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THE MIDDLE-UPPER TRIASSIC OF THE SAN DONATO UNIT *AUCT.* (NORTHERN CALABRIA): STRATIGRAPHY, PALEOGEOGRAPHY AND TECTONIC IMPLICATIONS

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Key-words: Middle Triassic, Upper Triassic, Southern Apennines, San Donato Unit, Calabria, Paleogeography, Carbonate Platform, Evaporites.

Riassunto. Vengono presentati dati stratigrafici e sedimentologici sulle successioni carbonatiche affioranti nel massiccio del Cozzo del Pellegrino (Cosenza), normalmente ascritte all'Unità metamorfica di San Donato.

Le successioni studiate hanno alla base delle filladi con intercalazioni carbonatiche contenenti alghe dell'Anisico e del Ladinico inferiore. Alle filladi segue (ed in parte ne è eteropica) la formazione denominata informalmente dei *calcari*, costituita da successioni di marmi calcarei neri (membro di Piano del Minatore), frequentemente marnosi, nodulari e bioturbati, con una fauna scarsa e banale rappresentata da ostracodi, gasteropodi e bivalvi. *Mounds* ad alghe, porostromata e crinoidi sono localmente intercalati in queste facies. Nella parte superiore della formazione queste facies fanno transizione lateralmente ad un complesso di scogliera (membro di Monte Caramolo) di età Ladino-Carnica, costituito da *boundstone* a spugne ed incrostanti e brecce di *fore-reef*. Questi litotipi sono interpretati come depostisi su una rampa carbonatica evolvente ad un solco lagunare scarsamente ossigenato e bordato dalle aree biocostruite. Nel Carnico inferiore, al culmine di una tendenza regressiva, depositi silicoclastici-evaporitici si diffondono su tutta l'area ma con spessori decrescenti da ovest verso est. La successiva formazione di Scifarello affiora prevalentemente nelle aree orientali ed è costituita da dolomie tidali localmente associate a tempestiti di piattaforma aperta, seguite da dolomie e calcari dolomitici laminati subtidali, frequentemente marnosi. Faune a bivalvi e foraminiferi consentono di ascrivere al Carnico superiore-Norico la parte alta di questa formazione. Nel Norico inferiore un'intensa attività tettonica è testimoniata da *mass-flows* e filoni sedimentari nelle aree più orientali.

L'evoluzione paleoambientale generale, tra Anisico e Norico inferiore, è quella di una sedimentazione carbonatica in zona di piattaforma degradante ad est verso ambienti a maggiore profondità, individuati dalla tettonica sinsedimentaria Ladinica e Norica, e bordati ad ovest da un'area peri-continentale a sedimentazione silicoclastico-evaporitica, meglio rappresentata nelle successioni dell'Unità di Cetraro.

Infine, le dolomie noriche dell' Unità di Verbicaro, normalmente ritenute in contatto di sovrapposizione tettonica con i carbonati triassici dell'Unità di San Donato, sono state localmente rinvenute in normale successione su questi ultimi ed interpretate pertanto come la loro prosecuzione stratigrafica. Inoltre, da un'analisi critica della letteratura, si evidenzia una carente documentazione sulla finora ipotizzata prosecuzione stratigrafica Giurassico-Miocenica dell'Unità di San Donato *AUCT.* Una completa ridefinizione delle unità tettoniche in tutta l'area appare quindi necessaria per una migliore ricostruzione paleogeografica.

Abstract. In this paper are presented stratigraphic and sedimentological data on the carbonate successions occurring in the Cozzo del Pellegrino massif (Cosenza), generally considered as pertaining to the metamorphic San Donato Unit.

The successions start with thick phyllites and intercalated carbonate lenses containing Anisian-lower Ladinian algae. To the phyllites follows the informally defined *calcari* formation, locally occurring also as its lateral equivalent. The *calcari* formation consists of two members, the first of which (Piano del Minatore Mbr.) consists of black, often marly, limestones, showing nodular and bioturbated textures, with a scarce and banal fauna represented by ostracods, gastropods and bivalves. Algal mounds, with porostromata and crinoids are locally intercalated in these facies. In the upper part of the formation the black limestones pass laterally to a reef complex (Monte Caramolo Mbr.) of Ladino-Carnian age, consisting mainly of boundstones with sponges and biogenic crusts, as well as of fore-reef breccias. These lithotypes have been interpreted as deposited on a carbonate ramp evolving to a restricted, poorly oxygenated lagoonal area, bordered by bioconstructed margins. In the lower Carnian a carbonate-marly horizon, containing traces of evaporites, whose thickness is decreasing toward the east, allows a lithostratigraphic correlation between most of the studied successions. The *calcari* formation is followed by the Scifarello formation, mainly outcropping in the eastern parts of the studied area. It consists generally of tidal dolomites with some tempestites deposited on an shallow open shelf, followed by dolomites and laminated, often marly, dolomitic limestones, deposited in a subtidal, restricted environment. On the basis of foraminifers and bivalves data, the upper part of the Scifarello formation has been ascribed to the upper Carnian-Norian. Moreover, a strong tectonic activity of Lower Norian age is evidenced by the presence of mass-flows and sedimentary dikes in the more easterly areas of the massif. The general paleoenvironmental evolution, in the period spanning between Anisian and Early Norian, can be envisaged firstly in a carbonate sedimentation on a wide shelf, grading toward the east to deeper, possibly basinal areas, whose location was controlled by the Ladinian and/or Norian synsedimentary tectonics. This shelf was bordered on the west by a peri-continental area, with silico-clastic to evaporitic deposits, better represented in the Cetraro area.

Finally, the Norian dolomites pertaining to the Verbicaro Unit, usually considered as have been thrusted onto the Triassic carbonates of the San Donato Unit, have been often observed to occur in normal stratigraphical superposition over the latter. Therefore, also considering the ambiguous evidence presented in the literature

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on the Jurassic-Miocenic evolution of the San Donato Unit *AUCT.*, we interpret the Norian Verbicaro dolomites as being the most natural evolution of the Anisian-Lower Norian San Donato lithotypes. It follows that for a really valid paleogeographic reconstruction a complete redefinition of the tectonic units in the whole area is needed.

Introduction.

The southern Apenninic chain is a fold and thrust belt consisting of sedimentary successions spanning in age, with few exceptions, from Norian to Late Miocene. Older, Lower and Middle Triassic rocks are known only in the basinal successions pertaining to the Lagonegro Units, because the carbonate platform ones have been detached at the Carnian-Norian level. It is generally assumed that this was due to the presence of Carnian evaporite beds, mainly known in the subsurface (Burano Anhydrite Formation).

In northern Calabria, however, the presence of important outcrops of Middle-Upper Triassic age below the Norian *Dolomia Principale* was suggested since the end of last century (Cortese, 1895) and later paleontologically documented by Bousquet & Dubois (1967). These consist of metamorphosed siliciclastics and carbonates (part of the San Donato Unit *AUCT.*), occurring in a wide, continuous area oriented NE-SW between the Pollino massif and the Tyrrhenian sea (Fig. 1). In this paper we will deal with the carbonates outcropping from the Timpone Scifarello on the NE to La Mula Mountain on the SW. We will refer to this mountainous area, representing the southern part of the Pollino National Park, as the Cozzo del Pellegrino massif.

These successions have been the subject, particularly over the last 30 years, of many different tectonic and paleogeographic interpretations; most of the successions, though, have never been described in detail. The aim of this paper is to provide this description, at least in what is concerning the carbonates present in the San Donato *AUCT.* meta-sedimentary successions. Our stratigraphic and paleoenvironmental reconstructions will be necessarily quite rough, due to the widespread recrystallization and the very poorly preserved fossil content. However, these data can be appreciated as an original contribution to the paleogeographic reconstruction of the Middle-Upper Triassic of the shallow Tethys realm. As a necessary basis to the exposition of our experimental data, we also present here a most needed extensive critical evaluation of the previous literature concerning the San Donato Unit *AUCT.* in order to show the contradictions introduced by the past literature and propose a possible orientation for future researches.

Geological setting.

Northern Calabria is a geologically complex region where many different tectonic units coexist (Fig. 1). In fact, in this area two major orogens are present: the Apenninic chain and the Calabria-Peloritani arc. The former consists of a discrete pile containing several nappes of Meso-Cenozoic sedimentary successions deposited on the African continental margin and folded and thrusted during Miocene and Pliocene toward the Apulian foreland. The Calabria-Peloritani arc, instead, has a contrasting Alpidic character which was recognised already by Lugeon & Argand (1906). It fact, this belt consists of crystalline and metamorphic Austroalpine- and Pennine-type nappes piled up during Paleogene, Europe verging, Alpine tectonics (Haccard et al., 1972; Amodio Morelli et al., 1976). The latter orogenic pile acted as the higher, most internal nappe during the Apenninic tectonics.

According to the "Structural Model of Italy" (Bigi et al., 1991), in the Apenninic nappes of northern Calabria the following tectonic units are recognised (Fig. 1):

- San Donato Unit;
- Alburno-Cervati Unit;
- Verbicaro Unit.

The Verbicaro Unit tectonically rests over both the San Donato Unit and the Alburno-Cervati Unit; the latter two are separated by a normal fault (Barbieri et al., 1984).

The Alburno-Cervati and Verbicaro Units consist of Triassic to Miocene sediments formed respectively in

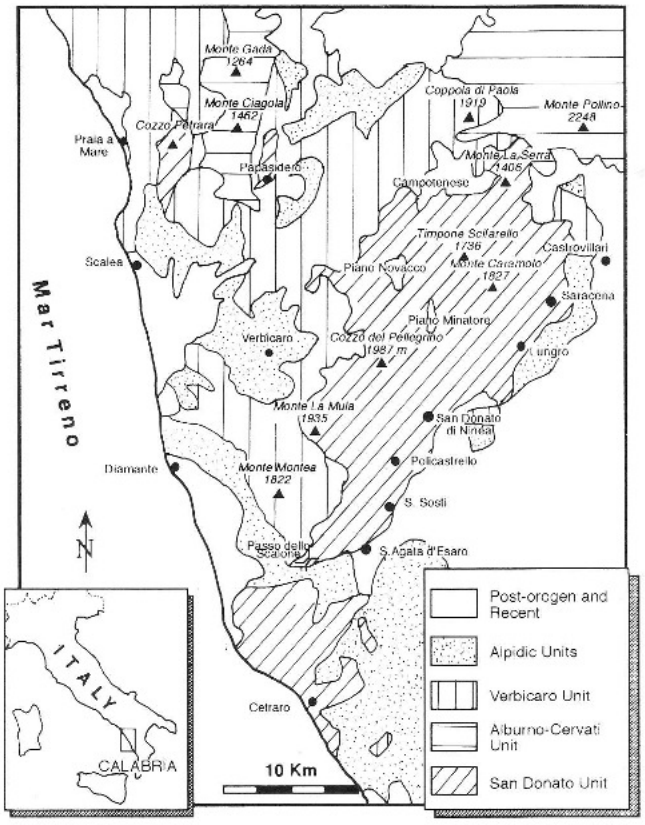


Fig. 1 - Structural framework of northern Calabria and localities cited in the text (after Bigi et al., 1991, modified).

inner-carbonate platform and margin to slope environments (Bousquet & Grandjacquet, 1969; D'Argenio et al., 1973). The San Donato Unit, as defined by Amodio Morelli et al. (1976), should also consist of Triassic to Miocene siliciclastic and carbonate platform sediments but characterised by a clear metamorphic imprint. In the San Donato Unit are generally comprised (Quitzow, 1935; Bigi et al., 1991) also the phyllites, carbonates and evaporites outcropping north of Cetraro (Cetraro Unit, Dietrich, 1976).

Previous studies.

It is very difficult to give an accurate report of the previous studies concerned with the Triassic terrains of northern Calabria. All along one century of researches, considerable disagreement existed on such basic questions as the age of the main formations and on the definition of the main units. This is certainly due to the absence of clearly defined marker lithologies, the metamorphic recrystallization, the bad preservation of fossils and the inaccessibility of many of the key areas. In the more recent past, too many reconstructions have been proposed based on the reinterpretation of only a limited part of ancient data (those produced in the sixties), without neither modern detailed descriptions nor a deep reconsideration of other, often contradictory, elements produced in older, but often better documented, papers.

To stop this tendency, we think it is necessary to go through the whole literature concerning these successions in order to distinguish what has been actually well documented from what is only hypothetical or even fancy. Thus, we will try to summarize in this chapter quite extensively the main data and interpretations contained in the existing literature (Fig. 2), indicating in parentheses, when necessary, what exactly each author was talking about with respect to the actual outcrops and to the stratigraphic scheme presented in Fig. 3. The latter is based on our previous studies (Boni et al., 1990, 1991, 1994a) and on the data presented in this paper. We will continue to use the informal stratigraphic terms *filladi*, *calcari* and Scifarello formations introduced by Boni et al. (1991) because we believe that there is still a need for more complete stratigraphic and tectonic studies before proposing a formal stratigraphic subdivision.

