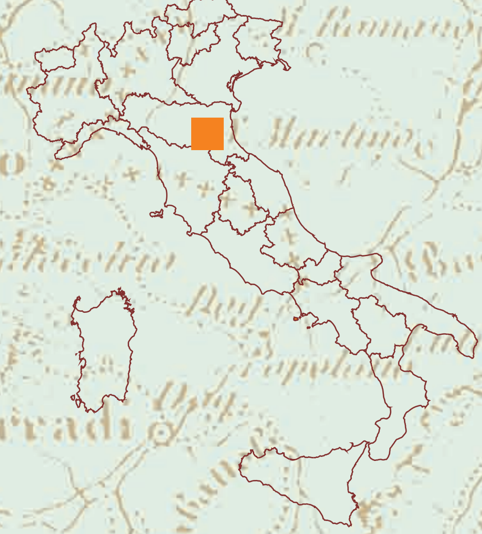

Mapping of foredeep turbidite successions: The Marnoso-arenacea example from the Northern Apennines

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ABSTRACT

Turbidite successions of the foredeep frequently seem as a monotonous alternation between sandstones and pelites and in almost all geological maps they are represented by a single undifferentiated unit. But the detailed survey of the changes of the sandstone/pelite ratio, the bed thickness, the macroscopic composition of the arenites, the stratigraphic position and the recognition of the marker beds, on a wide area, enable the mapping of the local and regional litostratigraphic units and sub-units.
The examples here presented are from the Geological Map of the Emilia-Romagna Region at 1:10,000 scale and from the new Geological Map of Italy at 1:50,000 scale. The turbiditic succession studied is the Marnoso-arenacea Formation (FMA), deposit of the Miocene foredeep of the Umbria-Marche-Romagna domain, cropping out in the Romagna Apennines.
Field data are integrated with optical microscope analyses of the arenitic detritus and biostratigraphic studies of the calcareous nannoplankton.
These survey criteria also permit improved definition of the tectonic framework and allow the determination of depositional systems sensu MUTTI & NORMARK (1987) and MUTTI (1992).
Detailed lithostratigraphic maps are also fundamental documents for the land use planning.

AIMS

The purpose of this work is to present detailed geological maps at a regional (Fig. 1, from Geological Map of Italy, at a 1:50,000 scale, Sheet 265 Bagno di Romagna) and local scale (Fig. 2, from Geological Map of the Emilia-Romagna Apennines, at a scale of 1:10,000, Ridracoli section 265110) and outline the criteria for the field survey of areas comprising seemingly monotonous successions such as foredeep turbidites.
A comparison between Figs. 1 and 2 shows that much of the detail on the maps at a scale of 1:10,000 is still visible at a scale of 1:50,000. The synthesis and regional setting for the maps at the 1:50,000 scale highlight stratigraphic units and sub-units and tectonic structures and units of regional importance.
In addition to allowing a better reconstruction of the stratigraphic and tectonic framework and evolution, detailed litostratigraphic maps are also fundamental towards improving territorial planning.

KEY WORDS

Northern Apennines, foredeep turbidites, Marnoso-arenacea Formation, lithostratigraphy, geological survey, cartography.

RIASSUNTO

Le successioni torbiditiche di avanfossa spesso si presentano come una monotona alternanza di areniti e peliti e in molte carte sono rappresentate come unità litostratigrafiche indistinte. Tuttavia, il rilevamento delle variazioni del rapporto arenite/pelite, dello spessore degli strati, della composizione macroscopica delle areniti, della posizione stratigrafica e il riconoscimento di orizzonti guida, su aree significativamente vaste, permette di descrivere unità e sottounità litostratigrafiche e riconoscere quelle di interesse locale e regionale. Questo tipo di rilevamento è stato adottato per la cartografia geologica 1:10.000 della Regione Emilia-Romagna E per il Progetto CARG 50.000 nell'Appennino Emiliano-Romagnolo. La successione torbiditica analizzata è la Formazione Marnoso-Arenacea romagnola, deposito dell'avanfossa miocenica del dominio Umbro-Marchigiano-Romagnolo.
I dati di terreno sono stati integrati con analisi del detrito arenitico al microscopio ottico e con analisi biostratigrafiche del nannoplancton calcareo.
Questo tipo di cartografia consente anche una migliore definizione dell'assetto strutturale e permette di riconoscere i vari sistemi deposizionali sensu MUTTI & NORMARK (1987) e MUTTI (1992).
Una dettagliata carta litostratigrafica è anche uno dei documenti di base per una corretta programmazione territoriale e pianificazione urbanistica.

GEOLOGICAL MAP OF THE UPER RIVER BIDENTE VALLEY (NORTHERN APENNINES)

