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Autor(en): **D'Atri, Anna / Dela Pierre, Francesco / Ruffini, Raffaella**

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Calcareous plankton biostratigraphy and $^{40}Ar/^{39}Ar$ dating of miocene volcaniclastic layers from Monferrato (NW Italy)

ANNA D'ATRI[1,2], FRANCESCO DELA PIERRE[1,2], RAFFAELLA RUFFINI[3,2], ANNA NOVARETTI[1], MICHAEL A. COSCA[4] & JOHANNES C. HUNZIKER[4]

Key words: Biostratigraphy, geochronology, Early-Middle Miocene, volcaniclastic layers

ABSTRACT

The results of $^{40}Ar/^{39}Ar$ dating integrated with calcareous plankton biostratigraphical data performed on two volcaniclastic layers (VLs) interbedded in Burdigalian to Lower Langhian outer shelf carbonate sediments cropping out in Monferrato (NW Italy) are presented. The investigated VLs, named Villadeati and Varengo, are thick sedimentary bodies with scarce lateral continuity. They are composed of prevalent volcanogenic material (about 87up to 90% by volume) consisting of glass shards and volcanic phenocrysts (plagioclase, biotite, quartz, amphibole, sanidine and magnetite) and minor extrabasinal and intrabasinal components. On the basis of their composition and sedimentological features, the VLs have been interpreted as distal shelf turbidites deposited below storm wave base. However, compositional characteristics evidence the rapid resedimentation of the volcanic detritus after its primary deposition and hence the VL sediments can be considered penecontemporaneous to the encasing deposits. Biostratigraphical analyses were carried out on the basis of a quantitative study of calcareous nannofossil and planktonic foraminifer associations, whilst $^{40}Ar/^{39}Ar$ dating were performed on biotite at Villadeati and on horneblende at Varengo.

The data resulting from the Villadeati section have permitted to estimate an age of 18.7±0.1 Ma for the last common occurrence (LCO) of *Sphenolithus belemnos* whereas those from Varengo allowed to extrapolate an age of 16.4 Ma ±0.1 Ma for the first occurrence (FO) of *Praeorbulina sicana*. This latter biovent is commonly used to approximate the base of the Langhian stage, that corresponds to the Early-Middle Miocene boundary.

RIASSUNTO

In questo lavoro vengono riportati i risultati di uno studio integrato geocronologico-biostratigrafico effettuato su due livelli vulcanoclastici (LV) intercalati in una successione di piattaforma esterna di età Burdigaliano-Langhiano inferiore affiorante in Monferrato (Italia nord-occidentale). In questo studio sono state effettuate datazioni radiometriche con il metodo $^{40}Ar/^{39}Ar$ su minerali contenuti nei livelli vulcanoclastici (biotite ed orneblenda) e analisi quantitative delle associazioni a nannofossili calcarei e foraminiferi planctonici contenuti nei livelli vulcanoclastici e nei sedimenti sotto e soprastanti. I LV studiati (Villadeati e Varengo) sono corpi sedimentari di spessore plurimetrico che presentano una scarsa continuità laterale; sono composti prevalentemente (fino al 90%) da materiale vulcanogenico costituito da vetro vulcanico, minerali vulcanici e, in minor quantità, componenti extra e intrabacinali. In base alle loro caratteristiche sedimentologiche i LV sono stati interpretati come torbiditi distali deposte sotto il livello di base delle onde da tempesta. Le caratteristiche composizionali evidenziano una rapida risedimentazione del detrito vulcanico; di conseguenza i sedimenti che costituiscono i LV possono essere considerati penecontemporanei ai depositi incassanti.

I dati ricavati dalla sezione di Villadeati hanno permesso di estrapolare un'età di 18.7±0.1 Ma per l'ultima comparsa comune di *Sphenolithus belemnos* mentre da quelli della sezione di Varengo si è ottenuta un'età di 16.4 Ma ±0.1 Ma per la prima comparsa di *Praeorbulina sicana*. Quest'ultimo bioevento è comunemente utilizzato per approssimare la base del Langhiano, che corrisponde al limite Miocene inferiore-medio.

1. Introduction

In the Lower to Middle Miocene succession of Monferrato (NW Italy) several volcaniclastic layers (VLs) are interbedded with calcareous sediments. The volcaniclastic layers, showing rhyolitic composition consist of impure vitric arenites and siltites that contain minerals (i.e. hornblende and biotite) suitable for radiometric age determination (Ruffini et al. 1991; 1995; d'Atri et al. 1999). This uncommon situation is of great interest in stratigraphy, since it permits a numerical time calibration of relevant biostratigraphic events.