After the discovery of Triassic in 1879 (by Lovisato, in Bassani, 1896), the first comprehensive and pioneristic work on the geology of Calabria was done by Cortese (1895), who mapped most of the region for the Real Ufficio Geologico of the young Italian Kingdom. He ascribed the *marmi* of the Lungro area (= the carbonate intercalations in the filladi formation) to the *zona più alta del Trias medio che dà quasi passaggio al superiore* (=upper Middle Triassic). This conclusion was based on a purely lithologic correlation with the *marmi inferiori* of the Apuane Alps which, according to present knowledge (Carmignani & Giglia, 1984), correspond to Ladinian marbles of the Massa unit. These marbles were seen to pass stratigraphically to Upper Triassic phyllites (= the *filladi*) and then to the Norian *Hauptdolomit* followed by Rhaetian and Liassic limestones (= *calcari* formation at Cozzo del Pellegrino).

The geological map realized after the extensive geological work of Cortese was partly revised by Di Stefano (1904). This author denied the existence of Middle Triassic strata while ascribing the marbles of Lungro, as well as all the limestones and dolomites overlying the phyllites (=*calcari* formation at Cozzo del Pellegrino and Scifarello formation) to the Upper Triassic.

Quitzow (1935), attributed a Carnian age to the phyllites with carbonatic intercalations and basic dykes of Lungro on the basis of a correlation with similar rocks of the Gargano Peninsula (Di Stefano, 1895). He referred to this formation as "metamorphic Trias" (*filladi* formation in Fig. 3), and mapped as *Hauptdolomit* all the overlying carbonates. However, he believed that the contact between the "metamorphic Trias" and his *Hauptdolomit* was a tectonic one.

The most important contribution to the geology of NW Calabria is due to Grandjacquet, who realized in the early sixties the 1:25.000 geological maps for the whole area. The main results of his work are sinthetized

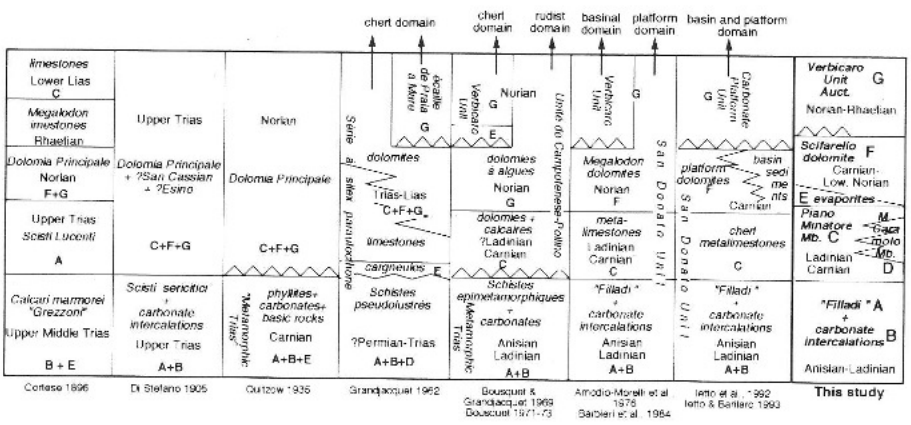


Fig. 2 - Synoptic picture of the stratigraphic framework of northern Calabria Triassic according to the existing literature compared with that assumed in the present paper (last column). Capital letters refer to the stratigraphic units proposed in the present paper (see also Fig. 3). Lines with triangles indicate tectonic contacts. Arrows indicate the Jurassic to Paleogene paleogeographic evolution of the Triassic successions according to each author.

in Grandjacquet & Grandjacquet (1961) and Grandjacquet (1962). In these papers the boundary between the the "metamorphic Trias" and the overlying limestones, with their partly interfingering dolomites (=*calcari* formation at Cozzo del Pellegrino and Scifarello formation), is considered normal and not of tectonic nature. Above these Upper Triassic lithologies, irregular beds of *cargneules* occur, followed in turn by a comprehensive series composed of Norian dolomites, Jurassic limestones with chert nodules, Paleocene breccias with chert clasts and then by Miocene *flysch*. It was also assumed that the presence of the *cargneules* should have caused the partial detachement of the Norian dolomites, together with the overlying sediments, from the Ladinian-Carnian formations. This allowed the distinction of two units: one parautochthonous and the allochthonous *écaille de Praia a Mare*. The successions were considered as representative of the *domaine à silex*, a Jurassic-Cretaceous deep water domain distinct from the *domaine à rudistes*, the latter represented in the Pollino area and in some tectonic windows below the *écaille de Praia a Mare*.

In the papers which followed by Bousquet & Grandjacquet (1969) and Bousquet (1971, 1973), the paleogeographic model of a "chert domain" well distinct, from the Jurassic onward, from a "rudist domain", is maintained. Instead, substantial differences, concerned with the tectonic relationships among the formations, were introduced. The Norian-Miocene formations of the "chert domain" are considered totally allochthonous, and are redefined as "Verbicaro Unit". The pre-Carnian carbonates of the former *autochthonous*, instead, are considered to evolve, in the Campotenese area, to a partly metamorphic succession consisting of:

- 600-800 meters of Norian dolomites;
- 100-300 Jurassic and Cretaceous platform limestones, passing laterally to laminated and recrystallized lithofacies (*calcaires plaquettés*), whose structure is resulting from isoclinal folding and metamorphism;
- few meters of calcarenites, sandstones and marls with macroforaminifers of Aquitanian age.

This lacunous succession was considered representative of a transitional domain lying between the two above mentioned paleogeographic domains. The pre-Carnian phyllites of Lungro area (*filladi* formation) were again considered as a discrete tectonic unit, representing the roots of the Campotenese succession. Finally, the metamorphic Campotenese successions and the non-metamorphic ones of the Pollino area (representative of the "rudist domain") were grouped in the "Campotenese-Pollino Unit" because, after Bousquet (1971), they are laterally heteropic. The transition from the metamorphosed *calcaires plaquettés* to non-metamorphosed limestones could be observed at Mt. La Serra and between Monte Gada and Monte Ciagola (east of Praia a Mare).

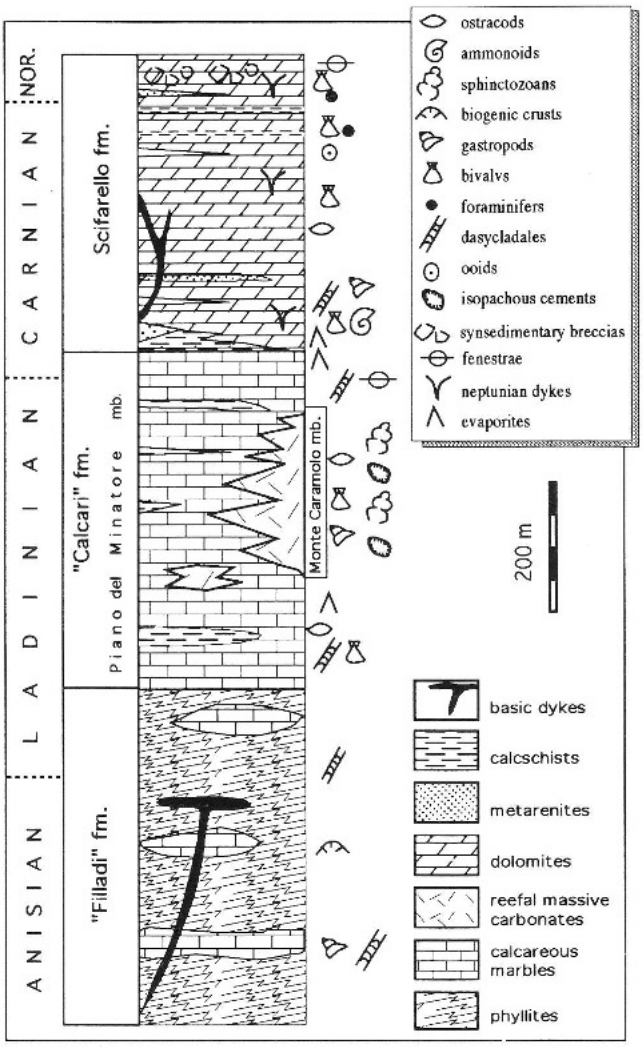


Fig. 3 - Stratigraphy of the San Donato Unit *AUCT.* in the Cozzo del Pellegrino massif.

Similar indications could be deduced also from the legend of the 1:100.000 geological map "Verbicaro" with respect to the outcrops between Monte Ciagola and Monte Gada.

Some structural data, concerning only the Triassic part of the Campotenese Unit, were produced by Pieratini (1975), who found a deformation pattern similar to that present in the Verbicaro Unit (Grandjacquet, 1962).

On the whole, it must be recognized to the French working group the merit of having documented paleontologically for the first time the Middle Triassic Series only hypothesized by Cortese (1895). In fact, they showed the presence of Anisian and Ladinian algae in the carbonates comprised in the "metamorphic Trias" (Bousquet & Dubois, 1967; Bousquet et al., 1978). In the same years the existence of the "metamorphic Trias" was totally denied by Ogniben (1969, 1973), who ascribed the corresponding lithotypes to the Cretaceous Ligurid *flysch* successions, tectonically overlying the Mesozoic platform carbonates of the Cozzo del Pellegrino massif. This assumption has been recently pro-

posed again by Cotecchia et al. (1988), disregarding the additional data produced by Bousquet et al. (1978) well after Ogniben (1973).

The term "San Donato Unit" was introduced by Amodio Morelli et al. (1976) who, even in the absence of new original data, challenged the approach followed by Bousquet (1971) when defining the Pollino-Campotenese Unit as consisting of coexisting metamorphic and non-metamorphic lithologies. They reaffirmed, though, the stratigraphic continuity between the phyllites of Lungro and the carbonates of Cozzo del Pellegrino. As a consequence, they distinguished a metamorphic unit (San Donato Unit = "Metamorphic Trias" + Campotenese succession) from a non-metamorphic one (Pollino-Alburno Cervati Unit). Both units should represent areas of persistent shallow water carbonate deposition throughout the Mesozoic and Paleogene (see also Bonardi et al., 1982). However, the reasons of Bousquet for assuming a gradual transition from metamorphic to non metamorphic rocks are not closely discussed before being rejected, neither is provided a map showing the boundary and the actual outcrops of the two newly created units.

In a subsequent paper (Barbieri et al., 1984), co-authored by some of the Amodio Morelli et al. group of authors, a schematic map was produced where the extension of the San Donato Unit was depicted. This should include: the phyllites with marbles intercalations of Lungro, the overlying carbonates of Cozzo del Pellegrino massif and some isolated and scattered recrystallized limestone outcrops (La Serra, Campotenese, Coppola di Paola, Papasidero, Cozzo Petrara). Some of these outcrops broadly correspond to the *"calcaires plaquettés"* outcrops of Bousquet (1971). Others (Papasidero and Cozzo Petrara), show the same metamorphic characters of the *calcaires plaquettés* (see for example Di Stefano, 1904, p. 41; Bousquet, 1971; Sheet 220 Carta Geologica d'Italia), but then it is not clear why the Monte Ciagola outcrops, which are locally metamorphic too (Bousquet, 1971; Sheet 220 Carta Geologica d'Italia) are attributed to the non metamorphic Pollino Unit.

New sedimentologic and paleontological data concerning the Triassic carbonates of Monte Caramolo-Timpone Scifarello (Castrovillari area) are provided by Boni et al. (1990, 1991, 1994a, 1994b). These Authors recognize a Ladinian-Carnian reef complex, documented by a rich fossil assemblage, similar to those of eastern Alps. The reef deposits, bordered by a restricted lagoon, are followed by Carnian dolomites deposited on an open ramp distally steepened by a strong synsedimentary tectonics (Santantonio & Sonnino, 1987; Boni et al., 1991, 1994b).

A stratigraphic reassessement of the San Donato Unit has recently been proposed by Ietto et al. (1992) and Ietto & Barilaro (1993). In the simple structural maps provided in these papers, to the San Donato Unit lithologies pertain the same areas of occurrence depicted in the map of Barbieri et al. (1984), with only minor differences. It is claimed, however, that the whole unit should be not younger than the Carnian, thus desdaining the stratigraphic data of Bousquet (1971). In fact, the latter author (in agreement with Di Stefano, 1904, p. 45 and 50) had clearly mentioned the presence of rudist limestones building the reliefs of Coppola di Paola, as well as of Jurassic organogenic limestones at Monte La Serra (again in agreement with Di Stefano, 1904, p. 46). Both the mentioned areas are included by Ietto et al. (1992) in their fully Triassic San Donato Unit.

In Ietto & Barilaro (1993) it is also proposed that the San Donato depositional domain should have corresponded during Carnian to a deep water environment, transitional to the Lagonegro basin (Scandone, 1967). After these Authors, in fact, the San Donato stratigraphic succession consists of:

a) Anisian phyllites with carbonate intercalations;

b) cherty metalimestones, often transformed in the *"calcaires plaquettés"* facies, considered by the Authors as the most characteristic lithology of the whole unit;

c) platform dolomites, outcropping at La Mula mountain, laterally passing to siliciclastic-cherty metasediments at Cozzo Nisco as well as on "most of the outcrops around Campotenese" to the north-east.

The Authors correlate these intervals respectively with the *"Monte Facito"*, the *"Calcari con selce"* and the *"Scisti Silicei"* formations of the Lagonegro succession (Scandone, 1967).

