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Evolution of the Sabatinian Volcanic District (central Italy) as inferred by stratigraphic successions of its northern sector and geochronological data

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ABSTRACT. — The Sabatinian Volcanic District (central Italy) consists of a system of several vents clustered around the lake-filled Bracciano volcano-tectonic depression. Its activity spans between 0.8 My and 0.04 My and overlaps that of the neighbouring Vico and Alban Hills Volcanoes in time and space. A field survey of the northern sector together with new geochronological and geochemical data allows us to reconstruct the stratigraphy and volcanic evolution of the Sabatinian Volcanic District. Six main phases of activity have been recognised on the basis of geological data, following the UBSU criteria. The presence of three unconformities of regional significance also enables us to distinguish three different synthems, representing the main stages in the volcanic evolution of the Sabatinian District. The initial phases of activity (from I to IV) are within the *Barca di Parma Synthem* (800-200 ky) and are dominated by pyroclastic fall and flow deposits and subordinate phonolitic tephritic lava flows. The phase V is related to the *Archi di Pontecchio Synthem* (200-155 ky) and characterised by prevailing strombolian deposits with a composition ranging from phonolitic tephrite to tephrite. During the phase VI (*Casalone Synthem*) both magmatic and phreatomagmatic eruptive cycles occurred in the northern sector. The magmatic cycle (154-134 ky) is dominated by pyroclastic fall and lava flows with a variable composition from phonolitic tephrite to potassic trachibasalt. The phreatomagmatic cycle marked the end of the volcanic activity (<134 ky) in the northern sector of the Sabatinian District and produced small, single eruptive centres (maars) or coalescent craters which are aligned in a NW-SE regional fracture system at a right angle to the tectonic orientation of the initial Sabatinian Volcanic activity. This fracture system could be connected to the main regional tectonic line that crosses the Vico Volcano and the eastern Sabatinian District.

RIASSUNTO. — Il Distretto Vulcanico Sabatino (Italia Centrale) è caratterizzato dalla presenza di numerosi centri eruttivi distribuiti attorno alla depressione vulcano-tettonica del Lago di Bracciano. La sua attività è compresa tra 0,8 e 0,04 Ma e si sovrappone, nel tempo e nello spazio, con quella degli adiacenti apparati vulcanici di Vico e dei Colli Albani. Un dettagliato rilevamento geologico del settore settentrionale, integrato con dati di carattere geocronologico e geochimico, ha permesso di ricostruire la stratigrafia e l'evoluzione vulcanologica del Distretto Sabatino. Sulla base dei dati di terreno ed in accordo con i criteri relativi all'utilizzo delle UBSU in ambiente vulcanico, nell'area studiata sono state riconosciute sei principali fasi di attività. La presenza di tre superfici di discontinuità a scala regionale ha inoltre permesso di distinguere tre diversi sintemi, che rappresentano

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tre stadi ben definiti nell'ambito dell'evoluzione vulcanologica del Distretto Sabatino. Le fasi iniziali di attività (fasi I, II, III e IV) sono riferibili al *Sintema Barca di Parma* (800-200 ka) e sono caratterizzate da depositi di caduta e di flusso piroclastico associati a colate di lava a composizione tefritico-fonolitica. La fase V si inquadra nel *Sintema Archi di Pontecchio* (200-155 ka) ed è caratterizzata da prevalenti depositi da attività stromboliana, con composizioni che variano da tefritico-fonolitiche a tefritiche. Durante la fase VI (*Sintema Casalone*) l'attività vulcanica, inizialmente di tipo magmatico, diventa prevalentemente freatomagmatica nel ciclo finale. Il ciclo magmatico iniziale (154-134 ka) di questa sesta fase è caratterizzato da depositi di caduta di tipo stromboliano e da colate laviche con composizioni variabili da tefritico-fonolitiche a trachibasaltiche. Il ciclo freatomagmatico finale, invece, conclude l'attività del settore settentrionale del Distretto Sabatino (<134 ka) e dà origine, nella parte orientale dell'area studiata, a centri eruttivi isolati (maars) o a crateri coalescenti. Questi apparati finali sono allineati lungo un sistema di fratture orientato NO-SE che è ortogonale alle direzioni tettoniche che hanno guidato le prime fasi dell'attività del Distretto Sabatino. Tale sistema NO-SE potrebbe essere legato ad una lineazione tettonica di importanza regionale che si osserva nel Vulcano di Vico e nel settore orientale del Distretto Sabatino.

KEY WORDS: *Sabatinian Volcanic District, volcanic stratigraphy, geochronology, alkaline ultrapotassic volcanism.*

INTRODUCTION

The Sabatinian Volcanic District is one of the most complex volcanic areas in Central Italy. The lack of a well-formed central edifice and the development of volcanic activity through several vents distributed over a large area make the reconstruction of its volcanic history difficult. In order to overcome this difficulty and gain a more complete understanding of the magmatological evolution in such a complex volcanic system, it is helpful to establish a complete volcanic stratigraphy with a detailed temporal and spatial framework. This can be achieved with greater precision using a radiometric dating tool. Moreover, identifying the areal distribution of the deposits and the chronology of the eruptive events is crucial to understanding a quiescent volcanic area like the Sabatinian District.

Although the general evolution and petrology of the Sabatinian District are quite well-known, detailed knowledge of its stratigraphy and the relationships among its volcanic products is still far from complete. This is particularly true of the northern sector of the District, where the stratigraphy is further complicated by the fact that the volcanic activity related to the different centres was frequently simultaneous and their deposits often overlap in the field. The northern Sabatinian sector is the focus of this study because of the lack of data regarding the relative and absolute stratigraphy of its outcropping volcanics. The peculiar interfingering between Vico and Sabatinian volcanic products in the northern Sabatinian District also makes this area a key sector to clarify the temporal and stratigraphic relationships between the activities of these two complexes and to improve the knowledge of the volcanic history of this part of the northern Latium.

Mattias and Ventriglia (1970) were the first authors to make stratigraphic study of the Sabatinian Volcanic District gaining important insights into the volcanological evolution of this area and drawing a geological map of the «Monti Cimini e Sabatini» with a scale of 1:100,000 (Mattias, 1968). An extensive and detailed revision of the whole geology of the Sabatinian volcanic area was subsequently made by the Italian Geological Survey, which published a geological map with a scale of 1:100,000 (AA.VV., 1971) with explanatory notes (Bertini *et al*., 1971). There have been attempts to investigate the stratigraphic correlation between different volcanic centres and the relationships of their products (Locardi *et al*., 1975; Nappi *et al*., 1979; De Rita and Sposato, 1986; De Rita and Zanetti, 1986; De Rita *et al*., 1983; Cioni *et al*., 1987; Cioni *et al*., 1993; Campobasso *et al*., 1994). These studies have been mainly focused on the western and southern sectors. More recently, a revised stratigraphy of the whole Sabatinian

District has been proposed by De Rita *et al.* (1993) in a new geological map with a scale of 1:50,000, while Karner *et al.* (2001) have identified and dated some significant Sabatinian eruptive units which crop out in the southern sector of the District and can be ascribed to the initial activity. Finally, a detailed geological survey of northern Latium has been carried out by Funiciello *et al.* (2003) and Nappi *et al.* (2003) for the new sheets of the Geological Map of Italy with a scale of 1:50,000. These investigations help us to understand the relationships between the various factors controlling the evolution of this area, and how the volcanic units relate to tectono-sedimentary events on a regional scale. Hence, several unconformities of regional importance have been identified and defined by Funiciello *et al.* (2003) and used to arrange the stratigraphy in the Northern Sabatinian sector.

The aim of this work is 1) to provide a detailed stratigraphy of the northern sector of the Sabatinian Volcanic District, including a characterisation of all the recognised volcanic units, 2) to present a set of new geochronological and geochemical data for the outcropping products and 3) to give insight into the volcanic evolution of this quiescent volcanic system. This study will also provide the basis for a companion paper on the mineralogy and petrology of the northern Sabatinian volcanics, which will contribute to our magmatological understanding of this intriguing District.

Geodynamic and volcanological background of the area under study

The western margin of the Italian peninsula has been the site of intense magmatism since the Pliocene period, caused by rifting in the Tyrrhenian Basin and post-orogenic extension in the Apennines (e.g., Peccerillo and Manetti, 1985; Locardi, 1988; Conticelli and Peccerillo, 1992; Serri *et al.*, 1993; Serri *et al.*, 2001).

After the pioneering works of Washington (1906) and Scherillo (1937, 1940, 1941, 1943, 1944) a number of geologists investigated the magmatism of central Italy to interpret the genesis and evolution of the volcanic activities and the petrology of the erupted products (e.g., Alvarez *et al.*, 1975; Vollmer, 1976; Turi and Taylor, 1976; Funiciello *et al.*, 1976; Cundari, 1979; Hawkesworth and Vollmer, 1979; De Rita *et al.*, 1983; Peccerillo *et al.*, 1987; Conticelli *et al.*, 1989; Cioni *et al.*, 1990; Beccaluva *et al.*, 1991;Conticelli and Peccerillo, 1992; Conticelli *et al.*, 2002; Peccerillo, 2002).

Within this area, the Sabatinian Volcanic District (SVD; fig. 1) is an excellent training ground for the study of the magmatic processes and their related volcanic history. Detailed investigations of the volcanic and tectono-magmatic evolution of the Sabatinian District have recently been conducted mainly by Cioni *et al.* (1993), De Rita *et al.* (1993), De Rita *et al.* (1996), Conticelli *et al.* (1997), De Rita *et al.* (1997) and Karner *et al.*, (2001). In short, these studies show that 1) the Sabatinian Volcanic District has been the site of intense magmatism with an alkaline ultrapotassic affinity from 0.8 Ma to 0.04 My, 2) the Sabatinian Volcanic District is characterised by the lack of a well-formed volcanic structure, since the volcanic activity extends over a wide area, and 3) the location of volcanic activity in the Sabatinian District, the styles of eruptions, and the relationships and distribution of volcanic units are strongly influenced by the pre-volcanic lithology and structure of the area. According to De Rita *et al.* (1993), there are three main sectors with different structural evolutions in the Sabatinian Volcanic District: in the western sector the volcanism is of a magmatic type, it is centred in the Bracciano volcano-tectonic depression and is often associated with fissures; in the eastern sector the activity is mainly phreatomagmatic and associated with deep aquifers, and it is centred in the Sacrofano volcano; in the northern part a magmatic-type volcanism is complicated by the presence of several monogenic craters produced by phreatomagmatic explosions, probably associated with shallow aquifers.

