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The Pre-Alpine Basement in the Alpi Apuane (Northern Apennines, Italy)

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Abstract

The Alpi Apuane is a well-known tectonic window in the Northern Apennines (Tuscany), in which a pre-Alpine lithostratigraphic sequence crops out widely and which appears to have been deeply affected, together with the Alpine cycle cover, by the Tertiary tectono-metamorphic evolution of the Apenninic chain.

The authors illustrate the main lithological and structural features of these formations and discuss the relationships between the Apuan Variscan basement and the regional Variscan system of southern Europe.

1 Introduction

The Northern Apennines are a nappe belt that formed during the Tertiary tectono-metamorphic evolution of the Italo-Dinaric palaeomargin. The palaeogeographic domains involved in this evolution are, from inland to foreland: Ligurian domain, Subligurian domain, Tuscan domain (internal and external), Umbrian domain and Marchean domain.

Several tectonic units originating from those domains are overthrust from the internal unit onto the more and more external ones. At present, the most complete exposure of this nappe belt is visible in the tectonic window of the Alpi Apuane where, from top to bottom, the following units are stacked: Ligurian units (Mt. Gottero unit and Helmintoidic Flysch unit), Canetolo unit, Tuscan nappe, Massa unit and "Autochthonous" Auct.[1] unit. The units belonging to the Umbrian domain crop out only beyond the main crest of the Tuscan-Emilian Apennines, but very likely their more internal sector is buried under the Apuan window.

The Massa unit and the "Autochthonous" Auct. unit (hereafter MU and AU, respectively) represent the external Tuscan domain and form the "Apuan metamorphic complex" (hereafter AMC). The AMC, unlike the overlying tectonic units, is characterized by a greenschist facies metamorphism of Tertiary age that accompanied a polyphase, ductile and pervasive deformation. This deformation is represented by an ensialic shear zone and by later uplift of this sector of the Apennines chain.

This tectono-metamorphic history affected both the Tuscan stratigraphic succession and the underlying Palaeozoic basement (Fig. 1); this fact and the Tertiary uplift of the Alpi Apuane provide us with the widest and best-exposed outcrops of Palaeozoic rocks in the Northern Apennines.

2 The Alpine Structural Frame of the Alpi Apuane

The Apuan structure is due to the already mentioned Tertiary deformation which involved two tectono-metamorphic events. They were connected (Carmignani et al. 1978; Carmignani and Giglia 1984 and references therein) to first, tectonic tangential shortening, linked to continental collision (the tectogenetic event), and second to a dome-like uplift related to the beginning of a generalized extensional regime that affected progressively lower and lower structural levels (the orogenetic event: Carmignani et al 1987; Carmignani and Kligfield 1990).

2.1 The Tectogenetic Event (D1)

The tectogenetic event (D1) is manifest as an Upper Oligocene thick, ensialic shear zone and results in a

[1] Auct. (Auctorum): Latin word which indicates a geological concept introduced by previous authors and at present partly or completely obsolete. In this case (and in other papers during the 1980s) wie use an "obsolete" geological concept (that is, "autochthonous") because of its large diffusion in the Italian literature concerning the Alpi Apuane.

