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QUATERNARY DISTAL TEPHRA LAYERS IN ITALY AND THE ADJOINING SEAS: CURRENT KNOWLEDGE AND PROSPECTS FOR FUTURE RESEARCH

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ABSTRACT
Tephrochronological studies on Quaternary sedimentary successions of the Central Mediterranean area are reviewed and critically evaluated, with emphasis on the use of distal ash layers for land-sea correlations. The longest tephra records are provided by the deep-sea sediments from the basins adjoining Italy, which have been extensively studied in the last 30 years. Shorter (<100 ka), yet still significant records of ash layers have been recovered in lacustrine basins of the Italian Peninsula. The longest successions show that the tephra layers increase toward the top of the Quaternary record. The dominant Pliocene and lower Pleistocene tephra sources were likely represented by the volcanoes of the Pontine Islands and the Aeolian arc, while in the middle-upper Pleistocene and Holocene times Aeolian and Campanian products have been predominant. Tephra correlation is made difficult by the fact that the volcaniclastic products are extensively reworked by epiclastic processes, even in the marine setting. Inconsistent analytical approaches used in the old and recent work (bulk sample versus grain-discrete analysis) hinder integration of the available evidence. The regional tephrostratigraphy of early and middle Pleistocene ages is not established yet, because data are scarce and fragmentary and ages of tephra are poorly defined. Tephra correlation is frequent in the late Quaternary time span, in which several widespread marker-tephras have been identified. Recent findings extend the known distribution of the main late Pleistocene markers and suggest complex dispersal patterns, including deposition towards north and northeast. Occurrence of Quaternary tephra layers of probable Italian origin in sites of Central and Eastern Europe opens the prospect for precise correlation of sedimentary records across the European continent. Finally, reliable linking of chemical spikes in North Polar records to Italian explosive eruptions could be critical for a better understanding of palaeoenvironmental issues.

RIASSUNTO
Tephra distali quaternari in Italia e nei mari adiacenti: stato delle conoscenze e prospettive di ricerca. *Questo lavoro prende in rassegna gli studi tephrocronologici effettuati sulle sequenze sedimentarie dell'area centro-mediterranea ed effettua una sintesi delle conoscenze disponibili, particolarmente per quanto concerne le informazioni utili per correlazioni fra successioni marine e successioni continentali. Le tephro-sequenze più rilevanti per continuità stratigrafica ed estensione temporale riguardano i sedimenti di mare profondo, i quali sono stati diffusamente campionati e analizzati nel corso degli ultimi 30 anni. In ambiente continentale, i risultati più significativi provengono dallo studio di lunghe sequenze lacustri dell'Italia peninsulare, campionate per indagini paleoclimatiche. I dati delle sequenze più lunghe indicano che i livelli piroclastici aumentano nel Quaternario superiore. Relativamente alle sorgenti vulcaniche, durante il Pliocene ed il Pleistocene inferiore prevalgono prodotti dei vulcani delle Isole Pontine e dell'arco eoliano, mentre nel Pleistocene medio-superiore e nell'Olocene sono preponderanti i prodotti eoliani e quelli campani. La correlazione tra livelli di tephra, compresi quelli contenuti nelle sequenze di ambiente marino profondo, è complicata dal rimaneggiamento del materiale piroclastico. La disomogeneità dei dati analitici, soprattutto di quelli relativi alla composizione geochimica del materiale piroclastico, non consente di integrare i risultati pubblicati di recente con quelli dei vecchi lavori. A causa dell'esigua disponibilità di osservazioni e delle scarse informazioni sull'inquadramento cronostratigrafico degli orizzonti piroclastici, non è stata ancora definita la tephrostratigrafia regionale per i periodi più antichi del Quaternario. La correlazione dei livelli di tephra è invece frequente nel Pleistocene superiore, nel quale sono stati individuati alcuni livelli guida per accurate correlazioni stratigrafiche fra successioni marine e continentali. Sulla base di nuovi ritrovamenti, la distribuzione areale di alcuni di questi livelli risulta alquanto complessa e comprende la dispersione anche verso i quadranti settentrionali. Recenti segnalazioni di tephra di probabile origine italiana in successioni continentali dell'Europa centrale aprono la prospettiva di future correlazioni su scala continentale. Infine, la corrispondenza tra alcuni segnali geochimici nelle carote di ghiaccio del Polo Nord ed eruzioni esplosive italiane, tuttora da dimostrare, potrebbe contribuire alla soluzione di importanti quesiti paleoclimatici.*

