VOLCANIC ASHES FROM FROSOLONE (ISERNIA, ITALY): MINERALOGICAL CHARACTERISATION AND FISSION-TRACK DATING

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ABSTRACT - This paper reports the occurrence of air-fall tephra in the “Colle dell’Orso” area, near Frosolone (Isernia), in the Molisean South-Central Apennines. A mineralogical and compositional investigation on clinopyroxenes, K-feldspars and glass, as well as an attempt at a geochronological dating by fission-track method on glass, were carried out to establish the source of the volcanic material found in this area.

The collected data show a compositional range of diopside to ferroan-diopside for the clinopyroxene, and a prevalent “orthoclasic” composition is found for the feldspars. The glass presents prevalently trachytic and/or trachy-andesitic (laticic) compositions. Fission-track dating on glass gives an age of 10,800 (±5,500) years.

The glass, clinopyroxene and feldspar compositions, fission-track age determination, and the morphological and structural appearance of the host-layering yellowish material would all seem to indicate that the Frosolone ashes are referable to the explosive products of the Phlegrean Fields (Campanian activity), in particular to the Neapolitan Yellow Tuff emission, thus ruling out all earlier Campanian activities and also other probable provenances from neighbouring volcanic complexes.

KEY WORDS: volcanic ashes, clinopyroxene, K-feldspar, glass, fission-track dating, Phlegrean activity, Frosolone, South-Central Apennines.

INTRODUCTION

The present work examines the results of a mineralogical and dating study carried out on volcanic ash deposits found at Colle dell’Orso, near Frosolone (Isernia), Molise, in the South-Central Apennines.

The finding of volcanic ashes in the Frosolone area concerns some current issues of general interest, namely: 1) the Quaternary stratigraphy of Central Italy, 2) the characterisation and areal spread of volcanic soils in the South-Central Apennines, and 3) recent issues on the probable intrapeninnic volcanism.

The area under study is situated on the boundary between the Central and South-East Apennines, and relatively borders on the volcanic complexes mostly distributed west, south-west and south of the Frosolone area. From north to south, these are the Alban Hills (Volcan Lattiale) and Roccamonfina complexes, both in the Latal region, the Phlegrean Fields complex (Campanian region), and the smaller Mount Vulture complex in the Basilicata region. Moreover, there should also be indications on probable intrapeninnic activity immediately to north of Frosolone, in the Abruzzo region (Barbieri et al., 1996; Bosi et al., 1991). Therefore, the material found in the studied area could actually be attributed to the activity of one of these neighbouring complexes, but it would also be reasonable to hypothesise a possible local intrapeninnic activity, albeit of a minor scale. To date, however, there is no evidence of occurrences of autochthonous volcanic material in the Molisean area and so the Frosolone volcanic ashes must be attributed to explosive eruptions of neighbouring volcanic activity.

The literature frequently presents works investigating the origin and provenance of volcanic products found prevalently in Central and Southern Italy. Volcanic paleosoils are often used as chronostratigraphic pedomarkers. Frezzotti & Narcisi (1996) identified two important pedomarkers in Central Italy, both referable to Phlegrean activity (Campanian Ignimbrite and Neapolitan Yellow Tuff); Giraudi (1989) reported a review of the lake levels and climate for the last 30,000 years in the Fucino area (Abruzzo, Central Italy), while Narcisi (1996) investigated fourteen tephra layers, all belonging to Campanian activity, in the Vulture district (Lago Grande di Monticchio, Basilicata, Southern Italy). Other similar studies have also been carried out (Arnoldus-Huyzendveld et al., 1985; Mizota & van Reeuwijk, 1989; Frezzotti & Giraudi, 1989, 1990, 1992; Frezzotti & Narcisi, 1989) because the regions of this area were widely affected during the Quaternary by the re-fall of products deriving from the explosive activity of the neighbouring Roman and Campanian volcanic districts.

The present paper firstly aims to notify the finding of a volcanic ash deposit in the Frosolone area – this kind of deposit never being reported here before – and also to report a simultaneous combination of mineralogical and dating results which are useful in order to explain the origin and source of the volcanic ashes found at Frosolone. The chemistry of the primary mineral phases (clinopyroxenes and feldspars) and the results of fission-track dating on glass, carried out in this work, significantly contributes to solving this problem.