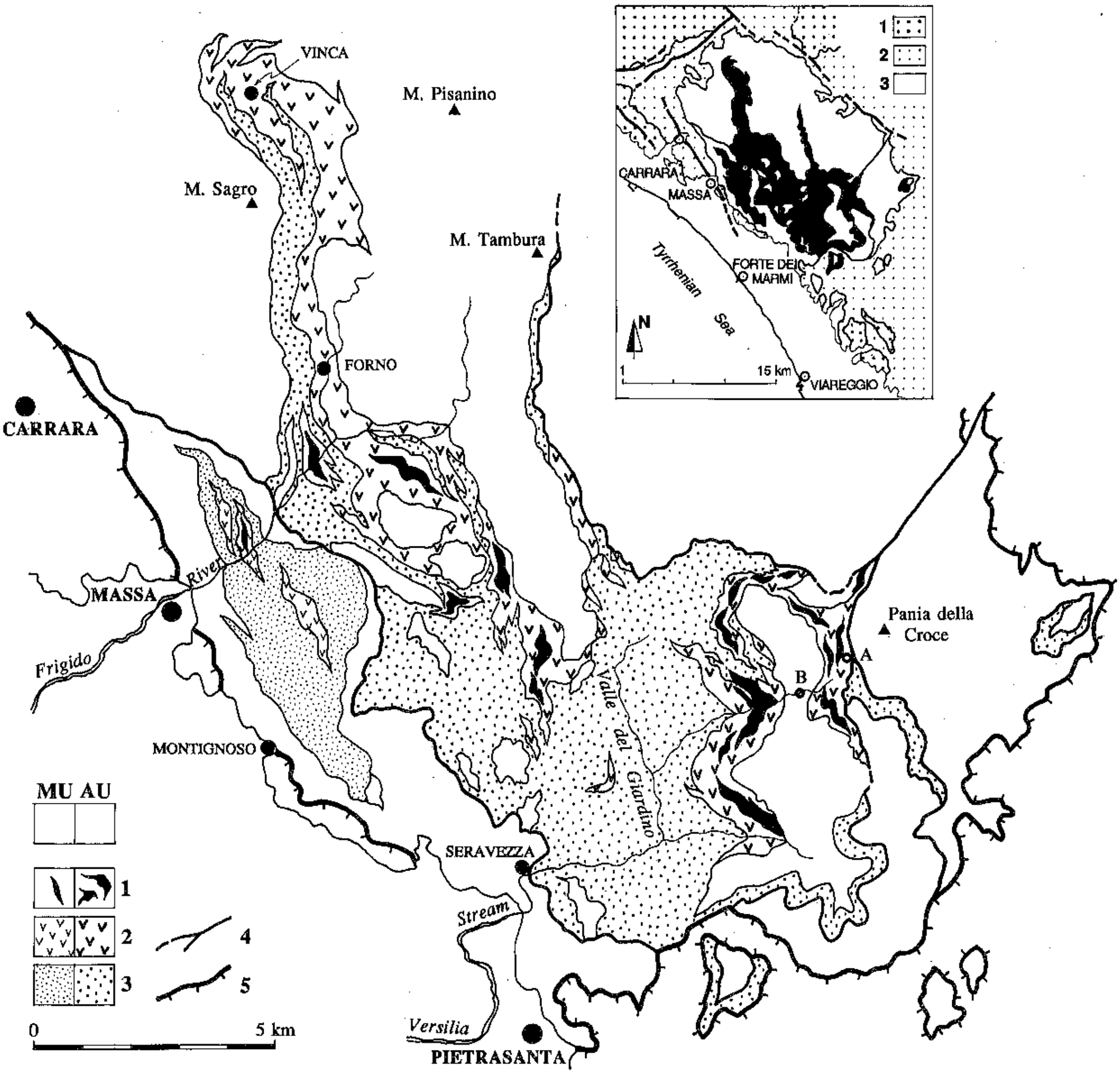

Fig. 1. Geological map of the Alpi Apuane Palaeozoic basement. *MU* Massa unit; *AU* "Autochthonous" Auct. unit; *box Symbols:* Alpine stratigraphic covers and recent sediments; *1* carbonate-phyllitic metasediments of Silurian-?Devonian age; 2 Pf+PfS+MQZ; *3* LP; *4* D1 and D2 ductile tectonic contacts and/or faults (north of Pania della Croce) inside the AMC; *5* tectonic boundary between the AMC and the overlying Tuscan nappe. On the map: *circle A* Foce di Mosceta; *circle B* Canale delle Volte. Regional tectonic sketch map, **(inset)** *1* Ligurian units and Canetolo unit; *2* Tuscan nappe; *3* AMC, the *black field* represents the Palaeozoic basement

complex structural setting, whose main structures are mentioned here:

1. Northeast-vergent mega-anticlines and mega-synclines with a similar geometry, and many minor folds ranging in size from microscopic to kilometric;
2. A pervasive axial plane foliation (S1) accompanies these folds, which more or less completely transposes the former sedimentary bedding and forms small angles with the shear zone boundaries;
3. Ductile shear horizons, from a microscopic size up to several metres thick, develop parallel to the S1 and are characterized by extreme elongation (on average SW/NE trending) and even strong obliteration of almost any stratigraphic feature. These shear horizons can reach regional importance as tectonic surfaces separating metamorphic subunits: the overturned flank of Mt. Tambura anticline (Fig. 1) is an example of this structure.

The L1 extension lineation everywhere indicates southwest-northeast tectonic transport. In contrast, the orientation of the fold axes is highly variable: in the western sector of the AU (i.e. in the uppermost structural levels of this unit) they trend mainly northwest, while in the central and eastern areas (i.e. towards deeper and deeper structural levels) they progressively become parallel to the L1 lineation, owing to a passive rotation of the fold axes on their own axial planes (i.e. S1 foliation: Carmignani et al. 1978; Günther and Wallbrecher 1979), according to the models of progressive simple shear deformation outlined by J.G. Ramsay (1967) and D.M. Ramsay (1979), Sanderson (1974), Escher and Watterson (1974), Rhodes and Gayer (1977), Williams (1978).

The regional attitude of all structural elements related to this event demonstrates that the tectonic movements had an Apenninic sense of motion (Carmignani and Giglia 1983), that is, from the internal (southwest) to the external (northeast) palaeogeographic domains.

The MU constitutes a tectonic wedge located between the AU and the anchimetamorphic Tuscan nappe. This structural position facilitated the development of many ductile shear zones which, together with S1, constitute the main structural features of this unit. As a consequence, its Triassic succession is preserved only in few and restricted areas. In spite of this, the MU may be considered a first-order anticline with a wide Palaeozoic core that is internally sheared and overthrust on the southwestern boundary of AU.

It must be noted that during this tangential episode the overlapping of all tectonic units (the nappe building) reaches its complete configuration and provides the lithologic charge under which the synkinematic metamorphism occurred.

2.2 The Orogenetic Event (D2)

This event, which seems to follow the first one without any appreciable break in time, is connected to the general uplift of the Apuan region. It affected both the AMC and the overlying units and led to a northwest-southeast trending dome structure that appears to have been controlled by the D1 antiformal stack (Carmignani and Kligfield 1990).

In the metamorphic units, this event deformed the S1 foliation into a complicated antiform with a thinned hinge and thickened limbs (Carmignani and Giglia 1979). In this antiform, many open folds developed with amplitudes up to a kilometre or more; these folds are asymmetric with vergences toward the flanks of the main structure, and they are accompanied by subhorizontal to slightly inclined axial plane schistosity (S2).

3 The Palaeozoic Basement of the Alpi Apuane

The Palaeozoic basement of the AMC is represented by a ?Late Cambrian–?Devonian lithostratigraphic succession, which has been recognized mainly on the basis of:

1. Rare palaeontological traces in some rocks (nautiloids: Meneghini 1880; conodonts: Vai 1972; Bagnoli and Tongiorgi 1980);
2. Constant and consistent geometric relationships between the various lithologic associations;
3. Comparison (Di Pisa et al. 1988) of these associations with the better known and dated formations of the Palaeozoic successions of southeastern Sardinia (Carmignani et al. 1982b, 1986; Carosi and Gattiglio 1989).

The recognized informal stratigraphic units are shown in a restored succession (Fig. 2) and are described next from oldest to youngest.

"Filladi Inferiori" (Barberi and Giglia 1966) (Lower Phyllite: hereafter LP; ?Late Cambrian-?Early Ordovician). The LP is made up of three main lithotypes: light to dark grey quartzite, dark grey and/or grey-greenish phyllitic quartzite and phyllite.

The most common and widespread lithologic combination is constituted by 10 cm or more thick layers of light quartzite, that alternate with bands of grey or greenish phyllite. Locally where the quartzite component dominates, lenticular quartzitic bodies form with lengths up to several tens of metres and thickness up to 10–15 m. These layers show rare but clear relics of sedimentary structures (gradation, bedding and cross-bedding). In other places, the main lithology is a homogeneous, dark grey or grey-green phyllite, with minor and small lenses of graphitic, blackish metapelite.

