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Paleozoic age for the Tuscan upper metamorphic sequences of Elba and its implications for the geology of the Northern Apennines (Italy)

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ABSTRACT

A Paleozoic age is proposed for the top of the metamorphic sequences ("Complex II" Auct.) outcropping in the eastern part of the island of Elba (Tuscany, Italy), on the basis of microstructural, petrographic, geochemical data and comparisons with known Paleozoic sequences of Sardinia and Tuscany.

The equivalence between the upper part of the Complex II and the Mesozoic-Tertiary part of the "Apuan Autochthon" ("Tuscanid I" Auct.), widely accepted in literature so far, seems no longer reliable.

Phyllites, overlying marbles and calcschists, show relics of an earlier, probably pre-Alpine, schistosity and rotated albite to oligoclase eyes with helicitic textures.

The chemical data corroborate the petrographical differences. The Phyllites (G_f) of Complex II show a wider range of Na/Al values and lower Na-content than similar Mesozoic-Tertiary metasediments of the Tuscanid I Complex.

The sequence "Spotted schist" – "Porfiroidi" and "Scisti Porfirici" – "Ortano marble" – "Calcschist" – "Phyllite" of Complex II is comparable to Cambrian-Devonian sequences of Sardinia, including the "Solanas-San Vito Sandstone" Formations (Cambrian-Arenig), the "Porfiroidi" and "Scisti Porfirici" (Middle Ordovician), Ashgill carbonate-siliceous and phyllitic lithotypes, and the metapelite with carbonate intercalations of Silurian-Devonian age.

The vacuolar carbonate formation between the "Ortano marble" and "Scisti porfirici", previously referred to the Triassic "Calcare Cavernoso" or "Grezzoni" Formations, is interpreted as a late Tertiary tectonic breccia including only fragments of "Ortano marble" and "Scisti porfirici".

RIASSUNTO

Si propone un'età Paleozoica per la parte alta della sequenza metamorfica del «Complesso II» Auct., affiorante nella parte orientale dell'Isola d'Elba, in base a dati microstrutturali, petrografici, geochimici e a comparazioni con le successioni paleozoiche di Toscana e Sardegna.

Le filladi sovrastanti i marmi mostrano relitti di un evento scistogeno probabilmente pre-Alpino e porfiroblasti di albite-oligoclasio con evidenze di rotazione e strutture di tipo elicitico.

Dati chimici confermano i dati petrografici. Le filladi G_f del «Complesso II» mostrano una maggiore variabilità del rapporto Na/Al e un più basso contenuto in Na rispetto ai metasedimenti Mesozoico-Terziari dell'«Autoctono Apuano» («Toscanide I» Auct.) con i quali sono stati finora correlati.

La sequenza «Scisti macchiettati» – «Porfiroidi e Scisti porfirici» – «Marmo di Ortano» – «Calcescisti» – «Filladi» risulta comparabile con le sequenze Cambro-Devoniche della Sardegna.

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Pertanto l'equivalenza tra la parte superiore del «Complesso II» e la parte Mesozoico-Terziaria della «Toscanide I», fino a questo momento largamente accettata in letteratura, non sembra attendibile.

La formazione carbonatica vacuolare tra il «Marmo di Ortano» e gli «Scisti porfirici» è qui interpretata come una breccia tettonica terziaria.

Introduction

The complex tectonic structure of the island of Elba was generated during the Alpine orogeny by the overthrusting and piling up of five westward dipping tectonic units ("Complessi" of BARBERI et al. 1967a, 1969), numbered from I to V going upwards (Fig. 1). The three lower Units, outcropping in the eastern part of the island of Elba, belong to the Tuscan (Paleo-African Alpine) domain while the two upper Units can be ascribed to the oceanic Ligurian domain (for more details on Tuscan and Ligurian paleogeographic domains, see SESTINI 1970).

These sequences are locally affected by an intense contact metamorphism produced by the emplacement of the Mio-Pliocene intrusive bodies (Monte Capanne granodiorite 6,7–6,9 Ma, W Elba, and Serra-Porto Azzurro monzogranite 4,9–5,4 Ma, E Elba, FERRARA & TONARINI 1985).

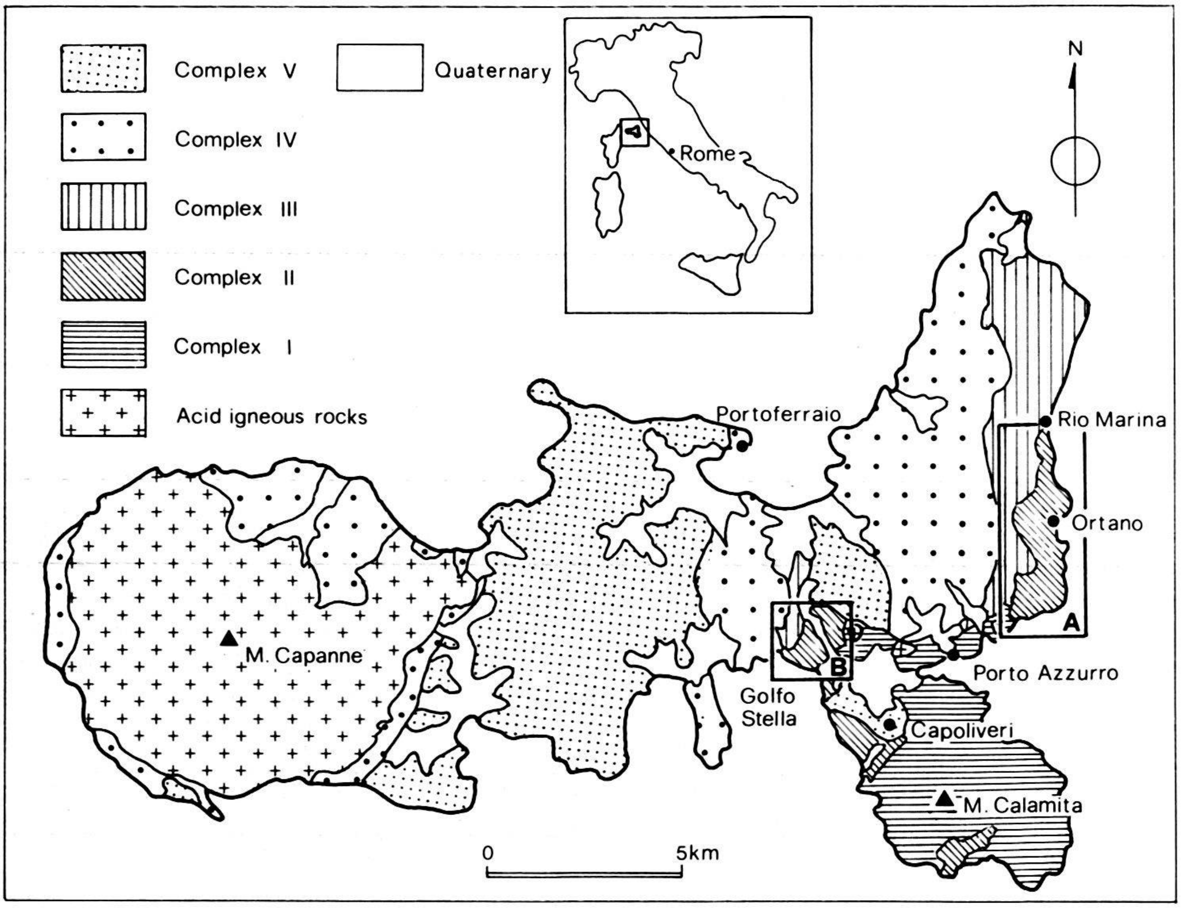


Fig. 1. Geological sketch map of the island of Elba (after BARBERI et al. 1969). A and B boxes represent the Ortano and Spiaggia del Lido areas of Fig. 2.