GEOLOGY AND GEOMORPHOLOGY OF THE AREA

The area of Colle dell’Orso (1393 m a.s.l.) is located in the municipality of Frosolone, in the province of
Isernia (Fig. 1). The landscape is predominantly mountainous (1200-1400 m a.s.l.) and is composed of a series of calcareous-dolomitic and selciferous reliefs characterized by rounded summits and slopes with a regular profile, abundant hilly pastures mostly located on the summits, on the subplateau levels or on the bottom of basins and small valleys, the latter relating to the local karst phenomena.

The geological arrangement of this Apenninic sector is very complex and developed over a long time period between the upper Trias and the Quaternary, during which rocks belonging to different sedimentary environments were deposited; moreover, the occurrence of tectonic phases has led to the present structural chain. A recent paper by Tozzi et al. (1999) reports the final results of a geological-structural survey carried out on a broad area of the Molise region, comprising the entire Montagnola di Frosolone, characterised by the transitional sequences of the Frosolone Unit. This shows sedimentological and lithological features of a typical transitional environment, where a continuous sedimentation of detritic limestones took place from the Dogger to the Middle Miocene.

Other previous general geological descriptions of the area are also reported in papers by Pescatore (1963, 1965), Cocco (1971), Sgrosso (1986), Naso et al. (1989), Patacca et al. (1992) and, more recently, by Corrado et al. (1997), De Corso et al. (1998), Di Luzio et al. (1999) and Scrocca & Tozzi (1999).

As regards local geology, the Frosolone hilly area may be ascribed to the “falda molisana”, composed of a pelagic succession sedimented between the upper Trias and the Miocene (Patacca et al., 1992).

RESULTS
Profile description

Some transect profiles were carried out in the Colle dell’Orso area, near Frosolone (Fig. 1), along an alignment including summit, slope and valley profiles. Of the series of profiles performed, the valley one in particular (Fig. 2) turned out to be more interesting for its stratigraphic sequences, which are characterised by yellowish layers with abundant glassy matrix. The other two profiles, summit and slope, showed substantial differences with the valley profile since they did not present yellow layers and contained no glass. Therefore, the present work will only consider the valley profile investigation, while a future separate work on the mineralogy of the other two profiles will be performed in detail in order to have an overview of the depositional situation of the Frosolone area.

The studied valley profile (Fig. 2) presents a yellow-ochre level, from ca. 130 to 200 cm depth, that is clearly different from the other upper and lower sequences, which are instead characterized by a brown-blackish colour. The yellowish level shows evident layering with...
variable colours ranging from yellow-ochre in the uppermost part, progressively shading to pale-yellow and to white in the lower part. It rests directly on a sediment of coarse material mainly composed of a thin clayey matrix of brownish or dark brown colour, with large siliceous splinters and Fe-Mn nodules of up to 260 cm in depth, and is overlapped by a very dark brown, almost black, deposit reaching the profile surface, composed of a very fine clayey material containing volcanic glass, clinopyroxenes, feldspars, quartz, and, subordinately, also other mineralogical phases (magnetite, biotite, apatite, Fe-Mn-oxides).

**Experimental**

**Materials and analytical techniques**

On the basis of morpho-structural characteristics and colour differences, 6 samplings were carried out at different depths in the valley profile (Fig. 2). The samples, named “Fro” and used in the present work, are the following:

- **Fro1** (10-30 cm), **Fro2** (40-50 cm), **Fro3** (130-140 cm), **Fro4** (145-155 cm), **Fro5** (175-195 cm) and **Fro6** (250-260 cm).

Grains of clinopyroxene (light green and dark green prismatic crystals), K-feldspar and glass (yellowish, brownish and black in colour; fibrous, vesicular and globular in shape) were collected from the sandy granulometric fraction (>0.25 mm) of the six loose samples under examination. The selected grains were separated into three aliquots, for SEM (ZEISS mod. DSM 940A), EMPA (CAMECA SX50 electron microprobe, equipped with 5 WDS spectrometers at 15 kV, 15 nA, 100 cps, with a Link EDS system controlled by Specta software) and geochronological determinations (Fission-Track dating method), respectively.

