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GEO-PETROLOGICAL FEATURES OF THE METAMORPHIC FORMATIONS OF TUSCANY

Riassunto — In questo articolo vengono presentate le note illustrate alla carta delle formazioni metamorfiche della Toscana preparata quale contributo alla carta delle formazioni metamorfiche d'Europa.

Le rocce metamorfiche della Toscana sono state suddivise in quattro facies, tenendo conto dei gruppi di facies e delle serie di facies (ZWART e al. [1967]).

Le facies e le loro principali caratteristiche sono:

- 1) Facies delle anfiboliti di pressione non determinata
principali affioramenti: Passo del Cerreto;
litotipi fondamentali: anfiboliti e micascisti;
minerali caratteristici: oligoclasio-andesina, granato, orneblenda.
- 2) Facies degli scisti verdi di pressione non determinata
principali affioramenti: Alpi Apuane, Monte Pisano, dorsale Monticiano-Roccastrada-M. Leoni, M. Romani;
minerali caratteristici: clorite; nel paraautoctono delle A. Apuane biotite e sporadicamente cianite.
- 3) Facies delle anfiboliti di bassa pressione
principali affioramenti: Campiglia, Isola d'Elba;
litotipi fondamentali: contattiti di vario tipo;
minerali caratteristici: andalusite, cordierite.
- 4) Facies di transizione fra la facies di scisti verdi e la facies degli scisti a glaucofane
principali affioramenti: I. di Gorgona, Poggio di Moscona, Pr. Argentario, I. del Giglio;
litotipi fondamentali: filladi, meta-ofioliti, calcescisti;
minerali caratteristici: glaucofane, crossite, fengite, stilpnomelano, lawsonite.

Nell'articolo si discute del significato del metamorfismo regionale in facies di scisti verdi e del metamorfismo di pressione medio-alta.

Per il metamorfismo in facies di scisti verdi viene ipotizzato un carattere di

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pressione intermedia per le scaglie paraautoctone (Alpi Apuane), mentre quello dell'autoctono dovrebbe essere di bassa pressione.

Il significato del metamorfismo di pressione medio-alta viene discussso sulla base di modelli geodinamici e vengono avanzate due ipotesi alternative.

Abstract — In this paper are reported the illustrative notes of the metamorphic map of Tuscany prepared as contribution to the metamorphic map of the Europe.

The metamorphic rocks have been subdivided in four facies taking in account the facies groups and the facies series (ZWART et Al. [1972]).

These four facies are:

- 1) Amphibolite facies, facies series unknown;
- 2) Greenschist facies, facies series unknown;
- 3) Low pressure amphibolite facies;
- 4) Facies transitional between glaucophanitic facies to greenschist facies.

The significance of the regional metamorphism of greenschist facies and that of the facies transitional between glaucophanitic to greenschist are discussed.

The greenschist facies metamorphism is hypothetically considered of intermediate pressure for the paraautochthonous wedge (A. Apuane) and of low pressure for the autochthon.

The significance of the medium-high pressure metamorphism is discussed on the basis of geodynamic models and two optional hypotheses are advanced.

The Servizio Geologico d'Italia, in January 1972, invited the Istituto di Mineralogia e Petrografia of the Siena University to contact Prof. H. J. ZWART, chairman of the working group for the cartography of the metamorphic belts of the world and co-ordinator for the metamorphic map of Europe (scale 1:2.500.000), for the preparation of the metamorphic map of Sardinia.

In occasion of the meeting of Leiden for the co-ordination of the metamorphic map of Europe, I was invited by Prof. Zwart to prepare besides the metamorphic map of Sardinia also that of Tuscany.

The metamorphic map of Tuscany has been sent to Prof. ZWART, in december 1972, together with short illustrative notes.

In what follows the map and its illustrative notes are reported.

* * *

The metamorphic rocks of Tuscany occur as isolated and sometimes very small outcrops which are distributed along the coast side.

On the basis of the facies groups and, as far as possible, the facies series (ZWART et Al. [1967]) the metamorphites have been subdivided in the following four facies:

- 1) Amphibolites facies, facies series unknown;
- 2) Greenschist facies, facies series unknown;
- 3) Low pressure amphibolite facies;
- 4) Facies transitional between glaucophanitic facies to greenschist facies.

AMPHIBOLITE FACIES, FACIES SERIES UNKNOWN

The only rocks referred to this facies occur in the Cerreto Pass area. The very small outcrop of crystalline rocks of the Cerreto Pass, has been studied from a petrographic point of view by RODOLICO [1937] and RICCI [1968].

