997). An early Pleistocene age is also consistent with the inverse magnetic polarity detected in the lignite beds (Napoleone & Albianelli, pers. com. 2002). Ricciardi (1961) and Lona & Bertoldi (1972) carried out the palynological analyses of this succession.

10. Montalbano Ionico, southernmost part of the Bradano trough (Basilicata, southern Italy). This marine succession consists of about 400 m of silty clays (“Argille subappenine” Formation), with nine volcanoclastic intercalations. The succession was found to straddle the Lower-Middle Pleistocene boundary on the basis of nannofossil and magnetostratigraphic evidence (e.g. Ciaranfi *et al.,* 1996; 2001). Preliminary palynological analyses were performed by Suc (Suc, pers. com. 1999).

11. The **Monte San Giorgio** succession, north of Caltagirone (Sicily), consists of 150 m of marine clayey and sandy marls intercalated to clays. Palynological analyses were carried out along a 60 m section where the continental and marine records indicated a dating from 1.23 to 1.095 Ma (Dubois, 2001).

12. Santarcangelo is a Pliocene to Pleistocene satellite basin in the southern Apennines (Basilicata, Southern Italy). Palynological research has been carried out in the lacustrine deposits of the San Lorenzo unit (Bertini in Sabato *et al.*, in press; Bertini, in progress). The latter is an over 200 m thinly bedded claystone and silty claystone with sandstone, carbonate and volcanoclastic intercalations. A late Biharian mammal assemblage was found in this succession (Masini *et al.*, in press). Palaeomagnetic investigations allow the identification of the Jaramillo subchron, as well as the base of the Brunhes chron (Sabato *et al.*, in press).

13. The **Colle Curti** and **Cesi** fluvio-lacustrine basins are located in the Umbria-Marchean Apennine Mountains (Central Italy), at about 850 m and 820 m above sea level, respectively. They were formed in the Early to Middle Pleistocene when extensional tectonics affected the mountain chain (e.g. Coltorti *et al.*, 1998). The Colle Curti mammalian faunal assemblage defines the homonymous Faunal Unit, which marks the beginning of the Galerian Mammal Age in Italy (e.g. Ficcarelli *et al.*, 1997). Magnetostratigraphical research identified the C1r.2r p.p., C1r.1n (Jaramillo), C1r.1r and C1n *p.p.* (Brunhes) Chrons and Subchrons. Pyroclastic sediments about 30 m above the top of the section, yielded an Ar/Ar date of 424 ka (Coltorti *et al.*, 1998). The palynological content of both sections was studied (e.g. Bertini, 2000).

14. The lacustrine succession of **Fornaci di Ranica**, at the outlet of the Seriana Valley in the Bergamo foothills (northern Italy). Multidisciplinary studies carried out throughout a 13 m long-core suggest that the sedimentation occurred in the late Early Pleistocene, apparently during the Jaramillo Subchron. Nevertheless, the impossibility to discriminate between *Cervalces latifrons* and C. *carnutorum* do not exclude a correlation to the cryptochron Cobb (Ravazzi *et al*., in press).

15. The **Valle di Manche** section, south-east of the San Mauro Marchesato area, in the Crotone basin (southern Italy). Here the Middle Pleistocene deposits underwent detailed stratigraphical studies (see in Massari *et al*., 2001 for references). The Valle di Manche section contains the three main units defined in the San Mauro Group (San Mauro 1, 2, 3) extending approximately just above the top of the Jaramillo and the “Parmenide ash” key bed. The Brunhes Matuyama boundary correlates with the“Pitagora ash”, in the mainly muddy San Mauro 2 unit. Capraro in Massari *et al.* (2001) performed palynological analyses from the base to the lower part of S. Mauro 3, which mainly consists of prograding sand bodies.

16. La Pineta - Isernia. The archaeological site of La Pineta lies at about 450 m a.s.l in the intermontane Isernia–Venafro lacustrine basin, in the upper part of the Volturno valley (southern Italy). The basin was filled up between 870 ±150 and 520 ±50 ka ago (van Otterloo & Sevink, 1983). Five units have been recognized (Cremaschi, 1983; Cremaschi & Peretto, 1988), with a lacustrine episode at the base. The latter is overlain by a fluvial unit containing mammal remains and lower Paleolithic lithic industry. Delitalia *et al.* (1983) obtained a K/Ar dating of 736 ±40 ka (for the archaeological bed). Such a dating, however, was first challenged by von Koenigswald & Kolfschoten (1996) because of the occurrence of *Arvicola cantiana*, and afterwards by Belluomini *et al.* (1997) who obtained an amino-acid dating of 550 ±140 ka. Pollen analyses were carried out by Lebreton (2001; 2002).

17. Pianico-Sellere, south of the Italian Alps, consists of an about 50 m varved lacustrine succession

(Moscariello *et al*., 2000). The K/Ar dating of a distal tephra in the sequence gave an age of 779 ± 13 ka. Palaeomagnetic analyses consistently detected the Matuyama/Brunhes transition. The latter is dated 780 ka (Pinti *et al*., 2001) and correlates both with the marine oxygen isotopic stage 19 (MIS 19) and with the oldest interglacial phases of the Cromerian Complex of Central Europe (e.g. Turner, 1996).

18. Vallo di Diano is a large tectonic basin in the Campanian Apennines (southern Italy). Here a borehole about 150 m deep was drilled through a lacustrine sequence. A 601 ± 7 Ka ^{40}Ar/^{39}Ar dating at the base of the sequence, matched with oxygen isotopic data, suggested that the pollen record (e.g. Russo-Ermolli, 1994; Russo-Ermolli *et al*., 1995) covers a 650 to ca 450 Ka span (MIS 16 to 13) (e.g. Russo-Ermolli & Chedaddi, 1997).

19. The Acerno basin (southern Italy) represents a Middle Pleistocene tectonic paleolake formed in the southern Apennines. A 98 m continuous coring drilled through a sequence consisting, from the base upwards, of fluvial conglomerates, silt and white marl alternations, and fluvial conglomerates with silt and sand interfingings. Thirty pyroclastic beds were identified. The thickest tephra bed correlates with MIS 9 and 8 because of the presence of the Lower White Trachytic Tuff marker horizon dated to 297 Ka (Munno *et al*., 2001). Pollen analyses of this sequence were carried out by Elda Russo-Ermolli (2000).

