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ANCHIZONE METAMORPHISM IN SEDIMENTARY SEQUENCES OF THE NORTHERN APENNINES

(PRELIMINARY RESULTS)

ABSTRACT. — More than 45 samples from predominantly shaly rocks from the Northern Apennines have been investigated by X-ray diffraction methods. Samples from the Monte Caio flysch (Monte Caio unit) are unmetamorphosed if based on evidence of illite crystallinity data and the presence of irregular mixed-layer illite/montmorillonite. All the other investigated formations (i.e.: Palombini shales, Giariette shales, Gottero sandstones, Calpionella limestone, Lavagna shales, Sopralacroce shales, Casanova complex), belonging to the Gottero unit, Bracco unit and Casanova complex, show unvarying illite+chlorite assemblage with illite crystallinity characteristic of the deep diagenetic zone or of the anchizone, while nearby ophiolitic rocks belong mainly to the prehnite-pumpellyite facies.

RIASSUNTO. — Durante gli ultimi anni lo studio delle trasformazioni metamorfiche subite dalle formazioni affioranti nell'Appennino Settentrionale è stato rivolto quasi esclusivamente alle rocce di associazione ofiolitica mentre le sequenze sedimentarie sono state molto trascurate sotto questo punto di vista. I risultati preliminari qui riportati si pongono nella prospettiva di contrbuire a colmare tale lacuna e di portare un contributo alla soluzione dei complessi problemi geologici riguardanti l'Appennino Settentrionale.

In via preliminare sono state prese in considerazione varie formazioni di origine sedimentaria appartenenti a distinte unità tettoniche affioranti in un'area a cavallo tra la Liguria orientale e l'Emilia: di esse vengono riportati dati mineralogici — tra cui la cristallinità dell'illite — molto importanti per la comprensione dei fenomeni diagenetici e di debole metamorfismo intervenuti dopo la deposizione. Le formazioni appartenenti all'unità del Gottero, del Bracco e almeno alcune costituenti il Complesso di Casanova hanno subìto un metamorfismo di basso grado, ciò che può essere dedotto dai valori della cristallinità dell'illite — il cui indice I.K. raggiunge valori piuttosto bassi negli argilloscisti di Val Lavagna — e dalla tipica paragenesi ad illite e clorite. In particolare alcune formazioni come, ad esempio, gli argilloscisti di Val Lavagna, gli argilloscisti a Palombini, i calcari a Calpionella, le marne di Sopralacroce e parzialmente il Complesso di Casanova, sono riferibili all'anchizona. Le temperature a cui tali formazioni sono state sottoposte dovrebbero essere comprese tra 200 e 300° C circa. Viceversa il flysch di Monte Caio (Unità di Monte Caio), analogamente al flysch dell'Antola ad ovest della linea Varzi-Levanto, non pare aver subìto fenomeni metamorfici di basso grado ed è riferibile ad un ambiente di diagenesi avanzata; tale formazione è caratterizzata dalla presenza di strati misti illite/montmorillonite, ciò che consente di ipotizzare un evento termico con temperature comprese, in prima approssimazione, tra 100 e 200° C.

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Introduction

In recent years new petrographic and geochemical data on the « eugeosyncline sequences » ([1]) of the Northern Apennines has been collected. However, the interest of the various authors was particularly concerned with ocean-floor basalts — mainly belonging to the prehnite-pumpellyite facies —, gabbros and ultramafics of ophiolitic association (GALLI and CORTESOGNO, 1970; BEZZI and PICCARDO, 1971; GALLI et alii, 1972; SPOONER and FYFE, 1973; BECCALUVA et alii, 1973, 1975, 1976; CORTESOGNO and OLIVIERI, 1974; FERRARA et alii, 1976; BOCCHI et alii, in press; etc.), the sedimentary sequences being mostly disregarded from this points of view. Although some geologists already suspected a number of sedimentary formations as having undergone a weak metamorphic process (e.g.: ABBATE et alii, 1970; ELTER and PERTUSATI, 1973; MALESANI, 1966) only recently mineralogical data have been reported (SCHAMEL, 1974): these are concerned with the low-grade metamorphic transformations which occurred in the geological units outcropping between Voltri Group and Monte Ramaceto area (central-western Liguria). Thus this work aims to provide new data on the late diagenesis-low metamorphism processes that took place in sedimentary sequences of the Northern Apennines and, particularly, on those sequences jointly outcropping with ophiolite complexes. In this preliminary paper, mineral data and illite crystallinity values are reported on about fifty samples of pelitic, marly and — in minor amounts — sandy rocks belonging to the Antola formation (Monte Caio flysch) ([2]), Giariette shales, Gottero sandstones, Lavagna shales, Calpionella limestones, Palombini shales, Sopralacroce shales and Casanova complex (Fig. 1 and 2).

