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STRUCTURAL FRAME OF THE TUSCAN PALEOZOIC: A REVIEW

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ABSTRACT

A revision of the knowledge of the Tuscan Paleozoic rocks of the metamorphic complexes from Alpi Apuane to M. Argentario-Monti Romani is here outlined.

Whilst all formations clearly show the results of Alpine low grade metamorphism and tectonics, only some of them display the signs of a pre-Alpine history, represented by a variously pervasive schistosity with a green schist facies blastesis. Only in the deepest portions of the geothermal drillings in the Larderello Field, the mineralogical associations indicate the amphibolitic facies.

South of the Arno River, the pre-Alpine foliation can be found within Risanguigno and Poggio al Carpino Sandstone Formations, in some lithotypes of M. Bellino metamorphic complex (Monti Romani) and in the deep geothermal drillings of the M. Amiata and Larderello areas.

North of the Arno River, this old schistosity is clearly present within the Buti Quartzite and Phyllite Formation (Monti Pisani) and in each Paleozoic formation of the Alpi Apuane basement.

In southern Tuscany, the age of this pre-Alpine episode is well constrained. In fact, it occured between Early Devonian of the Risanguigno Formation and Upper Visean-Lower Namurian of the Carpineta Formation; the latter is unaffected by that structure.

North of the Arno River, in the Monti Pisani this pre-Alpine episode pre-dates the Late Carboniferous metasediments.

In the Alpi Apuane area, there are no rocks representing the interval between Early Devonian and Late Permian, so the oldest metasediments that are unaffected by the pre-Alpine deformation are the Metaconglomerate at the base of the Vinca Formation (Verrucano p.p.) of Middle-Late Trias within the "Autochthonous" Auct. Unit, and the metaruditic-phyllitic-metacarbonatic sequence of Early-Middle Trias within the Massa Unit.

On the contrary, the lower chronological boundary is almost the same of southern Tuscany, being represented by the Late Silurian-?Early Devonian metacarbonatic-phyllitic sequence (Orthoceras-bearing Metadolostone Formation, ecc.).

In spite of the less accurate definition of the time boundaries, the similarity of the pre-Alpine picture in the Alpi Apuane with that of southern Tuscany allows us to refer them to the same tectono-metamorphic evolution.

KEY WORDS: *Paleozoic, Northern Tuscany, Southern Tuscany, structural setting.*

RIASSUNTO

In questo lavoro vengono riassunte le conoscenze sulle rocce paleozoiche metamorfiche della Toscana, dagli affioramenti delle Alpi Apuane fino a quelli più meridionali (M. Argentario e Monti Romani).

Mentre tutte le formazioni mostrano i segni della tettonica e del metamorfismo di basso grado alpini, soltanto alcune di esse conservano testimonianze di una strutturazione pre-alpina, in genere rappresentate da una scistosità variamente penetrativa con blastesi in facies scisti verdi.

Soltanto nella parte più profonda del campo geotermico di Larderello i sondaggi hanno messo in luce rocce caratterizzate da associazioni mineralogiche pre-alpine in facies anfibolitica.

A sud dell'Arno la foliazione pre-alpina può essere rinvenuta nella Formazione di Risanguigno e in quella delle Arenarie di Poggio al Carpino, in alcuni litotipi del complesso metamorfico di M. Bellino (Monti Romani) e nei sondaggi geotermici profondi del M. Amiata e di Larderello. A nord dell'Arno questa vecchia scistosità è chiara-

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mente presente all'interno delle Quarziti e Filladi di Buti (Monti Pisani) e in ciascuna delle formazioni paleozoiche del basamento apuano.

In Toscana meridionale l'età di questo evento prealpino è ben delimitata; esso è infatti compreso tra il Devoniano inf. della Formazione di Risanguigno e il Viseano sup.-Namuriano inf. della Formazione di Carpineta, che appare immune da strutturazioni pre-alpine.

A nord dell'Arno, nei Monti Pisani questo evento prealpino risulta precedente ai depositi del Carbonifero sup.

Nelle Alpi Apuane non ci sono rocce corrispondenti all'intervallo tra il Devoniano inf. e il Permiano sup., pertanto i più vecchi metasedimenti privi della deformazione pre-alpina sono i metaconglomerati alla base della Formazione di Vinca (Verrucano p.p.) del Trias medio-sup. nell'«Autoctono» Auct., e la successione metaruditico-filladico-metacarbonatica del Trias inf.-medio nell'Unità di Massa.

Al contrario, il limite cronologico inferiore è praticamente coincidente con quello riconosciuto in Toscana meridionale, essendo rappresentato dalla successione metacarbonatico-filladica del Siluriano sup.-Devoniano inf.? (Dolomie ad Orthoceras, ecc.).

Nonostante la scarsa accuratezza dei limiti cronologici, la stretta analogia tra i quadri pre-alpini delle rocce palcozoiche apuane e della Toscana meridionale ci permette di riferire entrambi alla stessa evoluzione tettono-metamorfica.

TERMINI CHIAVE: *Paleozoico, Toscana settentrionale, Toscana meridionale, assetto strutturale.*

INTRODUCTION

As is generally known, the continental Tuscan Paleozoic forms scattered, more or less wide outcrops along a large belt from Alpi Apuane-Punta Bianca, in the north, to M. Argentario-M. Bellino (Monti Romani), in the south. It constitutes the base of the tectonic units belonging to the Tuscan Domain and shows a polyphasic syn-metamorphic structure of Alpine age.

Here we want to recall only the main features of this Alpine structure, referring the reader to the vaste literature for a more complete information (1).

During the first tangential deformative episode (D_1 phase) isoclinal folds developed on every scale, accompanied by a pervasive schistosity (S_1) and a green schist facies metamorphism. This episode was followed by tectonic movements (D_2 phase) which deformed the previous structure with at least two events.

The first, mainly related to a general uplift, caused regionally sized folds with both eastward and westward vergences, and was accompanied by some low grade facies blastesis. These folds have a concentric to sub-isoclinal style, Apennic axial strike and a fracture to strain-slip cleavage. The second event performed a more weak deformation with more or less open folds, whose axes have a direction perpendicular to the chain, and local overthrusts.

This Tertiary tectonic building affected a tectono-metamorphic frame, which appears only in the pre-Visean formations and belongs to the Hercynian orogenesis. It is recognizable both in the field and in thin section.

In this paper, the main features of Tuscan Paleozoic are briefly outlined, with reference to its classic outcrops: Alpi Apuane, Monti Pisani, Iano - Monticiano - Roccastrada - Mt. Leoni High, Colline Metallifere (Boccheggiano, Fenice Capanne and Gavorrano), M. Argentario and M. Bellino (Monti Romani).

Recent deep geothermal drillings made by ENEL (Italian Electricity Board) in the Larderello and in the M. Amiata areas have provided us with new data. The synoptic table in fig. 1 summarizes all the findings here after discussed.

NORTHERN TUSCANY

ALPI APUANE (C.P., D.P.A., G.M. & M.M.)

A lithostratigraphic revision of the Paleozoic basement of the Alpi Apuane has recently been carried out (GATTIGLIO & MECCHERI, 1987) mainly of the basis of:

— some palcontological contents, i.e. nautiloids (MENEGHINI, 1880) and conodonts (VAI, 1972; BAGNOLI & TONGIORGI, 1980);

— mutual geometric relationships between the various lithotypes;

— comparison with the better known and dated Palcozoic succession of southeastern Sardinia (CARMIGNANI *et al.*, 1986; CAROSI & GATTIGLIO, 1989);

— in each lithotype, more or less recogniz-

(1) Among the most recent works we mention RAU & TONGIORGI, 1974; CARMIGNANI *et al.*, 1978, 1981; DECANDIA & LAZZAROTTO, 1981; BOCCALETTI *et al.*, 1981, 1985; CARMIGNANI & GIGLIA, 1985; KLIGFIELD *et al.*, 1986; MORETTI, 1987, 1989; COSTANTINI *et al.*, 1988; ELTER & PANDELI, 1990, 1991).

LOCALITY	HERCYNIAN CYCLE					ALPINE CYCLE				
	UNITS AND/OR FORMATION	DEFOR.	METAM.	PARAGENESIS	CHRONO DATA (MA)	OLDEST FORMATION WITHOUT HERCYNIAN CYCLE	DEFOR.	METAM.	PARAGENESIS	CRONO DATA (MA)
APUAN ALPS	Red Nod. M. limestone (?Early Devonian) Calcschist (?Early Devonian) Orthoceras-bearing M. Dolostone (Late Silurian) Graphitic Phyllite and Lidian Stone M.sandstone Quartzite and Phyllite Porphyroid and Porhyric Schist Lower Phyllite	Se	Me	tMs±Chl±Qtz ±Ab		Vinca Formation (Verrucano p.p.) (?Middle-Late Trias)	S_1 S_2	M_1 Mi M_2	fgMs±Chl±Bt ±Qtz±Ab±Cal ±Dol Cld±Ky±Ep fgMs±Ep±Ox	27 12
PISANI MOUNTS	Buti Quartzite and Phyllite (?Late Ordovician -?Devonian)	Se	Me	tMs±Bt±Qtz ±Ox	285 ±12	S.Lorenzo Schist Form. (Stephanian-Autunian)	S_1 - C_2,S_2	M_1 Mi M_2 M_{i2}	fgMs±Chl± ±Qtz±Ox±Ab - - fgMs±Ox cld	
MONTICIANO-ROCCASTRADA UNIT	EXTERNAL UNIT INTERNAL UNIT Risanguigno Formation (Early Devonian) P. Carpino Sandstone Formation	Se	Me	tMs(Phengite)±Qtz		Carpineta Formation (Upper Visean--Lower Namurian) Iano Schist and M.sandstone Formation (Stephanian)	S_1 - C_2,S_2	M_1 Mi M_2 M_{i2}	fgMs+Qtz± ±Chl - - fgMs+Ox Cld	
DRILLING OF THE LARDERELLO AREA	Phyllitic Quartztic Group Micaschist Group Gneiss Group	Se Sex Se Sex Se Sex	Me Mex Me Mex Me Mex	tMs±Qtz±Pl tMs±Ox tMs+Bt±Qtz ±Amp±Crd± ±And±Pl±Grt ±Cld±Stau tMs±Ox±Qtx Bt±Sil±Pl And±Crd+Qtz ±Kfs±tMs± ±Grt tMs+Qtz±Ox	285 +11	Graphitic phyllite and M.sandstone (?Carbonifereous); polymictic M.conglomerate and vulcanics-bearing M.sandstone (?Permian) in the "Tectonic Wedges Complex"	S_1 - C_2,S_2 - Mt	M_1 Mi M_2 Mt Mt	fgMs±Chl± ±Qtz±Ab Cld±Ky fgMs+Ox±Chl ±Qtz And+Bt+Kfs +Crn Bt±Crd	2.7/ 3.8
DRILLING OF THE AMIATA MT AREA	Formation B	Se	Me	Chl+tMs+Qtz ±Ox		Formations A and C (?Middle Carboniferous -Late Permian)	S_1 - C_2 S_2 - Mt	M_1 Mi M_2 M_2 M_{i2} Mt	fgMs+Chl+ +Qtz±Ab±Cal ±Dol Cld±Ab fgMs±Ox fgMs+Ox+Qtz ±Chl±Cal± ±Dol Cld Bt	
BELLINO MT. (ROMANI MTS)	Tegolaie Valley Carbonatic -Phyllitic Compl. Botro del Lecceto M.sandstone and Phyllite Roccaccia di Montauto Quartzite and Phyllite S. Pietro Bridge Dark Phyllite and M.sandst.	Se	Me	Qtz±tMs±Chl		Dark Phyllite and M.sandstone Compl. (Verrucano s.l.) (?Early Triassic--?Middle Triassic)	S_1 S_2	M_1 -	fgMs±Chl+ +Qtz±Cal± ±Dol Ox	
ARGENTARIO MT.						Argentario Mt. M.Sandstone (?Carbonifereous--?Permian)	S_1 - C_2,S_2	M_1 Mi M_2 M_{i2}	fgMs±Chl± ±Qtz±Cal±Ox ±Pl - - fgMs±Ox Cld	

Fig. 1 - Synoptic table of the structural and metamorphic features of the Tuscan Paleozoic. Symbols: Se and Me = Hercynian (Sudetic phase?) schistosity and metamorphism. Sex and Mex = probable Breton phase schistosity and metamorphism. S_1 and M_1 = first Alpine phase schistosity and metamorphism. Mi = interphase Alpine metamorphism. S_2, C_2 and M_2 = second Alpine phase schistosity, cleavage and metamorphism. Minerals: tMs = coarse-grained Ms; fgMs = fine-grained Ms; Amp = amphibole; Ox = oxides. All the other minerals are indicated according to KRETZ (1983).

able signs of a pre-Alpine tectono-metamorphic event (see later).