Keywords: airfall tephra, deep-sea cores, long-distance correlation, Quaternary, Italy, Central Mediterranean

Parole chiave: piroclastiti di caduta, carote di mare profondo, correlazione, Quaternario, Italia, Mediterraneo centrale.

INTRODUCTION

Compiling of an exhaustive review on Quaternary airfall tephra layers in the Central Mediterranean area is an arduous task, due to the massive published information pertaining to this topic. Suffice it to mention that the first record of the Greek term "tephra" (τεφρα) for volcanic ash, dated back to about 360 B.C., concerns just a Central Mediterranean explosive eruption, whose account was made by Aristotle in his book *Meteorologia*. Thus, while the modern term "tephrochronology" is less than 60 years old (in Thorarinsson, 1974), bibliography on Mediterranean tephra spans over two and half millennia of naturalistic and historical literature. Even when focusing on the geoscientific bibliography of the last decades, and excluding findings in the proximal setting (< 50 km from source), reports on Quaternary volcaniclastic deposits in the Central Mediterranean sediments are exceptionally numerous. Attempts to collect all the published documentation are hampered by the fact that it is dispersed through literature of disciplines as diverse as geoarchaeology, marine micropalaeontology, palynology, stable isotope geochemistry and sedimentology.

Although publications are so numerous, a part of the published information is not suitable for the development of the Quaternary regional tephrostratigraphy. In

fact in many cases reports of tephra deposits are not provided with appropriate laboratory data for characterisation of the volcaniclastic material, or fail in reporting details on the used analytical methods. In other cases tephra reworking is either apparent or not properly considered, or the chrono-stratigraphical framework of the tephra and of the tephra-bearing deposits is poorly defined.

Despite the aforementioned problems and limitations, a few contributions have been published that aim at reviewing the main evidence for Quaternary distal tephra layers in the Mediterranean region (Keller, 1981a; Narcisi & Vezzoli, 1999) and the Italian context (Narcisi, 1994) or at collecting systematically data on volcaniclastic deposits in the Apennine region (Guerrera & Veneri, 1989). The present paper represents advancement and updating of the previous reviews carried out by the Author. In particular, it is intended to focus on the published tephra information that is of interest for correlation between continental and marine successions. In addition, a few case studies of widely dispersed Italian tephra layers are presented and prospects for future research in the field of long-distance correlations are outlined.

THE PRINCIPAL AVAILABLE DATA

Marine successions

The most significant tephra records of the Central Mediterranean region, in terms of stratigraphic continuity, ash preservation and time span, are provided by the abyssal sediments. Since the late 1940's several deep-sea investigations have been carried out in the frame of international drilling programs and national enterprises (Fig. 1). Tephra studies have often been associated with micropalaeontological, sedimentological, stable isotope and magnetic investigations, and radioisotope dating of fossil shells, providing the chronostratigraphic framework of the recorded ash layers. Very recently, direct isotopic datation has been attempted on marine ash layers from Tyrrhenian core sequences (Bogaard *et al.*, 1999; Ton-That *et al.*, 2001).