Geological setting

The Alps-Apennines boundary has been placed for long time along the Sestri-Voltaggio line (north-south trending, near to Genoa); according to SCHNEIDER (1935), LANTEAUME (1962), ABOUIN (1961) and others, this line separates the Alps (to the west) from the Apennines (to the east) because of the opposite polariry of the thrusts. More recently ELTER and PERTUSATI (1973) and SCHAMEL (1974), mainly on the ground of tectonic evidence, have shifted the limit eastward along the Varzi-Levanto line.

All the formations occurring in the Northern Apennines are geologically well known and have been described mainly by Italian Authors. Readers unfamiliar

(1) In this paper eugeosyncline sequence is used as a comprehensive term to include all the formations attributed to the eugeosyncline environment by ABBATE et alii (1970) without any other specific geological meaning.

(2) Eastward of the « Bracco ridge » (DECANDIA and ELTER, 1969) the Monte Antola formation is called Monte Caio flysch (ZANZUCCHI, 1963).

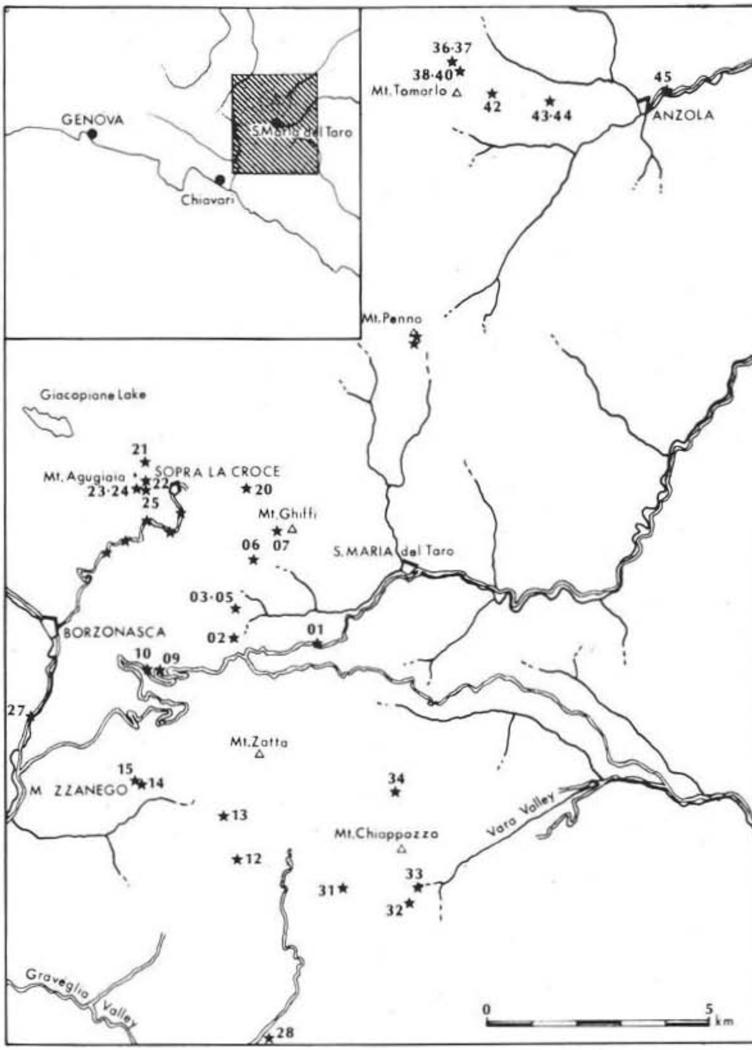

Fig. 1. — Simplified sketch map showing sample location in the Northern Apennines. The number of the samples are referred to Table 1. Sample numbers for the Mt. Penna area are not shown.

with italian complex nomenclature can find a detailed description of this area, on the basis of the classical geosyncline theory, in « Development of the Northern Apennines Geosyncline » (1970).

As far as more recent paleogeographic and tectonic reconstructions are concerned, one can see Barbieri et alii (1968), Gelati and Pasquarè (1970), Boccaletti et alii (1971), Giese et alii (1970), Laubscher (1971), Haccard et alii (1972), Braga et alii (1973), Decandia and Elter (1973), Zanzucchi (1972), Sturani (1973), Elter and Pertusati (1973), Schamel (1974), Dal Piaz (1974).

The investigated area is located NW of Chiavari on the boundary between Liguria and Emilia just east of the zone recently investigated by SCHAMEL (1974). Many formations occur in the region (see ABBATE and SAGRI, 1970) which have very different lithological characters and which constitute several sequences. According to the present geological interpretations, these formations may be grouped into different tectonic units all showing an eastward polarity typical of the Appeninic area (ELTER and PERTUSATI, 1973).