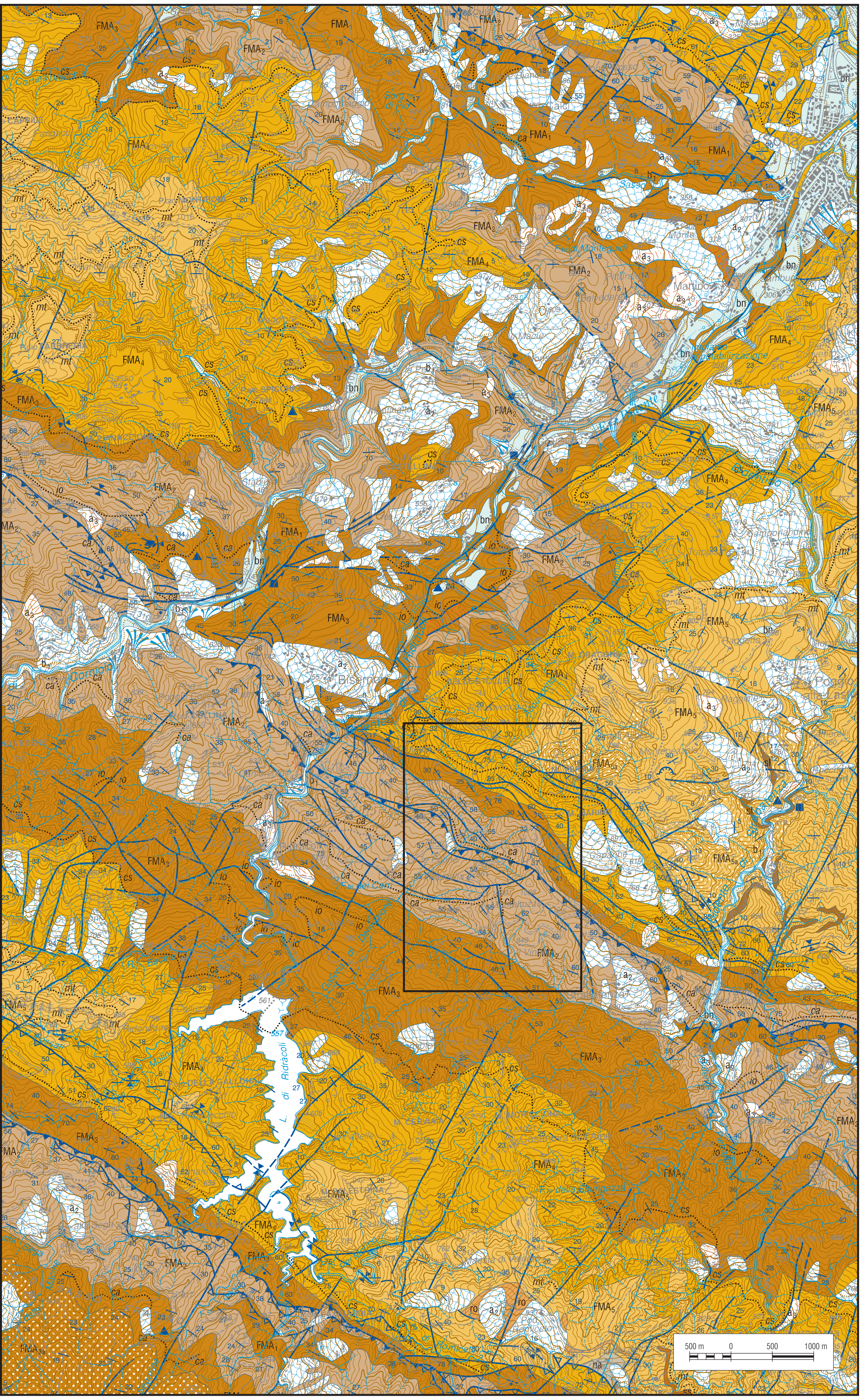

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Fig. 1 - *Example of the FMA as mapped for the Geological Map of Italy 1:50,000 scale, Sheet 265 Bagno di Romagna (SGI-RER, 2002); the box indicates the area of Fig. 2. For key see legend.*

a1 Active landslide

a2 Quiescent landslide

a3 Slope debris

b1 Active alluvial deposits

bn Terraced alluvial deposits

MARNOSO ARENACEA FORMATION

Arenaceous-shaly turbidites and hemipelagites; sandstone/pelite ratio (S/P) and mean thickness of beds variable. Sandstones are medium- to fine- grained, rarely coarse-grained; feldspathic and lithic sandstone with paleocurrents from the WNW, with less calcarenites and hybrid arenites with paleocurrent from the ESE. The formation is divided into members and lithozones, partially heteropic; contacts are generally gradational, sometimes on the marker beds. Thicknesses of the members varies greatly. The lower contact is not evident in outcrop; the upper contact with the San Paolo Marls (Verghereto Marls *Auctt.* p.p.) is sharp. The Formation is overthrusted by the Tuscan Nappe and Ligurides. Outcrop thickness exceeds 3000 m. Late Burdigalian-Early Messinian in age. Only the Langhian-Serravallian members and the marker beds outcrop in this map.

FMA6, sl — **Montecoronaro Member** (*Verghereto Marls Auctt. p.p.*). Primarily marls with lesser sandstone fraction, sometimes calcarenites, and hemipelagites, with 1/6>S/P>1/10. Thin- to medium-bedded sandstone. Slump deposits (sl) are present. Late Serravallian.

sl, na, ro, ss, FMA5, FMA5a — **Collina Member**. Mainly marls with lesser sandstone fraction, some calcarenites and hemipelagites, with 1/3>S/P>1/6, generally S/P =1/5. Thin- to medium-, rarely thick-, bedded sandstone. **Slump deposits (sl)** are present. The **Susinello slump (ss)**, the **Romiceto slump (ro)** and the **Nasseto slump (na)** have been distinguished. To the E. the **Le Cortine lithozone (FMA5a)** outcrops, with 1/3<S/P<2 and arenaceous layers up to 6 m thick. Early Serravallian.

FMA4 — **Galeata Member**. Marls and sandstones, some calcarenites, and hemipelagites; 1/2> S/P>1/3. Sandstones in thin to thick layers, sometimes very thick. The lower limit is sometimes found on the Contessa marker bed. Late Langhian-Early Serravallian.