From the bottom to the top, the restored succession is constituted as follows (fig. 2):

1) *Lower phyllite* («Quarziti e Filladi inferiori»: BARBERI & GIGLIA, 1966) - Metamorphites derived from an original alternance of quartzitic sandstone and argilloschist (TUCCI, 1980); the more common lithotypes are light to dark gray quartzite, dark gray and/or gray-greenish quartzite and phyllite, which form several and variously abundant associations.

In some places, scanty but clear relics of sedimentary structures (such as gradation and cross-bedding) are recognizable. Thin section observation shows a very common constitution, made up of alternance of lepidoblastic phyllites and granoblastic Qtz-rich levels (mineral symbols after KRETZ, 1983). This lithologic ensemble is correlated with the Solanas and San Vito Metasandstone Formations of the Sardinian Paleozoic succession.

2) *Porphyroid and Porphyritic Schist* («Porfiroidi e Scisti porfirici»: BARBERI & GIGLIA, 1966) - They are variously quartzitic and phyllitic rocks derived from acidic to intermediate volcanites and products of their subaerial erosion. Typically, they contain important amounts of original Qtz or Qtz and feldspar phenocrysts within the main Qtz+Ms+Chl matrix.

These rocks correspond to the calc-alkaline continental volcanism of southeastern Sardinia, related to an igneous post-orogenic activity (MEMMI *et al.*, 1983).

It must be stated that the contact between these lithotypes and the Lower Phyllite is locally outlined by the presence of rare lenses of a metaconglomerate and/or a whitish homogeneous quartzite: in the southeastern Sardinia analogous metasediments occupy the same stratigraphic position, corresponding to an early Caledonian event ("Sardinian Phase" by STILLE, 1939) and showing unconformable relationships with the overlying volcanic cover ("Sarrabese Unconformity": CALVINO, 1961).

3) *Metasandstone, quartzite and Phyllite* (GATTIGLIO & MECCHERI, 1987) - They partially correspond to the "Quarziti e Filladi superiori" by BARBERI & GIGLIA (1966) and are poorly phyllitic quartzite and less abundant quartzitic phyllite, frequently of an arenaceous texture and with few examples of graded bedding. These rocks often resemble the most mature types of Porphyritic Schist and often reveal cases of gradual transition to them. In southeastern Sardinia, these metasediments correspond to deposits containing abundant Upper Ordovician benthonic fossils (NAUD, 1979) and are transgressive on the underlying metavolcanites.

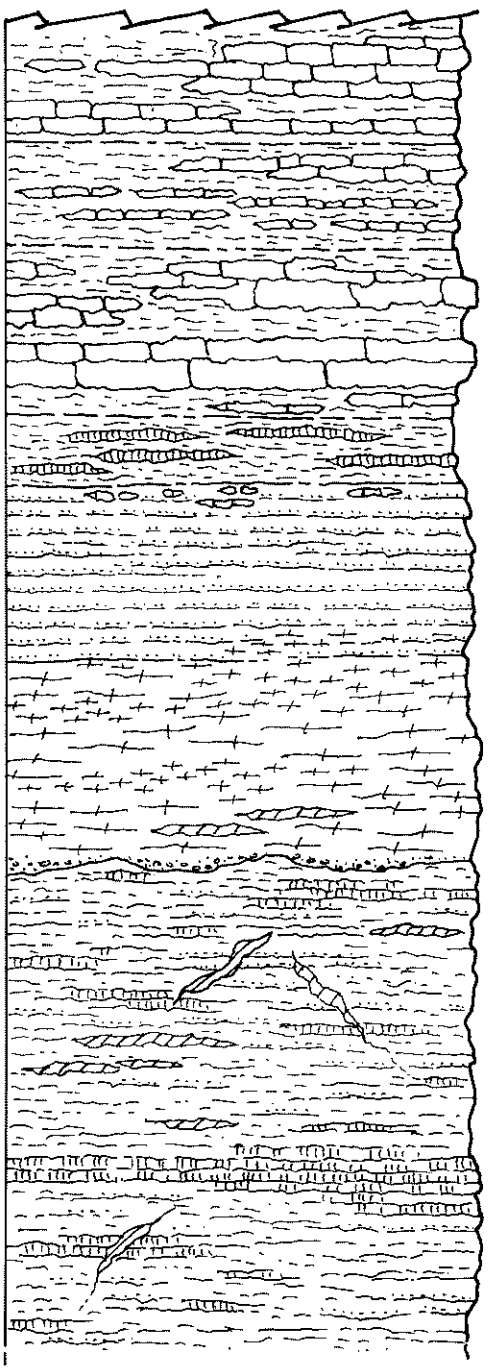
4) *Graphitic Phyllite and Lydian Stone* (GATTIGLIO & MECCHERI, 1987) - They are few, discontinuous and thin levels of black, locally feebly quartzitic phyllite, which often outcrop along the top of the previous formation and sometimes exhibit original stratigraphic relationships to it. Lydian Stone consists of blackish, Gr-bearing, fine-grained quartzite and forms thin and rare beds intercalated in the Graphitic Phyllite.

5) *Orthoceras-bearing Metadolostone and Dolomitic Metalimestone* (BARBERI & GIGLIA, 1966) - These rocks may be either in association with the previous phyllite, or alone. They have a fine granular texture and sometimes a phyllitic aspect owing to the abundance of thin graphitic films. They represent the only paleontologically dated lithotypes of the Apuan basement (Late Silurian-?Early Devonian: VAI, 1972; BAGNOLI & TONGIORGI, 1980).

6) *Calcschist and Red Nodular Metalimestone* (GATTIGLIO & MECCHERI, 1987) - The Calcschist is a dolomitic metalimestone with several thin layers of Ms+Chl bright green phyllite. The Red Nodular Metalimestone is a less abundant and reddish dolomitic metalimestone, massive and/or alternating with phyllitic layers: in the latter case it shows a typical, more or less preserved, nodular structure that may be primary.

The general frame of this succession has already been outlined by ZACCAGNA (1932), BONATTI (1938), IPPOLITO (1950), ELTER *et al.* (1966), BARBERI & GIGLIA (1966), CARMIGNANI *et al.* (1977), BAGNOLI *et al.* (1980), GIANELLI & PUXEDDU (1980), TUCCI (1980) and PUXEDDU *et al.* (1984). The lithological and stratigraphical correspondances of these rocks with those of southeastern Sardinia Paleozoic sequences are evident; this fact suggests a similar geodynamic framework for both areas (DI PISA *et al.*, 1988), even if a complete knowledge of the magmatic evolution in the Alpi Apuane basement is actually in progress (CONTI *et al.*, 1988) and mets some difficulties because of the strong Alpine overprint.

As stated above, the traces of a pre-Alpine tectono-metamorphic event are more or less clear in each basement rock, but we want to



HERCYNIAN OROGENIC EVENT

RED NODULAR METALIMESTONE — ?EARLY DEVONIAN

* CALCSCHIST

* ORTHOCERAS-BEARING METADOLOSTONE — LATE SILURIAN

* GRAPHITIC PHYLLITE AND LYDIAN STONE — SILURIAN

METASANDSTONE, QUARTZITE AND PHYLLITE — ?LATE ORDOVICIAN

PORPHYROID AND PORPHYRIC SCHIST WITH FEW METABASITE LENSES — ?ORDOVICIAN

THIN LEVELS AND LENSES OF METACONGLOMERATES (Caledonian discordance?)

LOWER PHYLLITE WITH METABASITE LENSES — ?EARLY ORDOVICIAN--?LATE CAMBRIAN

* Fossils — Porphyroid — Porphyric Schist — Metasandstone

Quartzite — Phyllite — Metabasite — Lydian Stone

Fig. 2 - Lithostratigraphic succession of the Alpi Apuane Paleozoic basement. The thickness of the formations is not at scale; distribution and thickness of the various lithotypes within each formation are simply qualitative.

emphasize them on every scale (see also CONTI *et al.*, 1991).

On a cartographic scale, the Late Triassic, mainly dolomitic Vinca and "Grezzoni" Formations, beginning the Alpine cycle in the "Autochthonous" Auct. Unit, lie unconformably on all Paleozoic lithotypes (fig. 3). Moreover, the last show both normal and overturned attitudes under the stratigraphic bottom of the "Grezzoni", which must have been horizontal before the Alpine tectonic history.

In spite of the strong and pervasive flattening and stretching performed by the syn-metamorphic Alpine D_1 phase (CARMIGNANI *et al.*, 1978, 1981), it is still possible to recognize some features of the pre-Alpine structure, such as folds and perhaps thrusts. For instance, if we consider the distribution of the Silurian-?Devonian rocks with regard to the regional S_1 building, we see that they correspond to ancient synclines developed along different geometric levels. The interference pattern between pre-Alpine and Alpine structures corresponds to the "oblique type 1" described by RAMSAY (1967). Bearing in mind the Alpine kinematics, we can tentatively estimate that the pre-Alpine trend of these synclines would have been almost east-west (± 30°), with regard to the actual geography.

In some cases, such as that in the southeastern slopes of M. Carchio (Massa inland), we can directly survey the interference geometry of the Alpine structural building on reliable, hectometric in size pre-Alpine folds (fig. 4). Here also, the "oblique type 1" by RAMSAY (1967) is recognizable.

On a smaller scale, almost all outcrops of Lower Phyllite and more rarely those of the other formations show the existence of an old schistosity in the lithons between the Alpine foliation surfaces, particularly where quartzitic lithotypes occur. Its presence within the Orthoceras-bearing Metadolostone obviously has the greatest geological meaning.