The top of LP is marked locally by the presence of a discontinuous level of matrix-supported paraconglomerate that contains quartzitic pebbles and grains of magmatic Qtz and Ab.[2] Where absent, this psephitic layer may be replaced by a few metre thick, whitish, homogeneous quartzite that shows a high textural and mineralogical maturity. Both the para-

[2] Mineral symbols after Kretz (1983).

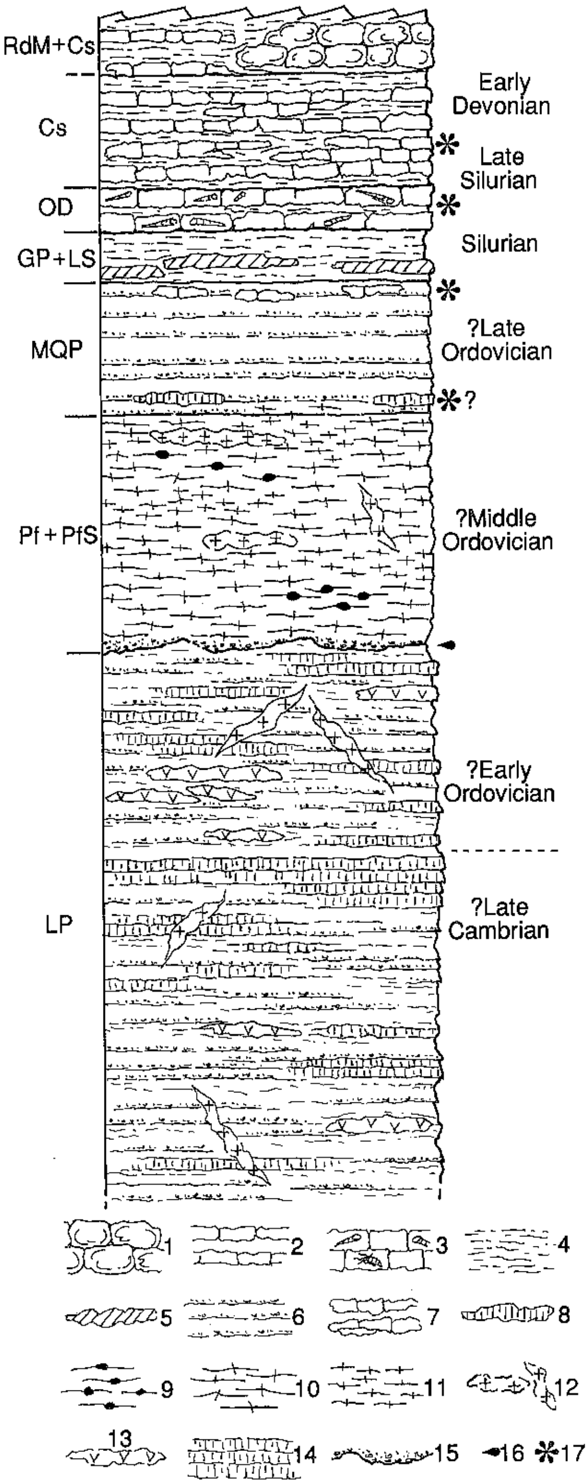

Fig. 2. The lithostratigrafic succession of the Alpi Apuane Palaeozoic basement. *1* Nodular metalimestone; *2* calcschist; *3* dolostone; *4* phyllite; *5* lydite; *6* metasandstone; *7* crinoid ossicle-bearing metalimestone; *8* carbonate metasiltite; *9* Pf with large K-feldspar phenocrysts; *10* Pf with small K-feldspar phenocrysts; *11* PfS; *12* subalkaline metabasite; *13* alkaline metabasite; *14* quartzite; *15* metaconglomerate; *16* inferred "Caledonian" unconformity; *17* fossils

conclomerate and the quartzite could outline an unconformity; unfortunately, the Alpine overprint (see later) obliterated the typical signs of such a structure, apart from the already described clastic metasediments. We will discuss this situation in the last Section.

In the field, the S1 Alpine foliation is the main regional schistosity everywhere, and it generally coincides with the described layering. It either develops as a spaced strain-slip cleavage in the quartzites or as a flow cleavage in the more phyllitic levels. The most common mineral association is Qtz + Ms + Chl + Ab, with Ap + -Ep + -Rt + -Zrn + -Tur + -Fe-oxides and hydroxides as accessories. An older foliation is recognizable in the "lithons" between the S1 surfaces where it often forms uprooted, intrafolial fold hinges. This planar anisotropy corresponds to a metamorphic layering and is usually marked by thin granoblastic Qtz-Ab-rich layers that pervasively alternate with micaceous films.

All of these features allow us to refer to the LP as primary pelitic-arenitic sediments that were deposited in a basin environment. Until now, no palaeontologic data have been available, nevertheless, the pre-Alpine foliation testifies to a tectono-metamorphic event that pre-dates the Alpine stratigraphic cycle.

Lenses of metabasic rocks (MBP, see later), consisting of greenish and grey-greenish basaltic metavolcanics and metagreywakes, form lenticular bodies inside the LP. They show a blastoporphyritic texture with subidiomorphic relic Pl porphyroclasts and often homogeneously distributed, abundant and stick-shaped, leucoxene-rimmed Ilm, in a Pl + -Chl + -Ep + -Fe-carbonate matrix.

"Porfiroidi e Scisti Porfirici" (Barberi and Giglia 1966) (porphyroid and porphyritic schist: hereafter Pf and PfS respectively; ?Middle Ordovician). These rocks represent the metavolcanic complex of the Apuan basement and are made up of two main varieties: porphyroid with small and large K-feldspar phenocrysts and porphyritic schist. On the whole, these rocks are homogeneous and massive and give abrupt and sharp features to the morphology.

The porphyroid containing small K-feldspars (Pf) is the more frequent type. It shows an augen structure of 3–4 mm Qtz and K-feldspar grains in a Qzt + Ms + Chl matrix. Qtz phenocrysts have resorbed boundaries (Barberi and Giglia 1966) and are clearly magmatic. The porphyroid with large K-feldspar porphyroclasts (up to 7–8 cm) is also present, but not as common as the previous type.

