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The Scaglia Toscana Formation of the Monti del Chianti: new lithostratigraphic and biostratigraphic data

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ABSTRACT

The Scaglia Toscana Formation (Scisti Policromi Auctt.) is one of the most investigated formations of the Tuscan Nappe. The formation is widely exposed in the Chianti Mounts and despite the number of studies in this area, some aspects remain poorly known and debated.

In this paper new litho- and bio-stratigraphic data from eight key-sections distributed over the entire area are provided and discussed in order to clarify the stratigraphic relationships among different lithostratigraphic members, as well as the depositional ages of each member. The formation was deposited in the Cretaceous-Oligocene time interval and it can be subdivided into five lithostratigraphic members: i) the "Argilliti di Brolio" (wine-red shales with sporadic siliceous calcilutites and rare interbedded cherts); ii) the "Marne del Sugame" (red and pink marls, calcareous marls and marly limestones with interbedded calcarenitic beds and ruditic lens-shaped bodies including calcareous-siliceous clasts); iii) the "Argilliti di Cintoia" (grey-green to black shales, locally with manganese-rich siliceous calcilutites and cherts); iv) the "Calcareniti di Montegrossi" (thin beds of calcilutites and calcarenites with varicoloured shaly-marly interbeds); and v) the "Argilliti e Calcareniti di Dudda" (alternating thin beds of calcilutites and calcarenites with varicoloured shaly-marly interbeds). These members were deposited in a marine environment and have been interpreted as deposited in a turbiditic system, in which shaly and calcareous turbiditic members have been attributed to a basin plain below the CCD, whereas the marls and marly limestones of the Marne del Sugame Member were deposited in a slope/ramp environment above or close to the CCD. Furthermore, the combination of these new data with structural informations coming from the literature allowed a better paleogeographic reconstruction of the paleobasin.

In order to better explain these data, the paper is accompanied by two geological maps realized in the past but never distributed. The two geological maps, at the scale of 1:25,000, cover the whole area from the Cintoia (south of Florence) to the San Gusmè (north of Siena) villages.

Key words*: Scaglia Toscana, stratigraphy, Cretaceous-Oligocene, pelagic deposits, Northern Apennines.*

INTRODUCTION

The Scaglia Toscana Fm. (also called "Scisti Policromi Auctt.") is a formation of the Tuscan Nappe that crops out in a wide area extending from eastern Liguria to northern Latium and western Umbria. The Scaglia Toscana Fm. marks the transition between the underlying Lower Cretaceous pelagic carbonates (Maiolica Fm.) and the overlying middle-upper Oligocene/Aquitanian foredeep siliciclastic turbidites (Macigno Fm.) (cf. Bortolotti *et alii*, 1970; Dallan Nardi & Nardi, 1972; Fazzuoli *et alii*, 1985, 1994b). This formation has attracted geoscientists since long ago and the firsts works date back to the 1960's (Canuti *et alii*, 1965; Merla, 1968; Azzaroli & Cita, 1969) when a type-section was described in the "Monti del Chianti" area. After these first studies, other authors investigated the formation mainly concerning its lithostratigraphic and biostratigraphic features (Hein, 1982; Fazzuoli *et alii*, 1985, 1996, 2004, and references therein), while detailed geological mapping have been performed since 1994 in the framework of the national geological cartographic (CARG) project of the Geological Survey of Italy (ISPRA) and of the Regione Toscana.

Despite the number of papers dealing with this formation, some aspects remain poorly known, as for example: i) the stratigraphic relationship between vertically and laterally stacked lithofacies; and ii) the time of deposition. The aim of this work is: i) to reconstruct the complex lithostratigraphic architecture of the Scaglia Toscana Fm. in the Monti del Chianti through the analysis of geological maps and of eight key-sections; ii) to provide a new and detailed biostratigraphic framework as a result of the combined analysis of calcareous nannofossils and planktonic foraminifera of about 250 samples collected in the key-sections. Moreover, these new data improve the knowledge concerning the stratigraphic and paleo-environmental framework of the Tuscan Domain during Cretaceous-Oligocene times, i.e. during a time interval that experienced the collisional processes that lead to the growth of the Northern Apennine belt (Fazzuoli *et alii*, 1994b; Bortolotti *et alii*, 2001; Vai & Martini, 2001). The paper is accompanied by two geological maps of the investigated areas at 1:25.000 scale; these maps were printed in the past and never distributed [San Gusmè-Gaiole map of Losi & Sandrelli (1994) and Albola-Cintoia map of Fazzuoli *et alii* (2011)].

GEOLOGIC SETTING

The Chianti ridge, also called "Monti del Chianti", consists of a closely spaced chain of hills NNW-SSE oriented and more than 35 km long. The area is limited by

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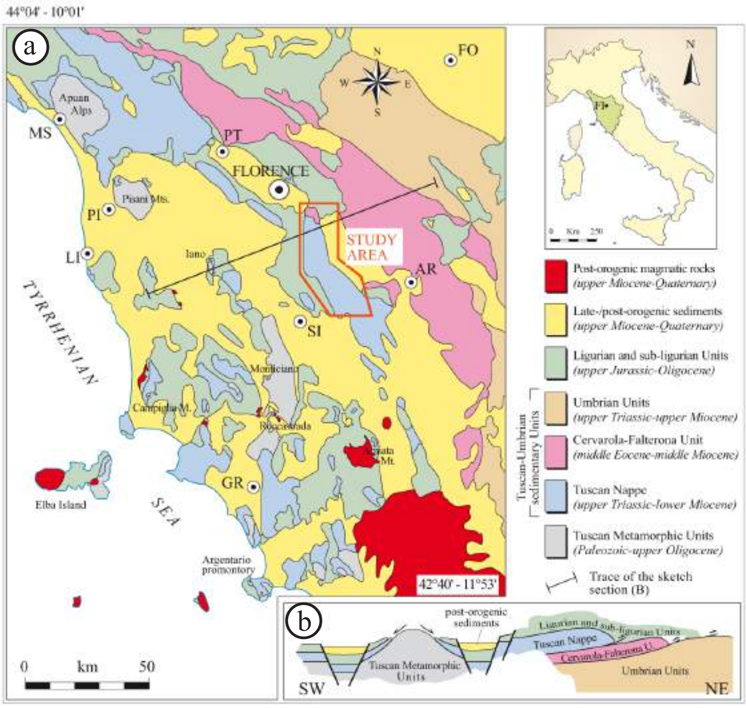

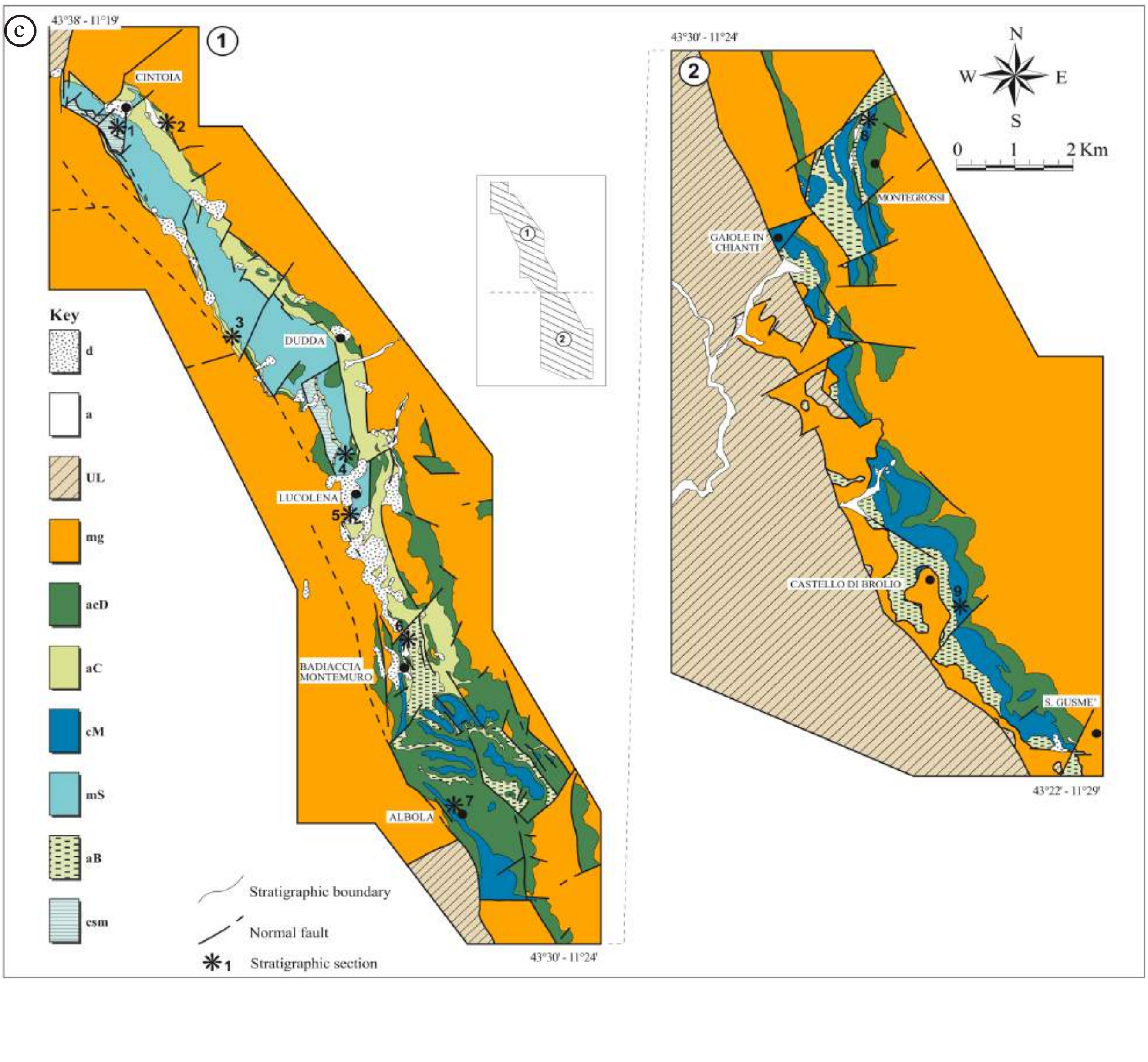

Fig. 1 - (a) Simplified tectono-stratigraphic map of Tuscany. (b) Simplified geological cross-section of Tuscany showing relationships among tectonic units. (c) Geological sketch map of the Monti del Chianti Area. The boundaries of the two enclosed 1:25.000 geological maps (1- Albola-Cintoia, 2- S.Gusmè-Gaiole) and the location of the detailed stratigraphic sections are shown. Legend: d) detrital cover; a) fluvial sediments; UL) Ligurian Units; Tuscan Nappe: mg) Macigno, acD) Argilliti e Calcareniti di Dudda, aC) Argilliti di Cintoia, cM) Calcareniti di Montegrossi, mS) Marne del Sugame, aB) Argilliti di Brolio; csm), underlying calcareous-siliceous Mesozoic formations. The asterisks refer to the location of the examined sections: 1) Cintoia west, 2) Cintoia east, 3) Passo del Sugame, 4) Lucolena north, 5) Lucolena south-west, 6) Badiaccia Montemuro, 7) Albola, 8) Montegrossi, 9) Castello di Brolio.

the Cintoia village to the north (some kilometres south of Florence) and by the San Gusmè village to the south (Fig. 1).

The Monti del Chianti Ridge corresponds to a morphologic element that separates intermontane late Miocene-Pliocene sedimentary basins to the west (Valdelsa, Casino and Siena Basins, characterized both by a continental to marine deposition, cf. MARTINI *et alii*, 2011) from the continental Plio-Pleistocene Upper Valdarno Basin, to the east (cf. FIDOLINI *et alii*, 2013).

The main tectonic structure of the Monti del Chianti area consists of an asymmetric to overturned/recumbent antiform of the Tuscan Nappe whose axis is oriented NNW-SSE (VALDUGA, 1948, 1952; MERLA, 1951; MERLA & BORTOLOTTI, 1967) (see the enclosed geological maps and Fig. 1). The Monti del Chianti antiform belongs to a main regional tectonic structure which is recognizable from the Monte Orsaro-Abetone (to the north) to the Monte Cetona (to the south) corresponding to the front of thrusting of the Tuscan Nappe over the Cervarola-Falterona Unit. This alignment was called in various ways by different Authors, e.g. i) fourth "tectonic ridge" in MERLA, 1951; SESTINI, 1970; ii) "Tuscan Nappe Front" in GIANNINI *et alii*, 1962; BALDACCI *et alii*, 1967; DALLAN NARDI & NARDI, 1972. In turn, the Tuscan Nappe succession rests tectonically over the sub-Ligurian (Senario Unit) and Ligurian (Monte Morello Unit) Units (SAGRI *et alii*, 2012).

The core of the Monti del Chianti main fold structure generally consists of the Scaglia Toscana Fm., even if to the north older formations of the non-metamorphic Tuscan Nappe are exposed. In stratigraphic order they consist of (see FAZZUOLI *et alii*, 2004 and SAGRI *et alii*, 2012 for details): i) middle Liassic Calcare Selcifero (grey calcilutites with nodules of chert); ii) Toarcian to Callovian Marne a Posidonia (grey and pink marly calcilutites and grey marls); iii) upper Bajocian to upper Kimmeridgian Diaspri Toscani (thin-bedded highly siliceous limestones to carbonate-free radiolarian cherts); iv) upper Tithonian to lower Neocomian Calcari ad Aptici (silicified marly limestones and limestones with beds of red chert); v) Neocomian-?Aptian Maiolica (light grey calcilutites with grey chert nodules).

The main structural features of the Tuscan Nappe in Monti del Chianti Ridge are well exposed at the mesoscale in two key areas, i.e. the Montegrossi quarry and the Cintoia area (see locations in Fig. 1). In both areas the main structure is defined by hectometre-kilometre scale NE-vergent overturned to recumbent folds, closely associated with parasitic folds (metre to decametre scale) characterized by a NW-SE and NNW-SSE axial strike (see Fig. 2 and cross sections of the enclosed geological maps) (FAZZUOLI *et alii*, 2004). These folds are in turn deformed by a successive family of folds, showing sub-vertical to SW steeply-dipping axial planes (Fig. 2). According to FAZZUOLI *et alii* (1994b) the main folding of the Tuscan Nappe occurred during the Serravallian compressional event, whereas the re-folding occurred in the early Tortonian.