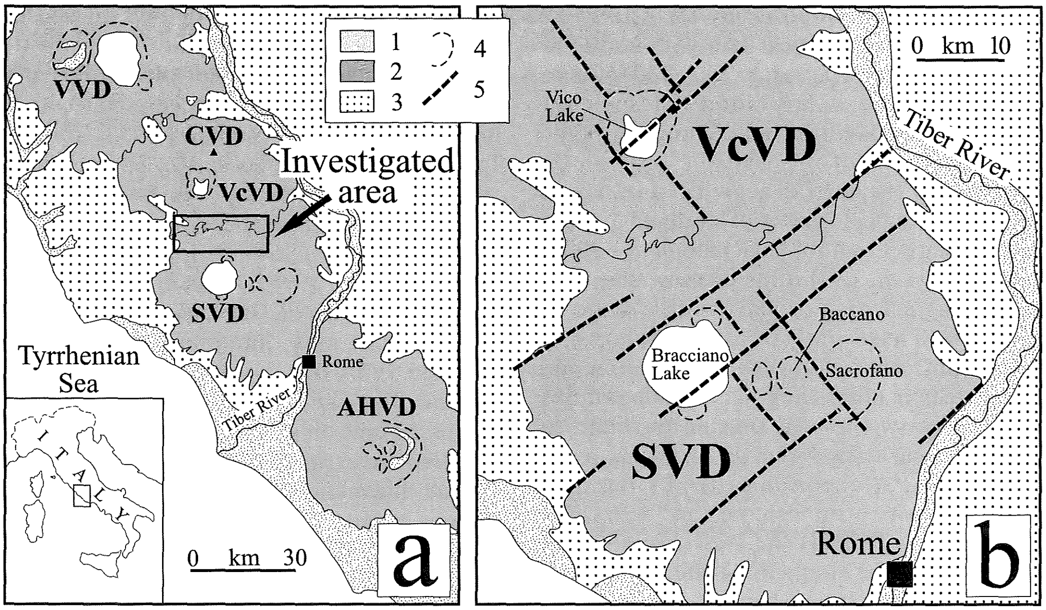

Fig. 1 – Sketch map of the northern Latium volcanic area, Central Italy, with (a) the location of the investigated area and (b) the main regional tectonic lines (modified from De Rita *et al.*, 1993; De Rita *et al.*, 1996). 1 = Recent alluvial deposits; 2 = volcanic units; 3 = sedimentary units; 4 = main caldera and crater rims; 5 = main faults. VVD = Vulsini Volcanic District; CVD = Cimini Volcanic District; VcVD = Vico Volcanic District; SVD = Sabatinian Volcanic District; AHVD = Albani Hills Volcanic District.

STRATIGRAPHIC METHODS AND ANALYTICAL TECHNIQUES

In accordance with the recommendations of the Italian Commission for Geological Mapping for these volcanic areas, the proposed volcanic succession was reconstructed on the basis of field recognition and identification of the main unconformities that markedly define different UBSU (Salvador, 1987a; Pasquarè *et al.*, 1992; De Rita *et al.*, 2000). In addition, all the defined UBSU were subdivided into other informal lithostratigraphic units, according to the terminology of Salvador (1987b) and Pasquarè *et al.* (1992).

About seventy samples of volcanic rocks cropping out in the northern Sabatinian Volcanic District were collected. Widespread leucite alteration limited the number specimens suitable for chemical investigations to those reported here; however, these specimens can be considered representative of the main recognised lithostratigraphic units. Whole rock analyses were carried out at the Actlabs Laboratory (Ontario, Canada) using ICP-OES (Inductively Coupled Plasma – Optical Emission Spectrometry) for major elements and ICP-MS (Inductively Coupled Plasma – Mass Spectrometry) for trace elements, after crushing and powdering the samples in an agate mortar to avoid contamination. Relative errors were ≤ 1 % for major oxides and ≤ 3% for trace elements.

Two samples were selected for $^{40}Ar/^{39}Ar$ analysis, which was performed at the same Actlabs Laboratory (Ontario, Canada). The J-values for these samples were monitored using the Fish Canyon Tuff Sanidine with an age of 27.95 My. The resulting $^{40}Ar_{rad}/^{39}Ar_K$ ratio was used to calculate the age using the J-value quoted above. All errors are two sigma of the mean.

STRATIGRAPHY, GEOCHRONOLOGY AND PETROGRAPHY

A detailed field survey allowed us to identify three main unconformities that have been correlated with some of the erosional surfaces already described in northern Latium (Funiciello *et al.*, 2003). These regional unconformities indicate the presence of three different synthems (fig. 2), which have been named according to the terminology proposed by Funiciello *et al.* (2003). The first unconformity consists of an erosional surface that separates the sedimentary units from the base of the *Barca di Parma Synthem*, which is the oldest recognised UBSU in the investigated area. Another regional discontinuity, often associated with a paleosoil, is the second main unconformity which is considered as a boundary between the *Barca di Parma Synthem* and the overlying *Archi di Pontecchio Synthem*. The third unconformity is also an erosional surface which corresponds locally to the present day topographic surface and separates the *Archi di Pontecchio Synthem* from the Tufo Rosso a Scorie Nere Vicano Unit (see later) and the youngest *Casalone Synthem*.

The deposits of the *Barca di Parma Synthem* are mainly pyroclastic deposits (tephra levels and ignimbrites) and minor lava flows; the *Archi di Pontecchio Synthem* also consists of pyroclastic deposits and lava flows, while the rocks of the *Casalone Synthem* are mostly composed of lavas at the bottom of the succession and mainly phreatomagmatic deposits towards the top.

Twelve lithostratigraphic units are also recognised and defined within these synthems and they constitute the base-units used for the geological mapping and stratigraphy; the lithostratigraphic units were generally named according to their best exposition in the area under study and designated by acronyms in figures and tables for the sake of simplicity. Because of similar characteristics and ambiguous naming, in the previous works it has been easy to misidentify some of the Sabatinian volcanic units. Additionally, it has been difficult to correlate the various names accurately with right volcanic products. This is particularly true in the case of deposits which cover a long span of time or have different historical names (e.g., «Tufi Stratificati Varicolori della Storta», «Tufi Varicolori di Sacrofano», «Pyroclastic fall deposits from local centers»). For clarity, Table 1 reports all the lithostratigraphic units identified in this study, together with their correlation with the nomenclature used in previous papers (Mattias, 1968; Bertini *et al.*, 1971; De Rita *et al.*, 1993; Karner *et al.*, 2001). The identified volcanic units will be described in the following sections, according to their stratigraphic order.

Barca di Parma (BDP) Synthem

The lower boundary of this synthem consists of a marked angular unconformity with the deposits of the sedimentary substratum, which are outlined by an erosional surface and a discontinuous paleosoil; these elements are clearly observable around the town of Sutri and Bassano Romano (fig. 2). The upper boundary is well represented both in the eastern (around Monterosi Lake) and western (near Bassano Romano) sectors of the investigated area by an erosional surface (disconformity), often associated with a paleosoil. This upper unconformity separates the products of the *Barca di Parma Synthem* from those of the overlying *Archi di Pontecchio Synthem* in the central sector of the area under study. In the other parts, the overlying units are mostly composed of the products from the *Casalone Synthem* which are widely distributed in the area. The *Barca di Parma Synthem* includes the following four lithostratigraphic units (Table 1): Bassano Romano, Valle Nobile, Macchia Bella and Palombara Units.

Bassano Romano (BaR) Unit – This unit comprises the oldest volcanic products cropping out in the northern sector of the Sabatinian Volcanic District and it forms the base of the volcanic pile, covering the sedimentary rocks of the substratum

TABLE 1

Stratigraphic successions and nomenclatures of the volcanic products recognised in the northern Sabatinian Volcanic District.

<table>
<tr><th>Mattias
(1968)</th><th>Bertini et al.
(1971)</th><th>De Rita et al.
(1993)</th></tr>
<tr><td></td><td rowspan="4">“Tufi stratificati finali”</td><td>“Hydromagmatic products from the local centers of the N sector”</td></tr>
<tr><td>“Tufi di Valle S. Martino”</td><td>“Hydromagmatic products from the Valle S. Martino crater”</td></tr>
<tr><td>“Tufo di Monterosi”</td><td>“Hydromagmatic products from the Monterosi crater”</td></tr>
<tr><td>“Tufi stratificati vari colori della Storta” and “Lave tefritiche e leucitiche”</td><td>“Pyroclastic fall deposits from local centers of the N sector”</td></tr>
<tr><td>“Tufo litoide a Scorie Nere”</td><td>“Ignimbrite III”</td><td>“Red tuff with black scoria”</td></tr>
<tr><td rowspan="2">–“Tufi stratificati varicolori della Storta” and “Lave tefritiche e leucitiche intercalate”</td><td>“Lave leucitiche”</td><td rowspan="2">“Pyroclastic fall deposits from local centers of the N sector” and “leucitic, tephritic and phonolitic lavas of the N sector”</td></tr>
<tr><td>“Tufi stratificati superiori”</td></tr>
<tr><td>“Tufo di Valle Nobile”</td><td>“Ignimbrite fonolitico-tefritica”</td><td>“Bracciano pyroclastic flow”</td></tr>
<tr><td>“Tufo Giallo di Sacrofano”</td><td>“Ignimbriti Trachitiche”</td><td>“Sacrofano Upper Pyroclastic Flow Unit”</td></tr>
<tr><td>“Tufo di Bracciano”</td><td>“Ignimbrite fonolitico-tefritica”</td><td>“Pizzo Prato, Bracciano, Vigna di Valle Pyroclastic Flows”</td></tr>
<tr><td>“Tufi stratificati vari colori della Storta”</td><td>“Tufi stratificati superiori”</td><td>“Pyroclastic fall products from Sacrofano and local scoria cones”</td></tr>
<tr><td>“Tufo Rosso a Scorie Nere”</td><td>“Ignimbrite fonolitico-tefritica”</td><td>“Red tuff with black scoria”</td></tr>
<tr><td>“Tufi stratificati vari colori di Sacrofano”</td><td>“Tufi stratificati”</td><td>“Pyroclastic fall products from Sacrofano and local scoria cones”</td></tr>
<tr><td>“Tufo Giallo della Via Tiberina”</td><td>“Ignimbriti Trachitiche”</td><td>“Sacrofano Lower Pyroclastic Flow Unit”</td></tr>
<tr><td></td><td>“Tufi inferiori”</td><td>“Pyroclastic fall deposits from Morlupo Edifice”</td></tr>
</table>