4. THE EARLY PLEISTOCENE

The marine composite section of **Semaforo-Vrica** (Crotone, Calabria) is used as reference to locate stratigraphically the main Late Pliocene to Early Pleistocene floral, vegetational and climatic changes. In the Vrica section, in particular, the GSSP of the base of the Pleistocene series has been ratified, whereas the Calabrian stage as well as the Emilian and Santernian substages have only been proposed (Aguirre & Pasini, 1985; Basset, 1985; Pasini & Colalongo, 1994; Ruggieri & Sprovieri, 1997; Pasini & Colalongo, 2001). Successive studies (e.g. Hilgen, 1991; Zijderveld *et al*., 1991; Lourens *et al*., 1966a,b; 1998; Raffi, 2002) provided further stratigraphic evidence completing the original definitions. Zijderveld *et al*. (1991) repositioned the Plio-Pleistocene boundary (PPB) placing it just below the top of the Olduvai Subchron. Lourens *et al*. (1996a) showed that the Pleistocene part of the Vrica section ranges from the standard oxygen isotope stage 65 to 36, stressing the substantial difference from previous interpretations (Combourieu-Nebout & Vergnaud-Grazzini, 1991; Sprovieri, 1993). In contrast to oceanic sequences, the base of the large *Gephyrocapsa* (blG) zone correlates with Stage 55 and not with Stage 48 (or with the top of Stage 49) (Raffi *et al*., 1993; Lourens *et al*., 1998; Raffi, 2002). Consequently, the FAD of the benthic foraminifer *Hyalina baltica* does not match with the base of the large *Gephyrocapsa* zone.

By carrying out the most detailed and accurate palynological studies of the Plio-Pleistocene composite sections of southern Italy, Combourieu-Nebout (e.g. 1993; 1995) reconstructed the changes in vegetation and climate during the 2.46 to 1.36 Ma time span. The main vegetation changes were shown to closely match global climatic variations (e.g. Combourieu-Nebout & Vergnaud–Grazzini, 1991). Forest to open herbaceous vegetation fluctuations, which reflect the climatic oscillations linked to glacial/interglacial cycles, are documented from the base of the Semaforo section (ca at 2.46 Ma). Likewise other Mediterranean sites (see references in Suc *et al*., 1995), the succession of four main vegetational assemblages attests to a gradual transition from warm and moist (interglacials) to cold and dry (glacials) conditions. The start of an interglacial event is marked, at first, by the expansion of deciduous forests, and then, by that of subtropical moist forests indicating an increase in temperature followed by an increase of the humidity. Subtropical moist forests progressively reduced from the late Pliocene on. The successive increase of high-altitude coniferous forest taxa indicates a temperature drop but no marked variations in humidity. Finally, the considerable spread of open vegetation with *Artemisia* indicates a substantial decrease in humidity. G/I cycles are marked by four following vegetation units in northern Italy as well. This is clearly documented in the marine succession of **Lamone** (north-eastern Apennines; Fusco, 1996), which is more or less equivalent in time to the Vrica section. Cycles, though, differ from those described at Vrica (e.g. Combourieu-Nebout, 1993) because of the lesser expansion of herbs (especially *Artemisia*) and wider spread of *Picea*. The diffusion of montane arboreal vegetation, in particular *Picea*, during glacial phases, as well as the limited expansion of the herbaceous vegetation, both in time and space is attested to in several Plio-Pleistocene marine and continental deposits of northern Italy (Leffe: Lona, 1950; Ravazzi & Rossignol-Strick, 1995; Castell'Arquato: Lona, 1962; Lona & Bertoldi, 1972; Stirone, Plio-Pleistocene portion: Lona & Bertoldi, 1972; Bertolani-Marchetti *et al*., 1979; Pliocene portion: Bertini, 2001; Marecchia valley: Rio *et al*., 1997). A phase characterized by high percentages of *Artemisia* but associated to *Picea* and *Larix*, is recorded from the upper part of the early Pleistocene continental succession of **Leffe** (Lombardy Pre-Alps) (Ravazzi & Rossignol-Strick, 1995). The limited expansion of steppe taxa seems due to local climatic constraints existing at the time in Northern Italy, more than to the apparent result of some taphonomic bias, or insufficient chronologic resolution. This strengthens the hypothesis that, roughly since the Pliocene, the Po region had a very peculiar vegetation and climate (Bertini, 2001; Fauquette & Bertini, in press).

Plio-Pleistocene glacial-interglacial cycles of continental intermontane sequences of central Italy have intermediate characteristics between those of southern and northern Italy. Typical examples are those of the **Upper Valdarno** (e.g. Bertini, 1994b; Albianelli *et al*., 1995; Torre *et al*., 1996; Albianelli *et al*., 1997; Bertini, in press), the Tiber basin (Pontini, 1997; Pontini & Bertini, 2000; Pontini *et al*., 2002), and **Pietrafitta** (Lona & Bertoldi, 1972).

On the basis of palynological, biostratigraphical and isotopical evidence from southern Italy, Bertoldi *et al.* (1989) observed a different response of vegetation to G/I cycling. In the Upper Pliocene to Lower Pleistocene sites of **Le Castella** and **Gela**, in particular, these authors proposed that glacials are marked by forests, while interglacials by open vegetation.