ELTER & SANDRELLI (1994) reported a more complex polideformed structure due to two folding phases in the central and southern part of the Monti del Chianti: the 1st Phase ("syn-nappe") is associated with a main planar anisotropy (i.e. fine-grained foliations in the pelitic lithotypes and spaced cleavage in carbonate rocks, generally parallel or at a low-angle to the bedding) which is rarely associated to scattered NE-vergent, tight to isoclinal folds characterized by an Apenninic (NNW-SSE) strike. According to ELTER & SANDRELLI (1994) these structures are related to the syn-orogenic collisional event (late Oligocene-early Miocene) of the Apennine tectogenesis. The 2nd phase ("post-nappe") is associated to the most evident, major and minor folds, that are characterized by a NE vergence and an Apenninic strike (NNW-SSE) (see AP2 in Fig. 2). The 2nd phase was related also with other major coeval east-verging structures located along the same structural alignment (e.g. Val di Lima, Monsummano, M. Cetona). Such structures were originated for the gravitation sliding of the Tuscan Nappe along the flanks of a main paleo-antiform (i.e. the Middle Tuscan Ridge from the Alpi Apuane to Monti Leoni) due to the "Core complex" – like exhumation of the deeper Tuscan metamorphic units that occurred during the Miocene (since the Burdigalian) extensional events of the chain (CARMIGNANI & KLIGFIELD, 1990; BERTINI *et alii*, 1991). A later 3rd re-folding phase characterized by sub-vertical axial planes also took place (AP3 in Fig. 2).

In contrast to this interpretation, BONINI (1999), who analysed both the Monti del Chianti ridge and the adjacent Pliocene and Pleistocene depressions, interpreted the Monti del Chianti structural evolution as derived from a polyphased WSW-dipping crustal thrustings with associated folds in a continuous compressive tectonic regime since Oligocene to late Pliocene times. Consequently, according to BONINI (1999) the three main stages of deformation of ELTER & SANDRELLI (1994) were referred to compressional events. In particular, the D1 stage resulted in NE-directed syn-sedimentary thrusting of the Macigno Fm. onto the Cervarola-Falterona Unit in the early Miocene times; the two successive deformation stages originated the main NE- or ENE-vergent thrust-related folds (D2) during the late Miocene and their refolding (D3) during late Pliocene. According to BONINI (1999), these events produced the development of the top-thrust Upper Valdarno Basin that predated the extensional tectonic evolution allowing to high angle normal faulting in the Pleistocene times.

Despite their origin, the tensional events produced NW-SE, WNW-ESE, NE-SW and NS – trending, high-angle normal faults systems which dissected the orogenic pile of nappes. The NW-SE trending high-angle fault system may be considered the main system of the area and is characterized by dips of about 60° to south-west and, subordinately, to north-east. Particularly, this main fault bounds for at least 10 km the south-western side of the main anticline from Cintoia to the Lucolena area. According to FAZZUOLI *et alii* (2004, 2011), the downthrown block generally consists of Macigno Fm., whereas the upthrown block generally consists of the Mesozoic formations and of the Scaglia Toscana Fm. in the Cintoia and Lucolena areas. In the Cintoia area and in particular near Borro di Cafaggio the Macigno Fm. is in lateral contact with the Calcare Selcifero or the Marne a Posidonia pointing to an extimated throw of the main fault of about 1000 m. LOSI & SANDRELLI (1994) recognized also low-angle normal faults dissected by high-angle normal fault systems (see the geological section n°4 in the geological map). These latter result geometrically compatible with the fault system delimiting the eastern margin of the Siena Basin reported by BAMBINI *et alii* (2010), whose activity was referred to the Pliocene.

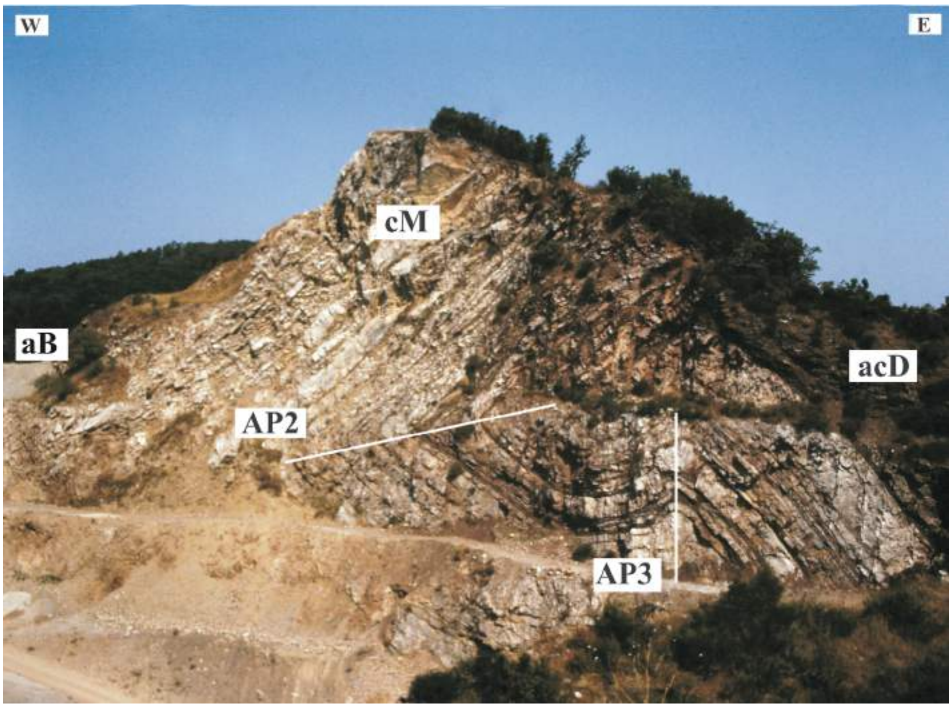

Fig. 2 - Foldings in the Montegrossi Quarry. aB) Argilliti di Brolio Member, cM) Calcareniti di Montegrossi Member, acD) Argilliti e Calcareniti di Dudda Member. AP (=axial plane) 2 and 3, according to the structural reconstruction of Elter & Sandrelli (1994).

The Scaglia Toscana Formation in the Monti del Chianti

The first detailed litho biostratigraphic and sedimentologic analyses of the Cretaceous to Oligocene Scaglia Toscana Fm. in the Monti del Chianti was performed by Canuti *et alii* (1965). Due to the lithological variability that typifies the Scaglia Toscana Fm., different Authors have given different stratigraphical interpretations over the years: i) it was generically named as "Scisti Policromi" by Merla (1951) and Bortolotti *et alii* (1970); ii) formalized as Scaglia Toscana by Merla (1968); iii) it has been considered as a Group of formations by Merla & Bortolotti (1967), Canuti *et alii* (1965), Boccaletti & Sagri (1966); Azzaroli & Cita (1969), Hein (1982), Bambini *et alii* (2010); iv) interpreted as a single formation subdivided in several members or lithofacies by others (Merla,1968; Bortolotti *et alii*,1970; Dallan *et alii,* 1981; Nardi *et alii,* 1981; Fazzuoli *et alii*, 1985, 1994b, 1996; Losi & Sandrelli, 1994; Costantini *et alii*, 1995; Sagri *et alii*, 2012). In particular, Fazzuoli *et alii* (1996; 2004) distinguished five main members in the investigated area, called: Argilliti di Brolio, Marne del Sugame, Argilliti di Cintola, Calcareniti di Montegrossi e Argilliti e Calcareniti di Dudda. In this paper, the subdivision proposed by Fazzuoli *et alii* (1996; 2004) has been taken into account because: i) members of the Scaglia Toscana Formation are mappable units and preserve their stratigraphic position all over the investigated area; ii) this is the official subdivision adopted in the recent CARG Project (see for example Servizio Geologico d'Italia, 2005a and Sagri *et alii*, 2012). The correlation between abbreviations adoped in this work and those adopted in the CARG maps is proposed in Table 1.

METHODS

Eight lithostratigraphic sections were measured for a total thickness of about 900 metres and sampled for biostratigraphic analyses (except for the Albola section). The location of measured sections is reported in Figure 1. Sections are called: 1- Cintoia west (74 samples in about 135 m of section), 2- Cintoia east (14 samples in about 25 m of section), 3- Passo del Sugame (20 samples in 85 m of section), 4- Lucolena north (79 samples in 110 m of section), 5- Lucolena south-west (10 samples in about 38 m of section), 6- Badiaccia Montemuro (21 samples in 110 m of section), 7- Albola, 8- Montegrossi and Castello di Brolio (68 samples in about 370 m of section). Stratigraphic features of each section and the position of the collected samples is reported in Plate 1.

The biostratigraphic methodology utilized for analysing the samples is evidenced in Plate 1 (* = dating by calcareous nannoplankton; o = by radiolarian; Δ = by foraminifera). For planktonic foraminifera assemblages, the analysis was generally performed in thin sections examined by light microscope and only few marly samples of the Lucolena

TABLE 1

Correlation between member's abbreviations adoped in this work and those adopted in the CARG maps.

Members	*This work*	*CARG Project*
Argilliti di Brolio Member	aB	STO2
Marne del Sugame Member	mS	STO1
Argilliti di Cintoia Member	aC	STO7
Calcareniti di Montegrossi Member	cM	STO3
Argilliti e Calcareniti di Dudda Member	acD	STO4

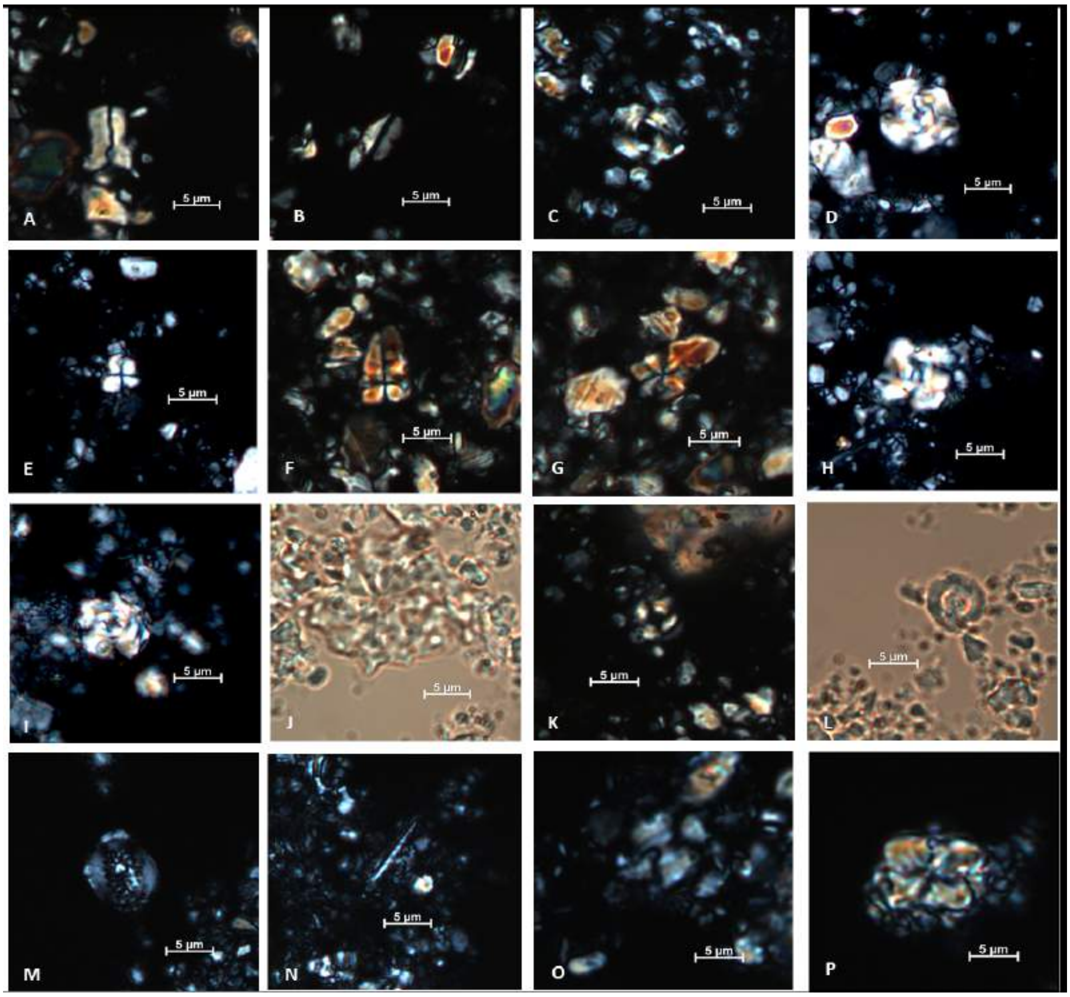

Fig. 3 - (A, B) *Zygrhablithus bijugatus* (Deflandre in DEFLANDRE & FERT, 1954) Deflandre, 1959, sample C24. (C) *Reticulofenestra samodurovii* (HAY et alii. 1966) Roth, 1970 sample C24. (D) *Dictyococcites bisectus* > 10 micron (HAY & MOHLER WADE, 1966) BUKRY & PERCIVAL, 1971 sample C24. (E) *Sphenolithus moriformis* (BRONNIMANN & STRADNER, 1960) BRAMLETTE & WILCOXON, 1967 sample C24. (F-G) 6: *Sphenolithus radians* Deflandre *in* GRASSÉ, 1952 - 0°; G: 45° sample C24. (H) *Reticulofenestra* sp. HAY *et alii* (1966) sample C24. (I) *Cyclicargolithus floridanus* (ROTH & HAY, *in* HAY *et al.*, 1967) BUKRY, 1971 sample C24. (J) *Discoaster barbadiensis* TAN SIN HOK (1927) emend BRAMLETTE & RIEDEL (1954) sample C22. (K-L) K: *Ericsonia formosa* (KAMPTNER, 1963) cross polarized light; L: plain light, sample C24. (M) *Cretarhabdus crenulatus* BRAMLETTE & MARTINI (1964), sample B8. (N) *Lithraphidites carniolensis* DEFLANDRE (1963), sample B8. (O) *Watznaueria barnesiae* (Black *in* BLACK & BARNES, 1959) PERCH-NIELSEN, 1968, sample B8. (P) *Quadrum* sp. PRINS & PERCH-NIELSEN *in* MANIVIT *et alii*, 1977, sample B8.

and Cintoia sections was treated with neodesogen and ultrasonic bath and the washed residues were analysed by reflected light stereo microscope. For analysing calcareous nannofossils, standard smear-slides were prepared using standard technique and light microscope have been used for qualitative analyses. The biostratigraphic data of the different members of the Scaglia Toscana Fm. are shown and discussed below, and summarized in the distribution charts for each of the studied sections (excluding the Castello di Brolio section) in the Appendices 3 to 9.

