doi:10.3304/JMES.2011.003

Journal of Mediterranean Earth Sciences **3** *(2011), 25-32*

Journal of Mediterranean Earth Sciences

New data on the Tuscolano-Artemisio phase of the Alban Hills: some insights on climatic conditions

Pio Bersani[1], Laura Corda[2,*]

[1] *Via Giulia 102, 00186 Roma, Italy*
[2] *Dipartimento di Scienze della Terra, SAPIENZA Università di Roma, P.le Aldo Moro 5 - 00185 Roma, Italy*

ABSTRACT - A pyroclastic flow 14 m thick embedding well-preserved wood remains has been retrieved at a depth of 120 m from a borehole drilled near the village of Lanuvio, about 9 km south of the Lake of Albano. 40Ar/39Ar analyses on a leucititic lava flow immediately overlying the drilled ignimbrite, gave an age of 485 ± 1ka. Facies and age constraints are consistent with pyroclastic products of the first Tuscolano-Artemisio phase.

The new findings presented here contribute toward reconstructing the early eruptive history of the Alban Hills. New chronological data further define the time interval and spatial distribution of the extrusive phase, coinciding with the transition from the first to the second Tuscolano-Artemisio phases.

It is also suggested that the pyroclastic products of the Latium region (Rome) with their embedded wood remains, represent an important "archive" of arboreal expansion, allowing better definition of the climatic conditions characterizing interglacial stages 13-15 of the Oxygen Isotope Curve.

KEY WORDS: Alban Hills volcano, Tuscolano-Artemisio phase, geochronology, Pleistocene, central Italy, arboreal fluctuations

Submitted: 28 October 2011 - Accepted: 2 December 2011

INTRODUCTION

The Alban Hills are one of the main volcanic districts of the potassic and ultrapotassic magmatic province extending along the Tyrrhenian sector of Italy. For many years, this area, characterized by frequent seismicity of low or very low magnitude, has been considered of great interest because of its proximity to Rome (less than 15 km) and because of the ongoing debate as to whether it should be interpreted as an extinct volcanic center (Voltaggio and Barbieri, 1995) or only quiescent (De Rita et al., 1995; Funiciello et al., 2003; Freda et al., 2006; Mariucci et al., 2008). Extensive urbanization and agriculture (the area is famous for its white wines) often makes it difficult to sample and analyse the deposits in order to reconstruct the detailed geological evolution and history of volcanic activity. In addition, because of the general lack of observable outcropping sites, little information on the products of the early stages of the Tuscolano-Artemisio phase are available. This is why the results of data analysis from the 120-m borehole drilled a few decades ago near the village of Lanuvio, south of Ariccia, provides the opportunity for insights into the pre-caldera activity which emplaced very large volumes of pyroclastic deposits. Fortunately, however, field logging and some samples have been obtained.

Recontructions of paleoclimatic changes are commonly based on pollen records, essential in identifying vegetation changes in the past. Long continental sequences are, however, exceptional, because their formation and preservation only occur in particular conditions and very few data are available for the time interval considered in this study. We report here the possible paleoclimatic significance of the wood remains recovered from the borehole and their potential future use in verifying the expansion of vegetation.

*Corresponding author: *laura.corda@uniroma1.it*

GEOLOGICAL SETTING

The Plio-Quaternary volcanism which developed widely along the Tyrrhenian coast of central Italy is a consequence of extensional tectonics affecting the internal Apennine chain in a post-collisional setting (Beccaluva et al., 2004). According to petrological and geochemical data, it has been subdivided into several magmatic provinces (Peccerillo, 2003). The magmatism found from Latium to Campania is known as the Roman Province and is of large compositional variability, from shoshonitic basalt to trachyte and leucitite (Conticelli et al., 2002). The Alban Hills district belongs to the Roman Province.

The Alban Hills volcano, located about 15 km south-east of Rome, exhibits a central morphological shape dominating the surrounding countryside (the Campagna Romana) (Fig. 1). Volcanic activity ranges between about 0.6 and 0.02 Ma, and is now considered quiescent by some authors (e.g., De Rita et al., 1995; Funiciello et al., 2003; Freda et al., 2006; Mariucci et al., 2008). The history of the volcano is subdivided into three main phases of activity (De Rita et al., 1988, 1995) (Fig. 2):

- The Tuscolano-Artemisio phase (T-A phase), which occurred between 600 and 350 ka, mostly derives from the central Tuscolano-Artemisio area. It is characterized by at least four major explosive eruptions, for a total volume of about 280 km^3 of material (De Rita et al., 1992), ending with the final collapse of the large central caldera.

- After this collapse, a small stratovolcano built up from the center of the caldera, emplacing the Faete succession. This phase mainly developed between 308 and 250 ka (Marra et al., 2003) and is made up of far lower volumes of material (not exceeding about 6 km^3) (De Rita et al., 1992).

- The last period of activity, starting at about 200 ka (Marra et al., 2003), is known as the Final Hydromagmatic Phase (De

