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Volcaniclastic layers in upper Triassic-Jurassic deep-sea sediments from the Lucanian Apennine, southern Italy: mineralogy, geochemistry, and palaeotectonic implications

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ABSTRACT. — In complex mountain chains such as the southern Apennines, analysis of ancient volcanics may provide new information on reliable palaeotectonic scenarios. In the lower part of the *Scisti silicei* Formation (upper Triassic-Jurassic, Lagonegro units) outcropping in the Agri Valley, Lucanian Apennine, volcaniclastic layers were found interbedded with pelagic sediments, showing facies changes over a narrow area. These layers are prevalently composed of quartz and feldspar. Compared with the UCC (Upper Continental Crust), the volcaniclastic beds are depleted in both large-ion lithophile (Rb, Sr) and high field strength (Ti, Nb, Hf, Zr, Th, RE) elements, and are strongly enriched in first-row transition elements (Mn, Ni, Cu) and Ce. Their volcaniclastic origin is clearly evidenced by the discrimination diagram based on first-row transition elements V, Cr and Ni and immobile elements Zr and Ti. The source rocks of these volcaniclastic layers were probably of dacitic-rhyolitic to rhyolitic composition, as suggested by chemical evidence. The chemical analyses of unaltered plagioclase, indicating albitic composition, are consistent with such a source. The distribution and concentration of REE are typical of andesitic magmas. The REE chondrite-normalized patterns of the sampled layers are similar to reported REE patterns of arc-related rhyolitic ignimbrites. The Ti-Y-Zr ternary plot and Y *vs* Nb and Y+Nb *vs* Rb discrimination diagrams proposed for felsics also indicate the affinity of the volcaniclastic layers with arc-related rhyolitic tephra in subacqueous environments. This suggests a more complex palaeogeographic scenario than the classic view, according to which the Lagonegro deep-sea basin was generated in an extensional regime and bordered by normal faults during the entire Mesozoic tectono-sedimentary evolution. A continental transform zone able to produce local transpressional structures and to emulate the magmatic context of collisional margins may be envisaged as partly responsible for the basin evolution in a general context of extensional tectonics. At shallower structural level, the transform fault system may have controlled the Triassic-Jurassic facies pattern of the Lagonegro basin whereas, at depth, such anisotropy probably influenced the crustal and magmatic evolution of this part of the *Adria* palaeomargin.

RIASSUNTO. — In orogeni complessi e con alti valori di raccorciamento come l'Appennino meridionale, l'analisi di vulcaniti o vulcanoclastiti antiche può permettere di fare luce sui possibili scenari paleogeografici e paleotettonici. Nella porzione basale della Formazione degli *Scisti silicei* (Trias superiore - Giurassico) affiorante in alta Val d'Agri (Appennino lucano) sono stati rinvenuti diversi livelli vulcanoclastici intercalati a pelagiti,

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che mostrano decisi cambiamenti di facies in ambiti geografici piuttosto ristretti. Tali livelli sono costituiti in prevalenza da quarzo e feldspati. I livelli vulcanoclastici risultano, se confrontati con la UCC (*Upper Continental Crust*), impoveriti sia in Rb e Sr che in elementi ad alta forza di campo (Ti, Nb, Hf, Zr, Th e Terre Rare) mentre sono arricchiti in alcuni metalli di transizione (Mn, Ni, Cu) nonché in Ce. L'origine vulcanoclastica dei livelli è chiaramente evidenziata nel diagramma di discriminazione basato sui metalli di transizione V, Cr, Ni e sugli elementi immobili Zr e Ti. I dati chimici suggeriscono che le vulcaniti dal cui smantellamento derivano i livelli vulcanoclastici avevano, con molta probabilità, composizione da dacitico-riolitica a riolitica. Le analisi chimiche di plagioclasi inalterati rinvenuti nei livelli vulcanoclastici mostrano una composizione albitica in accordo con l'ipotesi di una roccia sorgente acida. Anche la distribuzione degli elementi delle Terre Rare è tipica di magmi di natura andesitica. I *pattern* delle Terre Rare, normalizzati alle condriti, mostrano forti similitudini con i *pattern* di ignimbriti di composizione riolitica associate ad ambiente di arco vulcanico. Diversi diagrammi di discriminazione, su base geochimica, dell'ambiente geotettonico (Ti-Y-Zr, Y *vs* Nb, Y+Nb *vs* Rb) hanno fornito indicazioni relative all'appartenenza dei livelli vulcanoclastici a contesti sinorogenici di arco vulcanico. Poiché la storia geologica della regione permette di escludere una tale ipotesi, unitamente al retaggio dell'orogenesi ercinica, troppo lontana nel tempo, gli autori propongono che la messa in posto delle vulcaniti acide – il cui smantellamento erosivo ha poi fornito il materiale costituente i livelli studiati – sia stata dominata da una zona di trasferimento tettonico in ambiente continentale con locali condizioni transpressive legate a flessi, riseghe o disposizioni *en échelon* delle faglie principali. I sistemi transpressivi sono infatti spesso intrusi da magmi acidi a causa del gradiente verticale di pressione lungo le zone di taglio orizzontale e della loro capacità di spingere verso l'alto le masse magmatiche granitiche in sovrappressione. Tali condizioni avrebbero permesso di emulare i caratteri magmatici di margini collisionali nel più generale contesto estensionale del paleomargine mesozoico apulo-africano. Una simile anisotropia potrebbe inoltre essere responsabile della peculiare distribuzione delle facies altotriassiche-infragiurassiche del bacino di Lagonegro.

