Tephrochronology as a tool for active tectonics studies in peninsular Italy

Biagio Giaccio¹, Paolo Galli¹,², Paolo Messina¹, Edoardo Peronace¹

¹ Istituto di Geologia Ambientale e Geoingegneria, CNR, Rome, Italy
² Dipartimento di Protezione Civile, Rome, Italy

Vesúvius. Camillo Ripaldi (2012)
The study of the active tectonic is typically multidisciplinary. It in fact includes the application and integration of a number of methodological approaches that provide us with knowledge and information on a series of spatial, temporal, and physical parameters that depict the architecture and the behavior of active and capable faults.

Among other, the chronological constraints are essential for evaluating:

1) the general status of activity of a given structure,
2) its short- to long-term slip rate and its changes through time;
3) time recurrence of the fault ruptures.
In the framework of the Mediterranean geodynamic, most of the Italian active and seismogenetic faults are located along the axis of the Apennine chain.
The Apennine active faults often bound and drive the evolution of continental sedimentary basins hosting thick alluvial-fluvial-lacustrine successions.

The investigation and dating of this sediments is thus vital for studying the recent active tectonic. However, until recently these sediments were hardly datable and beyond the applicability limit of the radiocarbon (i.e., c. 40 ka), the chronological framework of the continental deposits were essentially relied on assumptions and qualitative regional cross correlations. The recent development of the tephra study in Central Mediterranean however is changing this frustrating circumstance.
During explosive eruption, Plinian or ignimbrite clouds can rise to tens of kilometers into the atmosphere. The volcanic particles, characterized by their explosive volcanic activity, can be transported by wind up to thousands of kilometers from the source and finally synchronously deposited as tephra layers in different sedimentary settings.

In fact, tephra layers are commonly found in sedimentary successions of the whole Apennine. On the western side of the backbone of the Italian peninsula are located a number of volcanic centers characterized by intense explosive volcanic activity.

Until some years ago the most common answer would have been not! But the recent development in tephra study allows now to answer, yes, maybe, let us see what we can do.

It can be doneee
What we can do?
The tephrochronological method consists in determining the peculiar geochemical features, a kind of chemical fingerprinting, that allow an unambiguous recognition and tracing of tephra layers in different sedimentary settings, so providing an effective way through which associated deposits can be reliably dated and correlated over wide regions.

As any other comparative technique, to be effective tephrochronology require a reliable and possibly complete reference geochemical and geochronological dataset. Although much work has to be still done, we can now dispose of a satisfactory reference dataset for the Upper Pleistocene and in part for the Middle-late Early Pleistocene, and investigations are continuously increasing.
The primary geochemical fingerprinting, on which we base the tephra recognition, is the major element composition of the glass determined by electron microprobe analysis.
This analysis provide the composition of the glass in terms of oxides of several elements.

<table>
<thead>
<tr>
<th>Setting</th>
<th>Tufo Pisolitico di Trigoria</th>
<th>Tufo di Bagni Albule</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carapelle (site 1)a</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Colli Albani b</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Acerno (site 14)b</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sulmona (site 2)b</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Oricola (site 13)c</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Colli Albani c</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Population</th>
<th>N° analyses</th>
<th>SiO₂</th>
<th>TiO₂</th>
<th>Al₂O₃</th>
<th>FeO</th>
<th>MnO</th>
<th>MgO</th>
<th>CaO</th>
<th>Na₂O</th>
<th>K₂O</th>
<th>P₂O₅</th>
<th>F</th>
<th>Cl</th>
<th>SO₃</th>
<th>Original</th>
<th>K₂O/Na₂O</th>
</tr>
</thead>
<tbody>
<tr>
<td>a</td>
<td>11</td>
<td>43.77</td>
<td>1.10</td>
<td>16.89</td>
<td>10.08</td>
<td>0.31</td>
<td>3.32</td>
<td>12.30</td>
<td>5.00</td>
<td>6.66</td>
<td>0.57</td>
<td>0.51</td>
<td>0.17</td>
<td>0.63</td>
<td>96.83</td>
<td>1.33</td>
</tr>
<tr>
<td>a</td>
<td>6</td>
<td>43.17</td>
<td>1.19</td>
<td>16.37</td>
<td>10.47</td>
<td>0.31</td>
<td>3.32</td>
<td>12.97</td>
<td>5.35</td>
<td>6.34</td>
<td>0.52</td>
<td>0.52</td>
<td>0.18</td>
<td>0.69</td>
<td>96.09</td>
<td>0.81</td>
</tr>
<tr>
<td>a</td>
<td>43.91</td>
<td></td>
<td>1.28</td>
<td>16.73</td>
<td>10.04</td>
<td>0.26</td>
<td>3.29</td>
<td>13.35</td>
<td>6.04</td>
<td>6.1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>100.00</td>
<td>1.00</td>
</tr>
<tr>
<td>a</td>
<td>44.73</td>
<td>1.28</td>
<td></td>
<td>19.48</td>
<td>8.17</td>
<td>0.36</td>
<td></td>
<td>12.35</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>96.73</td>
<td>1.34</td>
</tr>
<tr>
<td>a</td>
<td>45.62</td>
<td>1.28</td>
<td></td>
<td>19.03</td>
<td>8.36</td>
<td>0.32</td>
<td></td>
<td>13.35</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>95.56</td>
<td>1.07</td>
</tr>
<tr>
<td>a</td>
<td>45.74</td>
<td></td>
<td></td>
<td>19.16</td>
<td>7.80</td>
<td>0.32</td>
<td></td>
<td>13.35</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>98.02</td>
<td>0.76</td>
</tr>
</tbody>
</table>