The siliciclastic and cherty metasediments outcropping at Cozzo Nisco and in the surrounding areas are assumed to be Triassic only because directly overlying the newly defined cherty metalimestones (assumed to be Ladinian in age) and because of the absence of paleontological remains. Again, the paleontological data provided by previous authors granting a Jurassic and/or Cretaceous age to the many limestone outcrops in the Campotenese area, are not further discussed. The same is done for the siliciclastic sediments of Campotenese containing Miocene macroforaminifers fauna quoted by Bousquet (1971) and recently illustrated by Patacca et al. (1992). Finally, the hypothesized correlation between these cherty-siliciclastic sediments and the *Scisti Silicei* formation, the latter of well established Jurassic age (Scandone, 1967), strongly contrasts with the made assumption of a Triassic age for the whole San Donato succession.

Stratigraphy.

As mentioned in the previous section, the stratigraphic studies on these successions have been always

made difficult by the metamorphic recrystallization and deformation, the scarce fossil content and the assumed monotony of the lithologies. There is local evidence, too, of isoclinal folding at different levels in the successions, this fact being a strong obstacle for the evaluation of their exact thicknesses as well as for more detailed stratigraphic and sedimentologic studies. As a consequence, our stratigraphic reconstructions of the San Donato Unit are necessarily made on a broader scale and mainly based on two decisive findings which made the correlation possible in the first place:

1) the rich peri-reefal facies assemblage, occurring in the eastern areas, followed by lagoonal dolomites, which enabled us to document the Ladinian and Carnian stages;

2) the presence of evaporites, either still preserved or vanished, as well as of the relics of their dissolution (*cargneules* or *rauhwacke*), which allowed broad correlations of different successions using a criteria of local "event" stratigraphy.

Up to now, we were not able to perform any stratigraphic reconstruction in the *filladi* formation with their carbonate intercalations, because of the much more frequent and pervasive isoclinal folds which resulted into transposed stratification. However, we believe that, after the stratigraphic setting will be made clear for the carbonate lithologies, a specific study should be undertaken also on the phyllites. For the present study, we rely on the data of Bousquet & Dubois (1967), which attributed to the Anisian the "carbonate intercalation" of Ponte dei Colombi (2 km SW of Lungro) and to the Ladinian the uppermost intercalation in the *filladi* at Piano Pulledro, (3 km east of the Cozzo del Pellegrino peak). In fact, recrystallized remnants of *Diplopora* sp. frequently appear on the weathered surfaces of these carbonates, not only at the mentioned localities but also in other areas where the same stratigraphic levels occur. In this respect, the doubts raised by some Authors on the actual existence of the "metamorphic Trias" (Ogniben, 1973; Cotecchia et al., 1988) are no more acceptable.

Another statement by the older Authors (Bousquet, 1971, p. 26), that we were also able to confirm, is the lateral heteropy between the "Anisian" *filladi* and the limestones in the south-western areas. This fact could justify the anomalous thicknesses of the carbonate lithotypes observed in La Muletta section respect to the thinner Mt. Caramolo-Scifarello sections (Fig. 4).

The general scheme derived from our studies, shown in Fig. 3, is based on a combination of the stratigraphic columns presented in Fig. 4.

Monte Caramolo-Timpone Scifarello area.

The stratigraphy and sedimentology of this easternmost area has been already described by Boni et al., (1991, 1994b). We give here only a brief summary derived from the above mentioned papers.

In the two columns on the right in Fig. 4 is depicted how, on the eastern flank of Monte Caramolo, a Ladino-Carnian peri-reefal facies association of limestones and dolomites evolves to Carnian and Lower Norian peritidal dolomites, characterized by strong synsedimentary tectonics. Between Piano del Minatore and Monte Scifarello, instead, black, ostracod-bearing, calcareous marbles are present, evolving in turn also to Carnian dolomites similar to those of Monte Caramolo. By correlation between the Carnian dolomites of the two successions, the black marbles of Piano del Minatore are considered heteropic of the peri-reefal facies of Monte Caramolo.

The boundstone facies of the reef complex contains sphinctozoans, biogenic crusts, *Tubiphytes* and minor Problematica. The main reef building organisms include: *Colospongia catenulata catenulata* Ott, *Solenolmia manon manon* (Münster), *Uvanella irregularis* Ott etc. Rare corals and isolated concentrations or whole colonies of (?) *Holocoelia toulai* Steinmann (Fig. 5a) are also present. Multigeneration cements are very abundant, as radial-fibrous botryoids followed by isopachous crusts of recrystallized fibrous calcite. This boundstone facies corresponds to deposits in various environments of a well developed reef complex. However, by far the most widespread facies in the easternmost areas is the reef-debris rudstone (Fig. 5b). This facies quite obviously represents the product of resedimentation of reworked buildups in a fore-reef environment.

A *Teutloporella herculea* (Stoppani)-bearing packstone/grainstone facies occurs at the top of the reef facies succession. Laminated *fenestrae*, sheet-cracks and fractures filled with fibrous, isopachous cements are common. This facies has been interpreted as a near back-reef deposit because of its textural characters and due to the presence of the above mentioned alga together with Porostromata fragments.

The uppermost part of the succession consists in this area of white to pinkish limestones, sometimes dolomitized, thickly bedded and characterized by molds of large gastropods and bivalves. These rocks, which have been interpreted (Boni et al., 1994b) as subtidal lagoonal sediments, alternate with laminated, fenestral dolomitic limestones some dm-thick. In these intervals, pisolitic crusts and anhydrite molds have been observed, this indicating periodic subaerial exposures in a partly evaporitic environment.

The whole facies succession at Monte Caramolo records a regressive trend which can be interpreted as related to the progradation of the platform together with its marginal buildups over a preexisting carbonate ramp.

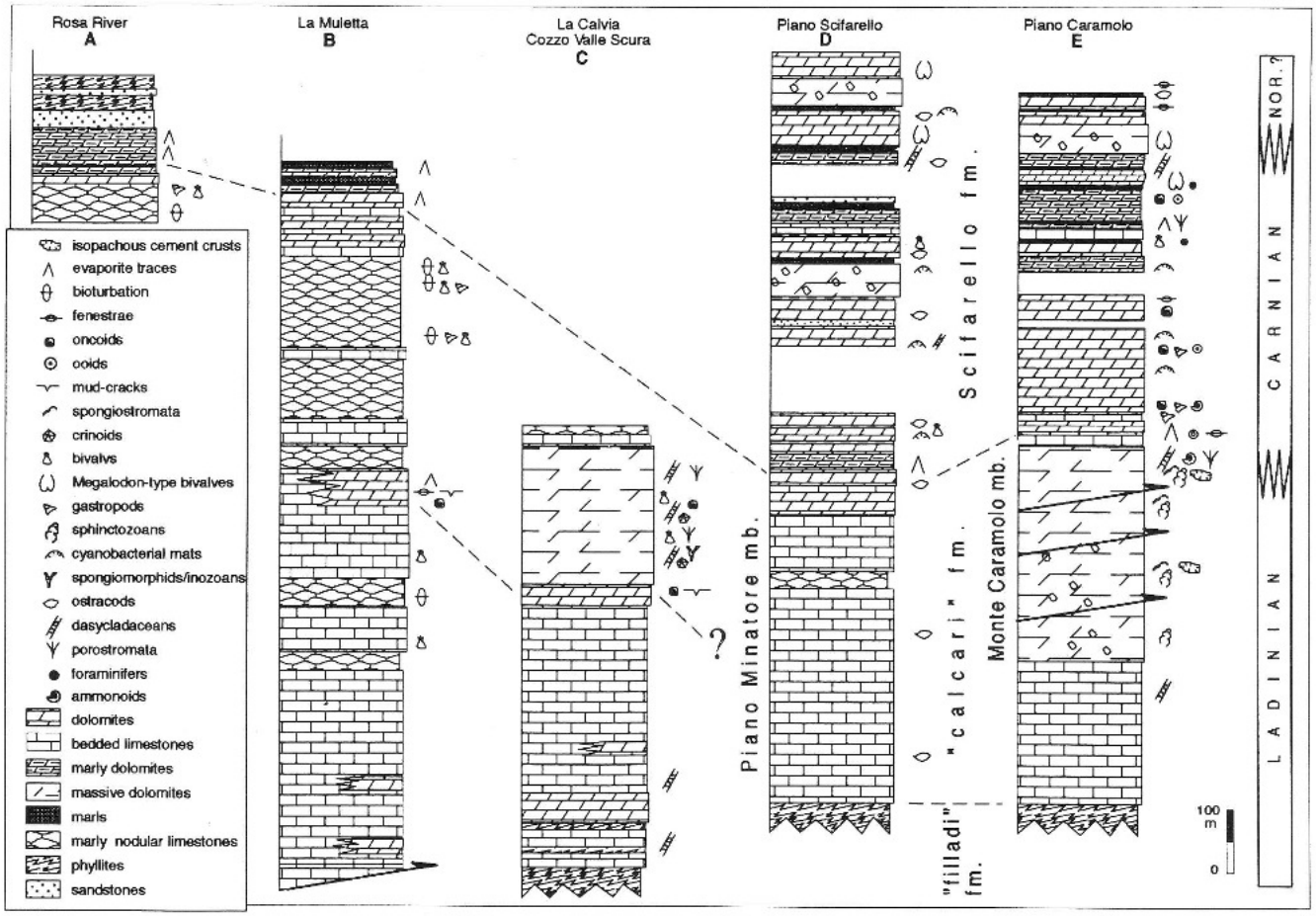


Fig. 4 - Stratigraphic columns of the San Donato Unit *AUCT.* in the studied area. Location for columns A to C can be found in Fig. 9; for columns D and E see Fig. 1 and Boni et al. (1994b).

This succession grades then upwards into the tidal (mainly subtidal) dolomites of the Scifarello formation (Fig. 6). These consist mainly of well-bedded, often brecciated, dark-gray dolomites, and of minor yellowish marly dolomites. Their thickness ranges from 400 to a maximum measured of 600 m. However, the dolomitic successions are generally cut by multiple faults and shear planes. It cannot therefore be excluded that some of the thicknesses of the measured profiles are biased from local repetitions.

A strong variability, both in the facies types and in thickness, has been noticed between the Scifarello

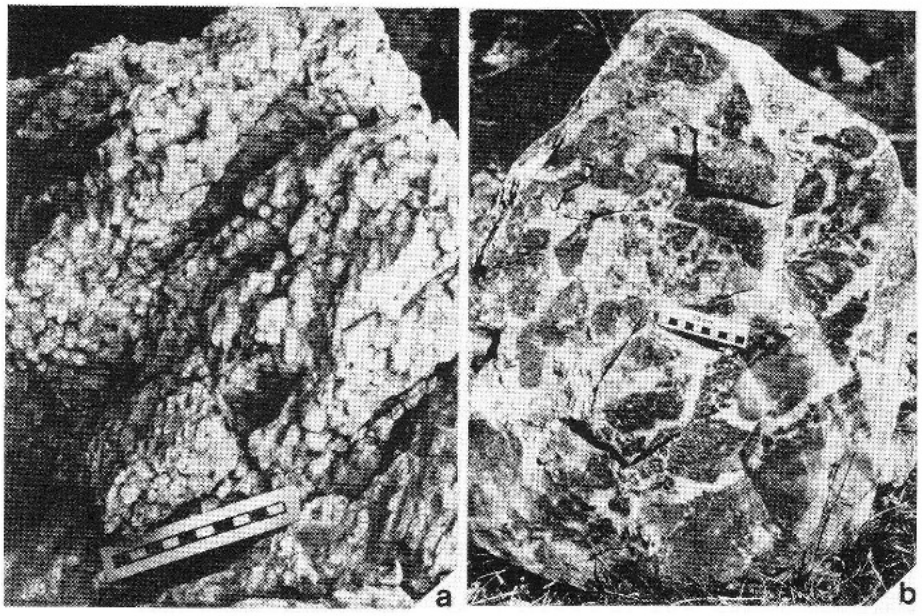


Fig. 5 - Monte Caramolo Member. (a) Reef-front facies: ?*Holocoelia toulai* Steinmann thickets (south of Mt. Caramolo). (b) Fore-reef facies: moderately sorted rudstone with rounded clasts representing reworked boundstone of the central reef area. The space among the clasts is filled mainly by white, isopachous fibrous cements (1 km east of Monte Caramolo).