The zonations adopted for the biostratigraphic analyses are after PREMOLI SILVA & VERGA (2004) for the Cretaceous, PREMOLI SILVA *et alii* (2003) for the Paleogene, and IACCARINO *et alii* (2005) for the Oligocene planktonic foraminifera assemblages. For the calcareous nannofossil, the zonal schemes of MARTINI (1971) and SISSINGH (1977) were utilized for the Paleogene and Cretaceous nannofossil assemblages, respectively.

The CCD abbreviation is used to indicate the carbonate compensation depth.

DATA AND RESULTS

In this chapter the litho- and bio-stratigraphic features of each members, with references to the sections where members are exposed, have been described and discussed. A synthesis is reported in Plate 1. Moreover, biostratigraphic data have been presented in Appendices 1 to 7. The nomenclature of members is according to FAZZUOLI *et alii* (1996).

ARGILLITI DI BROLIO MEMBER (aB)

Stratigraphic position and lithostratigraphic features

This member generally represents the base of the Scaglia Toscana Fm., with the exception of the Borro di Cerungoli area (south-west of Dudda) where the base of the formation is marked by the Marne del Sugame Member that stratigraphically lies directly onto the Maiolica Fm. (see Plate 1, Fig. 1 and the enclosed 1:25.000 scale geological maps). The thickness of the Argilliti di Brolio Member varies from about 10 m (Cintoia) to at least 65 m (Montegrossi).

In the central and southern areas of Monti del Chianti the Argilliti di Brolio Member are sharply overlaid by the Calcareniti di Montegrossi Member. On the contrast, in the northern area (i.e. at Cintoia sections) the Calcareniti di Montegrossi Member is lacking and the Argilliti di Brolio Member vertically pass to the Marne del Sugame Member, through a 5 m thick transitional interval constituted by an alternance of calcareous marls and marly shales beds.

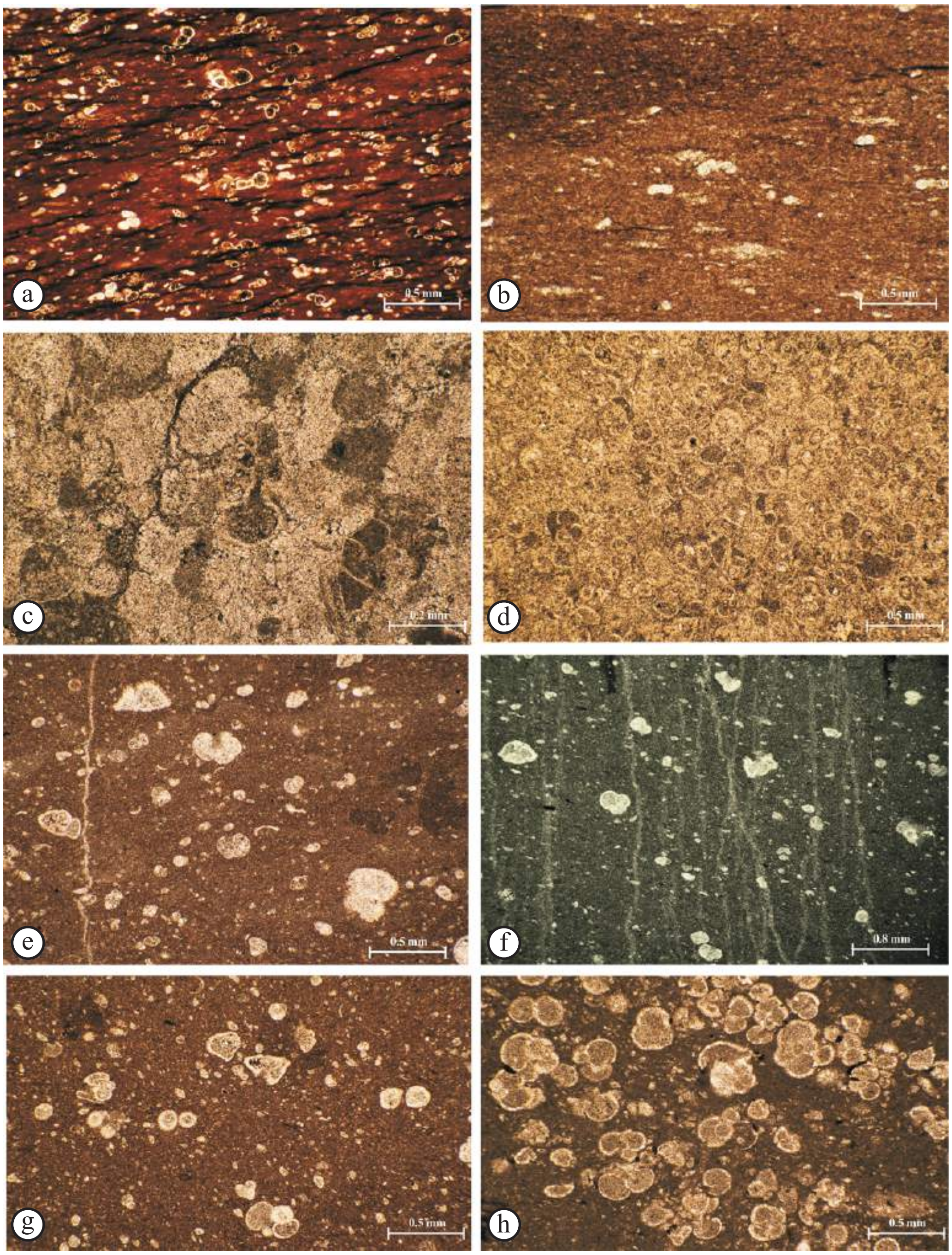

Fig. 4 - Representative foraminifera from the sampled sections. (a) *Praeglobotruncana delrioensis* (Plummer), 1931, *Ticinella roberti* (Gandolfi), 1942, *Globigerinelloides* sp., (sample C8, Cintoia west section, Marne del Sugame Member, Upper Albian, *Rotalipora ticinensis-R. appenninica* biozones). (b) *Hedbergella* sp., *Ticinella* sp., *Globigerinelloides* sp., (sample C9, Cintoia west section, Marne del Sugame Fm., late Albian *Biticinella breggiensis-R. appenninica* biozones). (c) *Globotruncana* sp., *Macroglobigerinelloides* sp. (sample B9, Badiaccia Monteuro section, Calcareniti di Montegrossi Member, early Campanian, *Globotruncana elevata- G. ita ventricosa* biozones). (d) *Akarinina* sp., *Morozovella* sp., *Subbottina* sp. (sample C107, Passo del Sugame section, Marne del Sugame Member, early-middle Eocene, P3-P13 biozones). (e) *Akarinina* sp., *Morozovella* sp., *Subbottina* sp. (sample L40, Lucolena southwest section, Marne del Sugame Member, early-middle Eocene, P3-P13 biozones). (f) *Akarinina* sp., *Globigerinateka* sp., *Morozovella aragonensis* (Nuttall), 1930, *Subbottina* sp., (sample C64, Passo del Sugame section, Marne del Sugame Member, middle Eocene, P7-P13 biozones). (g) *Morozovella spinulosa* (Cushman), 1927, *Pseudohastigerina danvillensis* (Howe and Wallace) (sample C65, Passo del Sugame section, Marne del Sugame Member, middle Eocene, P7-P13 biozones). (h) *Akarinina* sp., *Globigerinateka* sp., *Morozovella aragonensis* (Nuttall), 1930, *Subbottina* sp. (sample C67, Passo del Sugame section, Marne del Sugame Member., middle Eocene P7-P13 biozones).

The Argilliti di Brolio Member consists of wine-red dark (more rarely green to grey) shales (Fig. 5A), with subordinated siliceous shaly levels (Fig. 5B). The latter are characterized by scaly and acicular fabric with local black manganese impregnations and veins. Subordinated are, listed in order of abundance: i) manganese-rich radiolarites and cherts; ii) grey to grey-greenish siliceous calcilutites; iii) calcarenitic beds, up to 25 cm thick (intervals Tc-e and Td-e following the Bouma's subdivions), and iv) thin marly shales levels. Moreover, in some areas (e.g. Badiaccia di Montemuro section in Fig. 5C, south of Casale Mirra to NW of Case di Dudda; Casa Riccione-Casa La Vigna close to the Montegrossi quarry) a peculiar facies occurs in the upper part of the member, represented by a metric to decametric package of alternating cm- to dm- thick (max 30 cm) beds of varicoloured (essentially black, but also greenish and dark red), organic matter- and manganese-rich radiolarites and siliceous shales. Shaly levels often show a pervasive pencil cleavage.

Biostratigraphic data

Sampling on this lithostratigraphic unit have been carried out at the base of the Cintoia west (samples Ci1- Ci7), Lucolena north (samples L6-L13), Badiaccia di Montemuro (samples B1-B3) and Montegrossi (samples MG1-MG3) sections. Generally, the investigated samples show rare and poorly preserved calcareous nannofossil assemblages, except for some of these coming from the Cintoia

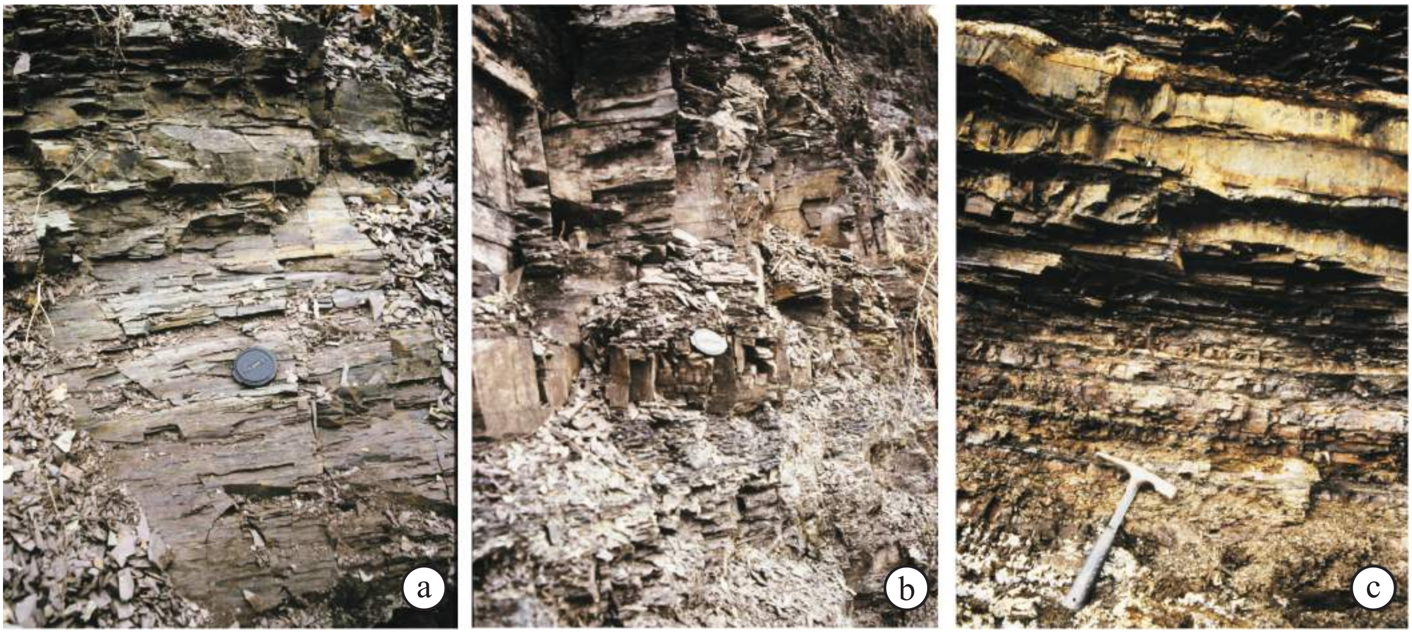

Fig. 5 - (a) Argilliti di Brolio Member in the Borro di Cintoia, Cintoia area. (b) Silicified shaly levels in the Argilliti di Brolio Member in the Lucolena north section. (c) Anoxic black cherts with siliceous shaly intercalations at the top of the Argilliti di Brolio Member in the Badiaccia di Montemuro section.

west section (Appendix 1). Radiolaria assemblages were found only in the siliceous lithofacies in the Badiaccia di Montemuro section.

- *Cintoia west section (Appendix 1)*

Sample Ci3 displays small isooriented specimens of *Muricohedbergella sp., Ticinella sp.* and *Macroglobigerinelloides sp.* This assemblage typifies the interval *Ticinella primula-Rotalipora apenninica* biozones (Albian p.p.). The assemblages of the remaining samples (Ci4, Ci5) consists of common *Muricohedbergella* sp., *Ticinella* sp. and *Macroglobigerinelloides* sp., and of *Rotalipora* sp., *Rotalipora subticinensis*, *R. ticinensis*, *R. preappenninica*, *R. appenninica, Macroglobigerinelloides casey*, *Ticinella roberti*, *T. raynaudi*, *Planomalina praebuxtorfi* and *P. buxtorfi*. These assemblages indicate the *Rotalipora appenninica* biozone (late Albian).

Moreover, few specimens and poorly preserved calcareous nannofossils are present in two samples (Ci1 and Ci6) of the lowermost part of the section. In sample Ci1 the assemblage is mainly composed by *Cretarhabdus spp.*, *Prediscosphaera cretacea* s.l., *Watznaueria barnesiae, Calculithes* cfr. *obscurus* and *Eprolithus* sp.. The occurrence of *Quadrum* sp. and *Calculithes* cfr. *obscurus* suggests a late Cretaceous interval (Turonian/Santonian CC11-15 biozones).

- *Lucolena north section (Appendix 2)*

Only sample L6 contains a poorly preserved calcareous nannofossil assemblage composed by *Prediscosphaera cretacea, Cyclagelosphaera margerelii, Retacapsa crenulata* and *Watznaueria barnesiae* suggesting a generic late Cretaceous age.

- *Badiaccia di Montemuro section (Appendix 5)*

In this section is present only a radiolarian assemblage (Chiari *et alii*, 2005), found in the black siliceous sediments in the lower portion of the section (see Plate 1). In the lower part of this siliceous horizon, the assemblage consists of *Dactyliosphaera silviae* Squinabol, *Guttacapsa biacuta* (Squinabol), *Holocryptocanium astiensis* Pessagno, *Pseudodictyomitra pentacolensis* Pessagno, *Pseudodictyomitra tiara* (Holmes), *Rhopalosyringium majuroensis* Schaaf, *Thanarla pulchra* (Squinabol), *Novixitus dengoi* Schmidt-Effing *and Novixitus mclaughlini* Pessagno, typical of the Cenomanian.

Instead, the radiolarian assemblage yielded by the upper part of the siliceous horizon is characterized by the occurrence of *Acanthocircus hueyi* (Pessagno), *Alievum superbum* (Squinabol), *Crucella cachensis* Pessagno, *Hemycriptocapsa polyhedra* Dumitrica, *Rhopalosyringium scissum* O'Dogherty, and indicates a Turonian age.