CAS = Casalone Synthem; ARP = Archi di Pontecchio Synthem; BDP = Barca di Parma Synthem; BaR = Bassano Romano Unit; VaN = Valle Nobile Unit; MaB = Macchia Bella Unit; VaM = Valle del Mulino Lava; MVa = Mola di Valdiano Lava; Pal = Palombara Unit; Asc = Ascarano Unit; FSt = Fosso della Stanga Lava; FSo = Fosso del Sorbo Lava; TRSNV = Tufo Rosso a Scorie Nere Unit; Cor = Cornacchia Unit; PoL = Poggio Licio Unit; Cre = Creti Unit; MoV = Monte

This table also distinguishes between previous mapping nomenclatures and nomenclature adopted for this study. The identified synthems and volcanic units have been designed by acronyms to simplify reference in figures and tables.

Karner *et al.* (2001)	Present work: *Phases*	Present work: *Synthem*	Present work: *Unit*		Age (ka)
"Hydromagmatic Activity"	VI	***CAS***	Cam		(< 134)
			MoG		
			MoR		
			PrF		**134±33**
			Cre	ScA Lava	(135-154)
				MoV Lava	
			PoL		
			Cor		**154±7**
		Vico Unit	TRSNV		151±3[1] 154±15[2] 155±10[1]
"Hydromagmatic Activity"	V	***ARP***	Asc	FSo Lava	(155-200)
				FSt Lava	
	IV	***BDP***	Pal		(200-285)
			MaB	MVa Lava	
				VaM Lava	
			VaN		
"Tufo Giallo di Sacrofano"			BaR		285±1[4]
"Tufi stratificati varicolori della Storta"	III				403±3[3] 410±1[4] 419±2[3]
"Tufo Rosso a Scorie Nere"	II				449±1[4]
"Tufo Terroso con Pomici Bianche"					488±2[4]
"Grottarossa Pyroclastic Sequence"					514±5[4]
"Tufo Giallo di Prima Porta" "U. Tufo Giallo della Via Tiberina" "L. Tufo Giallo della Via Tiberina"	I				548±4[4] 561±1[4]
"First Ash Fall Deposits"					800-580[4]

Vagnolo Lava; ScA = Schiena d'Asino Lava; PrF = Prato Fontana Lava; MoR = Monterosi Unit; MoG = Monte Gagliozzo Unit; Cam = Costa Campanella Unit. New radiometric age determinations are in bold; other radiometric data are from (1) Sollevanti (1983), (2) Laurenzi and Villa (1987), (3) Barberi et al. (1994), (4) Karner et al. (2001). Reasonable approximate ages are in brackets.

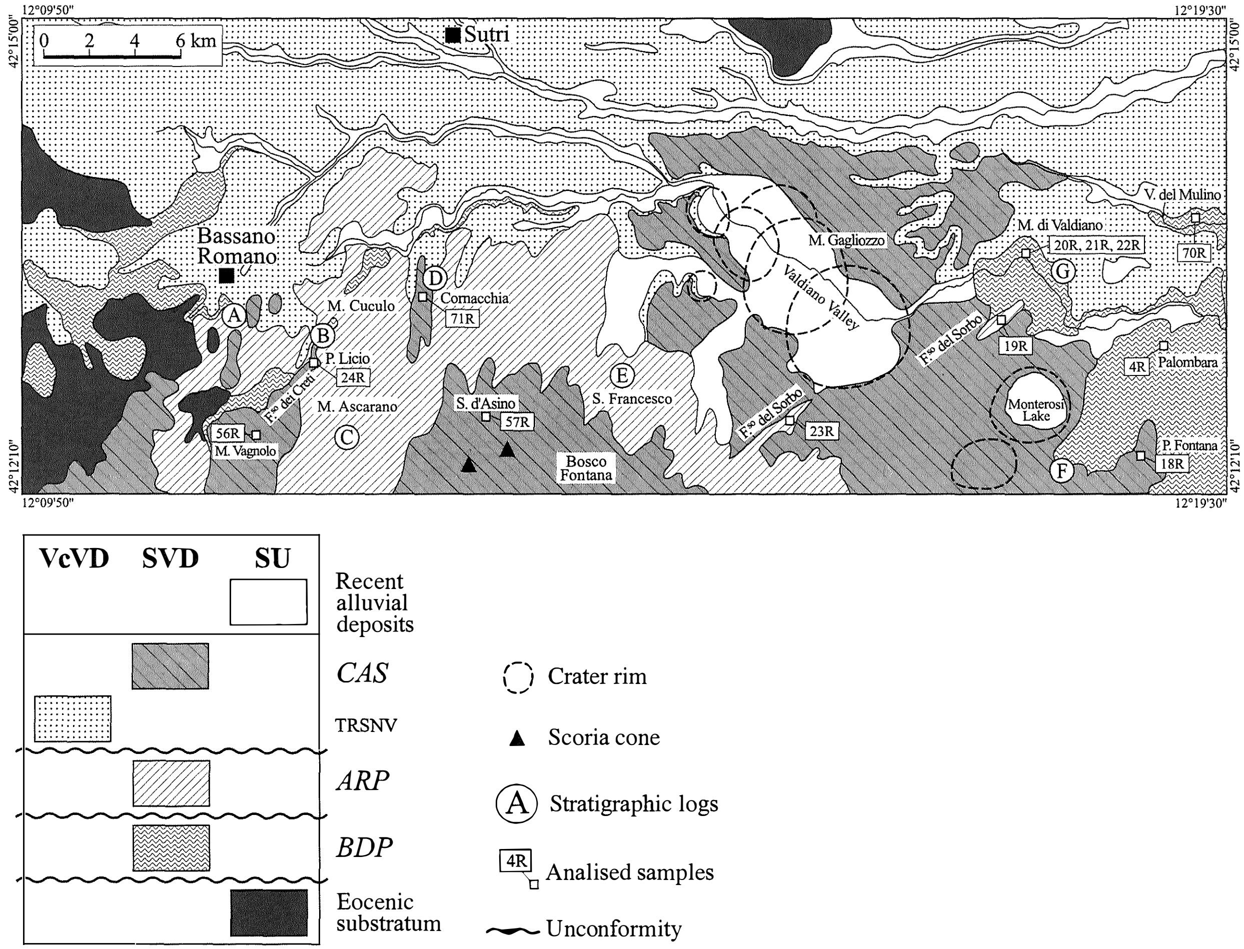

Fig. 2 – Geological sketch map of the northern sector of the Sabatinian Volcanic District showing the distribution of the products of the three recognised synthems. VcVD = Vico Volcanic District; SVD = Sabatinian Volcanic District; SU = Sedimentay Units; *CAS* = *Casalone Synthem*; *ARP* = *Archi di Pontecchio Synthem*; *BDP* = *Barca di Parma Synthem*. Letters within circles indicate the position of the stratigraphic logs reported in fig. 3. Number and letters within boxes indicate the position of the analysed samples reported in Table 2.

unconformably (fig. 3, log A). In the area under investigation the Bassano Romano Unit consists of a thick sequence of several pumice and scoria fall deposits alternating with ash layers, constituting the distal deposits of plinian- and strombolian-type eruptions and the ashy deposits of pyroclastic flow-forming eruption, respectively (fig. 3, logs A, B, C; fig. 4d). Occasionally, incipient pedogenised horizons, diatomitic and reworked levels separate the different tephra layers. However, in the southern and western sectors of the Sabatinian District (outside the investigated area) the Bassano Romano Unit contains important volcanic products (see Table 1) as «First Ash Fall deposits» (800-580 ky; Karner *et al.*, 2001), «Tufo Giallo della Via Tiberina» (Mattias and Ventriglia, 1970; dated at 548±4 and 561±1 ky by Karner *et al.*, 2001), «Tufo Giallo di Prima Porta» (514±3 ky; Karner *et al.*, 2001), «Tufi Stratificati Varicolori di Sacrofano» (Mattias and Ventriglia, 1970, dated at 514±5, 518±5 and 488±2 ky by Karner *et al.*, 2001), «Tufo Rosso a Scorie Nere» or «Sabatini Grey Tuff» or «Red tuff with black scoria» (Mattias and Ventriglia, 1970; Bertini *et al.*, 1971; Cioni *et al.*, 1993; De Rita *et al.*, 1993; dated at 499±1 ky by Karner *et al.*, 2001) and the lower part of the «Tufi Stratificati Varicolori della Storta» (Mattias and Ventriglia, 1970; dated at 410 ky be Karner *et al.*, 2001). Also considering the ages of the «Morlupo trachyte» (587±2 ky; Barberi *et al.*, 1994), some plinian fall levels which are interbedded in the upper part of the Bassano Romano Unit (419±2 to 403±3 ky; Barberi *et al.*, 1994) and the «Tufo Giallo di Sacrofano» (Mattias and Ventriglia, 1970; dated at 285±1 ky by Karner *et al.*, 2001), it can be assumed that the Bassano Romano Unit constitutes the distal equivalent of a huge volcanic succession covering a long span of time, from 800 to 285 ky ago. This Unit is found in the western, southern and eastern parts of the Sabatinian Volcanic District. The thickness of the Bassano Romano Unit in the investigated area is highly variable, with a maximum value of 15 m.

