TEPHROCHRONOLOGY AS A TOOL FOR ACTIVE TECTONICS STUDIES IN PENINSULAR ITALY

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Introduction. The study of the active tectonics typically requires the application and integration of a number methodological approaches enabling us to acquire data and information on a series of spatial, temporal, and physical parameters, fundamental for understanding the architecture and the behavior of the active and capable faults. Among others, the chronological constraints are essential for evaluating: i) the general status of activity of a given structure; ii) its short- to long-term slip rate and its changes trough time; iii) the time recurrence of the fault ruptures.

In the framework of the Italian active tectonics, most of the active and seismogenetic faults are located along the axis of the Apennine chain (Galadini and Galli, 2000; Galli *et al*., 2008). Usually, active faults bound and drive since early Quaternary the evolution of continental sedimentary basins hosting thick alluvial-fluvial-lacustrine successions. The investigation and dating of this sediments is thus pivotal to define the Pleistocene-Holocene tectonics. However, until few years ago these sediments were hardly datable, whereas beyond the applicability limit of the radiocarbon (i.e., ~40 ka) the chronological framework of the continental deposits were essentially relied on assumptions and qualitative-speculative regional cross correlations.

In this framework, the study of distal volcanic ash layers or tephra - ejected into atmosphere during large explosive eruptions and simultaneously deposited in different stratigraphic settings up to thousands of kilometers from the source - is changing this frustrating limits, assuming a strong relevance as reliable geochronological tool. Indeed, several volcanic centers are located along the western side of the backbone of the Italian peninsula, almost all characterized by an intense explosive volcanic activity; therefore, tephra layers are a common features of the sedimentary successions of the Apennine (Fig. 1), making this region an ideal setting for applying tephrochronology.

The tephrochronological method. The tephrochronological method essentially consists in determining the peculiar geochemical features of tephra - i.e., the so called chemical fingerprinting - that allow to unambiguously recognize and trace ash layers in different sedimentary settings, providing thus an effective way through which associated deposits can be reliably dated and correlated over wide regions. As any other comparative method, to be effective, tephrochronology require a reliable and possibly complete reference geochemical and geochronological dataset. Unfortunately, up to few years ago, this was really limited and incomplete, making the application of tephrochronology highly hazardous, weak and misleading. Today, due to recent and continuously enhancing development of tephra studies in central Mediterranean area (e.g. Wulf *et al*., 2004, 2012; Munno and Petrosino, 2007; Giaccio *et al*., 2012a, 2013, 2014; Paterne *et al*., 2008; Zanchetta *et al*., 2008; Bourne *et al*., 2010; 2015; Sulpizio *et al*., 2010; Smith *et al*., 2011; Tamburrino *et al*., 2012; Tomlinson *et al*., 2012; Insinga *et al*., 2014; Petrosino *et al*., 2014, 2016; Leicher *et al*., 2016), we can access to a satisfactory reference dataset for the Upper Pleistocene and partly for the Middle-late Early Pleistocene.

The primary geochemical fingerprinting, on which tephra recognition is based, is the major element composition of the glass. This is determined by microprobe analyses (wavelength dispersive spectroscopy; WDS) or SEM (energy dispersive spectroscopy; EDS) which provide the composition of the glass in terms of oxides of a dozen of elements. These data, together with those of the potential correlatives, are then plotted in classification diagrams (e.g. Total Alkali Silica, TAS) and in other covariant diagrams which, highlighting analogies and differences among tephra, allow to correlate the investigated layer to a specific proximal or distal dated counterpart. Moreover, further integrative geochemical analyses that help in making more