These rocks are constituted by amphibolites, micaschists, quartzites, phyllites and crystalline limestones.

Quartzites, phyllites and crystalline limestones, represent the products of the alpine metamorphism of the greenschist facies (chlorite zone) of a triassic sedimentary series.

The parageneses of amphibolites (hornblende, oligoclase-andesine, garnet) and micaschists (quartz, oligoclase, biotite, muscovite, garnet) indicate a metamorphic grade corresponding to the amphibolite facies. The amphibolites and the micaschists exhibit retro-metamorphic effects along mylonitic planes. These rocks have been interpreted (RICCI [1968]) as fragments of an old crystalline basement, perhaps hercynian, tectonically interposed in the triassic series.

GREENSCHIST FACIES, FACIES SERIES UNKNOWN

The rocks of this facies represent the most part of the Tuscany's metamorphites. The main outcrops occur in Alpi Apuane, Monte Pisano, Monticiano-Roccastrada range, Monte Leoni and Monti Romani.

Alpi Apuane

The metamorphic rocks of the Alpi Apuane crop out through a tectonic window surrounded by unmetamorphosed allochthonous units.

The metamorphites belong to two distinct tectonic complexes: the autochthonous and the parautochthonous wedges.

The age of the autochthonous complex ranges from Paleozoic to Oligocene and the age of the parautochthonous wedges from Middle-Triassic to Oligocene.

The autochthonous succession mainly consists of phyllites, quartzites, calc-alkaline and rhyolitic meta-volcanics, marbles, calc-schists and feldspathic meta-sandstones.

The most characteristic parageneses (BARBERI and GIGLIA [1965]): (quartz-albite-muscovite-chlorite; quartz-muscovite-chlorite-epidote; calcite-chlorite-muscovite-epidote (quartz)) indicate a metamorphic grade corresponding to the chlorite zone of the greenschist facies.

The parautochthonous succession differs from the autochthonous one because of the lack of the rhyolitic and calc-alkaline meta-volcanics and the presence of meta-basalts.

The metamorphism is still in the greenschist facies but changes within the complex. As matter of fact disappearance of chlorite and development of biotite can be observed in the western part of the Alpi Apuane (from Pietrasanta to Carrara). According to BONATTI [1938], TREVISAN et Al. [1965], GIGLIA [1966] and RICCI [1968] this indicate a higher metamorphism than that of the autochthonous succession.

The sporadic and irregular presence of kyanite (BONATTI [1938]) may indicate, in this respect, local metamorphic condition of intermediate pressure.

Monte Pisano

The metamorphic series of Monte Pisano has an age ranging from Paleozoic to Eocene. It consists of phyllites, quartzites, meta-conglomerates, marbles and feldspathic meta-sandstones.

In the north-western part the metamorphic series is covered by the unmetamorphosed tuscan nappe; in the other zones it is surrounded by the recent alluvial sediments.

According to SCHIAFFINO and TONGIORGI [1962] the most meaningful parageneses are:

Quartz, muscovite, chlorite (paragonite, albite); quartz, muscovite, pyrophyllite, chlorite (paragonite, albite).

On the basis of these parageneses the metamorphic grade can be referred to the chlorite zone of the greenschist facies.

Monticiano-Roccastrada range; Monte Leoni; Monti Romani

These outcrops consists of formerly sedimentary rocks of Middle-Lower Carboniferous to Upper Cretaceous age.

According to the literature (COCOZZA [1965]; GIANNINI and LAZZAROTTO [1970]; GELMINI [1969]; GIANNINI et Al. [1971]) and to some unpublished studies of our Institute, the paragenesis of the pelitic rocks is: quartz, sericite, chlorite (albite). This paragenesis and the lack of such minerals as montmorillonite an kaolinite, indicate a metamorphic grade higher than the zeolitic facies and corresponding to the chlorite zone of the greenschist facies.

* * *

Other minor outcrops of rocks of such metamorphic facies, occur near Iano (BARBERI [1966]) along the eastern coast of Elba island (RICCI [1968]) in the «Colline Metallifere» area (Gavorrano, Boccheggiano, Serrabottini) (MARINELLI [1961]; ARISI ROTA and VIGHI [1971]), in Monti dell'Uccellina, in the south-eastern part of Argentario Promontory and in Giglio island (LAZZAROTTO et Al. [1964]).

* * *

Metamorphic rocks have been also found by drillings and by mining works in several localities of Tuscany (Bagni di Lucca, GIANNINI and NARDI [1965]; Larderello area, LAZZAROTTO [1967], MAZZANTI [1966], GIANNINI et Al. [1970]; Colline Metallifere, ARISI ROTA and VIGHI [1971]; Monte Amiata, CALAMAI et Al. [1970]).