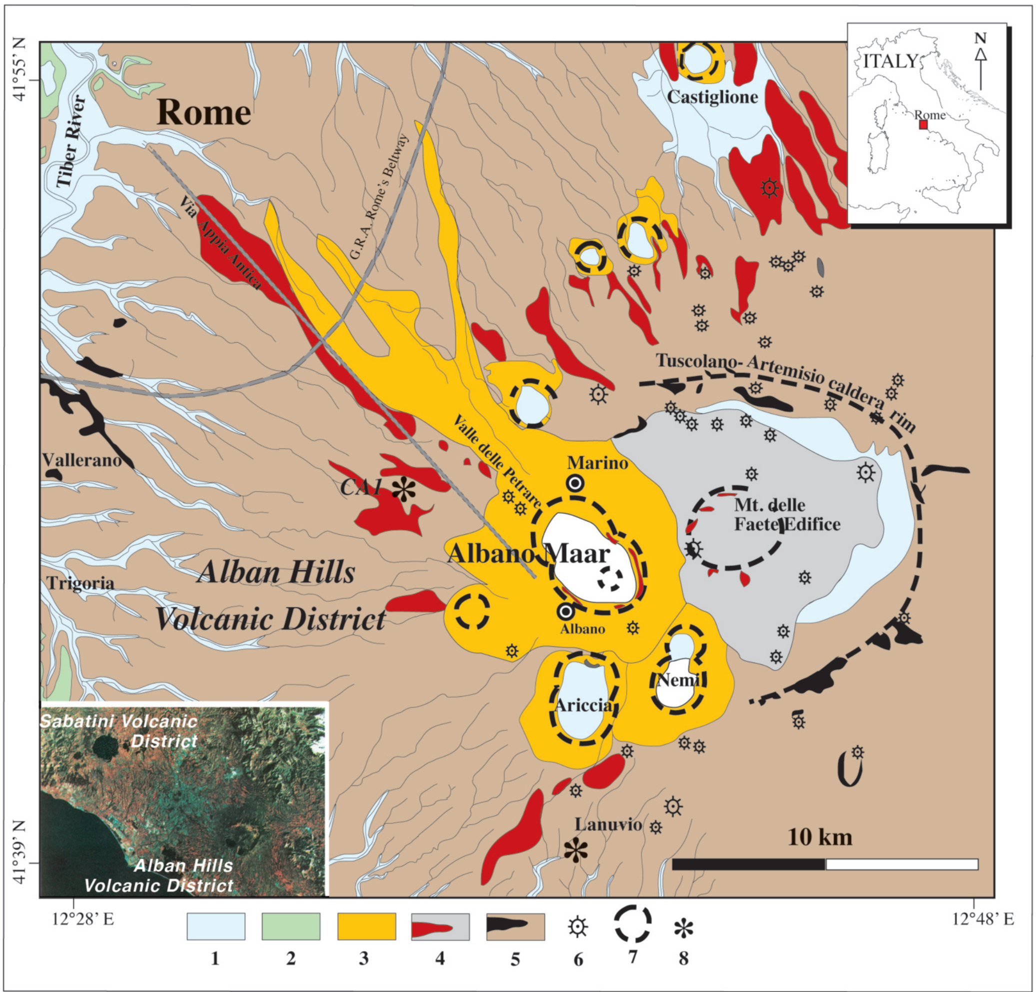

Fig. 1 - Location of Lanuvio borehole and geological sketch of Alban Hills volcano (modified after Freda et al., 2006). 1) Holocene alluvial deposits; 2) Plio-Quaternary sedimentary deposits; 3) Hydromagmatic deposits (200-36 Ka); 4) Pyroclastic deposits of the Monte delle Faete Phase and associated lava flows (red) (250-308 Ka); 5) Tuscolano-Artemisio phase pyroclastic flow with air flow deposits and associated lava flows (black) (350-600 Ka); 6) Scoria cone; 7) Caldera and crater rim; 8) Borehole locations (Lanuvio and CA1). Also shown: satellite image of Monti Sabatini Volcanic District and Alban Hills Volcanic District (respectively, north and south of Rome).

Rita et al., 1988) and called the Via dei Laghi Lithosome (Giordano et al., 2006). It is characterized by extensive phreatomagmatic activity from several maars, mostly located in the western sector of the former caldera (the best-known, in order of age, are Ariccia, Nemi, and Albano) (Fig. 1). Phreatomagmatism resulted from the interaction between magma and the many aquifers present in the highly permeable Mesozoic-Cenozoic substrate (Funiciello and Parotto, 1978; De Rita et al., 1988). The volumes of material emplaced are very small, about 1 km^3 (De Rita et al., 1992). The Albano multiple maar was the site of the most recent activity of the whole Alban Hills Volcanic District. Ages for the Albano maar products range between 45 ka (Villa et al., 1999) and 6 ka (Funiciello et al., 2003) or, according to more recent studies (Freda et al., 2006), between 69 and 36 ka.

STUDY AREA

Samples were collected from a borehole drilled near Lanuvio (Fig. 1) at a depth of between 85 and 120 m. The pyroclastic products exposed in this area are mapped as the Tuscolano-Artemisio peri-caldera fissure system (Giordano et al., 2010) and referred to the final explosive activity of the T-A phase. The lower products, called the first Tuscolano-Artemisio pyroclastic flow unit by De Rita et al. (1988) outcrop on the periphery of the Alban Hills and correspond to the Tufi pisolitici of Fornaseri et al. (1963) (Fig. 2). The flow consists at least of two eruptive units with accretionary lapilli, separated by a paleosoil, the units called Tufo pisolitico di Trigoria and Tufo del Palatino (Karner et al., 2001). The older Tufo pisolitico di Trigoria event, with a $^{40}Ar/^{39}Ar$ age, goes back to 561 ± 1 ka (Karner et al., 2001) and has been interpreted as a predominantly hydromagmatic eruption. Distinctive features are the abundance of accretionary lapilli, high degree of fragmentation, and the common occurrence of vegetation casts, whereas carbonate lithic clasts from deep rocks are quite rare (Palladino et al., 2001). A paleosoil separates the Tufo pisolitico di Trigoria flow from the overlying Tufo del Palatino unit, a dark gray lithified pyroclastic flow, dated to 520 ± 8 ka (Karner and Renner, 1998) and 528 ± 1 ka (Karner et al., 2001). A 10-15 cm-thick ash deposit containing several fossil trees, interpreted as a surge level, occurs between the main ignimbritic portion of the unit and the basal lapilli-rich fall deposit. This level outcrops in both the north-eastern sector (Bagni Albule, about 5 km north of Castiglione) and the western sector (Trigoria) (Fig. 1) (Kerner et al., 2001). The Tufo del Palatino reaches its greatest thickness in the Tiber

