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SCIENCE

Geology of the 'Coltre della Val Marecchia' (Romagna-Marche Northern Apennines, Italy)

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ABSTRACT

A detailed geological map at 1:50,000 scale of the Marecchia Valley and adjoining areas (Northern Apennines, NA, Italy) is presented here. The Marecchia Valley represents a geological 'unicum' for the NA and it has been the focus of scientific debate for a long time, due to the occurrence in the area of the 'Coltre della Val Marecchia (CVM)', a complex stack of allochthonous and semi-allochthonous units emplaced in a foredeep basin during the Late Miocene to Early Pliocene. In order to clarify the geological evolution for this area, the lithostratigraphic relationships and the tectonic framework have been studied, allowing better understanding of the complex relationships between tectonics and sedimentation. The main result has been a new evolutionary framework for this sector of the orogen during the Late Miocene-Early Pliocene. Several new findings about the geological-structural setting and stratigraphy, result from the geological map presented here. These are overall supported by stratigraphic and tectonic evidence, which suggest time and modes of the CVM allochthonous emplacement within the Messinian-early Pliocene foredeep successions. Relationships between the allochthonous and autochthonous formations allowed recognition of two different bodies in the CVM, gravitationally emplaced following different trajectories and timing.

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1. Introduction

The Marecchia Valley in the Italian Northern Apennines (NA) is located along the administrative boundary between the Emilia-Romagna and Marche regions of Italy and include the Republic of San Marino (Figure 1). In this area, a peculiar geological feature of the external part of the NA is exposed, the so-called 'Coltre della Val Marecchia (CVM)' (Val Marecchia allochthonous unit, Figure 1), consisting of a geological body formed of stacked slivers of oceanic crust as Ligurian rocks with the overlying Epiligurian sedimentary cover (allochthonous and semi-allochthonous structural position in the orogen, respectively, sensu Ricci Lucchi, 1987).

The area offers the opportunity to study the advancing front of the Ligurian Unit and the whole Apennine orogenic wedge during the Miocene pre-and post-evaporite phases of development of the orogen. Moreover, it has been extensively studied due to its complexity and role in the late development of the outer NA chain (Bonarelli, 1929; Capozzi, Landuzzi, Negri, & Vai, 1991; Cerrina Feroni et al., 1997, 2002; Conti, Fregni, & Gelmini, 1987; Ricci Lucchi, 1986b; Selli, 1954; Vai & Castellarin, 1992; Zattin, Picotti, & Zuffa, 2002) with respect to the inner NA chain (Carmignani, Conti, Cornamusini, & Meccheri, 2004; Carmignani, Conti, Cornamusini, & Pirro, 2013; Cornamusini, Ielpi, Bonciani, Callegari, & Conti, 2012). In more detail, questions arise about the processes and mechanisms of its development inside the Miocene-Pliocene orogenic and foredeep evolution. A pure tectonic mechanism versus gravitational driven emplacement have been debated for a considerable time in the geological literature of the area. The origin of the Val Marecchia allochthonous unit as a classic thrust sheet is supported by several tectonic studies (Bettelli, Conti, & Panini, 1994; Cerrina Feroni, Ottria, Martinelli, & Martelli, 2002; Conti & Fregni, 1989; Conti, 1994; Conti & Tosatti, 1996) and in recent years this has been supported by clast analysis in recent fluvial and coastal deposits (Zattin, Landuzzi, Picotti, & Zuffa, 2000), demonstrating a complex history of recent uplift and dismantling of the upper level of the orogen. An origin as gravitationally induced submarine glide masses has been supported by structural and stratigraphical data and by regional-mapping studies (De Feyter, 1991; Lucente, Manzi, Ricci Lucchi, & Roveri, 2002; Lucente & Pini, 2008; Merla, 1951; Veneri, 1986). Furthermore, a mixed process, consisting of a