Due to the difficulty of recovering long records, information on the early Pleistocene tephra layers in deep-sea cores is rather sparse. The longest successions, extending back up to Miocene, have been retrieved within the Deep Sea Drilling Project/Ocean Drilling Program (DSDP/ODP), which has dedicated several cruises (i.e. Legs 13, 42, 107, 160 and 161) to the Central Mediterranean area (Fig. 1). In addition to the DSDP/ODP cores, many shorter, but still important tephra records are available from the Tyrrhenian (e.g. Paterne *et al.*, 1986; 1988), the Adriatic (Calanchi *et al.*, 1998), and the Ionian seas (Keller *et al.*, 1978).

From the analysis of the most significant records some general trends can be traced, both in time and in space. The content of volcaniclastic material increases toward the top of the Quaternary succession. Although each core shows its own tephrostratigraphy reflecting the dominance of the closest tephra source, the data acquired in the recent ODP cruises performed in the Tyrrhenian Sea (McCoy & Cornell, 1990; Calanchi *et al.*, 1994; Bogaard *et al.*, 1999) show that the dominant Pliocene and lower Pleistocene tephra sources were likely represented by the volcanoes of the Pontine Islands and the Aeolian arc, while in the middle-upper Pleistocene and in the Holocene Aeolian and Campanian products were the most frequent. The content of volcaniclastic material in each core depends on the distance of the coring sites from the volcanic sources and on the influence by subaerial (i.e. transport of ash particles by dominant winds) and subaqueous (i.e. reworking before the final deposition) physical agents. Indeed, the role of reworking of volcaniclastic sediments in Tyrrhenian pelagic records had been emphasized by the earlier studies on cores collected in the abyssal plain (e.g. Bartolini *et al.*, 1974). Recently, detailed sedimentological and geochemical investigations on ODP core sequences have clearly demonstrated that tephra layers originating from ash fallout are rare in the Tyrrhenian Sea; remobilisation of pyroclastic material by turbidite currents and debris flows is a common phenomenon and it may lead to significant displacement of the tephra from its original stratigraphic position (McCoy & Cornell, 1990; Calanchi *et al.*, 1994; Bogaard *et al.*, 1999). Erosion of the thinner layers by sea-bottom currents and bioturbation may represent further factors influencing the record of tephra fall layers. In Fig. 2 striking differences can be observed in the frequency of primary tephras, up to one order of magnitude, in late Quaternary Tyrrhenian cores drilled in close sites with comparable physiographic conditions, as is the case of

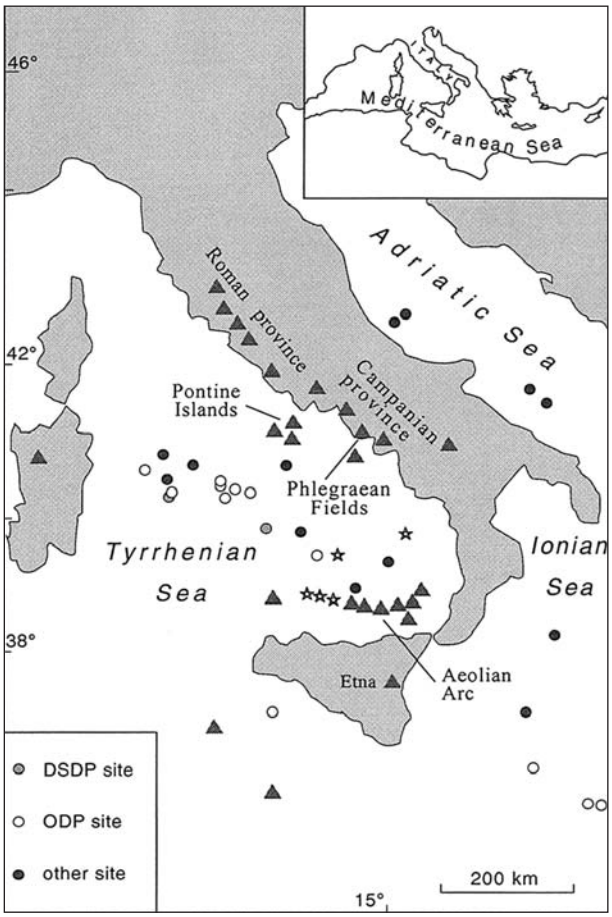

Figure 1 - Map of the Central Mediterranean showing the location of Quaternary volcanoes (triangles) and seamounts (stars), and of significant deep-sea tephra records.