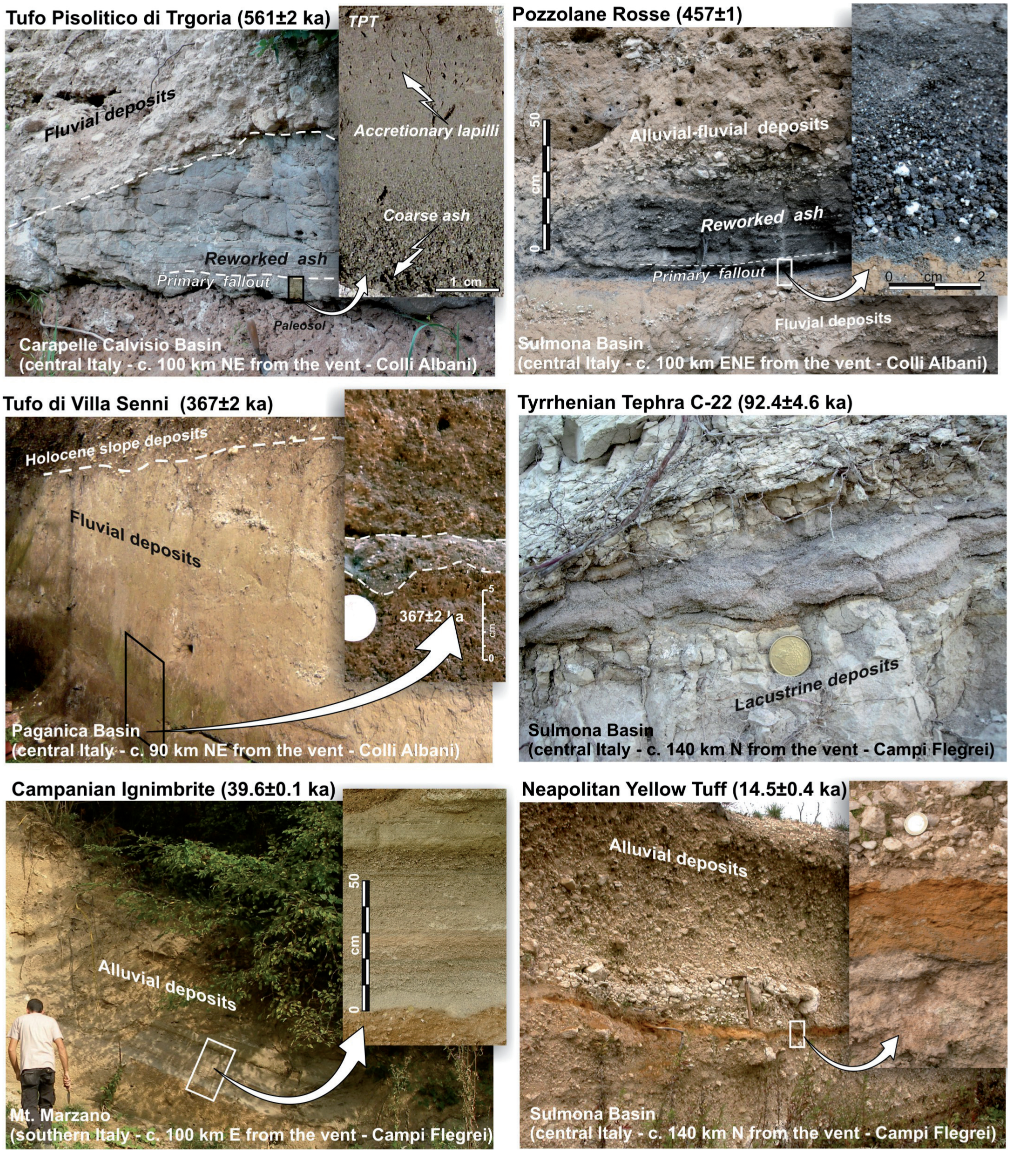

Fig. 1 – Examples of investigated and fingerprinted-correlated tephra occurring in alluvial-fluvial-lacustrine successions of central-southern Italy.

robust and effective tephra correlation comprise: i) trace element data acquired by Laser Ablation Inductively Couple Plasma Mass Spectrometry, ii) Sr-Nd isotope analyses of glass and/or mineral phases and iii) major and trace elemental analyses of mineral phases.