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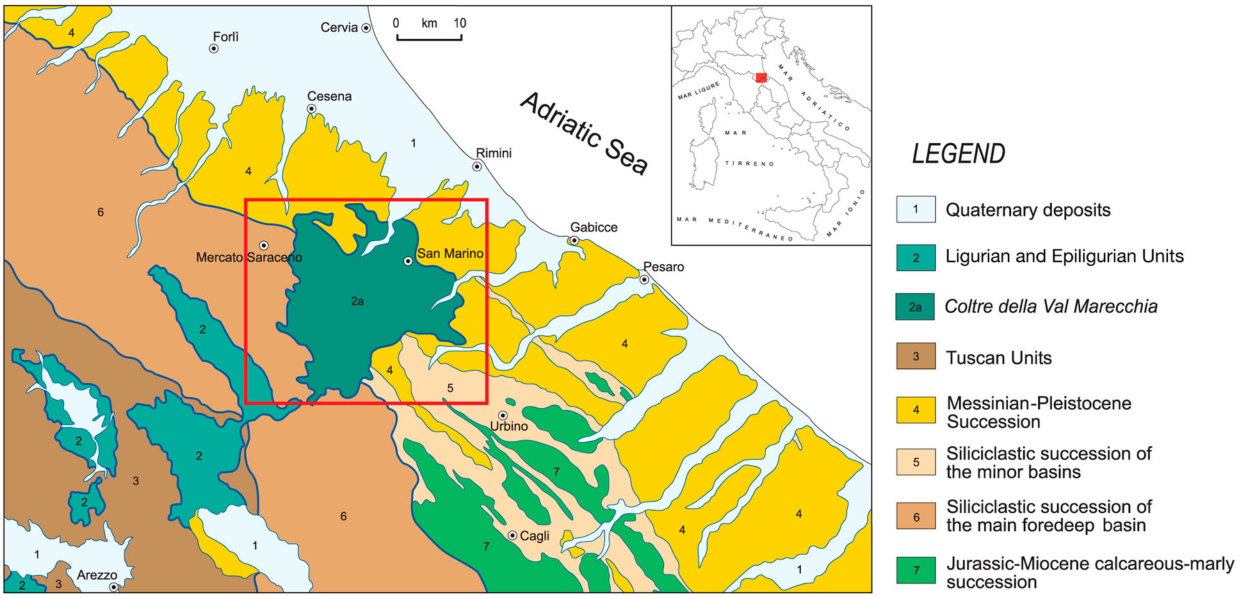

Figure 1. Tectonic sketch map of the Northern Apennines, the red box indicates the study area. The CVM consists of Ligurian and Epiligurian rocks.

tectonic trigger and a gravitational development has also been suggested (Bonciani, Cornamusini, Callegari, Conti, & Foresi, 2007, 2010; Ricci Lucchi & Ori, 1985; Ricci Lucchi, 1986b).

In order to contribute to the debate, and to discuss the relationships between tectonics and sedimentation of the successions of this outer sector of the NA foredeep, we provide a new detailed geological map of the whole CVM at 1:50,000 scale, based on field surveys at 1:10,000 scale undertaken in 1999–2003. Field work was carried out as part of mapping projects of the Emilia-Romagna and Marche regions and of the CARG Project of the Italian Geological Survey (Cornamusini, Conti, et al., 2009, Cornamusini, Martelli, et al., 2009). Previous modern geological maps for the area have been produced by several authors, such as Conti and Fregni (1989), De Feyter (1991), Conti (1994) and Bendkik, Boccaletti, Bonini, Poccianti, and Sani (1994).

2. Methods

The geological map of the Marecchia Valley is derived from reinterpretation and revision of geological maps the authors produced for regional projects and for the CARG Project of the Italian Geological Survey (Sheet 266-Mercato Saraceno: Cornamusini, Martelli, et al., 2009 and the Sheet 267-San Marino: Cornamusini, Conti, et al., 2009) and field work in nearby areas. Field mapping was at 1:10,000 scale. The stratigraphic setting has been defined by micropaleontological analyses, through foraminifera and nannofossil associations. Petrographic analyses of the terrigenous deposits have also been performed, to produce mineralogical composition and clastic provenance data. Sedimentological data, as well as structural data have been collected at key outcrops.