In the two lower Complexes ("Complex I" = "Monte Calamita Complex"; "Complex II" = "Ortano Complex") contact metamorphism overprinted regional Alpine and Hercynian metamorphism (Barberi et al. 1967b; Puxeddu et al. 1984). The complex metamorphic history easily explains the lack of fossils and the consequent uncertain chronologic attribution for the rocks of Complex I and II. Some Authors (Barberi et al. 1967b, 1969; Perrin 1975; Vai 1978) attributed a Carboniferous-Permian age to most of the Complex I sequence; more recently ages ranging from Precambrian-Lower Paleozoic to Ordovician-Silurian/Carboniferous have been proposed by many authors (Cocozza & Vai 1978; Bagnoli et al. 1979; Tongiorgi & Bagnoli 1981; Puxeddu et al. 1984; Vai & Cocozza 1986).

The base of Complex II has been ascribed to the Lower Paleozoic-Silurian (Tongiorgi & Bagnoli 1981; Vai & Cocozza 1986), Carboniferous (Cocozza et al. 1974; Vai 1978) or Carboniferous-Permian (Barberi 1966; Barberi et al. 1969; Perrin 1975), while the upper part has been correlated with the Mesozoic-Tertiary metamorphic formations of the "Apuan Autochthon" ("Tuscanid I" Auct.) (Barberi et al. 1969; Perrin 1975).

On the contrary, Bodechtel (1964) attributed a pre-Carboniferous to Carboniferous age to the Complex II, as a whole.

The correlation of the upper part of Complex II with the Mesozoic-Tertiary "Apuan Autochthon" was suggested mainly by observed lithologic affinities. A petrographic study was therefore carried out on the Complex II and comparisons were made with similar Tuscan and Sardinian metamorphic sequences so as to better define the lithostratigraphic sequence of the former.

Attention has been focussed on Complex II because this unit has so far been considered as the Southern extension of the "Apuan zone" south of the Arno river (Boccaletti et al. 1980) and, therefore, has had a key role in the geology of the Northern Apennines.

Geological outline of Complex II

Complex II ("Complesso di Ortano" Auct.) outcrops in the eastern part of Elba between Rio Marina and Punta delle Cannelle-Miniera di Terra Nera (Fig. 2a), tectonically overlying Complex I (Raggi et al. 1966; Barberi et al. 1969; Perrin 1975). Another outcrop is located between the coast of Spiaggia del Lido (NE of Golfo Stella) and Valdana locality (Fig. 2b), where a stratigraphic transition to the underlying Complex I was observed by Raggi et al. (1966) and Perrin (1975).

Barberi et al. (1969) distinguished the following stratigraphy from bottom to top (in brackets are the symbols used in the "Carta Geologica d'Italia 1:100,000"-Foglio 126 and the ages proposed by Barberi et al. 1969 after comparison with the sequence of the "Apuan Autochthon"): 1) Spotted Schist ("Scisti macchiettati" Auct.; "Scisti di Ortano" of Perrin 1975), often graphite-rich, alternating with metapsammite levels (go_1; Paleozoic l.s. – Upper Carboniferous); 2) Acidic metavolcanites and derived metasediments ("Porfiroidi" and "Scisti Porfirici") (go_2; Permian); 3) Vacuolar dolomitic limestone (T_c; Upper Trias); 4) Marble ("Marmi di Ortano" Auct.) (G_1; Lower Lias); 5) Calcareous chloritoschist and calcschist ("Calcescisti e Cipollini" Auct.) (G_2; Middle-Upper Lias); 6) Calcareous phyllite with local intercalations of calcschist (G_f; Dogger); 7) Serpentinite (o), tectonically overlying G_f.

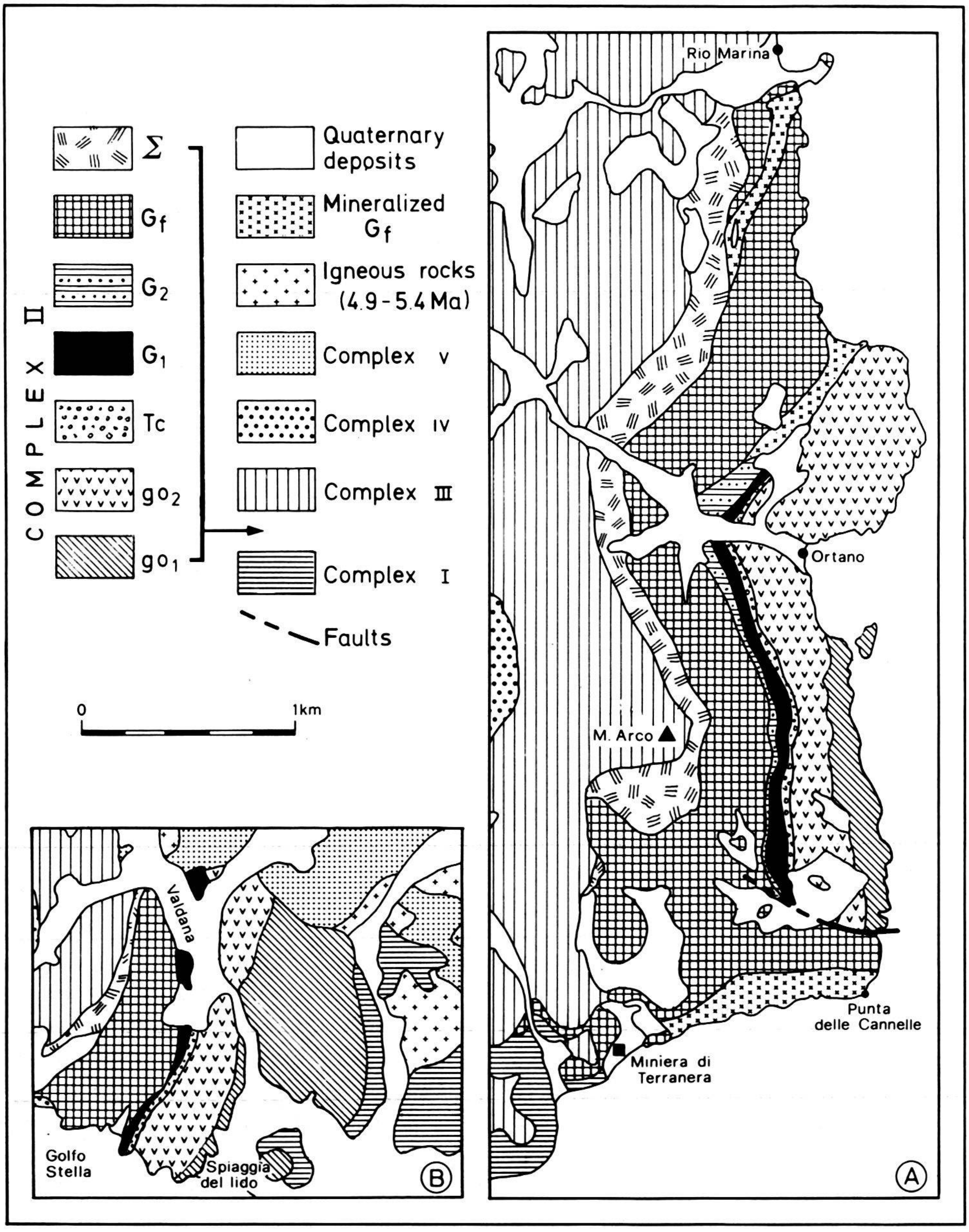


Fig. 2. Geological map of the Ortano-Rio Marina (A) and Spiaggia del Lido-Valdana (B) areas partly modified after BARBERI et al. (1967a): Σ: Serpentinite; G_f: Phyllite with local Calcschist intercalations: G_2: Calcschist; G_1: Ortano marble; T_c: Vacuolar limestone; go_2: "Porfiroidi" and "Scisti Porfirici"; go_1: Spotted Schist.