KEY WORDS: *mineralogy, geochemistry, palaeotectonics, volcaniclastic horizons, Mesozoic, Lagonegro basin, southern Apennines (Italy).*

INTRODUCTION AND REGIONAL OUTLINES

The pre-existence of major palaeotectonic structures affecting the Tethyan passive margins is often invoked to explain some present-day features of the peri-Mediterranean orogenic belts, although this is not always easy to prove in complex structural patterns. As a matter of fact, the restoration of the Mesozoic tectonic setting of the south-Apennines segment of the African passive palaeomargin is problematic, since the chain is strongly affected by Neogene contractional and Quaternary strike-slip and extensional tectonics. The occurrence of ancient volcanic layers in sedimentary successions is one of the most useful keys to better definition of the palaeotectonic picture and the geodynamic palaeoenvironment of a greatly shortened wedge like the southern Apennines. In the lower part of the *Scisti silicei* Formation (upper Triassic-Jurassic, Lagonegro units) outcropping near the village of Paterno in the high valley of the Agri River, Lucanian Apennine, we found for the first time three volcaniclastic layers interbedded with pelagic sediments, which were examined by means of geological, mineralogical and geochemical approaches. Recently, Di Girolamo *et al.* (2000) found upper Triassic andesitic tuffites in the shallow-water carbonates of the Calabrian Coastal Range (southern Italy). According to these authors, the geological and petrological features of these rocks suggest a geodynamic scenario related to the consumption of palaeo-Tethyan lithosphere by subduction. The Rhaetian age assigned by the authors to these felsic tuffites is close to the age of the volcaniclastic rocks examined in this paper (see next section).

The southern Apennines are a NE-verging fold-and-thrust belt, mainly derived from the deformation of the African-Apulian passive margin («Adriatic microplate» or western *Adria*, *sensu* D'Argenio *et al.*, 1980). The palaeomargin included the Lagonegro basin, generated by continental rifting since middle Triassic times (Scandone, 1975; Wood, 1981).

The Lagonegro successions identify a 40-km-wide belt limited by Meso-Cenozoic shallow-water carbonates (Fig. 1). The general stratigraphy may be summarised as follows (Pescatore *et al.*, 1999): i) Triassic to Oligocene pre-orogenic successions of the Lagonegro basin; ii) upper Oligocene-lower Miocene siliciclastic successions of the Numidian basin; iii) Langhian to Tortonian syntectonic successions of the Irpinian basin.

The most ancient rocks of the Lagonegro pre-orogenic successions are made up of shallow-water siliciclastic sediments, organogenic limestones and, towards the top, siliciclastic deposits, testifying progressive deepening of the basin (Monte Facito Fm, lower-middle Triassic). The overlying pelagic succession is characterised by predominant carbonate sedimentation up to the late Triassic (*Calcari con selce* Fm, cherty limestone), later replaced by Jurassic siliceous sedimentation (*Scisti silicei* Fm, mostly radiolarite and chert). During Cretaceous times, turbiditic sedimentation took place (*Galestri* Fm, siliceous marl and shale), followed by calcareous-clastic gravity flows interbedded with reddish marl and shale («Flysch Rosso» *Auct.*), indicating a substantial increase in tectonic activity along platform-basin boundaries, which produced uplift and erosion of shelf margins between the late Cretaceous and the Oligocene.

The chain was accreted from late Oligocene to Pleistocene times, and is composed of a Mesozoic-Cenozoic sedimentary cover from quite different palaeogeographic domains (i.e., Ligurian oceanic crust and western passive margin of the Adriatic plate), and of the Neogene-Pleistocene piggyback basin and foredeep deposits of the active margin. The average trend of the chain axis is about N150°, corresponding to the strike of the main thrusts and coaxial normal faults. Shortening of up to 100% is estimated for the southern Apennine

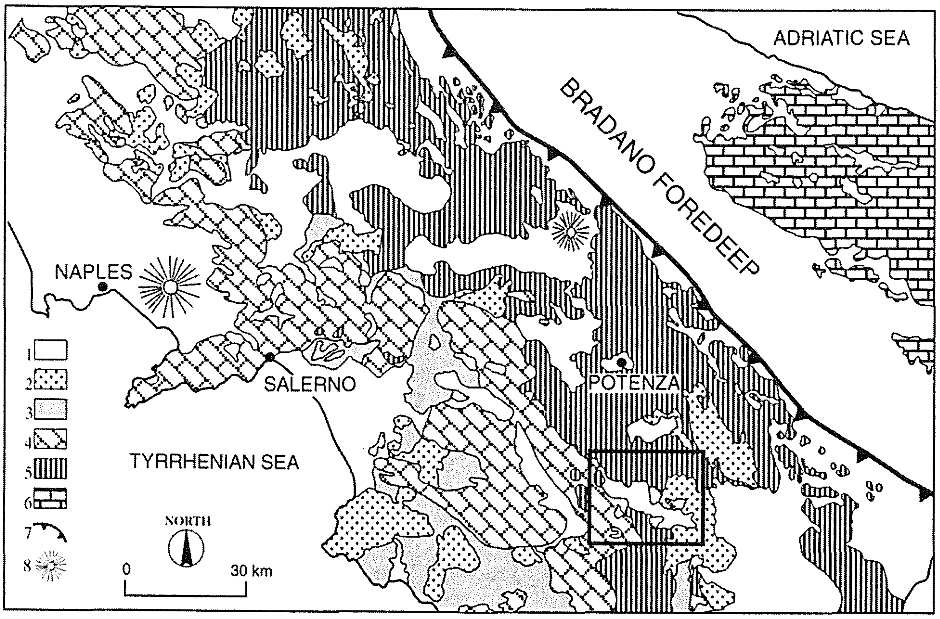

Fig. 1 - Geological sketch-map of southern Apennines. 1. Plio-Quaternary clastics and Quaternary position of volcaniclastic layers from *Scisti silicei* Fm; 2. Miocene syntectonic deposits; 3. Cretaceous to Oligocene ophiolite-bearing internal units (Ligurian units); 4. Meso-Cenozoic shallow-water carbonates of the Apenninic platform; 5. Lower-middle Triassic to upper Miocene shallow-water and deep-sea successions of the Lagonegro basin; 6. Meso-Cenozoic shallow-water carbonates of the Apulian platform; 7. Thrust front of the chain; 8. Volcanoes. In the frame: the high valley of the Agri River.

wedge, excluding the internal deformation of the Ligurian ophiolite-bearing units (Schiattarella *et al.*, 1997). The belt is also affected by Plio-Quaternary strike-slip faults, mainly oriented along N120°±10° and N50-60° trends (Schiattarella, 1998).