FMA3, FMA3a — **Premilcuore Member**. Mainly sandstones with lesser shale fraction, rare calcarenites and hemipelagites; 2>S/P>1/2. Sandstones in thick to very thick beds, sometimes medium thick. The lower limit is sometimes found on the Imolavilla marker bed. Langhian-Early Serravallian.

In the innermost structural element, the **Campigna lithozone (FMA3a)** has been distinguished: mainly sandstones with very small shale fraction, S/P>2, usually >4, sometimes >10. Very thick beds, sometimes amalgamated. Unit thickness varying from 50 to at least 770 m. Langhian.

FMA2 — **Corniolo Member**. Shales and sandstones, rare calcarenites and hemipelagites; 1/2>S/P>1/3. Sandstones in layers ranging from thin to thick, rarely very thick; sometimes only loosely cemented. Slumps at base. In the SE area, sandstone intercalations with S/P=1, thick and very thick sandstone layers are present. Late Burdigalian-Early Serravallian.

FMA1 — **Biserno Member**. Mainly shales with lesser sandstone fraction, rare calcarenites and hemipelagites. S/P<1/3, generally =1/5. Sandstone layers are thin and medium, rarely thick. Slumps are present. In the SE area, sandstone intercalations with total thickness up to about 20 m, with S/P=1, thick and very thick sandstone layers. Late Burdigalian-Langhian.

MARKER BEDS

mt — **Montellero bed**: carbonate- rich turbidite, with calcarenite varying in thickness from 50 cm to 90 cm, and with 2 m of marl; paleocurrent from the ESE; Early Serravallian.

cp — **Fosso Caprie bed** *(only in the 1:10,000 map)*: carbonate- rich turbidite, with calcarenite varying in thickness from 50 cm to 75 cm and marl varying from 2 to 2.5 m; paleocurrent from ESE; Early Serravallian.

va — **Valbura bed** *(only in the 1: 10,000 map)*: carbonate-rich turbidite, with calcarenite varying in thickness from 60 cm to 90 cm and marl varying from 2 to 2.5 m; paleocurrent from the ESE; Early Serravallian.

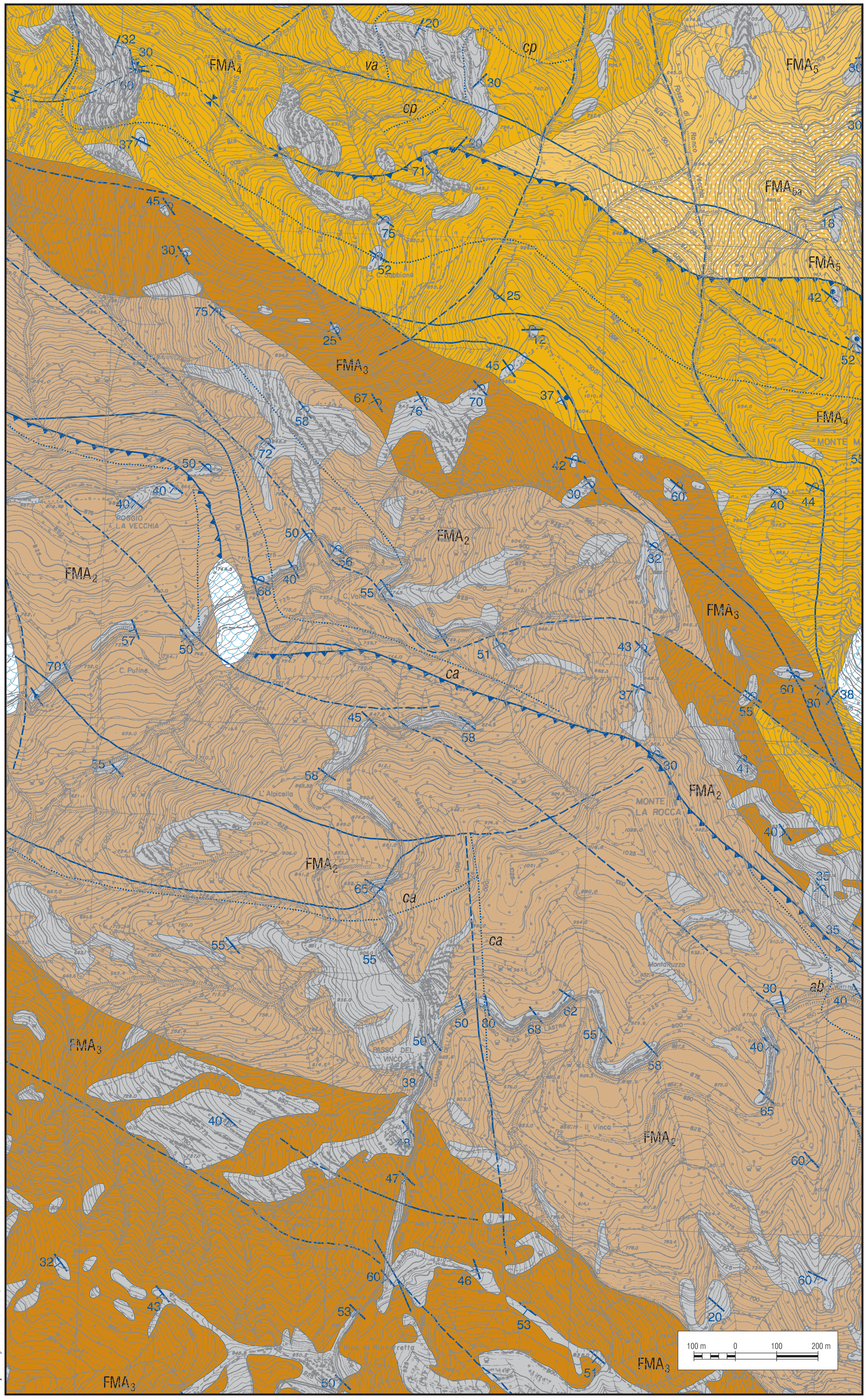
cs — **Contessa bed**: megaturbidite with a large carbonate fraction and a coarse base rich in lithic fragments (hybrid arenite); sandstone varying in thickness from 2.8 to > 5 m, marl varying from 5 to 8 m; paleocurrent from the ESE; Late Langhian.