According to Bonatti (1938), Barberi and Giglia (1966) and Tucci (1980), these rocks derived from primary, rhyolitic-rhyodacitic, volcanic-volcanoclastic rocks; Puxeddu et al. (1984) related them to original acidic-intermediate volcanics (Na-K rhyolite).

The PfS represents primitive, arkosic to orthoquartzitic terrigenous sediments derived from erosion of the acidic volcanics under subaerial conditions (Barberi and Giglia 1966; Gianelli and Puxeddu 1980; Tucci 1980; Puxeddu et al. 1984). As already reported by Tucci (1980), a pre-Alpine foliation is recognizable in Pf and PfS, although it is not as well displayed as in the LP (at the scale of the whole massif).

Minor basaltic to intermediate sub-alkaline bodies (blastophitic metabasites: MBO, see later) are also associated with this metavolcanic complex, that show original subvolcanic relationships with the underlying LP.

Metasandstone, quartzite and phyllite (MQP). This formation consists of a variety of lithologies (metasandstone, metagreywacke, phyllitic quartzite and phyllite) that were probably derived from the erosion of the pre-existing acidic to intermediate volcanics. In many cases, the actual metavolcanics (that is, Pf + PfS) show a gradual transition to the basal levels (containing minor arkosic metasandstone) of this ensemble.

The most characteristic lithotype of this suite is a metasandstone that consists of a compact, dark grey to grey-greenish Qtz-arenite and Qtz-wacke with a widespread blastopsammitic texture. It typically contains large amounts of magmatic Qtz grains that often form equigranular, mature, grain-supported horizons. Less commonly, this metasandstone also contains feldspar grains.

The micaceous component in these metasandstones, although generally scarce, locally creates more or less phyllitic varieties. The complicated tectono-metamorphic history has caused irregular distribution and re-organization of these rocks, however, sometimes it is possible to observe clear remnants of sedimentary structures, such as several metre thick sequences of levels that show internal sorting.

Rare carbonate levels are locally intercalated in the lower portion of MQP, near the boundary with the Pf + PfS: these consist of major brownish metasiltite with variable carbonate components, that are typically riddled and enriched with Fe oxides and hydroxides. These discontinuous, thin (few metres thick) horizons could correspond to the "schists truè" of the sequences of southeastern Sardinia, but up to now they have not provided any palaeontological content.

Other carbonate rocks (previously reported by Barberi and Giglia 1966) alternate with the dominant clastic metasediments and consist of dolomitic grey levels (up to 20 cm thick) with rare crinoid ossicles. Where the calcareous matrix occurs among metasiltites and phyllites, it is always variously enriched in Fe-oxides and hydroxides and Tur.

The characteristics of MQP suggest that sedimentary processes were active over a coastal plane that with time developed towards an epicontinental shallow sea environment. In these rocks a pre-S1 metamorphic foliation is easily recognizable.

Graphitic phyllite and lydian stone (hereafter GP and LS, respectively). The GP has a homogeneous, prevalently micaceous (mainly white micas) composition; it contains widespread and abundant Gr and minor Qtz, and shows a very fine lepidoblastic texture.

Within the GP there are rare layers of LS, that consist of a few centimetre thick beds of microcrystalline, granoblastic quartzite alternating with lepidoblastic films of GP. The quartzite beds often show the pre-S1 metamorphic layering, which constitutes the only evidence of a pre-Alpine deformation in these rocks.

Due to its composition, the GP has been severely thinned and strongly deformed during the Variscan and Alpine tectono-metamorphic evolutions. Nevertheless, reliable original relationships with both the MQP suite and the overlying Orthoceras-bearing metasediments are occasionally well preserved.

The GP has been referred to as a primary, graptolite-bearing, prevalently siltitic sediment (Gortani 1933; Vai 1972) which, together with carbonate sediments, formed a wide and uniform sedimentary "cover" over the entire Euro-African Silurian sea. The only palaeontologic report is from Gortani (1933), who found indeterminable relics of graptolites in the Vinca and Foce di Mosceta areas (see Fig. 1).

Orthoceras-bearing dolostone (hereafter OD). This is a well-known rock in the Apuan basement and consists of granoblastic-xenoblastic re-crystallized Dol and minor Cal, with scattered Qtz, Ms and xenoblastic Ab. In the field it is grey with a typical brown-reddish alteration patina. The dolostone appears massive, sometimes coarsely bedded, but locally the presence of thin graphitic-phyllitic levels provides a foliation.

These carbonate metasediments have yelded crinoid ossicles and several specimens of orthoceratides (Meneghini 1880, 1881; Zaccagna 1932; Gortani 1933); on the base of these fossils, many authors assigned those rocks to an undetermined Palaeozoic age. Mainly on the base of facies correlations with analogous and palaeontologically dated horizons in the Alps, and because of the poor preservation of the orthoceratides, Barberi and Giglia (1966) assigned a Triassic age to their "Dolomie scistose". Despite this, a pre-Variscan age of the Alpi Apuane basement has been accepted as a result of work by Vai (1972) and later Bagnoli and Tongiorgi (1980), who reported conodonts of Lower-Middle Ludlow (Frigido River) and to Upper Ludlow (Canale delle Volte: see Fig. 1).

Calcschist (hereafter Cs). This rock, first examined by Bagnoli and Tongiorgi (1980), consists of 10 cm thick layers of light grey and whitish carbonate that alternate with thinner (maximum 1–2 cm) intercalations of greenish and bright phyllites and carbonate phyllites. Both varieties are close to parallel with the S1 Alpine foliation.

The carbonate horizons, which are dominantly composed of Cal and minor Dol, microcrystalline Qtz, Ms and Chl, often contain abundant crinoid ossicles and show a granoblastic to lepidoblastic texture. The Chl content within phyllites and calcareous phyllites usually gives a typical green colour.

Red nodular dolomitic metalimestone (hereafter RdM). Rare and discontinuous outcrops of this rock have been found in the Seravezza inland and north of Pania della Croce. In both cases the RdM occupies the same stratigraphic position above the OD/Cs sequence.

The RdM consists of dark reddish-purple, calcareous and dolomitic metasediments that lack regular stratification and exhibit a sort of nodular, possibly original structure. Anastomosing layers and/or irregular films of phyllosilicates (mainly Ms and Chl) surround the nodular carbonate bodies emphasizing this particular structure on weathered surfaces.