The fission-track analysis of the volcanic glass was carried out in the Istituto di Geoscienze e Georisorse of the CNR of Pisa. The population dating method was used (Gleadow, 1981).

**Mineral characterisation**

The primary mineralogical assemblage is represented by prevalent clinopyroxenes and feldspars, while brown mica and magnetite are present in all levels subordinately (Tab. 1). Quartz, albite, apatite and other accessory phases are also present. Glass is abundantly present as far down as 195 cm in depth, while it is completely absent in the Fro6 sample (250-260 cm), where many abundant black Fe-Mn nodules, 0.5 to 2 mm in size, appear.

Since this study aims at establishing the volcanic district of possible origin of the volcanic material found at Frosolone, the research focused on the mineralogical phases that could yield useful data: clinopyroxenes, K-feldspars and glass. The significant compositional variability of these primary phases is a good indicator of the probable origin of the host volcanic material.

The clinopyroxenes, always present, are less than 1 mm in size and display a prevalently prismatic and elongated habit, with varying colour from light-green, dark-green up to dark brown and black. They are often found altered at their surface and compositional zonations are frequently observed in thin section.

The feldspars, always present, are generally splintery, thereby implying a derivation from larger crystals; they are generally larger than the clinopyroxenes (2 to 3 mm). Little altered at the surface, the feldspar crystals present a notable transparency and are colourless. In thin section they do not present any peculiar compositional zonation and, in some cases, they show a narrow contact with glass.

The glass, absent in the Fro6 sample, has different morphologies in the various levels and varies from fibrous-elongated to bubble-vesicular and filamentous up to solid-massive and globular (obsidian type) (Fig. 3), with very diversified colours from pale-brown through dark-brown to black. Generally, the bubbles and vesicles are filled with soft clay material of allophanic type (X-ray analysis), similar to the material mainly making up the matrix of the whole sediment.

<table>
<thead>
<tr>
<th>Level</th>
<th>Colour</th>
<th>Mineralogical assemblages*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fro1</td>
<td>Brown</td>
<td>Abundant clear feldspar; quartz; microcrystals of green clinopyroxenes; grey-yellow mica; many black managanesipherous sferules; very splintered fragments of silicoclasts of different colours.</td>
</tr>
<tr>
<td>Fro2</td>
<td>Dark brown</td>
<td>Abundant fibrous glass and obsidian; feldspar; quartz; black mica; little microcrystalline clinopyroxene; very little magnetite.</td>
</tr>
<tr>
<td>Fro3</td>
<td>Beige-yellowish</td>
<td>Abundant fibrous glass; little obsidian; large green clinopyroxenes crystals; abundant feldspar and little quartz; black mica; magnetite.</td>
</tr>
<tr>
<td>Fro4</td>
<td>Yellow-ochre</td>
<td>Abundant fibrous glass and obsidian; feldspar; quartz; black mica; little microcrystalline clinopyroxene; very little magnetite.</td>
</tr>
<tr>
<td>Fro5</td>
<td>Grey-yellowish</td>
<td>Little fibrous glass; abundant fresh vesicular glass; abundant clinopyroxenes, feldspar; quartz, little black mica; magnetite.</td>
</tr>
<tr>
<td>Fro6</td>
<td>Brownish</td>
<td>Abundant microcrystals of quartz and feldspar; scarce fibrous and obsidianic glass; green and black clinopyroxenes; black mica and magnetite.</td>
</tr>
</tbody>
</table>

* = granulometric fraction > 0.25 mm (sandy)

Tab. 1 - Mineralogical assemblage of the six examined samples from Frosolone.
Compositional data

Clinopyroxenes. Tab. 2 reports the averaged representative chemical analyses of the clinopyroxene cores of the six analysed samples. However, a complete analytical data set is disposable for consultation from A.G.