In this paper, we present the results of $^{40}Ar/^{39}Ar$ dating integrated with calcareous plankton biostratigraphical data performed on two VLs interbedded in Burdigalian to Lower Langhian outer shelf carbonate sediments. The results have permitted the calibration, for the Mediterranean region, of two important bioevents: the last common occurrence (LCO) of *Sphenolithus belemnos* and the first occurrence (FO) of *Praeorbulina sicana*. This second bioevent is commonly used to approximate the base of the Langhian stage.

[1] Dipartimento di Scienze della Terra, Via Accademia delle Scienze 5, Torino, Italy. E-mail d'atri@dst.unito.it
[2] CNR – C.S. geodinamica delle catene collisionali, Via Accademia delle Scienze 5, Torino, Italy.
[3] Dipartimento di Scienze Mineralogiche e Petrologiche, Via Valperga Caluso 37, Torino, Italy.
[4] Institut de Minéralogie- BSFH 2, Lausanne, Switzerland.

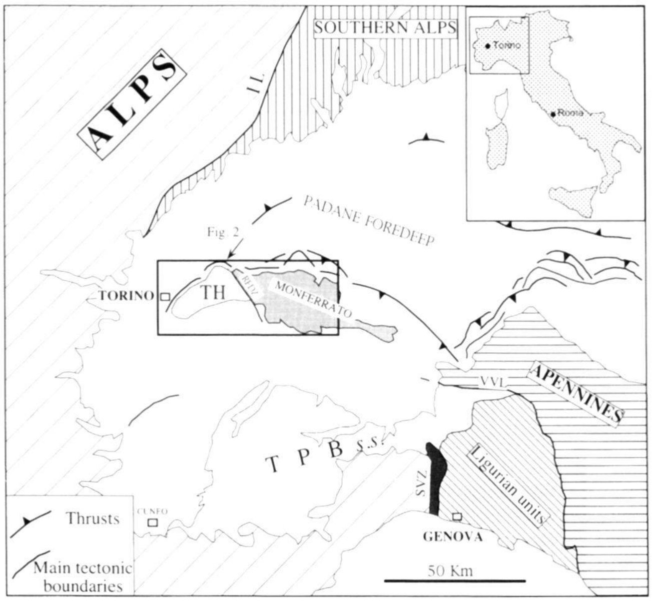

Fig. 1. Structural sketch map of NW Italy. IL: Insubric line; SVZ: Sestri-Voltaggio Zone; VVL: Villalvernia-Varzi line; RFDZ: Rio Freddo Deformation Zone; TPB s.s.: Tertiary Piemonte Basin s.s. Structural Model of Italy (1990), modified.

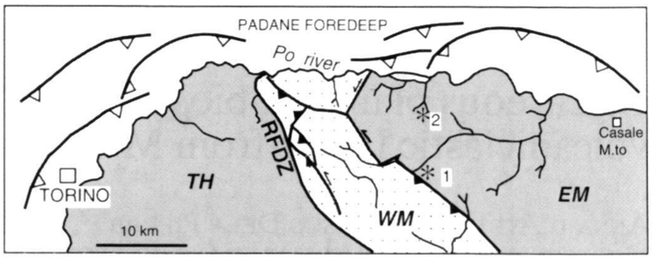

Fig. 2. Structural sketch map of Torino Hill and Monferrato domains, showing the location of the study volcaniclastic layers. 1: Villadeati; 2: Varengo. TH=Torino Hill; WM=Western Monferrato; EM=Eastern Monferrato; RFDZ=Rio Freddo Deformation Zone. Modified after Piana & Polino (1995).

Fig. 3. Varengo volcaniclastic layer. Four decimeter-thick beds are clearly recognisable.

2. Stratigraphy

The Monferrato (Fig. 1) corresponds to the NW termination of the Apenninic thrust belt and is composed of an Eocene-Miocene mainly terrigenous succession resting unconformably on Upper Cretaceous and Eocene Ligurian flysch (Clari et al. 1995). It is composed of two main tectonostratigraphic units, separated by a NNE-SSW trending fault system and characterized by distinct pre-Langhian successions (Piana & Polino 1995; Fig. 2):

a) the Western Monferrato, consisting of Oligocene to Burdigalian coarse terrigenous sediments deposited both in subsiding basins and on structural highs;
b) the Eastern Monferrato, composed of Oligocene to Aquitanian deep water terrigenous facies, followed unconformably by Burdigalian to Early Langhian carbonate shelf sediments, known as the Pietra da Cantoni (PDC) Group, in which the study VLs are interbedded. These carbonate sediments consist of "foramol" platform (*sensu* Carannante et al. 1988) biocalcarenites and biocalcirudites, grading upward and westward to glaucony rich calcarenites, deposited in a storm dominated shelf, and finally to outer shelf calcareous and siliceous marls.