- *Montegrossi section (Appendix 6)*

Microfossils have not been found in samples coming from this section.

Interpretation

The lithological features of the Argilliti di Brolio Member suggest a deposition in a pelagic environment, below the CCD, confirming as suggested by previous studies (Sagri, 1973; Fazzuoli *et alii*, 1985). Regarding the age of deposition, the Argilliti di Brolio Member was traditionally referred to the Aptian/Albian-Cenomanian interval (Canuti *et alii*, 1965; Nocchi, 1960). However, the collected data suggest a different age attribution, because: i) planktonic foraminifera assemblages point to a late Albian age for the base of the member, but ii) the calcareous nannofossils suggest a late Cretaceous age (Turonian- Santonian in the Cintoia W section) and iii) the Cenomanian-Turonian transition was defined by the radiolarian assemblage from the black siliceous horizon in the Badiaccia di Montemuro section (Chiari *et alii*, 2005).

Marne del Sugame Member (mS)

Stratigraphic position and lithostratigraphic features

This member is exposed only in the northern part of the studied area. The maximum thickness of the Marne del Sugame Member is more than 120 m in the Cintoia W section (see Plate 1). The transition to the overlying Argilliti di Cintoia Member is generally sharp.

The main rocktype is represented by rather homogeneous marls to calcareous marlstones and minor clayey marls ($CaCO_3$ is generally >45%), often bioturbated, and liver red or dark pink to light grey-brown in colour (Figs. 6a and b). These lithotypes are characterized by a huge content in planktonic foraminifera that sometimes are aligned and concentrated along millimetric laminae (Figs. 4a and b), probably due to the action of currents. At places, decimetric-sized, fine to coarse-grained calcarenites (Fig. 7a) and calcirudites (Fig. 7b), or pebbly mudstone levels (Fig. 7c) are present. In detail, the latter are characterized by alignments and concentrations of grey, reddish to whitish clasts made up of limestone, silicified calcarenites (characterized by Liassic fossils-bearing neritic and Calcare a Calpionella-like microfacies: see Canuti & Pirini, 1965; Canuti *et alii*, 1965 for details), even if reddish to grey-brown marly limestones with Cretaceous or Paleocene-early Eocene fossils (probable intraformational clasts) can be also found.

Marlstone and clayey marls typically form > 10 m thick massive bodies with rare traces of bedding (Fig. 6a), with common intercalations of: i) pink, reddish, light brown/ whitish or grey limestones, marly limestones (max 1,5 m in thickness) (Fig. 6b); and ii) decimetric (max 70 cm-thick) grey and brownish medium- to fine-grained calcarenites (intervals Tc-e, Td-e or structureless), often showing a lenticular geometry at the outcrop scale. Paleocurrents indicators in turbidite beds indicate a sediment transport from NNE (see also Sestini, 1964).

It is important to report that at Cintoia locality, occur at least three lenticular, matrix- to clast-supported massive breccia or poorly-mature conglomerate bodies, up to 6 metres in thickness (Fig. 8a). They are made up of angular/ subangular to subrounded calcareous, calcareous-cherty and cherty pebbles and cobbles, up to 35 cm in size, in a dark red shaly-marly matrix. Lithology and microfacies of clasts suggest they originated from Jurassic and Cretaceous formations of the Tuscan and maybe of the Umbrian successions (see details in Canuti & Pirini, 1965; Canuti *et alii*, 1965; Dallan, 1966; Fazzuoli *et alii*, 1985).

Biostratigraphic data

Data have been collected in four sections (see Plate 1): Cintoia west, Lucolena north, Lucolena south-west, Passo del Sugame.

- *Cintoia west section (Appendix 1)*

Most of the samples in the basal part (from Ci8 to C8) are characterized by a well differentiated planktonic foraminifera assemblage made up mostly of *Macroglobigerinelloides, Ticinella* (among which *Ticinella roberti)* and *Muricohedbergella*. Moreover, *Planomalina prebuxtorfi, P. buxtorfi, Biticinella breggiensis, Rotalipora preappenninica, R. appenninica, R. subticinensis, R. ticinensis, R. balarnaensis, Preglobotruncana delrioensis* and rare *Heterohelix* are also present. This association as a whole points to the *Rotalipora subticinensis-R. appenninica* biozones interval (late Albian). In the overlying sample Ci17a the occurrence also of *Rotalipora globotruncanoides* allows to recognize *R. globotruncanoides* biozone (basal Cenomanian). The uppermost sample (C9) of these lower portion of the section, contains a foraminifer association indicating *Biticinella breggiensis-Rotalipora cushmani* biozones (late Albian-Cenomanian).

The overlying part of the section (from sample C9f1) contains rich foraminifera associations spanning from the P3 to the P16-17 biozones (Paleocene-Eocene). In particular, in the samples from C9f1 to C9e, the occurrence of *Morozovella* sp., *M. subbottina and Acarinina* indicate the P3 to P13 biozones (middle Paleocene- middle Eocene). In the sample C9d, among the planktonic foraminifera, the occurrence of *M. gracilis* and *M. formosa* indicates the P6-P7 biozones (early Eocene).

The most common planktonic foraminiferal assemblages in the remaining part of the section (from sample C10 to Ci25, consisting of *Acarinina* (*Acarinina bullbrooki*), *Truncatulinoides rhori*, *Globigerinatheka (*among which *G.senni*, *Subbotina*, *M. aragonensis*, *M. spinulosa* and few *Hantkenina,* point out to P7-P14 Zone interval) (early Eocene-middle Eocene). The likely presence of *Pseudohastigerina danvillensis* in C16 sample suggests the P14-P16/17 Zones interval (middle-late Eocene).

The calcareous nannofossil assemblages from the lower part of the member from sample Ci 9 up to sample Ci17a (see Appendix 1) are poorly preserved and consist of generic upper Cretaceous specimens. The overlying sample C9f1 shows a Paleogene assemblage containing among others *D. multiradiatus*, *Sphenolithus moriformis*, *C. pelagicus* and *F. tympaniformis* suggesting NP9 Zone (late Paleocene). The following samples (C9e and C9d) contain few specimens of *C. pelagicus*, *S. anarrhopus, S. moriformis* and *Zyghrablithus bijugatus,* make difficult to attribute a precise age, suggesting a NP6-10 (middle Paleocene-early Eocene). From samples C10 to C16, calcareous nannofossils are not present or show a poorly preserved association made up, among others, of *C. pelagicus*, *Z. bijugatus*, *E. formosa, S. obtusus, R. samudorovi, R, umbilica, Dictyococcites bisectus,* and *D. scrippsae,* suggesting NP16 - NP17 biozones (early-middle Eocene). The following samples (from Ci26 to Ci29) in the upper portion of the section indicate a generic Eocene age. Only C28 can be assigned to NP12 biozone (early Eocene).

On the basis of planktonic foraminifera, in the Cretaceous portion of the Cintoia west section the following portions can be distinguished: the Ci4a-C8 portion with an upper Albian age; to the C17a-C9 interval can be assigned an age corresponding to the uppermost Albian-lowermost Cenomanian. The basal Paleogene part of the Marne del Sugame Member (C9f1-C9e) is referable to middle/late Paleocene- early Eocene. An early Eocene age can be assigned to sample C9d, whereas the overlying interval up to Ci25 is referable to early/middle Eocene. The assemblages of sample C15 points out to a middle Eocene and the uppermost part of the section can be attributed to middle – late Eocene.

- *Lucolena north section (Appendix 2)*

In the basal part (samples L14-L104), the planktonic foraminifers (*Acarinina bullbrooki, Truncatulinoides rohri, Morozovella aragonensis, M. spinulosa*) point out to the P7-P11 biozones (early-middle Eocene). In the L16-L107 inter-

Plate 1 - Detailed lithostratigraphic columns of the measured sections and location of the samples collected for the biostratigraphic analyses (* = calcareous nannofossils, o = radiolaria, Δ = foraminifera).


CINTOIA WEST
MIDDLE- (?) UPPER EOCENE
CINTOIA EAST
Argilliti di Cintoia
Argilliti e calcareniti di Dudda
Macigno
MIDDLE EOCENE - LOWER OLIGOCENE
MIDDLE-LOWER OLIGOCENE
PASSO SUGAME
Marne del Sugame
Argilliti di Cintoia
Argilliti e calcareniti di Dudda
MIDDLE EOCENE
MIDDLE EOCENE - LOWER OLIGOCENE
LUCOLENA NORTH
Argilliti e Calcareniti di Dudda
Argilliti di Cintoia
LUCOLENA SOUTH-WEST
Marne del Sugame
Argilliti di Cintoia
Argilliti e calcareniti di Dudda
Macigno
UPPER EOCENE - LOWER OLIGOCENE
MIDDLE-UPPER OLIGOCENE
BADIACCIA MONTEMURO
Argilliti e calcareniti di Dudda
Macigno
ORIZZONTE TETTONIZZATO
MIDDLE EOCENE - UPPER OLIGOCENE
?MIDDLE-UPPER OLIGOCENE
MONTEGROSSI
Montegrossi
Argilliti e calcareniti di Dudda
Macigno
LOWER-MIDDLE EOCENE
CASTELLO DI BROLIO
Argilliti e calcareniti di Dudda
Macigno
EOCENE - LOWER OLIGOCENE
?MIDDLE-UPPER OLIGOC.ENE
EOCENE

Fig. 6 - (a) Marne del Sugame Member along the road Cintoia-Dudda. (b) Alternating marls and calcareous marls along the road Cintoia-Dudda.

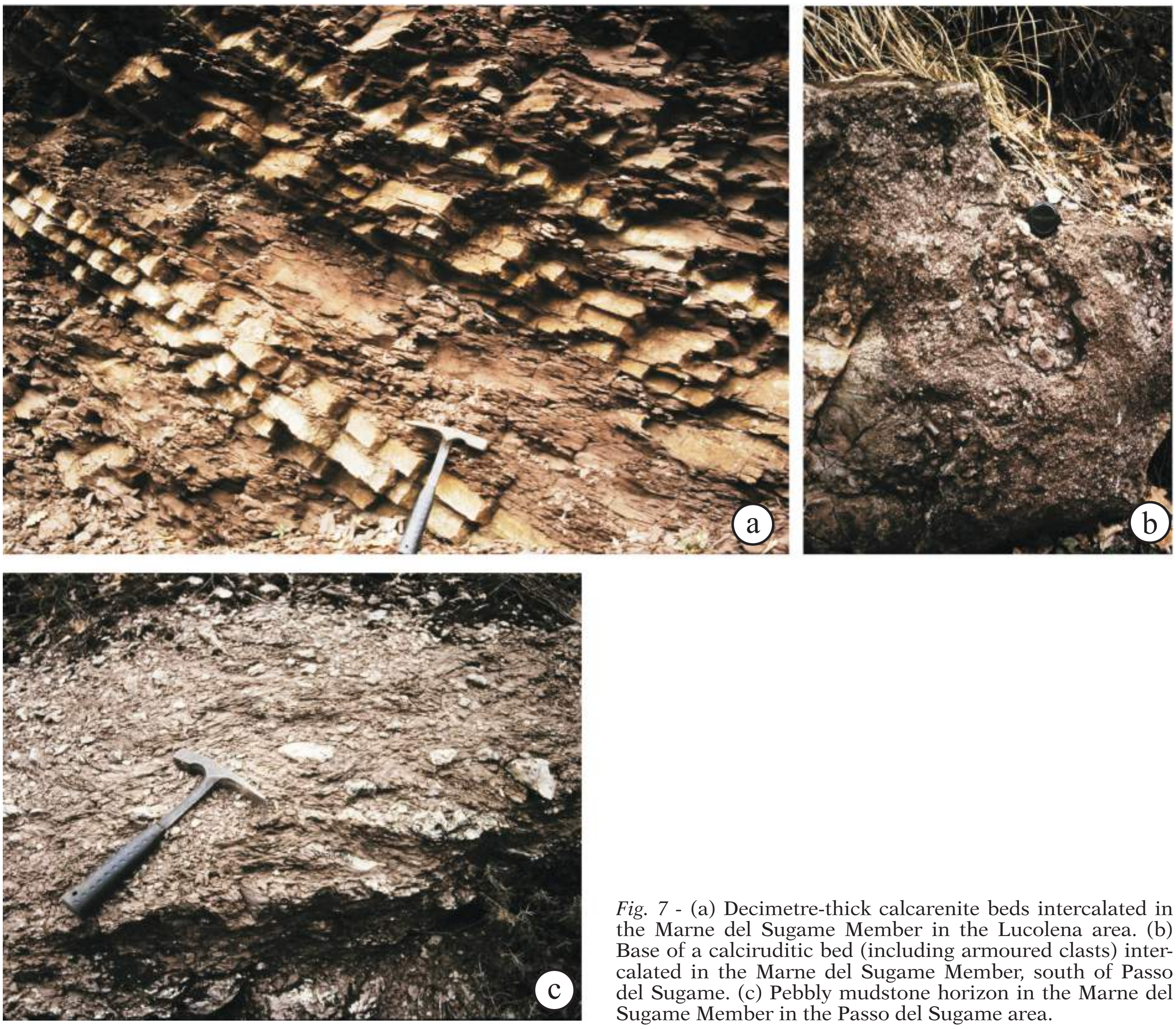

Fig. 7 - (a) Decimetre-thick calcarenite beds intercalated in the Marne del Sugame Member in the Lucolena area. (b) Base of a calciruditic bed (including armoured clasts) intercalated in the Marne del Sugame Member, south of Passo del Sugame. (c) Pebbly mudstone horizon in the Marne del Sugame Member in the Passo del Sugame area.

Fig. 8 - (a) Metric polymictic breccia bed (including carbonate, carbonate-cherty and cherty clasts) in the Marne del Sugame Member along the Borro di Cintoia, close to Cintoia. (b) Argilliti di Cintoia in the surroundings of Castello di Cintoia, SE of Cintoia.

val the occurrence of *Globigerinatheka kugleri, G. senni, G. index* indicates the P11 biozone (middle Eocene). The following sample L19 (where *Subbotina gortanii* is present) is referable to P16/17- P22 biozones (late Eocene -Oligocene). From L110 to L112 the assemblages (*Globigerinatheka index, Subbotina* sp.) indicate P12-P16/17 biozones (middle Eocene). From L113 to L25 samples, the associations (*Subbotina* sp., *Pseudohastigerina micra*, *P. barbadoensis*, *Chiloguembelina* sp., *Dentoglobigerina tripartita*, *Globigerina senilis*, *G. prasaepis*, *G. venezuelana*, *Catapsydrax dissimilis*, *C. unicavus*, *Globigerina ampliapertura)* can reliably indicate the P18/19-P22 biozones (late Eocene-Oligocene). Particularly, in this portion of the section, the L116 sample, due the occurrence of *Globorotalia tapuriensis,* points out to P21-P22 biozones (Oligocene).