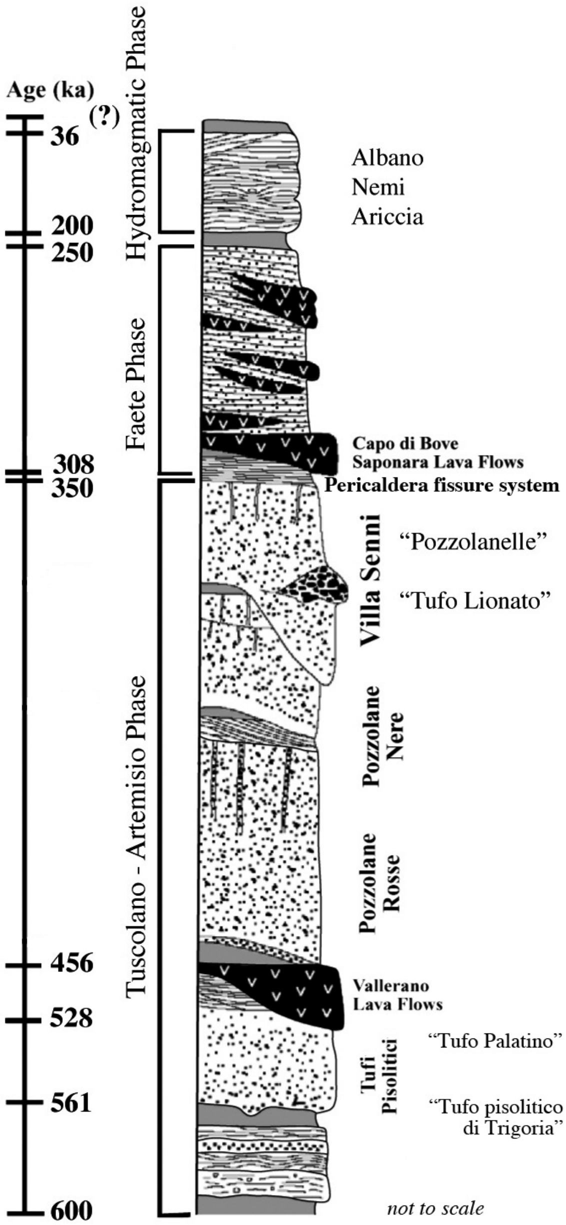

Fig. 2 - Schematic stratigraphy of Alban Hills volcano (modified after Watkins et al., 2002).

Valley and in central Rome; it thins to the north-east and south, except at Trigoria, where its thickness increases to 2 m. Karner et al. (2001) suggested a pyroclastic surge origin for these southern outcrops.

In the distal sectors of the volcano, particularly to the west, but also further north and south, several lava flow outcrops occur, probably representing a large extrusive event connected with regional extensional tectonics (De Rita et al., 1995). One lava outcrop has been studied south of Rome, near Vallerano (Fig.1). It consists of fine-grained microcrystalline lava (leucitite nefelinica in Fornaseri et al., 1963) about 20 m thick. Its $^{40}Ar/^{39}Ar$ age is 460 ± 4 ka according to Karner and Renne (1998) and 452 ± 4 ka according to Karner et al. (2001).

The second Tuscolano-Artemisio pyroclastic flow unit of De Rita et al. (1988) consists of one of the most important ignimbrites, in terms of volume and extent, the Pozzolane Rosse of Fornaseri et al. (1963) (Fig. 2). This loose, massive unit has a typically reddish matrix with abundant red and gray scoria, and sedimentary and lava clasts. It has an average thickness of 10-30 m without discontinuities (De Rita et al., 1988). The overlying Conglomerato giallo is a mixture of reworked and primary pyroclastic fall, surge and flow horizons of variable thickness (Karner et al., 2001).

The third Tuscolano-Artemisio pyroclastic flow unit of De Rita et al. (1988) includes the Pozzolane Nere of Fornaseri et al. (1963) (Fig. 2). The latter is a scoriaceous pyroclastic flow, with lithological characteristics very similar to those of the underlying Pozzolane Rosse. It outcrops mostly on the north-eastern sectors of the Alban Hills, where it reaches its greatest thickness.

The fourth Tuscolano-Artemisio pyroclastic flow unit of De Rita et al. (1988) is mostly represented by the Villa Senni Eruption Unit (Watkins et al., 2002) (Fig. 2). This unit comprises two major pyroclastic flow units, known from the base to the top as Tufo Lionato and Pozzolanelle (Fornaseri et al., 1963). The Tufo Lionato, typically orange in color, is a lithified pyroclastic deposit interpreted as an ignimbrite. It grades upward into the Pozzolanelle, which is a loose, massive, scoriaceous ash flow deposit, dark gray to red in color, with fresh leucite crystals. A relatively hot state of emplacement is inferred for both units by the presence of scoria spatter clasts (De Rita et al., 1995; Watkins et al., 2002). The $^{40}Ar/^{39}Ar$ age of the Tufo Lionato is 355 ± 2 ka (Karner and Renne, 1998) and that of the Pozzolanelle 357 ± 2 ka (Karner et al., 2001).

The hydromagmatic phase units crop out about 2 km north of the study area, and consist of phreatomagmatic products from several monogenic or polygenic maars (Giordano et al., 2006). The older products, most of which derive from the Ariccia maar, are dated to about 200 ka (Marra et al., 2003). The most recent products have been related to the Albano maar and range in age between 45 ka (Villa et al., 1999) and 6 ka for the Tavolato succession (Funiciello et al., 2003) or, according to more recent data, between 69 and 36 ka (Freda et al., 2006).