Microstructural analysis always reveals a mineralogical anisotropy along a surface net, both

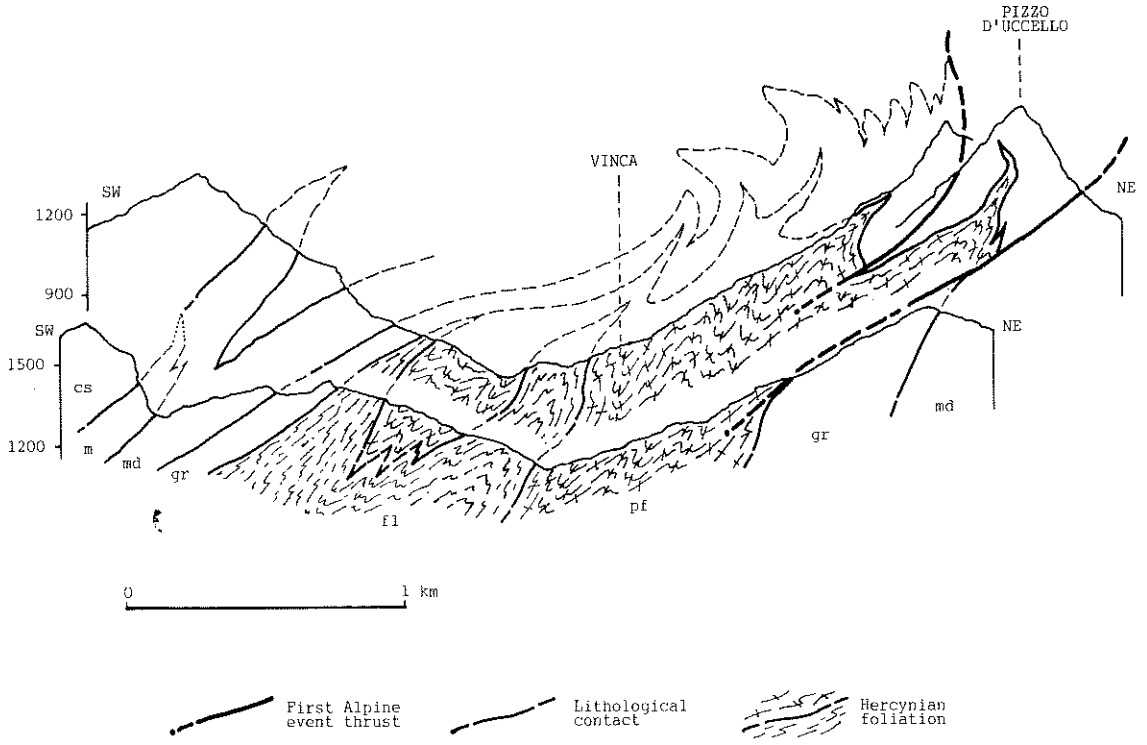


Fig. 3 - Cross-section through the northern sector of the Vinca-Forno anticline, northern Alpi Apuane, showing the discordance between the "Grezzoni" Formation (Late Trias) and the Underlying pre-Alpine structural building. Formations: fl = Lower Phyllite; pf = Porphyroid and Porphyritic Schist; gr = "Grezzoni" Formation (Late Trias); m = Marble Formation (Lower Lias); cs = Quartzite-bearing Metalimestone Formation (Middle-Upper Lias).

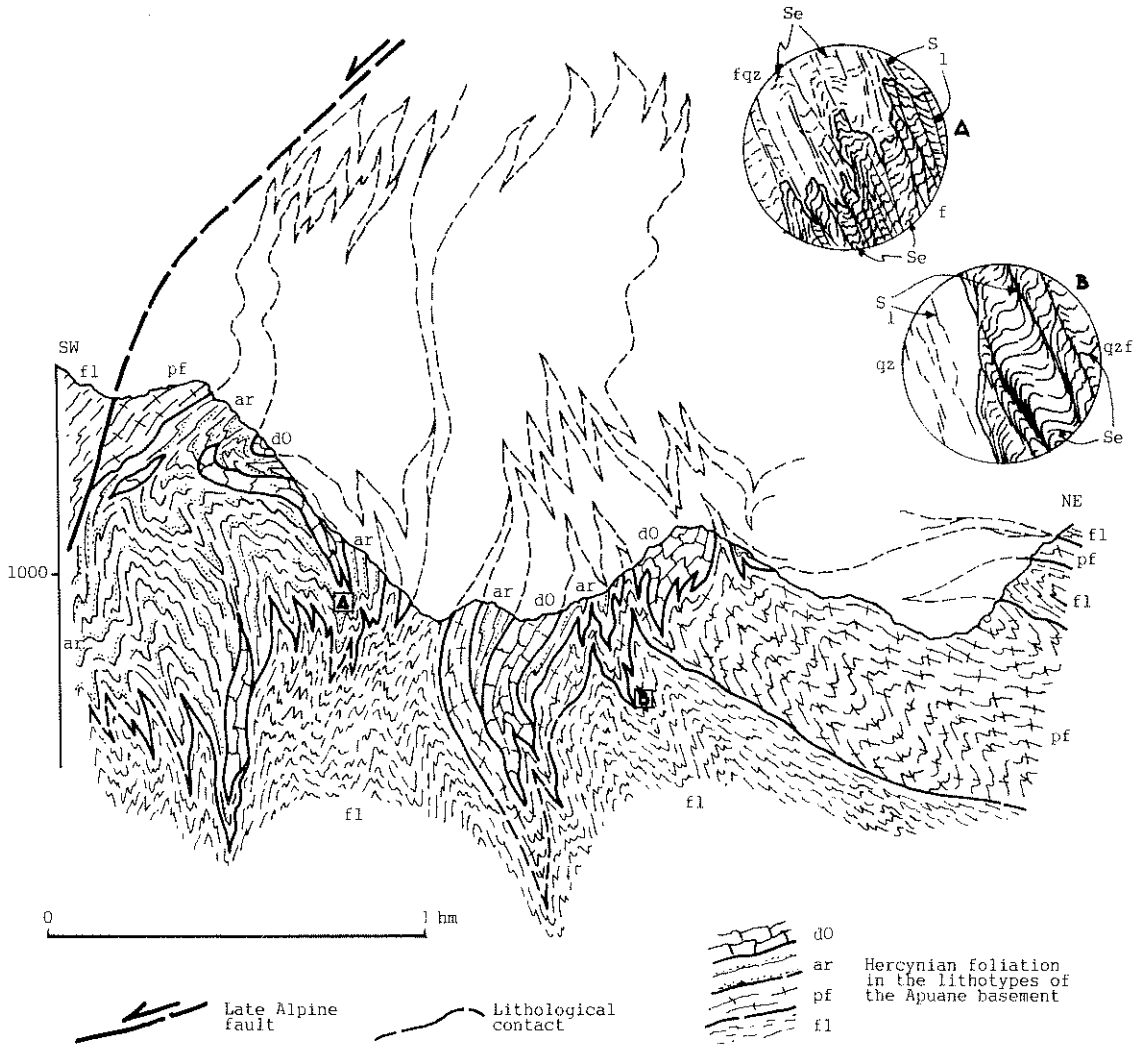


Fig. 4 - Cross-section through the eastern area of M. Carchio, western Alpi Apuane (Massa inland). Some pre-Alpine folds (possibly synclines), with a core made up of Orthoceras-bearing Metadolostone (Late Silurian), are deformed by the folds of the first Alpine episode. The schistosity, the axial planes and the flanks of these Tertiary structures are in turn refolded by the second Alpine event. Formations: fl = Lower Phyllite; pf = Porphyroid and Porphyritic Schist; ar = Metasandstone, Quartzite and Phyllite; dO = Orthoceras-bearing Metadolostone.

more or less well developed but clearly cut off and/or transposed by the first Alpine schistosity S_1. It is possible to recognize a lot of uprooted intrafoliar microfolds which deform that anisotropy; along the limbs of these microfolds, the S_1 obliterates all previous structure. This old layering is due to a metamorphic episode, very probably syn-kinematic, which developed the alternance of granoblastic quartzitic levels and thin lepidoblastic phyllosilicatic layers (white mica and less abundant Chl). The interference patterns recognized in thin section all correspond to types 3 and 4 of BELL & RUBENACH (1983).

The kinematic nature of the pre-Alpine anisotropy (a true foliation), the associated green schist facies blastesis, and the age of the youngest metasediments affected by it, are all proofs of the existence of the Hercynian orogenesis in the Alpi Apuane basement.

MONTI PISANI (R.A. & T.M.)

In the Monti Pisani the Paleozoic rocks, at the base of the Middle Triassic sequence of the Verrucano Group, outcrop in restricted and scattered areas. They are characterized by in-

tense Alpine diastrophism and metamorphism (RAU & TONGIORGI, 1974; TONGIORGI *et al.*, 1977; BAGNOLI *et al.*, 1980; MARTINI *et al.*, 1986).

These rocks consist of the pre-Sudetic Buti Quartzite and Phyllite Formation («Quarziti e filladi di Buti») and of the post-Hercynian/pre-Alpidic San Lorenzo Schist Formation («Scisti di San Lorenzo») and Asciano Breccia and Conglomerate Formation («Brecce e conglomerati di Asciano») (RAU & TONGIORGI, 1974).

The Buti Quartzite and Phyllite Formation consists of prevalently fine-grained quartzite levels. The quartzites are pure quartz-arenite with a Fe carbonate-rich, quartzose matrix. The mineralogical composition suggests that these metamorphic rocks derive from highly mature sediments. Lithological close affinities with the «Scisti porfirici» and the «Quarziti e Filladi superiori» (BARBERI & GIGLIA, 1966) of the Alpi Apuane (in this paper Porphyritic Schist and Metasandstone, Quartzite and Phyllite) are evident. BAGNOLI *et al.* (1980) and BAGNOLI & TONGIORGI (1980) suggested a Silurian-Devonian age for this formation (2). In the Monti Pisani area, the Buti Formation represents the remains of the Variscan European Belt.

The San Lorenzo Schist Formation consists of sediments ranging from predominant black silty shale to sandstone and conglomerate; graphitic levels are also present. Rhythmic sequences, a few meters thick, have been observed and comprise, from the bottom: a thin graphitic level, finely foliated graphitic shale, blackish phyllite and, at the top, a thick layer of coarse-grained pebbly sandstone or of quartzose conglomerate. Fossils and sedimentary features indicate a continental environment and a humid, inter-tropical climate (RAU & TONGIORGI, 1976).

The abundant fossil flora indicates a Late Carboniferous (Westphalian D?-Stephanian) to Permian (Autunian) age. The fossil content also includes pelecypods, ostracods and insects (see in RAU & TONGIORGI, 1974). The San Lorenzo Schist Formation represents, in the geodynamic and sedimentary evolution of this part of the Tuscan Domain, the infilling of limnic basins tectonically controlled by a transcurrent regime. This tectonic regime, active in the Tuscan segment of the Italian Hercynian chain, was closely connected to the megashear system which crossed the European Continental Mass from Late Carboniferous (RAU, 1990).

The Asciano Breccia and Conglomerate Formation consists of poorly bedded breccia and conglomerate. The coarser clasts are represented by Qtz and fragments of metamorphic rocks such as quartzite and phyllite, prevalently derived from the Hercynian Buti Formation. The relative abundance of lithic fragments indicates the low maturity of the sediment (BAGNOLI *et al.*, 1980). This formation has been interpreted as a continental fanglomerate, deposited in a subarid climate (RAU & TONGIORGI, 1974, 1976).

The age of the Asciano Formation has not yet been defined, but it is stratigraphically interposed between the Autunian deposits of the San Lorenzo Schist Formation and the Middle Triassic Verrucano (RAU & TONGIORGI, 1974). The Asciano Formation represents the local deposition of detritic material along the borders of an intensely eroded area (RAU & TONGIORGI, 1974, 1976), probably uplifted during a transpressive episode connected to the strike-slip fault system active in the Tuscan Domain since the Permian.