Petrographic data

The petrographic features of these formations are as follows (Table 1):

Spotted Schist (go_1)

Dark gray-greenish to gray-brownish phyllite with minor intercalations of gray quartzite and graphite-rich metasediments.

The main constituents are muscovite, quartz, chlorite and, locally, altered biotite. Rare subidiobilastic albite crystals sometimes occur. Iron oxides (probably derived from the alteration of primary sulphides) and/or graphitic bands are parallel to the main schistosity. Static crystallization of post-tectonic andalusite, biotite and rare cordierite (almost completely altered) is due to contact metamorphism produced by the late-Tertiary emplacement of the Serra-Porto Azzurro monzogranite.

"Porfiroidi" and "Scisti Porfirici" (go_2)

The former is a gray to brownish quartzitic phyllite and quartzite with relics of quartz, K-feldspar and rare acidic plagioclase phenocrysts in a fine-grained granoblastic matrix consisting of quartz, muscovite and minor chlorite, altered biotite and albite. The phenocrysts of quartz sometimes show magmatic embayments; those of K-feldspar are low temperature sanidine with Carlsbad twinning, $2V_\alpha = 26°$ and optic axial plane orthogonal to (010) (Barberi 1966). K-feldspar crystals are often altered into kaolinite, minor sericite, and rarely may be partially replaced by albite. Locally, in the matrix, were observed rare small quartz porphyroblasts with helicitic inclusions (sericite and/or rutile, sometimes discordant in respect to the main schistosity) and, more frequently, tourmaline ± quartz deformed aggregates (probably fragments of hydrothermal exhalative tourmalinites). Both the phenocrysts and porphyroblasts frequently show pressure shadows (quartz and muscovite; rarely albite) and evidence of rotation.

A gradual K-feldspar decrease marks the upward transition to gray-greenish granolepidoblastic "Scisti porfirici". Abundant graphite and microcrystalline pyrite were found in a decimetric black phyllitic quartzite interbedded within the "Scisti Porfirici" near Spiaggia del Lido.

Both lithotypes, the "Porfiroidi" and "Scisti porfirici", show the post-tectonic crystallization of andalusite and biotite. Andalusite is often mimetic on the main schistosity. Locally the top levels of go_2 are almost completely replaced by high temperature mineral assemblages consisting of biotite, tremolite-actinolite, tourmaline, andalusite and clinopyroxene ± quartz.

A discontinuous horizon of gray and gray-greenish metasandstones and quartzitic phyllites (including layers of whitish quartzitic metaconglomerates with a quartzose-micaceous matrix), passing upward to metasiltites and metapelites, frequently overlies (unconformably?) the "Scisti porfirici" lithotypes.

Vacuolar dolomitic limestone (T_c)

This level, of variable thickness (up to 10–15 m) appears as a pale gray to yellowish vacuolar carbonatic rock, roughly stratified with variable recrystallization. This rock is a vacuolar calcareous heterometric well-cemented breccia with predominantly marble elements and less abundant phyllitic elements. X-ray data indicate that the breccia is made up of calcite sporadically associated with low amounts of dolomite (in contrast with the dolomitic composition suggested by previous authors, e.g. Barberi 1966). The phyllitic elements, whose number increases downwards, may be concentrated in levels, thus giving a stratified aspect to the rock. In the uppermost part of T_c only marble elements were found. The elements, of extremely variable size and angular shape, are surrounded by fine heterometric marble fragments and/or by the phyllitic-calcareous matrix recrystallized into an impure microsparite. Cataclastic textures are frequent. The following lithotypes were distinguished among the elements: 1) marble, belonging to the overlying "Ortano marble"; 2) phyllite which could be refered to the underlying go_2 lithotypes, and 3) scattered crystals of quartz, chlorite, muscovite, feldspar and pentagonal dodecahedra of pyrite.

A local structural discordance, always accompanied by the T_c breccia, can be recognized between the "Ortano marble" and the underlying go_2 lithotypes.

All the features described suggest that the T_c is actually a tectonic breccia generated by the thrusting of the "Ortano marble" over the go_2 sequence. The lack of

FORMATIONS	TEXTURE	MAIN COSTITUENTS	ACCESSORIES	PARTICULAR REMARKS
Spotted schist ("Scisti macchiettati") (go_1)	lepidoblastic to grano-lepidoblastic.	Muscovite + quartz ± ± biotite ± chlorite; rare plagioclase.	Pyrite, Fe-Ti oxides hydroxides, zircon, apatite, tourmaline, graphite.	Quartz rods. Contact metamorphic green biotite, andalusite and cordierite (?). Strings of Fe oxides-hydroxides. Graphite-rich levels.
"Porfiroidi"	Porphyroblastic.	Porphyroclast: magmatic quartz, sanidine and rare acidic plagioclase Matrix: quartz ± muscovite ± acidic plagioclase ± biotite ± chlorite.	Tormaline, (sometimes in "tourmalinites" like aggregates), zircon, Fe-Ti oxides, apatite; rare graphite.	Contact metamorphic biotite and andalusite.
"Scisti Porfirici" (go_2)	Grano-lepidoblastic.	quartz + muscovite ± ± K-feldspar ± acidic plagioclase ± biotite ± chlorite. Porphyroclasts: quartz and rare K-feldspar.		At the top metasandstone and metaconglomerates passing to metasiltites and meta-pelites. In the upper part, local strong contact and hydrothermal metamorphism.
Vacuolar dolomitic limestone (Tc)				
Marble elements (see "Ortano Marble")	granoblastic to cataclastic.	calcite ± quartz ± chlorite ± muscovite ± plagioclase ± dolomite.	pyrite.	Sparite filling cavities. No evidence of Tertiary deformation phases. Number of breccia elements increasing upwards.
phyllite elements I (frequent)	grano-lepidoblastic.	muscovite + chlorite + quartz ± biotite ± albite.	apatite, pyrite, rutile, Fe-Ti oxides.	Similar to "go_2" lithotypes.
phyllite elements II (rare)	grano-lepidoblastic.	muscovite + chlorite, + quartz ± albite ± sanidine.	tourmaline (also "tourmalinites"), sphene, zircon.	Number of breccia elements increasing downwards.
Ortano marble (G_1)	xenoblastic to granoblastic polygonal.	calcite ± quartz ± muscovite; rare biotite and chlorite.	pyrite.	Local dolomitized horizon. Local crystal flattening parallel to the main schistosity.
Phyllite within Ortano marble	lepidoblastic to grano-lepidoblastic.	muscovite + biotite ± ± quartz.	tourmaline, pyrite, Fe-Ti oxides.	

Table I: Petrographic features of the Complex II formations.