In both the Eastern and Western Monferrato, Burdigalian to Early Langhian deposits are followed unconformably by Langhian-Serravallian shelf calcarenites (Tonengo Calcarenites). The succession ends with Tortonian slope marls and Messinian lagoonal facies recording the Messinian salinity crisis.

3. The volcaniclastic layers

Two VLs have been investigated in this work: Villadeati and Varengo (Fig. 2). They crop out in the Eastern Monferrato and are interbedded in the outer shelf marls of the PDC Group. In particular, the Villadeati VL is located in the lower part of the carbonate succession, whilst the Varengo VL is positioned in the upper part, at the boundary with the Tonengo Calcarenites. Both the VLs have been described in detail in d'Atri et al. (1999).

The study VLs are thick sedimentary bodies (10 m Villadeati; 6 m Varengo, Fig. 3) showing scarce lateral continuity; they are made up of a succession of several decimetric thick distinct beds, characterized by erosional basal contact and normal grading. Parallel laminae and elongated decimetric fragments of unconsolidated volcaniclastic sediment have been locally observed within the single beds, together with cm-sized firm ground burrows at the top (d'Atri et al. 1999).

The VLs (Fig. 4) correspond to coarse to medium impure vitric arenites and siltites with grain-size ranging from 0.6 to

Tab. 1. a) Recalculated modal point count data for the V10 and VR samples. % = modal percentage; b) Composition of the glassy and phenocrystic fractions analysed from V10 and VR samples. (n10) = n° analyses. StDev. = Standard deviation. The analyses were performed on a SEM-EDS system at the University of Torino.

Components	% mod	Villadeati V10		% mod	Varengo VR	
Extrabasinal grains	4.3%	White mica, blue amphibole, epidote		4.4%	White mica, blue amphibole, epidote	
Intrabasinal grains	3.2%	Bioclasts and glaucony		9.5%	bioclasts	
Volcanic component	92.5%	Glass	71%	86.1%	Glass	62%
		Plagioclase	7.8%		Plagioclase	9.5%
		Biotite	7.4%		Hornblende	5.1%
		Quartz	2.8%		Biotite	4.6%
		Sanidine	1.8%		Quartz	3.3%
		Amphibole	0.7%		Fe-Ti oxides	0.9%
		Zircon/Apatite	1.0%		Zircon/Apatite	0.7%

Tab. 1a

	Villadeati V10	Varengo VR
Glass (n.10)	SiO_2 = 72.6% StDev (1.17)	SiO_2 = 72.3% StDev (0.75)
	Al_2O_3 = 11.86 StDev (0.18)	Al_2O_3 = 12.41 StDev (0.33)
	Na_2O = 2.08 StDev (0.66)	Na_2O = 2.01 StDev (0.15)
	K_2O = 3.92 StDev (0.62)	K_2O = 3.03 StDev (0.26)
Plagioclase	$An_{41-33}Ab_{57-64}Or_{2-3}$	$An_{68-30}Ab_{32-69}Or_{0-1}$
Hornblende	Ferroan pargasitic Hornblende	Edenitic hornblende
Biotite	Mg/(Mg+Fet) =0.39-0.35	Mg/(Mg+Fet) =0.45-0.43
Sanidine	$Or_{60}Ab_{38}An_2$	

Tab. 1b

0.05 mm. They are composed (Tab.1a) of prevalent volcanogenic material (about 87%from 86% up to 92% by volume) and minor extrabasinal and intrabasinal components (Ruffini 1995; d'Atri et al. 1999) (Tab.1). Extrabasinal grains are mainly represented by metamorphic minerals (blue amphibole, white mica and epidote) and their content can reach the 4% by the volume. Intrabasinal grains are common and can represents about up to the 9% of the components; they are composed of bioclasts (benthonic and planktonic foraminifers, echinoid spines and bryozoan fragments), glaucony, phospates and pyrites.

The volcanogenic component consists of glass shards and minor volcanic phenocrysts. The main compositional features of the volcanic components are summarised in (Tab.1b). Glass shards are colourless and show predominantly platy and cuspate shapes; elongated pumice fragments are common. The volcanic phenocrysts are plagioclase, biotite, quartz, amphibole, sanidine and magnetite. Plagioclase mainly occurs as isolated slightly zoned crystals, whose composition ranges from labradorite to andesine. Biotite occurs as brown idiomorphic flakes. In the Varengo VL edenitic amphibole is the dominant mafic phase whereas in the Villadeati VL amphibole is hardly present. Sanidine is scarce in both layers. Zircons, apatite and Ti-rich magnetite are common accessory phases.

On the basis of their composition and their sedimentological features, the investigated VLs have been interpreted as distal shelf turbidites deposited below storm wave base. The turbidity currents, involving primary pyroclastic fall deposits and intrabasinal sediments, were triggered by storm activity acting in the more internal part of the shelf (d'Atri et al. 1999).