Stratigraphic succession in the area has been represented adopting lithostratigraphic units subdivided into tectonic units or main stratigraphic successions. Quaternary alluvial deposits have been subdivided and mapped on the base of the typology and supposed age, combining the Romagnan and Marchean UBSU, similar to Wegmann and Pazzaglia (2009). Lithostratigraphic units have been named using the original terms, in order to avoid misunderstanding in the regional stratigraphy. The cross-sections on the geological map were drawn at 1:10,000 scale, then reduced to 1:50,000 scale. Finally, a geographical information system (geodatabase) and the final map were created.

3. Geological setting

The main geological features of the area are represented by the peculiar relationships between the allochthonous oceanic-derived Ligurian Unit and the thick Neogene foredeep successions of the outer NA, representing the clastic wedge accompanying the later Alpine orogenic phase of the European and Adria plates collision (Argnani & Ricci Lucchi, 2001; Carmignani et al., 2004).

The geological framework of the mapped area, comprising the area between the Savio and the Foglia rivers, including the whole Marecchia Valley, is characterized by a complex setting, organized in stratigraphic-tectonic units, of which the CVM (Val Marecchia unit) is part (Figure 2).

The two main stratigraphic–structural complexes, representative of sedimentary successions belonging to different paleogeographic domains are (Figures 1 and 2): (a) the autochthonous Umbro-Marchean-Romagna Pre-Evaporite Succession and the Padano-Adriatic Post-Evaporite Succession, ascribed to the late Burdigalian–early Messinian and to the late Messinian–Pleistocene, respectively; (b) the allochthonous CVM formed by a strongly deformed Cretaceous-Tertiary succession (Ligurian Unit) and by an unconformable overlying less deformed Eocene-earliest Pliocene semi-allochthonous (sensu Ricci Lucchi, 1987) succession called the 'Epiligurian Succession' (see Molli, 2008, for an updated overview).

Based on the stratigraphic and tectonic relationships with the CVM, the autochthonous successions are divided in a portion underlying (Burdigalian to late Messinian for the northwestern area and to early Pliocene for the eastern area) and in a portion overlying the CVM (early-middle Pliocene to Pleistocene, Figure 2).

The autochthonous succession is deposited in a wide and complex foredeep basin system (Argnani & Ricci Lucchi, 2001; Ricci Lucchi, 1986b; Tinterri & Tagliaferri, 2015), whereas the allochthonous Ligurian Unit represents the deformed orogenic wedge, and the Epiligurian Succession deposited in a thrust-top basin system (Ricci Lucchi, 1986b). The Umbro-Marchean-Romagna Succession consists of Upper Burdigalian to Messinian turbiditic sandstones and marls, sedimented in foredeep basins and divided into two thrusted portions, an inner (Late Burdigalian to Messinian) and an outer (Tortonian to Late Messinian) one. The inner wide basin was infilled by classical turbidite systems of the Romagna Marnoso-arenacea Fm., whereas differently the outer basin consists of minor turbidite depocenters, the so-called 'minor molasse basins' (Cantalamessa, Centamore, Chiocchini, Micarelli, & Potetti, 1986; Centamore, Chiocchini, Cipriani, Deiana, & Micarelli, 1978; Ricci Lucchi, 1986b), characterizing the Marchean Marnoso-arenacea Fm. The Padano-Adriatic Post-Evaporite Succession consists of deposits subsequent to the Messinian salinity crisis, which are Late Messinian to Early Pleistocene in age, and unconformably lay above the Umbro-Marchean-Romagna Succession. The separating unconformity has regional significance and is linked with the intra-Messinian tectonic phase and sea-level drop (Roveri,