The formations sampled are as follows:

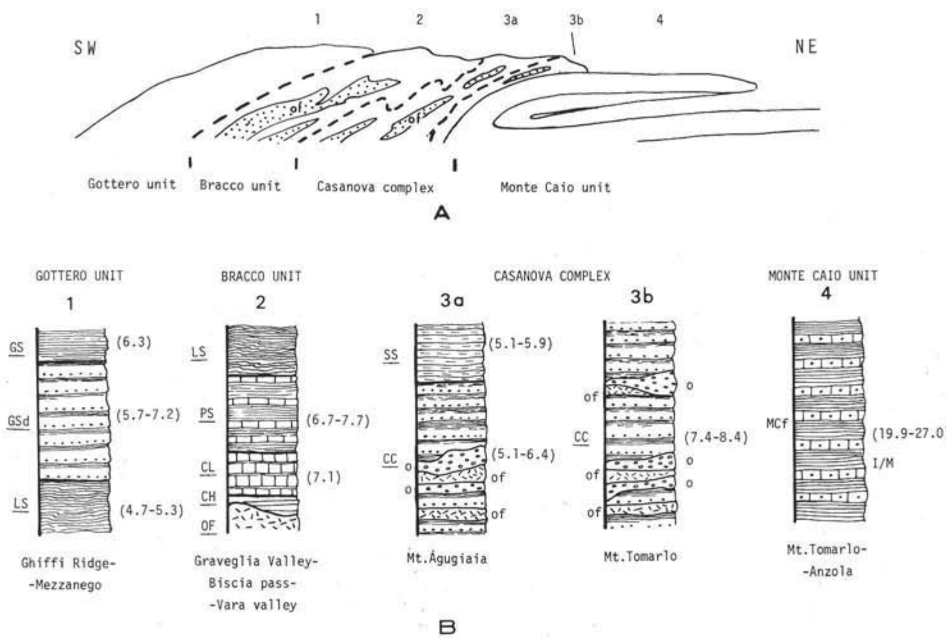

Fig. 2. — A - Simplified sketch of the tectonic relationships among some geological units occurring in the Northern Apennines (modified after ELTER, 1972, and ZANZUCCHI, pers. comm.). — B - Schematic columnar sections (not to scale) of the various tectonic units described in the text. The ranges of illite crystallinity values are reported in brackets. — Symbols: *GS* = Giariette shales; *GSd* = Gottero sandstones; *LS* = Lavagna shales; *PS* = Palombini shales; *CL* = Calpionella limestone; *SS* = Sopralacroce shales; *CC* = Casanova complex; *MCf* = Monte Caio flysch; *OF* = ophiolites; *of* = ophiolites mainly as olistoliths; *o* = olistostromes; *I/M* = mixed-layer illite/montmorillonite.

1. « GOTTERO UNIT »

MT. GHIFFI (GHIFFI RIDGE) - MEZZANEGO AREA

Giariette shales (Paleocene). Marly, shaly and silty rocks; the type area is near Giariette, a village between the Bocco pass and Santa Maria del Taro.

Gottero (Monte Zatta) sandstones (Upper Cretaceous - Paleocene). Graded, thick-bedded grey sandstones interbedded with dark shaly and marly rocks.

Lavagna shales (Upper Cretaceous). Slates, shales, laminated siltstones and small amounts of limestones essentially constitute the formation.

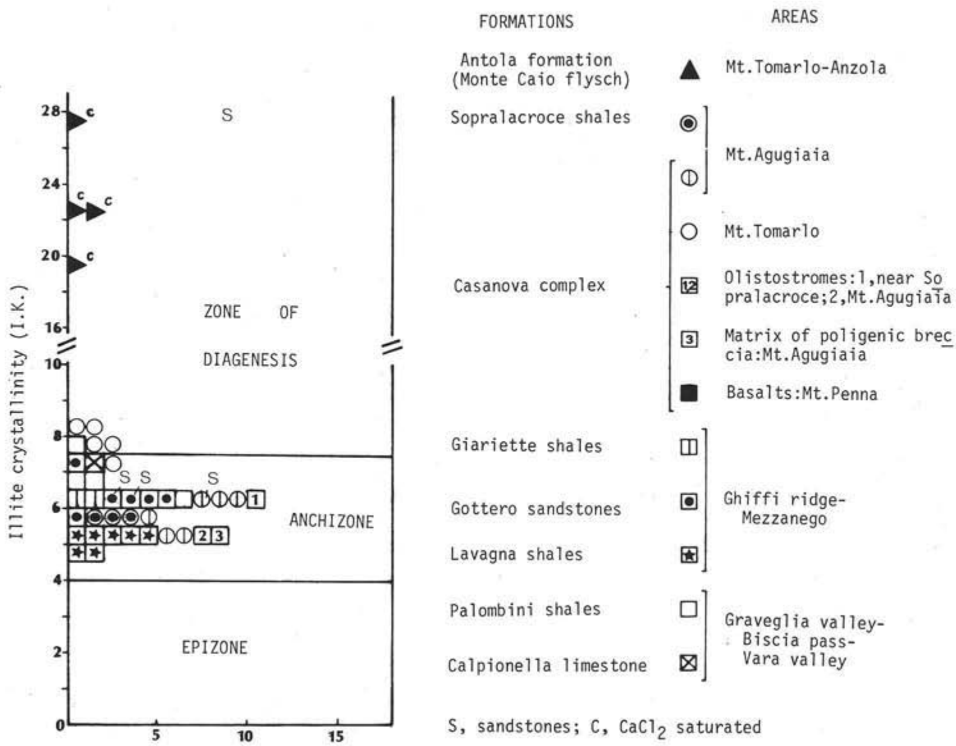

Fig. 3. — Histogram of illite crystallinity (I.K.) values (after KUBLER, 1968) for the different investigated formations. Two main groups can be defined: 1 - the Monte Caio flysch, which belongs to the diagenetic zone, 2 - all other formations which are typical of low-grade metamorphism environment. The lowest average value of I.K. is found in the Lavagna shales.