In the uppermost part of the section (from L28 to L38 samples), close to the contact with the overlying Argilliti e Calcareniti di Dudda Member, the planktonic foraminiferal assemblage cannot define any biostratigraphic assignment but samples L130 and L131 include only Paleocene forms (P3a biozone: *Globanomalina ehrenbergi, G. compressa, Guembelitria* sp., *Parasubbotina pseudobulloides, Praemurica inconstans, P. uncinata, Subbotina velascoensis*) and late Cretaceous likely reworked taxa (*Globotruncana, Globotruncanita, Heterohelix,* indicating the *Dicarinella asymmetrica-Abathomphalus mayorensis* biozones interval).

Common primitive agglutinants foraminifers are also found in the rare shaly lithotypes (*Glomospira*, *Bathysiphon*, *Spiroplectammina*) together with trochospiraled calcareous hyaline deep water forams (*Nuttalites*, *Gyroidinoides*, *Cibicidoides*, *Pullenia*) and *Stilostomella*. The absence of planktonic foraminifera suggests a strong dissolution and deposition below the planktonic foraminiferal lysocline.

As it regards the calcareous nannofossils, the investigated Lucolena north samples (Appendix 2) contain common to few assemblages and show poor and/or very poor preservation. Late Cretaceous reworking is present in the upper part of the studied section. Assemblages are mainly dominated by placoliths belonging to *Coccolithus, Ericsonia* and *Dictyococcites*. Sphenoliths are also present, even if not common, while *Chiasmolithus* and *Discoaster* are rare. Unfortunately, the identification at specific level is difficult due to the poor preservation. For these reasons it is difficult to provide a reliable and specific biostratigraphic assignments.

The lowermost part of the Marne del Sugame Member (samples L14 and L101 in Appendix 5) due to the co-occurrence of *Discoaster* spp. and *Fasciculithus tympaniformis* can be assigned to NP8-NP9 Zones. The following sample L102 due to the co-occurrence of *E. formosa* and *D. multiradiatus* could suggest NP10 Zone. In sample L15 the presence of *D. barbadiensis*, *E. formosa* and *C. solitus* suggests NP10-12 biozones (early Eocene).

In the following samples (from L16 to L19), the occurrence, of *Dictyococcites scrippsae* and *D. bisectus*, together with *Reticulofenestra umbilica*, that appear within NP13 and NP16 Zones respectively, suggests a middle Eocene age. Furthermore, the sporadically occurrence of *H. compacta* from sample L20 would suggest NP17 Zone, in fact this form has its LO (last occurrence) in the lower part of NP17 Zone.

The presence of *I. recurvus, E. formosa* and the absence of rosette shaped discoasters would suggest for L116 an early Oligocene age (NP21-Zone). From L119 up to L34, the presence *of R. umbilica, D. deflandrei, Dictyococcites* and the absence of *E. formosa* could suggest NP22 Zone (Oligocene).

- *Lucolena south-west section (Appendix 3)*

In this section (L39-L41) only the sample L40 contains foraminifera (*Acarinina bullbrooki, A. topilensis, Globiger-*

inatheka senni, Morozovella aragonensis, M. spinulosa, Truncorotaloides rhori) and points out a P9-P11 biozones interval (early-middle Eocene). Only two samples L39 and L40 show calcareous nannofossil assemblages not particularly rich but fairly well-diversified mainly constituted of *E. formosa, Chiasmolithus spp., C. floridanus, R. umbilica,* rosette-shaped discoasters and *I. recurvus*.

The co-occurrence of *I. recurvus* (its LO marks the base of the NP19 Zone), *D. barbadiensis* and *D. saipanensis* (the highest occurrence of the two discoasters identifies the upper boundary of the NP20 Zone), is indicative of the NP19-NP20 biozones (late Eocene), but a NP21 biozone (middle Eocene to Oligocene) could not be excluded**.**

- Passo del Sugame section (Appendix 4)

In the Marne del Sugame Member in the Passo del Sugame section (Appendix 6), the P7-P11 biozones interval (*Acarinina* sp., *Globigerinatheka* sp., *G. senni, Morozovella* sp., *M. aragonensis, M. spinulosa, Subbotina* sp.) can be defined for the lower part (C63-C105) (early-middle Eocene) and the P12-P14 biozones interval (*Morozovella spinulosa, Pseudohastigerina danvillensis*) (middle Eocene) for the C65-C67 portion. In the C101 sample of this section the same Paleocene (P2-P3a biozones), likely reworked associations described for the Lucolena north section (samples L130 and L131), are also present.

The calcareous nannofossil assemblages (C61a-C67 samples) are common in this section, even if not well diversified. The presence among the others of *C. floridanus, D. barbadiensis E. formosa*, *D. scrippsae, D. bisectus* and *R. umbilica* would suggest a early-middle Eocene interval from NP15 to NP 17 Zones. The occurrence of *R. umbilica* in the lowermost sample C61a suggests middle Eocene NP16 Zone. The interval NP15-NP21 (middle Eocene-Oligocene) can be defined for the samples C61b to C105. The presence of *S. obtusus* at the top of the section in sample C67 suggests NP16-17 Zone (middle Eocene) and so it testifies a reworking of Eocene taxa.

Interpretation

The lithological features suggest a deposition in hemipelagic settings above or near the CCD, in which fine-grained deposits are sometimes remobilized by bottom and turbiditic currents. Coarse-grained lithofacies suggests the occurrence of debris-flow and turbidite currents. Consequently, the depositional environment is possibly represented by the middle-lower portion of a submarine slope (or ramp) where gravity flows, deriving from intra-basinal and possibly also extra-basinal sources, occurred.

The new biostratigraphic data suggest that the base of the Marne del Sugame Member spans from Cretaceous (late Albian/Cenomanian in Cintoia west section) to the early Paleogene (late Paleocene in the Lucolena north section) evidencing an important diachronous beginning of sedimentation, probably relate to a major unconformity surface. As it concerns the middle-upper part of the formation, the data from both the planktonic foraminifera and calcareous nannofossil assemblages likely suggest a time span from early to late Eocene (in agreement with the biostratigraphic results of Canuti *et alii*, 1965; Merla & Bortolotti, 1967) to early Oligocene.

The new data seem confirm as hypothesized by Canuti *et alii* (1965), i.e. a paraconformity for the upper part of late Cretaceous in the Scaglia Toscana Fm. exposed in the investigated area, similarly to that present in other areas of northern and southern Tuscany (e.g. Val Gordana close to Pontremoli: Reutter & Serpagli, 1961; Rapolano: Bambini *et alii*, 2010; Monte Amiata: Canuti & Marcucci, 1967; 1970; 1971).

Argilliti di Cintoia Member (aC)

Stratigraphic position and lithostratigraphic features

The Argilliti di Cintoia Member was described for the first time by Fazzuoli *et alii* (1996) and crops out only in the northern part of the Monti del Chianti with a maximum thickness of 60 m. These deposits consists of sky-blue, grey-greenish to dark grey shales, generally characterized by slaty cleavage, with local irregular areas of red shales. Thin beds of siliceous limestones, often black-stained by Mn oxides, rarely occur within pelitic bodies (Fig. 8b). Limestone beds are generally decalcified and altered with yellow-ochre coatings. In the type-area, i.e. between Cintoia and Badiaccia di Montemuro, the passage to the overlying Argilliti e calcareniti di Dudda Member is transitional, with calcarenitic turbidites beds that appear and increase upwards and pelites became reddish.

A lithofacies similar to the Argilliti di Cintoia Member is also stratigraphically interposed between the siliceous lithofacies of the Argilliti di Brolio and Calcareniti di Montegrossi members in the Badiaccia Montemuro section (see Plate 1).

Biostratigraphic data

Samples for this member were collected in three sections: i) the Passo del Sugame section (C69b to C70), ii) the Lucolena north section (L38) and iii) Badiaccia Montemuro section (B4-B7).

All the investigated samples are barren for foraminifera. Calcareous nannofossils are present only in the sample (C69a) of the Passo del Sugame section (Appendix 6). However, the association not provide a precise age assignment, but the presence of *Sphenolithus moriformis* suggests a generic Paleogene age.

However, the stratigraphic position of the lithofacies at the Badiaccia di Montemuro section suggests a Cretaceous age, because of its stratigraphic interposition between the Argilliti di Brolio and the overling upper-Cretaceous Calcareniti di Montegrossi members (see Plate 1).

Interpretation

The lithological features suggest a depositional environment similar to the one described for the Argilliti di Brolio Member, e.g. below CCD. An Eocene-? Oligocene age was inferred by previous Authors (e.g. Fazzuoli *et alii*, 1996) for this lithofacies due to its stratigraphic position. However, the new proposed data and its stratigraphic relationship with the underlying Marne del Sugame Member and overlying Argilliti e calcareniti di Dudda Member point to a middle-late Eocene age.

In this framework, the interpretation of the Argilliti di Cintoia-like lithofacies exposed at the Badiaccia Montemuro section is problematic. The most plausible interpretation is that this peculiar lithofacies could be locally assigned also to the upper part of the Argilliti di Brolio Member, maybe expression of the lateral depositional variabilities between paleo-structural highs and basinal area, as suggested by Ielpi & Cornamusini (2013).

Calcareniti di Montegrossi Member (cM, "Nummulitico" Auctt.)

Stratigraphic position and lithostratigraphic features

This member crop out extensively in the southern part of Monti del Chianti, where it represents the intermediate portion of the Scaglia Toscana Fm. The thickness is up to 120 m, and Nocchi (1960) reports a maximum thickness of about 200 m. To the north the member is represented by decametre-thick lenticular bodies that pass laterally to the Argilliti e calcareniti di Dudda Member. The transition to the overlying Argilliti and Calcareniti di Dudda ("Sopra Nummulitico" di Losacco, 1959) is generally sharp even if locally it could be transitional, marked by the progressive decrease of beds thickness and the increase of pelitic intercalations (see Montegrossi and Castello di Brolio sections in Plate 1). This contact may be frequently tectonized because of a more plastic behaviour of the Argilliti e Calcareniti di Dudda Member (Fig. 9b).

The member mainly consists of grey bioclastic calcarenites and calcirudites, often cherty (grey nodules and minor levels/bands), alternating with thin fine-grained beds (generally millimetric to centimetric) (Figs. 2 and 9a). Calcarenites are generally graded and show Tab, Tac, Tbc, Ta/c/e Bouma's intervals, whereas Ta/e and Ta-e are subordinate. Cm-thick calciruditic lenses are locally present in some of the thickest pelitic intercalations in the lower part of the member (see Plate 1). Decimetric levels of polymictic breccias and conglomerates (similar to those intercalated in the Marne del Sugame Member) also locally occur, particularly in the basal part of coarser beds. The thickness of calcarenites beds generally varies from 30 cm to 3 m. The bases of the beds are generally flat even if local erosional scours (max 1.5 dm deep) can be recognized, sometimes leading to bed amalgamation. Grading (sometimes only coarse tail grading) is generally evident. The beds are typically tabular at the outcrop scale, but lenticular beds locally occur and they extend laterally up to some tens of metres. Current structures, as flute casts and groove casts, are rather rare due to the amalgamation of the beds and indicate a prevalent ENE/NE provenance, as already stated by Sestini & Pranzini (1964), Sestini (1964) and Parea (1965). Grains are mostly made up of bioclasts (micro and macroforaminifera, fragments of neritic pelecypods as *Inoceramus* and Rudists and of calcareous algae) and, subordinately, by lithic fragments similar to those of the pebbles in the Marne del Sugame Member (i.e. cherts and pelagic limestone of Tithonian to Eocene age and shallow water limestone characterized by Lower Jurassic microfacies: details in Sestini, 1964; Canuti et alii, 1965). Pelitic intercalations between calcarenites consist of wine-red, yellowish and minor grey-greenish shales, marly shales and rare marls.

At places, up to 2 metres thick bodies of "Argilliti e Calcareniti di Dudda-like" alternations of pelites with cm-thick fine calcarenites are intercalated within the thicker and coarser beds (see the lower part of the Montegrossi section in Plate 1). These levels help to evidence an internal cyclicity of the Calcareniti di Montegrossi Member represented mostly by negative-type cycles that locally are organized into complex, multiple-type cycles up to about 50 metres in thickness (see Brolio section in Plate 1). Fining- and thinning-upward sequences are not common and are generally at the top of some negative cycles producing composite-type main cycles (see in the Montegrossi section in Plate 1).

Biostratigraphic data

- Badiaccia di Montemuro section (Appendix 5)

The planktonic foraminifera association of the basal part of this member (sample B8 in Appendix 5) indicates a biozone interval from *Rotalipora ticinensis* to *Helvetoglobotrucana helvetica* (late Albian-middle Turonian) due to the presence of *Heterohelix and Praeglobotruncana*. The following B9 sample suggests *Globotruncanita elevata-Globotruncana ventricosa* biozones (Campanian) because of the presence of *Globotruncana* cf. *mariei*, *G. arca*, *Globotruncanita elevata*. The samples of the upper part (B10-B12), in which only *Globotruncana* sp. was recognized and indicating *Dicarinella concavata-Abathomphalus mayaroensis* biozones, are referred to a not well defined late Cretaceous age.

Calcareous nannofossil assemblages are rare and not well preserved (see Appendix 5). Only one sample (B8) contains a Cretaceous nannoflora. The assemblage is mainly characterized by *P. cretacea* s.l., *W. barnesiae*, *S. crenulata*, *M. decoratus*, *Q. gartneri*, and *L. carniolensis*. The occurrence of *Q. gartneri* suggests a Turonian-Santonian interval (CC11-15).

- Montegrossi section (Appendix 6)

Most of the recognized fossils are *Orbitoides*, *Siderolites calcitrapoides*, *Omphalocyclus* associated to *Inoceramus* prisms, rudist fragments and Globotruncanidae and Heterohelicidae.

In particular, samples in the lower portion of the member (samples MG5 to MG7) contain bioclasts made up of macro and planktonic foraminifers (*Globotruncana, Muricohedbergella* and *Heterohelix*) indicative of the *Dicarinella concavata-Abathomphalus mayaroensis* biozones interval (late Cretaceous). In the pelitic intraformational clasts, *Heterohelix* and *Muricohedbergella* occur, whereas in the matrix of the MG8 graded calcirudites only *Globotruncana* cfr. *rosetta* is present, indicating the *Globotruncana ventricosa-Abathomphalus mayaroensis* biozones interval (Campanian-Maastrichtian).