io — **Imolavilla bed**: carbonate- rich turbidite, with hybrid arenite varying in thickness from 90 cm to 1.8 m and marl varying from 2 to 3 m; paleocurrent from the ESE; Langhian.

ca — **Calanca bed**: mainly carbonate- rich turbidite, rich in lithics, with hybrid arenite varying in thickness from 1.8 to 2.5 m and marl varying from 3 to 5 m; paleocurrent from the ESE; Langhian.

SYMBOLS

- Bed showing dip
- Horizontal bed
- Overturned bed showing dip
- Vertical bed
- Vertical bed (dot = base)
- Slump
- Marker horizon
- Stratigraphic boundary
- Fault
- Strike-slip fault
- Thrust fault
- Minor thrust fault, reverse fault
- Syncline
- Anticline
- Cataclastic zone
- Alluvial fan
- Outcrop of stratigraphic and sedimentologic interest
- Outcrop of tectonic interest
- Cave



Graphic by SYSTEMCART, Rome

Fig. 2 - *Example of the FMA as mapped for the Geological Map of the Emilia-Romagna Region 1:10,000 scale, from "Ridracoli section 265110" (RER, 1993). For key see legend.*

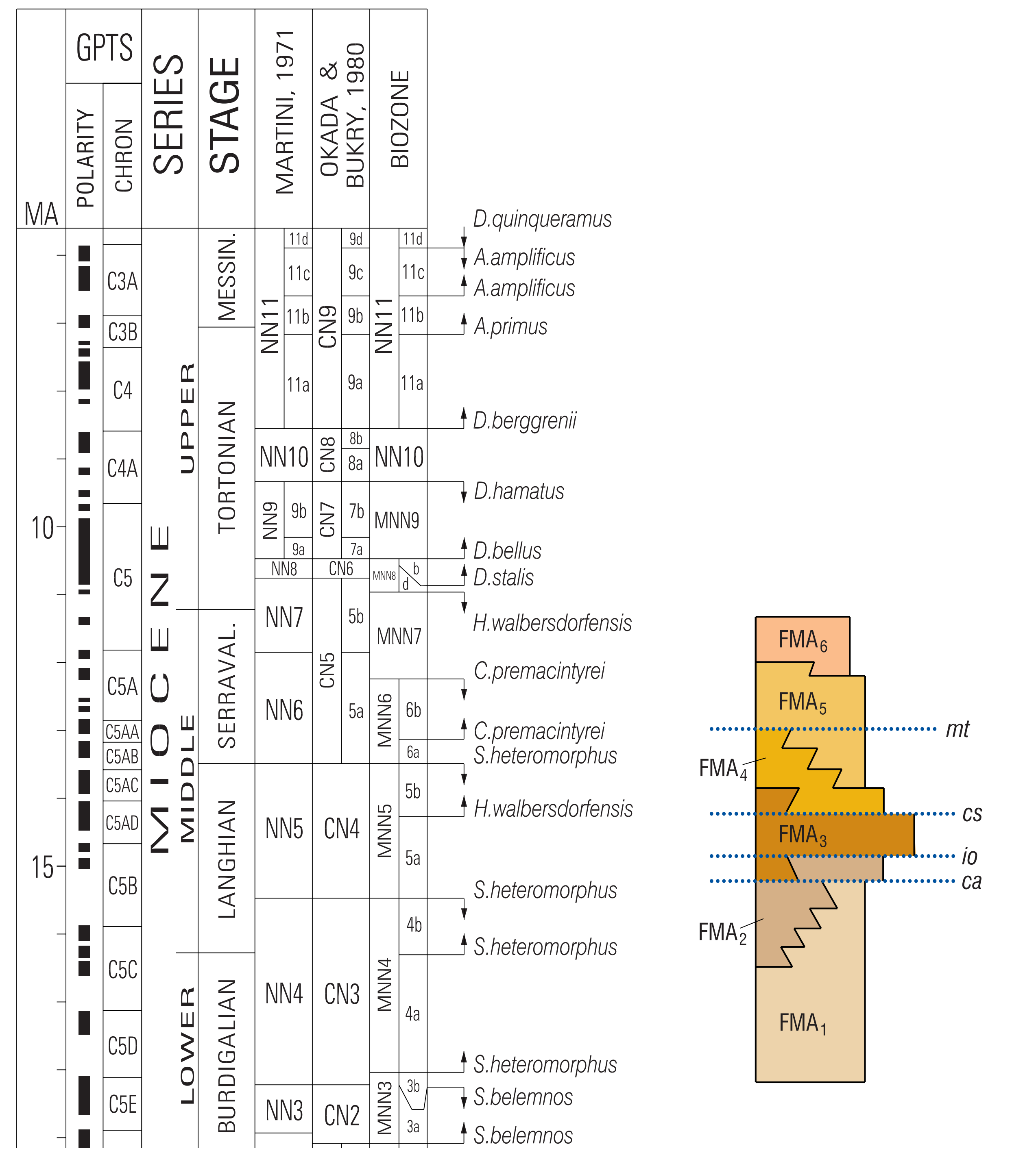


Fig. 3 - *Stratigraphic sketch of the* FMA *mapped in Figs.1 and 2. Timeframe from* FORNACIARI et alii *(1996). See the Fig. 1 legend for key.*