2. « BRACCO UNIT »

GRAVEGLIA VALLEY - BISCIA PASS - UPPER VARA VALLEY AREA

Lavagna shales (see above).

Palombini shales (Neocomian - Cenomanian?). The formation consists of alternating layers of very-fine grained limestones (« palombini ») with interbedded shaly sediments; the frequency of limestones decreases upwards.

Calpionella limestone (Barremian - Valanginian). Grey and/or white Radiolarian bearing limestone with concoidal fracture; the calcareous beds are separated by marly layers.

Cherts (Malm?). In thin beds generally red, more rarely greenish; at the transition with the Calpionella limestone, interlayerings of limestone and chert can be found.

Ophiolite rocks. Serpentinized ultramafics, gabbros and ocean-floor basalts.

3. « CASANOVA COMPLEX »

In the Monte Agugiaia area this complex includes the Sopralacroce shales formation.

3*a*. MONTE AGUGIAIA - SOPRALACROCE AREA

Sopralacroce shales (Paleocene). This formation is very similar to that of the Lavagna shales; it includes mainly shaly, silty and marly rocks.

Casanova complex (Upper Cretaceous). It consists of laminated siltstones and shales, graded sandstones (Dragonale sandstones), sometimes with interbedded limestones, breccias and conglomerates, olistostromes and olistoliths including slabs of basaltic and ultramafic rocks. In the Monte Agugiaia area grey sandstones interbedded with shaly beds are abundant.

3*b*. MONTE TOMARLO - ANZOLA - MONTE PENNA AREA

Casanova complex (Upper Cretaceous). The lithology is reported above. In the Monte Tomarlo area the sandstones are abundant and clearly visible.

4. « MONTE CAIO UNIT »

Antola formation (*Monte Caio flysch*: ZANZUCCHI, 1963) (Upper Cretaceous). Calcareous-sandy turbidites with interbedded shales; the formation belongs to the Helminthoid flysch sequence.

A schematic and very semplified sketch of the tectonic relations among the different units is reported in Fig. 2.

From diagenesis to metamorphism

The transformations undergone by the sheet silicates in claystones and marly rocks can indicate the degree of diagenesis or low-grade metamorphism which these rocks heve undergone (e.g.: DUNOYER et alii, 1976; KUBLER, 1967, 1968; FREY, 1970; ZEN and THOMPSON, 1974; FOSCOLOS et alii, 1976). In the diagenetic zone typical clay minerals include smectites, kaolinite, irregular mixed-layers minerals and 1Md illite; in the anchizone 1Md and 2M illite and chlorites are predominant over pyrophyllite, mixed-layer paragonite/phengite (FREY, 1969) and paragonite.

METHODS

About fifty samples of the previously mentioned formations have been studied by X-ray methods. From each sample the whole rock powder and the fraction $< 2\ \mu$ (air-dried, glycolated or heat treated where necessary) were analyzed with X-ray diffractometer. The relative abundance of the sheet silicates was determined semi-quantitatively from the intensity ratios of some basal reflections of the clay fraction. A Guinier camera was used to determine the d(060) values of illite and chlorite while the chlorite basal spacings were determined by X-ray diffractometry. In both cases quartz was used as the internal standard. The illite crystallinity has been determined as width at half-height of the 10 Å peak according to KUBLER (1967). The intensity ratio between the peaks at $d = 2.80$ and $d = 2.58$ Å was used to obtain relative amounts of the 2M and 1Md illite polymorphs (MAXWELL and HOWER, 1967). The composition of the chlorites was estimated from the basal spacings and d(060) values using the regression equations given by WETZEL (1973).