Valle Nobile (VaN) Unit – This unit crops out locally in the western sector of the area under study, south of Bassano Romano, and it is observable just on the north face of M. Cuculo. This unit corresponds (Table 1) to the «Tufo di Valle Nobile» of Mattias (1968), the «Ignimbrite fonolitico-tefritica o trachitica» of Bertini *et al.* (1971), and the «Bracciano pyroclastic flow» of De Rita *et al.* (1993). The Valle Nobile Unit is a pyroclastic flow deposit with a phonolitic-tephritic composition (Mattias, 1968) and, in the investigated area, it is constituted by at least two flow units: the lower one consists of a coarse ash pumiceous matrix typically rich in free crystals (up to 5 cm) of biotite, pyroxene and subordinate plagioclase, associated with volcanic and sedimentary rock fragments; the upper flow unit is made up of an ashy matrix with micropumiceous fragments and smaller quantity of lithic fragments, biotite and pyroxene crystals. Although no radiometric data on the Valle Nobile Unit are available, the field relationships which can also be observed outside the investigated area suggest that it is no older than 285 ky. The Valle Nobile Unit has a maximum thickness of 5 m.

Macchia Bella (MaB) Unit – This unit is observable in the eastern sector of the investigated area, just to the north of Monterosi Lake, and it is mainly formed by a pyroclastic succession with subordinate products of local centres. It corresponds (Table 1) to the «Tufi stratificati superiori» of Bertini *et al.* (1971) and the «Pyroclastic fall deposits from local centres of the northern sector» of De Rita *et al.* (1993). However, if we consider the wide temporal range which has been attributed to the «Tufi Stratificati Varicolori della Storta» by Mattias (1968) and Corda *et al.* (1978), the Macchia Bella Unit can also be correlated with the upper part of this formation. The pyroclastic succession (fig. 3, log G) is constituted by predominantly pumice fall levels, interbedded with ash deposits and pyroclastic flow levels of limited areal distribution that seem to decrease towards the top of the unit, where the pumice levels

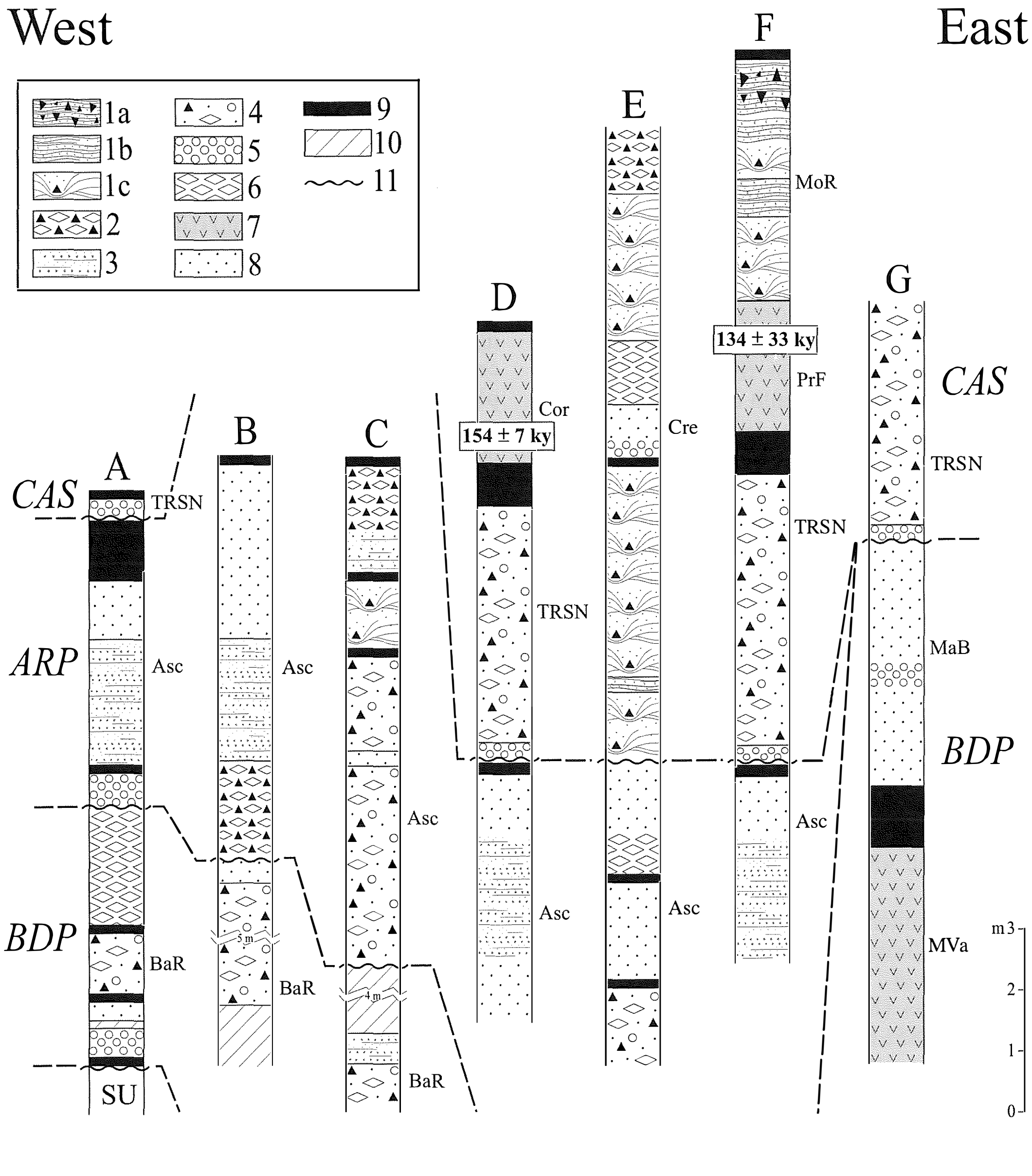

Fig. 3 – Representative stratigraphic logs of the northern Sabatinian Volcanic District (for location see fig. 2; for labels see Table 1. 1 = Pyroclastic surge deposits: a) coarse lapilli layers with large-size lithic fragments; b) ash and inversely-graded lapilli layers; c) ash and lapilli layers with cross bedding and impact sags; 2 = ash and scoria fall deposits with lithic fragments; 3 = ash and scoria fall deposits; 4 = pumice flow deposits; 5 = pumice fall deposits; 6 = scoria fall; 7 = lava; 8 = ash; 9 = pedogenised horizon; 10 = reworked level; 11 = main erosional surfaces; SU = Sedimentary Units.

Fig. 4 – a) Costa Campanella, south-west of Bassano Romano: phreatomagmatic products with typical depositional structures such as cross laminations or cross-bedding and impact sags of the Campanella Unit (*Casalone Synthem*); b) north of Monterosi Lake: large-size lithic boulders which characterise the phreatomagmatic deposits of the Monterosi Unit (*Casalone Synthem*); c) Cornacchia, east of Bassano Romano: poorly-vesiculated lava flow of the Cornacchia Unit (*Casalone Synthem*) which directly overlies the Tufo Rosso a Scorie Nere Vicano Unit deposits; d) south of Bassano Romano: sequence of pumice and scoria fall deposits alternating with pedogenised ash layers in the Bassano Romano Unit (*Barca di Parma Synthem*).

become dominant; subordinate pedogenised horizons and reworked levels are also present. No chronological data are available for the Macchia Bella Unit; nevertheless, field relationships suggest an age within the 285-200 ky range. Its total thickness is variable with a maximum value of 40 m. In the investigated area, the Macchia Bella Unit is also characterised by the presence of two main lava flows of limited extension.

The first one, called ***Valle del Mulino (VaM) Lava***, is dark-grey with a porphyritic texture (Porphyritic Index, PI = 10-15 vol.%) with dominant leucite phenocrysts (up to 4 mm) and minor clinopyroxene, which is sometimes zoned. The microphenocrysts in the groundmass are formed by a framework of leucite, clinopyroxene, plagioclase and sanidine; opaque minerals are present as accessory phase, whereas amphibole is rarely found in patches within the clinopyroxene. On the basis of chemical data the *Valle del Mulino Lava* is a phonolitic tephrite (fig. 5), with K_2O, MgO and CaO contents of about 8.5, 4.3 and 10.3 wt.%, respectively (Table 2, fig. 6); this lava also has high Sr, Zr and Ba contents (2070, 360 and 1670 ppm, respectively) and a K_2O/Na_2O ratio of 5.8.