With regard to the Hercynian structural setting of the Buti Quartzite and Phyllite Formation, very few observation can be made. In fact, because of the intense overprint of the Alpine polyphasic orogenesis, only a pre-Alpine schistosity demonstrates that this formation has been affected by Hercynian deformation. The Paleozoic rocks of the Monti Pisani are strongly involved in the Northern Apennines nappe building and outcrop in the core of Alpine anticlines and core-sheets.

SOUTHERN TUSCANY

In continental Tuscany, south of the Arno River, the Paleozoic basement crops out along the Iano-Monticiano-Roccastrada-M. Leoni High and at the Colline Metallifere (Boccheggiano, Fenice Capanne and Gavorrano), M. Argentario and M. Bellino (Monti Romani). Furthermore, deep drillings reached it in Larderello-Travale, Boccheggiano, Fenice Capanne, Niccioleta and M. Amiata areas.

IANO-MONTICIANO-ROCCASTRADA-M. LEONI HIGH (C.A., D.F.A., E.F.M., L.A., P.E. & S.F.)

This high (Monticiano-Roccastrada Unit

(2) An ?Ordovician age is instead here proposed, on the basis of lithostratigraphic comparison of these rocks with those of the Alpi Apuane and of southeastern Sardinia Paleozoic sequences (CONTI *et al.*, 1991; GATTIGLIO & MECCHERI, 1987).

Auct.) is mainly made up of Paleozoic, Early-Middle Triassic (Verrucano Group), Late Triassic (Tocchi Formation) and Triassic-Cretaceous (Montagnola Senese sequence) metamorphic formations (3).

According to RAU & TONGIORGI (1974) and BURGASSI *et al.* (1980), the Monticiano-Roccarada Unit is the southern exstension of the Massa Unit and consists of two tectonic sub-units (COSTANTINI *et al.*, 1988, 1989): the M. Leoni-Montagnola Senese sub-unit and the Montepescali-M. Quoio-Iano sub-unit.

In the former (External sub-unit) the outcropping Paleozoic formations have an Early-Middle to possibly Late Carboniferous age (Farma Stream and Sant'Antonio mine areas), while in the latter (Internal sub-unit) they are referrable to Early Devonian-?Early Carboniferous (Risanguigno and Farma Streams) and to Late Carboniferous Permian (Iano: COSTANTINI *et al.*, 1991).

M. Leoni-Montagnola Senese sub-unit

This sub-unit (1 in fig. 5) has a lenght of about 60 km and a visible width of about 6 km. From the oldest one, the Paleozoic formations are:

1) *Carpineta Formation* - Gray metasiltite and black, Gr-rich phyllite with siltitic-carbonatic/limonitic nodules. They contain many fossils of Upper Visean-Lower Namurian age (REDINI, 1941; COCOZZA, 1965; PASINI, 1978b, 1980a, 1980b, 1981).

2) *Farma St. Formation* - Alternating turbiditic metasandstone and dark gray phyllite, locally with a carbonatic megabreccia including lydian stone pebbles and Upper Moscovian fossils (COCOZZA, 1965; PASINI, 1978a, 1980a).

3) *Sant'Antonio Limestone* - Dark fossiliferous calcareous and calcareous-dolomitic formation on which the next Spirifer-bearing Schist Formation rests with the interposition of a paleosol horizon. The foraminifer content indicates a Lower Moscovian age (COCOZZA, 1965; PASINI, 1978a,1980b).

4) *Spirifer-bearing schist* - Dark gray, black and green quartzose phyllite of Upper Moscovian-?Lower Cantabrian age (PASINI, 1980b).

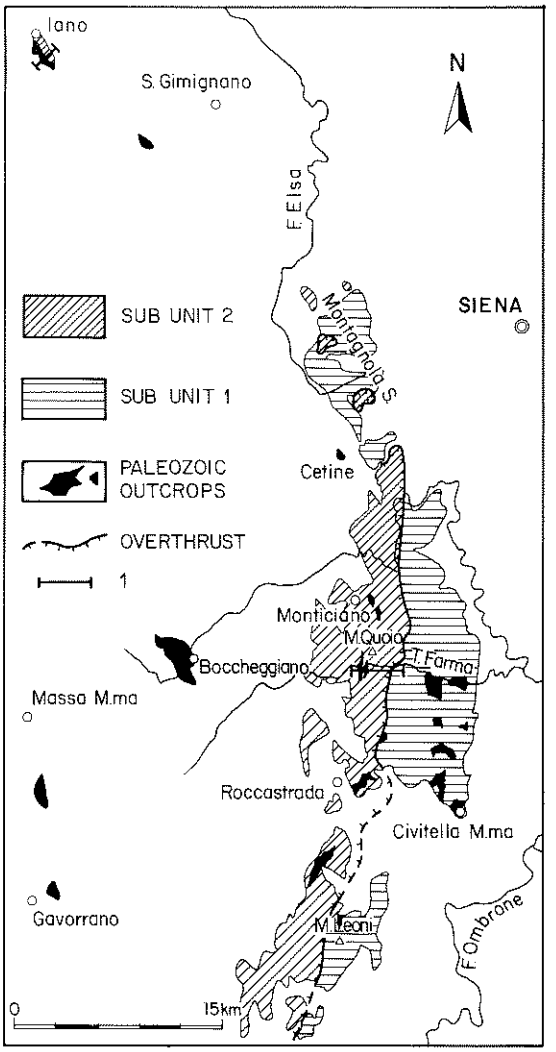


Fig. 5 - Tectonic sketch map of the Iano-Monticiano-Roccastrada-M. Leoni High (Monticiano-Roccastrada Unit Auct.), showing the relationships between the M. Leoni-Montagnola Senese sub-unit (sub-unit 1) and the Montepescali-M. Quoio-Iano sub-unit (sub-unit 2). The traces of the cross-sections reported in the figg. 7 and 8 (1) are also indicated.

This sub-unit has undergone four deformative events: three referrable to the Alpine tectonics (Fa, Fc and Ff by COSTANTINI *et al.*, 1988) and one, clearly the oldest, to a pre-Alpine episode (Fc by COSTANTINI *et al.*, 1988). Fig. 6 shows the correspondance of the structural in-

(3) In the Verrucano Group, unconformably overlying the Paleozoic formations, fusulinids-bearing carbonatic pebbles of Late Carboniferous-Early Permian age (ENGELBRECHT *et al.*, 1989), and others containing Early Triassic fossils (COCOZZA *et al.*, 1975) have been found in some areas.

dices used in the just mentioned work with those adopted in this paper.

The pre-Alpine deformative event is unschistogenous, but it is well recognizable in the Carpineta-Poggio alle Pigne area, where the Verrucano unconformably lies on the Carpineta (Early Carboniferous) and Farma (Middle Carboniferous) Formations. The discordance corresponds to an erosional surface and the Paleozoic deformation of the underlying rocks (possibly Asturic event: BAGNOLI *et al.*, 1980; TONGIORGI & BAGNOLI, 1981) pre-dates the Verrucano ?Permian-Triassic sedimentation (4).

Montepescali-M. Quoio-Iano sub-unit

This sub-unit (2 in fig. 5) has a lenght of about 80 km and a visible width of about 6 km. From the oldest, these are its Paleozoic formations:

1) *Risanguigno St. Formation* - It is made up of black-gray graphitic phyllite with intercalated green metasandstone, quartzitic phyllite and dolostone beds. At its base lydian stone and radiolarian chert form a few meters thick, discontinuous level. This formation has been attributed to Early Devonian on the basis of two conodonts-bearing samples (BAGNOLI & TONGIORGI, 1980).

2) *Poggio al Carpino Sandstone Formation* - Unconformably lying on the Risanguigno Formation, from the bottom it is made up of (COSTANTINI *et al.*, 1988, 1989): *a)* more then ten meters thick level of heterometric metaconglomerate with pebbles of white and black Qtz and minor clasts of black graphitic phyllite (mud-pebbles) and of gray and yellow-orange carbonate, in a gray metarenaceous matrix; *b)* alternating lenticular coarse-grained quartzitic metasandstone (sometimes with microconglomerate levels), metaconglomerate and black graphitic phyllite; *c)* gray and whitish quartzitic metasandstone with intercalated gray and black graphitic phyllite.

3) *Iano Schist and Sandstone Formation* - Gray quartzitic metasandstone and metaconglomerate with pebbles of white Qtz, light gray quartzite, phyllite, gray metasiltite and lydian stone in a quartzitic-phyllitic matrix. Its upper portion is characterized by alternating gray quartzitic metasandstone and metasiltite, with intercalations of black phyllite. By presence of plant relics and marine fossils (crinoids, pelecypods and possibly brachiopods), this deltaic-littoral formation has been attributed to Late Carboniferous (Stephanian: MAZZANTI, 1961; VAI & FRANCAVILLA, 1974 and references therein).

4) *Torri Breccia and Conglomerate Formation* (COSTANTINI *et al.*, 1989, 1991) - Polymictic metaconglomerate with a reddish and purple hematite-rich matrix, always characterized by a low maturity. Its pebbles are mainly constituted of phyllite, quartzitic phyllite and quartzitic sandstone. We want to emphasize the close analogies between this formation and the Asciano Breccia and Conglomerate Formation of the Monti Pisani, which has been referred by RAU & TONGIORGI (1974) to an interval between the end of the Autunian and the beginning of the Middle Trias.

5) *Iano porphyritic Schist Formation* - This formation consists of light gray to gray-greenish, sometimes purple, micro-augen phyllitic quartzite. It is characterized by presence of abundant fragments of acidic volcanics (embayed magmatic Qtz, clasts of rhyolite and flattened pumice) and minor clasts of phyllite and quartzitic phyllite. It has been attributed to Permian by BARBERI (1966).

In this sub-unit a structural pattern resulting from five deformative events (Fa, Fb, Fd, Fe and Ff by COSTANTINI *et al.*, 1988: see fig. 6) is recognizable.

It is noteworthy the angular unconformity between Poggio al Carpino and Risanguigno Formations, that indicates a deformation (Fa) pre-dating the deposition of the former and post-dating Early Devonian, the age of the latter.

The Fb event is well marked in the Poggio al Carpino Sandstone by presence of a Se schistosity, on which the S_1 schistosity is superimposed;

(4) The presence of fusulinids-bearing calcareous pebbles (Early Permian: ENGELBRECHT *et al.*, 1989) within the Verrucano (M. Quoio Formation) and the recent finding of Late Permian fossils in the M. Amiata geothermal drillings (PANDELI & PASINI, 1990) complicate the interpretation of the southern Tuscany pre-Alpine structure. In fact, the relationships between the Early Permian fossiliferous sequence and the Farma St.-like rocks are not clear enough. Therefore, we can propose two hypotheses about the above said deformation event:

a) it may pre-date Stephanian, the age of the Iano Formation (Asturic event?);

b) it may post-date Early Permian, the age of the above mentioned fusulinids-bearing sediments.

The second solution conflicts with the fact that at Iano the Stephanian sediments do not exhibit strong pre-Alpine deformations.

DEFORMATIVE EVENTS	COSTANTINI ET AL. (1988)	CONTI ET AL. (this paper)
Pre-Carboniferous Event	Fa	
Pre-Visean Event	Fb - - - - S_1	S_e
Westphalian Event	Fc	
Alpine Events	Fd - - - - S_2	S_1
	Fe - - - - S_3	S_2
	Ff	

Fig. 6 - Correspondence between the structural symbols used by COSTANTIN *et al.* (1988) and those adopted in this work.

the last is the axial plane foliation of eastward verging isoclinal folds (fig. 7), which also affect the Verrucano and represent the first Alpine deformation (Fd by COSTANTINI *et al.*, 1988).