ANALYSES

The borehole, drilled during the 1960s at Piastrarelle, a few km south-west of Lanuvio, is 156 m deep (see Fig. 1 for location); GPS coordinates are 41°40'01,5"N and 12°39'43,6"E, altitude about 170 m a.s.l. Although the borehole was drilled with continuous cores and many samples were obtained, only a block of lava flow and one sample of the pyroclastic flow embedding unburnt wood remains were recovered. Borehole stratigraphy was reconstructed (Fig. 3) according to the original description of the well and information from the owner of the surrounding farmland. The first 20 m contain strongly tilled and pedogenized material, mainly deriving from pyroclastic deposits. The underlying 65 m consist of loose multicolored pyroclastic units enclosing an ash-matrix supported layer, highly cemented.

The next about 20 m-thick layer (from 85 to 108 m in depth) is composed of a k-foiditic dark gray lava flow (Fig. 4). The lava sample is exhibited in the Museum of Geology of the SAPIENZA Università di Roma. When observed under a polarizing microscope (Fig. 4b), the lava shows holocrystalline, low-porphyritic (1-2%) texture, with rare idiomorphic crystals of clinopyroxene and leucite dispersed in a groundmass of leucite and clinopyroxene, with

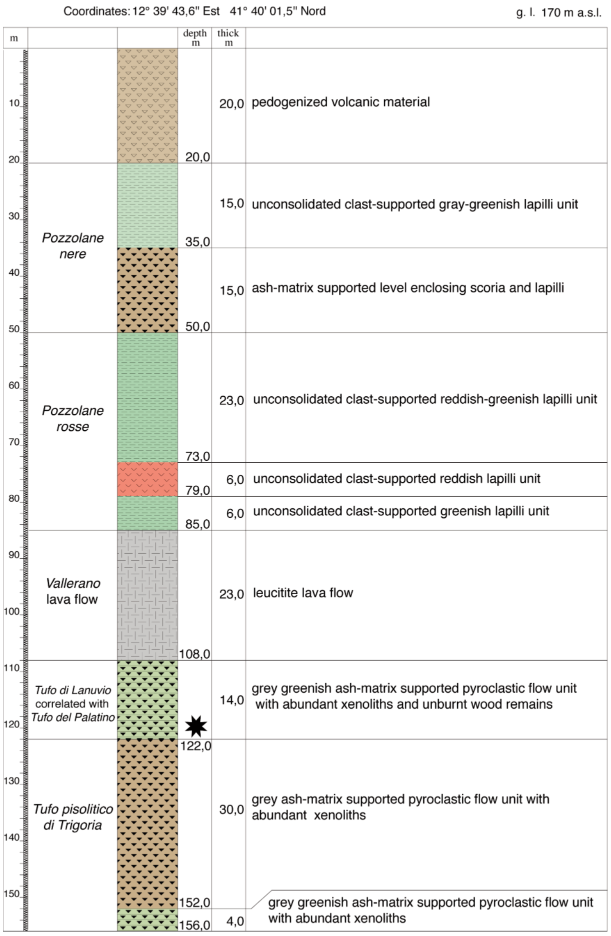

Fig. 3 - Schematic borehole stratigraphy. On the left side it is listed the name of volcanic formations, according to our interpretation. Asterisk: wood remains (at depth of 120 m).

subordinate iron oxides, interstitial phlogopite and occasional nepheline. Inside cavities and fractures are abundant idiomorphic crystals, which compositional and diffractometric analyses clearly identified as nepheline (Fig. 5a, b). $^{40}Ar/^{39}Ar$ dating on lava samples yielded an age of 485 ± 1 ka (analyses revealed plateau ages averaging 484 ka, with a standard deviation of ± 2 ka) (Fig. 5c).

The underlying 14 m consist of a dark gray, strongly cemented, ash-supported pyroclastic flow unit, embedding unburnt, well-preserved wood remains (Fig. 6). This layer is characterized by accretionary lapilli and abundant lava xenoliths (leucitite), as well as sedimentary xenoliths (limestone) scattered in the ash matrix. Among the latter, fragments of the Jurassic Calcare Massiccio Formation, deriving from the Mesozoic substrate, were identified. Thin sections of the pyroclastic flow are preserved in our Department of Earth Sciences, SAPIENZA Università di Roma.

The lowest 34 m of the borehole contain a greenish-gray ash-matrix supported pyroclastic flow unit with abundant xenoliths.

The wood remains (Fig. 6) were analysed and classified as Acer. The modern species of Acer living throughout Latium are typical components of mixed mountain and submontane forests. The wood remains are preserved as thin sections at the Department of Vegetal Biology, SAPIENZA Università di Roma.

In the following, the pyroclastic unit embedding these wood remains is informally called Tufo di Lanuvio.

a)

b)

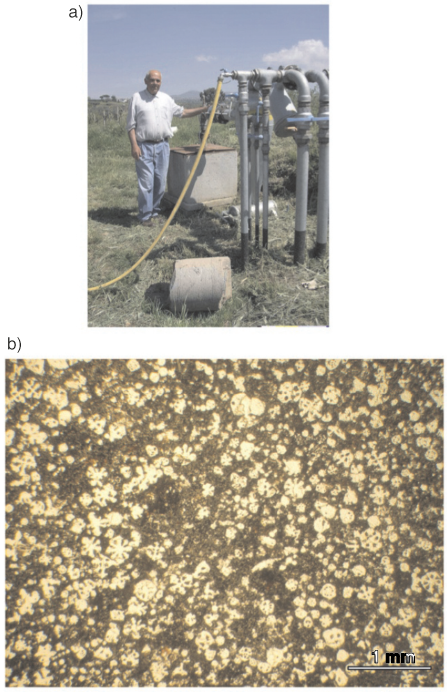

Fig. 4 - a) Present-day appearance of borehole: single lava core recovered, visible at feet of farm owner; b) photomicrograph of lava flow, with star-shaped leucite in groundmass (plane polarized light, bar for scale).