The metamorphic grade of the upper part of the series crossed by the borings corresponds to the chlorite zone of the greenschist facies. A deep bore-hole placed near Larderello has reached the Verrucano schistose-quartzitic series in the greenschist facies at a depth around 1300 m. The deepest samples (between 2428 m and

2730 m) are garnet, biotite, muscovite bearing micaschists which indicate the epidote-amphibolite facies (MARINELLI [1971]).

LOW PRESSURE AMPHIBOLITE FACIES

In this facies we have grouped the rocks affected by contact metamorphism developed around the upper Tertiary intrusive bodies of Tuscany.

Campiglia

A quite large metamorphic aureola is developed in the carbonate rocks surrounding the small granitic stocks (GIANNINI [1955]).

According to BARBERI et Al. [1967 a], most part of the aureola is affected by a hornblende hornfels facies metamorphism.

Elba island

Contact metamorphic rocks are related to the emplacement of the two granitic stocks of the island: Monte Capanne and Porto Azzurro (the latter is too small to be mapped).

According to MARINELLI [1959], BARBERI and INNOCENTI [1965, 1966], BARBERI et Al. [1967b] the metamorphic grade ranges from the pyroxene-hornfels facies to the albite-epidote-hornfels facies; however the most represented facies is the hornblende hornfels one.

* * *

Other very small outcrops of contact metamorphites occur around the granites of Giglio and Montecristo islands; at Gavorrano the hornfelsitic rocks have been reached only by mining works (BARBERI et Al. [1971a] and bibliography).

FACIES TRANSITIONAL BETWEEN GLAUCOPHANITIC FACIES TO GREENSCHIST FACIES

Under this facies we comprise the metamorphic rocks of Gorgona island, of the north-western part of the Argentario promontory, of the Giglio island and of Poggio di Moscona (M. Leoni area).

Gorgona island

Gorgona island has been studied from a petrographic point of view by MAZZONCINI [1965]. The series of the island was interpreted as a portion of the «schistes lustrés» with a facies similar to that exhibited in the Piedmonte region (Italy).

The described parageneses:

Quartz-albite-phengite-calcite-chlorite-epidote; calcite-quartz-albite-phengite-ferrostilpnomelane; phengite-ferrostilpnomelane-crossite (quartz); actinolite-albite-chlorite-epidote-lawsonite; may indicate a condition of metamorphic recrystallization intermediate between the greenschist facies and the glaucophanitic facies.

Argentario promontory-Giglio island-Poggio di Moscona

In these areas small fragments of metamorphic ophiolites and calcschists are interposed within the tuscan series.

The petrographical studies on these rocks have been carried out by GOTTAUDI [1957], MARINELLI [1964], RICCI [1968].

The great diffusion of Na-amphiboles, such as crossite and glaucophane and the sporadic occurrence (Giglio island) of lawsonite, may indicate a low grade metamorphism of medium-high pressure coupled with a weak sodic metasomatism.

GRANITIC ROCKS

The intrusive manifestations constitute 6 stocks; the largest is the granodioritic pluton of the M. Capanne (42 Km²) (BARBERI et Al. [1971b] and bibliography).

There are, however, many indications that other intrusions are present even if they do not outcrop. They consist of large thermal anomalies, acid dike swarms, mineralization and associated skarns, and fragments of intrusive rocks enclosed in volcanics (Larderello, Colline Metallifere, Monte Amiata) (BORSI et Al. [1965]; MAZZUOLI [1967]; VIGHI [1966]; MARINELLI [1963]).

All the granitic rocks are intruded into the upper part of the crust, that is, generally, in epizonal conditions.

The age of the emplacement ranges from 7 to 5 m.y. as reported in table 1, which shows a migration in the time of the magmatic activity of Tuscany from West to East.

TABLE 1

Locality	Lithological type	Method	Age	Authors
Elba I.-M. Capanne	Pegmatite (L)	Rb/Sr	7.0	FERRARA et Al., 1961
» »	Granodiorite (B)	K/Ar	7.0	EBERHARDT and FERRARA, 1962
» »	» » »	»	6.4	EVERDEN and CURTIS, 1965
» »	» » »	»	6.7	BORSI et Al., 1967
Elba I.-P. Azzurro	Granite (B)	»	6.2	BORSI and FERRARA, 1971
Montecristo island	» »	»	7.0	BORSI et Al., 1967
Giglio island	» »	»	5.0	» » »
Gavorrano	» »	»	4.9	» » »
Campiglia	» (Or)	»	5.7	» » »
»	Pegmatite (Ph)	»	5.0	» » »

L = Lepidolite; B = Biotite; Or = Orthoclase; Ph = Phlogopite.