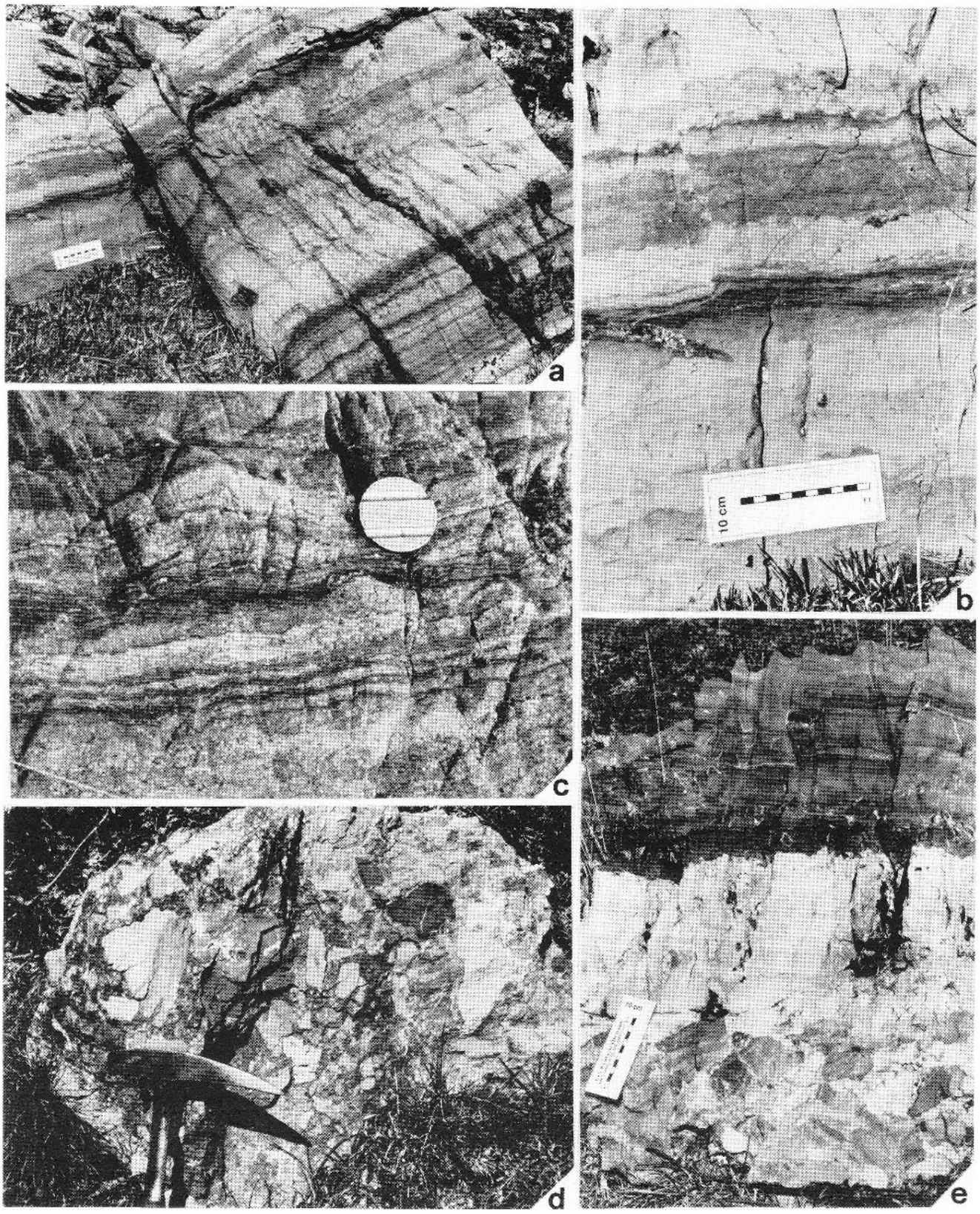


Fig. 6 - Scifarello formation. a) Subtidal, laminated dolomites, alternating with cyanobacterial bindstone and mudstone intervals (Vallone Palermo); b) enlargement of (a), showing the mudstone intervals with local disrupted layers (bottom left); c) cyanobacterial dolomitic bindstone (Piano Caramolo); d) synsedimentary breccia interval in the upper part of the formation (Piano Caramolo); e) alternations of laminated white and dark-gray dolomites with an interval of synsedimentary breccia at the bottom (Piano Scifarello).

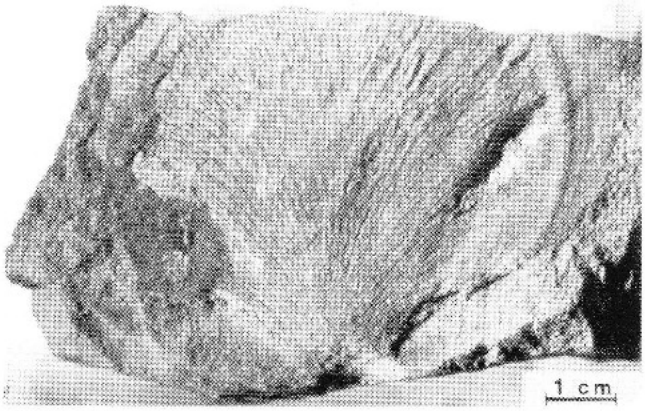


Fig. 7 - Scifarello formation. *Filopecten filosus* Hauer (Piano Scifarello).

formation dolomites at Piano Caramolo and at Piano Scifarello proper (Boni et al., 1991).

At Piano Caramolo the lower part of the succession consists of mainly laminated, fenestral, often oncolitic facies, alternating with numerous *coquina* beds, interpreted as tempestites (Santantonio & Sonnino, 1987). The latter contain abundant gastropod and bivalve shells, often in shelter position, but ammonoids and nautiloids orthocones are also frequent. Some reworked pisolitic crusts also occur. The remaining part of the succession consists mainly of homogeneous or thinly laminated, gray dolomites (Fig. 6a, b, c), often containing ostracods and microbial mats. Locally, bivalve shells and algae occur, as well as some oolitic beds. Many of the thin laminae are graded (microturbidites). In the whole succession, but especially in its middle part, dm- to m-thick beds of laminated marly dolomites are present, sometimes exhibiting a flaser texture. A strong inprint of synsedimentary tectonics, represented by frequent and thick neptunian dykes, filled with dolomitic breccias (Fig. 6d, e), as well as evidence of micro- and macrofaulting cutting the sediments, was already emphasized by Santantonio & Sonnino (1987). The infilling material of the dykes and the matrix of the breccias consists of a darker, fine-grained dolomite. The upper part of the succession is characterized by an alternation of mechanically and organically laminated dolomites.

The succession at Piano Scifarello (Boni et al., 1991) is characterized by a lesser amount of the lower, inter-supratidal facies, by the presence of truly arenaceous beds in the terrigenous intercalations and by local evidence of synsedimentary tectonics.

In the terrigenous levels of both successions a rich association of bivalves, comprising pectinides and pterides (gen. *Arcavicula*) has been recorded. The recognition of the species *Filopecten filosus* Hauer (Fig. 7) (Boni et al., 1991) and *Cornucardia hornigeri* (Broglio Loriga et al., 1994) allows to attribute a Julian-Tuvalian age to these beds, occurring in the middle-upper part of the Scifarello formation. In the overlying dolomitic beds a foraminifera association of Norian age has been determined (Zamparelli et al., in press). These typically occur in association with little (2 to 5 cm) megalodon-type bivalve shells. Thus, the presence of the Norian stage, which had been only "not excluded" in our previous papers, can be definitively confirmed.

Further research in other outcrops in the same area has been focussed on the transition from the *calcari* formation to the dolomites of the Scifarello formation. This transition is particularly well exposed, among ot-

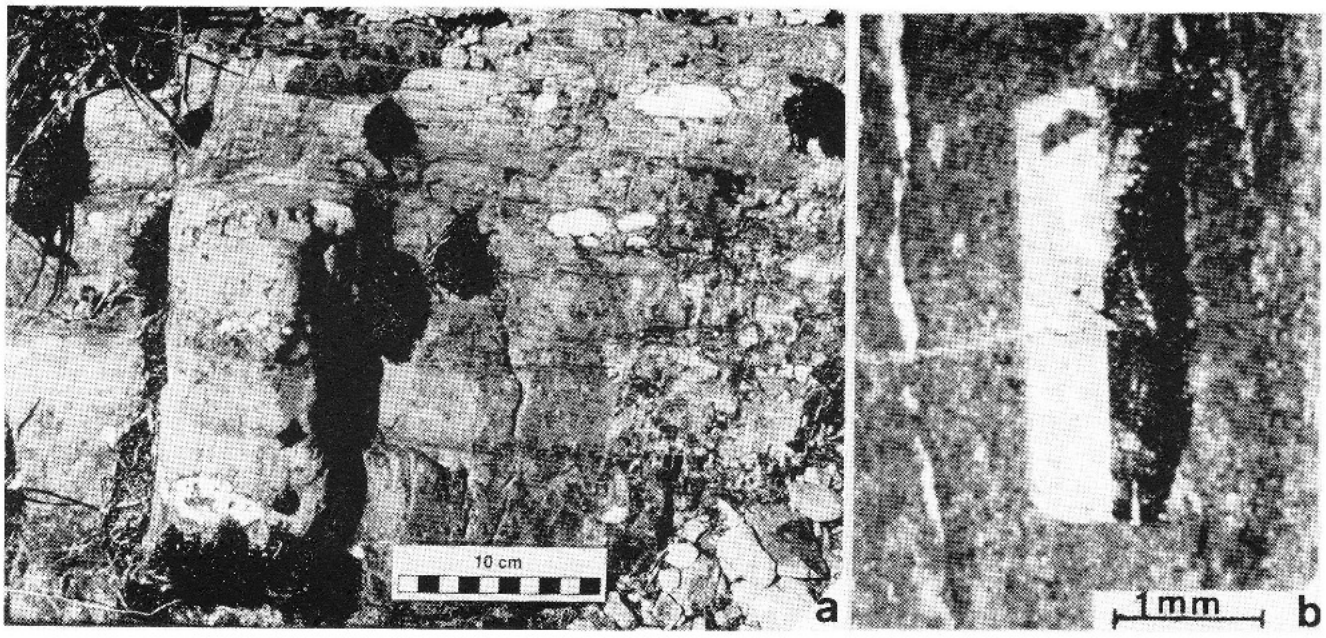


Fig. 8 - Scifarello formation. a) Gray mudstone with calcite nodules interpreted as chicken-wire structures (Piano di Vincenzo); b) anhydrite crystal in a dolomitic mudstone in the upper part of the formation, Crossed Nicols (Piano Caramolo).

her localities, along the unpaved road 300 meters south of Piano di Novacco. Here laminated subtidal grey dolomites alternate with calcareous marbles, representing the uppermost part of the *calcari* formation. After these calcareous marbles, some m-thick beds of yellowish, earthy-looking dolomitic calcschists are present as well as cavernous, yellowish breccias. We have interpreted the latter as *rauhwacke*-lithotypes also because of their association with sucrosic grey dolomites with molds of evaporite crystals. Furthermore, in some of the dolomite beds scattered nodules of calcite, some cm in diameter, have been found (Fig. 8a); we have interpreted them as replacement of evaporitic "chicken wire" anhydrite.

Similar lithologies are present, at exactly the same stratigraphic levels, i.e. at the transition limestone-dolomite, also on the southwestern flank of Timpone della Magara, along the road from Piano del Minatore to Piano di Novacco. Finally, near the radio station on the top of Timpone della Magara, again around the transition between the *calcari* and Scifarello formations, pinkish marbles with evaporite molds (Fig. 8b), similar to the lagoonal facies of Monte Caramolo, occur.

The presence of the described lithologies in the eastern areas, even if not very significant in thickness, is nevertheless very important because it might represent the key for a wide correlation with the more westernly regions where the true evaporitic facies, mentioned in the older literature, are much better represented.

Monte La Muletta area.

The most complete and well exposed succession of the carbonates pertaining to the San Donato Unit in the whole studied area, consisting of some 1100 meters of well bedded limestones and minor dolomites, occurs at Monte La Muletta (Fig. 9). Similar successions build also the reliefs of Monte La Mula, Serra Aulici and Serra Saettare.

This succession has been studied mainly along the south-eastern flank of La Muletta Mt., in a profile comprised from the height of m 1100 and the mountain's top. The exposures are quite bad in the first part of the succession, much better in the upper one. The entire section can be divided in three following intervals:

1) the first 700 meters consist of discrete horizons of well bedded black calcareous marbles alternating with more massive and light-coloured ones. The bedding is enhanced by thin levels of marls (frequently metamorphosed in sericitic phyllites), separating 5 to 10 cm-thick beds of coarsely crystalline limestone. The marly interlayers can become locally thicker and distinctly yellowish or reddish on the weathered surfaces. In this case, a pseudonodular texture develops (Fig. 10a). Where the rocks are less recrystallized, it is possible to define the microfacies as mudstone and/or wackestone.

These lithotypes alternate with grey, more massive marbles in which both strong recrystallization and internal microfolding have obliterated any former sedimentary structure. Some beds are locally dolomitized, even if the phenomenon never shows a great lateral continuity. However, the dolomitized lithotypes escaped the strong metamorphic recrystallization commonly occurring in their calcareous counterparts, therefore a few sedimentary structures have been better preserved in the former. The dolomites are fine grained, can be defined as mudstones-wackestones and are characterized by parallel or wavy lamination. Limited evidence of intertidal settings are witnessed by little mud-cracks. Some chert beds occur occasionally in these intervals.