The abundance of unaltered delicate shards and pumice fragments indicates a rapid resedimentation of the volcanic detritus after its primary deposition (e.g. Bull & Cas 1991), and hence the VL sediments can be considered penecontemporaneous to the encasing deposits. For this reason the Villadeati and Varengo VLs have been chosen for a biochronological study.

4. Methodology

The study VLs have been analyzed from a biostratigraphical and geochronological point of view.

Biostratigraphy

The PDC Group, encasing the Villadeati and Varengo VLs, is characterized by an abundant calcareous nannofossil and foraminifer content. The biostratigraphical data about this unit are reported in several works (Schüttenhelm 1976; Bicchi et al. 1994; Novaretti 1995; Bicchi 1998).

A quantitative study of calcareous nannofossil and planktonic foraminifer associations in the Villadeati and Varengo sections has been carried out. These sections include the VLs and few meters of under- and overlying sediments. In particular, 17 samples were collected in the Villadeati section and 10 samples in the Varengo one (Fig. 5, 6) The calcareous nannofossil samples were prepared following standard methods ("smear slides") and studied under the light microscope. The

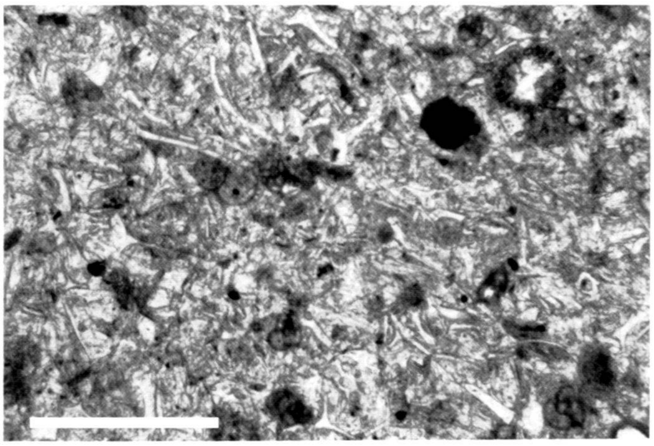

Fig. 4. Microphotograph showing the main petrographic features of the study VLs studied. The well preserved vitroclastic texture with glass shards and abundant bioclasts is well recognisable. From Villadeati volcanoclastic layerVL. The bar corresponds to 1 mm.

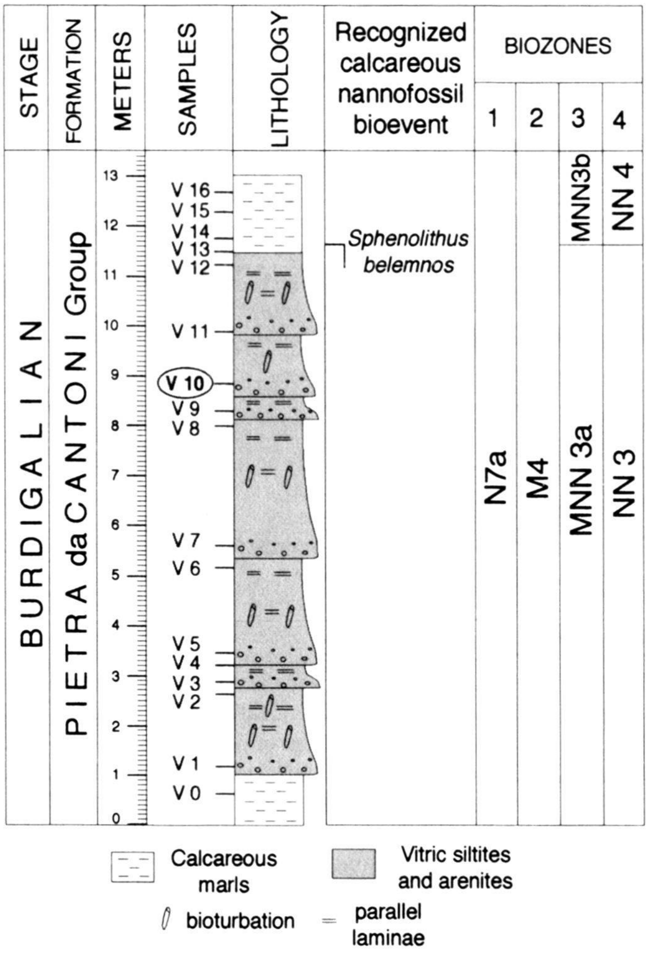

Fig. 5. Stratigraphic log of the Villadeati section showing the position of the study samples and of the recognized calcareous nannofossil bioevent. The dated sample is V10. Biozones are after: 1) Blow (1969); 2) Berggren et al. (1995); 3) Fornaciari & Rio (1996); 4) Martini (1971). For further explanations, see the text.

data were collected following the quantitative methods discussed in Rio et al. (1990). All fractions of washed residues were examined for a semiquantative study of planktonic foramininfers.