DISCUSSION

Based exclusively on outcrop data shown on the geological map of the Alban Hills (De Rita et al., 1988; Giordano et al., 2010) and on other recent regional sketches (Funiciello et al., 2003; Marra et al., 2003), the Tufo di Lanuvio studied here is probably part of the T-A phase. In detail, the - lower 50 m of the pyroclastic sequence of the Lanuvio borehole, from the bottom up as far as the lava flow which has been dated at 485 ± 1 ka, are interpreted as correlated with the early T-A eruptive phase, in particular with the two eruption cycles known as Tufo pisolitico di Trigoria and Tufo del Palatino (561 ± 1 Ka and 528 ± 1 ka respectively) (Karner et al., 2001). The lowest approximately 30 m of the borehole are consistent with the Tufo pisolitico di Trigoria and the overlying 14-m thick Tufo di Lanuvio with the Tufo del Palatino. In particular, the presence of accretionary lapilli, abundant ash content and fossil wood suggest similarities with the surge level at the base of the main ignimbrite portion of the Tufo del Palatino.

Some differences appear in the thicknesses of the Tufo pisolitico di Trigoria and Tufo del Palatino reported by Karner et al. (2001) and Marra et al. (2009), which are 6-10 m and 6-4 m thick, respectively. The greater thickness recovered from the Lanuvio core, with respect to that in the north-west sector (near Trigoria), may be the result of deposition in a local paleovalley. As suggested by Giordano et al. (2002), some topographically related pyroclastic flow transformations may induce facies changes and high deposition rates even in relatively cold ignimbrites. In any case, our findings show similarities, in terms of both thickness and characters, with data from the 350-m CA1 borehole (Fig. 1) described by Mariucci et al. (2008). Lastly, we propose that a paleovalley may have acted as a sedimentary trap, forcing the pyroclastic flow southward and

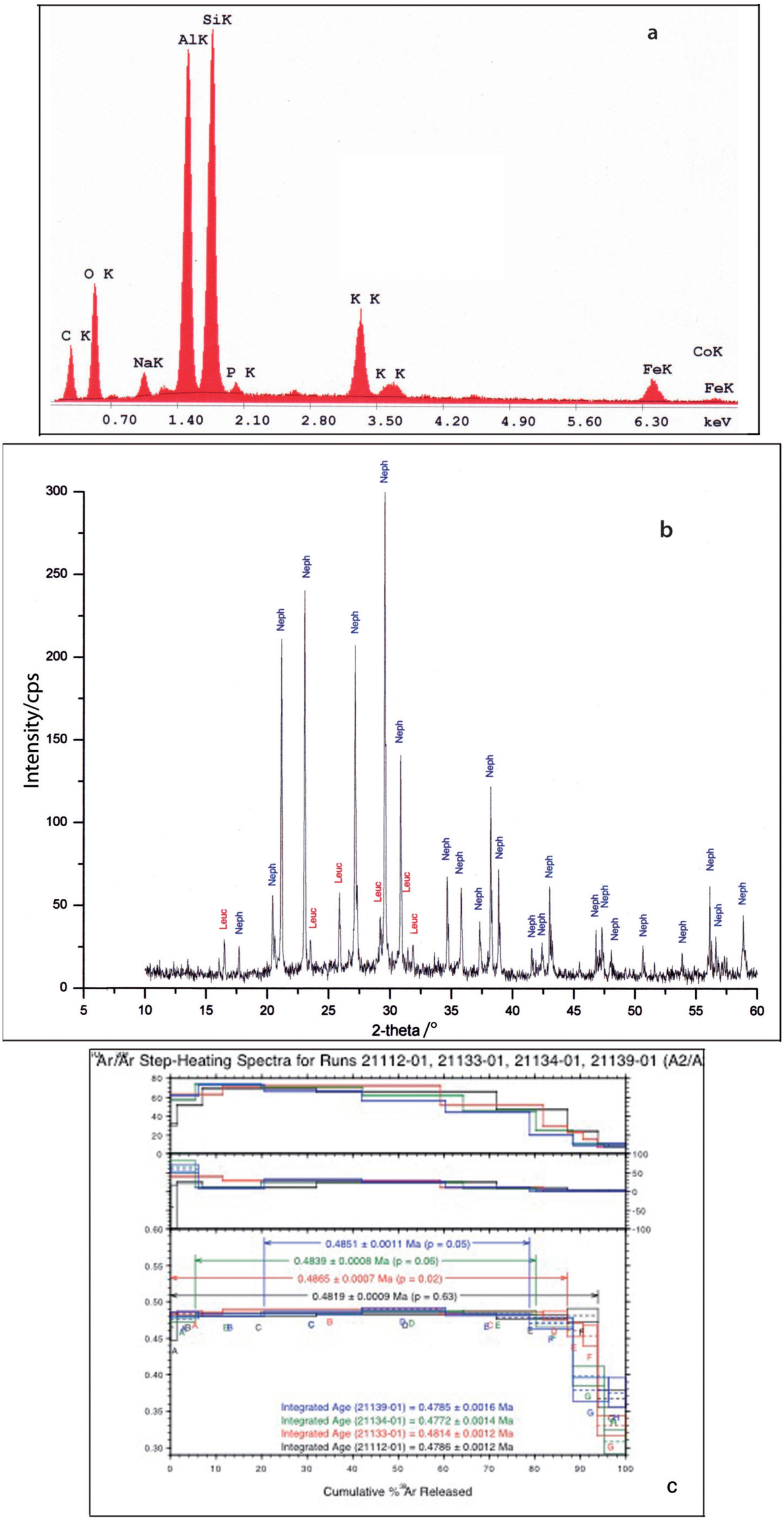

Fig. 5 - a) EDS spectrum and b) powder X-ray diffraction analyses of abundant nepheline crystals inside lava fractures. c) $^{40}Ar/^{39}Ar$ analyses on lava samples (all the 4-splits ran produced plateau ages averaging 484 ka with a standard deviation of ± 2 ka).