Table 1 (continued)

FORMATIONS	TEXTURE	MAIN CONSTITUENTS	ACCESSORIES	PARTICULAR REMARKS
Calcschist (G_2)				
carbonate levels	xenoblastic to granoblastic polygonal.	calcite ± dolomite ± ± quartz ± muscovite ± chlorite; rare albite and biotite.		Crystal flattening parallel to the main schistosity. Contact metamorphic amphiboles, clinopyroxene ± wollastonite.
phyllite levels	lepidoblastic to granolepidoblastic.	muscovite ± quartz ± biotite ± chlorite ± ± acidic plagioclase.	pyrite, tourmaline, sphene, Fe-Ti oxides, graphite.	More frequent and thick going upwards.
Phyllite (G_f)	grano-lepidoblastic.	quartz ±muscovite ±biotite ±chlorite ±calcite, ± acidic plagioclase (locally abundant).	Fe-Ti oxides, sulphides, graphite, tourmaline, apatite, zircon, sphene, epidote.	Graphite-rich levels Quartz rods. Contact metamorphic amphiboles, clinopyroxene, andalusite, wollastonite (calc-schist layers), garnet, feldspar, epidote, ilvaite.
Calc-schist intercalations (see Calcschist G_2)				

regional schistosities and the late matrix recrystallization indicate that this thrusting took place between the last Tertiary tectonometamorphic phase and the emplacement of the Serra – Porto Azzurro monzogranite (4,9–5,4 Ma ago).

Tectonic movements along this surface also led to the local thinning or disappearance of horizons T_c, G_1 and G_2 (see Fig. 2).

The related tectonic surface was an important pathway for hydrothermal fluids, which locally determined the complete replacement of the original rock and/or a strongly anastomosed network of hydrothermal veins at the contact between go_2 and the overlying formations (see also the mineralized contact between go_2 and G_f in the area north of Ortano: "Mineralized G_f" in Fig. 2a). The hydrothermal mineral assemblages consist of adularia, tremolite-actinolite, epidote ± calcite, ± Fe-oxides and -hydroxides, ± sphene, ± quartz, ± albite, ± pyrite.

The tectonic movement producing the T_c breccia probably developed along a previous stratigraphic contact occurring between the "Ortano marble" and go_2 within an originally continuous meta-sedimentary sequence. This is suggested by the possible stratigraphic transition that, although tectonized, can be envisaged between the two formations near Spiaggia del Lido.

Previous attributions:

Barberi et al. (1969) and Perrin (1975) correlated this formation with the Triassic "Calcare Cavernoso". Boccaletti et al. (1977) proposed an attribution to the "Grezzoni", which is generally the lowermost carbonate formation of the Mesozoic metamorphic sequence of the "Apuan Autochthon". However the "Grezzoni" *F*m is made up of dark massive to stratified dolostone and dolomitic limestone with local occurrence of dolomitic sedimentary breccias (Ciarapica & Passeri 1978; Carmignani et al. 1987), whereas the T_c of Complex II is a light-coloured tectonic calcareous breccia made up of G_1 marble (rarely dolomitic) and, minor go_2 phyllitic-quartzitic elements.

Ortano Marble (G_1)

This formation (15–20 m thick), is made up of a coarse to medium-grained saccaroidal massive (sometimes roughly stratified), gray-whitish marble, frequently with yellowish bands. Locally were observed rare discontinuous phyllitic levels. At Spiaggia del Lido, dolomitic horizons (X-ray data) occur in the upper part of the formation. The Ortano Marble is generally strongly recrystallized under static conditions. Only locally there is still evidence of carbonate-crystal flattening and of parallel orientation of mica flakes produced by dynamic metamorphism.

Alternating levels of marble and calcschist mark a 0.5–1.0 m thick transition zone to the overlying G_2 *Fm.* Although it could be envisaged as an original stratigraphic passage, a tectonic surface often clearly divides the two formations.

Previous attributions:

Barberi et al. (1969), Perrin (1975) and Boccaletti et al. (1977) consider the Ortano marble as the equivalent of the Hettangian marble of the Tuscan metamorphic sequence of the "Apuan Autochthon".

Calcschist (G_2)

This formation (20–80 m thick), observed only in the Ortano sequence, is made up of stratified (10–40 cm thick) gray and gray-greenish calcschist layers consisting of alternating decimetric to millimetric marble and minor gray to black phyllite levels. Siliceous white quartzitic bands and nodules were observed, particularly in the middle-upper part of the sequence. The carbonatic levels consist of medium to fine-grained marble, with calcite crystals flattened parallel to the main schistosity, and sometimes with variable amounts of quartz and sheet silicates. Locally small amounts of dolomite are revealed by X-ray analyses. Phyllite levels, compositionally very close to the overlying G_f levels, are characterized by the presence of graphite and by the occurrence of scattered albite to oligoclase porphyroblasts. The latter display simple to polysynthetic twinning, deformed internal foliations, zoning from oligoclase core to albite rim and rotation with respect to the main schistosity. G_2 shows a transition to the overlying phyllite (G_f), through a gradual increase in the number of phyllitic levels with respect to the carbonatic ones.

Previous attributions:

Barberi et al. (1969) correlate this formation with the Liassic "Calcescisti e Cipollini" of the "Apuan Autochthon". Boccaletti et al. (1977) attributed G_2 *Fm* to metamorphic Tuscan Dogger levels and the irregular surface between the "Ortano marble" and "Calcschist" to an erosion paleosurface. Perrin (1975) suggested a possible correlation of this formation (defined with the overlying G_f as "Unità degli Scisti e Cipollini") with the Lias-Dogger levels of the "Apuan Autochthon".

Phyllite with local calcschist intercalations (G_f)

The main lithotype of this Formation (max. 250–300 m thick) is represented by a dark gray-greenish to black quartzitic phyllite, locally alternating with gray calcschist of variable thickness (some dm to 4–5 m), similar to the G_2 carbonatic lithotypes.

The phyllites, consist of muscovite, quartz, chlorite and minor biotite, calcite Fe-Ti oxides and, locally, abundant graphite (Fig. 3). Sphene is frequently observed among the accessories. A significant feature is the occurrence of plagioclase-rich levels with pre- to syn-tectonic oligoclase (core) to albite porphyroblasts, showing simple to polysyn-

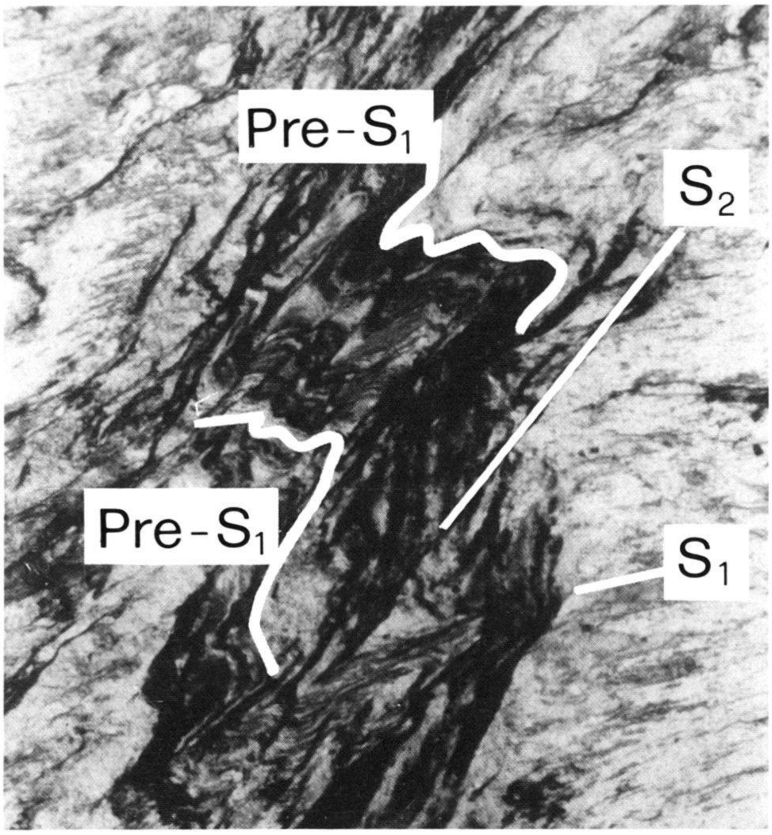


Fig. 3. Pre-S_1, S_1 and S_2 schistosities in the G_f phyllites of the Complex II. One polar: 20×.

thetic twinning, rotations, quartz + muscovite ± albite pressure shadows and evidence of deformed internal foliations (Fig. 4). The latter textures are also observed in some quartz blasts. Thin microcrystalline quartzitic levels are rarely interlayered within the phyllitic sequence. Quartz rods also occur.