In thin section the metasiltite of Poggio al Carpino Sandstone appears to have been affected by the first Alpine event schistosity (S_1), which transposes a layering made up of Qtz, phengite and Gr-rich levels alternating with phyllosilicates-rich levels. This is a metamorphic layering probably pre-Alpine in age, as it has never been seen within the post-Visean formations (e.g. Carpineta Formation of the M. Leoni-Montagnola Senese sub-unit).

At Iano, the northern end of the sub-unit 2, only the Alpine deformations are recognizable (fig. 8).

COLLINE METALLIFERE
(C.A., D.F.A., E.F.M., L.A., P.E. & S.F.)

In the surroundings of Boccheggiano, Fenice Capanne and Gavorrano (see location in fig. 5), some phyllitic-quartzitic sequences («Formazione filladica di Boccheggiano» Auct.) crop out. They are widely represented by dark gray and greenish phyllite and quartzitic phyllite, often graphitic, with intercalations of metarenites and, more rarely, quartzose metaconglomeratic beds (FRANCESCHELLI, 1980).

In the sub-surface of the same localities and in the Niccioleta mine (near Massa Marittima) and Travale-Radicondoli areas, mining and geothermal works (deep drillings, mines, ecc.) crossed, for over 1500 m, a complex sequence

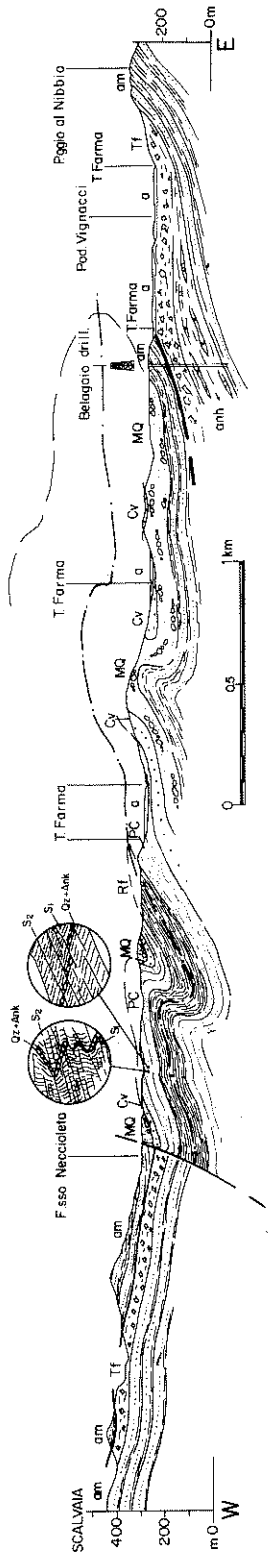


Fig. 7 - Cross-section along the Farma St. (see fig. 5). Paleozoic formations: Rf = Risanguigno St. Formation; Pc = Poggio al Carpino Sandstone Formation. ?Permian-Triassic formations: Verrucano Group (cv = Civitella Formation; MQ = M. Quoio Formation; an = Anageniti minute Formation); Tocchi Formation (Tf = Breccia; anh = Anhydrite and Chloritic Schist). For further detail about the ?Permian-Triassic formations, see COSTANTINI *et al.* (1988, 1989).

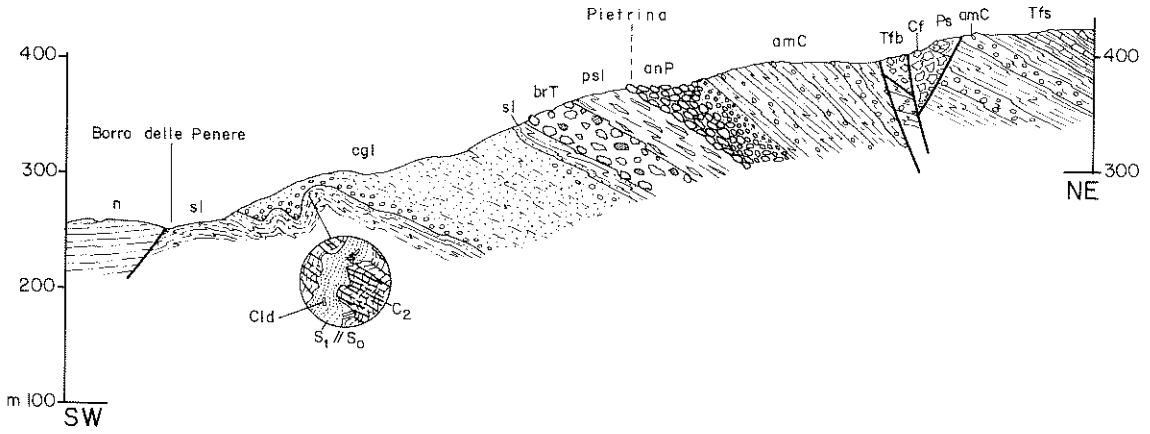


Fig. 8 - Cross-section through the Iano area. Paleozoic formations: sI = Iano Schist and Sandstone Formation; egI = Borro delle Penere Conglomerate and Sandstone (at the base of the former); brI = Torri Breccia and Conglomerate Formation; psI = Iano Porphyritic Schist Formation. Triassic formations: Verrucano s.s. (anP = Pietrina Anagenite Formation; amC = Poggio dei Cipressini Microanagenite and Metasiltite Formation); Tocchi Formation (Tfs = Phyllite and Carbonate; Tfb = Breccia); Cf = "Cavernoso" Formation. Ligurids: Ps = Palombini Shale Formation. Neogene: n = Pliocenic sandy and argillitic sediments.

consisting of phyllite and quartzose phyllite, often chloritic, sometimes graphitic, with intercalations of carbonatic quartzite, impure crystalline dolostone and anhydrite beds. Moreover, there are also metagraywacke and layers of basic metavolcanites (e.g. BAGNOLI *et al.*, 1980; TONGIORGI & BAGNOLI, 1981; CASTELLUCCI *et al.*, 1985).

Given the lack of fossils, the age of these sequences (both called «Boccheggiano Formation») has been for a long time the subject of debate. More particularly, they have been attributed either to the Paleozoic (Late Silurian?-Devonian according to BAGNOLI *et al.*, 1980, and TONGIORGI & BAGNOLI, 1981; Permian according to COCOZZA *et al.*, 1978, and COCOZZA & VAI, 1978), or to the Trias (TREVISAN, 1955; VIGHI, 1966; CORTECCI *et al.*, 1983).

A possibly Carboniferous age of Boccheggiano and Fenice Capanne outcrops has been hypothesized by PUXEDDU *et al.* (1984) on petrographical and geochemical bases.

From recent studies (Universities of Siena and Florence), still in progress, the oldest schistosity surface in the outcrops of the Boccheggiano Formation (S_1 in FRANCESCHELLI, 1980) would be Alpine in age, while relics of a pre-Alpine schistosity were found in the sub-surface sequences.

M. AMIATA DRILLINGS
(E.F.M. & P.E.)

The buried Paleozoic-Triassic low grade metamorphic sequence in the Piancastagnaio area of the M. Amiata region (PANDELI *et al.*, 1988; ELTER & PANDELI, 1990) consists of the following units (from top to bottom):

1) Middle-Late Trias Verrucano;

2) Gr-rich phyllite and metagraywacke (Formation A), similar to those of the Moscovian Farma Formation outcropping in the Monticiano-Roccastrada Unit Auct.;

3) Chl-rich, anhydrite-bearing phyllite with microcrystalline dolomitic levels (Formation B), probably pre-Visean in age, observed as a wedge within the Formation A;

4) thick crystalline carbonatic bodies with horizons of Gr-rich metasediments (Formation C).

At the passage between the Formations A and C was found a carbonatic level with Late Permian («Cancellina Zone»-Kubergandian) fusulinids and microforams (PANDELI & PASINI, 1990).

The structural picture is made up of two deformative events, one of Alpine age and the

other of pre-Alpine age. The latter is only present in the Formation B, while the former affects all the formations.

The Alpine structure was built up by three deformative phases. Their relationships at depth along the wells allow us to define two structural domains. In the first one (Domain 1), two planar anisotropies are recognizable: the more pervasive is a S_1 schistosity, which is deformed by a subsequent crenulation cleavage C_2. The second structural domain (Domain 2), peculiar of the lowermost part of the drillings, shows three planar anisotropies: the S_1 schistosity, another pervasive schistosity S_2 and a later crenulation cleavage C_3.

In the Formations A and C, S_1 transposes the stratification S_0, while in the Formation B it affects a pre-Alpine (Hercynian?) metamorphic layering made up of Chl + Ms + Qtz.

In the Domain 2 the transposition along the S_2 schistosity becomes increasingly stronger, so that a complete S_1 obliteration is reached.

The mesostructural analysis of the folds (Twiss, 1988) allows us to recognize the structural Alpine evolution. In the Domain 1, S_1 is associated with isoclinal to close-acute folds, while crenulation C_2 is associated with open-equant folds. In the Domain 2, S_2 foliation accompanies isoclinal to close-tight folds, while C_3 crenulation is associated with obtuse-fan folds.

The relationships of tectonic character between A and B Formations, and a possibly stratigraphic contact between A and C Formations (Elter & Pandeli, 1991) lead us to hypothesize the existence of a syn/post-D_2 reverse-recumbent folding (lately wedged), with Formation B at the core, or a complex pile of Alpine tectonic wedges.

Larderello Drillings
(E.F.M. & P.E.)

In between Canneto-Serrazzano, Monterotondo Marittimo-Lago, Larderello-Castelnuovo Val di Cecina and Pomarance areas, deep geothermal drillings have revealed the buried Paleozoic-Triassic metamorphic sequences (fig. 9) arranged in a quite complex framework. Such a complication is mainly due to the presence of a "Tectonic Wedge Complex" (Pandeli *et al.*, 1991) between the overlying Tuscan Nappe + Ligurid s.l. Units and the "basement" (?Precambrian -?Ordovician/?Silurian).

The "Tectonic Wedge Complex" is contituted by both portions of Triassic formations («Anidriti di Burano» Formation, Tocchi Formation, Verrucano s.l.) and wedged sequences of a likely Carboniferous-Permian age (ex. lithotypes similar to those of the Iano Schist and Sandstone Formation, Iano Porphyritic Schist Formation, Asciano Breccia and Conglomerate Formation, ecc.) and of Early Paleozoic (see below Phyllitic-Quarzitic Group).

From top to bottom the "basement" is made up of (Batini *et al.*, 1985; Elter & Pandeli, 1990, and references therein):

1) Phyllitic-Quartzitic Group, similar to the Lower Phyllite of the Alpi Apuane;

2) Micaschist Group;

3) Gneiss Group.

Except in the latter, the traces of the tectono-metamorphic epizonal Alpine event (D1, D_2 and D_3) are evident and pervasive. Moreover, the Phyllitic-Quartzitic and Micaschist Groups exhibit relics of blasteses (green schist to amphibolite facies) and foliations older than the first Alpine event (D_1) and referred to the Hercynian deformative evolution (Sudetic and possibly Breton events: e.g. Elter & Pandeli, 1990).

These relics represent the main planar anisotropy within the lithotypes of the Gneiss Group, which are only weakly affected by the Alpine tectonics. In addition, some mylonitic horizons, syn-tectonic to the Alpine deformations, are present at the top of the Gneiss Group.

A possible Alpine tectonic superposition of the Phyllitic-Quartzitic and Micaschist Groups from the underlying Hercynian Gneiss Group was hypothesized by Elter & Pandeli (1990).