The calcareous nannofossils are scarce but well preserved in the VL samples, while in the encasing sediments they are normally common and poorly preserved. The foraminifers are abundant and well preserved.

Calcareous nannofossil data have been referred to the Mediterranean zonation (Fornaciari & Rio 1996; Fornaciari et al. 1996) and compared to the standard zonations (Martini 1971; Okada & Bukry 1980). Planktonic foraminiferal data have been referred to the zonations of Blow (1969) (used according to Miculan, 1994; Novaretti, 1995; Novaretti et al., 1995) and of Berggren et al. (1995).

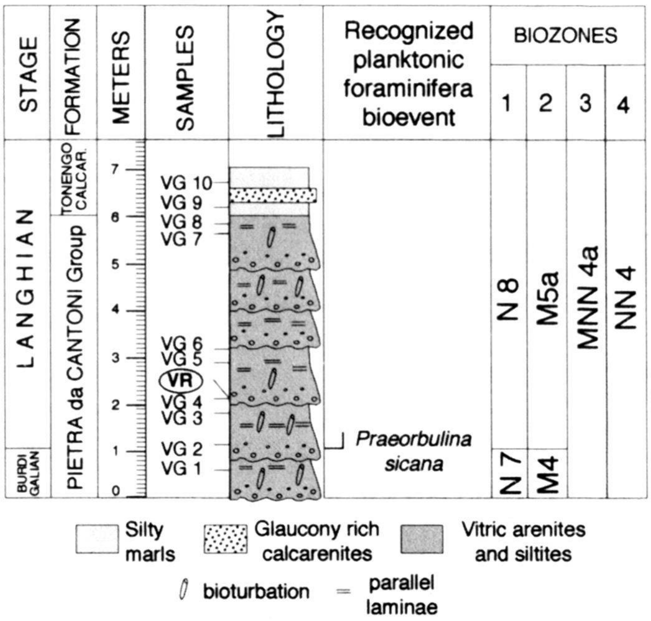

Fig. 6. Stratigraphic log of the Varengo section showing the position of the study samples and of the recognized planktonic foraminifera bioevent. The dated sample is VR. Biozones are after: 1) Blow (1969); 2) Berggren et al. (1995); 3) Fornaciari & Rio (1996); 4) Martini (1971). For further explanations, see the text.

Geochronology

Samples for geochronological purposes have been collected in the lower part of the single decimetric thick graded beds composing the VLs. In fact, in this portion of the beds grain size is coarser and richer in datable minerals. Samples V10 from Villadeati VL (Fig. 5) and VR from Varengo VL (Fig. 6) have been selected. The minerals (biotite for V10 and hornblende for VR) were separated by sieving in water the samples and by magnetic and densimetric treatment. They were cleaned for 5 min in an ultrasonic bath and finally hand-picked under a binocular microscope. EDS and X-ray diffraction analyses controlled the composition of the investigated material.

Standards of known age and samples were irradiated in the central thimble position of the USGS TRIGA reactor in Denver, Colorado (Dalrymple et al. 1981). The standard biotite HD-B1 (Fuhrmann et al. 1987) was used for the $^{40}Ar/^{39}Ar$ experiments using a refined K/Ar age of 24.21 Ma (Hess & Lippolt 1994). The $^{40}Ar/^{39}Ar$ analyses were made using a low blank, double vacuum resistance furnace at the Université de Lausanne, a MAP 215-50 mass spectrometer, and an electron multiplier. The raw isotopic data, extrapolated to time zero, were corrected for backgrounds, blanks, mass discrimination, radioactive decay, and interfering isotopic reactions (Cosca et al. 1992).

Typical ^{40}Ar blank values were 4×10^{-15} moles at temperatures below 1000°C rising to 9×10^{-15} moles at 1600°C.