However, all these analyses provide indications for an indirect dating of tephra, as we assign to each tephra the age of an eruptive unit dated elsewhere (e.g. in proximal volcanic or distal setting) via geochemical correlation. In turn, the recent development of the sensitivity of last generations mass spectrometers allows the direct dating of tephra by $^{40}Ar/^{39}Ar$ single crystal fusion method. This dating method can be successfully applied on very fine-grained K-rich crystals, with a high accuracy, precision and reproducibility. As matter of fact, its application on distal setting, combined with geochemical and isotope analyses, is becoming a routine and indispensable procedure (e.g. Giaccio *et al*., 2012, 2013, 2014, 2015; Iorio *et al*., 2014;

Petrosino *et al.*, 2014, 2016) and this multi-method approach has enormously improved the tephrochronology potential, making it a really robust and reliable geochronological tool.

Case studies. The tephrochronological method has been already successfully applied in different sectors of the Apennines, supporting and constraining the geological investigation aimed at defining the fault activity and the Quaternary tectonic evolution of the basins.

For instance, the Sulmona Basin (Abruzzo), bounded to east by the Mt. Morrone Fault system, hosts one of the most rich tephra succession with tens of layers dated directly and indirectly between 800 and 14 ka (e.g. Regattieri *et al.*, 2016; Giaccio *et al.*, 2015). Here the Mt. Morrone Fault crosses and displaces the apical portion of an alluvial fan system containing at its top a peculiar blackish reworked tephra layer, the chemically composition of which matches that of the products of the most recent eruption of the Colli Albani dated to ~36 ka (Galli *et al.*, 2015). This widely dispersal tephra (Giaccio *et al.*, 2013) allowed thus date the top of the alluvial fan and to evaluate the slip rate of the fault system over the last 36 ka which is of ~0.5 mm/yr. Moreover, the recognition of the C-22 tephra (a Tyrrhenian marker that dated at ~92 ka; Giaccio *et al.*, 2012a) in the underlying lacustrine sediments, both in the footwall and in the hanging-wall of the fault, allowed to extend the evaluation of the slip rate back to 92 ka, which resulted again on the order of ~0.5 mm/yr (Galli *et al.*, 2015).

In the area of the 2009 L'Aquila earthquake (Abruzzo), the identification of several Middle Pleistocene tephra in the sedimentary infill of the Paganica-San Demetrio-Castenuovo Basin provided reliable chronological constrain to evaluate the long-term slip rate of the seismogenic fault and the overall Quaternary tectonic-sedimentary evolution of the basin (Galli *et al.*, 2011; Giaccio *et al.*, 2012b).

Finally, in the Bojano Basin (Molise), the recognition of several tephra layers spanning the wide temporal interval of ~580-14 ka, most of which directly dated by $^{40}Ar/^{39}Ar$ method, allowed the characterization of the tectonic basin sedimentary-tectonic evolution since the early Middle Pleistocene. The tephrochronological constraints evidenced an uneven rate and distribution of tectonic strain for the fault segments composing the ~28 km-long N-Matese fault system over time. Briefly, following a strong tectonic activity occurred after ~580 ka along the presently buried fault segments bounding the Bojano plain, at least since 310 ka slip rates progressively decreased, dying out during the Late Glacial-Holocene. Conversely, the piedmont fault system, paralleling the northern Matese flanks, after an activity slowdown during the 480-110 ka time span, speed up with a consistent slip rate >0.5 mm/yr and up to >1 mm/yr, at least for the last 110 kyr (Peronace *et al.*, 2015; Galli *et al.*, submitted).

From the above, and In the light of the systematic occurrence of pyroclastics in the Apennine Chain, this method has a great, currently still barely exploited, potential as key tool for improve our knowledge of the active tectonic of this region, and its enhanced application is warmly recommended.

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