In the light of the information presented above, it is apparent that repeated G/I cycles contributed to the compositional and structural changes in the vegetation. The upper Pliocene of Vrica is particularly enlightening. A significant demise of the Taxodiaceae forests is attested to from about 2.38 Ma on, followed by a spread of *Cathaya*, especially from ca 1.92 to 1.74 Ma, as well as of *Artemisia*, from ca 1.87 Ma on. In the course of the same interval, warm temperate woodlands expanded at the expense of subtropical forests. The same occured in the Upper Valdarno, but the record in this case is rather less continuous (Bertini, 1994b; Bertini, in press). The distribution of Taxodiaceae in space and time, as well as their stratigraphical implications during the upper Pliocene to early Pleistocene time span, are analysed in more detail in paragraph 6.1. The arrival of the large *Gephyrocapsa*, at about 1.56 Ma, and successively of *Hyalina baltica* at the Santernian-Emilian boundary about 1.49 Ma, characterizes the marine realm. On lands, a general expansion of open vegetation at this time, in particular of steppe taxa, such as *Artemisia*, a taxon indicative of dry conditions, is recorded at Vrica. Here, roughly after 1.47 Ma (i.e. above laminite q), altitude trees reach their highest percentages, *Tsuga* replacing *Cathaya* in forest associations. This indicates cooler but relatively moist conditions. At Lamone (Fusco, 1996), in Northern Italy, a similar trend is observed near to the occurrence of *Hyalina baltica*. A well marked cyclic expansion and dynamism of different vegetations can also be observed. A similar evolution is documented at Stirone (Lona & Bertoldi, 1972; Bertolani-Marchetti *et al.*, 1979) and Leffe (Ravazzi & Rossignool-Strick, 1995). In the latter, in particular, high resolution pollen analyses recently permitted the identification of eleven cyclic changes in vegetation and climate (Pini & Ravazzi, 2002; in progress) from the end of the Late Pliocene to the early Pleistocene, just before the Jaramillo Subchron.

Palynological evidence stops at about 1.36 Ma at Vrica. Additional information from 1.23 and 1.095 Ma (the lower part of the Sicilian) is available at **Monte San Giorgio** (Caltagirone, Sicily). Here, glacial/interglacial cycles recall those detected at Vrica, with only minor differences (Dubois, 2001).

5. THE LATE EARLY AND MIDDLE PLEISTOCENE

The most complete late Early and Middle Pleistocene marine and continental successions outcrop in Southern Italy. The marine successions permit the formal definition of standard Pleistocene chronostratigraphic units.

The **Montalbano Jonico** section (Basilicata, Southern Italy), with its first occurrence of *Gephyrocapsa* sp. 3 near the top of the Jaramillo Subchron and in correlation with oxygen isotopic stage 25 (Ciaranfi *et al.*, 2001), was the proposed GSSP (Global Boundary Stratotype Section and Point) of the Middle Pleistocene. It is an alternative to the Japanese section of Boso Peninsula, where Kumai’s (1996) proposed GSSP lies in the proximity to the Brunhes-Matuyama magnetic reversal. Unfortunately, a pilot survey revealed that the uppermost part of the analysed samples from Montalbano Jonico section are barren in sporomorphs (Suc, pers. com. 1999). Instead, Pleistocene continental deposits (San Lorenzo cycle) from the neighbouring **Santarcangelo** basin offer a rich palynological documentation (Bertini in Sabato *et al.*, in press). Here the pollen record evidenced repeated alternations of open landscapes, dominated by steppe taxa such as *Artemisia* and *Ephedra*, and forests (mostly *Quercus*) throughout the late Early Pleistocene. Detailed palynological analyses of the upper part of the succession are in progress. The palynological analysis of both the Santarcangelo and Montalbano Jonico sections are expected to permit marine-continental correlations during a key moment of the Pleistocene. Preliminary pollen data (Capraro in Massari *et al.*, 2001) from the marine **Valle di Manche** section, about 150 Km south of Montalbano Jonico, in the Crotone area, are in agreement with those from Santarcangelo.

In central Italy, the main changes in the palaeoflora and vegetation detected in the **Colle Curti** and **Cesi** fluvio-lacustrine deposits (Bertini, 2000), occurred between 0.9 and 0.6-0.7 Ma (Ficcarelli *et al.*, 1997; Coltorti *et al.*, 1998), which is approximately the same time span covered by the Santarcangelo record. The two successions reveal a progressive increase in aridity, as well as a progressive decrease in temperature, which is associated to the Middle Pleistocene shift from the 41 to 100 Ka cyclicity in the Milankovitch orbital record (Bertini, 2000). During the successive open vegetation phases (glacials), Chenopodiaceae and *Artemisia* progressively increase, whereas Cyperaceae decline. Forest phases are first dominated by *Tsuga*, then by *Abies* plus *Picea* and, finally, *Pinus*; but these forests show no significant expansion of broad-leaved deciduous elements. Palynological, sedimentological, and taphonomic evidence reveal the occurrence of several hiatuses in the early parts of the interglacials. These hiatuses were considered the palaeoenvironmental response to climatic changes affecting local lithological and geomorphological settings (karst) (Bertini, 2000).

The same trend observed at Colle Curti and Cesi for *Tsuga*, with peak of abundance during the Jaramillo Subchron, was also observed at **Fornaci di Ranica** (Ravazzi *et al.*, in press), in Northern Italy. At C. Curti, *Tsuga* reaches another peak, before its final decline, in the post-Jaramillo inverse polarity interval.

In the **Pianico-Sellere** continental succession, near Fornaci di Ranica, *Tsuga*, as well as *Pterocarya*, *Carya*, and *Cedrus*, are lacking at about 779 ± 13 Ka, which is the date of a tephra included in the middle part of the succession (Pinti *et al.*, 2001). A much younger age, correlative with MIS 5, 7 or 9, was previously suggested for this succession, on the basis of the geological setting and macroflora studies (Moscariello *et al.*, 2000).

The previously mentioned climatic gradients, which characterized the Mediterranean area at least since the Neogene, account for the major expansion of herbs and reduced presence of relatively moister arboreal taxa in southern sites than in northern ones. *Tsuga* is less abundant in the south, as testified by the pollen records from Monte San Giorgio, Santarcangelo and **La Pineta** (Isernia) which, taken as a whole, extend in time from the upper part of the early Pleistocene to the beginning of the middle Pleistocene. The available pollen data (Suc & Bessais, 1990; Bertini *et al.*, 1998) shows that ever since the Neogene this taxon has never been an important element of the forests at the latitude of Sicily.

At **Vallo di Diano** (southern Italy) *Tsuga* is virtually absent from 650 to 450 Ka, whereas *Carya* is constantly present, and *Pterocarya* is sporadic. Two main climatic oscillations were recognized and correlated with the glacial–interglacial cycles MIS 16 to 13. As at Santarcangelo the glacial intervals are characterized by high concentrations of herbaceous and steppe pollen, while the interglacial intervals are dominated by arboreal pollen.