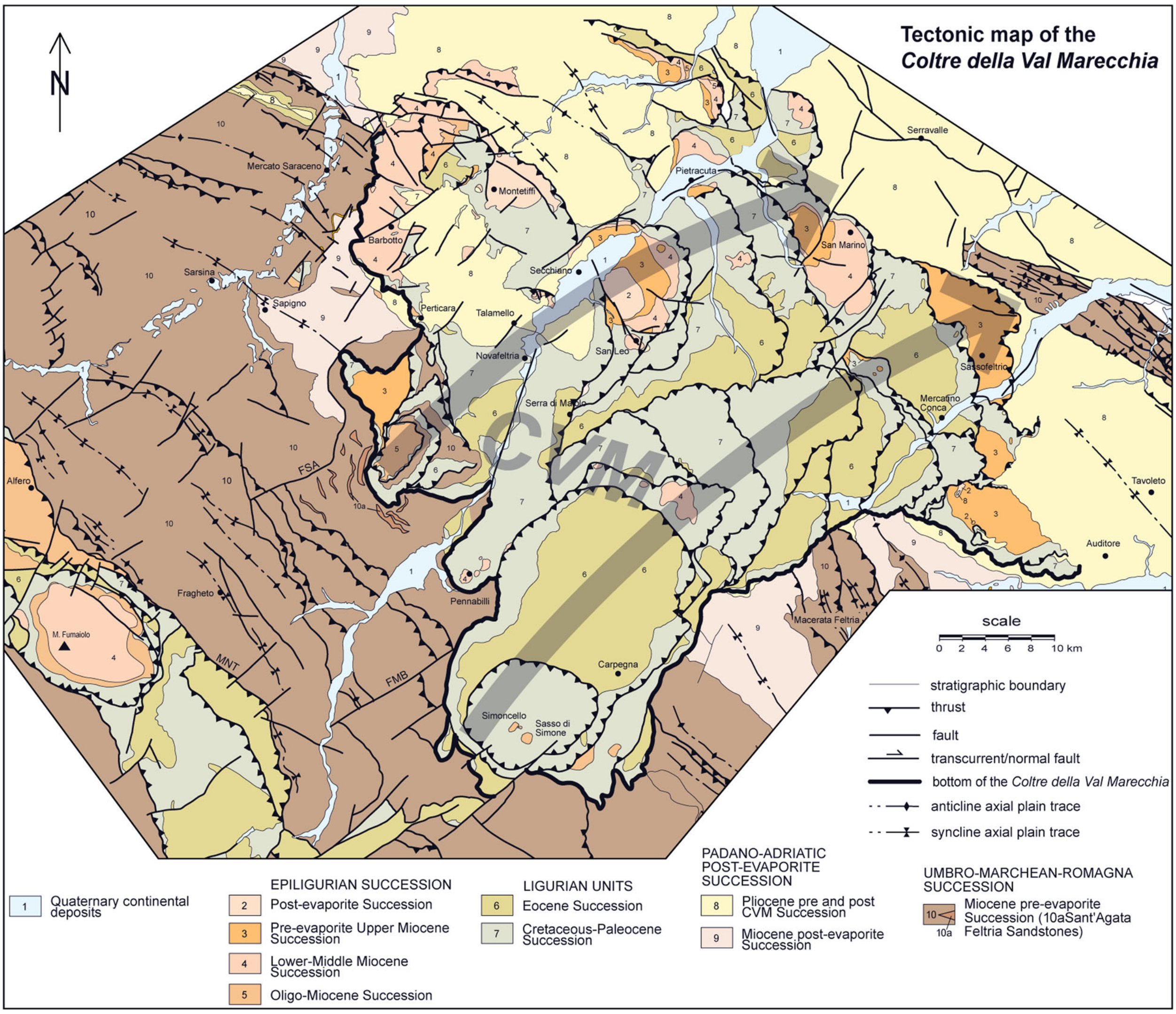

Figure 2. Stratigraphic map of the Marecchia Valley, with evidenced the CVM, formed by stacked slivers of Ligurian and Epiligurian units. The main tectonic structures as well as the main sedimentary successions are represented. FSA: Sant'Agata Feltria fault; FMB: Molino di Bascio fault. The gray arrows indicate the two supposed CVM emplacement trajectories.