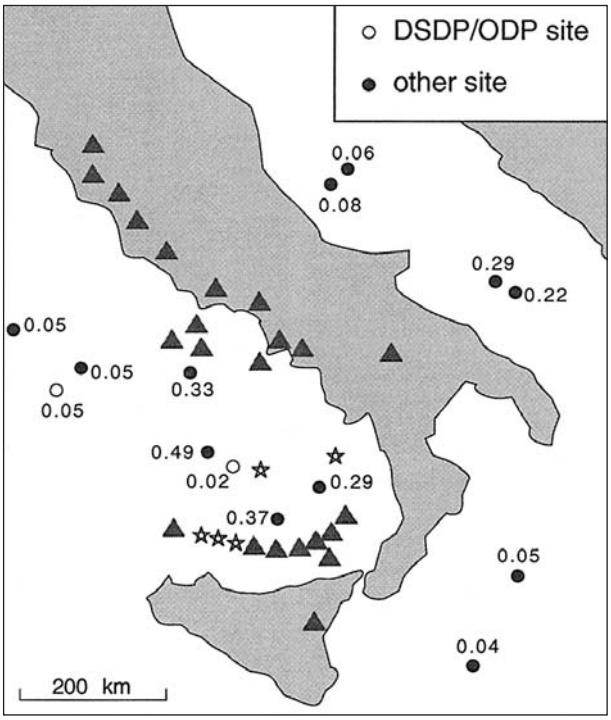

Figure 2 - Frequency of recorded primary tephra layers (per 1000 years) in selected late Quaternary deep-sea records of the Central Mediterranean. Data of frequency have been calculated from the tephra information reported in Cita *et al.* (1973); Keller *et al.* (1978); Keller (1981b); Paterne *et al.* (1988); Fontugne *et al.* (1989); McCoy & Cornell (1990); Kallel *et al.* (1997); Calanchi *et al.* (1998).

core KET8004 (Paterne *et al.*, 1988) and ODP site 650 sequence (McCoy & Cornell, 1990). These differences may be due to the different sampling resolution or may reflect different constraints applied by the various investigators on the definition of a "non-reworked tephra".

Integrating the recent deep-sea findings with evidence from old coring would certainly increase knowledge of stratigraphy and areal distribution of Mediterranean ash layers. However, attempts to collate these data are hindered by inconsistent methodological approaches (Narcisi & Vezzoli, 1999). Specifically, the earlier investigations were mainly descriptive; the few geochemical data presented were obtained from whole-rock analysis and are clearly influenced by weathering of the volcanic material and contamination by detrital clasts (see for example Nesteroff *et al.*, 1973). In the recent tephra studies, bulk sample analysis has been fully replaced by grain-discrete electron microprobe (EMP) analysis. Due to these differences, few correlations can be attempted between the Central Mediterranean tephrostratigraphy, resting on EMP data, and the well-defined tephra framework of the Ionian and Levantine seas (Keller *et al.* 1978), which was developed in the late 1970's on the basis of bulk analysis.

Reports of findings of tephra in terrestrial exposures of marine sediments are numerous. In Southern peninsular Italy, some volcaniclastic layers have origin from the nearby Vulture volcano (Ciaranfi *et al.*, 1996) while others derive from more distant sources (Spadea, 1986). In this region, marine ash layers have been extensively used for local correlation purposes (Ciaranfi *et al.*, 2001), for reconstruction of the magmatic evolution of the Pleistocene volcanism (Cello *et al.*, 1983; Spadea, 1986), and for inferring relationship between volcanism and tectono-sedimentary processes (Cortesogno *et al.*, 1984). Some layers have been subject to direct dating (Obradovich *et al.*, 1982). Petrographic and mineralogical evidence suggests that only few pyroclastic layers are coeval to deposition of bracketing sediments and/or are free from weathering (D'Elia *et al.*, 1987).