GEOLOGY OF AGRI VALLEY AND DESCRIPTION OF SAMPLING SITE

The high valley of the river Agri is a wide NW-SE trending intermontane basin located in the Lucanian Apennines (Fig. 1). It formed during Quaternary times along the axial zone of the chain after the major Miocene-Pliocene shortening and is filled with mid-Pleistocene alluvial deposits. Tectonics has strongly controlled the shape, morphology and sedimentary evolution of the basin up to the present, as testified by earthquakes such as that of 1857 and the occurrence of recent palaeosoils involved in faulting (Giano *et al.*, 2000). On the basis of recent structural studies (Giano *et al.*, 1997; Schiattarella *et al.*, 1998), the valley appears to be a basin more complex than an extensional graben (Ortolani *et al.*, 1992).

The pre-Quaternary bedrock (Fig. 2) is composed of Mesozoic-Cenozoic shallow-water and slope carbonates (Monte Marzano - Monti della Maddalena Unit, Bonardi *et al.*, 1988), prevalently outcropping along the western side of the basin, thrust over coeval pelagic successions (Lagonegro units, Scandone, 1967) which outcrop mainly along the eastern flank of the valley. The southern and eastern parts of the high valley are occupied by Tertiary siliciclastic sediments (Albidona Fm and Gorgoglione Flysch, Carbone *et al.*, 1991).

The volcaniclastic layers come from the lower part of the *Scisti silicei* Fm (Lagonegro units) outcropping in the Agri Valley close to the village of Paterno, in the footwall of the main thrust which brought the shallow-water carbonates on to the pelagic successions of the Lagonegro basin. The basal member of that formation marks the passage from upper Triassic to Jurassic (Miconnet, 1988) and shows facies and thickness changes over a narrow area. The layers are interbedded with marly pelagic sediments belonging to the *Armizzone* facies (Scandone, 1972), whereas a more proximal succession outcrops a few kilometres north of the sampling site (*Pignola-Abriola* facies).

The lowest volcaniclastic layer, grey to light brown in colour, is about 12-15 cm thick. It is a fine-depleted and poorly cemented coarse-grained sandy deposit (medium ash). Its grain size suggests a relatively proximal source. The intermediate thin layer (3-4 cm thick) is formed of incoherent dark ash. The highest layer is slightly thicker than the intermediate one and is composed of dark brown silty sand (fine ash). The detailed stratigraphy of the volcanic-bearing succession is sketched in Fig. 3.

METHODS AND TECHNIQUES

The mineralogy of bulk samples and the <2 μm grain-size fraction were determined by XRD (Siemens D5000, CuK_a radiation, graphite secondary monochromator, sample spinner) and distribution of mineralogical components was evaluated according to Laviano (1986). To estimate illite crystallinity, a known amount of the <2 μm grain-size fraction was crushed in a hand mortar and then transferred to a plastic container for ultrasonic treatment for 2-3 minutes. After settling, the suspension was decanted, pipetted, and dried at room temperature on glass slides to produce a thin-layer, well-oriented aggregate with a particle density of at least 3 mg/cm^2. The illite crystallinity index (IC), defined by the width of the first-order basal reflection (10 Å) at half-height above the background (Kübler, 1967), was measured on both air-dried and ethylen-glycol solvated slides, using analytical techniques and grain-size recommendations as well as calibration with interlaboratory standards, as suggested by Warr and Rice (1994).

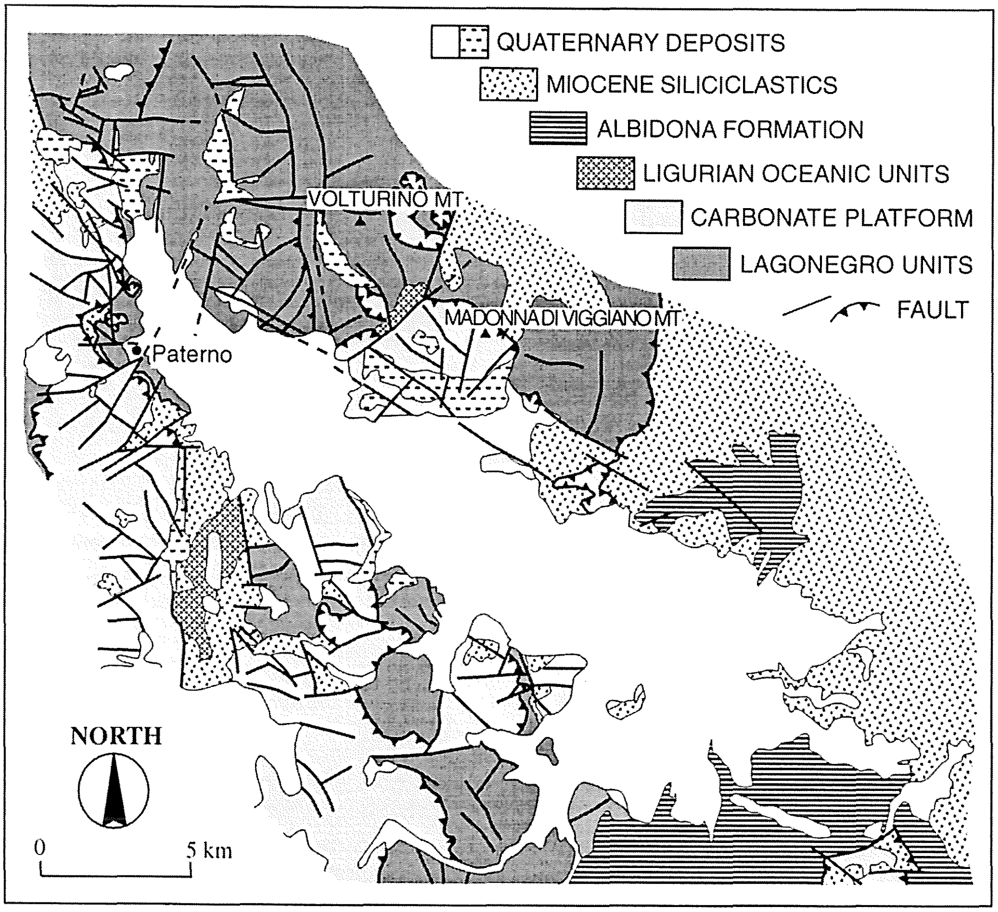

Fig. 2 – Geological map of Agri high valley.