Calcschist intercalations are petrographically identical to the lithotype previously described in G_2 *F*m. The abundance of chlorite, plagioclase and titaniferous minerals indicates that the phyllite probably corresponds to a psammitic-pelitic sediment partly derived from reworking of basic volcanites.

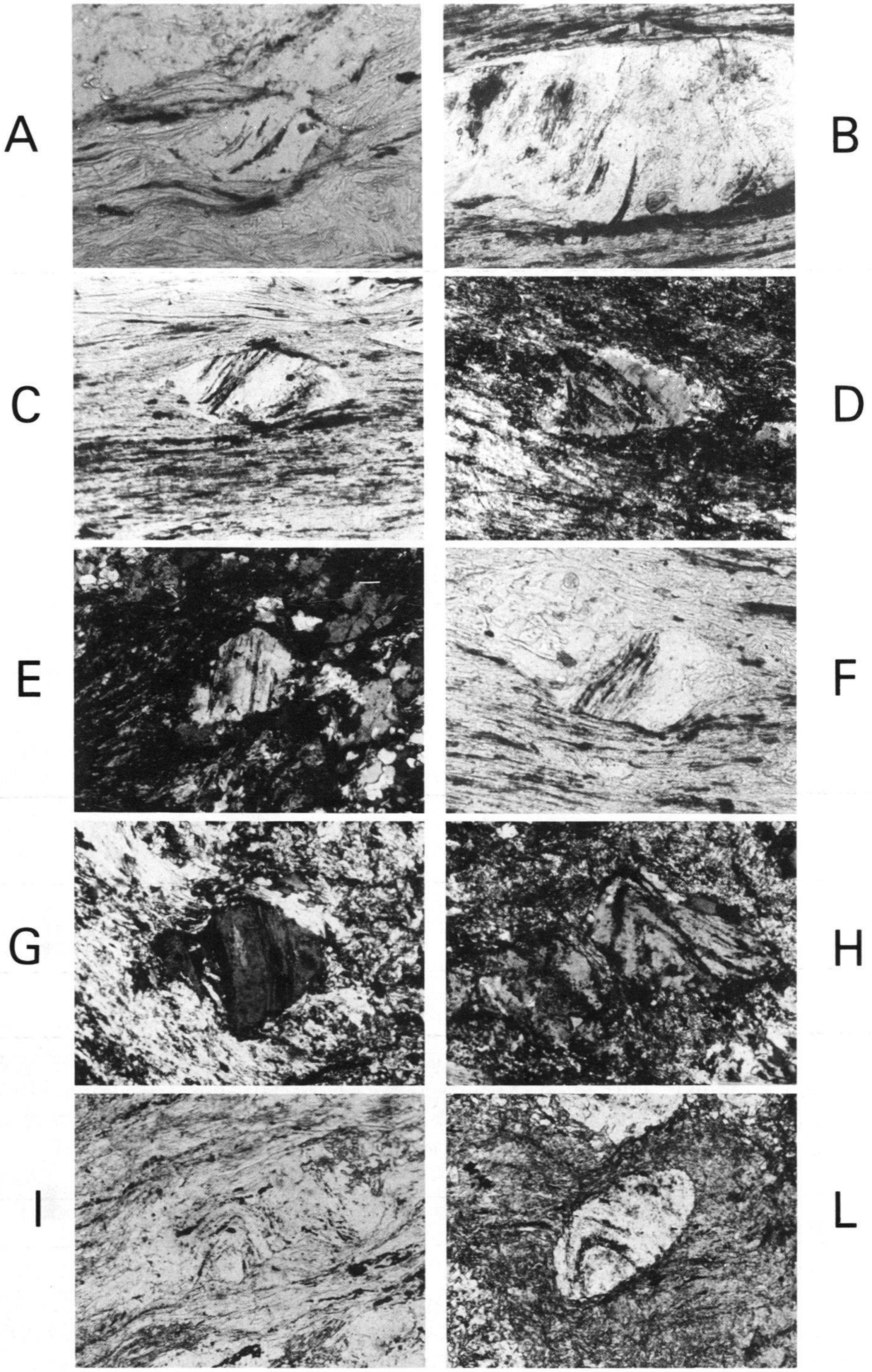
This formation is locally affected (e.g. "Mineralized G_f" horizons in Fig. 2a) by a strong contact and hydrothermal metamorphism produced by the Serra-Porto Azzurro intrusive body (hedenbergite + epidote + adularia ± ilvaite ± tremolite-actinolite ± Fe-oxides/hydroxides ± pyrite assemblages).

Previous attributions:

Barberi et al. (1969) considered G_f as a metamorphic equivalent of the Dogger "Marne a Posidonia" Formation (MP). Perrin (1975) and Boccaletti et al. (1977) correlated the whole G_f sequence with both the Dogger MP and the Cretaceous-Eocene "Scisti sericitici varicolori" Formation (SSV) of the "Apuan Autochthon".

Chemical data

Chemical analyses on 21 samples of G_f Formation, from Elba, and 21 samples of the "Marne a Posidonia" (MP) and "Scisti sericitici varicolori" (SSV) Formations, from the "Apuan Autochthon", were carried out in the ENEL-UNG laboratories, using Standard ASTM wet and instrumental (X-ray fluorescence) analytical methods.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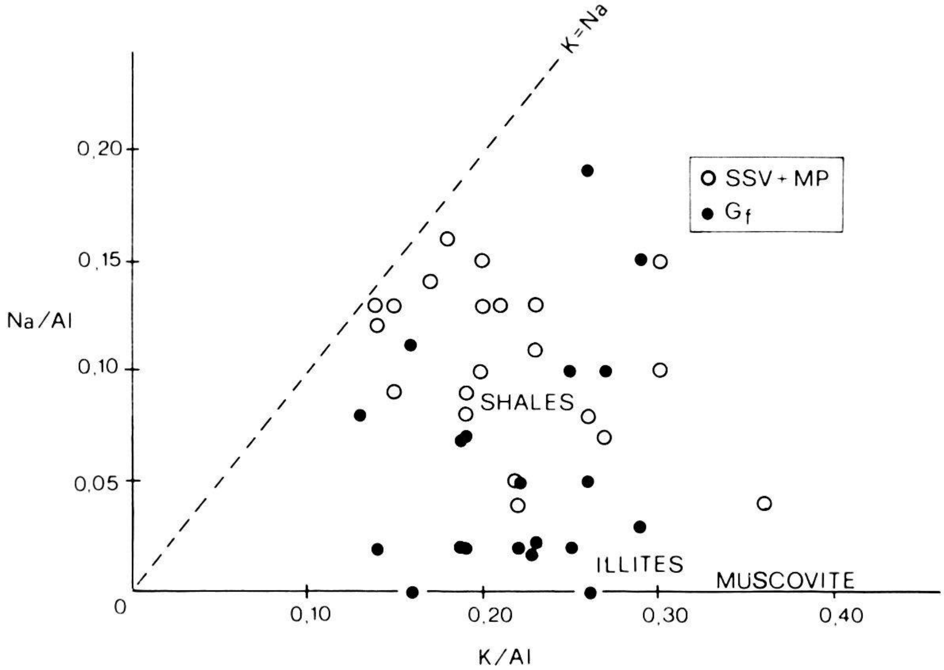

Fig. 5. Na/Al vs. K/Al diagram for the G_f phyllite of the Complex II from the Island of Elba and the "Marne a Posidonia" (MP) and "Scisti sericitici varicolori" (SSV) rocks of the Alpi Apuane.