AGE OF METAMORPHISM

The metamorphism of the amphibolite facies, series unknown, is prealpine in age and probably hercynian.

The metamorphism of the greenschist facies has an alpine age.

In the Alpi Apuane the age of metamorphic recrystallization is 11 m.y. for the autochthonous complex and 14 m.y. for the para-autochthonous wedges (GIGLIA and RADICATI DI BROZOLO [1970]).

There are, however, evidences that some paleozoic levels of the Monte Pisano (RAU and TONGIORGI [1966]) and of the Monticiano-Roccastrada range (COCOZZA [1965]; GIANNINI et Al. [1971]) have been affected by pretriassic deformations.

The age of 275 m.y. obtained by whole-rock Rb/Sr method for some paleozoic rocks of M. Pisano has been interpreted (BORSI et Al. [1966]) as that of the recrystallization during the asturian phase of the hercynian orogenesis.

The age of the contact metamorphism must be considered the same of the emplacement of the granitic stocks (see table 1), that is comprised between 7 and 5 m.y.

The metamorphic recrystallization of medium-high pressure has most probably an alpine age (see below the discussion of its possible meaning).

CONSIDERATION ON THE METAMORPHISM OF TUSCANY

On the basis of the reported data it seems useful to add some short considerations regarding the metamorphic series here described as greenschist facies, facies series unknown and facies transitional between glaucophanitic facies to greenschist facies. The series of the greenschist facies are those with tuscan facies⁽¹⁾.

The alpine regional metamorphism affected mostly the lowest parts of the sedimentary series of the alpine cycle (Verrucano, evaporitic series) probably as a consequence of an anomalous heat flow (MARINELLI [1971]; BARBERI et Al. [1971a]) related to the thinning of the continental crust in western Tuscany which occurred in upper Tertiary (MORELLI et Al. [1967]). MARINELLI [1971] suggests that « the almost always clear transition between the anhydritic formation affected by epizonal metamorphism and the unmetamorphosed giurassic calcareous series is very likely due to a sharp variation of thermal gradient as a function of the different formational permeability. The heat which reaches by conduction the triassic series, impermeable because not yet affected by the disjunctive tectonics, is transmitted to the fluids contained in the overhanging calcareous series. The consequent convective circulation of these fluids causes a rapid distribution of the heat over very important volumes of rocks, so preventing the increase of temperature required for the metamorphism».

MARINELLI [1971] has calculated that the geothermal gradient in the Larderello area, during the Miocene, i.e. during the metamorphic recrystallization, was of the order of 60-70°C/Km. The low pressure character of the metamorphism of the tuscan authochthon, at least in the areas south of M. Pisano, seems to be confirmed by some preliminar determinations or the b_0 value of white micas, whose petrological significance have been recently discussed by SASSI [1972].

The second question regards the presence of meta-ophiolite and paraschists of medium-high pressure sometimes interposed within weakly or not metamorphosed series with tuscan facies.

(1) The tuscan series begins with a middle triassic transgression (Verrucano) on the paleozoic basement. It is followed by the deposition of evaporites (middle-upper Trias) and by a prevalently carbonatic series (Giura-Cretaceous).

The deposition of shales (scaglia toscana) and of a turbiditic formation of feldspatic sandstones (Oligocene) closes the sedimentary cycle.

In order to explain the presence of Na-amphiboles bearing ophiolites and paraschists in Tuscany, two hypotheses can be put forth.

These rocks may represent the products of a high pressure metamorphism of portions of oceanic crust of the italo-dinaric plate subducted under the european plate. In this case they would represent fragments of the ligurian series, and therefore belonging to the apenninic domain.

An other possibility is that they represent fragments of alpine series (glaucophane bearing schists of Corsica?) metamorphosed along a subduction plane, dipping under the italo-dinaric plate, and that they have been transferred on the Apennines probably as a consequence of the supposed reversal of sense of the Benioff zone sometime during the Eocene-Miocene (BARBERI et Al. [1971a]; BOCALETTI et Al. [1971]).

At the present time the second hypotheses is preferred because in the northern Apennines the ophiolitiferous nappes are either unmetamorphosed or affected by a low burial metamorphism (according to GALLI and CORTESOGNO [1970], prehnite-pumpellyite facies). Furthermore the associated paraschists appear very similar to those of the nappe of corsican and piedmontese «schistes lustrés» and according to GIANNINI et Al. [1971] they do not show any evident affinity with the apenninic units.

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