Fig. 6 - Photo of wood remains embedded in Tufo di Lanuvio (classified in thin section as Acer).

promoting higher rates of deposition.

Accordingly, the overlying lava flow would be correlated with the Vallerano lava flow (Fig. 3), defined as nepheline leucititic lava by Fornaseri et al. (1963). The $^{40}Ar/^{39}Ar$ age of our sample (485 ± 1 ka) fits the ages of the Tufo del Palatino and the Vallerano lava flows, i.e., 528 ± 1 and 456 ± 3 ka, respectively (Karner et al., 2001) (Fig. 2). Marra (1999) interpreted the various lava flows outcropping south of Rome as the result of one single event with a mean age of 456 ± 3 ka (Karner et al., 2001). The ages of our samples indicate that the extrusive event closing the first T-A phase, connected by De Rita et al. (1995) with regional extensional tectonics, may have been more widely distributed and more prolonged than hitherto believed.

The overlying 85 m-thick pyroclastic deposits are mostly loose and, in the topmost part, strongly pedogenized (Fig. 3). Based on textural features and total thickness, these units have been related to the Pozzolane Rosse and subsequent Pozzolane Nere of Fornaseri et al. (1963) and partially to the Villa Senni eruptive unit (Watkins et al., 2002).

By comparing our results with previously published data, we also make a contribution to reconstructing relationships between climate, isotope stage and arboreal fluctuations.

The common occurrence of vegetation casts, tree molds and wood remains are reported in some pyroclastic units of the early phases, from both the Alban Hills Volcanic District and the Monti Sabatini Volcanic District (see Fig. 1 for location). Follieri and Magri (1961) and Follieri (2010) described leaves and trees from the Tufo Giallo della Via Tiberina of the Monti Sabatini volcano (Fraxinus and Quercus, and several conifer taxa). Karner et al. (2001) reported the occurrence of tree molds up to a few decimeters in diameter, with incipiently carbonized wood, from the Tufo pisolitico di Trigoria. Marra and Rosa (1995) described numerous tree molds in the Tufo del Palatino.

The Tufo di Lanuvio studied here, which we correlate with the Tufo del Palatino, exhibits well-preserved wood remains of Acer. As suggested by Karner et al. (2001), the stratigraphic position (560-540 ka) of the Tufo Giallo della via Tiberina outcropping north of Rome (Monti Sabatini Volcanic District) is consistent with the time interval of the Tufo Pisolitico di Trigoria of the Alban Hills Volcanic District. As a consequence, the more frequent occurrence of wood remains appears to be concentrated between the Tufo Pisolitico di Trigoria and the Tufo del Palatino and then in a time interval between approximately 561 and 520-528 ka, corresponding to marine isotope stages 13-15 according to Bassinot et al. (1994) (Fig. 7).

The macrofossil flora studied by Follieri (2010) show that

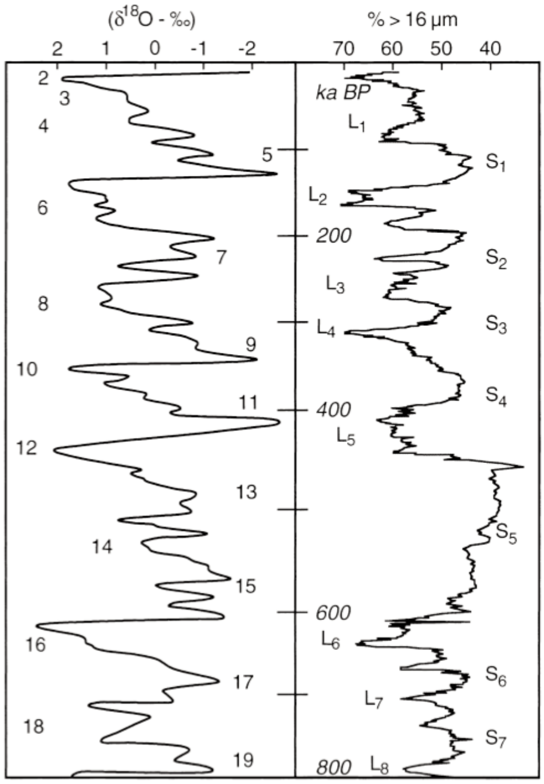

Fig. 7 - Comparison between marine oxygen isotope record (according to Bassinot et al., 1994) and paleosoil development in Chinese Loess Plateau (modified after Vandenberghe, 2000).

the Tufo Giallo della via Tiberina contains taxa coexisting nowadays in pluvial areas in China and Japan, swampy areas in North America, and temperate zones in Europe. In addition, there are leaves from trees typical of the rainy Colchic region, together with species still living in Latium.

The wood remains from the drilled Tufo di Lanuvio have been identified as Acer. Modern Acer species living throughout Latium are typical components of mixed mountain and sub-montane forest. Although no long pollen biostratigraphies for the last 600 ka are available for central Italy, in southern Italy interesting data come from the continuous pollen record of a Middle Pleistocene lacustrine sequence drilled in the Vallo di Diano (southern Campania) (Russo Ermolli and Cheddadi, 1997). According to a quantitative pollen study, the above authors propose a climatic reconstruction for the time interval corresponding to glacial stage 16 to interglacial isotope stage 13. As regards the time interval of our interest, i.e., interglacial stages 13-15, the Vallo di Diano pollen record indicates that the isotopic stage 13 was characterized by both high precipitation and temperature, and was accompanied by forest expansion (mostly deciduous oak, with Abies and Picea). In addition, interglacial 13 has been interpreted as warmer and more humid than interglacial 15.