The RdM has not yet provided palaeontological data but Bagnoli and Tongiorgi (1980) proposed a Devonian age on the base of striking analogies between these rocks and carbonate formations in the identical stratigraphic position in pre-Variscan sequences of southwestern Europe and Sardinia.

4 Geochemical Data of the Metabasic Rocks of the Alpi Apuane Variscan Basement

Although the metabasic rocks in the Apuan basement are quite rare, they show some interesting features that help us to infer a more complete geodynamic setting for the stratigraphic and tectonic evolution which has been described already and is discussed later in the text.

We must remember that the basic rocks we are dealing with have suffered two tectono-metamorphic cycles (Variscan and Alpine) and that such a complex history may have strongly influenced the absolute concentration of many of the elements usually detected in routine chemical analysis (expecially K, Na, Ca, Rb, Sr, Ba).

The original petrography is never preserved. Albitized Pl, Ap and leucoxene-rimmed Ilm phenocrysts represent the few relic mineral phases in some samples; by contrast, some well preserved magmatic textures are often present, now referable to blastoporphyritic and blastophitic types.

The mafic phases are completely metamorphosed into mineral aggregates that include neoblastic Chl ± Ep ± Cal±opaques and are fairly well distributed throughout the rock. Metamorphic condition with P(fluid) = P(tot) is marked by the widespread formation of these OH-bearing silicates and carbonates. Microtextural evidence shows that Cal formed in pre-Alpine times and that CO_2 was present in the metamorphic fluid phase since Variscan times. This condition seems, at least in these rocks, not to have been repeated during the Alpine metamorphism.

Any discrimination among the Apuan basement metabasites is only possible utilizing the HFSE (high field strength elements) which are considered immobile during metamorphism and alteration processes (assuming that the above mentioned two metamorphic cycles did not produce significant modification at least in their original ratios).

In the Variscan basement of the AMC two distinct suites (MBP: blastoporphyritic metabasites; MBO: blastophitic metabasites) of metabasic rocks occur. Their characters were previously discussed by Conti et al. (1988) who have shown a generally transitional chemical composition for both types, but a contrasting petrogenetic affinity. The composition of these metabasites is here reproposed with a more complete set of their chemical data (Table 1).

The MBP rocks that always appear effusive (see end of LP section) with a blastoporphyritic texture show a general basaltic composition and an alkaline petrogenetic affinity. The latter is pointed out by their high TiO_2 contents and Nb/Y ratios (see Table 1 A), as well as by their REE chondrite normalized patterns (Fig. 3 A). These patterns are characterized by high LREE/HREE fractionation, no Eu anomalies and similar (La/Sm)n = (2.4–2.2) and (Gd/Yb)n = (2.2–1.9) ratios, in spite of the difference of their total abundances (ΣREE = 168 and 105 ppm).

Similar characters are also displayed by other metabasic rocks, which crop out all over the Variscan chain in Europe (e.g. in Sardinia and in Maures Massif) and are generally linked to continental extensional or transpressive regimes of different ages from Tremadoc (Maures) to Carboniferous through Caradoc (Sardinia) Ricci and Sabatini 1978; Seyler and Boucarut 1979; Memmi et al. 1983; Seyler 1983; Di Pisa et al. 1991).

The MBO rocks appear as subvolcanic bodies (see end of Pf+PfS Sect.) with a blastophytic texture,

Table 1. Representative chemical analyses of metabasites of the Apuan Palaeozoic basement

A MBP metabasites

	R3-60	VG-2	T4-51	T4-78	T4-74	T4-75
SiO_2	45.34	45.77	45.28	49.41	46.25	46.71
TiO_2	3.72	1.92	1.87	2.12	1.75	1.87
Al_2O_3	13.56	16.13	15.21	17.79	15.71	17.39
Fe_2O_3	17.03	11.30	11.98	11.98	12.18	12.41
MnO	0.16	0.11	0.15	0.10	0.19	0.12
MgO	4.66	6.23	6.00	9.14	7.33	9.94
CaO	5.89	5.55	7.50	0.57	5.36	2.29
Na_2O	4.14	4.50	3.34	3.49	3.86	3.34
K_2O	0.40	0.04	0.60	0.30	0.23	0.23
P_2O_5	0.55	0.40	0.45	0.34	0.40	0.39
LOI	4.32	7.84	9.28	4.76	6.74	5.31
SUM	99.77	99.79	99.21	100.00	100.00	100.00
Ba (ppm)	106	6	219	138	83	106
Rb	16	<5	21	21	14	14
Sr	221	380	348	91	147	154
Nb	38	26	24	32	38	39
Y	38	28	31	30	37	35
Zr	263	220	213	288	335	328
Ni	51	142	113	137	105	104
Cr	58	141	121	168	91	99
V	394	129	139	195	166	18
Nb/Y	1.00	0.93	0.77	1.07	1.03	1.11
La	31.77	18.67	18.37	18	23	21
Ce	71.00	44.83	42.46	41	53	47
Nd	33.67	20.64	20.92	–	–	–
Sm	8.38	5.38	5.85	–	–	–
Eu	2.49	1.67	1.73	–	–	–
Gd	7.46	4.83	5.58	–	–	–
Dy	6.55	4.51	5.05	–	–	–
Er	3.21	2.29	2.58	–	–	–
Yb	2.75	2.06	2.33	–	–	–
Lu	0.59	0.35	0.39	–	–	–
ΣREE	167.87	105.23	105.26	–	–	–
$(La/Yb)_n$	7.8	6.1	5.3	–	–	–
$(La/Sm)_n$	2.4	2.2	2.0	–	–	–
$(Gd/Yb)_n$	2.2	1.9	1.9	–	–	–