In each sample, at least two mean compositions were found, ranging from diopside to ferroan-diopside (nomenclature according to Rock, 1990). Three different representative compositions were identified for sample Fro6. From the crystal chemical formula, calculated on the basis of 6 oxygens, the percentages of the Wo-En-Fs (Ca-Mg-ΣFe+Mn) end-members were calculated in

\[
\begin{align*}
\text{End-members Wo-En-Fs (\%)}: \\
\text{Ca} & \quad 45.94 \quad 46.67 \quad 46.91 \quad 46.75 \quad 47.61 \quad 49.35 \quad 48.05 \quad 48.63 \quad 47.55 \quad 48.84 \quad 48.46 \quad 48.79 \quad 48.68 \\
\text{Mg} & \quad 47.16 \quad 39.75 \quad 48.10 \quad 37.38 \quad 47.02 \quad 38.32 \quad 41.14 \quad 37.20 \quad 47.76 \quad 34.56 \quad 47.05 \quad 43.40 \quad 37.46 \\
\Sigma\text{Fe+Mn} & \quad 6.90 \quad 13.59 \quad 4.99 \quad 15.87 \quad 5.37 \quad 12.33 \quad 10.81 \quad 14.16 \quad 4.67 \quad 16.60 \quad 4.50 \quad 7.81 \quad 13.86 \\
\end{align*}
\]

(*) calculated according to Papike et al. (1974);

Tab. 2 - Average compositions of the clinopyroxene cores from Frosolone.

**Fig. 3** - SEM microphotographs of the fresh glass from Frosolone with different morphologies: a) prismatic elongated vescicules; b) rounded and ovoidal small bubbles; c) waved bundles; d) very elongated parallel and fibrous vescicules.
order to have a graphic representation of the compositions (Fig. 4). This graph clearly indicates only diopсидic and ferroan-diopsidic (Fe-Di) compositions for all the analysed clinopyroxenes. The same graph also shows the clinopyroxene compositions reported by Orsi et al. (1995), for the Neapolitan Yellow Tuff (NYT), and by Civetta et al. (1997), for the Campanian Ignimbrite (CI). The CI clinopyroxenes fall within a mostly narrow and central area of the ferroan-diopside field, while the NYT clinopyroxenes spread over the same field, but always nearest to the investigated Frosolone clinopyroxenes, which are distributed into two distinct groups, like the NYT clinopyroxenes. The CI clinopyroxenes are concentrated in an area in between these two groups where, in part, the Fro1 and Fro2 clinopyroxenes also fall.

**Feldspars.** Tab. 3 reports the representative analyses and percentages (%) of the Or-Ab-An end-members for the feldspars of the six horizons. Like the clinopyroxenes, the feldspars also show variable compositions; those of horizons Fro4, Fro5 and Fro6 show a broader compositional range with respect to the other samples; Fro1 and Fro2 are practically homogeneous. The highest Or content (~98%) is in sample Fro4, while the lowest (~45%) is found in sample Fro6. Obviously, these varying values of Or correspond to variable values of Ab, which range from ~ Ab2 to ~ Ab52. The content of An varies from 0 to ~ 3, on average keeping to very low values.

Fig. 5 gives a better compositional representation of the feldspars of Frosolone and clearly shows how samples Fro1 and Fro2 are concentrated around compositions of ~ Or90Ab17An3, while sample Fro3 – although relatively homogeneous – tends to differ from the previous samples for its low An content (from 0.3 to 2.4). Samples Fro4, Fro5 and Fro6 show a greater chemical variability (Or89Ab2 for Fro4 to Or15Ab52An3 for Fro6) with respect to the previous samples. The feldspars with greatest variability are those of sample Fro6 (Or86Ab14 to Or15Ab52An3), always close to the Ab-An side of the compositional triangle. On the other hand, apart the sample Fro6, the feldspars of samples Fro4 and Fro5 have a lower point scatter and reach a peak value of Ab27 for sample Fro4 and Ab37 for sample Fro5.