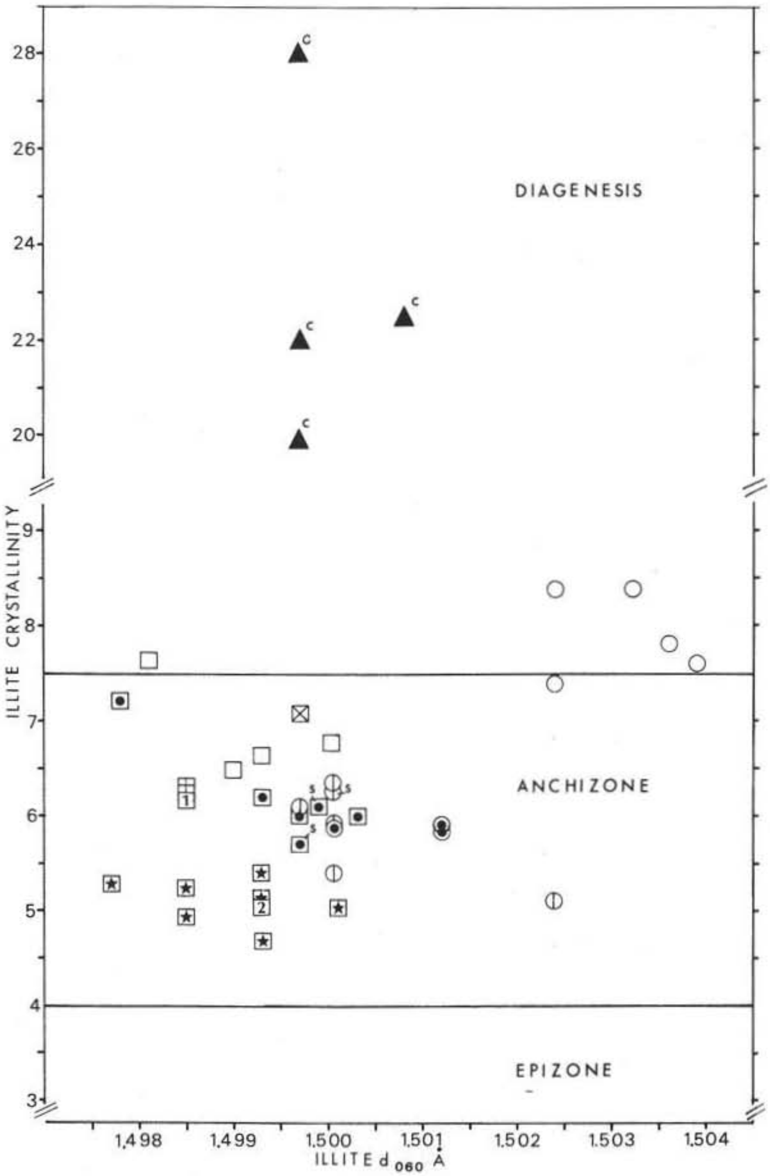

Fig. 4. — Illite crystallinity vs illite d(060) values. The samples from the Monte Caio flysch and from the Casanova complex (Mt. Tomarlo area) define two well separate fields. Symbols as in Fig. 3.

RESULTS

The sample locations are shown in Fig. 1 and the results are presented in Table 1 and in Figs. 1-8.

TABLE 1

Mineralogical data on clay minerals from some unmetamorphosed and anchimetamorphosed formations occurring in the northern Apennines

FORMATION AND SAMPLE NUMBER	CLAY MINERALS Relative distribution in the portion < 2 μ: I%	Pa/Mu%	Chl%	CRYSTALLINITY OF ILLITE Index after Kubler: I.K.	
1-Giariette shales					Chiffi ridge-Mezzanego
Z001	65	10	25	6.3	
Z002	65	10	25	6.3	
1-Gottero sandstones					
Z003-A(sandstone)	55	5	40	6.1	
Z003-B(sandstone)	90	?	10	6.0	
Z004	80	10	10	6.0	
Z005	80	?	20	6.2	
Z006	80	?	20	5.7	
Z007	90	?	10	7.2	
1-Lavagna shales					
Z009	75	5	20	4.7	
Z010	80	5	15	5.1	
Z012	80	10	10	5.3	
Z013	60	10	30	5.2	
Z014	70	5	25	4.9	
Z015	65	10	25	5.4	
Z027	80	10	10	5.3	
2-Palombini shales					Graveglia valley-Vara valley
Z028	55	10	35	6.5	
Z032	65	?	35	6.7	
Z033	80	?	20	6.8	
Z034	60	?	40	7.7	
2-Calpionella limestone					
Z031	45	10	45	7.1	
3-Sopralacroce shales					Aguglaia
Z018	85	?	15	5.9	
Z019	85	?	15	5.9	
Z026	80	?	20	5.9	
Z025	60	-	50	5.1	
3-Casanova complex					
Z024-A(sandstone)	70	-	30	6.3	
Z023	80	?	20	5.4	
Z022-B	70	?	30	6.1	
Z022-A	70	5	25	6.4	
Z021	70	?	30	5.9	
Z016(matrix of poligenic breccia)	20	-	80	5.3	
Z017(shale from olistostroma)	75	?	25	5.1	
Z020(shale from olistostroma,Sopralacroce)	70	?	30	6.2	
Z036	80	?	20	7.4	Tomarlo
Z037	50	?	50	7.8	
Z038	55	?	45	7.6	
Z039	35	-	65	8.4	
Z040	65	?	35	8.4	
4-Monte Caio flysch[a)]					Tomarlo-Anzola
Z042	85[b]	-	15	22.5[c]	
Z043	100[b]	-	tr	27.0[c]	
Z044	100[b]	-	tr	22.0[c]	
Z045	85[b]	-	15	19.9[c]	

— According to the present geological knowledges, in the studied area the above mentioned formations belong to: 1 - Gottero unit, 2 - Bracco unit, 3 - Casanova complex, 4 - Monte Caio unit.
— I %, Pa/Mu % and Chl % are the estimated percentages of illite, mixed-layer paragonite/muscovite and chlorite.
a, eastward of the Varzi-Levanto line, the Antola formation is called Monte Caio flysch; *b*, includes irregular mixed-layer; *c*, illite crystallinity values were determined on $CaCl_2$ saturated samples.