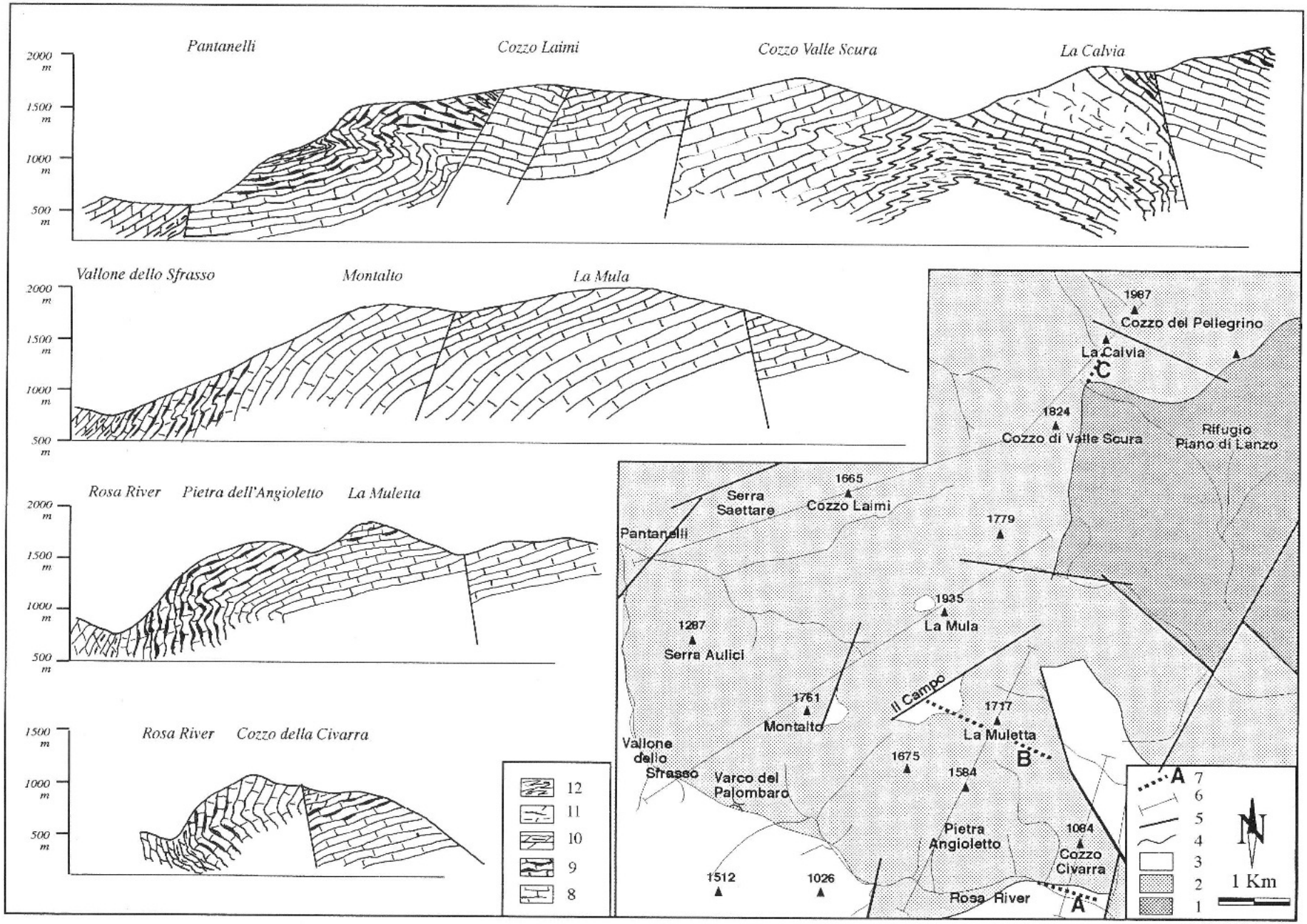
Few badly preserved dasycladacean algae have been observed. Their sizes and gross morphology are apparently those of *Diplopora* sp., which was already recorded by Bousquet at al. (1978) at comparable stratigraphic levels. Further fossils are represented by thin shelled, costated bivalves and turricolate gastropods (Fig. 10b), generally silicified or dolomitized.

2) The middle-upper part of the succession is mainly characterized by a higher percentage of marls as well as by more frequent dolomitized beds. As a consequence, the pseudonodular texture, already mentioned locally in the lowermost interval, is much more common in these black, thinly bedded, marly dolomites. Locally, some meter thick levels of pure dolomitic marls are present. In these more ductile horizons parasitic folds as well as boudinage structures commonly occur. The most spectacular examples of such structures can be observed on the southern flank of Serra Saettare (Fig. 9).

The most characteristic feature of the interval (2), however, is represented by the extensively burrowed textures which are locally dominant (Fig. 10c). They mostly consist of tubes, 1 cm across and some cm long, lying parallel to the bedding. The tubes are particularly evident on the yellowish, weathered bedding planes of the calcareous marls but, at closer examination, they can be observed also in the more carbonatic, black layers. These features were also described at Serra Saettare by Damiani (1970), who defined them as thick *"virgoloni"*(=big commas) without giving any genetic explanation.

The fossil shells, often organized in *coquina* layers, also become more and more abundant in this interval (2). In the uppermost layers heart-shaped bivalves, some

Fig. 9 - Schematic geological map and cross sections of the western part of the Cozzo del Pellegrino - La Mula Mountain area. 1) *Filladi* formation; 2) *Calcari* formation; 3) Scifarello formation; 4) stratigraphic contact; 5) tectonic contact; 6) traces of the geological sections; 7) location of the measured stratigraphic columns of Fig. 4; 8) bedded limestone; 9) marly nodular limestone; 10) dolomite and marly dolomite; 11) massive dolomitic limestone; 12) phyllite.


Pantanelli
Cozzo Laimi
Cozzo Valle Scura
La Calvia
2000 m
1500 m
1000 m
500 m
Vallone dello Sfrasso
Montalto
La Mula
Rosa River
Pietra dell'Angioletto
La Muletta
Rosa River
Cozzo della Civarra
1987
Cozzo del Pellegrino
La Calvia
C
1824
Cozzo di Valle Scura
Rifugio Piano di Lanzo
1665
Serra Saettare
Cozzo Laimi
Pantanelli
1779
1935
La Mula
1287
Serra Aulici
1761
Montalto
Il Campo
1717
La Muletta
B
Vallone dello Sfrasso
Varco del Palombaro
1675
1584
Pietra Angioletto
1064
Cozzo Civarra
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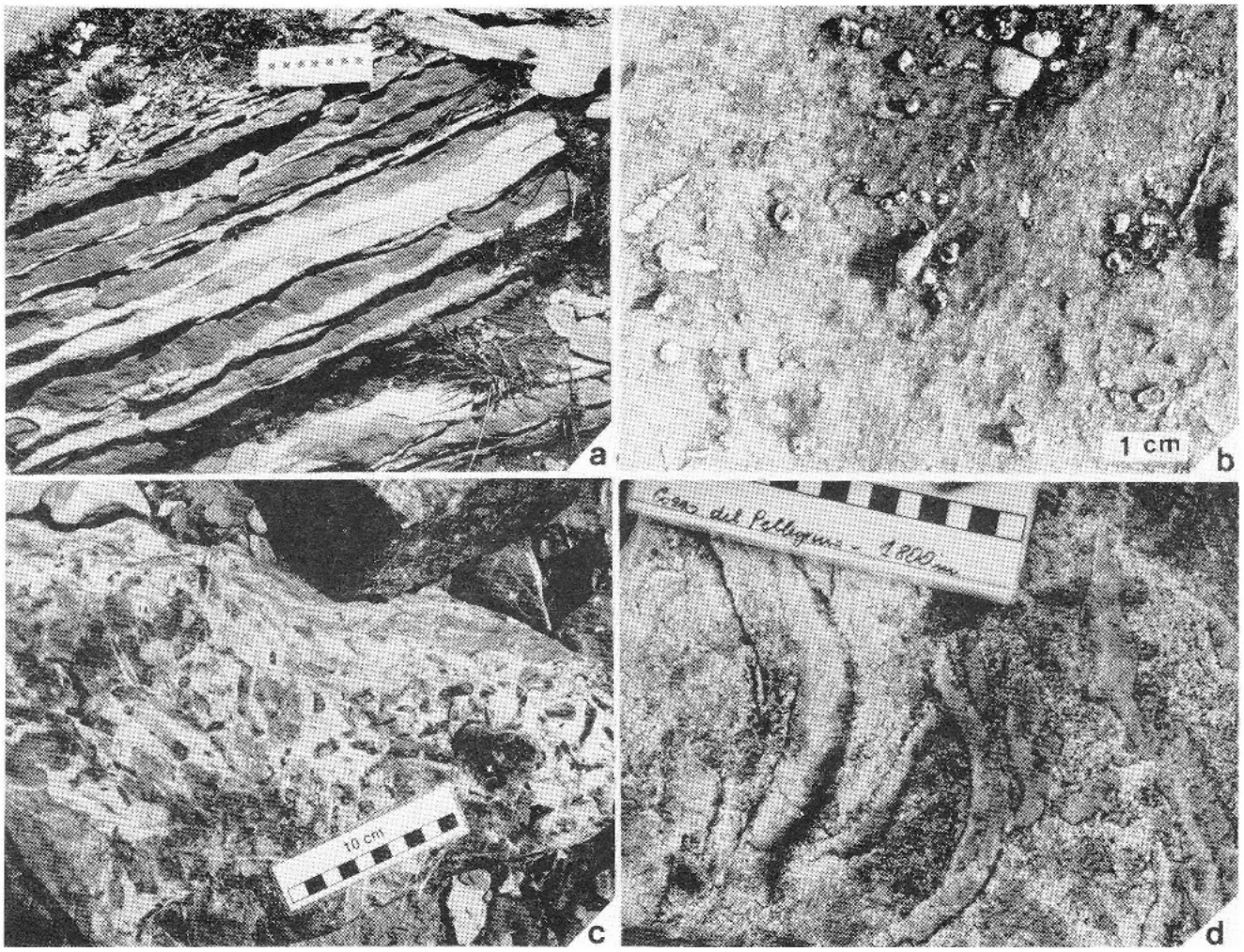

Fig. 10 - *Calcari* formation. a) Black limestone with marly intercalations and flaser structure (La Mula); b) biodetrital accumulation of gastropods and bivalves on a bed surface of the black limestone (La Muletta Mt.); c) burrowed structures in the black limestones (La Mula Mt.); d) problematic organic remnants possibly corresponding to "Spongiomorphyds"-Hydrozoans, in black limestones (Cozzo del Pellegrino).

centimeter large, occur. White, millimeter-sized circular spots, resembling to ostracods shells, are also frequent. In only one sample we found problematic remnants of porostromata or solenoporacean algae, as well as strongly recrystallized, cm-sized, ovoidal organisms which are dubitatively attributed to hydrozoans (Fig. 10d).

The dolomitized beds are more abundant with respect to the lower parts of the succession but they generally show similar facies as in the layers below. One of these horizons, as thick as 20 meters (La Muletta, 1530 meters height), consists in its lower part of white, fine-grained dolomites containing a few, some centimeters large sparry calcite nodules (Fig. 12a). Also, millimeter-sized prismatic, elongated molds are present. Both these findings point to limited amount of vanished evaporites. The upper dolomites are grey or black, fine-grained and generally laminated. The lamination is mechanical in origin with local evidence of graded bedding.

3) The dark laminated dolomites become gradually the dominant lithotype in the uppermost part of the succession. In this part of the section they contain true cyanobacterial mats and are characteristically associated to other facies: recrystallized yellowish marls (calcschists), sucrosic, late diagenetic grey dolomite, black slates, brecciated cavernous dolomitic limestones (*cargneules* or *rauhwacke*) (Fig. 11). These facies can be observed at Il Campo locality (Fig. 9), where this succession is also truncated by a fault.

The dolomitic levels can be better observed in the river Rosa valley, near the San Sosti village, on the reverse flank of the large recumbent fold (Fig. 9) forming the main structure of the whole La Mula-Muletta-Pietra dell'Angioletto group (Lucini, 1959). Entering the river valley from San Sosti, along the unpaved road, the following lithofacies can be observed (from the stratigraphic top to the bottom):

- green and reddish phyllites, black slates and brown metarenites.

- thin, centimetric beds of white dolomite alternating with yellowish marly dolomites. These dolomites

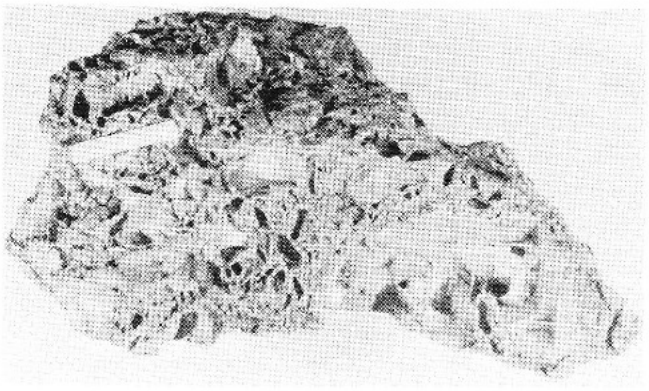

Fig. 11 - Hand specimen of *rauhwacke* or *cargneule* (Rosa River, San Sosti).

are very fine-grained, structureless and contain abundant molds after anhydrite crystals. Recrystallization is almost absent in these lithofacies. However, they could be the equivalent of the calcschists found at Il Campo. This interval is some tens of meters thick and presents a distinct ciclicity, due to regular variations of the carbonate/clay ratio;

- *rauhwacke*;
- black, laminated or nodular dolomitic limestones;

Proceding upstream along the Rosa River Valley, again the same gradual transition from the black, nodular limestones to the evaporitic dolomites, yellowish calcschists and rare black slates is observed. Actually, these lithotypes can be followed northward troughout the Vallone dello Sfrasso to Pantanelli area (Fig. 9); they always mark the boundary with the dolomites of Monte Montea, lying to the west. The latter dolomites consist of algal-rich deposits of Norian age (Di Stefano,1904; Grandjacquet & Grandjacquet, 1961), belonging, according to most recent literature, to the tectonically overlying Verbicaro Unit (Bousquet & Grandjacquet, 1969; Amodio Morelli et al., 1976; Barbieri et al., 1984; Ietto et al., 1992). On the contrary, our observations established that the contact between the dolomites of the San Donato Unit and those of Monte Montea, even if generally tectonized, can be recognized basically as stratigraphic. In their geological maps, both Grandjacquet (1962) and Damiani (1970) considered this boundary as a stratigraphic one.