As a comparison, the graph of Fig. 5 also plots the feldspar compositions reported by Orsi et al. (1995) for the Neapolitan Yellow Tuff and by Civetta et al. (1997) for Campanian Ignimbrite. The representative points of the above-mentioned compositions fall perfectly within a linear trend also including the feldspars of the Fro1 and Fro2 samples. While the latter two samples perfectly match the NYT feldspar compositions (Orsi et al., 1995), those of Civetta et al. (1997) show a more scattered trend, parallel to the feldspars of Fro6, Fro5 and Fro4, moving, respectively, from bottom up in the relative graph. Consequently, we have two compositional trends: one that is poorer in anorthite content but has a greater compositional scatter, shown by samples Fro3, Fro4, Fro5 and Fro6, and the other with more homogeneous compositions but with higher anorthite contents, as in samples Fro1 and Fro2, and the NYT and CI. Although the latter sample shows a greater An content, it also shows greater compositional scatter as with the feldspars of the other trend.

**Glass.** Tab. 4 reports the representative analyses of the volcanic glasses found until to about 200 cm in depth. Sample Fro1 display a large compositional variability (three different compositions), whereas the other samples show greater
<table>
<thead>
<tr>
<th>Analyses</th>
<th>Fro1</th>
<th>Fro2</th>
<th>Fro3</th>
<th>Fro4</th>
<th>Fro5</th>
<th>Fro6</th>
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<td>SiO$_2$</td>
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<td>62.80</td>
<td>64.09</td>
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<td>0.07</td>
<td>0.03</td>
<td>0.07</td>
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<tr>
<td>Al$_2$O$_3$</td>
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<td>0.26</td>
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<tr>
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<td>0.04</td>
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<td>0.17</td>
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<td>P$_2$O$_5$</td>
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<td>100.05</td>
<td>99.84</td>
<td>98.39</td>
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Unit formula (oxygens = 32)

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<th>Al</th>
<th>Fe</th>
<th>Mn</th>
<th>Mg</th>
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<tr>
<td>Total</td>
<td>99.72</td>
<td>99.40</td>
<td>99.05</td>
<td>100.05</td>
<td>99.84</td>
<td>98.39</td>
</tr>
</tbody>
</table>

Tab. 3 - Average compositions of the K-feldspar cores from Frosolone.
homogeneity in composition, for the same examined level.

The glass microprobe analyses were normalized to $\Sigma = 100$ in order to allow their representation and classification in the TAS (Total Alkali-Silica) compositional graph, according to Le Bas et al. (1986). In Table 4 are reported only the normalised values for SiO$_2$ and Na$_2$O+K$_2$O oxides.

Fig. 6a plots all the compositions of the Frosolone analysed glasses and, for comparison, the glasses reported in the literature for neighbouring volcanic areas: (AH) Alban Hills (Trigila et al., 1995), (RM) Roccamonfina (Giannetti & Luhr, 1983), (PF) Phlegrean Fields (de’ Gennaro et al., 1990; Orsi et al., 1992; Melluso et al., 1995; Orsi et al., 1995; Civetta et al., 1997; de’ Gennaro et al., 1999). Glasses from Frosolone prevalently fall within the Trachytic and Trachy-andesitic (Latitic) fields, overlapping those from the Phlegrean Fields (linear dashed area). Fig. 6b details the PF glass compositions present in the literature, including CI and NYT. Finally, Fig. 6c plots only the representative analyses of the Frosolone glass. This graph shows that, while the glass of sample Fro1 is characterised by a large compositional variability, the glass of the other samples have a more homogeneous composition. In fact, sample Fro1 shows variable compositions from Trachyte to Latite, while samples Fro3, Fro4 and partly Fro2, are only latitic. Sample Fro5 instead has a clear trachytic composition.

Fission-track analysis

As regards recent rocks, the problem of the experimental error magnitude of ages determined with fission-track dating is particularly serious because the uranium content commonly present in the rocks does not allow the accumulation of an adequate number of tracks in a short time. However, this method is at times the only one usable in dating recent volcanic rocks. In particular, volcanic glass is of great importance because it is the only datable phase of many tephra (Walter, 1989).