The samples chosen show no evidence of metasomatism or of contact/ hydrothermal metamorphism. Therefore they underwent only the isochemical transformation of the regional metamorphism. In order to further investigate the possible attribution of G_f to the SSV and/or MP formations, which has been accepted so far in the literature, chemical comparisons have been made between the G_f and SSV–MP sets of samples.

Some differences between the two groups can be recognized in the Na/Al vs. K/Al diagram (Fig. 5) of de LA ROCHE (1978).

The SSV–MP samples are characterized by an Na-enrichment and a more restricted range of Na/Al values.

The abundance of Na in the SSV–MP rocks is mainly related to the high paragonite content frequently revealed by X-ray data on these rocks.

On the contrary the wider range of the Na/Al values observed in the G_f phyllites can be explained by the occurrence of Na-rich samples with a remarkable modal percentage of acidic plagioclase.

Structural features

All the phyllites of Complex II have rather homogeneous microstructural features. In particular (Fig. 3), they are characterized by the ubiquitous presence of isoclinal

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Fig. 4. Textural comparison between the G_f phyllite (A, B, C, D, E, F) and the Paleozoic Calamita schist (G, H, I, L). The porphyroblastic plagioclase preserve relics of an internal pre-S_1 (Hercynian) schistosity. D, E, G, H: two polars. A, B, C, F, I, L: one polar. A: 70×. B: 150×. C, D, E, F, G, H, I, L: 90×.

folds whose highly pervasive axial plane foliation (S_1) generally corresponds to the main Tertiary schistosity observed on the mesoscopic scale. S_1 is characterized by a gentle westward dip, a syn-kinematic recrystallization of white mica, chlorite, quartz, albite and opaque minerals, and by a NE-SW trending mineral lineation.

A second deformation event (D_2) produced broadly spaced crenulations up to strain-slip cleavage (S_2), locally pervasive, characterized by alignments of white mica and opaque minerals. A late deformation event (D_3) is sometimes recorded by a gentle crenulation.

Two Tertiary tectono-metamorphic events, characterized by low-grade PT conditions and textural features similar to those observed for D_1 and D_2 in Complex II, were recognized in the Tuscan metamorphic sequences from the Apuan Alps to the Southern Tuscany (Franceschelli 1980; Moretti 1986; Carmignani et al. 1987; Costantini et al. 1987). Despite a lack of physical continuity between the different outcrops and the paucity of radiometric data, which refer only to the Apuan sequences ($D_1 = 27$ Ma; $D_2 = 11.5–12$ Ma: Kligfield et al. 1986), the two Tertiary phases have been correlated on a regional scale (Moretti 1986), because of a general uniformity of textural features all over Tuscany.

Among the Tertiary deformation events, D_1 is characterized, in north and south Tuscany, by isoclinal folds, by the highest metamorphic grade (high greenschist facies), by the strongest recrystallization and by the most penetrative S_1 surface with a NE-SW lineation of maximum extension. Crenulation to strain-slip cleavage, related to open-tight folds and a lower metamorphic grade (low greenschist facies), is generally associated with the D_2 event (Moretti 1986; Carmignani et al. 1987; Costantini et al. 1987).

Relics of a pre-S_1 schistosity, are recorded within go_1, go_2, G_2 and G_f phyllites of the Complex II (Fig. 3) as muscovite ± quartz ± chlorite ± opaque minerals alignments deformed by D_1 isoclinal folds. This "S-1" foliation is cut at medium-high angle by the regional S_1 surfaces. Further relics occur as deformed internal foliations marked by alignments of opaque minerals and white mica preserved within albite and/or quartz porphyroblasts from the go_2, G_2 and G_f phyllites (Fig. 4).

The attribution of this relict fabric to an Eo-Alpine (Cretaceous) or "Ligurian" (Eocene) compressional phase may be ruled out on the basis of the geological data available so far in the literature and of the absence of such pre-S_1 relics within the Upper Carboniferous-Lower Permian rocks of the "Rio Marina" *F*m (Complex III).

All these data indicate the existence of a pre-Alpine tectono-metamorphic event that could be ascribed to the Hercynian orogeny.

Discussion

All the Authors, except Bodechtel (1964), have so far considered the Elba formations overlying the "Porfiroidi" and "Scisti porfirici" as the equivalent of the Mesozoic epimetamorphic sequences of the "Apuan Autochthon".

However the new data presented in this paper suggest a possible Paleozoic age for these formations, also supported by the analogies with the Sardinian Paleozoic metamorphic sequences described by Carmignani et al. (1982a, 1986a).

The following differences have been observed between the "Tuscanid I" Mesozoic sequences (Apuan Alps) and the "Complex II" sequence (Elba):

1) the base of the carbonate Mesozoic sequence of "Tuscanid I" is represented by massive and/or stratified pure dolostones ("Grezzoni" Formation Auct.) including levels of dolomitic sedimentary breccias, while the basal carbonate formation of Complex II (T_c) is generally a tectonic mainly calcitic breccia with elements derived from the "Ortano marble" and the go_2 formations;
2) The siliceous formations (e.g. "Diaspri" Formation Auct.) occurring in the middle-upper part of the Tuscanid I sequence are completely missing in Complex II;
3) The Phyllite G_f of the Elba Complex II shows lithological, structural and metamorphic differences with respect to the Apuan Mesozoic-Eocene MP and SSV formation previously assumed to be its equivalent. In fact G_f is a strongly recrystallized meta-siltstone to meta-sandstone characterized by abundant graphite and relics of an earlier foliation similar to that occurring in the go_1 and go_2 phyllites (possibly of pre-Alpine age).
   On the contrary the SSV rocks mainly consist of weakly recrystallized variegated, often hematite-rich, metapelites that locally preserve sedimentary textures, and the MP calcschist and phyllite rocks are similar to those of the SSV *Fm*. Moreover both the MP and SSV sequences are devoid of meta-silicic-clastic levels, of graphite, of pre-S_1 relics and of the typical plagioclase eyes of the G_f phyllites.

Furthermore G_f *Fm* is strikingly similar to some lithotypes of Complex I ("Scisti muscovitico-biotitici a metablastesi plagioclasica" of the Calamita Complex: BARBERI et al. 1967) that are attributed to the Paleozoic by all the Authors (see Fig. 4). Considering all the lithotypes of the Tuscan Paleozoic, the Elba G_f *Fm* is comparable to rocks of the "Filladi inferiori" and "Micascisti" Groups (the latter including some lithotypes of the Calamita Complex) of supposed Ordovician-Silurian age or older (BAGNOLI et al. 1979; TONGIORGI & BAGNOLI 1981; VAI & COCOZZA 1986; CARMIGNANI et al. 1987). Some metagraywackes of the former group show, as in G_f *Fm*, high contents of plagioclase, chlorite and titaniferous minerals; the latter group is commonly characterized by the occurrence of rotated albite porphyroblasts with deformed internal foliation and by traces of pre-Alpine schistosity.

The sequence of Complex II, as a whole, also shows analogies with part of a Cambrian-Silurian/Devonian type sequence, as described for the Sardinian Paleozoic by Carmignani and his coworkers (GHEZZO & RICCI 1970; BARCA & DI GREGORIO 1979; CARMIGNANI et al. 1982 a, b, c, d; 1986 a, b; DI PISA & OGGIANO 1984).