Major elements, Ba, Rb, Sr, Y, Zr, Nb, V, Cr, Ni, Co, Cu, Zn, Hf and Pb were determined by X-ray fluorescence spectrometry (XRF). Estimated precision for trace element analyses are better than 5%, except for those elements found in quantities lower than 10 ppm (10-15%). La, Ce, Nd, Sm, Eu, Tb, Yb, Lu, Th, U and Sc were determined by Instrumental Neutron Activation (INA), their precision being better than 5%, with the exception of Yb and Lu (better than 7%).

Plagioclase analyses were performed using a JEOL JXA-8600 electron microprobe equipped with 4-WD spectrometers (Vaggelli *et al.*, 1999).

MINERALOGY AND GEOCHEMISTRY

The mineralogical and chemical composition of the layers interbedded with sediments from the *Scisti silicei* Fm sampled in the Agri Valley near Paterno revealed a volcanogenic nature. X-ray diffraction patterns show the presence of large amounts of primary minerals such as

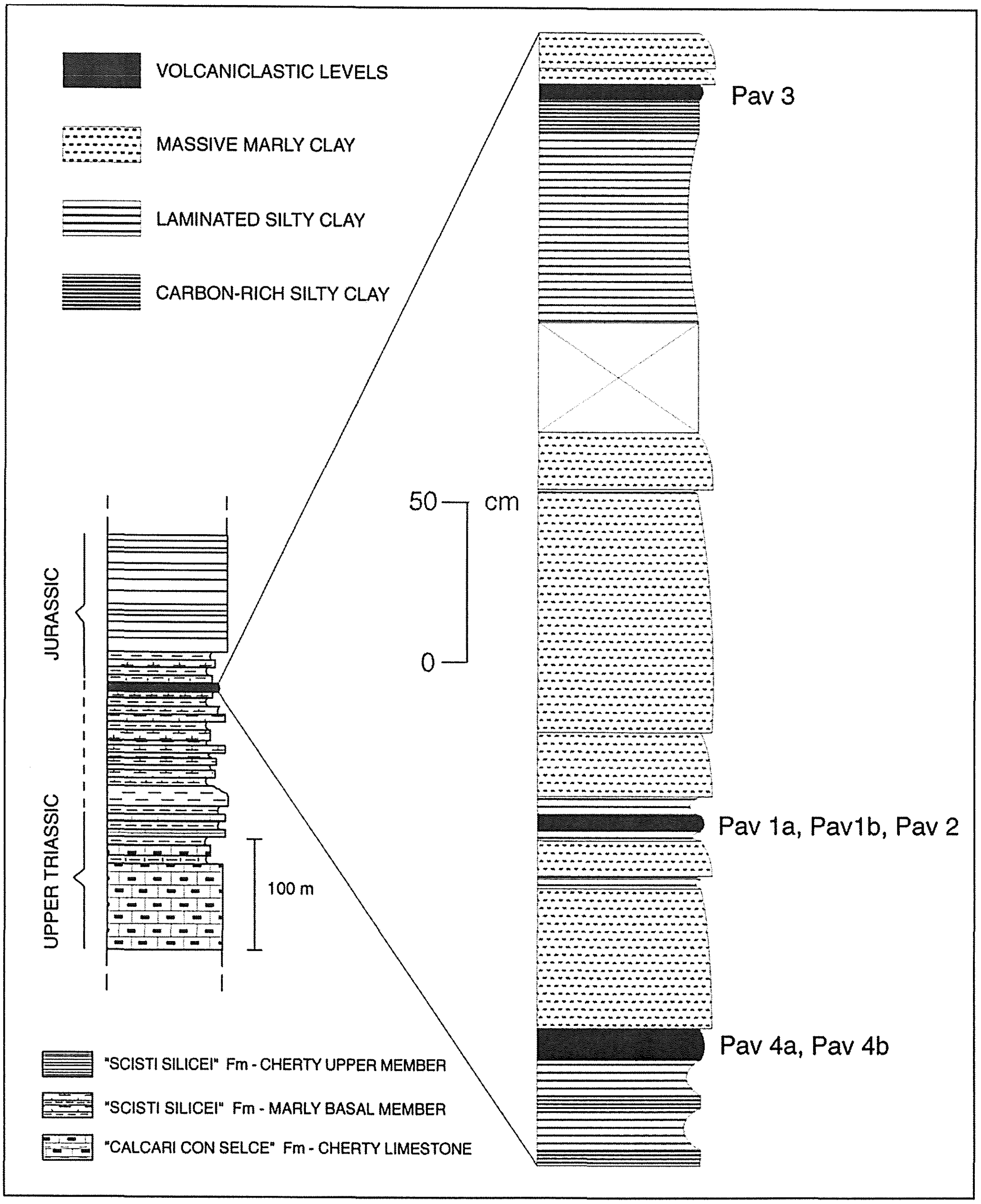

Fig. 3 - Measured stratigraphic section bearing volcaniclastic layers found in basal part of *Scisti silicei* Fm. Left: stratigraphic section showing part of Lagonegro deep-sea succession.