Only samples Fro1, Fro2 and Fro3 were considered for fission-track analysis because these levels yielded promising glass grain aliquots for dating, in view of their characteristics (transparency and amount). The results of the analyses are shown in Table 5. Despite the fact that a relatively large surface was analysed (0.586 cm$^2$), only 2 spontaneous tracks were found for samples Fro2 and Fro3 (counting surfaces 0.254 and 0.296 cm$^2$, respectively), whereas no tracks were observed for glasses from sample Fro1 in a significantly smaller surface (0.036 cm$^2$). Characteristics (such as track densities and sensitivity to chemical etching) of the glass fragments from samples Fro1–3, that yielded polished surfaces useful for counting, suggest that they make up a homogeneous population. Therefore, in order to obtain a better estimate for the age of these glasses, the age of the overall 3 samples was computed.

This age (10,800 ± 5,500 years) is affected by a large experimental error (> 50%), almost totally due to the fossil track area density determination.

Due to the low stability of fission tracks in glass during geological times, most glasses show partially rejuvenated ages. The presence of partial track annealing is detected by a reduction of the sizes of the spontaneous tracks in comparison with those of the “fresh” induced tracks (Storzer and Wagner, 1969). Although a spontaneous to induced track mean size ratio, $D_S/D_I$, very close to 1, 0.98 (± 0.10) had been determined (individual values $D_S = 5.63 ± 0.56$ and $D_I = 5.68 ± 0.11$ μm, errors are ± 1 σ), a certain amount of annealing of spontaneous tracks cannot be ruled out due to the large experimental error of $D_S/D_I$. However, the track-size data suggest that a possible rejuvenation would be negligible. In actual fact, this result was expected owing to the very young age of the material used for the investigation.

DISCUSSION AND CONCLUSIONS

General considerations

The volcanic ash deposit found near Frosolone, the subject of the present paper, demonstrates that in last period there was a fall-out of fly-ashes on the superficial geomorphological folds of the well-known Molisean geological area called “La Montagnola di Frosolone”.

These volcanic materials, which have been casually found south of the Colle dell’Orso locality (Fig. 1), do not have any correlations with the older geology of the
Parameters used for age calculation:

- $\lambda = 1.55125 \times 10^{-10}$ a$^{-1}$
- $\lambda_4 = 8.46 \times 10^{-17}$ a$^{-1}$
- $\sigma = 5.802 \times 10^{-22}$ cm$^{-2}$
- $^{238}\text{U}/^{235}\text{U} = 137.88$

Samples were irradiated in the Lazy Susan position (Cd ratio: 6.5 for Au and 48 for Co) of the LENA Triga Mark II reactor (Pavia University), with a neutron fluence of $1.75 \times 10^{15}$ cm$^{-2}$, referred to NRM IRMM-540 standard glass (De Corte et al., 1998).

Chemical etching for track development: 60 sec in 20% HF at 40°C. Track counting was carried out with a Leica Orthoplan microscope at 500x. Track size measurements were performed using a Leica Microvid equipment at 1000x.

Tab. 5 - Fission-track dating of Frosolone glass.

<table>
<thead>
<tr>
<th>Sample</th>
<th>$\rho_S$ (cm$^{-2}$)</th>
<th>$N_S$ (cm$^{-2}$)</th>
<th>C.S.S (cm$^{-2}$)</th>
<th>$\rho_I$ (cm$^{-2}$)</th>
<th>$N_I$ (cm$^{-2}$)</th>
<th>C.S.I (cm$^{-2}$)</th>
<th>$p(\chi^2)$ (%)</th>
<th>Age (± 1σ) (a)</th>
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<tr>
<td>Fro1</td>
<td>□□□□□□□□□□□□□□□□□□□□□□□</td>
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<tr>
<td>Fro2</td>
<td>7.88 2</td>
<td>361</td>
<td>129</td>
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<td>Fro3</td>
<td>6.75 2</td>
<td>0.296</td>
<td>53.300</td>
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<tr>
<td>Fro4</td>
<td>6.82 4</td>
<td>0.586</td>
<td>54.800</td>
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ρ$_S$ (ρ$_I$) surface density of spontaneous (induced) tracks;

$N_S$ ($N_I$): number of spontaneous (induced) tracks;

C.S.S (C.S.I): counting surface for spontaneous (induced) tracks;

$p(\chi^2)$: probability to obtain calculated values in applying the $p(\chi^2)$ test to confront the counts distribution of induced tracks with the Poisson distribution.