The lacustrine succession of **Acerno**, southern Italy, was correlated with isotopic stages 9 and 8 because of the presence of the Lower White Trachytic Tuff (WTT) marker horizon which is dated 297 Ka (Munno *et al.*, 2001). Pollen analyses confirmed an interglacial-glacial cycle. Interglacial conditions are indicated by a phase of oak forest expansion, while glacial conditions are marked by a sharp drop in all arboreal taxa, as well as by the simultaneous spread of herbaceous and steppe elements. Here *Tsuga* and *Carya* are absent.

6. DISCUSSION

The selected pollen data contribute substantially to the reconstruction of the lower and middle Pleistocene landscapes in Italy because they permit a direct comparison of the main palaeonvironmental (e.g. climatic and tectonic) events, at both global and local scale, with significant floristic and vegetation changes. They also address some key stratigraphic questions relevant to this time interval.

6.1. The PPB, the Tiberian boundary, and the Plio-Pleistocene range of Taxodiaceae

The PPB, located at the base of the marls overlying sapropel marker bed 'e' in the Vrica section, corresponds to the beginning of a glacial period, as attested to by the spread of herbaceous and steppe vegetation after a long period of relatively homogenous, warm conditions (interglacial) (e.g. Combourieu-Nebout *et al*., 1990). In the Semaforo-Vrica composite section, on the other hand, the glacial-interglacial cycling starts 350 m below marker bed "e" (e.g. Combourieu-Nebout, 1995). Therefore this event is not an unequivocal climatic signal. G/I cycles seem to set off limited change in the composition of flora associations after 2.46 Ma. They must therefore be distinct. *Artemisia* progressively gained importance in the open vegetation communities of glacial intervals, whereas warm-temperate taxa prevailed on subtropical taxa, which progressively disappeared, in forest associations during interglacials. Continental sites lack most of the stratigraphical information available in marine settings. Therefore, the glacial event near marker bed "e" at Vrica may be a useful reference for identifying the PPB only when it is associated to the palaeomagnetic record. In fact, in the fluvio-lacustrine **Upper Valdarno** basin (central Italy), the recognition of the split Olduvai (Zijderveld *et al*., 1991) permitted the same resolution of marine sediments in calibrating the pollen assemblage zones to climate zonation, as well as in correlating mammal fauna biochronology with marine biostratigraphy (Albianelli *et al*., 2002). The changes in vegetation, in particular, closely matched the climatic fluctuations, which were recorded by oxygen isotopic stages. In particular, near the PPB, an 89 % peak of herbs (glacial) follows a warm-and humid phase dominated by forest taxa (interglacial).

In the past, some Italian palynologists placed the PPB in correspondence to the disappearance (or better the dramatic fall) of Taxodiaceae. Lona *et al.* (1969; 1971) observed the sudden disappearance of *Taxodium* pollen just after an acme phase in the lacustrine **Pietrafitta** succession and called this event the " Tiberian boundary". Later on, the Tiberian boundary was also recognized in the marine section of Stirone about 10 meters below the level where Papani & Pelosio (1963) found *Arctica islandica* (and where the PPB was placed). Lona *et al.* (1969) and Lona & Bertoldi (1972) correlated this event with the beginning of the Calabrian and with the PPB, pointing out the delay in the appearance of the northern marine guests. In 1977 the recovery of *A. islandica* specimens (Pelosio & Raffi, 1977) at the top of the "calcarenite" of the Stirone section permitted a repositioning of the PPB. Iaccarino (1996) argued that the Plio-Pleistocene transition occurs about 3 m below the base of the "calcarenite", in correspondence to a downward-shift (Mutti pers. com. in Capotondi, 1992). These new data cleared the discrepancy between the arrival of the northern marine guests and the disappearance of the Taxodiaceae, and confirmed the position of the Tiberian boundary (and of the PPB). Bertoldi (1977) recognized the Tiberian boundary at the marker bed in the marine section of Le Castella. In the Upper Valdarno, a strong decrease in *Taxodium* type pollen after an acme phase was observed close to the PPB (Bertini, in press), as well as in Pietrafitta and Stirone.

Nevertheless, it is important to stress that the recurrence of the episodes of sudden fall in the pollen percentage of Taxodiaceae during the upper part of the Late Pliocene does not make these events an unequivocal signal. Moreover, Taxodiaceae survive the PPB in many Italian sites (e.g. Bucha *et al*., 1975; Bertolani-Marchetti *et al*., 1979; Fusco, 1996; Ravazzi & Rossignol-Strick, 1995; Combourieu-Nebout, 1993; 1995; Bertini, 2001). This prevents an exact location of this limit, especially in short and discontinuous successions without the support of marine stratigraphy or time-diagnostic elements; the latter remark was also made by Lona & Bertoldi (1972).

The climatic requirements and geographic distribution of some extant Taxodiaceae, which are shown in Table I, can explain why different components of this family disappeared during the late Pliocene and Pleistocene in the Mediterranean area (see also the interpretations of Lona, 1963; Lona *et al*., 1971; Lona & Bertoldi, 1972; Bertolani-Marchetti, 1978). In the Italian pollen record, Taxodiaceae are mainly represented by *Sciadopitys*, *Taxodium* type (which includes *Taxodium cf. distichium and Glyptostrobus*) and *Sequoia* type (which includes *Sequoiadendron giganteum, Sequoia sempervirens, Metasequoia, Cunninghamia* and *Cryptomeria*). Both *Taxodium* type and *Sequoia* type include different genera with similar pollen morphology which prevents their specifical identification at the optical microscope. Taxodiaceae were among the most important components of the Zanclean and early

Piacenzian thermophilous forests. Starting from the late Piacenzian, and especially during the Gelasian, after the start of G/I cycles, Taxodiaceae considerably declined. The analysis of the sections selected permit the tracking of their spatial and temporal distribution in Italy during the late Pliocene and Pleistocene (Fig. 3).