M. Argentario
(D.F.A. & L.A.)

The Paleozoic rocks are well exposed in the southeastern sector of the promontory (panoramic road south of Porto Ercole). They are represented by very low grade dark metasandstone, metasiltite and carbonatic phyllite (M. Argentario Sandstone Formation), whose age has been referred to an uncertain Late Carboniferous (Lazzarotto *et al.*, 1964; Gasperi & Gelmini, 1973). This formation is unconformably covered by the ?Permian-Triassic Verrucano sequence (Civitella Formation in Costantini *et al.*, 1988).

The M. Argentario Sandstone Formation ex-

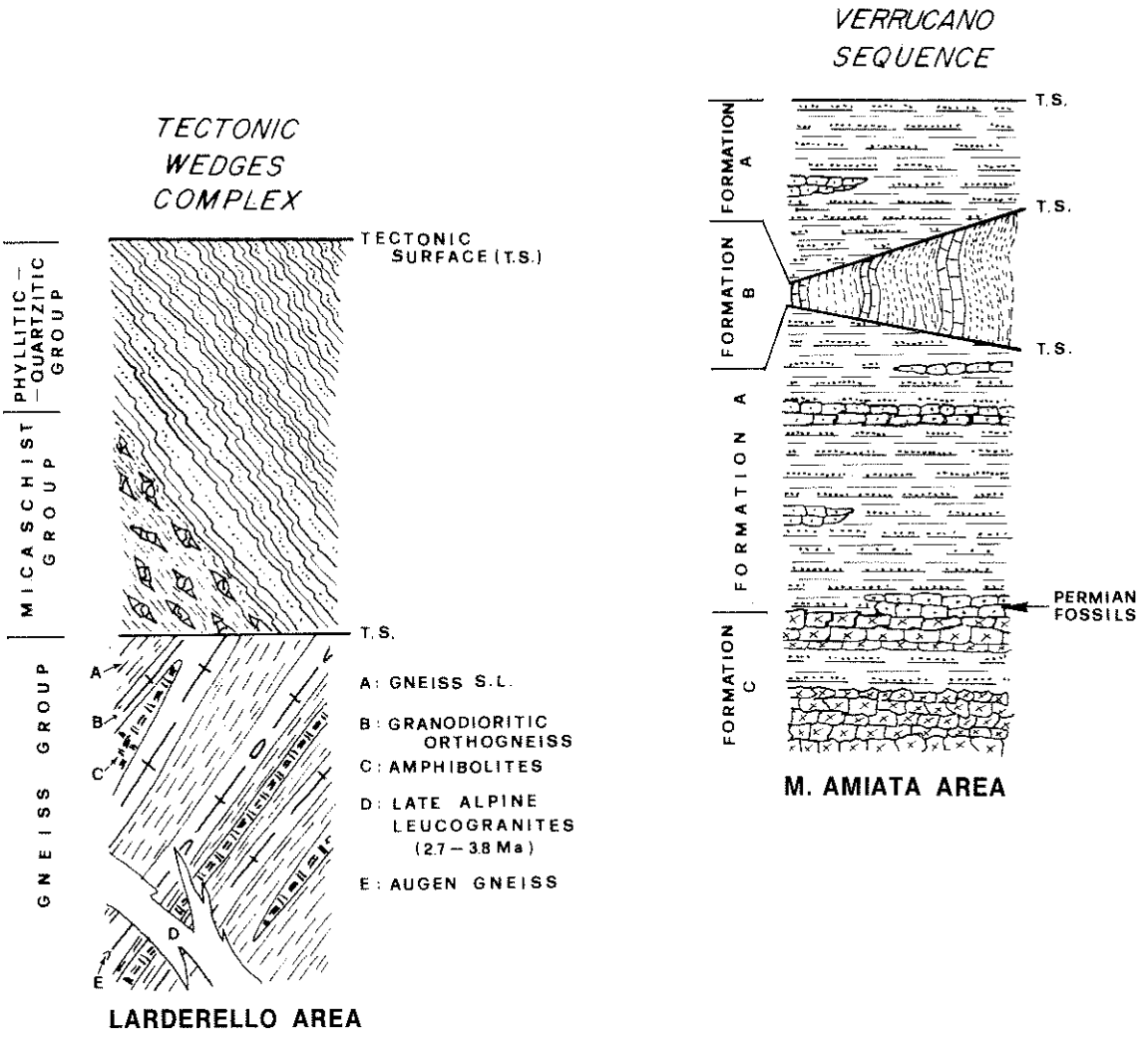


Fig. 9 - Lithological columns from the ENEL deep geothermal drillings in the Larderello and M. Amiata (Piancastagnaio) areas.

hibits a complicate structural frame, in which three deformative events are recognizable (GALADINI & PALIERI, 1988).

During the first episode (D_1), a first order anticline (fig. 10) and several smaller folds have been generated, with a northeastern vergence and a N130-150°E axial direction. An axial plane schistosity (S_1) accompanies these folds, which is parallel or at very low angle with regard to the S_0 bedding.

This foliation transposes the contact between the M. Argentario Sandstone and the Civitella Formations, and the blastesis is made up of fine-grained Ms + Chl + Qtz ± Cal ± oxides.

The S_1 schistosity is in turn deformed by a new generation of folds (D_2), with a western vergence and associated to a well developed S_2 cleavage in the hinge zones. This cleavage is characterized by a paragenesis of oxides and fine-grained Ms ± Qtz.

The interference pattern, resulting from superposition of D_2 folds on the previous structure, is referrable to the type 3 (coaxial refolding).

During the third event (D_3) open, kink-shaped folds developed with a N40°E main axial

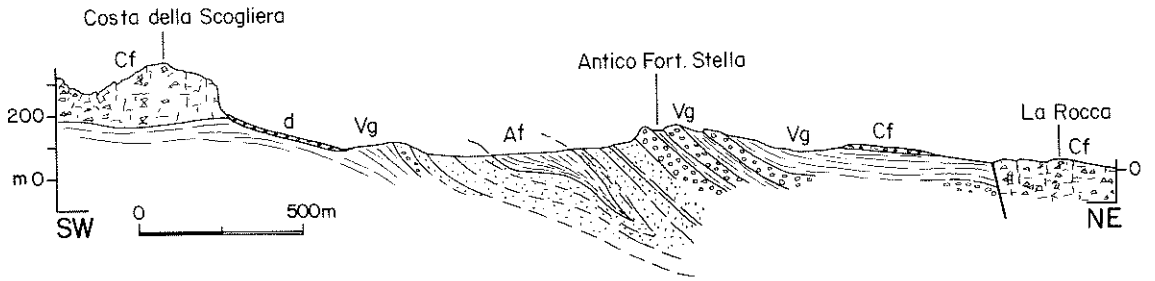


Fig. 10 - Cross-section along the panoramic road of Porto Ercole, in the southeastern part of M. Argentario promontory (Grosseto) (after DECANDIA & LAZZAROTTO, 1980, modified by GALADINI & PALIERI, 1988). Paleozoic formations: Af = M. Argentario Sandstone Formation. Triassic formations: Vg = Verrucano Group; Cf = "Cavernoso" Formation. Actual sediments: d = debris.

direction. The interference pattern between D_2 and D_3 folds shows a type 1 picture (dome and basin structures).

M. BELLINO (MONTI ROMANI) (M.M.)

The study of this area is still in progress. No fossils have been found up to now, and the lithologic, informal sequence has been restored mainly by comparison to the formations of the well known successions of southeastern Sardinia and Alpi Apuane. This succession is the following, from its hypothetical bottom (MORETTI, 1987; GATTIGLIO *et al.*, 1989; MORETTI *et al.*, 1991).

1) *San Pietro Bridge Phyllite and Metasandstone* - More or less regular alternance of quartzitic dark phyllite, sometimes Gr-bearing, and fine-grained gray metasandstone with phyllitic and volcanic grains. The phyllite often contains thin layers of whitish quartzite. Primary turbiditic sedimentation structures (grading, ecc.) are locally recognized.

2) *Roccaccia di Montauto Quartzite and Phyllite* - Centimetric alternance of light gray and gray-green quartzarenite (coarser than the previous metasandstone) and gray phyllite. An arenitic to fine-ruditic quartzite, containing several grains (up to 3-4 mm in size) of magmatic Qtz, also occurs in small outcrops. These lithotypes show quite clear primary relationships and seem to correspond to the sedimentation of materials derived from erosion of areas partly constituted by magmatic rocks.

3) *Botro del Lecceto Metasandstone and Phyllite* - Dark to light gray and gray-green quartzitic metasandstone, with frequent phyllitic intercalations, light to dark gray phyllitic metasiltite and minor levels of fine-grained sandstone. At the base of this lithologic alternance, a dark gray or black, 4-5 m thick phyllite marks the contact with the underlying association.

4) *Tegolaie Valley Carbonatic-Phyllitic Complex* - Gray metadolostone forms up to 2 m thick beds that alternate with 20-30 cm thick levels of dark, strongly foliated phyllite and metasiltite; these lithotypes constitute a some decameters thick sequence. Green, mainly chloritic phyllite with intercalated whitish carbonatic levels, minor metasandstone (similar to the Botro del Lecceto one) and rare light quartzite are also present. Owing to occurrence of carbonate metasediments, this association suggests to have been deposited in a marine platform environment.

Bearing in mind that also M. Bellino metamorphic complex has undergone a Tertiary polyphasic deformation perfectly similar (as it concerns geometry and age) to that of the other Tuscan Paleozoic metamorphic sequences (MELETTI, 1986; OTTRIA, 1986; MORETTI, 1987, 1989; MORETTI *et al.*, 1991), the existence of a pre-Alpine (Hercynian orogenic event?) tectonometamorphic pattern in these rocks is supported by an evident planar anisotropy older than the first Alpine episode schistosity (S_1), by which is pervasively transposed.

Such anisotropy reveals to be a metamorphic layering (green schist facies), constituted by a regular alternance of thin (1-2 mm) phyllosilicatic (white mica and Chl) films and more thick (up to some centimeters) quartzitic levels.

