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Combined Sr-Nd isotopic and geochemical fingerprinting as a tool for identifying tephra layers: Application to deep-sea cores from Eastern Mediterranean Sea

M. D'Antonio [a,*], R. Mariconte [a], I. Arienzo [b], F.C. Mazzeo [a], A. Carandente [b], D. Perugini [c], M. Petrelli [c], C. Corselli [e], G. Orsi [a], M.S. Principato [e], L. Civetta [a,d]

[a] Dipartimento di Scienze della Terra, dell'Ambiente e delle Risorse, University of Naples Federico II, Largo S. Marcellino 10, 80138 Naples, Italy
[b] Istituto Nazionale di Geofisica e Vulcanologia – Sezione di Napoli Osservatorio Vesuviano, Via Diocleziano 328, 80124 Naples, Italy
[c] Dipartimento di Fisica e Geologia, University of Perugia, Via A. Pascoli, 06123 Perugia, Italy
[d] Istituto Nazionale di Geofisica e Vulcanologia – Sezione di Palermo, Via U. La Malfa 153, 90146 Palermo, Italy
[e] Dipartimento di Scienze dell'Ambiente e del Territorio e di Scienze della Terra, University of Milano-Bicocca, Piazza della Scienza 4, 20126 Milan, Italy

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ABSTRACT

Tephra layers from six deep-sea cores, recovered between the Ionian and the Aegean Seas, and covering a time span between ~102 and ~8.2 ka BP, were investigated with the aim of identifying their volcanic source. The stratigraphic position of each tephra layer defined by means of nannofossil biostratigraphy and occurrence of sapropel layers was integrated with a thorough geochemical characterization of glass shards based on major oxides and trace elements content, and Sr-Nd isotope ratios. Major oxides composition permitted their subdivision into three groups (K-trachyte, peralkaline rhyolite, andesite), confirmed by Principal Component Analysis on trace elements data. Primordial mantle-normalized trace elements distribution patterns allowed for precise identification of the geochemical affinity and geodynamical setting of each group. Although the Sr isotopic composition of some investigated tephras was deeply affected by seawater alteration as expected, the $^{143}Nd/^{144}Nd$ values discriminate well the three groups of tephras in combination with major oxides and trace elements data. Therefore, La/Yb and Th/Y vs. $^{143}Nd/^{144}Nd$ discrimination diagrams are proposed for identification of potential volcanic sources active in the 102–8.2 ka BP time span in the Eastern Mediterranean area for unknown tephras.

The obtained results have permitted the attribution of six K-trachytic tephras to the Y-5 stratigraphic marker (Campanian Ignimbrite eruption of Campi Flegrei, Southern Italy, ~39 ka BP), and two pantelleritic (= peralkaline rhyolite) tephras to the Y-6 stratigraphic marker (Green Tuff eruption of Pantelleria Island, Sicily Channel, ~46 ka BP). The andesitic tephra, stratigraphically constrained between ~39 and ~83–102 ka BP, might correspond to the X-1 stratigraphic marker, found in several deep-sea cores of the Eastern Mediterranean Sea, although its attribution is still debated in the literature. On the basis of trace elements content, supported by Sr-Nd isotopic features, it is here hypothesized that this tephra could be related to a volcanic source located in the Aegean Sea area, probably the island of Santorini. More generally, this study demonstrates that the combination of Sr-Nd isotopic with major oxide and trace element geochemical fingerprinting on selected and purified glass shards is a very effective tool for identifying nature and source of doubtful tephra layers.

1. Introduction

The Eastern Mediterranean Sea is an ideal region for the preservation of tephra layers, that are easily buried under pelagic sediments, because of the contemporary favorable factors of being surrounded by numerous volcanic centers active in historical times, a high sedimentation rate, and dominant southeasterly winds. Over the last sixty years, about thirty tephra layers have been characterized and identified in Eastern Mediterranean deep-sea sediments, some being widespread over large sectors of the basin. These tephras cover a time span of at least 200 kyr, and have allowed for assessment of a detailed and reliable tephrostratigraphy (e.g., Keller et al., 1978; Vinci, 1985; Narcisi and Vezzoli, 1999; Margari et al., 2007; Bourne et al., 2010, 2015; Insinga et al., 2014; Morabito et al., 2014; Tomlinson et al., 2015; Matthews et al., 2015; Satow et al., 2015). The investigation of tephras and cryptotephras (i.e., those not identifiable by the naked eye) has been favored by the relatively rapid pelagic sedimentation on the floor of Eastern Mediterranean basin, causing undisturbed deposition of the volcanic ash. Moreover, the available detailed bio- and stable isotope-

* Corresponding author.
E-mail address: massimo.dantonio@unina.it (M. D'Antonio).