Biotite V10					J= 0.0025445		wt= 2.74 mg			
T (°C)	^{40}Ar	^{39}Ar	^{38}Ar	^{37}Ar	^{36}Ar	^{40}Ar*/^{39}ArK	^{39}Ar (%of tot)	%^{40}Ar*	K/Ca (mol/mol)	Age (Ma)
700	75.74 ± .17	5.447 ± .018	0.412 ± .005	0.066 ± .010	0.1876 ± .0033	3.73 ± 19	4.86	26.8	40.63	17.0 ± .9
870	75.17 ± .18	14.413 ± .042	0.991 ± .006	0.173 ± .019	0.0509 ± .0020	4.17 ± .04	12.86	79.9	40.77	19 .0± .2
970	92.74 ± .13	19.452 ± .047	1.338 ± .005	0.224 ± .028	0.0376 ± .0006	4.19 ± .02	17.36	87.9	42.64	19.1 ± .1
1050	104.06 ± .21	22.188 ± .071	1.543 ± .005	0.384 ± .016	0.0409 ± .0014	4.14 ± .03	19.80	88.3	28.31	18.9 ± .2
1100	87.39 ± .19	20.329 ± .071	1.367 ± .007	0.168 ± .015	0.0181 ± .0011	4.03 ± .02	18.14	93.8	59.23	18.4 ± .1
1145	109.08 ± .22	26.598 ± .078	1.723 ± .009	0.157 ± .016	0.0091 ± .0013	3.99 ± .02	23.74	97.4	83.27	18.2 ± .1
1190	16.16 ± .030	3.612 ± .012	0.232 ± .003	0.067 ± .014	0.0046 ± .0012	4.09 ± .10	3.22	91.4	26.24	18.7 ± .5

Tab. 2. Incremental heating analytical measurements for V10 and VR samples (gas in 10^{-15} mol; analytical errors bars ± 2 σ).

Hornblende VR					J= 0.002558		wt= 8.48 mg			
T (°C)	^{40}Ar	^{39}Ar	^{38}Ar	^{37}Ar	^{36}Ar	^{40}Ar*/^{39}ArK	^{39}Ar (%of tot)	%^{40}Ar*	K/Ca (mol/mol)	Age (Ma)
850	15.38± .04	0.893± .005	0.115 ± .001	0.422 ± .026	0.0362 ± .0012	5.27 ± .42	1.92	30.6	1.04	24.1 ± 1.9
1000	23.83± .04	2.023± .009	0.600 ± .005	5.318 ± .069	0.0472 ± .0015	5.09 ± .23	4.34	43.1	0.19	23.3 ± 1.0
1050	61.22± .14	13.736± .027	6.761 ± .012	71.783 ± .255	0.0603 ± .0021	3.57 ± .05	29.39	79.9	0.09	16.4 ± .20
1075	32.96± .13	8.455 ± .021	4.019 ± .016	43.839 ± .049	0.0221 ± .0007	3.54 ± .03	18.09	90.4	0.09	16.2 ± .20
1100	25.52± .08	6.517 ± .027	2.767 ± .014	32.798 ± .091	0.0184 ± .0017	3.48 ± .08	13.95	88.6	0.10	16.0 ± .40
1150	35.11± .09	8.872 ± .026	3.693 ± .010	47.474 ± .173	0.0230 ± .0004	3.61 ± .02	18.98	91.0	0.09	16.6 ± .10
1200	18.32± .04	4.555 ± .023	2.043 ± .003	25.793 ± .150	0.0137 ± .0016	3.58 ± .11	9.74	88.7	0.09	16.4 ± .50
1300	12.64± .02	1.681 ± .005	0.757 ± .007	10.593 ± .054	0.0246 ± .0010	3.69 ± .19	3.59	48.9	0.09	16.9 ± .80

In order to remove most of the adsorbed gas, the samples were heated in the crucible under vacuum for some time just before measurements: 30 min at 750°C (Hornblende VR) and 20 min at 550 °C (Biotite V10). The portion of the gas released at these temperatures is extremely small and does not significantly influence the total gas age for the material dated. All errors are given at the (2s) 95% confidence level. Summarized analytical data are gathered in Tab. 2.

5. Results

Villadeati VL (Fig. 5)

Biostratigraphy

The calcareous nannofossil assemblage of this section is characterized by the presence of *Helicosphaera ampliaperta*, *H. carteri* and *Sphenolithus belemnos*; this association points to Subzone MNN3a (*S. belemnos* Total-Range Zone, Late Burdigalian, Fornaciari & Rio 1996), which corresponds to the upper part of Zone NN3 (Martini 1971) and to the lower part of Zone CN2 (Okada & Bukry 1980).

At the top of the section (between samples V13 and V14, Fig. 5) the LCO of *Sphenolithus belemnos* has been recognized; this bioevent defines the MNN3a-MNN3b (Fornaciari & Rio 1996) and the NN3-NN4 (Martini 1971) zonal boundaries.

The planktonic foraminifer assemblage is characterized by abundant *Globigerinoides* (*Gs. trilobus*, *Gs. subsacculifer*, *Gs. quadrilobatus*, *Gs. subquadratus*, *Gs. trilobus-bisphericus* transition) and *Paragloborotalia* (*P. acrostoma*, *P. mayeri* gr., *P. siakensis*); *Globoquadrina dehiscens*, *Globigerinella obesa* and *Globorotalia scitula* gr. are also present to a lesser extent. The absence of typical *Gs. bisphericus* assignes the section to Subzone N7a, Late Burdigalian in age, above the last occurrence (LO) of *Catapsydrax dissimilis* and below the FO of *Gs. bisphericus*. This Subzone corresponds to the lower part of Zone M4 of Berggren et al. (1995). No planktonic foraminiferal event has been detected in this section.