Area and are mostly found in the valley part of the folds. This observation leads to the hypothesis that the volcanic materials were first at length deposited on the hilly surface and were then very likely affected by valley shifts due to natural events such as ice or snow melts, floods, etc. Thus, the volcanic ashes of the yellow part of the valley profile (Fig. 2) almost surely underwent a removal and reworking with respect to the original deposition after the eruptive event. This hypothesis should also be confirmed by the total absence of both yellow deposits and volcanic glass in the slope and summit profiles, simultaneously carried out with the valley one. Therefore, the present work has only considered the valley profile, and the investigations were made to establish the origin and the source of the unknown volcanic material.

In fact, the aim of this paper is firstly to notify, for the first time, the finding of a volcanic ashes deposit in the Frosolone area, and then to correlate the mineralogical, compositional, and datational results of the more significant mineralogical phases and glass investigated, in order to trace the source of the host volcanic material.

Discussion of the experimental data

The data reported in this work refer to the study of the primary volcanic mineral phases (clinopyroxenes and feldspars) and coexistent glass, and they allow us to make the following considerations.

As regards the composition of the analysed clinopyroxenes, which range from diopside to ferroan-diopside, the graph of Fig. 4 shows that the NYT pyroxenes have similar behaviour to Frosolone ones, while, in contrast, the CI pyroxenes fall within a more restricted area of the ferroan-diopside field. However, this limited area also includes the Fro1 and Fro2 samples, even if at a lower limit, and this fact leads one to think that the two samples are more similar to those of the CI. In effect, the Fro1 and Fro2 samples are the most superficial with respect to the valley profile and, always with reference to the same graph, we note a certain sequence related to the content of the calcic component in the clinopyroxenes, with respect to the sampling depth. A good correlation could also obviously result by taking into consideration the magmatic evolutionary process of the NYT, described in detail by Orsi et al. (1995). The authors described a three-layer magma chamber for the magmatic and evolutionary history originating the Neapolitan Yellow Tuff, distinguishing three different magma (magma1, magma2 and magma3) on the basis of a geochemical, mineralogical, and isotopic study of the volcanic formation. Although not being the object of the present work, it is, however, interesting to see a certain sequential correlation in the compositional data reported on the clinopyroxenes.

As regards the behaviour of the analysed feldspars, also with respect to those from the CI and NYT formations taken for comparison, the graph of Fig. 5 shows a double compositional trend. While for the clinopyroxenes there is a contemporary presence of the same sample in the two well-distinguished compositional groups (Diopside – Fe-Diopside), in the case of the feldspars we have a more clear distinction for the analysed feldspar crystals. Samples Fro1 and Fro2, for example, find themselves alone in the very limited group of ~ Or80Ab20 composition, and have an anoritic content that is certainly higher than all the others, while as regards the parallel trend, characterised by a lower anoritic content, we found the feldspars of a much greater heterogeneous composition. This behaviour can again be justified, as for the clinopyroxenes, by the evolutionary magmatic process described by Orsi et al. (1995). Moreover, the high compositional heterogeneity of the feldspars from sample Fro6, which are shifted in the lower part of the graph of Fig. 5 and are correlated to those of CI (with higher Ab and An content), allow us to put forward the hypothesis that the volcanic material of the Fro6 sample could belong to another activity, perhaps the CI eruption.
Fig. 6 - TAS graph representation for glass compositions.

a) Frosolone glass (black solid circles) compared with the compositions of the glass from Alban Hills (AH area; Trigila et al., 1995), Roccamonfina (RM area; Gianetti & Luhr, 1983) and Phlegraean Fields (PF delimited area; various authors: see legend. Fig 6b). T-Ph= Tephri-phonolite; Ph=Phonolite; T=Trachyte; L=Lavite (K) (according to Le Bas et al., 1986).

b) Plot of the compositions of the glass from the Phlegraean Fields (references in legend; graphic abbreviations as in 6a).

c) Plot of the average compositions of the glass from Frosolone (graphic abbreviations as in 6a).
Not finding any glass in the Fro6 sample, it was not possible to date the material using the fission-track method. However, the fact that the Fro6 sample does not contain glass shows that this material (already under about 200 cm in depth, Fig. 2) has a different, and certainly older, origin.