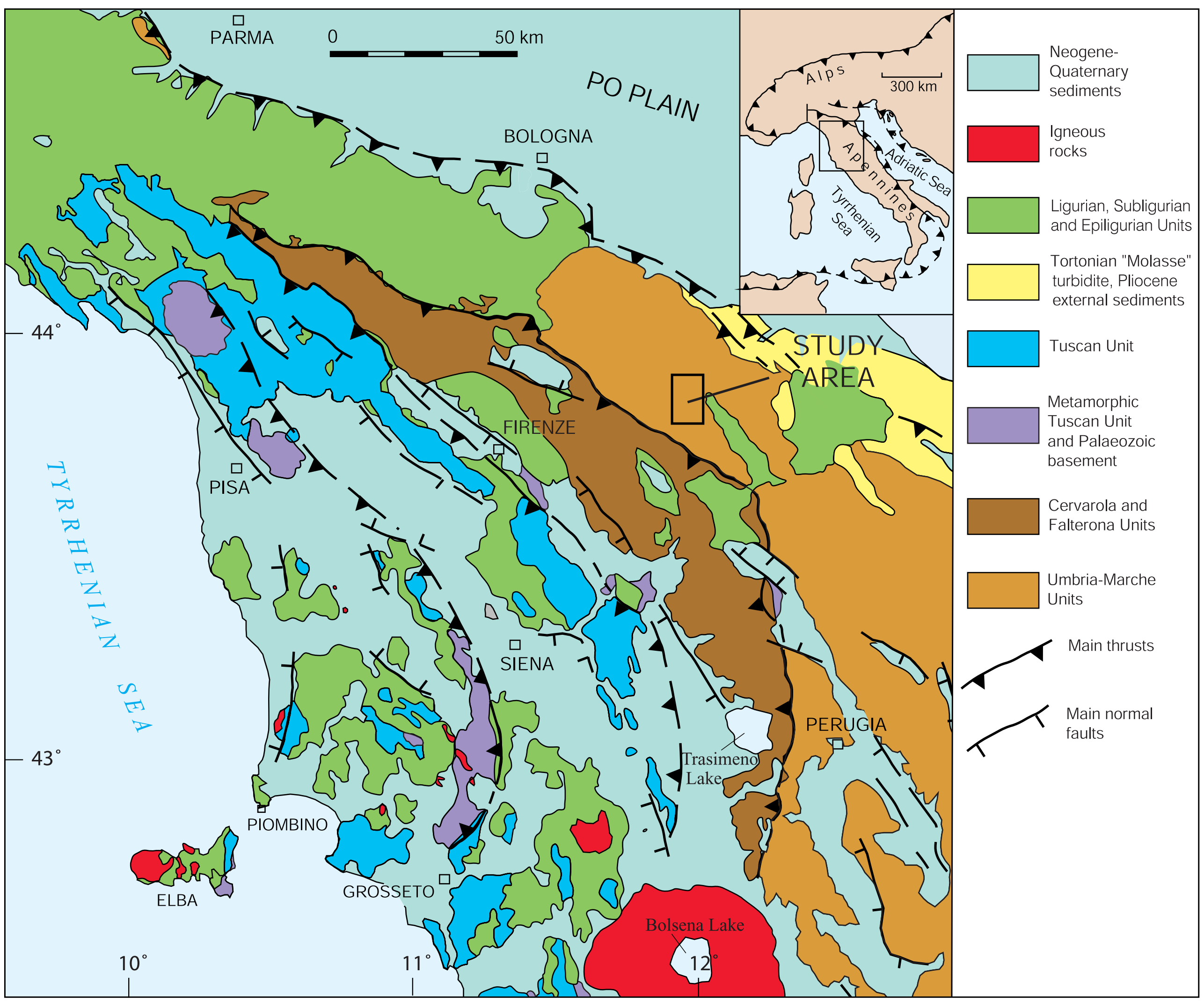


Fig. 4 - *Geological sketch of the Northern Apennines.*

INTRODUCTION

Turbidite successions of the Apennine foredeep, such as the Marnoso-arenacea Formation (FMA), the Mt. Cervarola Sandstones, the Macigno sandstone, the Laga Formation, etc., frequently appear as monotonous alternations of sandstones and pelites, and are represented by a single unit on almost all geological maps. For example, in the second edition of the Geological Map of Italy (1:100,000 scale), the FMA has been mapped as one indistinguishable lithostratigraphic unit, with the exception of a few chaotic horizons and of the Tortonian molasse; this despite the presence of thicknesses of over 3,000 m and a temporal duration of over 10 million years (late Burdigalian to early Messinian). Nevertheless, these successions are lithologically competent, and frequently characterized by extensive outcrops which lend themselves to detailed stratigraphic observations. Thus valuable information, potentially useful towards the reconstruction of the stratigraphic evolution of the basin-and-range, or towards improved territorial planning, is not conveyed.