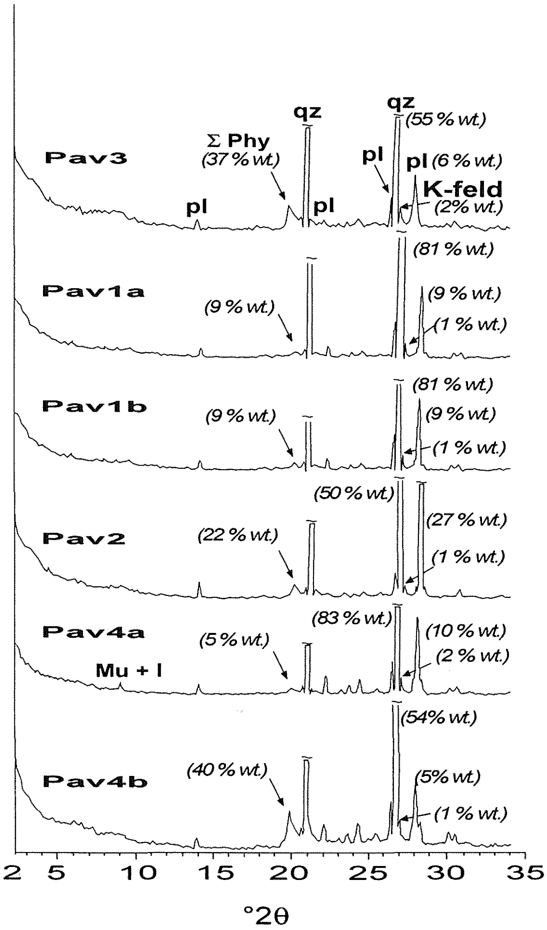

Fig. 4 - XRD patterns of bulk samples. Most abundant mineralogical phase observed in all samples is quartz. Plagioclase and small amounts of alkali feldspar also occur.

quartz and plagioclase (Table 1, Fig. 4). Observed clay minerals are largely dominated by diagenetic illite (average IC = 1.34; Kübler, 1967; Warr and Rice, 1994), with only a little kaolinite (Fig. 5).

The mineralogical and chemical composition observed in the volcaniclastic layers from the *Scisti silicei* Fm reveal both primary characters and diagenetic modifications. Although there were considerable variations in local and regional conditions, estimates of temperatures of ˜ 100-130 °C and a burial depth of 4-5 Km are considered to be the probable conditions for the basal portion of the *Scisti silicei* Fm where the volcaniclastic layers were found, as evaluated by Di Leo *et al.* (2002) using illite crystallinity, illite contents in I/S mixed layers and white mica polytypes. The above temperatures are sufficient to have caused recrystallisation of original clay minerals and formation of diagenetic illite (Hower *et al.*, 1976) and accounts for the lack in smectite

TABLE 1
Mineralogical composition (wt %) of bulk samples.

	Qz	Σ Phy	Pl	K-f
Pav3	55	37	6	2
Pav1a	81	9	9	1
Pav1b	81	9	9	1
Pav2	50	22	27	1
Pav4a	83	5	10	2
Pav4b	55	40	5	1

Qz = quartz; S Phy = clay minerals; Pl = plagioclase; K-f = K-feldspar.

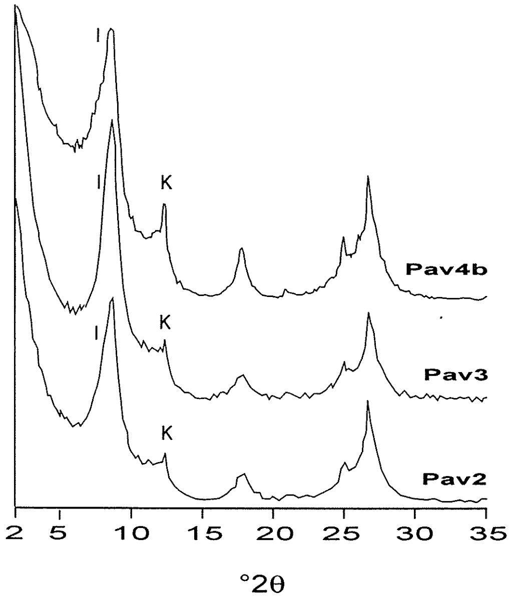

Fig. 5 - XRD patterns of air-dried oriented amounts of the < 2 μm fraction. Most abundant clay mineral is illite (I). Kaolinite (K) also occurs, although in small amounts.

usually expected as a product of early diagenetic volcanic glass alteration.

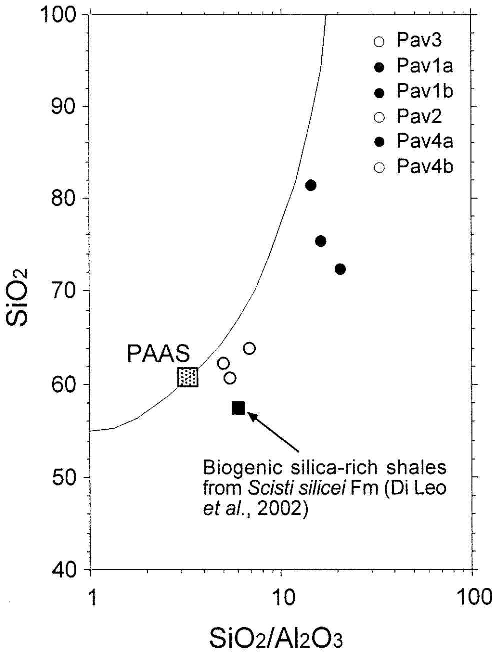

Fig. 6 – SiO_2 *vs* SiO_2/Al_2O_3 diagram (modified after Di Leo *et al.*, 2002).

The chemical composition and some elemental ratios of the volcaniclastic layers are shown in Table 2. Overall, the samples have small amounts of Na_2O+K_2O (0.56-1.3 wt %) and Al_2O_3 (3.51-12.58 wt %) as well as SiO_2 in the range 60-82 wt % and MnO in the range 0.94-2.87 wt %. The high SiO_2 observed in some samples may be a consequence of passive enrichment in this element during sedimentation and/or diagenesis (Fig. 6). Compared with the UCC (Upper Continental Crust), the volcaniclastic beds from the Agri high valley are depleted in both large-ion lithophile (Rb, Sr) and high field strength (Ti, Nb, Hf, Zr, Th, RE) elements, and are strongly enriched in first-row transition elements (Mn, Ni, Cu) and Ce.