An idealized stratigraphy of the Sardinian Paleozoic in the "Nappe Zone" (Central Sardinia) can be summarized as follows from bottom to top (CARMIGNANI et al. 1986a, Fig. 2, p. 14):

1) metasandstone, shale and metasiltstone of the "Arenarie di San Vito" and "Arenarie di Solanas" Formation (Middle Cambrian to Upper Arenig);
2) Rhyodacitic-rhyolitic metavolcanites, metagranites and derived clastic sediments, mainly referred to "Porfiroidi" and "Scisti Porfirici" (Middle Ordovician);
3) metasandstone, metaconglomerate and metarkose (Caradoc transgression);
4) metasiltstone and metapelite, grading upward into locally silicified metalimestone with metapelitic and marly intercalations (Ashgill);

5) gray-greenish to black phyllite locally associated with metabasite, metalimestone, metasandstone, metasiltstone and lydites (Silurian-Devonian);
6) metaconglomerate and metasandstone grading upwards into metasiltstone and metapelite (Upper Devonian-Lower Carboniferous).

Comparison of the different metamorphic sequences of Sardinia and Elba reveals the following significant analogies.

The "Spotted schist" (go_1), including phyllite and quartzite, are similar to the shale and metasandstone of the Upper Cambrian to Upper Arenig sequence of Sardinia, although the limited extent of the studied outcrops precludes a more detailed comparison.

The "Porfiroidi" and "Scisti Porfirici" (go_2) represent feldspar-rich, completely recrystallized metasediments derived from the reworking of acidic, often K-rich, volcanites. They cannot be correlated, as previously done by BARBERI (1966), to the Permian Red Porphyries. In fact the Permian volcanites, found as pebbles within the Permo-Triassic sedimentary sequences ("Iano porphyritic schist"; "Castelnuovo red sandstone" and basal levels of the "Verrucano" in BAGNOLI et al. 1979) are in fact poorly welded rhyolitic ignimbrites with glass shards still recognizable under a weak recrystallization, and characterized by a very low alkali content, owing to the complete lack of feldspar crystals (BAGNOLI et al. 1979; PUXEDDU et al. 1984; FRANCESCHELLI et al. 1987).

On the contrary the Tuscan "Porfiroidi" and "Scisti Porfirici" closely resemble those of Sardinia and have entirely different features (abundant relics of feldspar phenocrysts and strong recrystallization) from the Red Porphyries. The Llanvirn-Llandeilo age of these lithotypes in Sardinia could, therefore, also be attributed to the analogous lithotypes of Tuscany. Similar rocks of comparable age are very common in the Hercynian sequences of Northeastern Spain and Southern France (BOURROUILH et al. 1980 Fig. 11, p. 182; DURAN et al. 1984; JULIVERT et al. 1986). The analogy is further supported by the occurrence of metasandstone with metaconglomerate levels above the "Porfiroidi" and "Scisti porfirici", similar to the "Caradoc Transgressive Deposit" of the Sardinian sequence.

More problematic is the correlation of the "Ortano marble" and the overlying "Calcschist" with Sardinian Paleozoic rocks, because of the strong recrystallization and the high-T contact metamorphism.

On the other hand the metasiltstone and metapelite at the top of go_2 (also known as fragments within T_c), together with the overlying "Ortano marble" and "Calcschist", could recall the Ashgill sequences of the Sardinian Nappe zone (BARCA & MAXIA, 1982; BARCA et al. 1986; CARMIGNANI et al. 1986a). A good example of this sequence is given by the "Tuviois Formation" of BARCA & DI GREGORIO (1979) consisting of more or less calcareous siltstone and shales grading upward into a locally silicified limestone and calcschist horizon.

Another possible correlation could be tentatively proposed with the Silurian "Orthoceras limestone" and/or Devonian carbonatic formation, showing an average thickness of 20–30 m in the European African sequences (VAI written communication) and widespread in Sardinia.

Silurian-Devonian(?) carbonatic levels are also well known in the Tuscan Paleozoic sequence of the "Apuan Autochthon", above metasandstone and meta-arkose of supposed Upper Ordovician age (CARMIGNANI et al. 1987). The hypothetical occurrence of "Orthoceras" dolostone as intercalation within the go_2 *Fm* of Complex II was first proposed by TONGIORGI & BAGNOLI (1981, n. 16 in Fig. 1, p. 322) and then assumed by VAI & COCOZZA (1986, Fig. 3, and p. 100) in their general framework of the Hercynian chain in Italy. Silurian fossils were also found by MENEGHINI (in LOTTI, 1910) in the graphitic schists of Vigneria (north of Rio Marina) that were ascribed, in the geological maps of BARBERI et al. (1967a, 1969), to the fossiliferous Upper Carboniferous-Lower Permian (DE STEFANI 1914; BODECHTEL 1964; KAHLER 1969; COCOZZA et al. 1974) "Rio Marina" *Fm* (Complex III).

Mining research at Vigneria revealed the existence of a carbonate sequence, between the "Rio Marina" *Fm* and the "Serpentinite" (at the top of the Complex II). It consists of gray to pink marbles and calcschists with a schist intercalation of unknown age ("Vigneria Limestone" of Gillieron in DESCHAMPS, 1980). The Meneghini's Silurian fossils in the graphitic schist of Vigneria ("Orthoceras limestone" intercalation? or olistoliths?) and the occurrence of this carbonate sequence buried below the "Rio Marina" *Fm* may suggest a Silurian-Devonian(?) age for the "Vigneria limestone", which shows some lithological affinities with the G_2 *Fm* lithotypes of the Complex II. The possible existence of tectonic slices of Silurian-Devonian(?) rocks at the base of "Rio Marina" *Fm* cannot be excluded.

Finally, the G_f phyllites are comparable to the Silurian-Devonian schist of Sardinia and, more generally, of Southern Europe. Their Ti minerals may suggest a sedimentary supply from reworking of basic igneous rocks that are very common in the Silurian-Devonian sequences of Sardinia and Spain.

Paleogeography and metamorphic zonation of the Northern Apennines

The petrographic data discussed in this paper, the recent advances in knowledge of the Tertiary metamorphic zonation of the Northern Apennines (FRANCESCHELLI et al. 1986) and the discovery of Upper Cretaceous-Lower Tertiary metasediments in South Tuscany (Fontalcinaldo area: PANDELI et al. 1988; location in Fig. 6b), suggest a new paleogeographic framework for the metamorphic sequences belonging to the Tuscan domain. Some Authors, considering the Complex II as the extension of the Apuan zone south of the Arno River (BARBERI et al. 1969; BOCCALETTI et al. 1980; and references therein) suggest the following paleogeographic zonation (Fig. 6a), which has already been criticized (for instance VAI & COCOZZA 1986; VAI 1988):

1) *The Massa Zone,* including Massa zone s.s. (Punta Bianca and Massa unit) and the "Dorsale metamorfica medio-toscana" (Monti Pisani, Iano, Montagnola Senese, Monticiano-Roccastrada, Monti Leoni).
2) *The Apuan Zone* consisting of the Apuan and Elban Complex II sequences.

According to BOCCALETTI et al. (1980) (see also bibliography therein), the Massa zone is characterized by the widespread occurrence of thick Triassic Verrucano metasediments and by important unconformities during Mesozoic-Tertiary times; on the contrary the Apuan zone shows only sporadic occurrence of the Verrucano (of very limited areal extent and thickness), and continuous Mesozoic-Tertiary sequences.