The second lava flow, called ***Mola di Valdiano (MVa) Lava*** (fig. 3, log G), is grey and its texture ranges from porphyric (PI = 10 vol.%) to nearly aphyric. Leucite and variably zoned clinopyroxene are the dominant phenocrysts, while the groundmass is composed of the same minerals present as phenocrysts, together with plagioclase, sanidine and rare magnetite; amphibole is also present in patches within the clinopyroxene. On the basis of chemical data the *Mola di Valdiano Lava* is a phonolitic tephrite (fig. 5), with a slightly variable composition in terms of SiO_2 (from 47.9 to 48.2 wt.%), Fe_2O_3 (from 7.4 to 8.6 wt.%) and K_2O (from 8.1 to 9.2 wt.%) contents (Table 2, fig. 6). CaO and MgO are

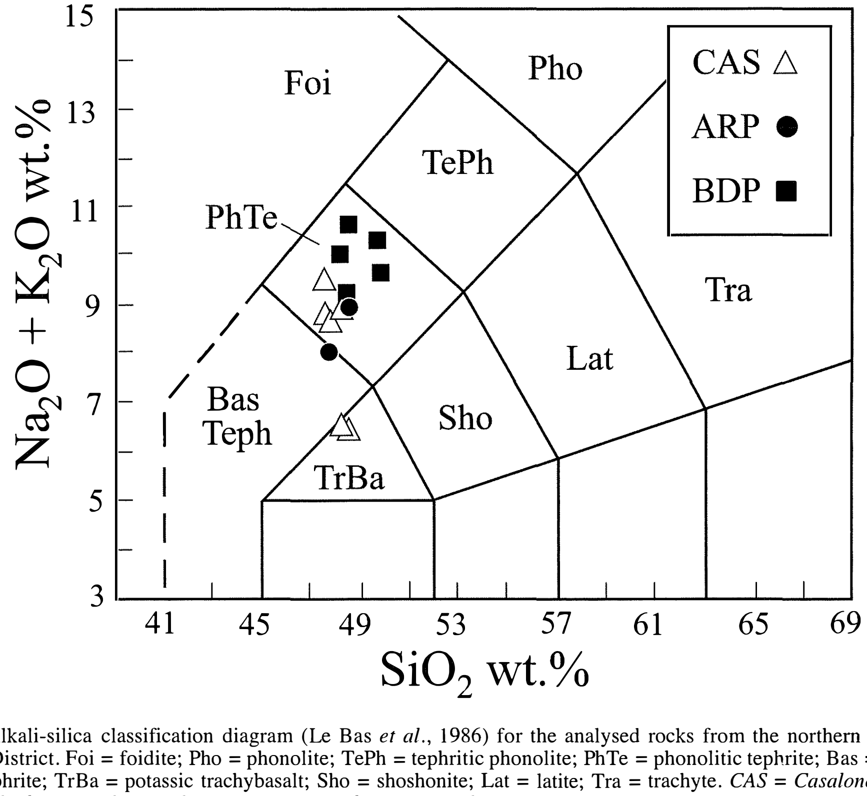

Fig. 5 – Alkali-silica classification diagram (Le Bas *et al.*, 1986) for the analysed rocks from the northern Sabatinian Volcanic District. Foi = foidite; Pho = phonolite; TePh = tephritic phonolite; PhTe = phonolitic tephrite; Bas = basanite; Teph = tephrite; TrBa = potassic trachybasalt; Sho = shoshonite; Lat = latite; Tra = trachyte. *CAS = Casalone Synthem*; *ARP = Archi di Pontecchio Synthem*; *BDP = Barca di Parma Synthem.*

TABLE 2

Chemical data of major (wt%) and selected trace (ppm) elements of the analysed rocks from the northern Sabatinian Volcanic District. For labels see Table 1.

Locality	Prato Fontana	Monte Vagnolo	Schiena d'Asino	Poggio Licio	Cornacchia	San Francesco	Fosso del Sorbo	Fosso della Stanga	Palombara	Mola di Valdiano	Mola di Valdiano	Mola di Valdiano	Valle del Mulino
Longitude^	12°18'30''	12°11'40''	12°13'13''	12°12'10''	12°13'00''	12°14'40''	12°16'00''	12°17'30''	12°18'40''	12°17'40''	12°17'40''	12°17'40''	12°19'00''
Latitude	42°12'00''	42°12'10''	42°12'20''	42°12'40''	42°13'00''	42°12'20''	42°12'10''	42°12'50''	42°12'30''	42°13'10''	42°13'10''	42°13'10''	42°13'30''
Synthem	**CAS**						**ARP**		**BDP**				
Phase	**VI**	**VI**	**VI**	**VI**	**VI**	**VI**	**V**	**V**	**IV**	**IV**	**IV**	**IV**	**IV**
Unit	**PrF**	**MoV**	**ScA**	**PoL**	**Cor**	**(°)**	**FSo**	**FSt**	**Pal**	**MVa**	**MVa**	**MVa**	**VaM**
Sample	18R	56R	57R	24R	71R	48R	23R	19R	4R	20R	21R	22R	70R
SiO_2	47.39	47.54	47.66	47.08	47.51	48.03	47.48	47.07	46.70	48.19	48.26	47.85	47.14
TiO_2	0.78	0.77	0.83	0.84	0.87	0.84	0.82	0.81	0.80	0.76	0.77	0.80	0.77
Al_2O_3	14.11	14.23	16.13	15.92	16.02	16.20	15.82	15.27	16.55	16.93	16.94	17.33	16.54
Fe_2O_3*	9.05	8.87	8.86	8.92	9.18	9.20	8.99	9.66	7.81	7.43	7.93	8.59	8.20
MnO	0.15	0.15	0.15	0.16	0.16	0.16	0.16	0.16	0.17	0.15	0.14	0.18	0.17
MgO	7.28	7.22	4.99	5.07	5.45	5.60	4.83	5.67	4.35	4.01	4.01	3.58	4.25
CaO	12.67	12.66	10.52	10.81	11.06	11.22	10.83	11.35	10.66	9.46	9.33	9.26	10.30
Na_2O	1.23	1.22	1.70	1.21	1.29	1.18	1.27	1.19	1.23	1.38	1.47	1.30	1.45
K_2O	5.41	5.20	7.23	8.24	7.57	7.43	7.62	6.84	7.89	8.78	8.10	9.18	8.46
P_2O_5	0.46	0.48	0.55	0.49	0.63	0.61	0.40	0.52	0.40	0.49	0.48	0.55	0.45
LOI	1.06	1.62	0.96	1.02	0.90	0.27	1.28	1.27	1.97	1.42	1.15	1.53	1.03
Total	99.59	99.96	99.59	99.76	100.64	100.74	99.49	99.81	98.53	98.99	98.58	100.14	98.76
Ba	729	773	1450	1460	1450	1390	1890	1440	1670	1670	1600	1490	1670
Ni	60	68	33	21	bdl	bdl	bdl	65	35	28	bdl	bdl	27
Rb	548	664	621	594	496	503	657	606	580	583	545	589	518
Sr	1320	1370	1810	1710	1760	1370	2240	1560	1920	2060	2020	1880	2070
Y	28	29	35	33	33	29	40	33	39	36	35	35	38
Zr	256	266	314	282	311	261	390	304	336	363	351	313	360
Nb	14	16	17	17	14	11	19	11	23	23	19	15	25

"^ From the Greenwich Meridian; (°) lava dike injected into the ARP products; *total iron as Fe_2O_3; LOI == loss on ignition; bdl = below detection limit"

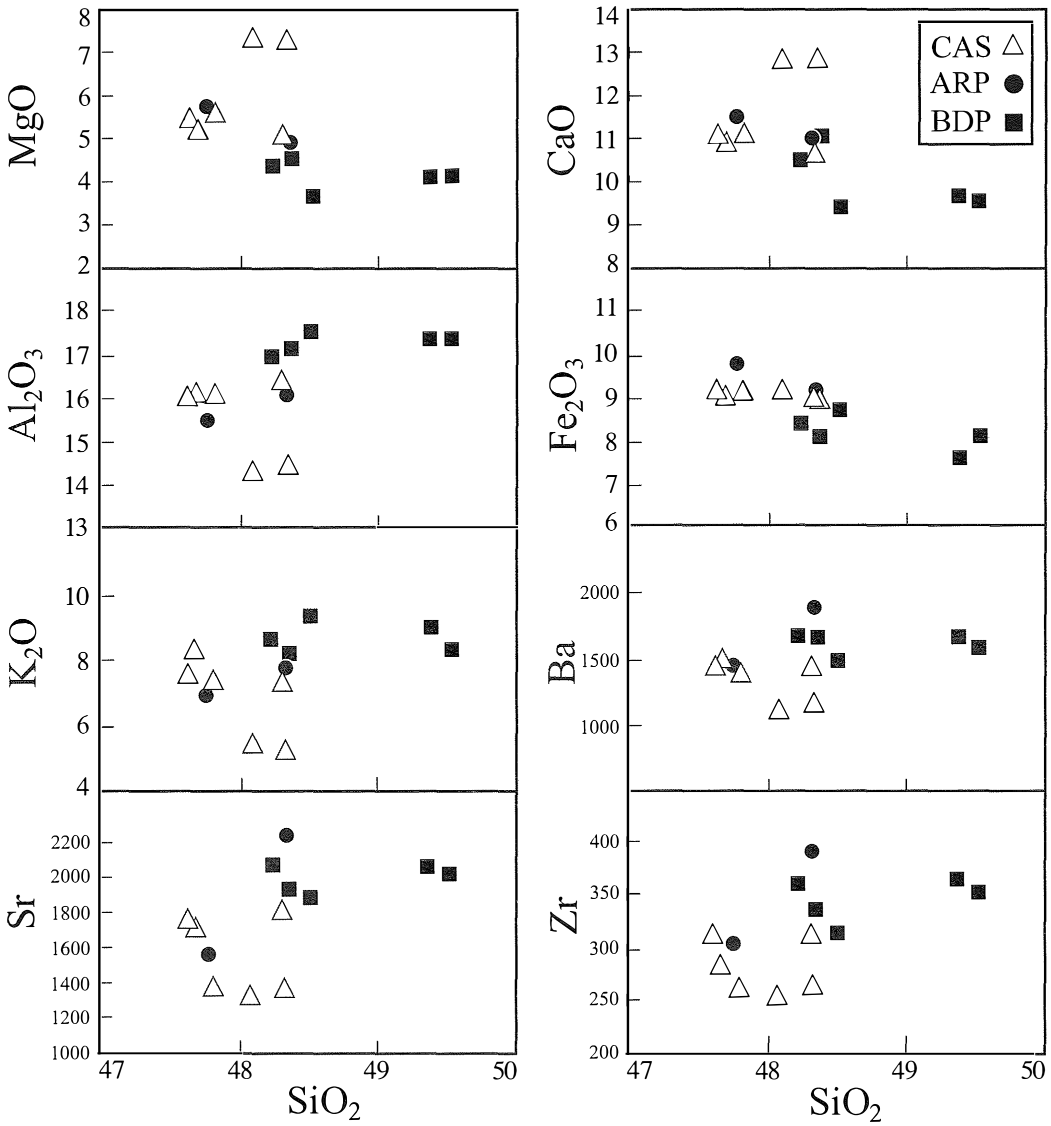

Fig. 6 – Variation diagrams of selected major (wt.%) and trace (ppm) elements of the analysed rocks from the northern Sabatinian Volcanic District. Major elements analyses are reported on water-free basis. *CAS = Casalone Synthem*; *ARP = Archi di Pontecchio Synthem*; *BDP = Barca di Parma Synthem*.

low (about 9.6 and 3.9 wt.%, respectively), whereas Al_2O_3 is high (about 17.1 wt.%). The K_2O/Na_2O ratio is about 6.3.