Manzi, Bassetti, Merini, & Ricci Lucchi, 1998; Vai & Castellarin, 1992; Zattin et al., 2002).

The allochthonous Ligurian Unit is structured in tectonic slivers with the less deformed semi-allochthonous unit (Epiligurian Succession) on top. The thick slivers forming the CVM, occur enclosed in two distinct main autochthonous depositional units, which are the Messinian deposits (Ghioli di letto Fm.) and the Pliocene deposits (Argille Azzurre Fm., Figure 3). The Ligurian Unit formations span in age from Early Cretaceous to Middle Eocene for the Marecchia Valley area (part of these units are ascribed to a more external domain by Perrone, De Capoa, & Cesarini, 1998, 2014 and by De Capoa et al., 2015).

The Epiligurian Succession, indicated as semi-allochthonous (sensu De Feyter, 1991; Ricci Lucchi, 1987), unconformably deposited in satellite or piggy-back basins (sensu Ori & Friend, 1984) on the top of the allochthonous Ligurian Unit, during its tectonic translation toward the foreland (Ricci Lucchi, 1986b). In the Marecchia Valley, it testifies to the timing of the allochthonous Ligurian thrust sheet and ranges with formations spanning from the Oligocene until earliest the Pliocene. It shows some internal angular unconformities due to the active syn-sedimentary tectonics, typical of the satellite basins, subdividing it in depositional sequences (Ricci Lucchi, 1986a; Conti, Fioroni, Fontana, & Grillenzoni, 2016).

Finally, the Quaternary alluvial and littoral deposits lay unconformably on all the older units.

3.1. Stratigraphic and structural features of the CVM and adjoining units

The CVM represents the outermost allochthonous Ligurian bodies of the NA. The CVM is structured in several embricate slivers, bordered by arcuate-shaped thrusts, with convexity toward the NE or ENE and moderate SW dip, showing 'top-NE' transport direction (Figure 1; see also Conti & Tosatti, 1996; Conti, 2002; Conti et al., 2016). The listric geometry of these surfaces is evident if we compare the dip of the surfaces in different sectors of the arcs: the frontal parts of the slivers show dip of the slip surfaces between 30° and 45°, whereas laterally the surfaces become more horizontal (dip < 20°), up to sub-horizontal close to the bottom of the CVM. All the slip surfaces merge at depth at the bottom of the CVM (Figure 2). So, the thrusts at the bottom of the CVM do not deepen or originate from the underlying Umbro-Marchean-Romagna Succession.

All the tectonic slivers forming the CVM are structured with strongly deformed, often chaotic lithologies of the Varicolored Shales Fm. at the base, with more competent formations (Sillano Fm. and Monte Morello Fm.) in the upper part, or passing directly to the