Geochemical comparisons of these samples with sediments belonging to the basal member of the *Scisti silicei* Fm (Di Leo *et al.*, 2002) give insights into their nature and origin. The volcaniclastic nature of the layers in the lower part of *Scisti silicei* Fm is clearly evidenced by the discrimination diagram between transformed volcaniclastic and «normal» sediments (Andreozzi *et al.,* 1996), based on first-row transition elements V, Cr and Ni and

TABLE 2

Chemical composition of volcaniclastic beds. Major elements, Ba, Rb, Sr, Y, Zr, Nb, V, Cr, Ni, Co, Cu, Zn, Ga, Hf, Pb and S determined by X-ray fluorescence spectrometry. Estimated precision for trace element determinations better than 5%, except for elements in quantities lower than 10 ppm (10-15%). La, Ce, Nd, Sm, Eu, Tb, Yb, Lu, Th, U and Sc determined by instrumental neutron activation. Estimated precision (except for Yb and Lu) better than 5%; that for Yb and Lu better than 7%.

	Pav3	Pav1a	Pav1b	Pav2	Pav4a	Pav4b
SiO_2	60.68	72.38	75.47	63.78	81.48	62.29
TiO_2	0.3	0.28	0.23	0.35	0.35	0.37
Al_2O_3	11.22	3.51	4.67	9.4	5.62	12.58
Fe_2O_3	6.56	7.6	5.93	7.02	4.03	4.49
MnO	2.72	4.52	3.45	2.87	1.46	0.94
MgO	0.78	0.1	0.21	0.63	0.87	1.13
CaO	0.18	0.15	0.18	0.32	0.28	0.38
Na_2O	0.03	0.44	0.4	0.32	0.58	0.39
K_2O	1.04	0.12	0.19	0.85	0.33	0.91
P_2O_5	0.11	0.14	0.09	0.12	0.12	0.11
L.O.I.	16.38	10.77	9.2	14.35	4.89	16.41
Ba	346	375	448	454	213	250
Rb	77	23	25	64	24	79
Sr	41	33	31	43	45	59
Y	34	17	20	37	35	57
Zr	132	164	104	168	102	116
Nb	16	10	8	15	5	16
V	69	45	43	67	44	67
Cr	54	30	37	52	28	55
Ni	66	33	84	67	37	59
Sc	11	9	6	10	5	11
Co	17	18	10	14	6	7
Cu	70	98	127	102	11	27
Zn	69	57	68	45	47	62
Hf	1.1	2.1	0.9	1.7	1.1	1.7
Th	3.7	3.5	2.1	4.4	2.3	5.3
U	1.4	2	1.6	1.1	0.8	1.1
Pb	170	36	30	30	11	7
La	14	11.2	8.9	12.8	13.3	16.1
Ce	163	143	95	99	51	63
Nd	23	14	10	16	15	15
Sm	7.8	4.5	3	4.5	3.9	3.4
Eu	1.7	1	0.8	1.1	0.9	0.9
Tb	1.2	0.6	0	0.7	0	0.5
Yb	2.4	1.5	1.2	1.8	1.3	1.7
Lu	0.34	0.2	0.18	0.25	0.19	0.26
Ti/Al	0.03	0.08	0.05	0.04	0.06	0.03
$(La/Yb)_{ch}$	3.9	5	5	4.8	6.9	6.4
Eu/Eu*	0.67	0.71	-	0.75	-	0.83
Ce/Ce*	4.7	5.6	4.8	3.4	1.7	1.8

$(La/Yb)_{ch} = (La/La_{ch})/(Yb/Yb_{ch})$; $Eu/Eu^* = Eu_{ch}/\sqrt{(Sm_{ch} \bullet Gd_{ch})}$. Gd_{ch} calculated as $(2/3Tb_{ch} + 1/3\ Sm_{ch})$; $Ce/Ce^* = (3Ce/Ce_{ch})/(2La/La_{ch} + Nd/Nd_{ch})$. Condrite values from Taylor and McLennan (1985).

immobile elements Zr and Ti (Fig. 7). Geochemical discrimination between volcaniclastic and terrigenous sediments is particularly effective if «immobile» elements and transition metal data are combined: the former are mainly controlled by primary differences, the latter are more strongly influenced by diagenetic reactions which modified original distributions. Discrimination between terrigenous sediments and volcaniclastic sediments may be possible using transition elements such as V, Fe, Cr, Zn and Ni (Andreozzi *et al.,* 1996), which are particularly sensitive to variations in redox conditions (V, Fe, Cr), affinity for organic matter (V, Fe, Ni, Zn) and adsorption processes on clay minerals (Zn, Ni, Cr, V). They are mobilized during diagenetic transformation, such as degradation or modification of organic matter, formation of redox fronts (Pearce and Jarvis, 1995, and references therein), and clay mineral recrystallisation (Hower *et al.*, 1976). For these reasons, they are suitable for highlighting differences between sediments of different origins, especially when combined with immobile elements. Fig. 7 shows the genetic differences, mostly indicated by the Zr/TiO_2 ratio (which may help to define magmatic source compositions for lithified ash layers) and post-depositional transformations.

Information about the magmatic sources of volcaniclastic layers from the *Scisti silicei* Fm comes from the classification diagram of Winchester and Floyd (1976), based on low-mobility element ratios (Fig. 8). The studied samples fall on the subalkaline side of the diagram, in the dacite-rhyodacite and rhyolite fields. The chemical composition of unaltered plagioclase, showing albitic composition, are consistent with a rhyolitic magmatic source (Table 3).

Of the trace elements, Rare Earth Elements (REE) are the least mobile during alteration, reflecting the original chemical composition of volcaniclastic sediments and volcanic ash

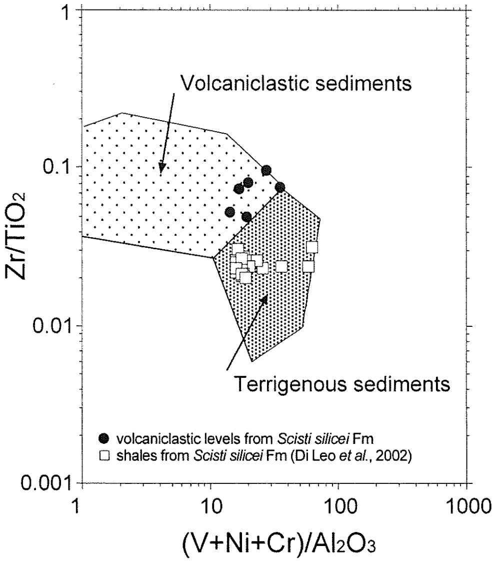

Fig. 7 – Discrimination diagram between transformed volcaniclastic and «normal» sediments (from Andreozzi *et al.*, 1996). Non-volcaniclastic sediments used for comparison are shales from basal member of *Scisti silicei* Fm (Pignola section, Di Leo *et al.*, 2002).