Palombara (Pal) Unit – This unit crops out in the south-east corner of the investigated area and it is formed by a black to grey lava flow which forms a wide plateau. Petrographically it has a porphyritic texture (PI = 5 vol.%) with leucite and clinopyroxene as phenocrysts; the groundmass is made up of leucite, clinopyroxene, plagioclase and sanidine, with minor amounts of magnetite and amphibole often within the pyroxene core. The *Palombara Lava* is a phonolitic tephrite (fig. 5), with K_2O, MgO and CaO contents of 7.9, 4.4 and 10.7 wt.%, respectively, whereas the K_2O/Na_2O ratio is about 6.4 (Table 2, fig. 6).

Archi di Pontecchio (ARP) Synthem

The deposits of this synthem are widespread in the central-southern sector of the investigated area (fig. 2) and they are separated from the underlying products of the *Barca di Parma Synthem* by an erosional surface, locally associated with a paleosoil. The upper unconformity is well exposed in the central-southern sector of the investigated area (between Ascarano and S. Francesco; fig. 2), where it is marked by a disconformity associated with paleosoil that separates the volcanics of the *Archi di Pontecchio Synthem* from the Tufo Rosso a Scorie Nere Vicano Unit or from the volcanics of the younger *Casalone Synthem*. In places, this upper unconformity is identified by the present day topographic surface. In the area under study the *Archi di Pontecchio Synthem* is only represented by the Ascarano Unit.

Ascarano (Asc) Unit – This unit is extensively exposed in the southern part of the investigated sector (fig. 2) and it corresponds in part (Table 1) to upper «Pyroclastic fall deposits from local centres of the northern sector» of De Rita *et al*. (1993). It is formed by a sequence of dominant distal and proximal pyroclastic fall deposits, associated with subordinate small ash flow units (fig. 3, logs A, B, C, D, E, F). The pyroclastic fall succession consists of predominant strombolian layers of scoriae, red to dark grey normally graded lapilli and lithic fragments of a mostly lavic type, with subordinate pedogenised horizons. With regard to the flow units, the most prominent deposit is present at the base of the succession and it consists of a micropumiceous matrix with dominant white pumice clasts up to 5 cm in diameter, sanidine and leucite crystals. At the top of this flow unit a sequence of pumiceous, coarse ash layers interbedded with thin ashy layers and typical crystal-rich horizons has been identified; its wide areal distribution makes it a stratigraphic marker bed for the whole northern sector of the Sabatinian Volcanic District. As regard its stratigraphic position, the Ascarano Unit deposits are sandwiched between the regional unconformity that separates the *Barca di Parma Synthem* from the *Archi di Pontecchio Synthem* and the marker bed Tufo Rosso a Scorie Nere Vicano Unit. Hence, the unit's age is probably within the 200-155 ky range. Its total thickness varies from 10 to 50 m. In the investigated area, the Ascarano Unit is also characterised by the presence of two lava flows of limited extension.

The first is the ***Fosso della Stanga (FSt) Lava***, which is light grey in colour; petrographically it is characterised by a sub-aphyric texture (PI < 2 vol.%) with rare phenocrysts of leucite and zoned clinopyroxene in a groundmass formed by plagioclase, leucite, clinopyroxene and opaque minerals. The *Fosso della Stanga Lava* plots between the tephrite and phonolitic tephrite fields (fig. 5); the K_2O and MgO contents are 6.8 and 5.7 wt.%, respectively, whereas CaO and Fe_2O_3 are 11.4 and 9.7 wt.%, respectively (Table 2, fig. 6). The K_2O/Na_2O ratio is about 5.8 (Table 2).

The second lava flow, called ***Fosso del Sorbo (FSo) Lava***, is grey and generally very vesicle poor; nevertheless, lineations characterised by high concentrations of vesicles are also present, simulating intense fissuration phenomena. The *Fosso del Sorbo Lava* shows a seriate porphyritic texture, with an PI ranging from 12 to 17 vol.%. Phenocrysts consist of leucite (up to 5 mm) and clinopyroxene (up to 1 mm), whereas the groundmass is made up of the same minerals present as phenocrysts associated with minor amounts of plagioclase and sanidine. The *Fosso del Sorbo Lava* is a phonolitic tephrite (fig. 5) and shows K_2O, MgO and CaO contents of 7.6, 4.8 and 10.8 wt.%, respectively (Table 2, fig. 6). This lava is also characterised by the highest Sr, Ba and Zr contents (2240, 1890 and 390 ppm, respectively), if compared with the other studied lavas. The K_2O/Na_2O ratio is about 6.

Tufo Rosso a Scorie Nere Vicano (TRSNV) Unit – This unit is related to the volcanic activity of the Vico Volcano District (Lago di Vico Synthem, Perini *et al*., 1997) and represents a peculiar stratigraphic marker bed of regional importance. Although it belongs to a different volcanic system, the Tufo Rosso a Scorie Nere Vicano Unit marks both the top of the *Barca di Parma Synthem* and the bottom of the *Casalone Synthem* boundaries; this unit will therefore also be described for its chronostratigraphic importance.

The Tufo Rosso a Scorie Nere Vicano Unit corresponds (Table 1) to the «Tufo litoide a Scorie Nere» *auct*. (Sabatini, 1912; Scherillo, 1940; Locardi, 1965; Mattias, 1968; Mattias and Ventriglia, 1970), the «Ignimbrite III» of Bertini *et al*. (1971), the «Ignimbrite C» of Bertagnini and Sbrana (1986), the «Red tuff with black scoriae» of De Rita *et al*. (1993) and the «Sutri Formation» of Perini *et al*. (1997). This unit extends as a continuous plateau throughout the northern sector of the investigated area. According to the above-mentioned authors, the Tufo Rosso a Scorie Nere Vicano Unit is formed by several pyroclastic units and is widely distributed around the Vico Volcano. In the area under study, the most common outcropping sequence is represented by a well-sorted basal fall deposit and an overlying matrix-poor, lithic-rich pyroclastic flow deposit, followed by several flow units which are red, welded and characterised by light-grey to dark-grey scoriae with an eutaxitic texture and extremely variable size (up to decimetres). The juvenile scoriae that characterise the red, welded facies are microvesicular, with a generally very low phenocryst content composed of leucite and sanidine, with subordinate clinopyroxene, plagioclase and biotite. This juvenile fraction is phonolitic in composition (Perini *et al*., 1997). There are few lithic fragments and they consist of sedimentary rocks and tephritic, phonolithic lavas. Radiometric $^{40}Ar/^{39}Ar$ datings on sanidine and leucite from the Tufo Rosso a Scorie Nere Vicano Unit (Sollevanti, 1983; Laurenzi and Villa, 1987) yield ages of 155±10, 154±15, 151±3 and 150±7 ky. The thickness of the Tufo Rosso a Scorie Nere Vicano Unit is highly variable in the investigated area, with a maximum value of 80 m.

Casalone (CAS) Synthem

The volcanics of this synthem crop out extensively in the northern, southern and eastern sectors of the area under study and are well exposed at Bosco Fontana and around the Valdiano Valley (fig. 2). The bottom boundary of the *Casalone Synthem* is marked by a disconformity that separates the *Casalone* volcanics from the Tufo Rosso a Scorie Nere Vicano Unit and the products of *Archi di Pontecchio* and *Barca di Parma Synthems*; the upper unconformity is constituted by the present topographic surface. This synthem includes the following lithostratigraphic units (from the oldest): Cornacchia, Poggio Licio, Creti, Prato Fontana Units and the younger Monterosi, Monte Gagliozzo and Costa Campanella Units.

Cornacchia (Cor) Unit – This unit corresponds to a distinct lava flow which crops out just to the east of Bassano Romano village and directly overlies the Tufo Rosso a Scorie Nere Vicano Unit (fig. 4c). It is dark-grey in colour and sub-aphyric in texture (PI < 5 vol.%). Rare phenocrysts consist of leucite and strongly zoned clinopyroxene; the groundmass is made up of leucite, plagioclase, sanidine, clinopyroxene and rare amphibole. This lava is a phonolitic tephrite (fig. 5), with a K_2O content of 7.6 wt.% and a K_2O/Na_2O ratio of about 5.8 (Table 2). To establish the age of the Cornacchia Unit and to evaluate the past time interval between the Tufo Rosso a Scorie Nere Vicano Unit and the Cornacchia lava, radiometric analyses have been carried out using the $^{40}Ar/^{39}Ar$ method. The Cornacchia Unit was found to be 154±7 ky. It has a maximum thickness of 5 m.

Poggio Licio (PoL) Unit – This unit is formed by a distinct lava flow outcropping on the north face of M. Ascarano. It is light-grey in colour and porphyritic in texture (PI = 10 vol.%). Dominant phenocrysts are leucite and zoned clinopyroxene, whereas plagioclase is found in much smaller quantities; groundmass is composed of the same minerals which appear as phenocrysts, associated with minor amounts of alkali feldspar, whose composition ranges from sanidine to hyalophane, and magnetite. On the basis of chemical data, this lava is a phonolitic tephrite (fig. 5) and is characterised by low SiO_2 content (47.1 wt.%), with K_2O, MgO and CaO values of 8.2, 5.1 and 10.8 wt.%, respectively (Table 2, fig. 6). The K_2O/Na_2O ratio is 6.8. The maximum thickness of the Poggio Licio Unit is 5 m.