This conclusion does not derive from detailed biostratigraphic analyses, even though the successions in contact, because of the comparison with similar series in other outcrops, can be grossly dated as Ladinian-Carnian and ?Carnian-Norian respectively. For a stratigraphic continuity mainly speaks the fact that all along the folded contact surface always the same association of lithotypes occurs: laminated marbles (alternating calcareous and dolomitic), evaporitic dolomites (*rauhwacke* and vacuolar sucrosic dolomites), yellowish calcschists and black slates. In the contact area, nowhere a clear unconformity neither a well defined cataclastic or milonitic contact surface has been observed. As additional evidence, the Carnian-Norian dolomites belonging to the Verbicaro Unit, locally (Varco del Palombaro) underly the Ladinian-Carnian marbles, this implying that both successions, being involved in the overturned flank of the La Mula fold, shared a common tectonic behaviour. We think that this evidence, particularly the presence of *rauhwacke* and the "along bedding" deformation, matches better the characteristics of a detachement shear zone. Specific structural researches should be carried out on this point.

Finally, it must be mentioned that several outcrops with the same evaporitic carbonates as those of the Rosa River (Fig. 9), can be followed all along the road from San Sosti to San Donato di Ninea (S.S.105) and especially in the surroundings of Policastrello.

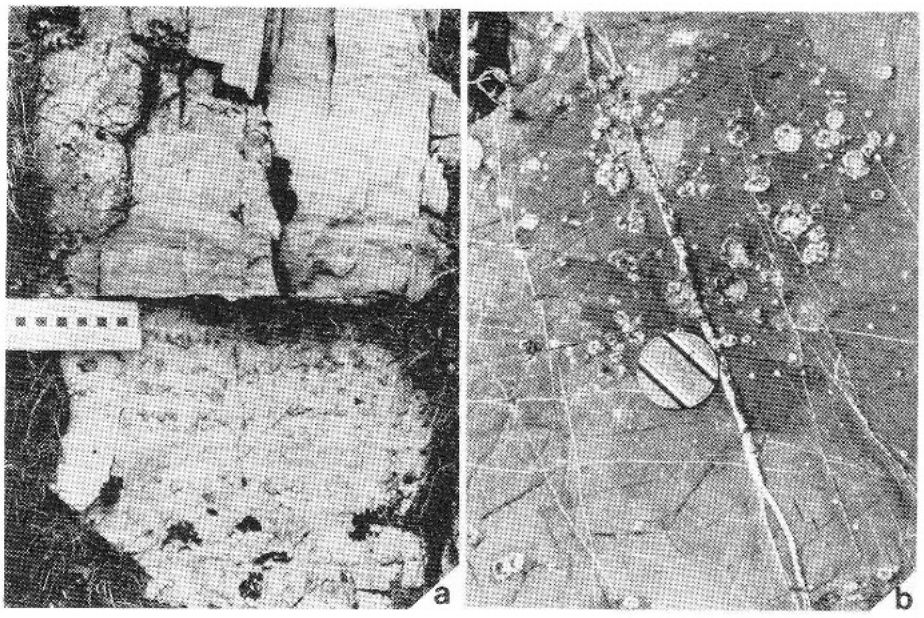

Fig. 12 - a) Chicken-wire structures in a dolomitic interval of the *calcari* formation, at the Muletta Mt.; b) chicken-wire structures, filled with two generations of cements (I dolomite - II calcite) in the lowermost Scifarello dolomites (trail to Piano Scifarello).

Cozzo del Pellegrino succession.

At the Cozzo del Pellegrino Mt., the highest peak (1987 m) of the region, the lower half of the carbonate succession outcrops. Good observations were possible at Cozzo di Valle Scura and La Calvia mountains (Fig. 9).

At the height of about 1550 meters, a gradual transition from phyllites to grey marbles occurs, the latter being comparable to those outcropping at La Muletta. At Cozzo di Valle Scura however, they contain more frequently ghosts of dasycladacean algae (*Diplopora?*) which, due to their stratigraphic position, should correspond to those described by Bousquet et al. (1978) at Piano Pulledro. These algae are observable on the weathered surfaces of the limestones and appear as white, sparry rings 0.5 cm across and with a relatively thick wall. They are characteristically stained by iron oxydes and in thin section it is almost impossible to distinguish them from the recrystallized matrix. In this area there is also a clear evidence of mesoscopic tight to isoclinal folds as well as of pseudonodular, boudinated textures.

After some 350 meters, there is a gradual transition from limestone to dolomite. At Cozzo di Valle Scura the latter lithotype starts with oncolitic facies containing abundant echinoderm plates, echinoids spines and ghosts of dasycladacean algae (Fig. 13c). These dolomites are light grey and white on the weathered surfaces. They are followed by grey to dark grey, laminated dolomites more similar to those described as subtidal deposits in the intercalations of La Muletta mountain.

More interesting facies occur on the highest part of the La Calvia mountain (Fig. 9). Here, at around 1700 meters of altitude, there is a short interval of laminated mudstone with thin mudcracks, followed in turn by a rich mound biofacies up to the top. The same facies can be found also near the western edge of the Cozzo del Pellegrino peak.

The main facies types can be grouped as follows:

- crinoidal-bivalve packstone;
- ?"spongiomorphid"/hydrozoan-crinoidal floatstone;
- dasycladacean-crinoidal packstone;
- porostromata-bivalve boundstone;

The crinoids (Fig. 13b) are present as mm-sized isolated plates or as little fragments of the *columna* consisting of only few plates. They are surrounded by a fine grained, bioclastic matrix.

The bivalves are thin shelled, and sometimes occur as rich accumulations with a distinct orientation, always associated to crinoid plates.

Together with the crinoids, a problematic organism is often found, generally as large fragments. These consist of 5 to 15 dm large, irregularly digitate or branched, bulb-like structures which are easily seen in relief on the weathered surfaces of the carbonates. In thin section, instead, these structures are almost completely recrystallized. Only in few cases the above mentioned reticulate texture can be recognized, this suggesting a possible classification of this organism as "spongiomorphid"/hydrozoan. The taxonomy of the latter group is quite controversial and in the more recent literature both "spongiomorphids" and hydrozoans are actually comprised in the larger *taxon* of demosponges (Reitner, 1991).

A rich and diversified dasycladacean algae assemblage (Fig. 13c) is also present but only in a few cases it is possible to give a specific determination. The presence of *Aciculella* Pia, and more specifically of *Aciculella bacillum* Pia var. *perforata* Bystricky (Fig. 13a) is quite well constrained. Other forms can be possibly ascribed to the genus *Diplopora* and to the group *Oligoporella/Physoporella*. Among the forms with larger sizes, also *Teutloporella* sp. might be dubitatively present.

Porostromata are the main organisms in bafflestones. Quite frequently they are represented by branching thickets, up to 15 centimeters large, belonging to the genus *Cladogirvanella* (more specifically *Cladogirvanella cipitensis* Ott) (Fig. 13d). Others, fan-like forms can be dubitatively attributed to solenoporacean algae (Fig. 13e). Biogenic crusts are quite rare but their presence could be masked by the strong recrystallization of the carbonates. Two small specimens of the sphinctozoan *Celyphia zoldana* Ott, Pisa & Farabegoli (Fig. 13f) have been also found, as well as some baby ammonoids and small, turricolate gastropods.

Referring to the stratigraphic position of the dasycladacean algae, associations containing *Aciculella*, and more specifically *Aciculella bacillum* var. *perforata*, have been mentioned both in the Ladinian of the Carpathians (Bystricky, 1975) and in the Anisian of the Eastern Alps (Senowbari-Daryan et al., 1993; Bucur et al., 1994). Among the other forms, *Cladogirvanella cipitensis* has a generical Ladinian occurrence (Senowbari-Daryan & Flügel, 1993), while the sphinctozoan *Celyphia zoldana*, generally described in the Anisian reefs, has been found also in the Ladinian (Brandner et al., 1991).

S. Agata d'Esaro-Passo dello Scalone area.

In this area we did not perform a detailed mapping but tried to integrate our own punctual observations with significant informations which can be derived from the 1:25000 geological maps of Calabria ("tavolette" San Sosti and Belvedere Marittimo).

In the deep Esaro canyon some 700 meters of well bedded limestones are exposed, whose characteristics are comparable to those of La Mula area. The best outcrops can be easily observed at the end of the canyon, near the S. Agata d'Esaro village, where the whole succession is verticalized by a large scale fold.

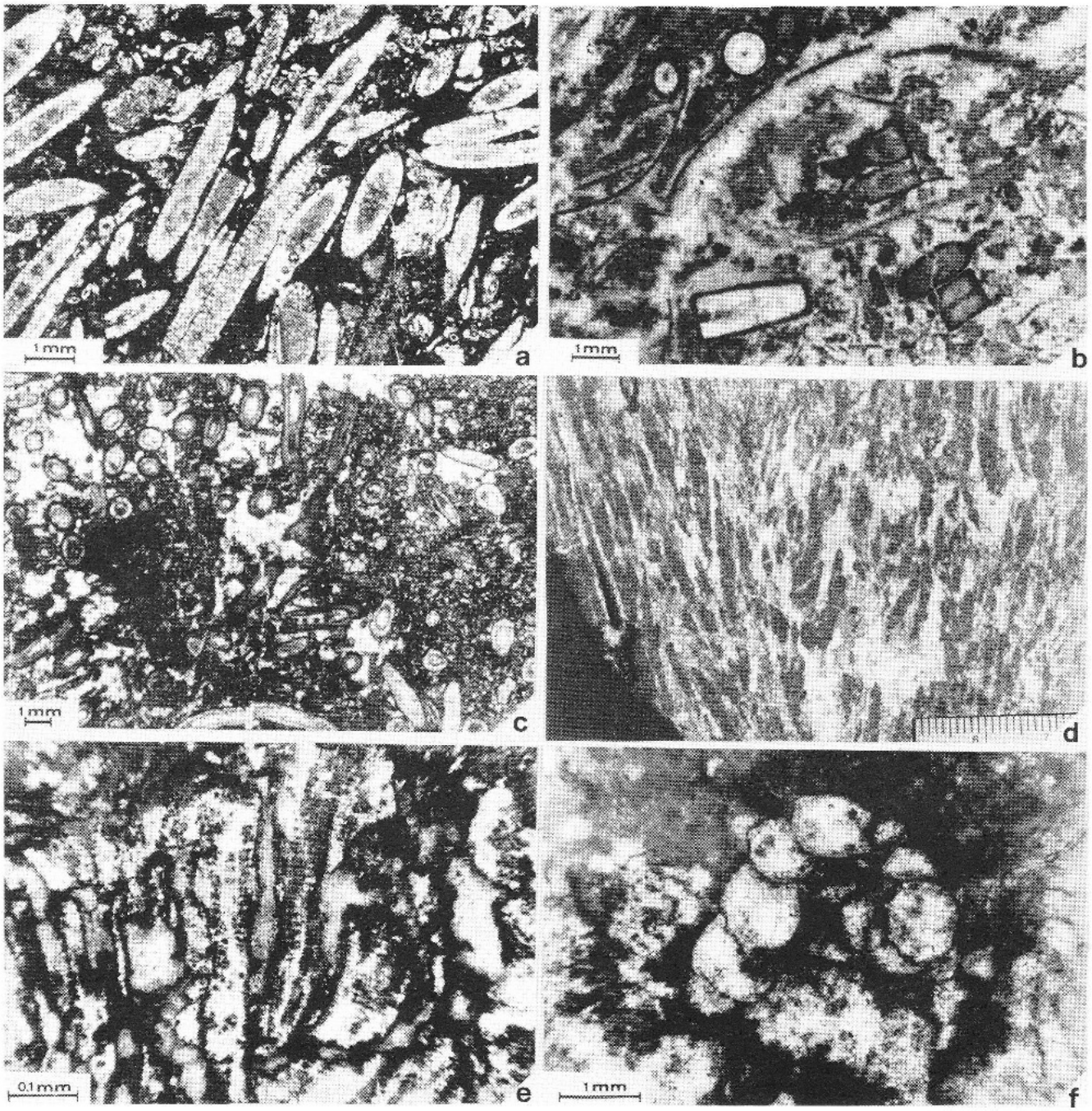

Fig. 13 - *Calcari* formation. Different faunas in the Cozzo del Pellegrino succession. a) *Aciculella* sp. Pia association; among others *Aciculella bacillum* Pia var. *perforata* Bystricky; b) crinoids and bivalve packstone; c) dasycladacean algae association; d) bush-like and multi-branched problematic alga *Cladogirvanella cipitensis* Ott; e) solenoporacean fragment (?*Parachaetetes*); f) *Celyphia zoldana* Ott, Pisa & Farabegoli.