This work presents a comparison between two geological maps of the same area at different scale. Its purpose is an experimental approach about the transition from a detailed scale (Fig. 2) to a synthetic final representation at a regional scale (Fig. 1). The maps of Figs. 1 and 2 belong to the National Mapping Project, originally at 1: 50,000 and 1:10,000 scale. Moreover it outlines the criteria for the field survey of areas of seemingly monotonous successions such as the foredeep turbidite systems.

A comparison between Figs. 1 and 2 shows that much of the detail on the maps of Fig. 2 is still visible at a regional scale (Fig. 1). The synthesis and the regional setting for the maps at a 1:50,000 scale highlight stratigraphic units and sub-units and tectonic structures and units of regional importance.

In addition to allowing a more detailed reconstruction of the stratigraphic and tectonic framework and evolution, detailed lithostratigraphic maps are also fundamental towards improving territorial planning.

GEOLOGICAL SETTING

The area studied is located in the high Romagna Apennines, the central sector of the Northern Apennines facing the Po Plain (Fig. 4).

The Northern Apennines are part of the major system of chains occurring in the central Mediterranean. They are mostly composed of NE-verging tectonic units piled up first during the Cretaceous-Eocene pre-collisional convergence, and then during the Oligocene-Neogene collisional steps.

The top of the nappe stack is composed of Ligurian units, including ophiolites and their sedimentary cover (Jurassic to Eocene) originally deposited in the Ligurian-Piedmont ocean (NW sector of the Tethyan Ocean), Subligurian units (Cretaceous to Oligocene) and Epiligurian units (Middle Eocene to Pliocene) deposited in the thrust-top basin at the top of the Ligurian and Subligurian units, progressively accreted at the convergent margin. The Ligurian, Subligurian and Epiligurian units tectonically overlie the Tuscan and Umbria-Marche-Romagna units. The latter were detached from

Fig. 5 - *Example of sub-unit with high S/P ratio (>1), thick and very thick beds (Premilcuore member,* FMA3*).*

the Adria passive margin during the Oligocene-Miocene collisional setting, which developed at the western margin of the Adria Plate.

The Tuscan and Umbria-Marche-Romagna units consist of a mainly carbonate Meso-Cenozoic succession, with Triassic evaporites at the base, topped by 2,000-3,000 m thick Oligocene-Miocene deep-sea siliciclastic sediments accumulated in the morphologically complex foredeep system that developed at the leading edge of the Northern Apennines chain.

Provenance studies on the foredeep sediments indicate that they were mostly fed from the rapidly uplifting central-western Alps at the northern end of the basin.

Currently, these Oligocene-Miocene turbidite complexes are widely exposed (Fig. 4); they become progressively younger eastwards and downwards in the nappe pile due to the eastward migration of the thrust front. From west to east, they are classically named Macigno, Cervarola-Falterona and Marnoso-arenacea (FMA) units.

The high Romagna Apennines are characterised by the FMA, believed to be the filling of the Miocene foredeep (Late Burdigalian-Early Messinian) belonging to the Umbria-Marche-Romagna domain

GEOLOGICAL SURVEY AND CARTOGRAPHY CRITERIA

The survey presented herein follows the survey standards and guidelines established for the Geological Map of the Emilia-Romagna Apennines (RER, 1990).

The survey guide to the new Geological Map of Italy at a 1:50,000 scale (SERVIZIO GEOLOGICO D'ITALIA, 1992) recommends the use of lithostratigraphy (see Part I, Paragraph 1.3) and that the survey be based, at least initially, on the S/P ratio, especially with regard to the subdivision of turbidite successions (see Part II, Subparagraph 1.2.1). The application of the mapping strategy proposed here is therefore checked against the criteria proposed in the SERVIZIO GEOLOGICO D'ITALIA guide (1992).

The variations observed in the S/P ratio (see for example Figs. 5 and 6), which became evident from the measurements made in many strata in numerous stratigraphic sections, were then systematically integrated into the observations on the mean thicknesses of the sandstone layers and beds (Table 1), on the macroscopic composition of the sandstones and on stratigraphic position (Figs. 3 and 8).

Marker horizons were defined and thereafter used to verify the stratigraphy. The marker horizons of these successions are usually megabeds or arenaceous bedsets comprising thick and very thick, often amalgamated, beds, or turbidites of varying composition and provenance, such as marly-calcareous beds in a siliciclastic succession or volcaniclastic beds (Fig. 7).

The bed-by-bed measurement of stratigraphic logs is very useful towards valuing the S/P ratio and the mean thickness of the beds and defining the marker beds (for example to identify a turbidite of a different provenance, recognizable from the different direction of the floote casts and different composition of the arenite).

thickness	*class*
>10 m	Megabed
1-10 m	very thick bed
30-100 cm	thick bed
10-30 cm	medium bed
3-10 cm	thin bed
<3 cm	very thin bed

Tab. 1 - *Classes of bed thickness,* BOSELLINI et alii *(1989).*

The FMA has therefore been differentiated on the field into several sub-units (members, lithozones, and marker horizons) (Figs. 3 and 8). Generally speaking, the transitions in these successions between sub-units are gradual and no unconformities at least none of regional importance are present.

Sub-unit boundaries have been defined in accordance with the more significant variations in both the S/P ratio and mean thickness of the beds. In order to enable them to be more easily distinguished on the field, where possible these boundaries have been made to coincide with the marker horizons.