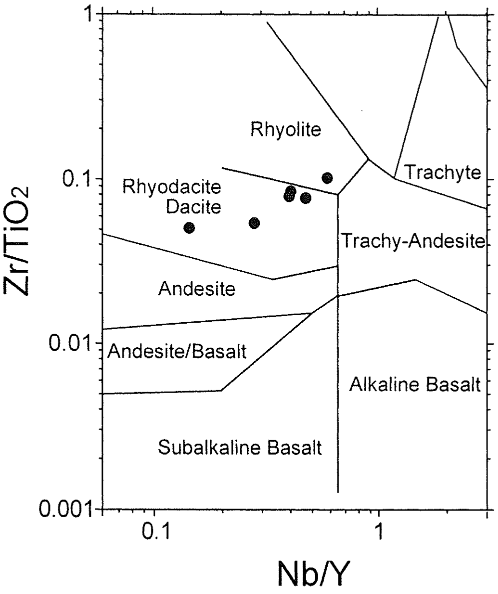

Fig. 8 – Classification diagram of volcaniclastic layers from *Scisti silicei* Fm (Winchester and Floyd, 1976).

TABLE 3

Electron microprobe analyses of plagioclase from volcaniclastic layers.

	Pav 2	Pav 2	Pav3	Pav3	Pav4a
SiO_2	69.54	68.97	69.54	69.33	73.03
TiO_2	0.04	0.02	0.03	0.06	0.02
Al_2O_3	20.11	20.35	21	20.81	21.16
FeO	0.07	0.1	0.2	0.09	0.03
MnO	0.06	0.04	0.03	0.11	0.05
MgO	0	0	0	0	0
CaO	0	0.03	0.04	0.03	0.02
Na_2O	10.92	10.39	9.6	8.92	8.36
K_2O	0	0	0.01	0.01	0.02
Total	100.75	99.93	100.52	99.38	102.68

(McLennan *et al.*, 1980). The REE chondrite-normalized patterns (Taylor and McLennan, 1985) of the sampled layers (Fig. 9) show LREE/HREE fractionation (La_n/Yb_n = 5.3 ± 1.1), negative Eu anomaly (Eu/Eu* = 0.74 ± 0.07) and positive Ce anomaly (Ce/Ce* = 3.66 ± 1.64). The distribution and concentration of REE are typical of andesitic magma. The REE patterns are similar to those reported for arc-related rhyolitic ignimbrites (Ikeda *et al.*, 1980, Leo *et al.*, 1980; Masuda, 1980) and altered ash layers from the Indonesian volcanic arc (Martín-Barajas and Lallier-Verges, 1993).

A peculiar feature of the REE patterns from the studied layers is the positive Ce anomaly. Although REE are reported to be affected during diagenesis in the sea bottom (De Baar *et al.*, 1987), this modification mainly occurs in reducing marine conditions. Therefore, a positive Ce anomaly may suggest the effects of a hydrogenous phase (Fleet, 1984). Amorphous

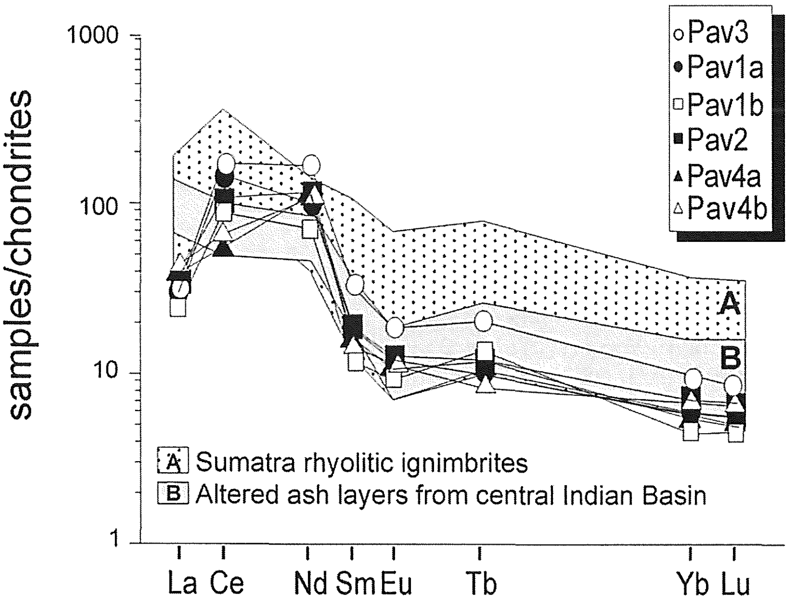

Fig. 9 – Chondrite-normalized REE distribution pattern of volcaniclastic layers from *Scisti silicei* Fm. REE pattern fields are rhyolitic ignimbrites from Sumatra (Ikeda *et al.*, 1980; Leo *et al.*, 1980; Masuda, 1980) and altered ash layers from central Indian Basin (Martín-Barajas and Lallier-Verges, 1993).

Fe-Mn oxy-hydroxides and other authigenic minerals are considered responsible for positive Ce anomalies in pelagic environments (Piper, 1974; Toyoda and Masuda, 1991), as Mn and Ce have a similar oxidation mechanism and very similar oxidation kinetics in sea-water. Mn-oxides, as consequence of both associated bacteria mediation and surface chemical properties, act as scavenging agents for Ce^{4+} and determine its fractionation with respect to other REE (see Fig. 9).

In conclusion, the volcaniclastic layers found in the basal portion of the *Scisti silicei* Fm show peculiar compositional features which differentiate them considerably from other volcaniclastic horizons observed so far in the southern Apennines.

PALAEOTECTONIC IMPLICATIONS

For more specific constraints on the palaeotectonic setting associated with the volcanic source of the volcaniclastic beds from the *Scisti silicei* Fm, the Ti-Y-Zr ternary diagram (modified after Yamamoto *et al.*, 1986) and the Y *vs* Nb and Y+Nb *vs* Rb discrimination diagrams proposed for granites (Pearce *et al.*, 1984), which also proved to be useful for felsic volcanic rocks (Twist and Harmer, 1987), were applied.