From MG9 upwards Paleocene-Eocene foraminifera are present in the assemblages: Paleocene macroforaminifera (Nummulitidae, *Discocyclina*) begin from the MG9 sample, whereas middle Paleocene-early Eocene planktonic foraminifera (*Morozovella velascoensis*) of the P3a-P5 are present from sample MG14. From MG 14 upwards, Paleogene macroforaminifers (small *Nummulites*, *Miscellanea*, *Cuvillierina*, *Linderina* and *Eoanularia)* can also be identified and red algae are very abundant (*Polystrata alba*). The MG18 and MG19 samples are characterized by a greater number of species (*Praemurica uncinata*, *P. trinidadensis*, *Morozovella aequa, Acarinina mckannai, M. angulata, Globanomalina compressa, Subbotina pseudobulloides)*, although associated with reworked Globotruncanidae, suggesting a P4c-P5 biozones interval (late Paleocene-early Eocene).

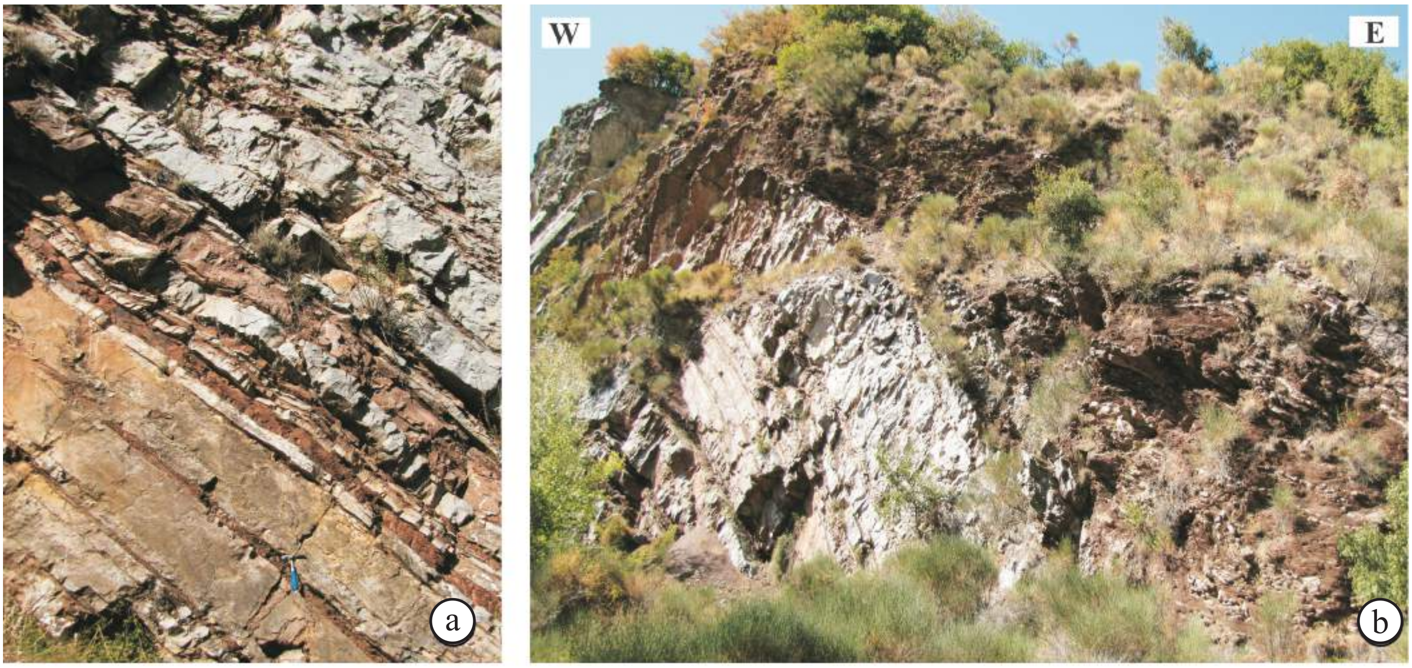

Fig. 9 - (a) Calcareniti di Montegrossi Member in the Montegrossi quarry. (b) Disharmonic tectonic contact between the Calcareniti di Montegrossi and the overlying Argilliti e Calcareniti di Dudda Members in the Montegrossi Quarry. (c) Sedimentary polymictic breccia in the upper part of the Calcareniti di Montegrossi Member (Montegrossi quarry).

In the samples MG20, 21 and 23 only undetermined planktonic foraminifera are present. From the samples MG25 to MG34 planktonic foraminifera associations generally indicates the P6-P14 biozones interval due to the occurrence of *Pseudohastigerina danvillensis*, *Morozovella spinulosa*, *Hantkenina, Planorotalites*, *Globanomalina ehrenbergi* (early-middle Eocene). However, the sample MG31 contains only reworked Cretaceous and Paleocene (*Praemurica trinidadensis, P. uncinata)* planktonic foraminifera. This level could be the equivalent of the C101 sample of the Passo del Sugame section and of L130-L131 samples in the Lucolena north section.

As far as the nannofossil content is concerned (see Appendix 6), a pelitic level in the basal part of the Calcareniti di Montegrossi Member (sample MG4) is characterized by a relatively rich Campanian-Maastrichtian assemblage, although with a low degree of preservation. This assemblage is mainly represented, among others, by rare to common *Arkhangelskiella cymbiformis* and *W. barnesiae*, rare *Micula* sp., very rare *Microrhabdulus decoratus*, *Lithraphidites praequadratus and Lucianorhabdus cayeuxii.* The presence of *A. cymbiformis* and *L. praequadratus* suggests an interval spanning Zones CC21-26.

Only few other samples (MG30-33) collected in marly levels of the upper part of the Calcareniti di Montegrossi Member showed a nannofossil content. The assemblages of these samples, poorly preserved and less diversified, consist mainly of *E. formosa*, *Chiasmolithus grandis*, *C. consuetus*, *C. pelagicus*, *Zygrhablithus bijugatus* and *Brarudosphaera bigelowi*. Cretaceous taxa, clearly reworked are quite common. The co-occurrence of *E. formosa* and *C. grandis* and the lack of *R. umbilica* is indicative of Zones NP12-17 (early-middle Eocene).

- *Castello di Brolio section*

No biostratigraphic distribution chart is shown here for this section because a few samples (thin sections) of calcisiltites and calcarenites were examined. In addition their microfossil content is not definable due to their bad preservation and re-cristallization. Only in the sample BR28 (lower part of the section) large Globotruncanidae can be recognized pointing to Turonian-Maastrichtian age.

Interpretation

Sedimentological features suggest that deposition occurred in a deep sea fan turbiditic system within a basinal plain and placed transversally with respect to the axis of the present Apenninic chain and likely below the CCD (see Discussion). In more detail, according to Fazzuoli *et alii* (1985) the deposits of the Calcareniti di Montegrossi Member can be referred to turbiditic lobe deposits with minor channelized areas at their top in an external part of a deep sea turbiditic fan. The regular lateral-vertical transition of the Calcareniti di Montegrossi Member with the Argilliti e Calcareniti di Dudda members seems to indicate a flat sea bottom morphology. The nearby occurrence of Marne del Sugame Member in the Cintoia-Lucolena area points also to the presence of a morphological-structural high that bounds the turbiditic basin towards north (Fazzuoli *et alii,* 1985; 1996).

The lower part of the member is traditionally attributed to the late Cretaceous whereas the middle and the upper part to the Paleocene-Eocene through foraminifers (Nocchi, 1960; Canuti *et alii*, 1965). This age attribution is confirmed by the samples B8-12 of the Badiaccia di Montemuro section and from the samples collected in the lower part of the member in the other sections, that would be assigned to Campanian-Maastrichtian interval.

In the upper part of the member, the fossiliferous content confirms the traditional Eocene accepted age. Moreover, the Cretaceous-Paleogene transition and the middle Eocene can be approximately recognized in the three different sections.

Argilliti e Calcareniti di Dudda Member (acD)

Stratigraphic position and lithostratigraphic features

This member is the younger of the Scaglia Toscana Fm. and, in the studied area, forms a substantially continuous level at the top of the investigated formation. The thickness varies from some tenth of metres at Cintoia (where it can locally lack) to about 60 metres in southern areas. Moreover, between Badiaccia Montemuro and Albola this member is the stratigraphic lateral equivalent of the Calcareniti di Montegrossi Member and is interposed between the Marne del Sugame and Argilliti di Cintoia members in the Lucolena north section (see the enclosed Albola-Cintoia geological map). The transition with the arenaceous and thick turbidite beds of the overlying Macigno Fm. is rather sharp (cfr. Ferrini & Pandeli, 1983; Cintoia east section in Plate 1), even if rare thin intercalations of carbonate siltstones or impure calcarenites may occur at the top of the Argilliti e Calcareniti di Dudda Member.

This unit consists of an alternance of varicoloured shales (mainly wine-red), at times marly, and of decimetre-thick (max 60 cm) beds of turbiditic calcarenites and calcilutites, grey to grey-greenish in colour and showing Tb-e, Tc-e and Td-e intervals (Fig. 10). The pelite/arenite ratio varies from 1:4 to 4:1. Reddish marls and shaly marls, as well as grey-green siliceous limestones, are also locally present. Beds show a tabular geometry with flat bases. Occasionally, decimetric coarser and lenticular (over a few kilometres) calcarenite beds occur. This member generally not show a clear cyclic organization, but some m-thick (up to 4 m) single negative cycle (i.e thickening- and coarsening-upward) can be locally found. The occurrence of flute and groove casts allows to determine the provenance of turbiditic flows from the NE/NNE (see also Sestini & Pranzini, 1964; Sestini, 1964 and Parea,1965). At one locality (i.e. at Casale Mirra to NW of Case di Dudda) a “Montegrossi calcarenite-like” body is present within the Argilliti e Calcareniti di Dudda Member.

A peculiar lithofacies of the Argilliti e Calcareniti di Dudda Member occurs at the base of the Calcareniti di Montegrossi Member in the Albola section area (see the enclosed Albola-Cintoia geological map) and immediately to the east of the studied area in the Valdarno area (i.e. in Le Scaglie Quarry about 3,5 km south of Castelnuovo dei Sabbioni) and it is expressed by grey to greenish marls and clayey marls with intercalations of grey, centimetric to decimetric-thick calcarenites and calcilutites. This lithofacies can be correlated to the “Sotto Nummulitico” of Losacco (1959).

Biostratigraphic data

This member was sampled in the Cintoia east section (C40-53), Montegrossi section (MG35-38), in the Lucolena south-west section (L43-L48), Passo del Sugame section (C71) and Badiaccia di Montemuro section (B14-B21). In all the sections the calcisiltites contain mainly planktonic foraminifers of different ages: Globotruncanidae, *Morozovella*, *Acarinina*, *Globigerinatheka* and *Subbotina*. The calcarenites contain abundant planktonic Cretaceous-Tertiary foraminifers and nummulitid, discocyclinid and linderinids fragments. At the top of the Passo del Sugame section, grey- reddish shales, interbedded within the calcareous detrital beds, contain only agglutinant foraminifers *(Cyclammina*, *Haplophragmoides*, *Glomospira*, *Recurvoides* and Bathysiphonidae, characteristic of an environment below the CCD). Reworking processes are widely recognized and consequently the age indications are very scarce and uncertain.

- *Cintoia east section (Appendix 7)*

In the upper part of the member some samples (C45, C46, C48 and C50) show a microfacies represented by grey packstones containing only common *Subbotina* and *Catapsydrax* and nummulitids indicating a very wide time interval (late Paleocene-Oligocene). Calcareous nannofossils are absent in samples C41 and C42, and poorly preserved in samples C40, C43-45, C48. The assemblage is mainly represented by placoliths and sphenoliths. The age assignment is difficult due to the scarcity and preservation of the nannofossils; but however the occurrence of *C. floridanus*, *D. scrippsae*, *Reticulofenestra samudorovi* e *R. umbilica* can suggest an interval from middle Eocene (NP15 Zone) to Oligocene or younger age.

- *Lucolena south-west section (Appendix 3)*

In the lower part of the section, the foraminifera association of the samples L40, constituted by *Acarinina*

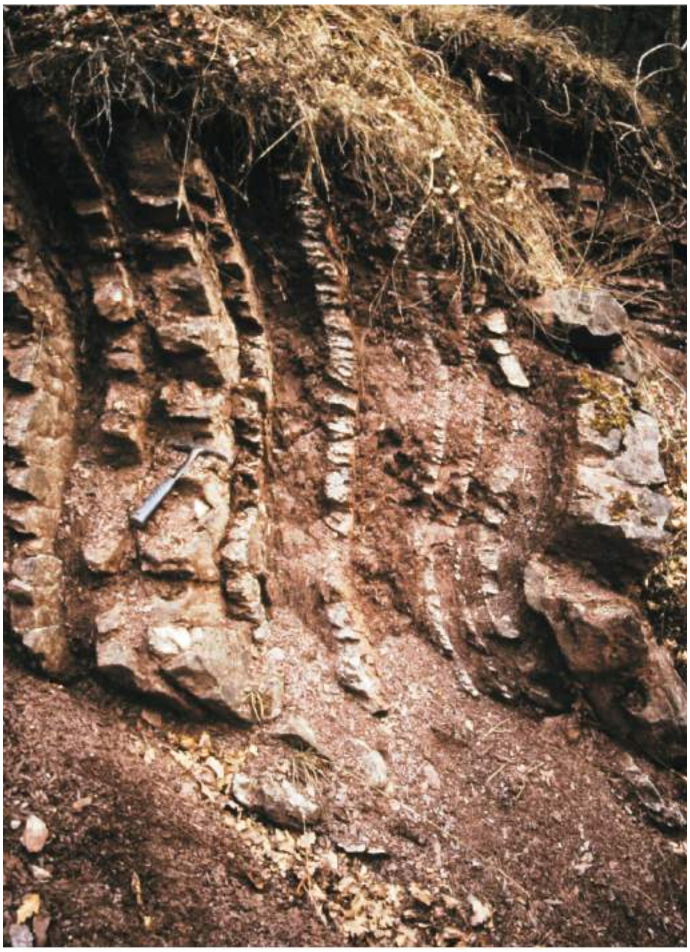

Fig. 10 - Argilliti e calcareniti di Dudda Member in the Badiaccia Montemuro section.

bullbrooki, A. topilensis, Globigerinateka senni, Morozovella aragonensis, M. spinulosa, Truncorotaloides rohri, defines a P9-11 biozones interval (early-middle Eocene). In the sample L45, *Inoceramus* prisms and Cretaceous planktonic foraminifers are associated with *Morozovella* (P6-P11 biozones) (early-middle Eocene). In L47 *Catapsydrax* sp. (from P14 biozone upwards) is locally present in some mudstones clasts, suggesting an Oligocene age. Instead, the nannofossil content of L39 and L40 in the lower part of the section defines a NP19-NP20 biozones interval (late Eocene).