In the Stirone and Lamone successions, *Taxodium* type is quite well represented, whereas *Sequoia* type is scattered. At Lamone, the former reaches 11.2 % in abundance in the Santernian, and 4.6 % in the Emilian. Aside from Leffe, *Taxodium* type is absent during the Emilian; it occurs at low percentages only in the lower part of cycle M, which was correlated with isotopic stages 51/50 or 53/52 by Ravazzi & Rossignol-Strick (1995). At Pietrafitta, as mentioned above, Taxodiaceae (*Taxodium* type, principally) are supposed to disappear at the PPB (Lona *et al.*, 1969), but this section lacks a precise chronostratigraphic reference. Taxodiaceae are absent along the whole Colle Curti and Cesi record (i.e. from about the upper part of C1r.2r subchron on). In the south, the dominant Taxodiaceae at Vrica is *Sequoia* type, and its occurrence is testified until about 1.3 Ma; at Monte San Giorgio they are sporadic between 1.23 and 1.095 Ma. At Santarcangelo, Taxodiaceae are sparsely present only in the basal part of the succession. They are absent in the younger sites of Isernia, Vallo di Diano (here sparse grains of Taxodiaceae were interpreted as probably reworked elements), and Acerno. The analysis of the vegetation assemblages and of their spatial distribution, together with the geological and sedimentological features of the deposits, evidenced a predominant climatic control on the Taxodiaceae disappearance. Edaphic and depositional factors played a subordinate role, which explains their survival as relicts (or in previous times phases of particular wide spread) in swamp environments, predominantly with *Taxodium* type (e.g. in the Tiberino or Upper Valdarno basins), or close to slopes (e.g. at Crotone, close to the Sila), mostly with *Sequoia* type.

The Taxodiaceae stratigraphical range shows that their disappearance cannot be considered as an isochronous and sudden event matching exactly the PPB. It is therefore impossible to use such event (i.e. the Tiberian boundary) to cross-correlate Italian successions. Using the Tiberian boundary to establish wide-scale correlations resulted incorrect (Lona, 1971) [see, for instance, the correlation of the Tiberian boundary with the Reuverian/Pretiglian transition of The Netherlands (Zagwijng, 1975). The latter in fact is correlatable with the Piacenzian/Gelasian boundary (at ca 2.6 Ma) and not with the PPB (at ca 1.8 Ma), on the basis of chronostratigraphical considerations].

6.2. The disappearance of subtropical to warm temperate/temperate taxa

During the Neogene and the Pleistocene, the progressive decrease of temperature in Italy, as well as the change in amount and distribution of precipitations, caused not only the already mentioned gradual disappearance of Taxodiaceae, but also that of many other taxa with present day tropical to subtropical, or even extra-European warm-temperate/temperate range. Some of them, such as *Cathaya, Tsuga, Cedrus, Carya, Pterocarya, Liquidambar*, survive for a while as relicts under microclimatic and/or edaphic conditions, before becoming thoroughly extinct. ***Cathaya*** is a Pinaceae which now lives at various altitudes, from less than 300 m to over 1800 m a.s.l. (Liu *et al*., 1997), only in a restricted area of Northern China (Wang, 1961; Liu *et al*., 1997). The climatic requirements of *Cathaya* identified by Faquette *et al.* (1998a, b) are shown in Table I, although this taxon probably has a wider potentiality of occurrence. *Cathaya* shows repeated phases of expansion during the middle (e.g. at Stirone; Bertini, 2001) and late (e.g. at Vrica; Combourieu-Nebout & Vergnaud-Grazzini, 1991) Pliocene, when it became one of most important components of the mesophilous forests, remplacing Taxodiaceae which characterized the Zanclean thermophilous forests. *Cathaya* progressively declined during the early Pleistocene (along with *Pinus haploxylon* type), while at the same time *Tsuga* shows successive peaks in abundance. Nowadays ***Tusga*** occurs with 14 species in temperate zones of the Northern Hemisphere (North America, China, Japan and Himalaya), where it grows both alone and in association with deciduous elements. It is more tolerant than any other Pinaceae to the shade, but it is also the less resistant to drought; in fact, it requires at least 1000 mm of annual precipitation. The aridity was an important limiting factor also in the past distribution and expansion of *Tsuga*; in fact, as already discussed in paragraph 5, it has never been a major component of the vegetation in southern sites. In northern and central Italy, *Tsuga* expanded repeatedly since the early Pleistocene, especially close to the Jaramillo interval; the Ranica, Upper Valdarno, Cesi and Colle Curti samples clearly attest this. In the Cesi and Colle Curti successions, the disappearance of *Tsuga*, during the lower part of the Brunhes Chron, followed repeated phases of peak abundance between the Jaramillo and the overlain C1r.1r subchron. Bertini (2000) related this to the shift in global aridity. In the Netherlands and at Tenaghi Philippon III (Macedonia, Greece), *Tsuga* shows a similar trend during the same time-interval (Zagwijn, 1963; Zagwijn & de Jong, 1984; van der Wiel & Wijmstra, 1987). These data confirm the global effects of the Mid-Pleistocene climate transition at ca 0.9 Ma (Ruddiman *et al*., 1989; Raymo *et al*., 1997). In the pollen diagrams, *Tsuga* is often associated to ***Cedrus*** to form the so called "*Tsuga-Cedrus* complex " (e.g. Bertoldi, 1995). Today *Cedrus* has a discontinuous range restricted to the montane or high montane areas between latitudes 30-40° N in three main separated regions in Northern Africa and Southern Asia. According to Combourieu-Nebout *et al.* (2000) its climatic requirements are 4 to 10 °C of TA, and 500 to 2000 mm of PA whereas Fauquette *et al.* (1998a) propose a larger range (Tab. I).

Because of its greater tolerance, *Cedrus* lasted longer than *Tsuga* (Tab. I), though at generally lower percentages in the late Early Pleistocene records (e.g. Cesi, La Pineta and Vallo di Diano). *Cedrus* is absent only at Pianico-Sellere and Acerno.