Samples from diagenetic zone

The four samples analysed from the Monte Caio flysch show illite crystallinities in the range from 19 to 27 and therefore belong to the diagenetic zone (Fig. 3 and 4). The main mineral assemblage consists of illite, mixed-layer illite/montmorillonite, minor amounts of chlorite (Fig. 5), albite, quartz and calcite. The irregular mixed-layer illite/montmorillonite show a broad basal reflection with a maximum at about 11 Å for air-dried samples saturated with $CaCl_2$. On glycolation, this reflection shifts to 11.6-12 Å (Fig. 5), indicating the presence of 20-25 % expandable layers (MACEWAN et alii, 1961). In the only analyzed sample the illite is predominantly a1Md polymorph (Fig. 7).

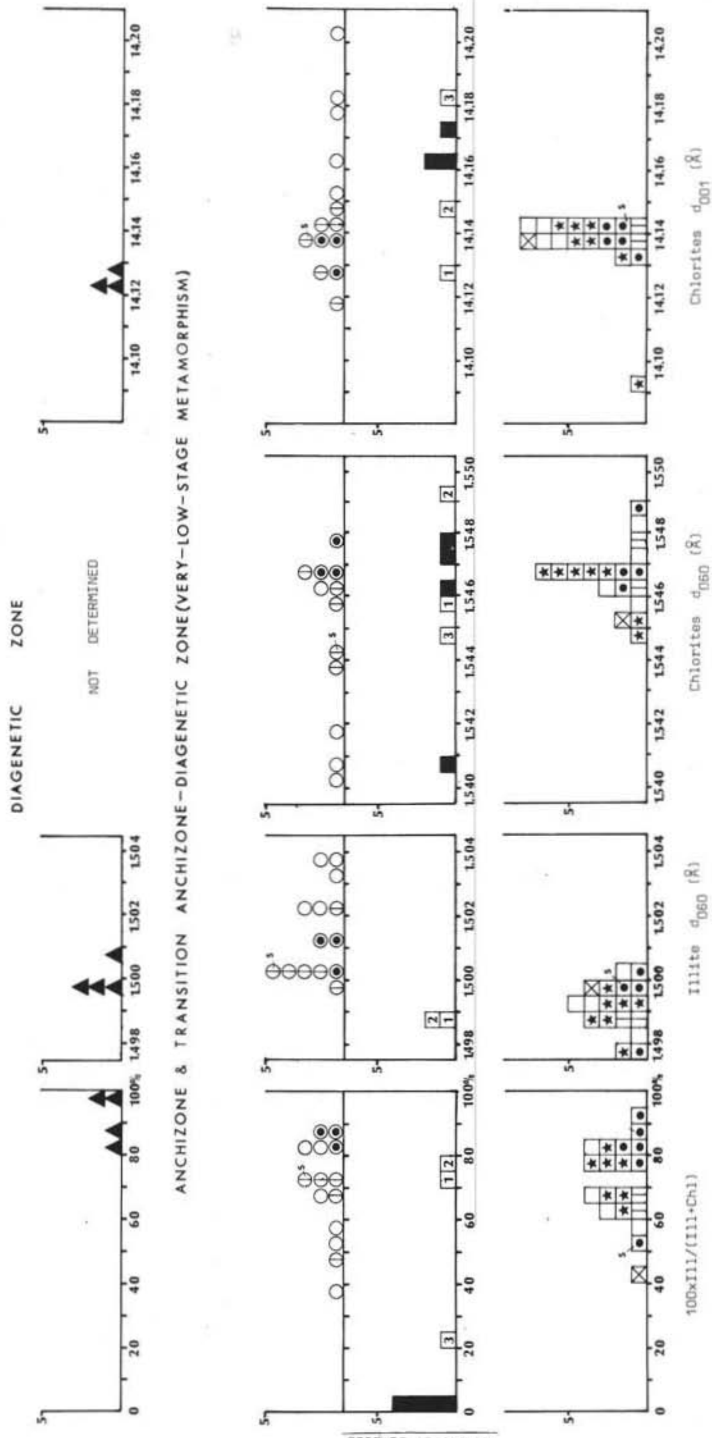

Fig. 5. — Some mineralogical characters of the analysed samples based on X-ray data. Note the wide variations in mineralogy found in the Casanova complex with respect to all the determined parameters. Symbols as in Fig. 3.