Geochronology

In the sample V10 argon was released in seven steps (Tab. 2). The corresponding age spectrum is not perfectly flat and the total gas age is 18.6 ± 0.1 Ma (Fig. 7a). The plateau spectrum yielded an age of 18.7 ± 0.1 Ma comprising five successive steps for a total gas released of about 92%. The little disturbance observed in the spectrum plateau age could be related to alteration of a very small proportion of the sheets during the irradiation (Odin et al., 1995). Inverse isochron diagram, com-

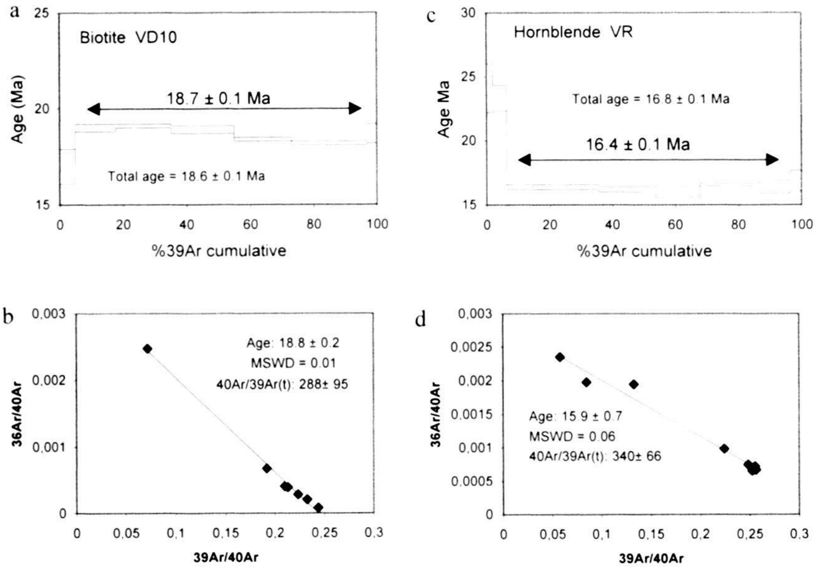

Fig. 7. Age spectra and isochron plots for minerals extracted from volcaniclastic layers. a) age spectrum of biotite V10; b) isochron plot for biotite V10; c) age spectrum of hornblende VR; b) isochron plot for hornblende VR.

monly used to identify the trapped $^{40}Ar/^{36}Ar$ ratio, was drawn for this sample and shown in Fig. 7b. The correlation plot $^{36}Ar/^{40}Ar$ vs. $^{39}Ar/^{40}Ar$ displays an identical age of 18.8 ± 0.2 Ma (MSWD = 0.01) and an initial $^{40}Ar/^{36}Ar$ ratio of 288± 95, very close to the atmospheric ratio.

The good agreement among the total gas age, the plateau age and the isochron age confirmed the geological significance of the calculated age. We interpret the 18.7 ± 0.1 Ma to represent the age of the eruption, i.e. the time of the explosive volcanic activity which originated the ashes.

Varengo VL (Fig. 6)

Biostratigraphy

In the Varengo section, calcareous nannofossil association is dominated by *Sphenolithus heteromorphus*, whereas *Helicosphaera ampliaperta* is discontinuously present in very low frequency. The assemblage indicates the uppermost part of Zone MNN4a (Fornaciari et al. 1996), above the LCO of *H. ampliaperta* and below the paracme beginning of *S. heteromorphus*; it correlates with upper part of standard Zones NN4 (Martini 1971) and CN3 (Okada & Bukry 1980). Because in the Mediterranean region the LCO of *H. ampliaperta* approximates the Burdigalian-Langhian boundary (Fornaciari et al. 1996), the Varengo section can be referred to the Lower Langhian.

No calcareous nannofossil event has been recognized in this section.

The planktonic foraminifer association comprises abundant *Globigerinoides* (*Gs. trilobus*, *Gs. bisphericus*, *Gs. subquadratus*), *Dentoglobigerina* (*D. altispira*, *D. langhiana*), *Paragloborotalia siakensis* and *Globorotalia scitula* gr. Near the base of the Varengo VL (between sample VG1 and VG3) the FO of *Praeorbulina sicana* was recognized, allowing to ascribe the section to Zone N8 (*sensu* Miculan 1994 and Novaretti et al. 1995) and to Subzone M5a of Berggren et al. (1995), Langhian in age.

The FO of *P. sicana* is an important bioevent that, following a well established practice, approximates the base of the Langhian Stage (Miculan 1994; Berggren et al. 1995).