Together with the earlier coniferous forest taxa, many subtropical to warm temperate deciduous taxa, typical of the warm mixed forests, progressively disappear following climatic gradients; some of the disappeared taxa live today in the eastern Mediterranean. Among the Juglandacee, *Engelhardia*, *Carya* and *Pterocarya* progressively disappeared from the Pleistocene records. Among the numerous Pliocene and Early Pleistocene

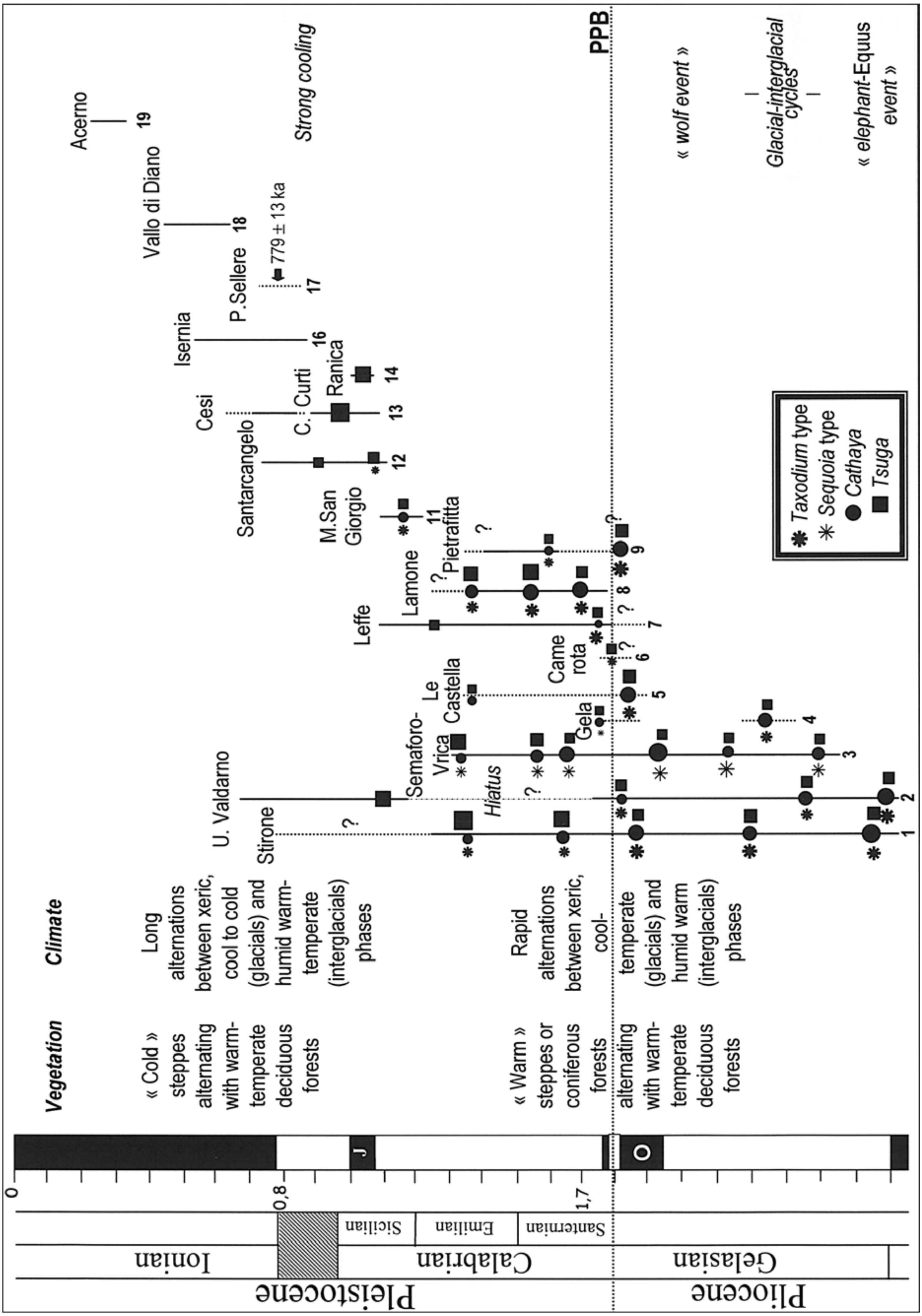

Fig. 3 - General scheme of vegetation and climate in Italy during the late Late Pliocene and the Middle Pleistocene. The main floristic events detected in the successions are shown on the right.

genera of Hamamelidaceae, *Embolathera, Distylium, Parrotiopsis, Parrotia persica*, and *Liquidambar* disappeared one after another. The climatic requirements of some of these taxa are reported in Table I. *Zelkova*, a genus of Ulmaceae, a family also including *Ulmus* and *Celtis*, represents a typical example of *Lazarus* taxon. It was widespread during early and middle Pleistocene, with variable abundances. It then survived in the Eemian during forest phases and finally disappeared from central Italy at about 31 Ka (Follieri *et al.*, 1986; 1988). No other records testified its presence later than this time in Italy until it was discovered in a relict station in Sicily (Di Pasquale *et al.*, 1992).

6.3. Vegetation and climatic history during the early and middle Pleistocene

The early Pleistocene pollen assemblages originated from a thorough restructuring of the Neogene palaeonvironmental settings. The changes in temperature and precipitation following the maximum expansion of the Arctic ice at 2.6 Ma, as well as the new topography resulting from the rise of Apennines caused the already mentioned progressive disappearance of tropical and subtropical forest taxa, a spread of both altitudinal arboreal taxa and herbs, and the creation of new competition patterns (Fig. 3). The effects of the climatic modifications at the transition to the Middle Pleistocene gave rise to new major changes in the floristic and vegetal assemblages, which progressively attained a modern aspect.

The **Early Pleistocene** is a time when open vegetation (arid and cool to cold climate conditions) and forest (humid and warm-temperate climate conditions) alternated, reflecting G/I fluctuations. The open vegetation assemblages include a large amount of steppe taxa, among which *Artemisia* and *Ephedra*, and sometimes also thermophilous taxa, such as *Cistus* and *Phlomis fruticosa*. The warm temperate forest assemblages include deciduous taxa, such as *Quercus, Carya, Carpinus, Pterocarya, Ulmus* and *Zelkova*. In northern Italy, G/I cycles are marked by alternations of coniferous forests (especially formed by *Picea*, with minor abundance of *Cedrus* and *Tsuga*) and deciduous forests (especially formed by *Carya, Quercus, Carpinus, Pterocarya,*) which translate relatively humid and cool to cold /humid warm temperate fluctuations.