The limestones are then capped by a dolomitic breccia, also outcropping at Passo dello Scalone, which has been interpreted by many Authors as an evaporitic *cargneule* (Cortese, 1895; Grandjacquet, 1962; Ogniben, 1969). The transition carbonates-evaporitic breccias is well evidenced on the geological map and can be observed along the east-west path going through the canyon.

The successions of S.Agata d'Esaro and Passo dello Scalone areas (marbles followed by evaporitic dolomites) can be roughly correlated with those occurring both at La Muletta and at Piano del Minatore, even though at Passo dello Scalone the evaporites have a greater thickness.

This fact indirectly documents the Carnian age of the Passo dello Scalone evaporite lithofacies, as originally suggested by Quitzow (1935).

Paleoenvironmental reconstruction.

The data presented in the previous section, although not exceedingly detailed to define beyond any doubt the stratigraphical and sedimentological setting of

this part of Calabria, can be nevertheless interpreted in a coherent evolutive scenario. We exclude from this reconstruction the Anisian phyllites (=*filladi* formation) because the available data are still insufficient. The interpretation we are going to present here is made on larger scale and more detailed with respect to that we outlined in a previous study (Boni et al., 1994b).

The general trend for the whole Middle-Upper Triassic (?Anisian-Carnian) in northern Calabria should imply the transition from a continental, siliciclastic-evaporitic area in the SW, to a platform margin and slope to the NE throughout a carbonate shelf domain. Several steps can be recognized in this lateral and vertical evolution (Fig. 14).

a) The initial evolutionary stage, which broadly corresponds to the Anisian-Early Ladinian, can be only tentatively characterized. In fact, the basal part of all the studied sections is represented by grey to white marbles and some laminated, subtidal dolomites. The preserved fossils are rare but, significantly, most of them are dasycladacean algae. Among the other fossils there are bivalves and gastropods. Hence, it can be assumed a relatively shallow depositional environment, generically a continental shelf with a limited terrigenous input. With this limited data set it is almost impossible to discriminate between a lagoonal and an open ramp environment. In a previous paper (Boni et al., 1994a), however, we preferred the interpretation of a ramp environment because of the lack of any positive evidence of coeval barrier facies, which could define an internal lagoon, and because in the eastern sections the grey marbles are overlain by the prograding fore-reef facies. However, if we take into account the greater thicknesses of the carbonates observed at La Muletta area, it might follow that the lower part of these successions could be the lateral equivalent of parts of the phyllites and carbonate intercalations in the eastern areas. Most of the carbonate intercalations contain abundant dasycladacean algae: the only exception are the carbonates occurring at Lungro (Boni et al., 1990), where chert nodules as well as radiolarian remnants have been found. This points to a mixed carbonate-siliciclastic ramp environment, on which the carbonate sedimentation is progressively advancing from shallower areas in the SW to deeper areas in the NE.

The Cozzo del Pellegrino mounds can be possibly envisaged to be growing on the distal part of the hypothesized ramp, this especially considering the abundance of crinoid plates which accompany a very differentiated biota, comprising several species of dasycladacean algae, porostromata and spongiomorphids.

b) A rimmed platform developed during Ladinian in the Monte Caramolo area, where sponges and inozoan buildups started to develop along a marginal, high energy domain. They were feeding with biogenic detritus a fore slope environment, located in the easternmost area. The exact location of this marginal area was controlled by a topographic relief created by synsedimentary tectonics, whose evidence are the brecciated facies occurring at the base of the reef complex succession (Boni et al., 1994a). It is more difficult, though, to demonstrate the existence of a possible link between the initiation of the reef building and a sea level fall, the latter evidenced by some meters of intertidal-supratidal facies occurring in the middle part of the La Muletta section.

During most of the Ladinan, and possibly in the early Carnian, the platform facies prograded over the fore-reef area, as evidenced by the vertical arrangement of facies in the Monte Caramolo reef complex (see fig. 6 in Boni et al., 1994b). Most of the shelf area, however, was occupied by a restricted, subtidal lagoon characterized by an oligotypic fauna. A terrigenous input from the continent was present in the westernmost areas, whereas it became unimportant toward the east, where the reefs could thrieve.

c) At the apex of the regressive trend, restricted conditions, which had initially prevailed in the west, spread over the entire shelf, as far as in the near-back-reef zone of the Monte Caramolo area. This led to the precipitation of sulfates and to the dolomitization of the lagoonal sediments in the early diagenetic stages. Moreover, the siliciclastic input of continental origin reached the more eastern areas. At the same time, pisolitic crusts developed in emergent areas at the shelf margins, this indicating that this evolutionary step was controlled by a sea level fall. Both the evaporitic event and the siliciclastic input can be envisaged at the main reason for the crisis of the organic buildups.

d) During the Early-Middle Carnian transgression which followed, the rimmed platform became again a carbonate ramp. In the more marginal eastern areas, oncolitic-pisolitic facies alternated with tempestitic beds, while in the western regions the evaporitic conditions, associated to a higher siliciclastic input, were more persistent. The dolomitization processes became widespread, involving the whole platform belt and even the deeper facies, probably as an effect of large scale reflux of supersaturated fluids from the internal, pericontinental evaporitic-siliciclastic domains.

e) In the Late Carnian the terrigenous input increased in the distal part of the ramp (d-e). The biostratigraphic data indicate that this event could be correlated with the deposition of the Raibl Group, well known in the Alps (Pisa et al., 1980; Brusca et al., 1982; Bechstädt & Schweizer, 1991) and Carpathians (Haas, 1994), and recorded also in the Southern Apennines. More data are however necessary to confirm such a correlation.

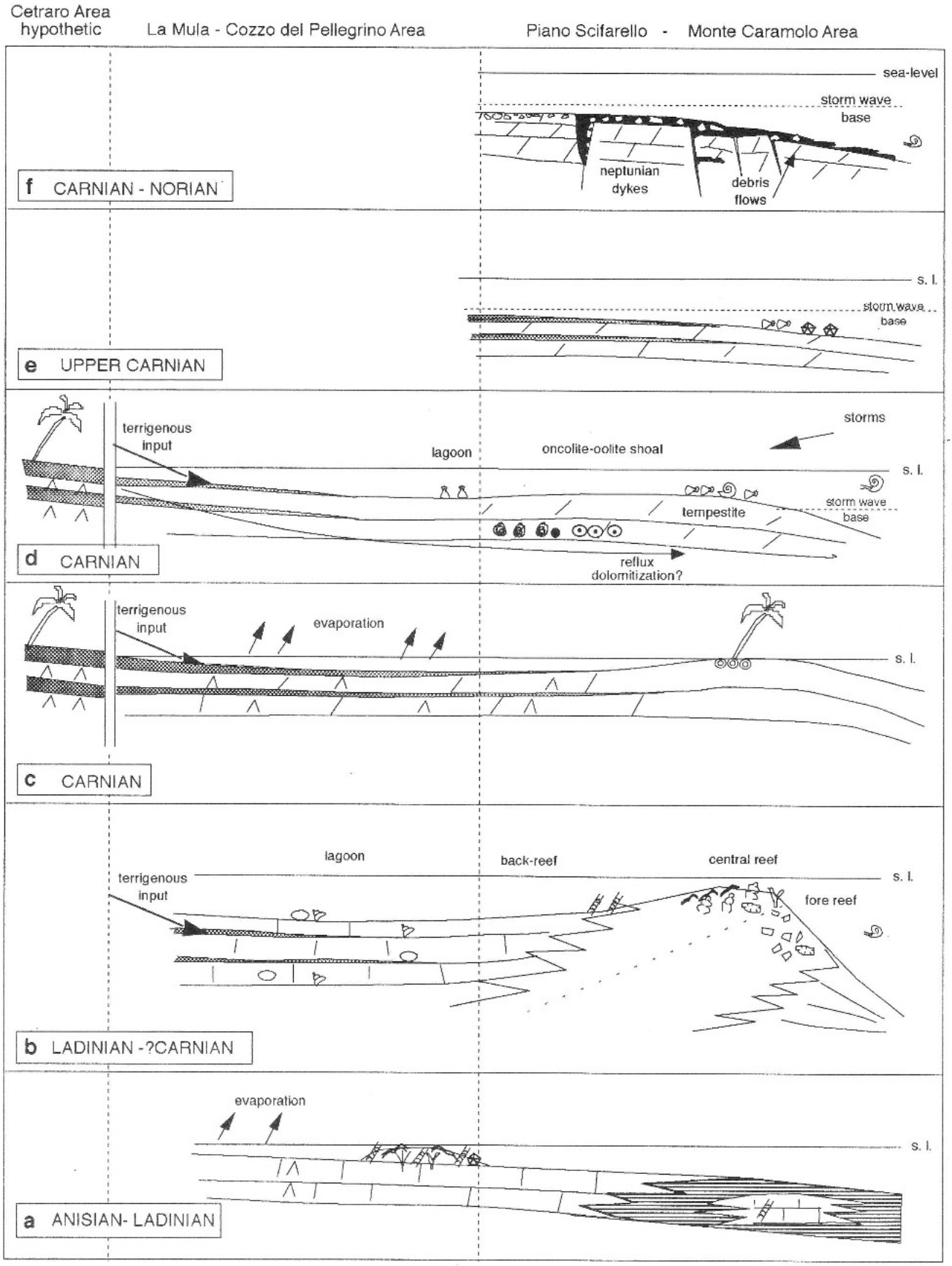

Fig. 14 - Schematic interpretation of the main Middle-Upper Triassic evolutionary stages in the S. Donato Unit in the studied areas. The various evolutionary steps are illustrated in the text. Legend of the symbols as in Fig. 4.

f) Immediately after, in the Lowermost Norian the platform margin was deeply dissected by faults which reached the underlying reef sediments. The whole facies belt deepened and the ramp became distally steepened.

Lithotypes younger than Upper Carnian are known only in the Scifarello area and are represented by subtidal, laminated dolomites alternating with fenestral dolomites. These facies, which can be dated as Norian in age (Boni et al., 1991; Zamparelli et al., in press), testify a new regressive trend. However, the whole problem of the Norian evolution of the carbonate successions in northern Calabria will be briefly examined in the next chapter.

Discussion.

In the previous chapters we have depicted what should be the paleoenvironmental evolution of northern Calabria during Ladinian and Carnian, as recorded in the successions outcropping in the Cozzo del Pellegrino massif. Even though such a detailed reconstruction had never been tried before, nevertheless, most of the regional geology studies concerned with the Triassic successions in northern Calabria always agreed in assuming a shallow water carbonate/siliciclastic/evaporitic depositional domain (Bousquet, 1973; Amodio-Morelli et al., 1976; Bonardi et al., 1982; Barbieri et al., 1984). In this respect the results of our research can be viewed both as a confirmation as well as an extension of these earlier assumptions.

However, due to the totally different scenario claimed by Ietto & Barilaro (1993), some additional discussion is needed in order to clarify a few basic concepts. In fact, according to the latter Authors, the Triassic San Donato succession should pertain to the same basin where the Lagonegro Units (Scandone, 1967) were deposited. Particularly, the thick carbonate succession of La Muletta mountain should consist of *"calcari con selce"*, correlable with those of the Lagonegro Units and consequently interpreted as hemipelagic, deep-water deposits. During the Upper Carnian the San Donato depocenter should have corresponded to a transitional domain between the Lagonegro basin and the Apenninic carbonate platform domain.

We have already shown the reasons why the scenario proposed by Ietto and Barilaro (1993) seems not to be supported by sufficient data. To this criticism, purely derived from the critical re-evaluation of the whole existing literature on the whole San Donato Unit, we must add that based on our own field data. In fact, as we have documented in the present paper (in agreement with Di Stefano, 1904, pp. 25 and 27), in the thick and widespread limestone successions of La Mula-Cozzo del Pellegrino-Piano del Minatore areas there is no evidence of the *"calcari con selce"* lithofacies, which might have been lithostratigraphically comparable with the well known successions of Lagonegro. Chert beds and nodules only seldom occur in these successions, this being not a conclusive evidence of deep water sedimentation. On the contrary, in the studied successions are recorded Ladinian-Carnian carbonate platform settings, comprising a restricted lagoon bordered by small patch-reefs with dasycladaceans and other algae and by the Monte Caramolo shallow water reef-complex. It is evident that nowhere can these sediments be attributed to a basinal domain, as affirmed by Ietto & Barilaro (1993).

An hypothetical possibility exists, nevertheless, that the Ladinian-Carnian sediments here concerned could have represented during Triassic the shelf area flanking the Lagonegro basin, if not only because the Lagonegro sediments are the only coeval basinal deposits known so far in the Southern Apennines. We think, however, that the tectonic setting of the San Donato terrains is still poorly understood to try such speculative exercises.