The following points suggest a different reconstruction:

1) If all of the Complex II is of Paleozoic age, as suggested in this paper, the Tuscan Mesozoic-Tertiary metamorphic sedimentary sequences are exposed only in the Alpi Apuane (CARMIGNANI & GIGLIA 1975; CARMIGNANI et al. 1987), Monti Pisani

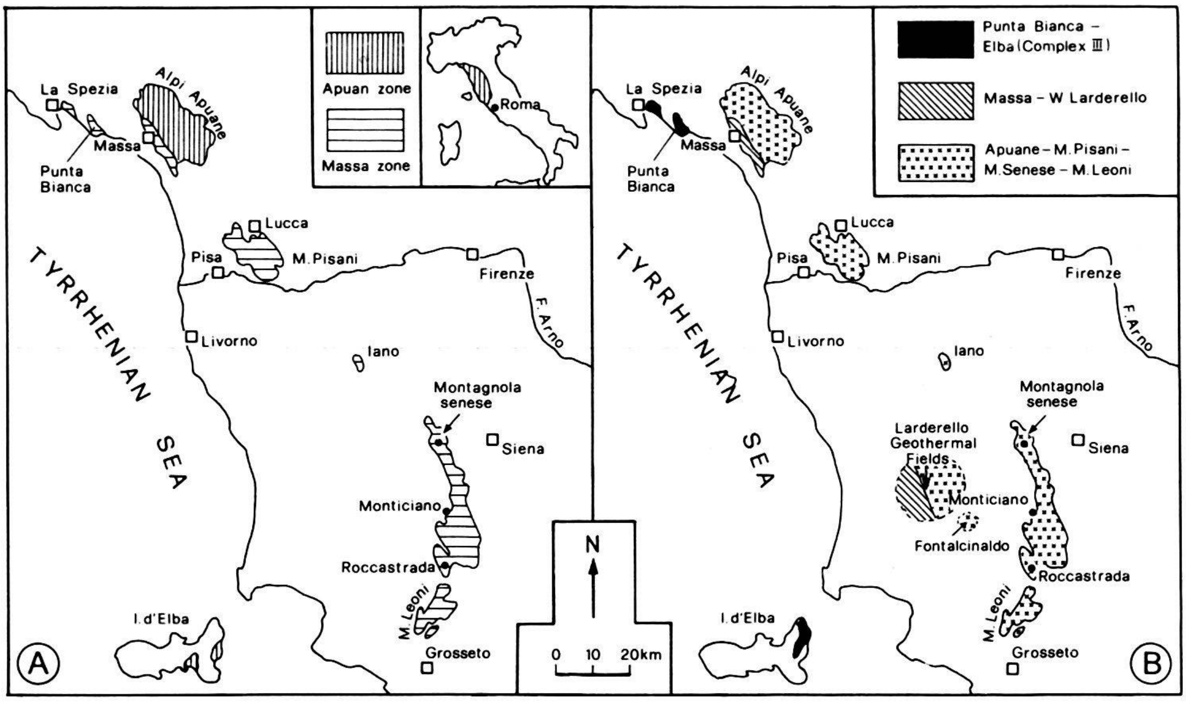

Fig. 6. A): Paleogeography of the Northern Apennines and the Island of Elba. A) Reconstruction accepted so far in the literature; B) New framework proposed in this paper.

(Giannini & Nardi 1965; Rau & Tongiorgi 1974), Montagnola Senese (Giannini & Lazzarotto 1970; Pandeli et al. 1988) and Monti Leoni areas (Tongiorgi et al. 1987).

Therefore in the island of Elba only the Complex III includes a Middle Triassic to Tertiary Tuscan-type sequence overlying the Paleozoic "Rio Marina" *F*m.

2) Intercalations of carbonatic levels (locally with frankly open-marine facies) within Verrucano metasediments are known only in the sequences of Punta Bianca (Passeri 1985; Martini et al. 1986), Elba Complex III, (Deschamps 1980; Deschamps et al. 1983), Massa Unit s.s (Elter et al. 1966; Ciarapica & Passeri 1982) and in the geothermal wells in the western part of the Larderello area (Franceschelli et al. 1984).

   On the contrary, the only silicic-clastic sequences in the Monti Pisani and southern Tuscany (Montagnola Senese, Monticiano-Roccastrada ridge, Monti Leoni etc.) never exceed a transitional-coastal environment (Gelmini 1969; Giannini et al. 1971; Gasperi & Gelmini 1973, 1975; Rau & Tongiorgi 1974; Decandia & Lazzarotto 1980; Tongiorgi et al. 1977; Costantini et al. 1987; Tongiorgi et al. 1987; Moretti et al. 1989).

3) Proceeding from E to W across the Northern Apennines, the "Verrucano" sequences show a gradual increase of metamorphic grade up to the alignment Massa-western wells of Larderello, and then a decrease towards Punta Bianca and Elba (Complex III) (Franceschelli et al. 1986). The following zones were distinguished: a) kaolinite-pyrophyllite to pyrophyllite zone (Alpi Apuane – Monti Pisani – Iano – Monticiano-Roccastrada – Monti Leoni); b) kyanite-pyrophyllite to

kyanite zone (Massa-western Larderello areas); c) pyrophyllite zone (Punta Bianca-Elba).

Considering the stratigraphic analogies and the comparable metamorphic grade between the above-mentioned Tuscan metamorphic sequences, the following paleogeographic-tectono-metamorphic zones may be proposed from west to east (see Fig. 6b): 1) Elba (Complex III) – Punta Bianca; 2) Massa – western Larderello; 3) Alpi Apuane – Monti Pisani – Montagnola Senese – Monticiano – Roccastrada – Monti Leoni.

Vai (1988) suggested a zonation of the Tuscan metamorphic units that is similar in some respects to the reconstruction proposed here. Vai (1988) distinguishes an inner Elba – Punta Bianca Unit and an outer Passo del Cerreto Unit, located on the western and eastern side of the intermediate Massa and Apuane Units respectively (Baldacci et al. 1967; Boccaletti et al. 1980).

Concluding remarks

The revised geology of Complex II from the island of Elba, leads to the following remarks:

1) A Paleozoic age can probably be ascribed to all the lithotypes overlying the "Porfiroidi" and "Scisti porfirici". Evidences supporting this hypothesis are given by: a) relics of an early foliation that predated the regional schistosity S_1. The latter shows features that are generally attributed to the first Tertiary deformation event (D_1) in the metamorphic sequences of north and south Tuscany; b) frequent occurrence of albite porphyroblasts showing rotation and deformed internal foliations, comparable to those found in the Paleozoic "Calamita schist"; c) mineralogical and chemical compositions that differ from those of the Tuscan Mesozoic to Tertiary metasediments.
2) Complex II resembles, as a whole, the Cambrian-Ordovician to Silurian-Devonian sequences of Sardinia. In particular: a) the "Spotted schists" can be correlated with the Cambrian-Upper Arenig shale and metasandstone of Sardinia ("Solanas" and "San Vito Sandstone" Formations); b) the "Porfiroidi" and "Scisti porfirici" can be correlated with the acidic metavolcanites and derived metasediments of the Sardinian Middle Ordovician, while the overlying metasandstone and meta-conglomerate recall the clastic transgressive Caradocian deposits; c) the whole metasiltite-metapelite sequence, at the top of go_2, with the overlying carbonate levels (G_1, G_2) may be tentatively correlated with the Ashgill sequences of central-south Sardinia. On the other hand G_1 and G_2 may also be compared with the Silurian to Devonian carbonate levels of Sardinia (also present in the Tuscan Paleozoic sequence); d) phyllite G_f, owing to its graphite-rich levels, the carbonate intercalations and the volcanoclastic basic material, may be compared with Silurian-Devonian sequences of Sardinia.
3) The "Vacuolar Dolomitic Limestone" may be reinterpreted as a late Miocene tectonic breccia produced by the thrusting of the "Ortano marble" over the "Porfiroidi" *Fm.*
4) The suggested attribution to the Paleozoic of Complex II, would, on the whole, preclude identification of an "Apuan zone" in Elba.

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