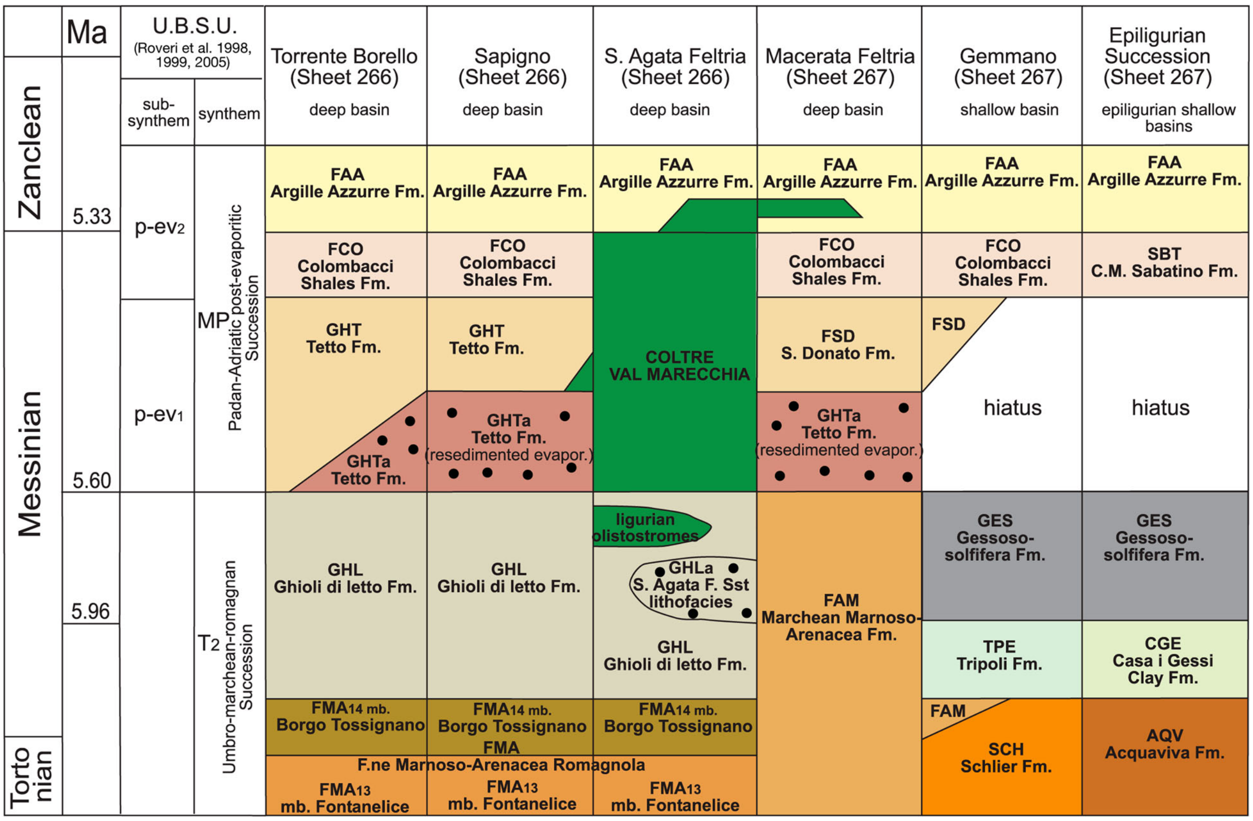

Figure 3. Tectono-stratigraphic scheme showing the relationships among the lithostratigraphic units belonging to the Umbro-Marchean-Romagna Succession, Padano-Adriatic Post-Evaporite Succession and Epiligurian Succession, of significant sectors of the study and adjoining areas. UBSU subdivisions are from Roveri et al. (1998, 1999, 2005). The lithostratigraphic formational labels and the sheet numbers derive from the Italian Geological Survey CARG Mapping Project.

Epiligurian formations (Figure 4), through marked angular unconformities or local tectonic contacts. The Epiligurian formations form competent layers always lying onto the Varicolored Shales Fm., floored by Oligocene-Burdigalian formations for the inner and western part of the CVM and the Messinian formations for the outer and eastern part (Figure 4). The CVM is thicker in the central sector (at least 1500 m), and thinner both westward and eastward, where deposits show an increase of internal chaoticity