B MBO metabasites

	VG-1b	T4-76	T4-93	R3-34	R3-33	T7-35
SiO_2	47.17	56.07	56.30	56.49	57.07	57.78
TiO_2	1.37	0.96	0.84	1.24	1.08	0.90
Al_2O_3	16.51	16.62	15.90	16.83	17.95	16.26
Fe_2O_3	8.44	8.54	6.77	9.67	8.17	7.89
MnO	0.14	0.13	0.09	0.11	0.12	0.11
MgO	5.84	3.89	2.89	4.99	5.43	4.89
CaO	6.33	3.12	4.03	1.43	0.80	2.26
Na_2O	3.64	5.98	4.90	5.62	4.72	4.68
K_2O	1.11	0.31	1.37	0.16	0.93	0.72
P_2O_5	0.35	0.53	0.42	0.63	0.41	0.45
LOI	8.21	3.85	6.50	2.83	3.37	4.05
SUM	99.11	100.00	100.01	100.00	100.01	99.99
Ba (ppm)	220	75	260	64	272	128
Rb	33	18	58	13	57	30
Sr	284	149	143	189	166	131
Nb	10	20	17	16	17	18
Y	28	36	31	36	32	32
Zr	168	409	340	366	348	358
Ni	65	19	18	22	18	15
Cr	166	27	22	24	23	26
V	162	115	103	137	103	110
Nb/Y	0.36	0.55	0.55	0.44	0.53	0.56
La	17.45	33.39	28.80	29.69	22.05	27.55
Ce	41.55	71.17	63.14	68.08	49.44	62.11
Nd	20.40	33.83	28.17	32.92	23.40	28.80
Sm	4.98	7.37	6.30	7.39	5.56	6.50
Eu	1.30	1.62	1.52	1.72	1.55	1.54
Gd	4.40	6.08	5.27	6.44	4.91	5.40
Dy	4.34	5.69	4.91	5.73	4.65	4.93
Er	2.44	3.18	2.72	3.20	2.65	2.79
Yb	2.26	3.14	2.80	3.12	2.55	2.80
Lu	0.30	0.51	0.50	0.57	0.48	0.46
ΣREE	99.42	165.98	144.13	158.86	117.24	142.88
$(La/Yb)_n$	5.2	7.2	6.9	6.4	5.8	6.6
$(La/Sm)_n$	2.2	2.8	2.9	2.5	2.5	2.7
$(Ga/Yb)_n$	1.6	1.6	1.5	1.6	1.5	1.6

Major and trace elements were determined by XRF after Franzini et al. (1975) and Leoni and Saitta (1976). The same method was employed for La and Ce determinations of samples T4-78, T4-74 and T4-75. REE were determined by plasma emission spectroscopy at C. R. P. G. of Nancy. The samples R3-60, VG-2, T4-51 and VG-1b were completely analyzed at C. R. P. G.

range from basaltic to intermediate compositions and exhibit a subalkaline affinity (see Table 1B). They show TiO_2 contents and Nb/Y ratios lower than MBP and a general negative correlation of Ti and V vs. any independent fractionation index (e. g. FeO tot/MgO, SiO_2 or Zr): this fact suggests fractionation processes under relatively high fO_2 (Miyashiro and Shido 1975; Shervais 1982).

The REE patterns (Fig. 3B) differ from the previous ones essentially by either the presence of a slight negative Eu anomaly, in both analyzed samples, or a less pronounced HREE fractionation $(Gd/Yb)_n = 1.5–1.6$. Such a REE distribution has been encountered in many andesitic rocks and indicates, together with the other previously discussed chemical characters, a calc-alkaline affinity for the MBO samples.

The available geochemical data here reported for the Apuan basement metabasites, also supported by geological field observations, lead to hypothesize the occurrence of two magmatic suites representing two different geodynamic settings.

5 The Pre-Alpine Structure and the Alpine Tectonic Overprint

As already pointed out, the traces of a pre-Alpine tectono-metamorphic event are usually detectable in

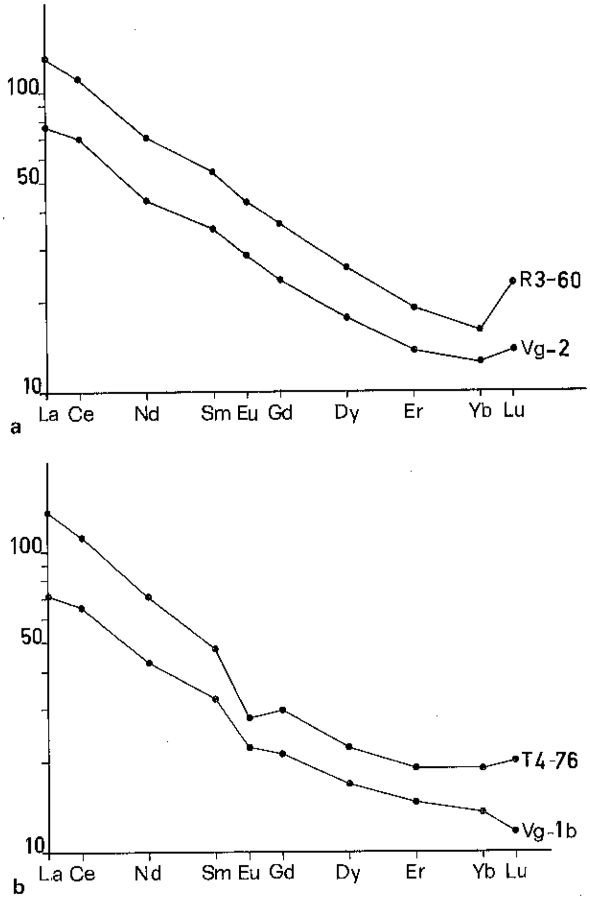

Fig. 3 A, B. REE abundances normalized to chondrite C1 (Evensen et al. 1978). **A** MBP metabasites **B** MBO metabasites

all basement rocks. Here, we want to show briefly the existence of pre-Alpine structures on every scale, referring the reader to previous work (Conti et al. 1991) for further details.

On a regional scale, the predominantly dolomitic Upper Triassic Vinca and "Grezzoni" formations represent the beginning of the Alpine sedimentary cycle of the AU. These units lie uncomformably on the Palaeozoic sequences, which are both upright and overturned with respect to the stratigraphic layering of the first Alpine sediments. This indicates that the latter were deposited on an already deformed and eroded basement.