At a mesoscopic scale this pre-S_1 layering is well recognizable in all quartzitic varieties (more rarely in the phyllitic ones), but in thin

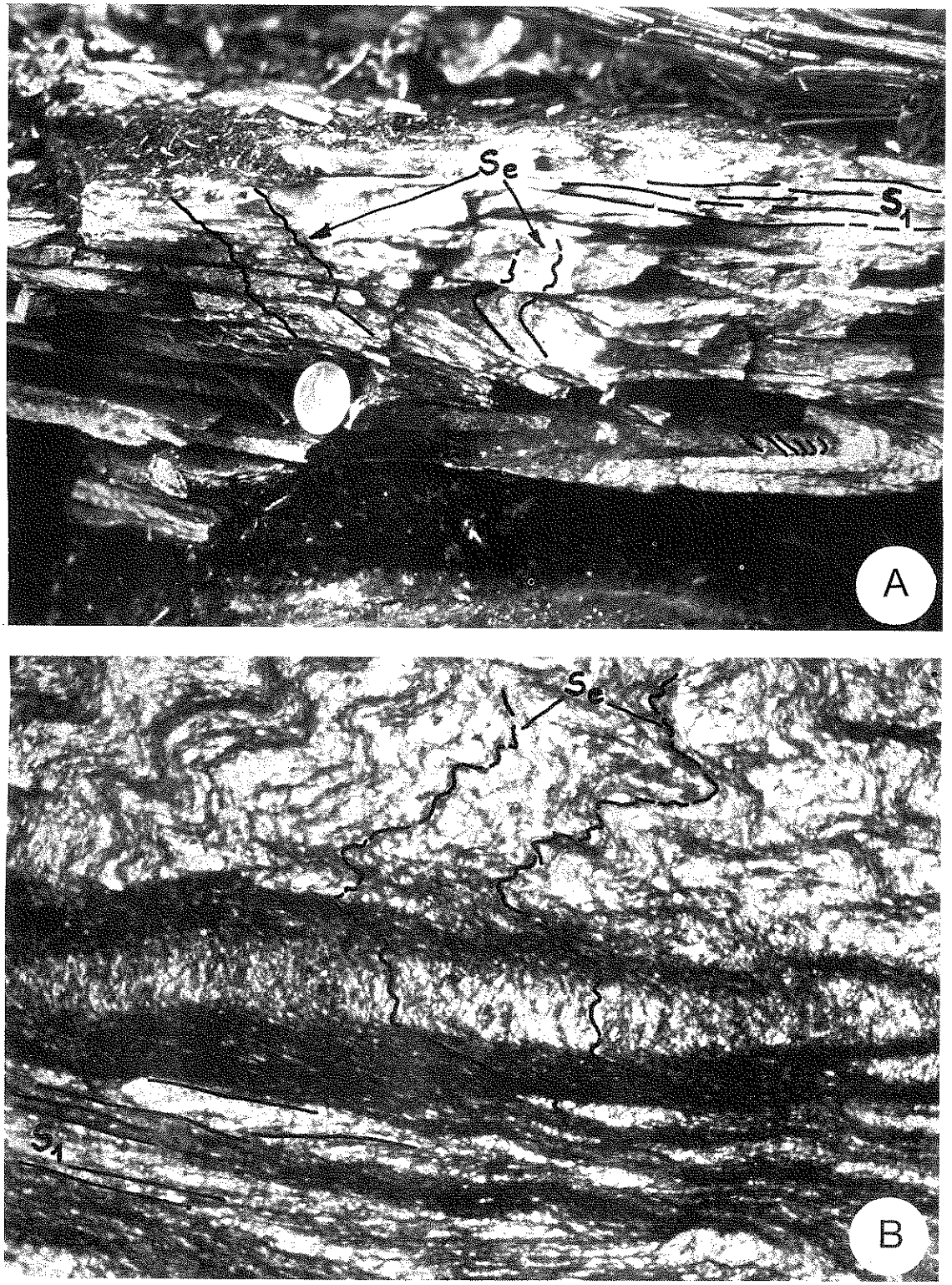


Fig. 11 - The overprint of the Alpine schistosity (S_1) on the Hercynian foliation (Se) in the San Pietro Bridge Phyllite and Metasandstone Formation of the M. Bellino metamorphic complex. A) Decimetric folds of the first Alpine generation deform a pre-Alpine metamorphic anisotropy. B) A thin section shows the same picture at a microstructural scale.

section it is everywhere present, especially in the several, more or less uprooted, intrafoliar microfolds between the planes of the Alpine S_1 foliation. As shown in fig. 11, the structural pattern is identical to that of the Alpi Apuane basement lithotypes.

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REFERENCES

BAGNOLI G. & TONGIORGI M. (1980) - *New fossiliferous Silurian (Mt. Corchia) and Devonian (Monticiano) layers in the Tuscan Paleozoic.* Mem. Soc. Geol. It., **20**, 301-313.

BAGNOLI G., GIANELLI G., PUXEDDU M., RAU A., SQUARCI P. & TONGIORGI M. (1980) - *A tentative stratigraphic reconstruction of the Tuscan Paleozoic Basement.* Mem. Soc. Geol. It., **20**, 99-116.

BARBERI F. (1966) - *I porfiroidi della Toscana e la loro posizione stratigrafica.* Atti Symp. Verrucano, Soc. Tosc. Sci. Nat., Pisa, 35-54.

BARBERI F. & GIGLIA G. (1966) - *La serie scistosa basale dell'autoctono delle Alpi Apuane.* Boll. Soc. Geol. It., **84**, 41-92.

BATINI F., BERTINI G., GIANELLI G. PANDELI E. & PUXEDDU M. (1985) - *Deep structure of the Larderello field: contribution from recent geophysical and geological data.* Mem. Soc. Geol. It., **25**, 219-235.

BATINI F., BERTINI G., GIANELLI G., PANDELI E., PUXEDDU M. & VILLA I. (1985) - *Deep structure, age and evolution of the Larderello-Travale area geothermal field.* Geothermal Resources Council - Int. symp. on geothermal energy - Kailua Kona - Hawaii, 26-30 august 1985, Transact, **9** (1), 253-269.

BELL T.H. & RUBENACH M.L. (1983) - *Sequential porphyroblast growth and crenulation cleavage development during progressive deformation.* Tectophysics, **92**, 171-194.

BOCCALETTI M., COLI M., DECANDIA F.A., GIANNINI E. & LAZZAROTTO A. (1981) - *Evoluzione dell'Appennino settentrionale secondo un nuovo modello strutturale.* Mem. Soc. Geol. It., **21**, 359-373.

BOCCALETTI M., CAPITANI S., COLI M., FORNACE G., GOSSO G., GRANDINI G., MILANO P.F., MORATTI G., NAFISSI P. & SANI F. (1985) - *Caratteristiche deformative delle Alpi Apuane settentrionali.* Mem. Soc. Geol. It., **26**, 527-534.

BONATTI S. (1938) - *Studio petrografico delle Alpi Apuane.* Mem. Descr. Carta Geol. d'It., **26**, 116 pp.

BURGASSI P.D., COSTANTINI A., DELL'AGNELLO L., LAZZAROTTO A. & SANDRELLI F. (1980) - *Esame dei rapporti tra le formazioni metamorfiche del basamento nella Toscana a sud dell'Arno.* Mem. Soc. Geol. It., **20**, 123-133.

CALVINO F. (1961) - *Lineamenti strutturali del Sarrabus-Gerrei (Sardegna sud-orientale).* Boll. Serv. Geol. It., **81**, 481-556.

CARMIGNANI L. & GIGLIA G. (1985) - Il problema della doppia vergenza sulle Alpi Apuane e la struttura di Monte Corchia. Boll. Soc. Geol. It., **26**, 515-525.

CARMIGNANI L., GIGLIA G. & KLIGFIELD R. (1978) - *Structural evolution of the Apuane Alps: an example of continental margin deformation in the northern Apennines Italy.* Journ. of Geology, **86**, 487-504.

CARMIGNANI L., GIGLIA G. & KLIGFIELD R. (1981) - *Nuovi dati sulla zona di taglio ensialica delle Alpi Apuane.* Mem. Soc. Geol. It., **21**, 93-100.

CARMIGNANI L., RAU A., SQUARCI P., TONGIORGI M. & VAI G.B. (1977) - *Le successioni paleozoiche-triassiche della Sardegna centrale e dell'«Autoctono» apuano: analogie e possibili correlazioni.* In: G.B. VAI (Ed.): *Escursione in Sardegna 1977 - Risultati e commenti.* Boll. Gruppo di Lavoro Paleozoico, suppl., 11-14.

CARMIGNANI L., COCOZZA T., GHEZZO C., PERTUSATI P.C. & RICCI C.A. (1986) - *Guide-book to the excursion on the Paleozoic Basement of Sardinia.* IGCP n. 5 Newsletter, Special Issue, 102 pp.

CAROSI R. & GATTIGLIO M. (1989) - *Stratigraphic correlation forms concerning the Sardinian Paleozoic Basement (Italy).* Rend. Soc. Geol. It., **12**, 143-172.

CASTELLUCCI P., MINISSALE A. & PUXEDDU M. (1985) - *Nature and tectonic setting of the Travale-Radicondoli basement in the Larderello geothermal field (Italy).* Mem. Soc. Geol. It., **25**, 237-245.

COCOZZA T. (1965) - *Il Carbonifero del Gruppo Monticiano-Roccastrada.* Ric. Scient., **35** (IIA), 1-38.

COCOZZA T., LAZZAROTTO A. & PASINI M. (1975) - *Segnalazione di una fauna triassica nel conglomerato di Monte Quoio (Verrucano del Torrente Farma, Toscana meridionale).* Riv. It. Paleont., **81**, 425-436.

COCOZZA T. & VAI G.B. (1978) - *Paleozoic of Tuscany within the Paleogeographic evolution of Europe.* In: M. TONGIORGI (Ed.) - *Report on the Tuscan Paleozoic Basement.* C.N.R.: Rapp. Interno Sottopr. Energia Geotermica Prog. Fin. Energetica, Pisa, 51-57.

COCOZZA T., COSTANTINI A., LAZZAROTTO A. & SANDRELLI F. (1978) - *Continental Permian in Southern Tuscany (Italy).* In: M. TONGIORGI (Ed.) - *Report on the Tuscan Paleozoic Basement.* C.N.R.: Rapp. Interno Sottopr. Energia Geotermica, Prog. Fin. Energetica, Pisa, 35-49.

COCOZZA T., DECANDIA F.A., LAZZAROTTO A., PASINI M. & VAI G.B. (1987) - *The marine Carboniferou its bearing for Hercynian paleogeography and tectofacies.* In: E. FLUGEL, F.P. SASSI & K. GRECULA (Eds.): *Pre-Variscan and Variscan events in the Alpine-Mediterranean mountain belt.* Miner. Slov., 135-144.

CONTI P., GATTIGLIO M. & MECCHERI M. (1991) - *The overprint of the Alpine tectono-metamorphic evolution on the Hercynian orogen: an example from the Apuan Alps (Northern Apennines, Italy).* Tectonophysics, **191**, 335-346.

CONTI P., DI PISA A., GATTIGLIO M., MECCHERI M. & VIETTI N. (1988) - *Nuovi dati sulle metabasiti di Valle del Giardino del basamento paleozoico apuano (Appen-*

nino settentrionale). Atti Soc. Tosc. Sci. Nat., Mem. A, **95**, 89-103.

CORTECCI G., KLEMM D.D., LATTANZI P., TANELLI G. & WAGNAR J. (1983) - *A sulfur isotope study on pyrite deposits of Southern Tuscany, Italy.* Mineral. Deposita, **18**, 285-297.

COSTANTINI A., DECANDIA F.A., ELTER F.M., LAZZAROTTO A., PANDELI E. & SANDRELLI F. (1989) - *Guida alla dorsale medio-toscana nel tratto Iano-Roccastrada.* Siena, 26-28 settembre 1989, Tip. Senese, 40 pp.

COSTANTINI A., DECANDIA F.A., LAZZAROTTO A. & SANDRELLI F. (1988) - *L'Unità di Monticiano-Roccastrada tra la Montagnola Senese e il Monte Leoni (Toscana meridionale).* Atti Tic. Sci. Terra, **31**, 382-420.

COSTANTINI A., ELTER F.M., PANDELI E. & SANDRELLI F. (1991) - Carta geologica dell'area di Iano, 1:25.000. S.EL.CA., Firenze.

DECANDIA F.A. & LAZZAROTTO A. (1981) - *Le unità tettoniche del Monte Argentario (Toscana meridionale).* Mem. Soc. Geol. It., **21**, 385-393.

DEL MORO A., PUXEDDU M., RADICATI DI BROZOLO C. & VILLA I. (1982) - *Rb-Sr and K-Ar ages on minerals at temperatures of 300-400° C from deep wells in the Larderello geothermal field (Italy).* Contrib. Mineral. Petrol., **81**, 340-349.