Continental successions

Compared with the deep-sea records, land sequences of tephra are less significant due to intensive erosion and reworking processes acting on the continental realm. In Italy, the best continental successions of ash layers are provided by the lacustrine sediments, which have extensively been studied in the last two decades for palaeoclimatic purposes (Calanchi *et al.*, 1996; Karner *et al.*, 1999; Narcisi, 1996; 2002). Results worthy to be mentioned have been obtained also on other clastic sequences (Narcisi, 1993; Bigazzi *at al.*, 1994) and on volcanic palaeosols and related parent materials (Frezzotti & Narcisi, 1996). Cases of direct datation of continental ash layers are common (e.g. Bigazzi *et al.*, 1994; 2000; Karner *et al.*, 1999).

The findings of continental ash layers so far published are almost exclusively located in peninsular Italy. To some extent, this distribution reflects proximity of the sites to the explosive volcanic sources; certainly, it is strongly influenced by non-uniform surveying. In fact, entire continental sub-regions that most probably were repeatedly blanketed by ash fallout during the Quaternary, are still unexplored from the tephra point of view. Similarly, knowledge on land distribution of the identified ash markers is still very patchy as it is defined by casual findings rather than by geographic systematic studies. Consequently, an unequivocal and continuous Quaternary reference stratigraphy of the distal tephras in the various land regions is still lacking.

LONG-DISTANCE CORRELATION AND WIDELY DISPERSED TEPHRA LAYERS

In the older Quaternary record, correlations of individual tephra layers from marine cores have been achieved in a limited number of cases (Cita *et al.*, 1973; Bogaard *et al.*, 1999). In theory, regional-scale correlation of tephra in early Pleistocene records would be facilitated by the fact that ash layers in this period are not so abundant as in the late Quaternary (Cita *et al.*, 1973; Calanchi *et al.*, 1994). In practice, identification of older marker tephras is made difficult by the scarce and fragmentary available information, and by uncertainties in the age of the tephra. Thus, although chemical and mineralogical features of the 0.6 Ma tephra occurring in Tuscan continental deposits (Nencini, 1983; Bigazzi *et al.*, 1994) resemble those of two Middle Pleistocene ash layers encountered at the Tyrrhenian DSDP site 373 (SSP, 1978; Keller, 1981a), their correlation cannot be demonstrated because the age of these marine layers is poorly constrained. Besides, whilst generic comparison between deep-sea ash layers and volcaniclastic depo-

sits in land exposures can be attempted (e.g. Calanchi *et al.*, 1994), correlation of specific tephra horizons is more difficult. As an example, on the basis of the sapropel correlation proposed by de Kaenel *et al.* (1999) and of biostratigraphic and palaeomagnetic evidence, the chrono-stratigraphic position of ash turbidite vt-7539/vt-7538 from Tyrrhenian ODP site 974 (Bogaard *et al.*, 1999) matches well that of the ash layer *m* at Vrica, Southern Italy (Selli *et al.*, 1977; Pasini & Colalongo, 2001). According to Spadea (1986) and Bogaard *et al.* (1999) both tephras can be classified as high-K rhyolite; close analysis of the data however reveals significant mineralogical and geochemical differences that make correlation between these two layers problematic.

While there are few identified early and middle Pleistocene marker-tephras (Bogaard *et al.*, 1999) and consequently correlation among sites is rarely attained, tephra correlation becomes frequent when late Quaternary records are considered (Paterne *et al.*, 1986; 1988; Narcisi, 1996; Calanchi *et al.*, 1998). Identification of marker-tephras in this time interval is facilitated by both preservation of deposits and more rigorous age control.