The chemical and datational analyses carried out on the glass support what has been said so far. The variable composition from trachyte to trachy-andesite (latite) of the glass, as highlighted by the three TAS compositional graphs (Figs. 6a, 6b and 6c), demonstrates how the chemistry of the glass contained in the volcanic ashes found at Frosolone can be referred to an evolutionary magmatic activity. This could also be demonstrated by the different morphologies of the glass fragments, as seen in Fig. 3, which also shows that the glass is quite fresh. The general TAS graph of Fig. 6a shows that the analysed glasses from Frosolone can be referred to Phlegrean Field activity, ruling out other origins, such as the Alban Hills products (Trigila et al., 1995) or those of Roccamonfina (Gianetti & Luhur, 1983), the nearest volcanic districts to Frosolone. The graph of Fig. 6b highlights the compositional differences of the glasses of Campanian Ignimbrite with respect to those of the NYT. Even if the latter are fairly scattered in the graph, falling within the four compositional fields (T, L, Ph and T-Ph), it is obvious that the CI and Phlegrean Field glasses (Civetta et al., 1997; de’ Gennaro et al., 1999; Melluso et al., 1995) are generally less scattered and fall mainly within the Ph-T fields. Fig. 6c reports only the mean compositions of Frosolone glass and shows a fair correlation between these compositions and those of NYT, at least as regards the Latite-Trachy-andesite evolutionary trend. The results of the fission-track dating on glass contribute to confirming what has been said here and, even if flawed by a high degree of experimental error, they agree with the indications already found in the analytical compositions concerning the probable origin of the material under study. The age of 10,800 (±5,500) years falls well within the period of Phlegrean Field activity, which gave rise to the Neapolitan Yellow Tuff formation. Thus, the determined age rules out the earlier activity that produced the Campanian Ignimbrite, for which an age of about 35,000 years was established, as reported in Rosi & Sbrana (1987). On the other hand, glass is the only datable phase in these types of tephra and, in the specific case of Frosolone, the experimental data were in any case significant despite the high degree of error.

Finally, as regards the features of the investigated volcanic material, such as structure and texture, laminar layering and relative colour differences, variability in composition of the analysed phases), have allowed us to attribute the Frosolone volcanic materials to a Phlegrean origin, in particular to the products of the Neapolitan Yellow Tuff eruptive period, as also shown by the dating analyses that attribute an age of 10,800 ± 5,500 years to the investigated glass. This allows us to confirm the source as the late period of Phlegrean activity (NYT), ruling out the products of Campanian Ignimbrite that date back to about 35,000 years ago. However, at moment, we do not consider it appropriate to provide further details on the exact reconstruction of the volcanic events, which require another type of investigation, and also because we did not aim to make this sort of considerations. Instead, we wanted to stress how this type of research, focusing on mineralogical and dating determinations, can establish the period as well as the origin and provenance of the volcanic products of the material found in the “Montagnola di Frosolone” area. The experimental data presented in this work could also suggest the need for further study of these volcanic ashes by focusing more on the identification and attribution of the exact periods of the relative volcanic activities and their deposition modality.

CONCLUSIONS

In view of what has been said in the present paper, we can conclude that the features of the analysed material (structure and texture, laminar layering and relative colour differences, variability in composition of the analysed phases), have allowed us to attribute the Frosolone volcanic materials to a Phlegrean origin, in particular to the products of the Neapolitan Yellow Tuff eruptive period, as also shown by the dating analyses that attribute an age of 10,800 (± 5,500) years to the investigated glass. This allows us to confirm the source as the late period of Phlegrean activity (NYT), ruling out the products of Campanian Ignimbrite (NYT), or those of Roccamonfina (Gennetti & Luhur, 1983), the nearest volcanic districts to Frosolone in subsequent times.

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