Similar to those reported for the Cintoia east section, the samples suggest a late Eocene-Oligocene age interval.

- *Badiaccia di Montemuro section (Appendix 5)*

The first fossiliferous sample (B16) contains only *Macroglobigerinelloides* sp. that suggests a generic Cretaceous (Albian-Maastrichtian). From B18 upwards the samples from calcareous beds include *Subbottina, Pseudohastigerina, Hantkenina, Globigerinateka, Acarinina* indicating the P10-P14 biozones interval (middle Eocene). The nannoflora in the samples (B14-B19) contains assemblages including *D. barbadiensis*, *C floridanus* and *S. pseudoradians* suggesting the NP16-20 biozones interval, but a younger age could not be excluded (NP21?) (middle Eocene to Oligocene?).

- *Montegrossi section (Appendix 6)*

Samples MG35-38 show a foraminifera association (*Acarinina topilensis, Morozovella aragonensis, M. spinulosa* and *Linerina)* that indicate P8 to P11 biozones interval (early-middle Eocene).

Interpretation

The fine-grained turbiditic deposits of this member represent the lateral and possibly the down-current evolution of more dense turbidites represented by the Calcareniti di Montegrossi Member within the same calcareous turbiditic system. In particular we attribute the Argilliti e Calcareniti di Dudda Member to the inner and distal part of the fan fringe and, partly, to interlobe deposits (see also Fazzuoli *et alii*, 1985). In the northern part of the studied area, this member stratigraphically overlies the Argilliti di Cintoia Member, from which it differs mainly for the abundance of detrital calcareous cm- to dm-thick beds. The Argilliti e Calcareniti di Dudda Member together with the Calcareniti di Montegrossi Member, testify a continuous calcareous turbiditic supply above the Argilliti di Brolio Member in the southern sections.

Based on faunal content the member is traditionally attributed to the middle-late Eocene (Canuti *et alii*, 1965), but, for stratigraphic reasons, an Oligocene (p.p.) age must also be inferred for the upper part of this unit (Fazzuoli *et alii*, 1996, 2004). Data collected in this work confirm a (?) middle-upper Eocene age. In the upper part of Lucolena south-west section, the presence of only *Catapsydrax* can testify a younger age (Oligocene). This attribution cannot be excluded by the nannofossil assemblages. In this frame, it is also to underline the gradual contact with the overlying upper Oligocene Macigno Fm., that strengthens the possibility of an Oligocene age for the uppermost part of this member.

DISCUSSION

General features of the Scaglia Toscana Fm. in the Monti del Chianti area

The study integrates the geological surveys carried out from the 60's along the Monti del Chianti Ridge with new lithostratigraphic and biostratigraphic data, confirming the subdivision of the Scaglia Toscana Fm in five members or lithofacies as proposed respectively by Canuti *et alii* (1965), Fazzuoli *et alii* (1996, 2004). These units were attributed to three main sub-environments of the Adriatic passive-type margin. The Argilliti di Brolio and the Argilliti di Cintoia Members can be referred to a basin plain or to lower slope areas below the CCD. This is confirmed by the lack of calcareous microfossils and by the dissolution degree of nannoplancton, which typifies an environment below or near the CCD (with the exception of some thin marly shales levels of the Argilliti di Brolio Member in the Cintoia west section where well preserved foraminifera are present).

The Marne del Sugame Member was deposited in an emipelagic ramp and can be subdivided in two lithofacies related to the middle-upper (essentially marly-calcareuos) and to the lower part of pelagic ramps (e.g. with turbiditic intercalations and debris flows). Samples from this member are characterized by an overall abundance of well-preserved microfossils that point to a sea bottom above the CCD. Instead, the Calcareniti di Montegrossi and the Argilliti e Calcareniti di Dudda represent a turbiditic fan in a basin plain mostly placed below the CCD.

As regards the calcareous turbiditic members (Calcareniti di Montegrossi and Argilliti e Calcareniti di Dudda), their mostly carbonate-free pelitic intercalations suggest a basinal area below the CCD that locally interfinger with the lower slope (see calcarenitic beds in the Marne del Sugame Member) close to, but over the CCD.

Moreover, the microfossil assemblages present in the Scaglia Toscana Fm. often show evidence of reworking, probably due to gravitational flows processes (e.g. pebbly mudstone levels in the Marne del Sugame Member).

Stratigraphic relationships between members and implications for palaeoenvironmental reconstruction

As demonstrated by the geological surveys, by physical correlations (see Fig. 11) and by biostratigraphic data (Appendices 1 to 7), lithological variations between the members of the Scaglia Toscana Fm. (at the scale of few hundred meters) are evident both vertically and laterally in the different areas (see stratigraphic sections in Plate 1). This variability can be related to the different bathymetric conditions at the sea bottom, to the location of the calcarenitic main turbiditic systems and to evolution of their source areas. A scheme of the lateral and vertical relationships among the different lithofacies along the Monti del Chianti area is shown in Figure 11, which is transversally oriented (NW-SE) respect to the inferred axes of the turbiditic systems, that are characterized by clastic inputs coming from NE/ ENE.

NE-SW strikes are well-known for the main Jurassic-Eocene sedimentary basins and structural highs of the Adriatic margin, at least in the northern Tuscany area (e.g. Val di Lima trough in Fazzuoli *et alii*,1985, 1994a). Instead, NS-trending Jurassic tectono-sedimentary trends are present in southern Tuscany (e.g. Monti del Chianti-Cetona basin in Fazzuoli & Sguazzoni, 1986; Fazzuoli *et alii*, 1994b; see Fig. 12a). All these narrow basins are related to Mesozoic to Tertiary extensional/trans-tensional evolution of the passive Adria margin in which anti-Apennine (i.e. NE-SW striking) tectonic lines were active (e.g. the Livorno-Prato-Sillaro line in Bortolotti, 1966; Fazzuoli *et alii*, 1985; Fazzuoli & Sguazzoni, 1986), and consequently played an important role in the architecture of the basins and in the stratigraphic features of their filling deposits. In this view, for example, the basal member of the Scaglia Toscana Fm. (i.e. the Argilliti di Brolio), is present throughout the area but with different thickness, i.e. throughout towards the southern sectors of the basin. The overlying Marne del Sugame Member shows a more articulated stratigraphic architecture, showing marly-calcareous sediments in the northern areas (e.g. Cintoia, Lucolena) passing basinward to calcareous turbidites southward (Fig. 12b). These evidence and the aforementioned considerations about the CCD made for the different lithofacies, suggest that the southern sectors of the Scaglia Toscana Fm. recorded deposition in a deeper depositional environments respect to the northern ones. Maybe, this peculiar paleogeography configuration is responsible of the concentration of the calcareous turbiditic inputs in a deep sea fan system fed from an eastern source area.

However, the areal extent (more than 20 km) and the continuity of the main turbiditic body of the Calcareniti di Montegrossi Member, as well as their lateral interfingering with the low-density turbidites of the Argilliti e Calcareniti di Dudda, suggest a relatively flat basin plain that was gradually connected to the north with the marly slope of the Marne del Sugame. The sedimentological data show that the body of the Calcareniti di Montegrossi can be mostly referred to the outer part of the deep sea fan that was characterized by thick depositional lobes locally prograding on interlobe/fan fringe deposits (cf. Mutti & Ricci Lucchi,1972; Mutti & Normark, 1987; 1991). Given that the Calcareniti di Montegrossi and the overlying Argilliti e Calcareniti di Dudda Members belong to the same turbiditic system, their overall fining- and thinning upward megasequence suggests an overall retrogradational trend, maybe connected with the progressive deactivation of the deep-sea fan.

The sharp contact of the calcareous turbidites onto the Argilliti di Brolio Member in most of the southern areas suggests a sharp arrival of the coarse-grained turbiditic flows in the basin. However, at places the Argilliti e Calcareniti di Dudda Member occurs between the Argilliti di Brolio and the Calcareniti di Montegrossi Members (e.g. the Albola section area but also in the Valdarno area, immediately to the east of the study area) and suggests a basal progradational trend of the calcareous turbiditic fan (see Fig. 11). Similar bodies of Calcareniti di Montegrossi-like lithofacies occur also in the Scaglia Toscana Fm. of SE Tuscany (Monte Amiata area: Hein, 1982; Pandeli *et alii*, 2005) and western Umbria (Trasimeno Lake area: Nocchi, 1962; Canuti *et alii*, 1965; Damiani & Pannuzi, 1985; Ghelardoni, 1962; Pirini & Mosna, 1962) and these deposits possibly belong to a single turbiditic body. In fact, the Calcareniti di Montegrossi-like in SE Tuscany was separated from the Montegrossi-Brolio fan by the Rapolano area, in which the Scaglia Toscana Fm. mainly consists of Brolio- and Dudda- like lithofacies (Hein, 1982; Canuti *et alii*, 1965; Canuti & Marcucci, 1967; Bambini *et alii*, 2009, 2010; see Fig. 12b).

It is not easy to recognize the source area (i.e. carbonate platforms) of the calcareous turbidites of the Scaglia Toscana Fm. because it is difficult to explain the occurrence of shallow water carbonate grains within these deposits taking into account the eastern provenance of the turbiditic inputs. In fact shallow water carbonates are lacking in the neighbouring western part of the Umbrian Domain (Passeri, 1994), as well as the carbonate clastic inputs from coeval carbonate platforms stopped in the eastern Umbria-Marchean Domain and in the southern Umbrian basinal areas, i.e. Umbria-Sabina Domain in front of the Latium-Abruzzo platform (Capuano *et alii*, 1988, 1993; Capuano, 1990; Civitelli *et alii*, 1988; Colacicchi & Baldanza, 1986). A possible hypothesis is that these sediments derived from an area interposed between the Tuscan and Umbrian Domain (see Fig. 12b), completely destroyed due to the Miocene thrusting of the Tuscan Units (Tuscan Nappe and the outermost Cervarola-Falterona Unit) onto the western Umbrian Units (see Aruta *et alii*, 1998). In this area, a restricted Cretaceous-Tertiary carbonate platform could be grow, similarly to the Bagnolo Platform (Bosellini *et alii*, 1981)

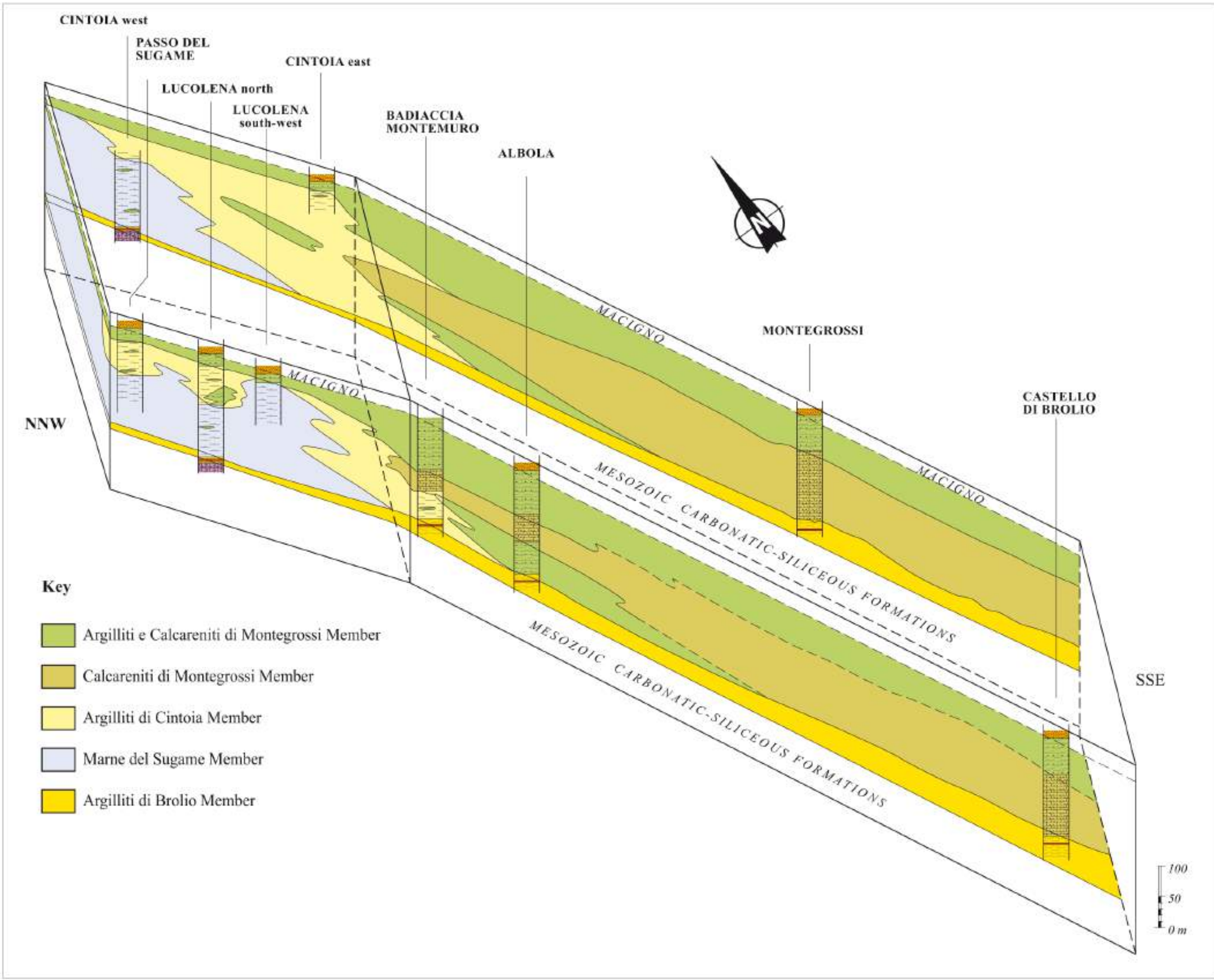

Fig. 11 - Three dimensional correlations of the Scaglia Toscana members from Cintoia to Castello di Brolio. Reference surface (datum): contact with the underlying Maiolica and overlying Macigno Formations.

evidenced by oil wells in the Pianura Padana near Carpi (Modena) that was considered by FAZZUOLI *et alii* (1985) the source area for the calcareous turbidites of the Scaglia Toscana Fm. in the Val di Lima Basin. This western Umbria platform probably continued its sedimentation until Oligocene-early Miocene feeding the carbonate turbidites key beds intercalated in the Cervarola-Falterona siliciclastic foredeep body (BRUNI & PANDELI, 1980; ARUTA *et alii*, 1998).