During the **Middle Pleistocene**, the climate keeps alternating, and vegetation accordingly. The southern Italian sites show alternations of *Artemisia* (plus *Ephedra*) steppes and temperate to warm-temperate deciduous forests. Nonetheless, a generalized drop in temperature in both steppe and forest phases is indicated by changes in the floristic assemblages. For example, *Hippophaë rhamnoides* expanded during the steppe phases, whereas thermophilous taxa, such as *Cistus* and *Phlomis fruticosa*, disappeared. The most thermophilous arboreal taxa progressively declined during the forested phases in accordance with climatic gradients (e.g. *Parrotia persica, Carya, Pterocarya* and *Liquidambar*). This is in agreement with the marine oxygen isotopic records, and the so called Mid-Pleistocene climate transition.

6.4. The palynological record from other Italian sites

Palynological studies were carried out in many other sites, which were not included here because of their controversial stratigraphic position.

The palynological content of three cores (VE-I, VE-I bis, VE-II), collected from the Holocene - upper Pliocene succession (CNR 1971; Favero *et al.*, 1973) of the Venise area, at the northern end of the Adriatic sea, in a foreland wedged between the eastern Southern Alps and the Apennine chain, has been analysed by Mullenders *et al.* (1996), who proposed to place the Plio-Pleistocene boundary at about 900 m and the Tiberian boundary at about 820 m giving rise to an evident conflict. More recently Kent *et al.* (2002) made an integrated magneto-bio-cyclostratigraphical study ena-

Tab. I - Climatic indications yielded by selected taxa, and their present geographic distribution (from Fauquette *et al.* 1998 a, b). P_A: total annual precipitation; T_A: mean annual temperature, T_C: mean temperature of the coldest month, T_W: mean temperature of the warmest month. The reader should refer to Thompson *et al.* (1999) for additional information on climatic parameters. In this paper one can find alternative observations to Fauquette *et al.*'s (1998 a, b) data, especially about *Sequoia sempervirens*.

Taxa	P_A (mm	T_A (°C)	T_C (°C)	T_W (°C)	Modern distribution
Engelhardia	800-2000	15-25	10-20	25-35	Mexico, SE Asia, India, South China, Taiwan, Malaysia
Dystilium	800-2000	15-25	10-20	25-35	SE Asia, China, Indonesy
Parrotia persica	300-1500	14-20	4-8	24-35	Iran
Parrotiopsis	300-1000	7-13	-7-3	17-24	Afghanistan, Pakistan, India
Metasequoia	800-1600	10-20	0-10	20-30	China
Sciadopitys	1000-2500	5-15	-5-5	15-25	Japan
Sequoia sempervirens	1200-2500	15-18	5-15	10-25	California
Sequoiadendron giganteum	900-1500	8-15	0,5-11	9-26	California
Taxodium distichium	1100-2400	16-25	5-20	25-30	SE USA
Cathaya	1000-1600	10-20	5-10	15-30	North China
Liquidambar	1000-1600	10-23	0-18	20-30	North America, Mexico, East Asia and Turkey, Japon
Tsuga	1000-2000	0-12	-10-6	5-15	North America; Japon, China, Himalaya
Phlomis fruticosa	400-800	15-20	5-15	20-30	East Mediterranean, Sicily, Middle East
Cedrus	500-1500	7-18	-1-11	18-28	Northern Africa and Southern Asia
Cedrus	750-1250	8-13	1-5	17-23	

bling the reconstruction of the Pleistocene history of sea-level changes in the Venice region, in a 950 meter-deep drill core, named **Venice-1** which corresponds to the composite section of the two cores VE-I and VE-I bis. Kent *et al*.'s (2002) study permits the detection of the Brunhes and upper Matuyama chrons (not older than 1.7 Ma) from the top of the core to 727.8 m, and from 727.8 m at least to the unconformity at 813 m, respectively. The interpretation of the succession from the break to the base of the measured section is debated. According to Kent *et al.* (2002) the lower Matuyama might extend from 813 to 887.2 m, with a hiatus cutting out at least the whole Olduvai subchron (including the PPB). In this case, the Matuayama/Gauss boundary (at 2.58 Ma) would occur at 887.2 m. Alternatively, the normal polarity interval extending from 887.2 m downwards could correspond to an extremely long Reunion subchron (2.14-2.15 Ma) section. In spite of its above mentioned hiatus from the upper Pliocene to the lower Calabrian, Venice-I, appears to be a significant succession to document the major lower and middle Pleistocene floristic and vegetational changes in a prevalently marine environment of northern Italy. The accurate revision of the palyological record (e.g. not all the recognized taxa are shown in the palynological diagrams, sporae are included in the pollen sum) made by Mullenders *et al.* (1996) needs to be included in an adequate stratigraphical framework. Such an integration has been tempted (Luca Capraro, 2003: pers. com.; Massari *et al*., submitted). On the basis of Kent *et al*.'s (2002) stratigraphical evidence, I supposed that Mullenders *et al*.'s (1996) location of the PPB and of the Tiberian boundary must be rejected. In fact, the Tiberian boundary would fall below the unconformity at 813 m, i.e. in the Matuyama reverse polarity interval, at least at 1.95 Ma. The *Taxodium* acme event (value up to 20%) used by Mullenders *et al.* (1996) to define the Tiberian boundary could correspond to one of the repeated climatic fluctuations which occur between 2.6 and 1.95 Ma. In the succession from 950 to 820 m, the sparse occurrence of *Taxodium* (2.2%, 14% and 0.8%), as well as the absence of repeated changes in the palynological assemblages (Mullenders *et al*., 1996) which match the G/I cycles possibly suggest a younger age as well as a shorter overall extent of this portion (i.e. it would be the only occurrence of the Reunion) than in the case of an occurrence of the Gauss/Matuyama boundary. The absence of significant changes near the top of the supposed Gauss/Matuyama boundary, where the first glacial phases start, at 2.6 Ma, apparently supports this hypothesis. *Taxodium* is almost completely absent from the Pleistocene section of the sequence, with only a virtually occurrence of 0.2% and 0.6% at 561 m and 453.65 m, respectively. *Cathaya* is not included in the floristic taxa, but it might not have been distinguished, at least in the Pliocene interval, from the *Pinus haploxylon* type, which is present up to 518 m. *Tsuga* shows important acme phases throughout the upper Matuayama. Just above the highest occurrence of the Large *Gephyrocapsa* (Kent *et al*., 2002) *Tsuga* strongly decreases to show an isolate peak in the lower part of the Brunhes (close to MIS 18; Kent *et al*., 2002). Mullenders *et al.* (1996) recognized the first cold phase ("cryomère") in the section from the so-called Veneziano" boundary, just under the base of the Brunhes, up to 576 m. The absence of evidence of previous cold phases (e.g. those corresponding to MIS 22) in the palynological record is perplexing. Furthermore, drops in the abundances of many taxa, such as *Cedrus, Carya, Zelkova, Pterocarya*, also occur before this boundary. Later on, occurrences generally maintain very low (only *Pterocarya* and *Zelkova* show significant expansions).