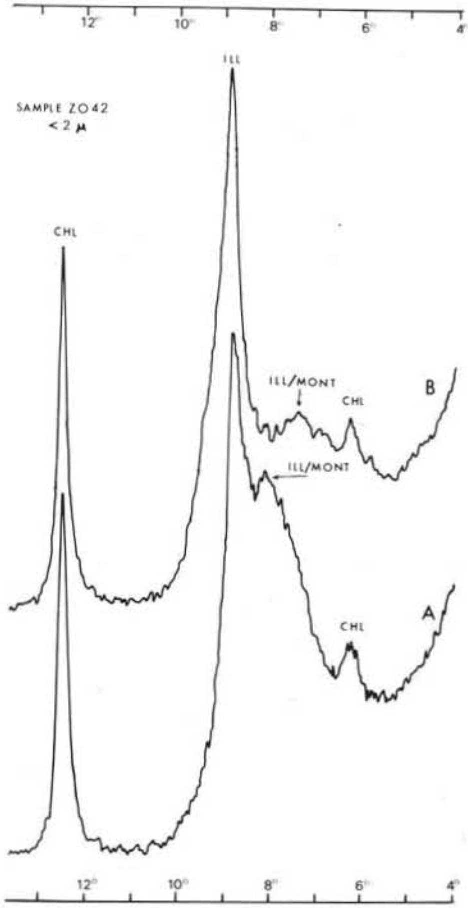

Fig. 6. — Diffractometer traces obtained from a sample of the Monte Caio flysch (A). The position of the illite/montmorillonite peak shifts to lower angle values after treatment with ethylen glycol (B).

Samples from the anchizone (3) *and from the transition diagenesis-anchizone*

With the exception of the Monte Caio flysch samples, all the analysed rocks belong to this group. The main mineralogical assemblage of the shaly portion is constituted by illite, chlorite, quartz and albite; calcite is also present is variable amounts; dolomite has been detected only in a few samples from the Lavagna shales, Palombini shales and Sopralacroce shales.

A large gap in the illite crystallinity separates the Monte Caio flysch from the other investigated formations (Figs. 2, 3 and 4). The lowest values in illite crystallinity index (I.K.) were found in the Lavagna shales of the Gottero unit. The samples from the Casanova complex of Monte Tomarlo, on the other hand, show the highest values and belong to the deepest part of the diagenetic zone. Moreover, these samples are characterized by high illite d(060) values suggesting relatively high iron and/or magnesium contents. In Fig. 4 the Monte Tomarlo samples define an area clearly separated from the rocks of all other formations.

The chlorite composition (as estimated from X-ray studies) shows a relatively narrow Si distribution (5.3-5.9) and a somewhat larger range in the Fe-Mg distribution ($Fe^{2+}/(Fe^{2+} + Mg) = 0.18\text{-}0.51$), Fig. 8. Following HEY's classification these chlorites should be termed ripidolite, pycnochlorite and clinochlore. It is noteworthy that no penninite was found in metabasalts from Monte Penna (BECCALUVA et alii, 1975, 1976) although this chlorite variety is mentioned in many petrographic studies on basaltic rocks of the Northern Apennines. The chlorites from the Casanova complex (with the exception of the Monte Agugiaia area) show the highest Si contents observed.

(3) Note added in proof. Recently PERTUSATI and HORRENBERGER (1975) have reported structural evidences of anchimetamorphism for the Lavagna shales belonging to the Gottero unit (Boll. Soc. Geol. It., 94, 1375-1436).

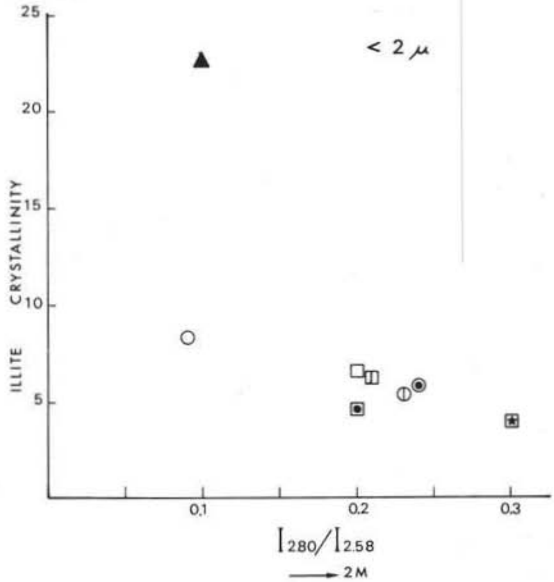

Fig. 7. — Illite crystallinity vs intensity ratio of the peaks at 2.80 and 2.58 Å areally computed (see MAXWELL and HOWER, 1967); the ratio values are directly proportional to 2M illite content. In the plot, the 2M polymorph content ranges roughly from 30 to 100 % as the illite crystallinity increases (i.e. the numerical values of I.K. decrease). Symbols as in Fig. 3.

Summary and conclusions

Most of the sedimentary formations studied from the Northern Apennines constituting the Gottero unit, the Bracco unit and the Casanova complex belong to the low-grade metamorphism (sub-greenschist).