According to data from loess in northern China and paleosoils in southern China, Yin and Guo (2008) report an unusually warm, wet climate during marine isotope stage 13, suggesting the influence of extremely strong summer monsoons. In particular, the loess record from the Chinese Loess Plateau region shows a pronounced soil complex (S5) (Fig. 7), corresponding to interglacial periods which are well correlated with the "warm" interval of marine isotope stages

13-15 (Vandenberghe, 2000). The reported long, intense period of S5 soil formation, characterized by a double peak, shows strong similarities with the Oxygen Isotope Curve, exhibiting an interval with well-expressed interglacial stages 13 and 15, separated by a modest, weakly expressed cooling phase (stage 14).

The pollen succession from Ferdinandow in Poland (Krzyszkowsky, 1992) shows two climatic optima, constituting the Ferdinandowian interglacial, with deciduous forest separated by an interval with taiga. This interglacial interval shows almost identical characteristics with the soil complex (S5) with a double peak interrupted by modest cooling. In the eastern Mediterranean, a thick sapropel, dated at 528-525 ka by astronomical tuning, indicates unusually heavy monsoon rainfall (Rossignol-Strick et al., 1998). The pollen record from this sapropel is interpreted as being mainly controlled by moisture availability.

Although at present the available data support just a suggestion, it is worth emphasizing the consistency between many data from different regions at different elevations, from China to Europe to the eastern Mediterranean. Most of the available data indicate that the Middle Pleistocene was an anomalously long period with "warm", humid conditions, interrupted by a modest cooling phase. We suggest that the frequent occurrence of tree remains inside the pyroclastic products of the early phases of the Monti Sabatini and Alban Hills Volcano Districts testifies this unusual warm and humid period. Although, clearly, the good preservation of wood remains is strongly dependent on emplacement conditions and temperature, we suggest that the pyroclastic products of the Lazio region, with their embedded wood remains, represent an important "archive" of arboreal fluctuations, to an even greater extent than the pollen record, which may suffer from the effects of long-distance transport. We would certainly like to emphasize the possible paleoclimatic significance of wood remains and their potential for use in the future.

CONCLUSIVE REMARKS

Substantial urbanization and agriculture in the fertile Alban Hills very often conceals the lithology, features and structures of the outcropping pyroclastic units. This is why reports from a 160-m borehole represent a good opportunity to improve our knowledge of the eruptive history of the Alban Hills. The present study provides new data to better define the time interval and areal distribution of the early stages of the T-A eruptive phase.

A pyroclastic unit having a lithofacies very similar to the Tufo del Palatino underlying a leucitite lava flow, was recovered from a depth of 108 m, about 9 km south of the Lake of Albano. $^{40}Ar/^{39}Ar$ analyses from some lava samples yielded ages of 485 ± 1 ka.

The occurrence of an approximately 14-m thick pyroclastic unit correlated with the Tufo del Palatino, in terms of both age and characters, allowed us to assess the areal distribution and thickness of the early products of the T-A phase. In particular, the greater thickness of the recovered unit, with respect to that currently known, is interpreted here as related to a morphological trap, forcing the pyroclastic flow southward and promoting higher rates of deposition. This interpretation is also consistent with data from the 350-m borehole described by Mariucci et al. (2008), located approximately 14 km northwest of the study area.

The age of the leucitite lava flow - 485 ± 1 ka - which we correlate with the Vallerano lava flow, indicates that the extrusive event closing the first T-A phase, connected with regional extensional tectonics, may be more widely distributed and more prolonged than previously thought.

Lastly, the finding of well-preserved wood remains in the pyroclastic unit, in addition to previously reported findings from both the Monti Sabatini and Alban Hills Volcano Districts, indicates arboreal expansion over a time interval between approximately 561 and 528 ka, favored by the anomalously long period with "warm", humid conditions during marine isotope stages 13-15.

ACKNOWLEDGEMENTS - The authors are particularly grateful to G. Mariotti for constructive discussions, comments and suggestions and to an anonymous referee for criticism and suggestions. Many thanks also go to Laura Sadori and A.M. Conte for botanical and petrographical analyses, respectively. Brent Turrin, at the Wright-Rieman Laboratories, Rutgers State University of New Jersey, is thanked for $^{40}Ar/^{39}Ar$ analyses. Particular thanks go to Giampiero Gibellini for borehole stratigraphy and lava and "tufo" samples, and to A. Mancini and S. Stellino for EDAS and X-ray analyses.

This research was supported by AST funds from the SAPIENZA Università di Roma and is part of the activities of its Museum of Geology.

REFERENCES

Bassinot F., Labeyrie L., Vincent E., Quidelleur X., Shackleton N., Lancelot Y. 1994. The astronomical theory of climate and the age of the Brunhes Matuyama magnetic reversal. Earth and Planetary Science Letters: 126, 91-108.

Beccaluva L., Bianchini G., Siena F. 2004. Tertiary-Quaternary volcanism and tectono-magmatic evolution in Italy. Special Volume of the Italian Geological Society for IGCP, 32, Florence.

Conticelli S., D'Antonio M., Pinarelli L., Civetta L. 2002. Source contamination and mantle heterogeneity in the genesis of Italian potassic and ultrapotassic volcanic rocks: Sr-Rb-Pb isotope data. Mineralogy and Petrology: 74, 189-222.

De Rita D., Funiciello R., Parotto M. 1988. Geological Map of the Alban Hills Volcanic Complex. CNR, Rome.

De Rita D., Funiciello R., Rosa C. 1992. Volcanic activity and drainage network evolution of the Colli Albani area (Rome, Italy). Acta Vulcanologica: 2, 185-198.

De Rita D., Faccenna C., Funiciello R., Rosa C. 1995. Stratigraphy and volcano-tectonics. In: Trigila R. (Ed.), The Volcano of the Alban Hills. Tipografia SOS, Rome, 33-71.

Follieri M. 2010. Conifer extinction in Quaternary Italian records. Quaternary International: 225, 37-43.

Follieri M., Magri D. 1961. I legni fossili della Via Flaminia (Cava Bianca) presso Roma. Annali di Botanica (Roma): 27, 152-168.