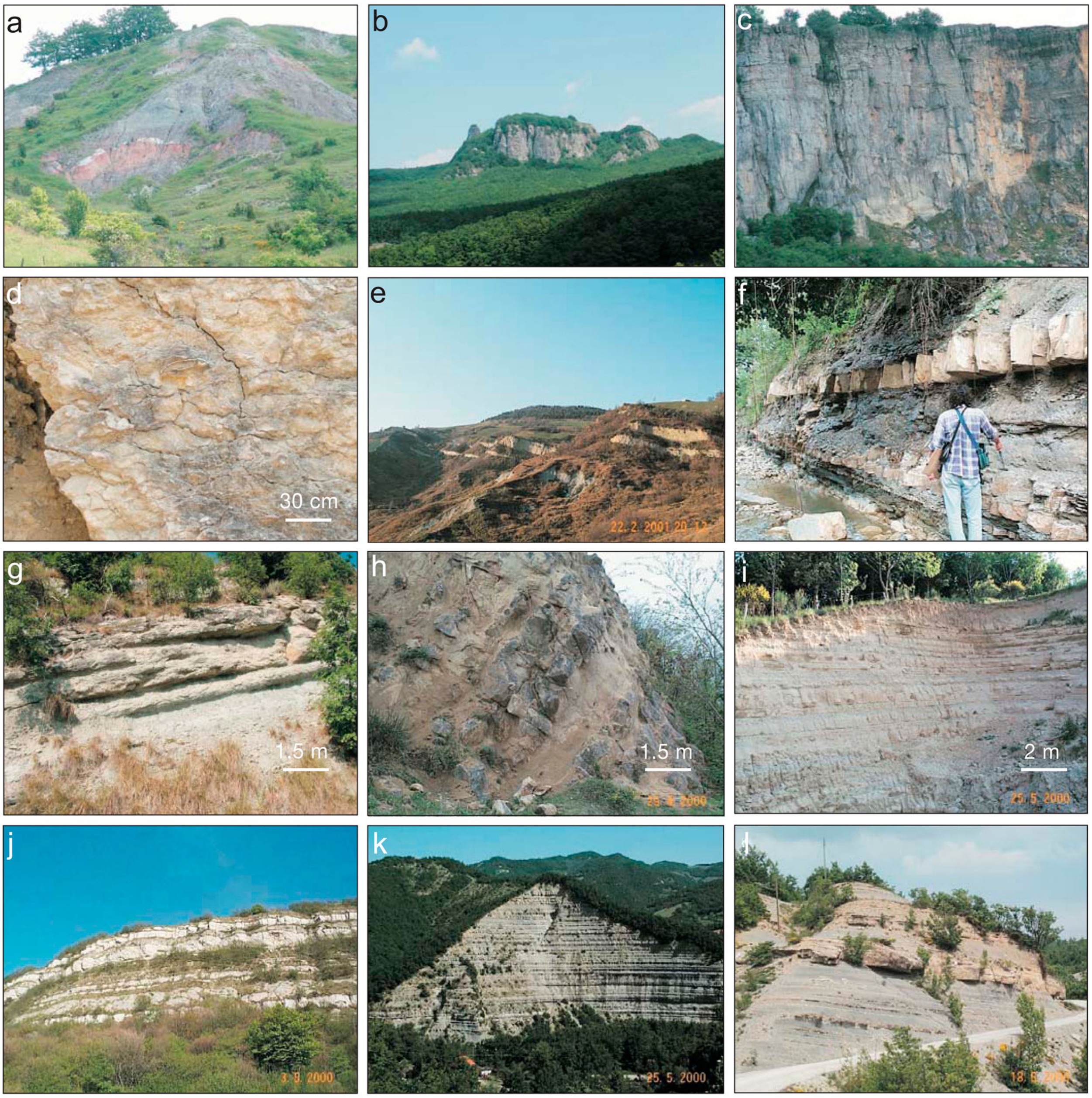

Figure 4. Photographs of field outcrops. (a) Highly deformed polychromatic shales of the Varicolored Shales Fm. (Ligurian Unit of the CVM); (b) limestone cliffs of the San Marino Limestone Fm. (Epiligurian Succession), unconformable resting on to the Breccia di Sasso di Simone (Epiligurian Succession, see the Main Map) and the Varicolored Shales fms; (c) detail of (b), with a thinning upward trend in the limestones and low-angle cross-bedding; (d) San Marino Limestone Fm. (Epiligurian Succession, see the Main Map), detail showing massive or faintly wavy stratification in calcarenites and calcirudites. They are rich in fossils, as Pectinidae, Echinoderms, Ostreidae and Bryozoa, locally with rodoliths; (e) Auditore area (southeastern part of the geological map) showing tabular or gently lenticular sandstone beds interlayered with gray mudstones, mapped as Sandstone and Mudstone-sandstone lithofacies of the Montecalvo in Foglia Mb., upper part of the Argille Azzurre Fm., early–late Pliocene in age; in the left side of the photo the Pliocene deposits onlap onto the easternmost termination of the CVM; (f) alternating fine limestone and gray shale beds of the Sillano Fm. (Ligurian Unit); (g) sandstone and sandy marlstone beds of the Mt. Fumaiolo Sandstone Fm. (Epiligurian Succession, see Main Map); (h) coarse sandstone amalgamated beds forming lenticular bodies, belonging to the Sant'Agata Feltria Sandstone; as detectable on the map, they are interlayered within the Ghioli di letto Fm., upper part of the Messinian foredeep infilling; (i) Marly clay and fine sandstone beds of the upper part of the Pliocene Montecalvo in Foglia Mb., Argille Azzurre Fm.; (j) Marly limestone and marlstone beds of the Mt. Morello Fm. (Ligurian Unit, see the Main Map), southern cliff of Mt. Carpegna (Ligurian Unit); (k) thick turbidite succession showing the alternances between sandstone and mudstone beds (Galeata Mb. of the Romagna Marnoso-arenacea Fm.); (l) thin and thick turbidite sandstone beds interlayered with mudstone beds (Collina Mb., Romagna Marnoso-arenacea Fm.).

(i.e. bed disruption, marked bed discontinuity, lacking of stratigraphic organization, etc.).