Better worthwhile could be the attempt to correlate them with the lithotypes of the Cetraro Unit, occurring along the Tyrrhenian coast, only some kms to the SW. In this area, in fact, thick, brecciated dolomites and gypsum beds are associated to phyllites with marbles intercalations. The Cetraro succession, highly deformed and metamorphosed in the greenschists facies, has been traditionally (Quitzow, 1935; Amodio Morelli et al., 1976; Dietrich, 1976) considered a lateral equivalent of the San Donato phyllites and of the Passo dello Scalone evaporites. No biostratigraphic data have ever been produced in the past to support this correlation. After our recent data, however, if we accept to correlate the Cetraro evaporites with those of Passo dello Scalone area, then, according to our stratigraphy, the same correlation can be applied to the small levels with traces of evaporitic minerals found in the easternmost areas as far as the Monte Caramolo and well dated as Carnian. From this hypothesis it follows that a Carnian episode of widespread evaporite deposition characterized the entire area, allowing a lithostratigraphic correlation across the whole Cetraro-San Donato belt. The thickness of the evaporite and evaporite-derived beds should increase from NE to SW, showing a paleoenvironmental trend which is compatible with the one suggested from our sedimentological data, and pointing to more open marine conditions in the NE.

If this is true, however, the Cetraro phyllites can hardly be the stratigraphic equivalents of the Anisian phyllites (*filladi* formation) of the San Donato Unit, as reported in Dietrich (1976) and generally accepted in the literature, because, in this case, the absence of some hundreds of meters of Ladinian carbonates will require a sound explanation. We think, instead, that the Cetraro phyllites could be better correlated with the Carnian phyllites of the Rosa River Valley. Contrary to the San

Donato Anisian *filladi* formation s.s., in fact, these phyllites are strictly associated to the evaporites and contain brown metarenites of probably continental origin, both characterizing the Cetraro outcrops too. The greater thickness of the phyllites-evaporites association in the Cetraro area, compared with that of the same association at the Rosa River, can be explained with a paleoenvironmental change from the westernmost areas to the eastern ones. Therefore, the prevalently carbonatic successions of the Cozzo del Pellegrino area could laterally grade to part of the Cetraro phyllites and evaporites, as we show in Fig. 14.

It is clear that the correlation proposed here is very rough because very few marker beds exist and strong heteropies can be expected. In this respect, it will be very important to establish, as closely as possible, the age of the Cetraro succession.

Another important point to be further discussed is the Norian evolution of the described Ladinian-Carnian successions. Our preliminary observations from the upper Rosa River Valley to the Pantanelli area have shown that, even if the Carnian evaporites and associated calcschists have acted as ductile, highly deformed detachement horizons, there is a substantial continuity between the Ladinian carbonates of La Mula and the Norian dolomites of Monte Montea. These views match those earlier expressed by Grandjacquet (1962) and Damiani (1970), which were successively discarded in favour of a tectonic relationship between these two formations (Bousquet & Grandjacquet, 1969; Amodio Morelli et al., 1976; Ietto et al., 1992). Thus, we believe that the Norian evolution of the Carnian evaporitic carbonates of La Mula mountain could be identified in the dolomites outcropping at Monte Montea and in other surrounding dolomites, all belonging to the Verbicaro Unit *AUCT.* The abundance of dasycladacean algae, corals and sphinctozoans in these Norian dolomites, already quoted by Cortese, and recently studied and re-interpreted in other areas of northern Calabria (Iannace et al., 1994), seems to indicate platform and platform margin environments.

The definition of the San Donato Unit and the "*calcaires plaquettés*".

The definition of the San Donato Unit *AUCT.*, as we have shown in the Previous Studies section, has been mostly done in a quite unorthodox manner, without full documented stratigraphic studies or an exhaustive discussion on the previous data. Particularly, the significance of the *calcaires plaquettés* lithofacies (Fig. 15), which for many Authors has become synonymous of the San Donato Unit, is quite critical. It is not the aim of this paper, though, to give a complete reassessement on the regional geology of the San Donato Unit *AUCT.* Nevertheless, we want to stress some ancillary remarks, derived from our work, which could help to unravel among the confusing literature, putting at the same time the basis for future research on the geology of the whole area.

a) The most characteristic Ladinian-Carnian lithotypes in the Middle-Upper Triassic of the Cozzo del Pellegrino massif are black limestones and bioturbated marly limestones, as well as early diagenetic dolomites, as described and documented in the present paper. Even when heavily recrystallized, these lithofacies can be easily recognized. Only locally these limestones appear similar to the *"calcaires plaquettés"* lithotype, but they never reach either the thicknesses or the characteristic features of the *"calcaires plaquettés"* of Piano di Campotenese (Fig. 15).

b) The *"calcaires plaquettés"* are indeed characteristic of several outcrops, which have been ascribed to the San Donato Unit by Barbieri et al. (1984) and by Ietto et al. (1992) (Piano Campotenese, Papasidero, Monte Ciagola, Cozzo Petrara). These scattered outcrops, however, are physically distinct from the huge outcrops of the well dated Ladinian-Carnian limestones of Cozzo del Pellegrino massif. In some of the mentioned localities (i.e. at Papasidero, Monte La Serra), the *"calcaires plaquettés"* overlie, with an ambiguous, tectonized contact, either Rhaetian megalodon-bearing limestones or Norian-Rhaetian dolomites. This was certainly one of the reasons (together with the paleontological content quoted by Di Stefano, 1904 and Bousquet, 1971 at Campotenese) why these outcrops are always considered Jurassic-Cretaceous on the geological maps.

c) The effectiveness of the *"calcaires plaquettés"* as a lithostratigraphic unit is highly questionable, particularly if we recognize that they represent a tectono-metamorphic facies (Bousquet, 1971; Ietto & Barilaro, 1993). In this respect, it must be emphasized that also many

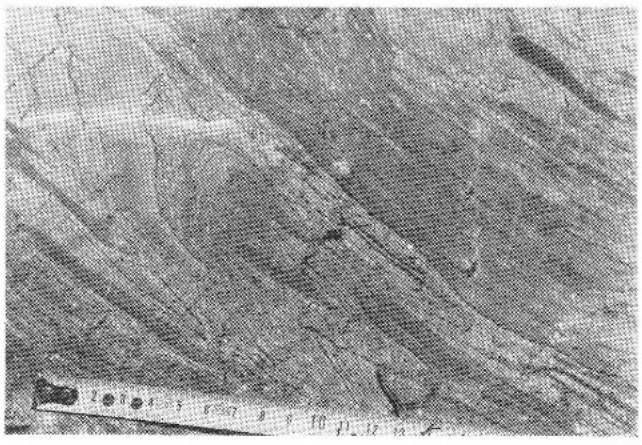

Fig. 15 - Typical sample of *"calcaires plaquettés"*, showing graded bedding and intrafolial folding (Campotenese).

calcareous intercalations in the Anisian-Ladinian phyllites have the same textural characteristics.

d) The stratigraphic continuity between the Ladinian-Carnian carbonates of the Cozzo del Pellegrino massif, the Norian dolomites and the Jurassic-Cretaceous *calcaires plaquettés* has been reported by Bousquet (1971, 1973), and later acknowledged by Amodio Morelli et al. (1976) in the areas north-west of Saracena. This fact has been fundamental to define the Campotenese-Pollino Unit, and later the San Donato Unit, as an unique succession, consisting mainly of shallow water carbonates, spanning in age from Anisian-Ladinian to Miocene. Bousquet (1971), however, says clearly that this whole succession was reconstructed from a puzzle of sparsely outcropping tectonized fragments. From one of his drawings (fig. 5 in Bousquet, 1971) it appears also that his large scale correlation between pre-Norian and post-Norian successions is based on a single marker-bed found in a poorly described series of Upper Triassic dolomites. We have no additional data to criticize this point, even if we consider that this correlation is too weak to establish a final definition of the tectonic units in the area. Further researches should be focussed on this point.

Correlation with other Triassic successions.

The correlation of the San Donato lithotypes with other Ladinian-Carnian occurrences in the Southern Apennines is quite difficult because, as already mentioned, most carbonate platform successions present in the Southern Apennines are truncated at the Norian level. It is generally assumed (D'Argenio et al., 1973) that this was due to the presence of Upper Triassic evaporites which acted as *"décollement"* horizon. The only known Carnian shallow water carbonates are outcropping in the Picentini Mountains (Galdieri, 1908). Here, "Raibl type" marly limestones are stratigraphically sandwiched between Carnian and Norian dolomites. No detailed data, though, exist on these sediments.

Some intervals of the Cozzo del Pellegrino Massif succession seem to have their equivalents in the lithotypes found in thrust belt of westernmost Sicily, structurally comparable to Southern Apennines. In the Marettimo island, Carnian evaporitic dolomites and *Avicula* marls are contained in the Panormide nappes and are interpreted as formed in the innermost part of a carbonate platform (Abate et al., 1982). The margin of this shallow water environment should be recorded in the carbonatic olistholites present in the Mufara Formation consisting of *Tubiphytes* and dasycladaceans boundstones (Senowbari-Daryan & Abate, 1987).

Some similarities exist also with the Middle-Upper Triassic of the Southern and Eastern Calcareous Alps, this particularly between the Monte Caramolo reef facies and the Esino and Wettersteinkalk reefs, as already suggested in our previous contributions (Boni et al., 1991, 1994a). This parallel apparently also held for the lagoonal limestone succession of the Cozzo del Pellegrino massif, which shares some resemblance with the Varenna member (Perledo-Varenna formation) of the Southern Alps (Gaetani et al., 1992). The Varenna succession, however, interpreted as deposited in an anoxic intraplatform basin, lacks the evaporites and the siliciclastics which characterize the Calabrian successions.

From this point of view, the Cozzo del Pellegrino massif and the Cetraro successions can, on the whole, be more satisfactorily compared with the Triassic of Sardinia (Gandin et al., 1982), of the French *Briançonnais* (Baud & Mégard-Galli, 1982) and of Spain (Iberian and Betic range, Orti-Cabo & Bayo, 1977; Martin & Braga, 1987; Calvet et al., 1987, 1990). All these successions are considered to be transitional between the Alpine Triassic and the Germanic Triassic. The most similar, though, in terms of thicknesses and facies evolution, are the Spanish successions. These comprise Ladinian (Upper Muschelkalk) black, bioturbated marly limestones, sponges-*Tubiphytes* buildups and a dolomitic-evaporitic Keuper, followed by a Norian *Hauptdolomit* facies (Calvet et al., 1987, 1990; Martin-Algarra, 1987).

A final remark should be done about the frequently reported correlation between the San Donato Unit, together with the overlying Verbicaro Unit, with the tectonic units of the Tuscan domain. In the maps of the Structural Model of Italy (Bigi et al., 1991), the San Donato Unit is compared with the authocthonous Tuscan domain, whereas the Verbicaro Unit is correlated to the Tuscan nappe. This follows the assumption of Amodio Morelli et al. (1976) of a Verbicaro Unit consisting of Norian to Miocene sediments detached at the level of the Carnian evaporites, tectonically superposed to an autochthonous Anisian to Miocene San Donato Unit.

We believe that this model, with its implication of ensialic shear tectonics and metamorphism, appears certainly as the most reliable working hypothesis for the tectonic evolution of the area. The widespread presence of evaporitic horizons, acting as detachement levels, and the style of the folds are further evidence for such a correlation. However, the observed substantial stratigraphic continuity between the Anisian-Carnian lithotypes of the San Donato Unit and the Norian Verbicaro dolomites, together with the doubts we put in evidence about the stratigraphic position of the *calcaires plaquettés*, implies that the definition of the tectonic units, as reported in the most recent literature, has to be partly revised before a complete understanding of the paleogeography and tectonic evolution could be achieved.

Conclusions.

The main aim of this paper was to illustrate the stratigraphy and facies characteristics of the Middle-Upper Triassic carbonate successions of northern Calabria and to discuss their paleoenvironmental and paleogeographic significance. This result has been largely obtained, even though many unresolved problems still exist on the exact biostratigraphic definition of these strongly deformed and recrystallized lithotypes. Nevertheless, the following points can be now basically evidenced:

1) The general paleoenvironmental characters of the evaporitic-carbonatic-siliciclastic Middle to Upper Triassic successions from Monte Caramolo in the NE to Cetraro in the SW seem now satisfactorily assessed. A coherent scenario of a pericontinental shelf, with a siliciclastic-evaporitic depositional area landward in the SW, passing laterally to a rimmed carbonatic platform, characterized by tectonic instability, lagoonal to restricted basinal sediments, moderate but constant siliciclastic input, and then by bioconstructed facies and high energy forereef environments in the NE is quite well constrained.

2) The evaporitic and evaporite-derived lithofacies are much more widespread as thought before. They can be traced from their traditional outcrops at Cetraro-Passo dello Scalone, throughout the San Sosti mountains to the Scifarello-Novacco area in the NE. In the last two localities they can be broadly referred to the Lower-Middle Carnian.

3) The successions of northern Calabria had a transitional character between a Germanic and an Alpine type Triassic. However, it is not possible to indicate which was the emergent land to which the Calabrian carbonate-evaporitic shelf was linked (paleoEurope? Calabria microcontinent?), neither the basin to which it eventually made transition.

4) The stratigraphic continuity between the Ladinian-Carnian (San Donato Unit) and the Norian-Rhaetian (Verbicaro Unit) carbonates in Northern Calabria, already hypothesized by Grandjacquet (1962), has been confirmed. On the contrary, the stratigraphic continuity between the Middle-Upper Triassic succession of Cozzo del Pellegrino massif and the Jurassic-Cretaceous *calcaires plaquettés* traditionally attributed to the San Donato Unit, is not enough documented. It follows that a redefinition of the tectonic units present in the whole northern Calabria is necessary, as well as a re-evaluation of their stratigraphic and sedimentologic significance, before attempting a full paleogeographic reconstruction.

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