Creti (Cre) Unit – This unit is mainly composed of a pyroclastic sequence of both phreatomagmatic and magmatic origin, associated with two small scale lava flows; these products originated from different centres, but they have been grouped together because of their contemporaneous activity. The Creti Unit partially corresponds (Table 1) to the lower part of the «Tufi stratificati finali» of Bertini *et al.* (1971) and to the upper «Pyroclastic fall deposits from local centres of the northern sector» of De Rita *et al.* (1993). The Creti Unit sequence crops out in the central-southern part of the investigated area; good exposures are visible all around the Bosco Fontana area. The lower part of the Creti sequence (fig. 3, log E) is of phreatomagmatic origin and is mainly composed of a thin layer of lapilli-sized coarse ash and laminated ashy layers rich in lithic fragments of sedimentary and lavic type, often showing impact sags. The upper part of the Creti sequence is constituted by volcanic products of magmatic origin formed by normal-graded scoriaceous lapilli layers with the two interbedded lava flows of *Monte Vagnolo* and *Schiena d'Asino*.

The ***Monte Vagnolo (MoV) Lava*** is grey in colour and shows a variable degree of vesiculation. Petrographically, it shows a seriate porphyric texture (PI = 8-10 vol.%) with clinopyroxene phenocrysts of different size and subordinate leucite; plagioclase, sanidine, leucite, nepheline and clinopyroxene are found in the groundmass. The *Monte Vagnolo Lava* is a potassic trachibasalt (fig. 5), with low K_2O and Al_2O_3 (5.2 wt.% and 14.2 wt.%, respectively) and high MgO and CaO contents (7.2 wt.% and 12.7 wt. %, respectively) (Table 2, fig. 6). This lava is also characterised by low contents of Sr, Ba and Zr (1370, 1173 and 266 ppm, respectively), and the highest Ni content (68 ppm), with a K_2O/Na_2O ratio of 4.3. The maximum thickness of the *Monte Vagnolo Lava* is 5 m.

The ***Schiena d'Asino (ScA) Lava*** is grey and has a porphyritic texture (PI = 15 vol.%) characterised by peculiar megacrysts of leucite and clinopyroxene and plagioclase phenocrysts, set in a groundmass which is composed of the same phases associated with rare sanidine and Fe-Ti oxides. On the basis of chemical data, this lava is a phonolitic tephrite (fig. 5); K_2O, MgO and CaO contents are 7.2, 5 and 10.5 wt.%, respectively (Table 2, fig. 6), whereas the K_2O/Na_2O ratio is 4.3. The minimum thickness (the base is not exposed) of the *Schiena d'Asino Lava* is 5 m.

Prato Fontana (PrF) Unit – This unit is formed by a single lava flow which crops out in the south-east sector of the investigated area, near Monterosi Lake, and it constitutes the last effusive event to be identified in the northern Sabatinian Volcanic District. It is dark-grey and sub-aphyric in texture (PI < 3 vol.%). Rare phenocrysts are clinopyroxenes, whereas the groundmass is made up of leucite, clinopyroxene, plagioclase and altered olivine; much smaller amounts of Fe-Ti oxides are also present. The Prato Fontana Unit is a potassic trachibasalt (fig. 5), showing low K_2O (5.4 wt.%) and Al_2O_3 (14.1 wt.%) contents, and high MgO (7.3 wt.%), and CaO (12.7 wt.%) values (Table 2, fig. 6). This lava is also characterised by the lowest Sr, Ba and Zr contents (1320, 1119 and 256 ppm, respectively) and high Ni (60 ppm), with a K_2O/Na_2O ratio of about 4.4. $^{40}Ar/^{39}Ar$ radiometric analyses have been performed on the Prato Fontana Unit to determine when the magmatic activity in this sector ended; the calculated age of the Prato Fontana Unit is 134±33 ky. The observed maximum thickness of this lava is 5 m.

Monterosi (MoR) Unit – This unit is well exposed in the south-eastern sector of the investigated area, all around Monterosi Lake, and it is constituted by volcanic products of phreatomagmatic origin. This unit corresponds (Table 1) to the «Tufo di Monterosi» of Mattias (1968), the «Tufi Stratificati Finali» of Bertini *et al.* (1971) and the «Hydromagmatic products from the Monterosi crater» of De Rita *et al.* (1993). The Monterosi Unit mainly consists of ashy-lapilli layers and ashy levels with sandwave structures, which are interbedded with lithic-rich levels characterised by impact sags (fig. 3, log F); lithic clasts are generally lava fragments of considerable size (up to 1 m; fig. 4b). The thickness of the Monterosi Unit ranges from 2 to 5 m.

Monte Gagliozzo (MoG) Unit – This unit can be observed in the western sector of Monterosi Lake and partially corresponds (Table 1) to the «Tufo di Valle S. Martino» of Mattias (1968), the «Tufi Stratificati Finali» of Bertini *et al.* (1971) and the «Hydromagmatic products from the S. Martino crater» of De Rita *et al.* (1993). The Monte Gagliozzo Unit is constituted by phreatomagmatic-type deposits in a sequence which is stratified from laminated- to thick-bedded and consists of several different layers, both in terms of thickness and grain-size (fig. 3). Very thick-bedded, fine grey ashes with impact sags and lava blocks of boulders (up to 2 m) alternate with thinly stratified, fine- to coarse-ash characterised by cross and planar lamination and occasional impact sags, and minor well sorted dark-grey lapilli. The maximum observed thickness of the Monte Gagliozzo Unit is 4 m.

Costa Campanella (Cam) Unit – The products of this unit are the youngest volcanics which crop out in the area under investigation; they can only be observed in the south-western sector of the northern Sabatinian Volcanic District, near Bassano Romano village. We correlate this deposits with the upper part of the «Tufi Stratificati Finali» of Bertini *et al.* (1971) and the «Hydromagmatic products from the local centres of the northern sector» of De Rita *et al.* (1993). The Costa Campanella Unit is constituted by a series of phreatomagmatic products which show typical depositional structures such as planar and cross laminations or cross-bedding (fig. 4a). The matrix is generally fine and very rich in lithic fragments of mainly sedimentary and plutonic (gabbro, foid-bearing gabbro, syenite, foid-bearing syenite, foidite) origin, up to the diameter of about 1 m. In places, the fine matrix has been completely worn away by weathering and this unit is only constituted by loose lithic fragments. Towards the top of the Costa Campanella Unit a continuous and characteristic interval composed by centimetres-thick layers of scoriae and lapilli is also present. The observed thickness of this unit ranges from 1 to 3 m.

DISCUSSION

Previous authors have studied the Sabatinian Volcanic evolution mainly on the basis of broader investigations of the geology, chronology and petrology of the whole District. With regard to the radiometric measurements, a complete set of the Sabatinian data is provided by Cioni *et al.* (1993), De Rita *et al.* (1993) and Karner *et al.* (2001), who also summarize the analyses found in literature (Nicoletti, 1969; Alvarez *et al.*, 1976; Fornaseri, 1985; Laurenzi and Villa, 1987). The most recent and comprehensive investigations of the mineralogy, bulk-rock chemistry and isotope data of the Sabatinian Volcanic District was conducted by Conticelli *et al.* (1997). These authors suggest important relationships between the evolutionary processes and the volcanic activity.

The proposed detailed stratigraphy of the northern Sabatinian sector puts new constraints on the history of the whole District. We describe and name several volcanic units that have not been identified previously, placing them in proper stratigraphic context. We also re-examine the whole Sabatinian stratigraphy on the light of these data, endeavouring to distinguish unequivocally the ambiguous deposits.

Based on previous literature together with the new results emerging from this study, the volcanic evolution of Sabatinian District can be divided into six main phases (I to VI) during which several calderas and the main Bracciano volcano-tectonic depression were formed. These phases can be arranged in three different synthems and characterised by rocks with particular compositions. A schematic view of the stratigraphy and the geometric relationships associated with the identified synthems and units outcropping in the northern Sabatinian District is provided in fig. 7.

In the phase I the activity was concentrated in the eastern sector with significant explosive eruptions from the Sacrofano (leucite phono-trachytic «Via Tiberina Yellow Tuff»; Nappi *et al.*, 1979; Cioni *et al.*, 1993; Karner *et al.*, 2001) and Morlupo (haüyna phono-trachytic scoriae; Cioni *et al.*, 1993) vents. In this phase initial collapses in the eastern sector gave rise to the formation of the Sacrofano caldera. Radiometric data for these products suggest an age of 590-514 ky (Cioni *et al.*, 1993; Karner *et al.*, 2001). Nevertheless, the «Via Tiberina Yellow Tuff» is underlain by several pyroclastic deposits which have $^{40}Ar/^{39}Ar$ ages in the range of 800-580 ky (Karner *et al.*, 2001), suggesting that there was a substantial eruptive activity in the early history of this district. If we attribute this entire pyroclastic sequence to the Sabatinian complex, this first phase of activity may have developed within the interval 800-514 ky. Some of the distal pyroclastic layers interbedded in the lower part of the Bassano Romano Unit (*Barca di Parma Synthem*) could be related to this early eruptive Sabatinian activity.

During the phase II plinian and ignimbrite-forming eruptions took place giving rise to a larger magmatic explosive activity extending from the east («Sacrofano stratified tuffs» and «Sacrofano lower pyroclastic flow» with the associated Sacrofano caldera; De Rita *et al.*, 1993) to the west («Peperini Listati», «Sabatini Grey Tuff» or «Red tuff with black scoria» or «Tufo Rosso a Scorie Nere»; Bertini *et al.*, 1971; De Rita *et al.*, 1993) of the Sabatinian District. This period, which can probably spanned from 514 to 449 ky (Cioni *et al.*, 1993; Karner *et al.*, 2001), may include the building of a stratovolcano as well as the initial stage of the Bracciano volcano-tectonic depression. In the northern Sabatinian sector there is a little evidence of this phase and it can only be related to some distal pyroclastic level («Tufo Terroso con Pomici Bianche»; Palladino, *personal communication*) within the Bassano Romano Unit (*Barca di Parma Synthem*).