Illite crystallinity data and the predominance of illite and chlorite suggest the samples from the Giariette shales, the Gottero sandstones, the Lavagna shales, the Palombini shales, the Calpionella limestone and the Sopralacroce shales of the studied area all belong to the anchimetamorphic zone, while the samples from the Casanova complex belong both to the anchizone (Mt. Agugiaia) and to the deepest part of the diagenetic zone (Mt. Tomarlo area). The Monte Caio flysch (the equivalent of the Antola formation in the east), on the other hand, is unmetamorphosed.

In the Monte Tomarlo-Anzola area, the Monte Caio flysch and the Casanova complex are in tectonic contact and have distinctly different values in illite crystallinity. This suggests that the Monte Caio flysch as well as the Monte Antola formation (see SCHAMEL, 1974) had a somewhat different geological histories in comparison to the other investigated formations.

In the field the Casanova complex is chaotic and lithologically inhomogeneous

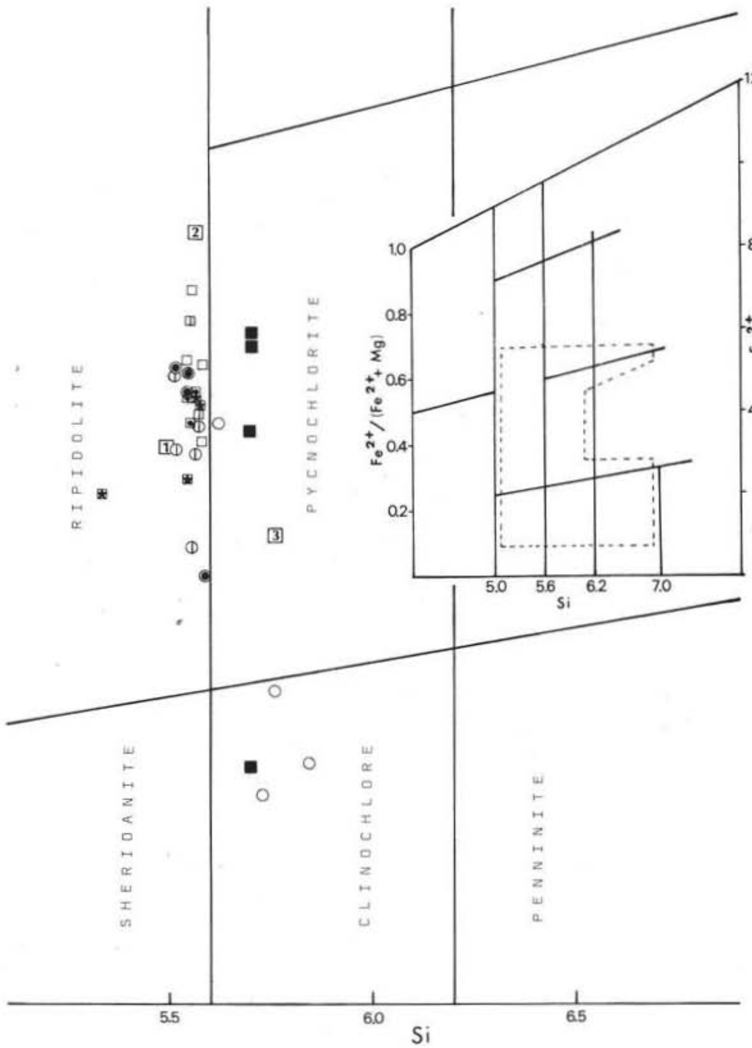

Fig. 8. — Chlorite classification scheme after Hey (1954) (modified considering only the divalent iron) with position of samples from the studied formations. The Fe^{2+}, Mg and Si values were determined using the regression equations proposed by Wetzel (1973). The scattering of magnesium and iron is very wide; moreover, the chlorites from the Monte Penna metabasalts and from the Casanova complex of the Monte Tomarlo area show the highest silica contents. Symbols as in Fig. 3.

characterized by olistostromes and olistoliths of basaltic and ultramafic composition. The pelitic rocks from this formation, sampled in the Mt. Agugiaia and Mt. Tomarlo areas, show some differences in illite and chlorite composition as well as in illite crystallinity.

Comparisons with other areas (e.g.: Muffler and White, 1969; Zen and Thompson, 1974) suggest that the Monte Caio flysch and the Monte Antola formation (east and west of the Varzi-Levanto line rispectively) reached temperatures in the range of 100-200° C, while the other formations experienced temperatures of about 200-300° C at some time of their geological history.

Such metamorphic imprint, which agrees to the prehnite-pumpellyite facies of the metabasalts, could be referred to orogenic metamorphism; K/Ar age dating already in progress on the illites of the Lavagna shales and on the metabasalts from the Casanova complex, would be very useful to connect this metamorphism to the tectonic events of the Northern Apennines.

Obviously further investigations are needed to get the geological and tectonic meaning of the mineralogical characters reported above; in any case the present results should be taken into account for future interpretations of the geological history of the Northern Apennines.

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