Geochronology

Eight steps were measured from hornblende obtained from sample VR of the Varengo VL (Tab. 2). Even if the corresponding age spectrum (Fig. 7c) is slightly disturbed in the first two steps, it shows a large flat portion with a total gas age at 16.8 ± 0.1 Ma. The plateau age is 16.4 ± 0.1 Ma (Fig. 7d) and comprises five successive steps for a total gas released of 88.2%. The first two steps can be interpreted taking into account the sympathetic behaviour of the K/Ca ratio and the step ages. In fact, the sudden increment of the K/Ca ratio could be explained by the presence of little inclusions of biotite in the analysed hornblende.

The isochron age (Fig. 7d) reveals an age of 15.9 ± 0.7 Ma (MSWD = 0.06), that is younger than the obtained plateau age and an initial $^{40}Ar/^{36}Ar$ ratio of 340± 66, higher than the atmospheric ratio. As in the case of volcanic ashes erupted in the atmosphere, the presence of non-atmospheric argon is *a priori* unlikely (Odin et al. 1995), this imprecise value of atmospheric ratio could be due to the large errors on the initial or trapped $^{40}Ar/^{36}Ar$ ratios which is consistent with tight clustering of the data points.

For this sample the age of the plateau (16.4 ± 0.1 Ma) is proposed as the age of the eruption.

6 . Discussion and conclusions

The study VLs correspond to resedimented deposits whose compositional characteristics evidence the rapid resedimentation of the volcanic detritus after its primary deposition (d'Atri et al. 1999). As a consequence, the geochronological data can be confidently used for biochronological purposes.

The data resulting from Villadeati VL have permitted to estimate the age of the LCO of *Sphenolithus belemnos*, whereas those of Varengo allowed to calibrate the FO of *Praeorbulina sicana*.

Age of the LCO of *Sphenolithus belemnos*

In the Villadeati section, the LCO of *Sphenolithus belemnos* has been recorded between samples V13 and V14, that are respectively located 2,65 m and 2, 95 m above the dated sample (V10). Sedimentological characteristics of the VL suggest that it has been deposited by turbidity currents triggered by storm activity (d'Atri et al. 1999). Since deposition by turbidity currents can be considered as an "instantaneous" geological event (Einsele et al. 1991), the thin stratigraphic thickness separating the dated sample from the recorded bioevent, that is located at the very base of the carbonate sediments overlying the VL, can be assumed to represent a scarcely significant time interval. As a consequence, we can confidently extrapolate an age of 18.7 ± 0.1 Ma for the LCO of *Sphenolithus belemnos*.

No data about tha LCO of *Sphenolithus belemnos* are available from the Mediterranean region. As a consequence, the results from Villadeati section can be only compared with data obtained from DSDP and ODP holes drilled in the oceans. The available ages for the LO of this taxon range from 18.1 Ma (indirect biostratigraphic interpolation; Ryan et al. 1974) to 18.8 Ma in Western equatorial Indian Ocean (Backman et al., 1990); in the North Atlantic Gartner (1992) placed the LO of *S. belemnos* at the top of Chron 5E, corresponding to 18.78 Ma in the GPTS of Cande & Kent (1995). Finally, according to Berggren et al. (1995) the last appearance datum (LAD) of *S. belemnos* has an age of 18.3 Ma.

Age of the FO of *Praeorbulina sicana*

In the Varengo section, the FO of *Praeorbulina sicana* has been recorded within the VL, between samples VG1 and VG3, whereas the dated sample (VR), has been collected in the bed immediately overlying sample VG3. Hence, the biostratigraphic event and the geochronological datum are separated by a stratigraphic interval ranging from 150 cm (distance between sample VG1 and sample VR) to 30 cm (distance between sample VG3 and sample VR). Considering that the biostratigraphic event and the geochronological datum nearly coincide and are recorded in sediments deposited by turbidity currents, the maximum age of the FO of *P. sicana* can be extrapolated to be 16.4 ± 0.1 Ma.

This result is in good agreement with recently published data. According to Berggren et al. (1995) the first appearance datum (FAD) of *P. sicana* has an age of 16.4 Ma (see also Barron et al. 1985), that is slightly older of the interpolated age of 16.02 ± 0.16 Ma for this bioevent in the Mediterranean region (Moria section, Umbria Marche basin; Deino et al. 1997).

The FO of *P. sicana* is commonly used to approximate the base of the Langhian stage, that corresponds to the Early-Middle Miocene boundary. The biochronologic result obtained from the Monferrato are in agreement with the ages of this chronostratigraphic boundary proposed by Odin & Odin (1990) and Berggren et al. (1995), that are respectively of 16 Ma and 16.4 Ma.

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