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stratigraphy of these deep-sea sediments provides a valuable chronostratigraphy for the intercalated tephra layers (Cita et al., 1972, 1977, 1981; Castradori, 1993). The presence of widespread synchronous sapropel episodes has also been useful in establishing correlations over wide abyssal areas (e.g., Narcisi and Vezzoli, 1999).

The complex geodynamical evolution of the Mediterranean area has generated several volcanoes in its Eastern sector over the Plio-Quaternary, mostly in Italy and the Aegean Sea, and some in Anatolia (Fig. 1). The area has been affected by compression tectonics and related subduction processes of the African Plate beneath the European and Anatolian Plates. These processes, lasting since Upper Miocene times, are still ongoing in Calabria (Southern Italy), Northern Aegean Sea, and Anatolia (e.g., Faccenna et al., 2007, 2014). This is testified by a several thousand km long trench system marking the margins among the abovementioned lithospheric plates, that includes the Calabrian, Aegean and Cyprus trenches (Dilek, 2006, and references therein; Fig. 1). These compression tectonics features are accompanied by widespread subduction-related volcanism with K-alkaline products in Southern Italy (e.g., Aeolian Islands Arc), Aegean Sea (Hellenic Arc), and Anatolia. Conversely, extensional tectonics and continental rifting occur in the Sicily Channel Rift Zone (e.g., Boccaletti et al., 1987), accompanied by intra-plate volcanism with Na-alkaline products.

Most of the Mediterranean volcanoes have been characterized by both effusive and explosive activity through time, giving rise to several pyroclastic deposits, some of them dispersed over large areas. Indeed, the source regions for all tephra layers cored in the Eastern Mediterranean can be identified in either the Italian or Aegean volcanic areas. Despite post depositional modifications that may significantly mask the primary areal distribution, the most widespread Mediterranean tephra layers show an overall south-easterly dispersion, due to the dominant stratospheric wind directions (Keller et al., 1978; McCoy, 1980, 1981). This implies that it is unlikely to find tephras produced by Anatolian volcanic centers in the Eastern Mediterranean Sea, given their position (Fig. 1).

The products of the activity of the Eastern Mediterranean volcanoes are generally well constrained regarding their absolute age, and well characterized from the mineralogical, geochemical as well as radiogenic and stable isotopes viewpoints. This holds certainly for Plio-Quaternary volcanoes of Italy (e.g., Peccerillo, 2005, and references therein; Pappalardo et al., 1999; D'Antonio et al., 2007; Di Renzo et al., 2007, 2011; Francalanci et al., 2007; Frezzotti et al., 2007; Pabst et al., 2008; Rouchon et al., 2008; Santacroce et al., 2008; Arienzo et al., 2009; Boari et al., 2009; Conticelli et al., 2009; Gaeta et al., 2011; Giaccio et al., 2013a; Brown et al., 2014; Marra et al., 2014) as well as for several volcanoes of the Aegean Sea area (e.g., Fytikas et al., 1984; Briqueu et al., 1986; Francalanci et al., 2005; Pe-Piper and Piper, 2005; Agostini et al., 2007). This wealth of data allows for a rather certain identification of many largely dispersed tephras found intercalated in either marine or continental sedimentary sequences, through their geochemical fingerprints. Laser ablation-inductively coupled-plasma mass spectrometry (ICP-MS) techniques allow for fast, high-quality determinations of trace element contents needed for a thorough evaluation of the geochemical affinity of glass shards (e.g., Westgate et al., 1994; Bryant et al., 1999). In the last few decades, attribution of tephras collected from Mediterranean deep-sea cores to widespread pyroclastic deposits of known age has been successfully achieved through a geochemical characterization based on trace element patterns and abundances (e.g., Margari et al., 2007; Tomlinson et al., 2010, 2012a, 2012b, 2015; Wulf et al., 2012; Petrosino et al., 2015; Wutke et al., 2015).