Minor and local variations in the S/P ratio and mean thickness of the beds can be frequent in these sub-units; therefore, in order to define the more significant variations, large and frequent outcrops are required, as small outcrops with minor variations can lead to errors being made. Fortunately, this is not always a problem, as the chain sectors comprising foredeep units, such as the high Romagna Apennines, the watershed between the Tuscan and the Emilia Apennines, the high Marche Apennines and the Laga Mountains often show frequent and extensive outcrops.

Where outcrops are unusual or absent, the morphology of the landscape can prove useful. Usually, a substratum with high S/P ratio (>1/2 -1/3) and thick and very thick beds makes for stable mountainsides, with high reliefs and steep slopes, often covered by woods, while a substratum with low S/P ratio (<1/3) and thin and medium beds makes for lands subject to landslides and low reliefs, often covered by grass and grazings.

However, outcrops are more frequent where the rocks have a high S/P ratio; furthermore, the sandstone layers often outcrop in the woods too. This is true particularly for the sandstones of the carbonate- rich turbidites, that are usually well-cemented and very hard, such as the marker beds.

The data from the geological survey has been combined with that from optical microscope analyses of the arenitic detritus and biostrati-

Fig. 6 - *Example of sub-unit with medium-low S/P ratio (<1/2, =1/3), bed thickness usually from thin to thick, sometimes very thick (Civitella di Romagna member,* FMA9*).*

graphic studies of the calcareous nannoplankton. This has provided better control over the stratigraphic and structural position and improved resolution of the cartographic sub-units, in particular of major facies changes and marker horizons (Fig. 8). A comparison of Figs. 1 and 2 shows that much of the detail of the lithostratigraphic sub-divisions defined on the maps at a detailed scale is still visible at a regional scale. 20 sub-units and 23 marker horizons have been differentiated at a detailed scale.
Through synthesis and classification at a regional-level for the maps at a 1:50,000 scale, the members and marker horizons of regional importance have been highlighted, and the number of sub-units represented (Figs. 3 and 8) reduced. For example, on Sheet 265 - Bagno di Romagna, the number of members of regional importance has been reduced to 7, while 7 lithozones of local importance and 6 marker horizons have been represented. The reduction in number of the marker horizons is not only due to the fact that a lower number of these are of regional importance, but also to the need to make the map legible. Almost all the marker beds which have been mapped at a detailed scale are still evident at the regional scale.
However, the representation of all the marker horizons, some of which are only stratigraphically separated by a few tens of meters, at a 1:50,000 scale, would render the map illegible owing to the lines being too closely spaced, separated from each other by only a few millimetres.
Therefore, priority was given to the cartographic representation of those marker horizons having a significant thickness or lateral extent, and which would also be more easily recognizable on the field. Where possible, priority was also given to those horizons separated by significant and homogenous thicknesses, generally, that is, of between 250 and 500 meters.
A cartography that follows the aforementioned guidelines (Figs. 1 and 2) also permits an improved definition of structural setting. During field mapping, it was possible to define structural elements overlain by detritic burden (of landslide, detritus, alluvial deposits). Furthermore, the systematic application of cartographic criteria at a regional scale allowed the correlation and evaluation of the ranking of the structural units. Finally, this type of field mapping and cartography allowed the determination of turbidite systems, turbidite stages and turbidite complexes, as described by MUTTI & NORMARK (1987) and MUTTI (1992), thereby improving our knowledge of the evolution of the basin and range. The lithostratigraphic sub-units defined according to the criteria described here are turbidite stages. CIBIN *et alii* (2004) have recognized that the FMA and Mt. Cervarola Sandstones consist of several turbidite systems and that these formations can therefore be considered to be turbidite complexes.

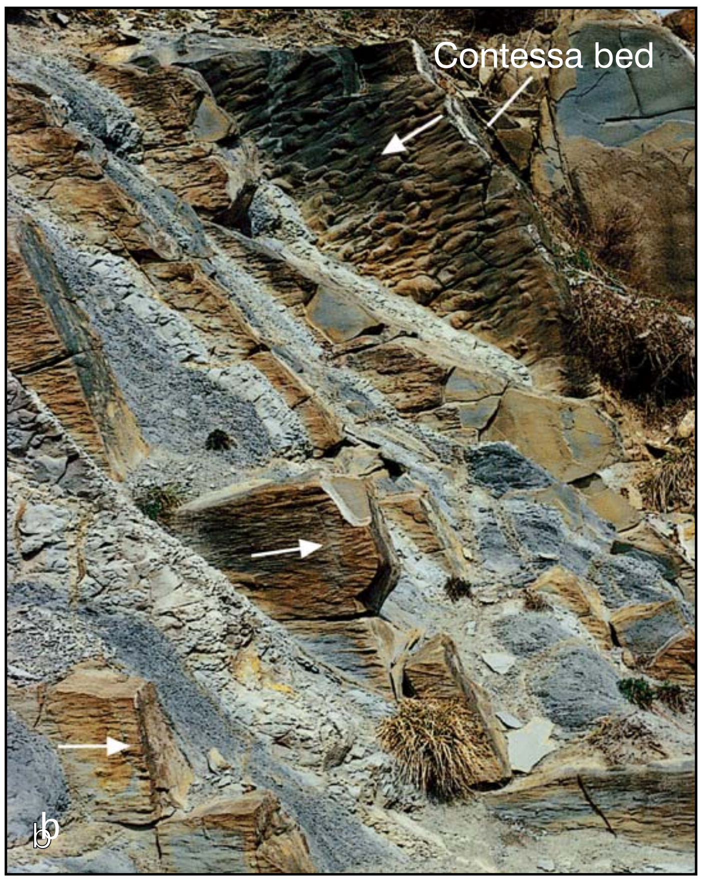


Fig. 7 - *Example of marker horizon - the Contessa bed; the larger thickness (megabed) and the different colour due to different composition,* (a) *and the difference in the paleo-current directions are noted* (b).