In the phase III, there was intense volcanic activity in the eastern and central sectors of the district, producing the «Sacrofano Upper Pyroclastic Flow» (De Rita *et al.*, 1983, 1993) and a significant volume of both primary and epiclastic volcanics («Tufi Stratificati Varicolori della Storta» or «La Storta Stratified Tuffs», Mattias and Ventriglia, 1970; Bertini *et al.*, 1971; De Rita *et al.*, 1993), which can be related to fissural-type explosive eruptions in the Bracciano area. The stratigraphic position of this pyroclastic-epiclastic sequence, which was always emplaced above the Sabatinian «Tufo Rosso a Scorie Nere» (449 ky), is consistent with the $^{40}Ar/^{39}Ar$ age of 410 ky calculated for a white pumice horizon outcropping in the southern Sabatinian area and attributed to this unit (Karner *et al.*, 2001). However, it should be noted that previous authors suggest a wide stratigraphic interval for «La Storta Stratified Tuffs», extending these volcanics up to the «Tufo Rosso a Scorie Nere Vicano Unit» (Mattias and Ventriglia, 1970) or even up to final phreatomagmatic phase (Corda *et al.*, 1978).

In the phase IV several small volcanic centres developed along the margins of the collapsed areas (e.g., «Sacrofano»,

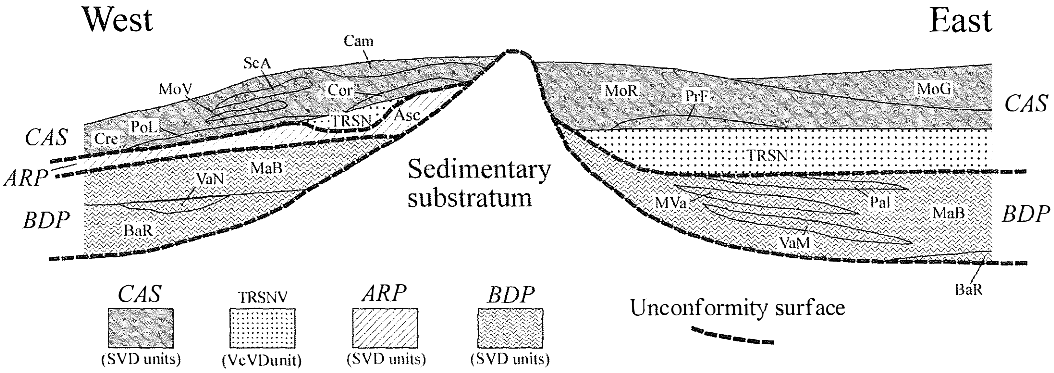

Fig. 7 – Sketch of stratigraphic relationships among the recognised synthems and relative lithostratigraphic units of the northern Sabatinian Volcanic District. For labels see Table 1.

«Bracciano», «Pizzo Prato», «Vigna di Valle»; De Rita *et al.*, 1993), producing widespread pyroclastic flows in the western sector («Tufo di Valle Nobile»; Mattias, 1968) and pyroclastic successions in the eastern area («Sacrofano pyroclastics»; De Rita *et al.*, 1993; Conticelli *et al.*, 1997). In the northern Sabatinian District we suggest the correlation of this phase with the Valle Nobile Unit emplacement, which is directly followed by the Macchia Bella tephra (with the *Valle del Mulino* and *Mola di Valdiano* intercalated lavas) and the effusive event of the Palombara Unit (upper part of the *Barca di Parma Synthem*). During this phase, the composition of the analysed erupted products is within the phonolitic tephrite field and also includes the most evolved rocks identified in the investigated area (fig. 5). According to the radiometric data of Karner *et al.* (2001) this period of activity probably dates back to the interval 410-200 ky.

The phase V, in the investigated area, is represented by the pyroclastic succession of the Ascarano Unit, comprising the *Fosso della Stanga* and *Fosso del Sorbo* lava flows (*Archi di Pontecchio Synthem*). The rocks belonging to this phase show a limited compositional variation, ranging from phonolitic tephrites to tephrites (fig. 5). The dominant strombolian-type activity of this period probably occurred from a number of local centres located in the northern sector of the Bracciano and collapsed Sacrofano areas (De Rita *et al.*, 1993). Field relationships with the overlying Tufo Rosso a Scorie Nere Vicano Unit suggest that this synthem is older than 155 ky (Sollevanti *et al.*, 1983).

The activity during the last phase VI was mainly of phreatomagmatic type with the formations of tuff cones, tuff rings and maars, and small effusive subordinate eruptions. The products of such phreatomagmatic activity are found throughout in the northern Sabatinian sector and correspond to the units of the *Casalone Synthem*. The oldest deposit of this phase is the Tufo Rosso a Scorie Nere Vicano Unit, which is related to a plinian eruption in the Vico Volcanic District and can be considered a stratigraphic marker level for the entire area under investigation. The interfingering of pyroclastic products from the two volcanic apparatus (Sabatinian and Vico Volcanic Districts) observed in the investigated area provides insight into their chronology. On the basis of the eruptive style the Sabatinian units (*Casalone Synthem*) can be divided into two cycles of activity. A first cycle with a prevailing magmatic-type, where lavas and pyroclastic deposits predominate, and a second cycle of largely phreatomagmatic-type. Field observations clearly show that the Tufo Rosso a Scorie Nere Vicano Unit is stratigraphically overlain by the Cornacchia Unit lava, which constitutes the oldest deposit of the first cycle of this phase. To assess the time interval between these two units exactly, the Cornacchia lava has been dated using the $^{40}Ar/^{39}Ar$ method; its estimated age is 154±7 ky. This shows that the Cornacchia Unit was outpoured soon after the Tufo Rosso a Scorie Nere Vicano eruption. Subsequently, a series of effusive (Poggio Licio and Prato Fontana Units) and explosive (Creti Unit) eruptions occurred in the northern Sabatinian Volcanic District, bringing the first cycle of this sixth phase to an end. The large amount of sedimentary fragments that are present as lithics in the Creti Unit deposits suggests an increase in the eruptive energy during the Creti eruption. In order to establish the age of the last effusive eruption in the northern sector of the Sabatinian District a radiometric $^{40}Ar/^{39}Ar$ analysis of the upper Prato Fontana lava was performed. According to the analysis this lava dates back to 134±33 ky. The volcanic products belonging to this cycle show a wider compositional variation (from phonolitic tephrite to potassic trachibasalt, Fig. 5) and also comprise rocks with particular characteristics (low alkali, Al_2O_3, Ba, Sr, Zr and high MgO and CaO contents, fig. 5). After this cycle, activity resumed with a series of phreatomagmatic explosions producing small, single maars (Monterosi, fig. 2) or coalescent craters along regional tectonic fractures in the eastern part of the investigated area (Valdiano Valley, fig. 2), most likely connected with shallow aquifers (De Rita *et al.,* 1993). A series of phreatomagmatic products (Monterosi and Monte Gagliozzo Units) were emplaced mainly in the eastern sector of the northern Sabatinian Volcanic District, although minor outcrops of the last erupted pyroclastic surges of the northern Sabatinian District (Campanella Unit) are also found in the south-western part of the investigated area. It should also be noted that the Campanella Unit is very rich in lithic fragments of prevailing sedimentary and plutonic origin, suggesting an important increase of the eruptive energy in this last phase. This paroxysmal eruption could be responsible of a deeper interaction with a relative involvement of the subvolcanic body. According to the radiometric data presented in this study and considering the most younger ages obtained in the surrounding areas (De Rita and Zanetti, 1986), the sixth phase probably dated back to the interval 155-40 ky.

Most of the phreatomagmatic products of the eastern sector are referred to a single (Monterosi) and coalescent (Valdiano Valley) eruptive centres that are located along a NW-SE fracture system (fig. 2), which is at a right-angle to the tectonic orientation of the initial Sabatinian Volcanic District activity (De Rita *et al.*, 1993). This NW-SE system could also be related to the main regional tectonic line that crosses northern Latium from the Vico Volcano to the eastern sector of the Sabatinian Volcanic District (fig. 1).

FINAL REMARKS

Stratigraphical and geological observations of the northern sector, together with geochronological and geochemical data, made it possible to reconstruct the volcanic evolution of the Sabatinian Volcanic District. This evolution is marked by important volcano-tectonic and erosional episodes, and can be subdivided into six phases. The new volcanic succession, illustrated in fig. 7, can be summarised in the following steps.

a) During the initial phases (I to IV, from 800 to 200 ky) the Sabatinian District was the site of intense volcanic activity which gave rise, in the investigated area, to the emplacement of important pyroclastic deposits (Bassano Romano, Valle Nobile and Macchia Bella Units) and phonolitic tephritic lava flows (*Valle del Mulino* and *Mola di Valdiano* lavas, Palombara Unit). These units are related to the oldest *Barca di Parma Synthem.*

b) After a strong erosional phase, subsequent explosive strombolian-type eruptions occurred in the northern Sabatinian Volcanic District (phase V), with the emplacement of the Ascarano Unit and the *Fosso della Stanga* and *Fosso del Sorbo* lava flows of phonolitic tephritic to tephritic compositions. They are grouped in the *Archi di Pontecchio Synthem*, which is within the interval 200-155 ky.

c) At about 155 ky there was strong explosive volcanic activity in the neighbouring Vico Volcanic District giving rise to the emplacement of the Tufo Rosso a Scorie Nere Vicano Unit, which constitute a stratigraphic marker bed of regional importance. Subsequently, there was important volcanic activity (phase VI) in the northern Sabatinian Volcanic District from 154 ky to <134 ky. This phase is related to the *Casalone Synthem* and began with effusive (Cornacchia, Poggio Licio and Prato Fontana Units) and explosive (Creti Unit) eruptions of phonolitic tephritic to potassic trachibasaltic compositions. Final phreatomagmatic explosions ended this phase as well as the volcanic activity of the northern sector of the Sabatinian Volcanic District giving rise to the emplacement of a sequence of pyroclastic surge deposits (Monterosi, Monte Gagliozzo and Campanella Units) from NW-SE aligned eruptive centres.

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