Al and Ti contents are useful parameters for identifying the tectonic setting of volcaniclastic sediments (e.g., Hein and Scholl, 1978; Yamamoto *et al.*, 1986). The Ti/Al ratios of the sampled volcaniclastic layers (Table 2), ranging from 0.03 to 0.08, are indeed consistent with other Ti/Al ratios of volcanic ash and bentonite layers attributed to arc volcanism (Martín-Barajas and Lallier-Verges, 1993, and references therein). In the Ti-Y-Zr ternary diagram, the volcaniclastic samples plot in the area of arc-related rhyolitic tephra in subaqueous settings (Fig. 10). In both Y *vs* Nb and Y+Nb *vs* Rb diagrams, the samples fall in the field of volcanic-arc felsites (Fig. 11), in contrast with the classical view, according to which the Lagonegro basin was generated in an

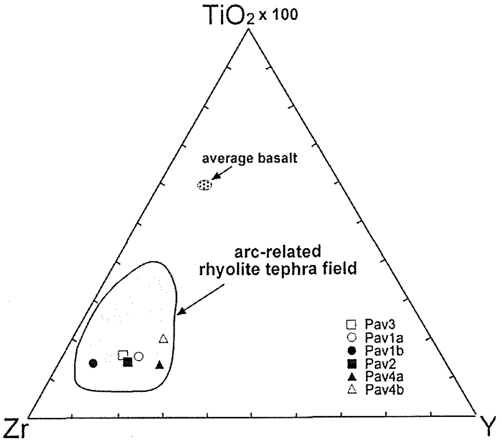

Fig. 10 – Ti-Y-Zr ternary diagram (modified after Yamamoto *et al.*, 1986) showing composition of volcaniclastic layers from *Scisti silicei* Fm.

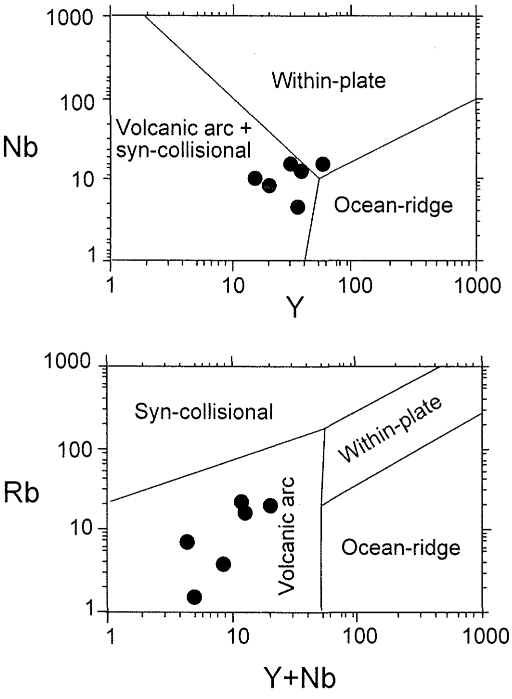

Fig. 11 – Y *vs* Nb and Y+Nb *vs* Rb tectonic discrimation diagrams for felsites (after Pearce *et al.*, 1984, and Twist and Harmer, 1987).

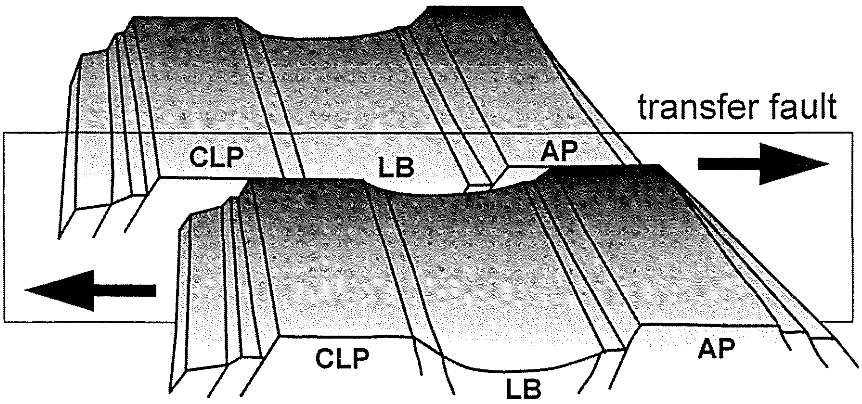

Fig. 12 – Block diagram showing possible Mesozoic palaeotectonic scenario of a portion of African-Apulian palaeomargin. Acronyms: CLP: Campania-Lucania Platform; LB: Lagonegro Basin; AP: Apulian Platform.

extensional regime and bordered by normal faults during the entire Mesozoic tectono-sedimentary evolution.

On the above basis, a more complex palaeotectonic setting of the deep-sea basin may be hypothesized. The presence of a syn-collisional volcanic arc during the Triassic-Jurassic transition must be ruled out, since the Lagonegro basin is close to the boundary of divergent plates and included in the African passive margin. Also, the effects of the Hercynian orogeny, too distant in time to have had an appreciable influence on magmatic evolution, may be neglected. It is therefore suggested that a different geodynamic environment characterised the Mesozoic scenario. A continental transform zone able to produce local transpressional structures and to emulate the magmatic features of collisional margins may be envisaged as partly responsible for the basin evolution, in a more general context of extensional tectonics (Fig. 12). Transpressional systems are in fact often intruded by magmas (D'Lemos *et al.*, 1992), because of the steep pressure gradients in vertical strike-slip shear zones and their ability to force magma upwards. Such dynamic conditions cause some magma overpressuring, which in turn expels granitic magma upwards, following the vertical pressure gradient (Saint Blanquat *et al.*, 1998).

At a shallower structural level, the transform fault system may have controlled the Triassic-Jurassic facies pattern of the Lagonegro basin whereas, at depth, such an anisotropy probably influenced the crustal and magmatic evolution of that part of the *Adria* palaeomargin.

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