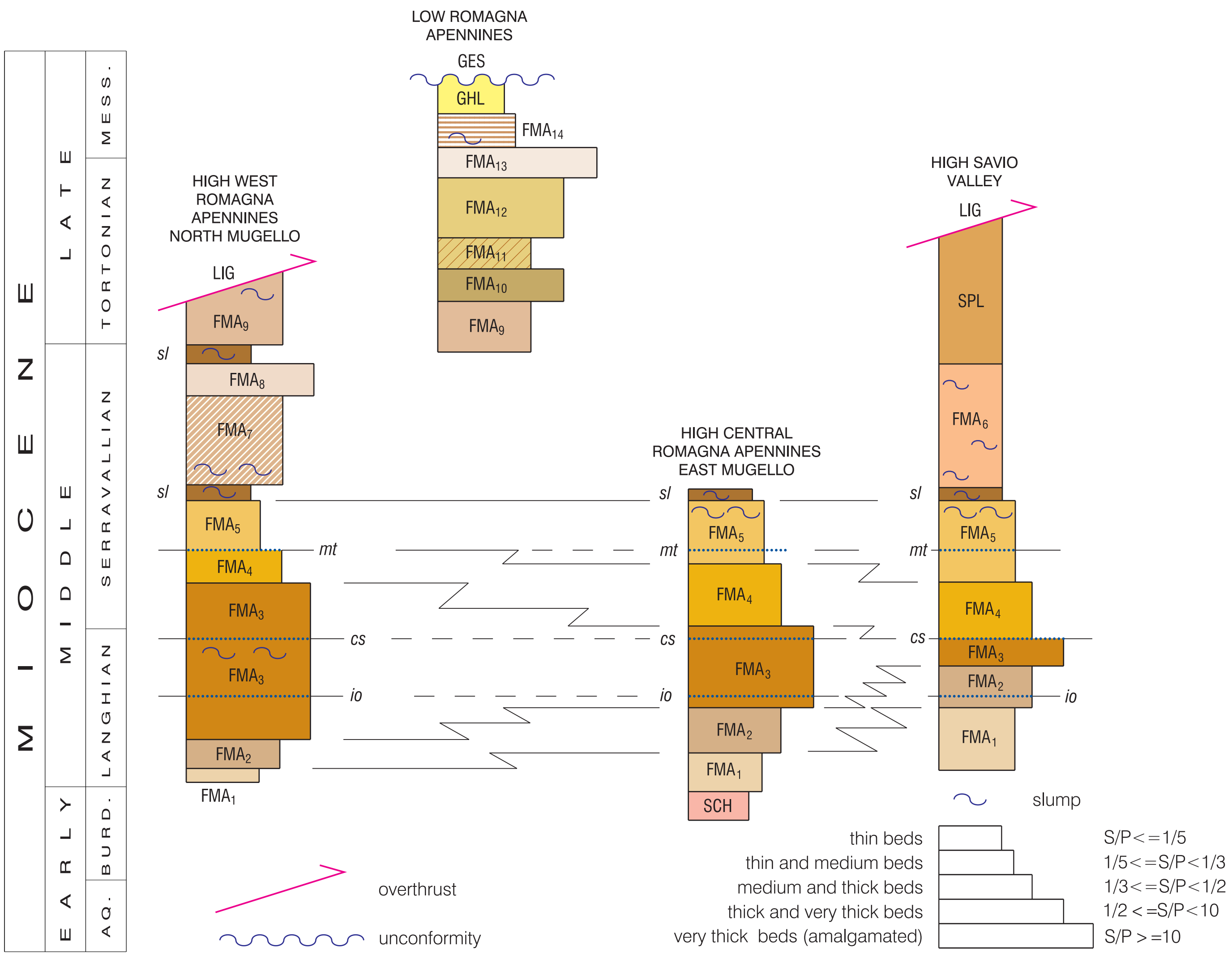


Fig. 8 - *Stratigraphic framework of the* FMA *mapped in geological maps at 1:50,000 of the Romagna Apennines;* FMA1: *Biserno member;* FMA2: *Corniolo member;* FMA3: *Premilcuore member;* FMA4: *Galeata member;* FMA5: *Collina member;* FMA6: *Montecoronaro member;* FMA7: *M. Bassana member;* FMA8: *Nespoli member;* FMA9: *Civitella di Romagna member;* FMA10: *Dovadola member;* FMA11: *Modigliana member;* FMA12: *Castel del Rio member;* FMA13: *Fontanelice member;* FMA14: *Borgo Tossignano member;* io: *Imolavilla bed;* cs: *Contessa bed;* mt: *Montellero bed;* sl: *chaotic unit of regional interest;* SGH: *Schlier marls;* SPL: *S. Paolo Marls;* GHL: *Ghioli di Letto Formation;* GES: *Messinian evaporites;* LIG: *Ligurian, Subligurian and Epiligurian Units.*

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