N° analyses: 11, s.d.: ±0.36, ±0.18, ±6.04, ±0.19, ±0.09, ±0.07, ±0.05, ±0.34, ±0.81, ±1.19, ±0.22, ±1.01, ±0.41, ±0.18, ±0.18, ±0.13, ±0.18.
Although the classical classification diagrams (e.g. Total Alkali Silica, TAS) commonly do not allow an easy and unambiguous discrimination, by plotting these compositional data in different covariant diagrams, we are able to evidence more precisely analogies and differences among tephra, and thus often to correlate the investigated layer to a specific proximal or distal dated counterpart.
Other important integrative geochemical analyses comprise:

- Trace element glass composition acquired by Laser Ablation Inductively Couple Plasma Mass Spectrometry
- Sr-Nd isotope analyses on mineral and/or glass phases
- Major and trace elemental analyses on mineral phases

All these analyses provide indications for the **indirect** dating of tephra, i.e., they allow to assign the age of an eruptive unit dated elsewhere, in proximal volcanic or distal setting.
The recent development of the sensitivity of the last generation of the mass spectrometers, allows however also the direct dating of tephra by 40Ar/39Ar single crystal fusion method.

The high sensitivity allows the application of the method also on very fine K-rich crystal (100 micron or less). The accuracy, precision and reproducibility of the ages obtained with this method is really high, and its application on distal setting is becoming a routine, indispensable procedure.

Indeed, the combination of the indirect, based on geochemical fingerprinting, and of the direct 40Ar/39Ar dating is recently enormously improved the tephrochronology as robust and reliable geochronological tool.
Study cases in Central and Southern Apennine: Sulmona basin

The Sulmona tectonic basin is bounded to east by the Mt. Morrene Fault system and its infill contain one of the most rich and well-studied tephra succession with tens of layers dated directly and indirectly dated between 800 and 14 ka.
Study cases in Central and Southern Apennine: Sulmona basin

The Mt. Morrone Fault crosses and displaces the apical portion of an alluvial fan system contain at its top a peculiar bleakish reworked tephra layer.

Its chemically composition matches that of the glass from the most recent eruption of the Colli Albani dated to c. 36 ka.

This widely dispersal tephra allowed thus date the top of the alluvial fan and to evaluate the slip rate of the fault system over the last 36 ka.

0.5 mm/yr
Study cases in Central and Southern Apennine: Sulmona basin
Again in Sulmona basin, the recognition of a the C-22 tephra, a Tyrrhenian marker dated at Sulmona at c. 92 ka, in lacustrine sediments on the footwall and 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 c. 0.5 mm/yr.
In the area of the 2009 L'Aquila earthquake, the identification of several Middle Pleistocene tephra in the sedimentary infill of the basin, provided fundamental chronological constrain to evaluate the long-term slip rate of the fault system and the overall Quaternary tectonic-sedimentary evolution of the basin.
Overall Quaternary tectonic-sedimentary evolution of the Paganica-Castelnuo-San demetrio basin.

**Ca. 360 ka-Late Pleistocene**
Persisting prevalence of the fault activity along the Paganica-San Gregorio segment.
Deposition of the late alluvial fan complex. Further denudation of the San Mauro basin.
Finally, in Bojano basin, southern Italy, the recognition of several tephra layers spanning the wide temporal interval of c. 580-14 ka, most of which directly dated by Ar/Ar method, allowed the characterization of the tectonic as well as the associated Bojano 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. After 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, running parallel to the northern Matese flanks, after the slowdown of its activity during the 480-110 ka time span, restarted, with a consistent slip rate >0.5 mm/yr and up to >1 mm/yr, at least for the last 110 kyr.