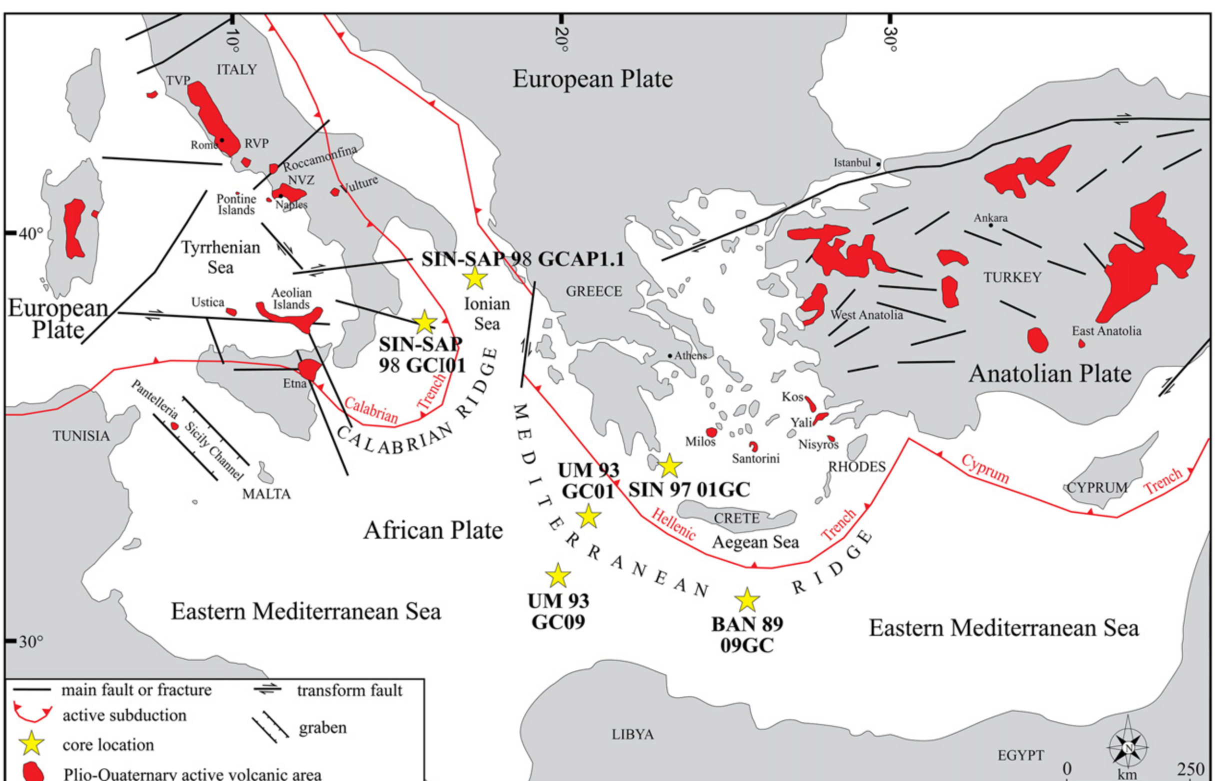

Fig. 1. Schematic map of the Eastern Mediterranean area showing the location of the investigated deep-sea drilling sites (yellow stars; all coordinates were converted through UltraSoft3D, http://www.ultrasoft3d.net/Conversione_Coordinate.aspx). The areas hosting volcanic centers active in Plio-Quaternary times are marked in red. The main trenches related to subduction of the African Plate beneath either the European or the Anatolian Plates are also indicated. Minor plates such as Adria and Arabian have been omitted for clarity. TVP = Tuscan Volcanic Province; RVP = Roman Volcanic Province; NVZ = Neapolitan Volcanic Zone. Simplified after Dilek (2006).