In spite of the severe and pervasive deformation that involved stretching during the D1 Alpine event (Carmignani et al. 1978, 1980), some features of the old structures, such as folds and probably also thrusts, are still recognizable. In fact, the distribution of the Silurian-?Devonian rocks in relation to S1, reveals the existence of ancient synclines that developed at different geometric levels within the pre-Alpine building. Taking into account the Alpine kinematics, we can tentatively estimate that the pre-Alpine trend of these folds would have been almost E-W (± 30°).

The regional interference pattern between Alpine and pre-Alpine structures may be referred to as the "oblique type 1" as described by Ramsay (1967).

On a mesoscopic scale it is directly possible, in some outcrops, to map the pre-Alpine/Alpine folds interference geometry. Both anticlines and synclines with well-preserved limbs can be distinguished on a metre to hundreds of metres scale. Also, in this case the "oblique type 1" of Ramsay is recognizable.

On a smaller scale, all rocks, especially LP, show a pre-existing foliation inside "lithons" between the S1 Alpine-spaced surfaces. This geometric relationship within the Silurian OD has a particular geological meaning. The interference patterns all correspond to types 3 and 4 of Bell and Rubenach (1983).

6 Palaeotectonic Evolution of the Apuan Basement

The severe overprint of Alpine tectonics on the Palaeozoic sequence, that was already deformed and metamorphosed during the Variscan history, makes it rather difficult to reconstruct the palaeotectonic evolution of the Apuan basement. Most of the sedimentary and palaeontological record was nearly completely destroyed by the two orogenies and, as a consequence, the lithostratigraphic succession has been restored only on the basis of seldom preserved fossils (which indicate a Late Silurian age) and reciprocal relationships between the mapped lithologies.

The reconstruction of the stratigraphic sequence, shown in Fig. 2, has been performed through comparison with other Palaeozoic sequences in the Mediterranean area, particularly those cropping out along the "Zona a Falde" (nappe zone) of the Sardinian sector of the Variscan chain (Carmignani et al. 1977; Di Pisa et al. 1988; Gattiglio 1988).

The geometric relationships between the various lithotypes, and clear, although few data on the stratigraphic polarity suggest that the LP is the oldest formation of the Apuan Palaeozoic sequence. The lithologic and sedimentary features of LP indicate that it was a primary pelitic-arenitic sequence that may be related to the basal, silico-clastic deposits of the most important tectonic units of Variscan Sardinia.

In Sardinia these sediments provided a Late Cambrian to Early Ordovician (Arenig) age (Barca et al. 1982 a, b; Tongiorgi et al. 1984; Albani et al. 1985) and have been interpreted as turbiditic deposits in a submarine fan or basin floor environment (Barca and Marini 1980; Barca et al. 1982).

The same age can be attributed to the alkaline metabasites which stratigraphically lie within the LP, as already pointed out by Tongiorgi and Bagnoli (1981 a, b) and Puxeddu et al. (1984). In fact, alkaline volcanism of this age is reported from several Variscan massifs of South Europe, for instance from the "Serie du Collobrières" of the Maures Massif (Seyler and Boucarut 1979), where such rocks have been dated at 498 ± 12 Ma (U/Pb on Zrn: Lancelot et al. in Seyler 1983) corresponding to the Cambrian-Ordovician boundary (Harland et al. 1985).

Following Seyler's proposal for the Maures Massif, we assume an extensional regime within continental crust during the LP deposition. This regime would also be suggested by presence of the alkaline metabasites, and continued at least up to the Early Ordovician (Tremadoc). It could have been linked to development of a passive continental margin, rather than to a continental rifting: no sedimentary evidence is available for the latter situation. On the contrary, compressional events would have occurred during Early-Middle Ordovician. These events are well known in Sardinia where the uppermost portion of the Cambrian-Ordovician terrigenous sediments represents the progressive infilling of the basin (Tongiorgi et al. 1984), during a regression which ultimately led to its emersion.

In the Alpi Apuane, this emersion would be represented by rare metaconglomerate horizons, containing sandstone, quartzite and minor volcanic pebbles, which are interbedded along the boundary between LP and Pf + PfS (Gattiglio et al. 1989). In Sardinia the top of the Cambrian-Ordovician terrigenous sediments shows erosional channels and depressions filled by conglomerates. The latter correspond to an important unconformity ("Discordanza Sarda" in southwest Sardinia: Stille 1939; "Discordanza Sarrabese" in southeast Sardinia: Calvino 1961) related to "Caledonian tectonic movements" ("Sardische Phase" by Stille 1939).

These movements, which developed in a time span between Arenig (488–478 Ma) and Caradoc (458–448 Ma) Barca et al. 1987), were not accompanied by important tectono-metamorphic phenomena (Barca et al. 1985) and generated only gentle folds with a subvertical cleavage in southwest Sardinia (Arthaud 1963, 1970; Poll and Zwart 1964; Poll 1966; Carmignani et al. 1982 a), and angular unconformities in the other Variscan sequences of the island.

In the Alpi Apuane, we believe the metaconglomerates at the top of LP have the same significance, that is, they represent a "Caledonian event", even though the two subsequent orogenies (Variscan and Alpine) have, until now, prevented us from recognizing any "Caledonian" structures (but, it is possible that the "Caledonian" tectonics would not have been important, as in Sardinia).

It is therefore likely that the geodynamic setting changed from extensional, during Late Cambrian-Tremadoc, to compressional, during Arenig-Middle Ordovician.

The widespread and abundant, acidic to minor intermediate volcanics (Pf + PfS) represent the most significant marker of such a change. They consist of original ignimbrite covers and lava flows (and joined erosional products) and represent a coeval lithologic association in any Variscan sequence of South Europe (Austrides, Southern Alps, Calabria, Sardinia, etc.).

In the Sardinia Variscan sequences, continental volcanics unconformably overlie ("Sarrabese-Sarda" Unconformity) the Late Cambrian-Arenig metasandstone and are, in turn, covered by fossiliferous metasediments of Caradoc-Ashgill age (Calvino 1961; Naud 1979; Carmignani et al. 1986, 1989; Carosi et al. 1987). These volcanics, composed mainly of porphyritic acidic lavas and rhyolitic-rhyodacitic ignimbrites with minor andesitic lavas and basalts, represent a well-defined subalkaline suite (Memmi et al. 1983) resulting from magmatism which occurred during the evolution of an active continental margin.