Main features and chronology of the principal distal tephras of the last 200,000 years are reported elsewhere (Narcisi & Vezzoli, 1999). Recent advances in the knowledge of some late Pleistocene tephra markers are worthy to be mentioned in this contribution.

Layer Y-5 – the most widespread tephra layer of the Mediterranean related to the eruption of the Campanian Ignimbrite from the Phlegraean Fields area – has recently been the subject of radiometric assay (Ton-That *et al.*, 2001). Ar/Ar analysis of sanidine crystals from this layer cored in the Tyrrhenian abyssal plain (site KET8004) indicate a most probable age of 41 ka, which is at least 2-3 ka older than estimates on both proximal land exposures (Deino *et al.*, 1992; De Vivo *et al.*, 2001) and the distal ash in marine and lacustrine cores (Thunell *et al.*, 1979; Narcisi, 1996; Watts *et al.*, 1996). The presence into the dated tephra layer of crystal populations older than 41 ka deserves notice. In marine cores collected not far from KET8004 this Campanian marker is represented by a few metres-thick volcaniclastic debris flow comprising vitric particles of heterogeneous origin and also shallow-water mollusc shells (McCoy & Cornell, 1990; Calanchi *et al.*, 1994; Cini Castagnoli *et al.*, 1995). However, Ton-That *et al.* (2001) reject a turbiditic origin of the dated tephra and opt for mixing of xenocrysts into the juvenile ash fraction to explain the observed age heterogeneity.

Currently, the areal distribution of Y-5 is defined by some hundred of recovery sites, mainly related to the Eastern Mediterranean marine setting (Fig. 3 of Narcisi & Vezzoli, 1999); however, a broader, and more complex dispersal is strongly suggested by occurrence in Eastern Europe of a tephra layer with age and composition similar to Y-5 (Melekestzev *et al.*, 1984). Surprisingly, this tephra has not been recovered or identified in the newly studied piston cores drilled in the Eastern Mediterranean within the known Y-5 dispersal area (Clift & Blusztajn, 1999). Given its wide distribution, speculations have been made on the potential interference of the Y-5 related eruption with the Mediterranean ecological and social system (Fedele *et al.*, 2002).

Increasing attention has recently been deserved to the two marker-tephras that characterise the tephrostratigraphy of the Lateglacial period. Recent findings of the older marker Y-1 (Et-1 according to Paterne *et al.*, 1988) extend the areal distribution of this tephra far beyond the previously recognised dispersal. In fact, current knowledge indicates that this marker, which is related to the 14 uncal. ka Etna multiple eruption that produced the Ellittico caldera collapse (Coltelli *et al.*, 2000), is distributed towards Southeast in the Eastern Mediterranean and towards North in Central Italy and adjoining seas (Narcisi, 1999a). New occurrences of the younger marker C-2 dated 12.5 uncal. ka and related to the Neapolitan Yellow Tuff from the Phlegraean Fields area (Scarpati *et al.*, 1993), have enabled to trace with more confidence its dispersal area. Findings in Central Italy and in the Tyrrhenian and Adriatic seas suggest a north-easterly distribution (Narcisi, 1999b) and the recent discovery of a Lateglacial tephra correlated on geochemical grounds to C-2 in lacustrine records of the Northern Apennines (Davies *et al.*, 2002) and in Austria (Schmidt *et al.*, 2002) confirms this pattern besides extending significantly dispersal of this tephra.