DI PISA A., GATTIGLIO M. & MECCHERI M. (1988) - *Le unità metamorfiche di basso grado della Calabria (Unità di Bocchigliero e Paleozoico di Stilo-Bivongi): considerazioni strutturali e analogie con l'ercinico sardo e toscano.* Rend. Soc. Geol. It., **11**, 29-32.

ELTER F.M. & PANDELI E. (1990) - *Alpine and Hercynian orogenic phases in the basement rocks of the Northern Apennines (Larderello Geothermal field, Southern Tuscany, Italy).* Eclog. Geol. Helv., **83**, 241-264.

ELTER F.M. & PANDELI E. (1991) - *Structural features of the metamorphic Paleozoic-Triassic sequences in deep geothermal drilling in the Mt. Amiata area (SE Tuscany, Italy).* Boll. Soc. Geol. It., (this volume).

ELTER P., GIGLIA G., RAU A. & TONGIORGI M. (1966) - *Il Verrucano della Verruca (Monti Pisani) nel quadro delle serie del Carbonifero, del Permiano e del Trias della Toscana settentrionale.* Atti Symp. Verrucano. Soc. Tosc. Sci. Nat., 3-33.

ENGELBRECHT H., KLEMM D.D. & PASINI M. (1989) - *Preliminary notes on the tectonics and lithotypes of the "Verrucano s.l." in the Monticiano area (Southern Tuscany, Italy) and the linding of fusulinids within the Mt. Quoio Fm. (Verrucano Group).* Riv. It. Paleont. Strat., **94**, 361-382.

FERRARA G. & TONARINI S. (1985) - *Radiometric geochronology in Tuscany: results and problems.* Rend. Soc. It. Min. Petr., **40**, 111-124.

FRANCESCHELLI M. (1980) - *Lineamenti geologico-petrografici delle formazioni paleozoiche affioranti nell'area di Boccheggiano (Toscana meridionale).* Atti Soc. Tosc. Sci. Nat., Mem. A, **87**, 65-92.

GALADINI F. & PALIERI L. (1988) - *Caratteri strutturali del settore orientale del Promontorio Argentario (Grosseto).* Mem. Soc. Geol. It., **35**, 569-577.

GASPERI G. & GELMINI R. (1973) - *Ricerche sul Verrucano - 1. Il Verrucano del Monte Argentario e dei Monti dell'Uccellina in Toscana.* Boll. Soc. Geol. It., **92**, 115-150.

GATTIGLIO M. & MECCHERI M. (1987) - *Preliminary considerations on the lithostratigraphic succession of the Apuane Alps Paleozoic basement (Northern Tuscany, Italy).* In: F.P. SASSI & R. BOURROUILH (Eds.) - IGCP n. 5, Newsletter, **7**, 57-59.

GATTIGLIO M., MECCHERI M. & TONGIORGI M. (1989) - *Stratigraphic correlation form of the Tuscan Paleozoic.* Rend. Soc. Geol. It., **12**, 247-257.

GIANELLI G. & PUXEDDU M. (1980) - *An attempt at classifying the Tuscan Paleozoic: geochemical data.* Mem. Soc. Geol. It., **20**, 435-446.

IPPOLITO F. (1950) - *Le Alpi Apuane.* In: *Contributo alla geologia del Monte Pisano e delle Alpi Apuane.* Mem. e Note Ist. Geol. Applicata Napoli, **3**, 49-96.

KLIGFIELD R., HUNZIKER J., DALLMEYER R. & SCHAMEL S. (1986) - *Dating of deformation phases using K/Ar and $^{40}Ar/^{39}Ar$ tecniques: results from Northern Apennines.* Journ. of Struct. Geol., **8**, 781-798.

KRETZ R. (1983) - *Symbols for rock-forming minerals.* Am. Mineral., **68**, 277-279.

LAZZAROTTO A., MAZZANTI R. & MAZZONCINI F. (1964) - *Geologia del Promontorio Argentario (Grosseto) e del Promontorio del Franco (Isola del Giglio, Grosseto).* Boll. Soc. Geol. It., **83**, 1-124.

MARTINI I.P., RAU A. & TONGIORGI M. (1986) - *Syntectonic sedimentation in a Middle Triassic rift, Northern Apennines.* Sedimentary Geology, **47**, 191-219.

MAZZANTI R. (1961) - *Geologia della zona di Montaione tra le Valli dell'Era e dell'Elsa (Toscana).* Boll. Soc. Geol. It., **80**, 75-105.

MELETTI C. (1986) - *Rilevamento litostratigrafico e studio strutturale del complesso metamorfico del M.te Bellino (Monti Romani, Grosseto).* Tesi di Laurea inedita, Univ. Pisa.

MEMMI I., BARCA S., CARMIGNANI L., COCOZZA T., ELTER F., FRANCESCHELLI M., GATTIGLIO M., GHEZZO C., MINZONI N., NAUD G., PERTUSATI P.C. & RICCI C.A. (1983) - *Further geochemical data on the pre-Hercynian igneous activity of Sardinia and on their geodynamic significance.* IGCP n. 5, Newsletter, **5**, 87-93.

MENEGHINI C. (1880) - *Nuovi fossili delle Alpi Apuane.* Soc. Tosc. Sci. Nat., Proc. Verb., **2**, 102-109.

MORETTI A. (1987) - *The poliphasic metamorphic building of Monte Bellino (Monti Romani, Italy).* In: F.P. SASSI & R. BOURROVICH (Eds.) - IGCP n. 5, Newsletter, **7**, 79-84.

MORETTI A. (1989) - *La virgazione medio toscana: nuovi dati strutturali.* Mem. Soc. Geol. It., **35**, 555-567.

MORETTI A., MELETTI C. & OTTRIA G. (1991) - *Studio stratigrafico e strutturale dei Monti Romani (GR-VT). 1: dal Paleozoico all'Orogenesi Alpidica.* Boll. Soc. Geol. It., **109**, 557-581.

NAUD G. (1979) - *Les shales de Rio Canoni, formation-repère fossilifère de l'Ordovicien supérieur de la Sardaigne sud-orientale. Consequences stratigraphiques et structurales.* Bull. Soc. Geol. France, XXI, 155-159.

OTTRIA G. (1986) - *Rilevamento e studio litostratigrafico del Verrucano e delle Unita alloctone non metamor-*

fiche nel Gruppo dei Monti Romani (Grosseto). Tesi di Laurea inedita, Univ. Pisa.

PANDELI E. & PASINI M. (1990) - *Fusulinidi permiani nella successione metamorfica del sottosuolo del M. Amiata. Toscana meridionale (Italia).* Riv. Ital. Paleont., **96,** (in press).

PANDELI E., PUXEDDU M., GIANELLI G., BERTINI G. & CASTELLUCCI P. (1988) - *Paleozoic sequences crossed by deep drillings in the M. Amiata geothermal region (Italy).* Boll. Soc. Geol. It., **107,** 593-606.

PANDELI E., BERTINI G. & CASTELLUCCI P. (1991) - *The Tectonic Wedges Complex of the Larderello area (South Tuscany).* This volume.

PASINI M. (1978a) - *Further paleontological records from the Upper Paleozoic outcrops of the Farma Valley.* In: M. TONGIORGI (Ed.) - *Report on Tuscan Paleozoic.* C.N.R., Rapp. Interno Sottopr. Energia Geotermica, Prog. Fin. Energetica, Pisa, 35-49.

PASINI M. (1978b) - *Edmondia scalaris* (M'COY, 1884) *e Phestia cfr. attenuata* (FLEMING, 1828) *nella Formazione Carpineta (Paleozoico superiore della Toscana meridionale).* Riv. Ital. Paleont., **84,** 849-864.

PASINI M. (1980a) - *I Fusulinidi della valle del Torrente Farma (Toscana meridionale).* Mem. Soc. Geol. It., **20,** 323-342.

PASINI M. (1980b) - *Gli Archeodiscidi dell'affioramento di Poggio delle Pigne nella Valle del Farma (Toscana meridionale).* Mem. Soc. Geol. It., **20,** 343-346.

PASINI M. (1981) - *Carboniferous Brachiopods from the locality Poggio alle Pigne in the Farma Valley (Southern Tuscany Italy).* Riv. Ital. Paleont., **86,** 459-468.

PUXEDDU M., SAUPE F., DECHOMETS R., GIANELLI G. & MOINE B. (1984) - *Geochemistry and stratigraphic correlations. Applications to the investigation of geothermal and mineral resources of Tuscany, Italy.* Chem. Geol., **43,** 77-113.

RAU A. (1990) - *Evolution of the Tuscan Domain from the Late Carboniferous to the Mid Triassic: a new hypothesis.* Boll. Soc. Geol. It., **109,** 231-238.

RAU A. & TONGIORGI M. (1974) - *Geologia dei Monti Pisani a Sud-Est della Valle del Guappero.* Mem. Soc. Geol. It., **13,** 227-408.

RAU A. & TONGIORGI M. (1976) - *Sedimentation, climate and development of landforms in the post-Hercynian North-Tuscany: a contribution.* In: H. FALKE (Ed.) - *The continental Permian in Central, West and South Europe.* NATO Advanced Study Inst. Series, **22,** 169-180.

RAMSAY J.G. (1967) - *Folding and Fracturing of Rocks.* McGraw Hill, New York, 568 pp.

REDINI R. (1941) - *Rinvenimento di Antracolitico nel Gruppo Monticiano-Roccastrada.* Boll. Soc. Geol. It., **60,** 331-334.

STILLE H. (1939) - *Bemerkungen betreffend die "Sardische" Faultung un den "Ophiolitisch".* Zs. Deutsc. Geol. Ges., **91,** 771-773.

TONGIORGI M. & BAGNOLI G. (1981) - Stratigraphie du socle paleozoic de la bordure continentale de l'Apennin septentrional (Italie centrale). Bull. Soc. Geol. France, **23,** 319-323.

TONGIORGI M., RAU A. & MARTINI I.P. (1977) - *Sedimentology of Early Alpine, fluvio-marine, clastic deposits (Verrucano, Triassic) in the Monti Pisani (Italy).* Sedimentary Geology, **17,** 311-332.

TREVISAN L. (1955) - *Il Trias della Toscana ed il problema del Verrucano triassico.* Atti Soc. Tosc. Sci. Nat., Mem. A, **62,** 1-30.

TUCCI P. (1980) - *Le metamorfiti della serie scistosa basale del M. Corchia (Alpi Apuane).* Per. Miner., **49,** 57-148.

TWISS R.T. (1988) - *Description and Classification of Folds in single surface.* Journ. of Geol., **6,** 607-623.

VAI G.B. (1972) - *Evidence of Silurian in the Apuane Alps (Tuscany, Italy).* Giorn. Geol., **38,** 349-372.

VAI G.B. & FRANCAVILLA F. (1974) - *Nuovo rinvenimento di piante dello Stefaniano a Iano (Toscana).* Boll. Soc. Geol. It., **93,** 73-80.

VIGHI L. (1966) - *Descrizione di alcuni sondaggi che hanno attraversato lenti anidritico-dolomitiche intercalate alle filladi triassiche (Verrucano) nei dintorni di Massa Marittima (Grosseto-Toscana).* Atti Symp. Verrucano, Soc. Tosc. Sci. Nat., 72-95.

ZACCAGNA D. (1932) - *Descrizione geologica delle Alpi Apuane.* Mem. Descr. Carta Geol. d'It., **25,** 420 pp.