The **Compiano** continental basin is located in Northern Italy (Val di Taro). Pollen analyses were carried out in 6 main short sections by Bertoldi (1995). In the lower portion of the outcrops *Sciadopitys* reaches 19.4 %, followed by *Taxodium* type (at 7.4%). Moving upwards in the sequence, *Tsuga, Cedrus, Pinus haploxylon* s.s. dominate the assemblages, whereas *Carya* and *Pterocarya* are scanty and sporadic. In the upper beds, all these taxa are missing. On the basis of this paleobotanical evidence, and in particular of the occurrence and disappearance of *Taxodium* type, Bertoldi (1995) referred the lower part of the Compiano succession to the Plio-Pleistocene transition, and dated the overlying part of the sequence to the early and middle Pleistocene.

Tsuga, Pinus haploxylon type, *Cedrus, Carya, Pterocarya* and *Zelkova* also occur in the continental sediments of the **Gubbio** (Perugia) and **Leonessa** (Rieti) basins (central Italy), at 425 m and 900 m above sea level, respectively (Lona & Ricciardi, 1961a; Ricciardi, 1965). *Zelkova* is also reported in the **Mercure** basin (southern Italy), at 500 m above sea level, while *Tsuga, Pinus haploxylon* type and *Cedrus* are missing (Lona & Ricciardi, 1961b); here, rare pollen grains of *Carya* and *Pterocarya* are regarded as reworked elements.

In the light of this palynological evidence, the Gubbio and Leonessa deposits seem older than the Mercure succession, which in turn seems to correlate with the previously described Cesi sequence (Bertini, 2000).

Unfortunately, the different latitude and altitude of the latter four continental sites, added to the already mentioned absence of an ascertained time reference, make any interpretation and attempted correlation very doubtful. Lacking a well-defined palynostratigraphical framework for the early and middle Pleistocene, integrated by time-diagnostic elements, correlations based solely on ecobiostratigraphical events, including last occurrences of specific key taxa, are hazardous.

Nevertheless, this summary singled out several key-sections in northern, central and southern Italy with well calibrated major floristic and vegetational events. These can represent significant reference sections provided that geographical and edaphic factors are duly inspected.

7. CONCLUSION

This paper aimed at showing the power of the pollen record in paleoenvironmental reconstructions and stratigraphical research, especially associated to mighty time-diagnostic implements such as tephras, magneto- and/or bio-magnetostratigraphy. This is the basis for high resolution studies and reliable correlations.

The sites selected here delineate the following history of the Italian Early to Middle Pleistocene flora and climate:

- The unsuitable climatic conditions of this time progressively depleted the flora. In the early Pleistocene, the G/I cycles caused the disappearance of extreme thermophilous taxa which are prevalently distributed in subtropical to warm temperate habitats today. The transition to the Middle Pleistocene was marked by a drop in the temperature and by a change in the dominant ciclicity; the effects on the flora were thus amplified. Taxodiaceae, *Cathaya* (plus *Pinus haploxylon* type), *Tsuga, Cedrus, Carya, Pterocarya*, along with other taxa, progressively disappeared throughout the Pleistocene. Climatic gradients linked to the latitude, altitude, physiography of the sites justify their different calendar of extinction: a precise chronological reference for all these events thus is mandatory to establish reliable correlations with other such records in northern Europe as well as in other Mediterranean areas.
- Changes in vegetation, also linked to G/I cycles, have been detected in both the Early and Middle Pleistocene. Glacials are generally marked by a dominance of herbaceous taxa indicative of steppe-like conditions. Nevertheless, herbs never became important components of the landscape in the northern sites; on the contrary, coniferous forests dominated. Interglacials are indicated by the expansion of mesophilous deciduous trees. Middle Pleistocene G/I cycles were characterized by lower temperatures, which caused the disappearance of extreme thermophilous taxa. On this basis we can distinguish between Early Pleistocene “warm’ steppes and Middle Pleistocene “cold’ steppes.
- The Early Pleistocene is characterized by short alternations of xeric-cool-temperate phases (or only cool-temperate phases with irrelevant decreases in humidity, in the north) (glacials) and warm moist phases (interglacials) with a predominance of 41 Ka cycles. Long alternations of xeric cool to cold phases (glacials) and humid warm temperate phases (interglacials) with a predominance of 100 Ka cycles characterized the Middle Pleistocene.

The selection of reference sections is indispensable to correlate sites with a controversial stratigraphical position. The information provided by the selected sections form an indispensable reference for most reliable climate quantifications and mappings of the vegetation for the Early to Middle Pleistocene interval. The combination of these two approaches has secured striking results in studies of Neogene sites (e.g. Suc *et al*., 1999; Fauquette *et al*., 1998a, b; Fauquette & Bertini, in press; Fauquette *et al*., submitted).

ACKNOWLEDGMENTS

The works of Adele Bertini were financially supported by M.I.U.R. funds. This work also contributed to the projects: " La biodiversité végétale méditerranéenne depuis 6 Ma - Environnements, Vie et Sociétés: Institut Français de la Biodiversité" and Galileo 2003 (C.R.U.I.). Special thanks to Paul Mazza for improving the English of the manuscript.

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