While earlier studies in the Mediterranean showed an overall south-easterly ash dispersal ascribed to supposed persistent north-westerly palaeowind directions over the last 200,000 years (McCoy, 1980), the presented examples, together with increasing findings in very remote European sites (see below), suggest that some Italian airfall tephra layers might have complex distribution patterns, including also dispersal towards north and northeast. Support of evidence of northward aeolian dust transport is provided by recent palynological studies that have pointed out the significance over the Western Mediterranean of air masses coming from the south, at least during the Upper Pleistocene and Holocene (Magri & Parra, 2002). Previously reconstructed south-easterly distribution of Mediterranean tephra might, at least in some cases, be an artefact due to inadequate surveying and non-uniform spatial distribution of sampling sites.

CONCLUDING REMARKS AND PROSPECTS FOR FUTURE RESEARCH

Distal tephra layers are powerful tools for unambiguous linking of sites from different environmental settings, and across regions and even continents. The Central Mediterranean represents one of the most suitable regions of our planet for Quaternary tephra investigations, due to the following features (Fig. 1): a) abundance of volcanic sources that are quite scattered over the whole region, b) occurrence throughout the Quaternary of large-scale explosive volcanism producing significant pyroclastic sheets, c) favourable location of the volcanoes in relation to the land-sea distribution, enabling distal ash fallout to involve simultaneously marine and continental environments, d) marked differences in geochemical signatures from province to province (Peccerillo, 2001) that make it possible to discriminate among tephra sources.

On the whole, knowledge of Quaternary distal tephra in Italy has advanced significantly over the last two decades. However, the potential for establishing a detailed tephrostratigraphy is not fully exploited yet.

Stratigraphical and analytical problems remain in some reports. Integration of stratigraphic data with radiometric and palaeomagnetic information is recommended for future work. In addition, more rigorous protocols of characterisation of the identified tephra horizons should be applied, including careful investigation of sedimentary features and detailed microstructural, petrographic and petrochemical studies (Westgate & Gorton, 1981). In addition to studies on future tephra records, re-examination of ash layers studied in old work might be carried out by means of both routine analysis of grain discrete shards for geochemical characterisation and radioisotopic dating.

There is the need to enhance knowledge of dispersal of the identified marker tephras, which is still incomplete and non-uniform in space. As for dispersal in very distal areas, a further hint for future research is suggested by the increasing findings of Quaternary tephra likely originated in Italy within continental successions of middle and Eastern Europe (Jahns & Bogaard, 1998; Pyle *et al.*, 1998; Pouclet *et al.*, 1999; Horvath, 2001; Pinti *et al.*, 2001; Schmidt *et al.*, 2002). Together with earlier evidence (Melekestzev *et al.*, 1984; Harkovska *et al.*, 1990), they strongly suggest that some Italian ash layers might have enormous areal distribution. Future tephra studies could be addressed towards investigation of distal sequences so far considered free of tephra layers. New analytical techniques are available to this purpose that enable identification and characterisation of tephra horizons that are not detectable by visual inspection (e.g. Rose *et al.*, 1996). Extension of Italian ash layers to regions external to the Mediterranean would open the prospect for precise correlation of palaeoenvironmental records across the European continent. Reliable reconstruction of ash dispersal might also contribute to infer the atmospheric circulation patterns over the past.

Finally, the huge explosive character of the Quaternary Mediterranean volcanoes suggests that the largest eruptions might have produced significant atmospheric perturbation, even on a global scale. Actually, a few sulphate peaks in an ice core record collected in Greenland are thought to be related to Italian eruptions occurred in historical and prehistoric times (Zielinski, 1995; Zielinski *et al.*, 1994; 1997). Matching of these chemical signals with Italian events is still to be demonstrated by the occurrence in the ice of the related volcanic glass. When this relationship will be proved unambiguously, then firm correlation will become possible between sedimentary successions of the Central Mediterranean and climate records from the North Polar region. This will represent a substantial advance towards investigating still open palaeoenvironmental issues as for example the relationship between the North Atlantic millennial scale climate variability (i.e. Dansgaard-Oeschger cycles and Heinrich events; Broecker, 1994) and the Mediterranean climate and environment.

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