Fornaseri M., Scherillo A., Ventriglia U. 1963. La regione vulcanica dei Colli Albani. Vulcano Laziale, CNR Rome, 561 pp.

Freda C., Gaeta M., Karner D.B., Marra F., Renne P.R., Taddeucci J., Scarlato P., Christensen J.N., Dallai L. 2006. Eruptive history and petrologic evolution of the Albano multiple maar (Alban Hills, Central Italy). Bulletin of Volcanology: 68, 567-591.

Funiciello R., Parotto M. 1978. Il substrato sedimentario nell'area dei Colli Albani: considerazioni geodinamiche e paleogeografiche sul margine tirrenico dell'Appennino centrale. Geologica Romana: 17, 233-287.

Funiciello R., Giordano G., De Rita D. 2003. The Albano maar lake (Colli Albani Volcano, Italy): recent volcanic activity evidence of pre-Roman Age catastrophic lahar events. Journal of Volcanology and Geothermal Research: 123, 43-61.

Giaccio B., Sposato A., Gaeta M., Marra F., Palladino D.M., Taddeucci J., Barbieri M., Messina P., Rolfo M.F. 2007. Mid-distal occurrences of the Albano Maar pyroclastic deposits and their relevance for reassessing the eruptive scenarios of the most recent activity at the Colli Albani Volcanic District, Central Italy. Quaternary International: 171-172, 160-178.

Giordano G., De Rita D., Cas R., Rodani S. 2002. Valley pond and ignimbrite veneer deposits in the small-volume phreatomagmatic 'Peperino Albano' basic ignimbrite, Lago Albano maar, Colli Albani volcano, Italy: Influence of topography. Journal of Volcanology and Geothermal Research: 118, 131-144.

Giordano G., De Benedetti A.A., Diana A., Diano G., Gaudioso F., Marasco F., Miceli M., Mollo S., Cas R.A.F., Funiciello R. 2006. The Colli Albani mafic caldera (Rome Italy): stratigraphy, structure and petrology. Journal of Volcanology and Geothermal Research: 155, 49-80.

Giordano G., Mattei M., Funiciello R. 2010. Geological map of the Colli Albani Volcano. The Geological Society, London. Spec. Publ. IAVCEI: 3, insert.

Karner D.B., Marra F., Renne P. 2001. The history of the Monti Sabatini and Alban Hills volcanoes: groundwater for assessing volcano-tectonic hazards for Rome. Journal of Volcanology and Geothermal Research: 107, 185-219.

Karner D.B., Renne P. 1998. $^{40}Ar/^{39}Ar$ geochronology of Roman volcanic province Tephra in the Tiber River Valley: age calibration of Middle Pleistocene sea-level changes. Geological Society of American Bulletin: 110, 740-747.

Krzyszkowski D. 1992. The polyinterglacial Czyzow Formation in the Kleszczow Graben (central Poland). Folia Quaternaria: 61-62, 257 pp.

Mariucci M.T., Pierdominici S., Pizzino L., Marra F., Montone P. 2008. Looking into a volcanic area: an overview on the 350 m scientific drilling at Colli Albani (Rome, Italy). Journal of Volcanology and Geothermal Research: 176, 225-240.

Marra F. 1999. Low-magnitude earthquakes in Rome: structural interpretation and implication for local stress-fields. Geophysical Journal International: 138, 231-243.

Marra R., Rosa C. 1995. Stratigrafia e assetto geologico dell'area romana. Memorie descrittive della Carta Geologica d'Italia. Vol L. La Geologia di Roma. Istituto Poligrafico e Zecca dello Stato.

Marra F., Freda C., Scarlato P., Taddeucci J., Karner D.B., Renne P.R., Gaeta M., Palladino D.M., Trigila R., Cavarretta G. 2003. Post-caldera activity in the Alban hills volcanic district (Italy) $^{40}Ar/^{39}Ar$ geochronology and insights into magma evolution. Bulletin of Volcanology: 65, 227-247.

Marra F., Karner D.B., Freda C., Gaeta M., Renne P.R. 2009. Large mafic eruptions at Alban Hills Volcanic District (central Italy): chronostratigraphy, petrography and eruptive behavior. Journal of Volcanology and Geothermal Research: 179, 217-232.

Palladino D.M., Gaeta M., Marra F. 2001. A large k-foiditic hydromagmatic eruption from the early activity of the Alban Hills volcanic district, Italy. Bulletin of Volcanology: 63, 345-359.

Peccerillo A. 2003. Plio-Quaternary magmatism in Italy. Episodes: 26(3), 222-226.

Rossignol-Strick M., Paterne M., Bassinot F.C., Emels K.C., De Lange G.J. 1998. An unusual mid-Pleistocene monsoon period over Africa and Asia. Nature: 392, 269-272.

Russo Ermolli E., Cheddadi R. (1997) - Climatic reconstruction during the Middle Pleistocene: a pollen record from Vallo di Diano (Southern Italy). Geobios: 30 (6), 735-744.

Vandenberghe J. 2000. A global perspective of the European chrostratigraphy for the past 650 ka. Quaternary Science Reviews: 19, 1701-1707.

Villa I.M., Calanchi N., Dinelli E., Lucchini F. 1999. Age and evolution of the Albano crater lake (Roman Magmatic Province). Acta Vulcanolologica: 11, 305-310.

Voltaggio M., Barbieri M. 1995. Geochronology. In: Trigila R. (Ed.), The Volcano of the Alban Hills. Tipografia SOS, Rome, 167-193.

Watkins S.D., Giordano G., Cas R.A.F., De Rita D. 2002. Emplacement processes of the mafic Villa Senni Eruption Unit (VSEU) ignimbrite succession, Colli Albani volcano, Italy. Journal of Volcanology and Geothermal Research: 118, 173-203.

Yin Q.Z., Guo Z.T. 2008. Strong summer monsoon during the cool MIS-13. Climate of the Past: 4, 29-34.