These volcanics can be correlated with the Apuan units Pf and PfS, thereby assigning them to an age ranging from Early to Late Ordovician (Di Pisa et al. 1988). At present, radiometric ages of these rocks are not available. The geochemical data that exist on the rare basic rocks of intermediate composition indicate a subalkaline character: thus, also the subalkaline basites that are present as dykes within LP (Conti et al. 1989) might belong to the same magmatic cycle.[3]

The Pf + PfS suite of the Apuan basement can also be correlated with analogous rocks in the sequences of the Austro-Alpine nappes (Flajs and Schönlaub 1976) and South-Alpine Palaeozoic, where they are present either as wide volcanic flows ("Piattaforma

[3] These dyke-like products were previously reported also from inside Pf and related to a generic, Late to post-Ordovician magmatism (Conti et al. 1989). More careful field analyses have since raised some uncertainty as to whether the relationship between the two lithologies is actually intrusive. Moreover, recent findings of rare basic rocks of intermediate composition in association with Pf, lead us to think that the subalkaline lithologies must relate, more likely, to the Middle Ordovician cycle. We cannot, however, exclude the possibility of younger magmatic cycles.

porfirica pre-ercinica": Sassi and Zirpoli 1965, 1968; Sassi et al. 1978. "Porphyroid-platte": Mostler 1970. Interpreted as Late Ordovician products: Dal Piaz et al. 1975; Flajs and Schönlaub 1976; Sassi et al. 1980), or as intrusive bodies within the prevolcanic basement (450–420 Ma old orthogneiss: Sassi and Zirpoli 1980; Borsi et al. 1980; Del Moro et al. 1984).

Both Austro-Alpine and Southalpine granitoids and porphyroids of Ordovician age (Ordovician "evento granitico-riolitico": Schmidt and Söllner 1982) were derived from crustal anatexis and show a calc-alkaline character (Peccerillo et al. 1979; Sassi and Zirpoli 1980; Sassi et al. 1980). This magmatism has been related (Sassi and Zirpoli 1980) to a "Caledonian" tectono-metamorphic episode (Sassi and Zanferrari 1972; Borsi et al. 1973; Sassi et al. 1974, 1978, 1980; Purtscheller and Sassi 1975; Peccerillo et al. 1979; Söllner and Schmidt 1981).

We consider that the Apuan basement subalkaline magmatism and the Austro-Alpine, Southalpine and Sardinian calc-alkaline magmatism developed during the same tectonic processes (the "Caledonian" event), in a geodynamic setting typical of an active continental margin.

During and after this subalkaline magmatism, the volcanoes were partly eroded and variously covered by the products of this erosion. These products show an evolution indicating progressive transition from subaerial to submarine sedimentation (metasandstone, carbonate metasiltite and minor, crinoid ossicle-rich metalimestone: Gattiglio et al. 1989), although only a general transgression is inferrable because, at present, no palaeontological data are available.

In the Sardinia sequences, typical transgressive features are also represented by the deposits between the subalkaline volcanics and the Silurian fossiliferous sediments: these deposits correspond to the "Trasgressione Caradociana" Auct. and contain populous fossil associations of Caradoc (458–448 Ma) and Ashgill (448–438 Ma) age (Maccagno 1965; Laufeld 1973; Naud 1979).

The MQP sequence of the Apuan basement may also have been deposited in the Late Ordovician, and represents transgression on the previous volcanics. This phenomenon is common in the South Europe Variscan sequences (for instance, in the "Catena Paleocarnica": Spalletta et al. 1982) and is probably due to:

1. The melting of the Sahara inland ice;
2. The initiation of extension throughout the crustal sector that was previously deformed and thickened by the "Caledonian" event.

This extensional period (indicated by Spalletta et al. 1982, als "Stadio di piattaforma strutturale soggetta a rifting abortivo") caused important lateral variations within the MQP deposits of the Alpi Apuane. In Sardinia, extension is also marked by rare, basic alkaline lavas (within-plate basalts: WPB, Beccaluva et al. 1981; Memmi et al. 1983) that are interlayered with the Late Ordovician sediments.

The subsequent palaeotectonic history of the Apuan Variscan cycle is analogous to that in the other Variscan massifs in South Europe: slow crustal extension led to a Silurian epicontinental shallow sea with neritic sedimentation of Gr-bearing pelite and minor lydite (GP+LS), and deposition of fossiliferous dolomite (OD). Everywhere in the Mediterranean province, during this period the basin was relatively stable, with reduced sedimentation (Spalletta et al. 1982). Gradually, this environment changed to a more open sea in which the first carbonate platforms began to develop.

Although the subsequent evolution is difficult to detect in the Apuan basement because of the scarcity of the youngest sediments, the few RdM outcrops reveal (according to the reconstruction of Bourrouilh 1980, based on nodular limestone genesis) a new rifting episode during the ?Devonian which caused the drowning of the carbonate platforms. This extension is more completely documented in the Carnia Alps (Vai and Spalletta 1982) and in Sardinia; in the latter area, the nodular calcareous cover is widespread (Bourrouilh 1980) and metagabbroic bodies with a continental alkaline character (Memmi et al. 1983) form intrusions inside the blackish Silurian schist (northwest sector of the island).

The onset of the Variscan deformation caused cessation of the pelagic carbonate deposition in the Apuan sequence, in which synorogenic foredeep sediments have not been found.

A tentative location of the Apuan basement in the circum-Mediterranean Variscan chain must take into account either the absence of flysch-like, pre-/synorogenic deposits, or the pre-Alpine metamorphism (up to green schist facies) and deformation. Both factors indicate a primary position of Apuan Palaeozoic between the Variscan axial zone (with higher deformation and metamorphism) and the foreland domains (with thick and widespread synorogenic deposits). Such a position might be recognized as the "Zona a Falde" (nappe zone) of the Sardinian Variscan chain.

The palaeotectonic frame of the Alpi Apuane Variscan basement, discussed in this Section, is outlined mainly on the basis of its correlation with the wide Sardinia Palaeozoic sector, whose geodynamic and palaeogeographic evolution has recently been described by Carmignani et al. (1991).

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