The transition from the Argilliti di Brolio Member to the Marne del Sugame and Calcareniti di Montegrossi Members points to a substantial and rapid morphologic modification of the homogeneous context of the Argilliti di Brolio basin plain. Particularly, in spite of the passage to the Marne del Sugame Member is locally gradual (e.g. in the Cintoia section, see Plate 1), in other sections is sharp and marked by important unconformities generally extending from Cenomanian p.p. to the early Eocene p.p. In this framework, it is noteworthy the lack of the Argilliti di Brolio Member at Fosso Cerungoli (between Passo del Sugame and Lucolena) where the direct contact of the Cenozoic Marne del Sugame Member above the Maiolica Fm. is exposed (see the enclosed Albola-Cintoia geological map and CANUTI *et alii*, 1965). Based on the new biostratigraphic data, this basin physiography modification occurred in the Upper Cretaceous-early Paleogene time interval and can be referred to the transtensional reactivation of older (Mesozoic?) tectonic lineaments due to the beginning of the closure of the Tethys Realm (Ligurian-Piedmontese Ocean) (see also FAZZUOLI *et alli*, 1994b; VAI & MARTINI, 2001). These syn-sedimentary tectonic events are also outlined by the local intercalation of coarse-grained debris flow (see the late Cretaceous breccias with Mesozoic calcareous-siliceous, cherty and calcareous clasts of Tuscan facies in the Cintoia section), probably sourced by highs of the Tuscan Domain, and by the frequent resedimentation of the emipelagic deposits in the Marne del Sugame Member (as suggested by the local abundance of late Cretaceous and Paleocene microfossils within the Eocene sediments).

Since Oligocene (taking into account the biostratigraphic data of the Marne del Sugame Member in Lucole-

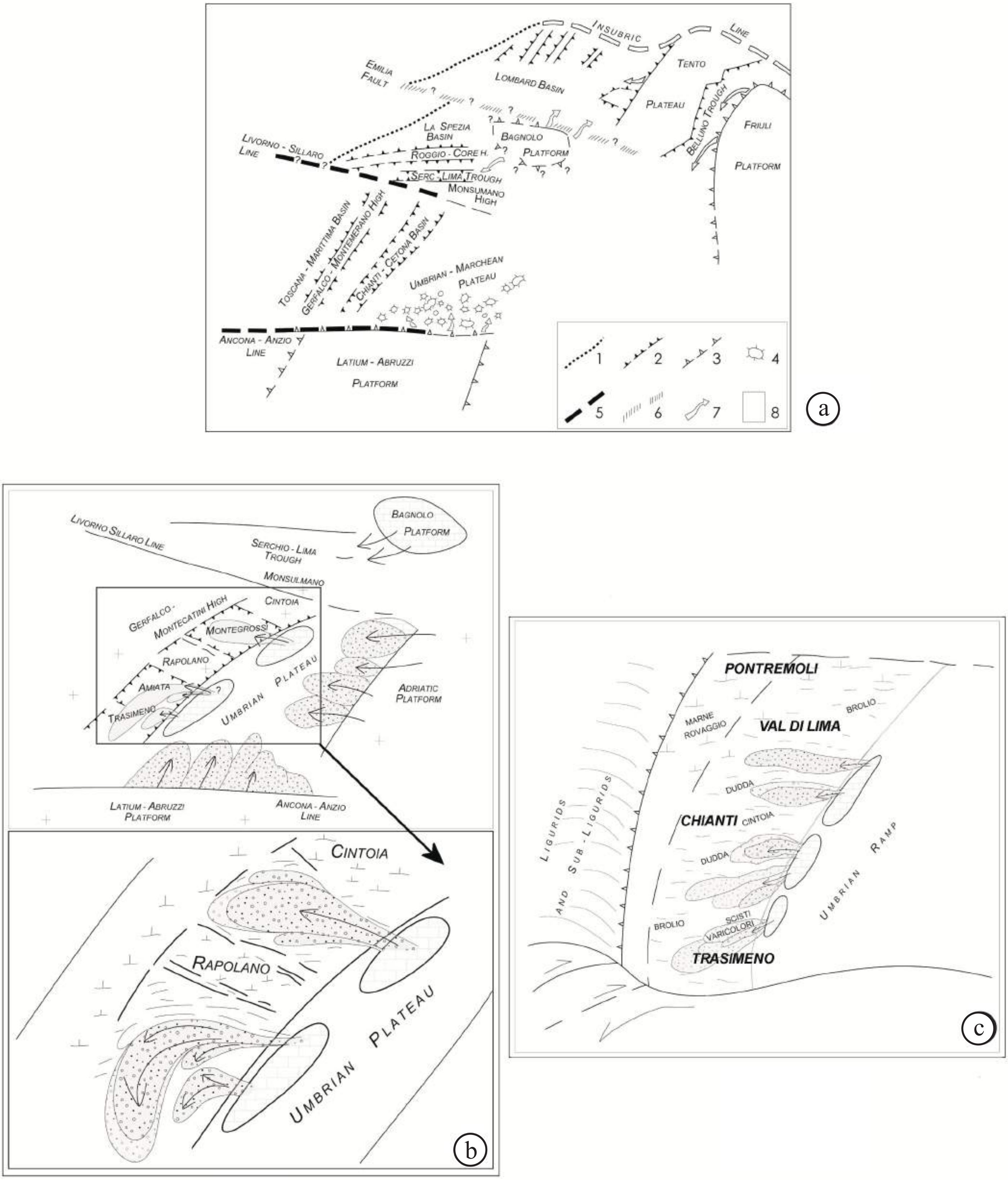

Fig. 12 - Sketches of the tectono-sedimentary evolution of the Tuscan Domain and surrounding areas in the a) Late Jurassic-Early Cretaceous (after FAZZUOLI & SGUAZZONI, 1986), b) Late Cretaceous-Middle Eocene and c) Late Eocene-Early Oligocene spans of time.

na north section) the depositional environment was characterized by an overall deepening accompanied with a reduction of the coarse-grained clastic turbiditic inputs. This is suggested by the shaly Argilliti di Cintoia Member that deposited above most of the Marne del Sugame Member in the northern sectors, whereas the Calcareniti di Montegrossi Member pass upward to the Argilliti e Calcareniti di Dudda Member. We suggest that this retrogradational trend of the calcareous turbiditic system can be referred to a more free expansion of the turbiditic flows in the wider basinal that was substancially levelled and interfingered with the shaly sedimentation at regional scale. The batimetric smoothing could be related to the filling of the relative morphological lows by the coarse-grained turbiditic sedimentation. Instead, the general deepening of the studied area below the CCD could be due to the initial stages of the flexure of the whole Adriatic margin which allowed the formation of the Apenninic foredeep during the late Eocene-Oligocene syn-collisional event (see Fig. 12c). This new main, NW-SE oriented depocenter will receive the siliciclastic turbidites of the ?middle/late Oligocene-Aquitanian Macigno sourced from the central-western Alps (Fazzuoli *et alii*, 1994b; Ricci Lucchi, 1986; Boccaletti *et alii*, 1990; Pandeli *et alii*, 1994).

Comparison with the Scaglia Toscana Fm. exposed in other areas of the Northern Apennines

Strong analogies can be recognized with the Scaglia Toscana Fm. exposed to the north of the study area, i.e. between Monsummano-Montecatini and south-eastern Val di Lima (W and NW of Pistoia) (Fig. 12 a, b, c). In these areas the Argilliti di Brolio Member underlie a relevant thickness of Marne del Sugame Member that pass vertically to shaly sediments locally with calcareous turbiditic intercalations which are instead more typical to the north, i.e. in the central part of the Val di Lima trough (Fazzuoli & Maestrelli-Manetti, 1973; Hein, 1982; Dallan *et alii,* 1981; Fazzuoli *et alii,* 1985, 1994a). There, thick bodies of Montegrossi-like calcareous turbidites directly overlie the Neocomian Maiolica Fm. and underlie a top lithofacies constituted by shales and rare thin-bedded calcarenitic intercalations ("Argilliti "superiori" or "Brolio 3" in Fazzuoli *et alii*, 1985, 1994a). Passing more to the NW (i.e. the northern margin of the Val di Lima trough), the stratigraphic settings of the Scaglia Toscana suggest the presence of another Mesozoic-Eocene morphological-tectonic high (Roggio-Corfino high in Fazzuoli *et alii*, 1985). This is testified by an angular unconformity of the Scaglia Toscana Fm. onto the Jurassic formations, also marked by an horizon of calcareous-siliceous breccia ("Breccia cenomaniana" in Hein, 1982; Fazzuoli *et alii*, 1985). Upward, the Scaglia Toscana Fm. continues with marly pelites of Upper Cretaceous-Oligocene age with sporadic calcilutitic/calcarenitic intercalations.

The regional paleoenvironmental smoothing at the top of the Scaglia Toscana is also testified in areas located to the south-east of the Monti del Chianti-Rapolano Ridge. In fact, a final mainly shaly sedimentation is present above the "Nummulitico" calcarenites in the Scisti Varicolori at the base of the Monte Falterona turbiditic siliciclastics, in the area extending from Arezzo to the Trasimeno lake (Damiani & Pannuzi, 1985; Ghelardoni, 1962; Pirini & Mosna, 1962; Nocchi, 1962).

Instead, a completely different situation is shown in the northernmost areas of the Scaglia Toscana (e.g. Pontremoli area as far as Val di Lima), where the Oligocene marly-silty "Marne di Rovaggio" top member is widespread (Hein, 1982; Fazzuoli *et alii*, 1985) (Fig. 12c). In the regional architecture of the Scaglia Toscana Fm., this member can be interpreted as the evidence of the "dirty" marly sedimentation above CCD on the western slopes of the proto-foredeep basin (see Fig. 12c).

Anoxic levels within the Argilliti di Brolio Member

At the top of the the Argilliti di Brolio Member we reported the local presence of black, organic matter and Mn-rich cherts and shales of Cenomanian-Turonian age. Similar levels were recognized in other sections of the Scaglia Toscana Fm. at regional scale (see Passerini, 1965; Hein, 1982; Marcucci *et alii*, 1994; Pignotti, 1994; Bambini *et alii*, 2009, 2010) and are coeval with the well-known Bonarelli level in the Scaglia Bianca of the Umbrian successions (cfr. Piergiovanni, 1989; Chiari *et alii*, 2005 and references therein) and with other correspondent anoxic levels in pelagic successions of both south (cf. Gallicchio *et alii*, 2008) and north Italy (cf. Salvini & Marcucci, 1998). These black sediments stratigraphically correspond to those linked to the late Cretaceous marine anoxic event pointed out by many authors at a global scale (Schlanger & Jenkyns, 1976; Schlanger & Cita, 1982; Arthur & Premoli Silva, 1982; Piergiovanni, 1989; Scholle & Arthur, 1980; Arthur *et alii*, 1987).

CONCLUSIONS

The sedimentological, lithological and biostratigraphic analyses performed on the Scaglia Toscana Fm. outcropping along the Monti del Chianti Ridge lead to these conclusions:

1) Five members of Scaglia Toscana Fm. have been distinguished and mapped in the studied area, that in stratigraphic order are: Argilliti di Brolio, Marne del Sugame, Argilliti di Cintoia, Calcareniti di Montegrossi e Argilliti e Calcareniti di Dudda;

2) The shaly and calcareous turbiditic members have been attributed to a basin plain below the CCD, whereas the marls and marly limestone of the Marne del Sugame Member can be settled in a slope/ramp environment above or close to the CCD;

3) The physical correlations of the lithofacies and the biostratigraphic data point to a complex lateral and vertical distribution of the defined members of the Scaglia Toscana Fm. especially in its middle-upper part. In particular the northern marly sedimentation area (Marne del Sugame in the Cintoia-Lucolena area) pass southward to a deeper environment characterized by huge calcareous turbiditic sedimentation (Calcareniti di Montegrossi Member in the Montegrossi-Brolio area). These physiographic framework of the basin can be referred to the prosecution of the tensive or trans-tensive tectonics that modelled the Tuscan paleomargin during the Mesozoic-Eocene time span. Late Cretaceuos and Paleocene unconformities and the reworking of older or coeval plankton in the Eocene sediments confirm the presence of active tectonic lineaments in the

Tuscan Domain. In the upper part of the Formation, shales (Argilliti di Cintoia Member) and diluted calcareous turbidites (Argilliti e Calcareniti di Dudda Member) testify a substancial levelling and deepening of the paleoenvironment, possibly due to the flexure of the whole Adriatic margin for the onset of the Oligocene continent-continent collision (Corsica-Sardinia block against Adria) occurred during the Apenninic tectogenesis;

4) The biostratigraphic data evidenced for the first time the Oligocene age for the upper part of the Marne del Sugame Member instead of the Eocene age suggested by previous Authors (Canuti *et alii*, 1965);

5) The correlation between the data obtained in the investigated area with those available for the Scaglia Toscana Fm. in northern Tuscany (e.g. Marliana-Monsummano and Val di Lima) evidenced the occurrence of a paleomorphologic high (from Cintoia to Monsummano) characterized by almost exclusively emipelagic sedimentation, that separated two deeper basins (the Val di Lima trough to the north and the Monti del Chianti basin to the south) that hosted the main calcareous turbiditic inputs. More to the south, another morphological high (the Rapolano high) divided the Monti del Chianti Basin respect to the Trasimeno-Amiata basin mostly fed by calcareous turbidites;

6) The presence of Cenomanian-Turonian siliceous-shaly anoxic sediments at the top of the Argilliti di Brolio Member allows their correlations with the Bonarelli level in the Scaglia Umbra and more in general with the coeval anoxic global event.

Authors Contribution

MF, EP and FS performed geological surveys, lithological logs and sampled the investigated section. MN and GV analysed calcareous plankton (foraminifera), RM and SM analysed nannofossils. EP, FS and IM wrote the paper.

Marco Pantaloni (Geological Survey of Italy – ISPRA) and Michele Marroni (University of Pisa, Italy) are thanked for their constructive comments, which helped to improve the manuscript.

ELECTRONIC SUPPLEMENTARY MATERIAL

The article contains electronic supplementary material (Appendices 1 to 7 consisting of detailed paleontologic distribution charts for each of the studied sections and plate 1) which is available online to authorised users.

ERRATA CORRIGE

In the enclosed 1:25000 scale geological map of the Albola-Cintoia area (Fazzuoli *et alii*, 2011), to the north of Casale Mirra, the faulted outcrop of Argilliti e calcareniti di Dudda is erroneously coloured as Argilliti di Cintoia.

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