The basal surface of the CVM and its areal distribution are influenced by the basin bottom morphology and paleobathymetry, as well as by the morphostructural lineaments present during the emplacement phases. The basal tectonic surface, well exposed in the Macerata Feltria area (southern part of the geological map and Figure 2), shows the tendency to 'adjust' to the irregular morphology of the underlying autochthonous substratum, sealing faults affecting the underlying succession. Such a geometry is well exposed in the Avellana Valley (southeastern part of the geological map), where the relationships between CVM and autochthonous succession show the former bypassed during its eastward movement of the already structured Macerata Feltria anticline (see also De Feyter, 1991; Zattin et al., 2002), and its emplacement in the Montecalvo in Foglia depocenter basin (Figures 2 and 5). Therefore, the base of the CVM is strongly unconformable with respect to the underlying autochthonous succession, already structured in anticlines and synclines (Macerata Feltria area), with a progressive smoothing and erosion of the advancing CVM (De Feyter, 1991; Zattin et al., 2002). In this area, the CVM was then sealed by Lower-Upper Pliocene sediments, and pinches-out toward the NE, inside the Pliocene succession (Figures 5 and 6), close to the Montecalvo in Foglia syncline (see also Capuano, Tonelli, & Veneri, 1987). It is likely that the Montefiore-Montescudo anticline (corresponding to the Montescudo-Serraungarina anticline of Selli, 1954) formed a ridge internal to the basin during the Messinian, and this could have represented a morphological obstacle, preventing the advancement of the CVM allochthonous body, which seemed to adapt to the morphology of the syncline substratum.

The relationships among autochthonous, semi-allochthonous deposits and the allochthonous units allow definition of the timing of the emplacement and development of the CVM. The later transversal-Apennines tectonic transcurrent/normal lineaments further complicated the structure of the basins, forming within them additional morphological highs and

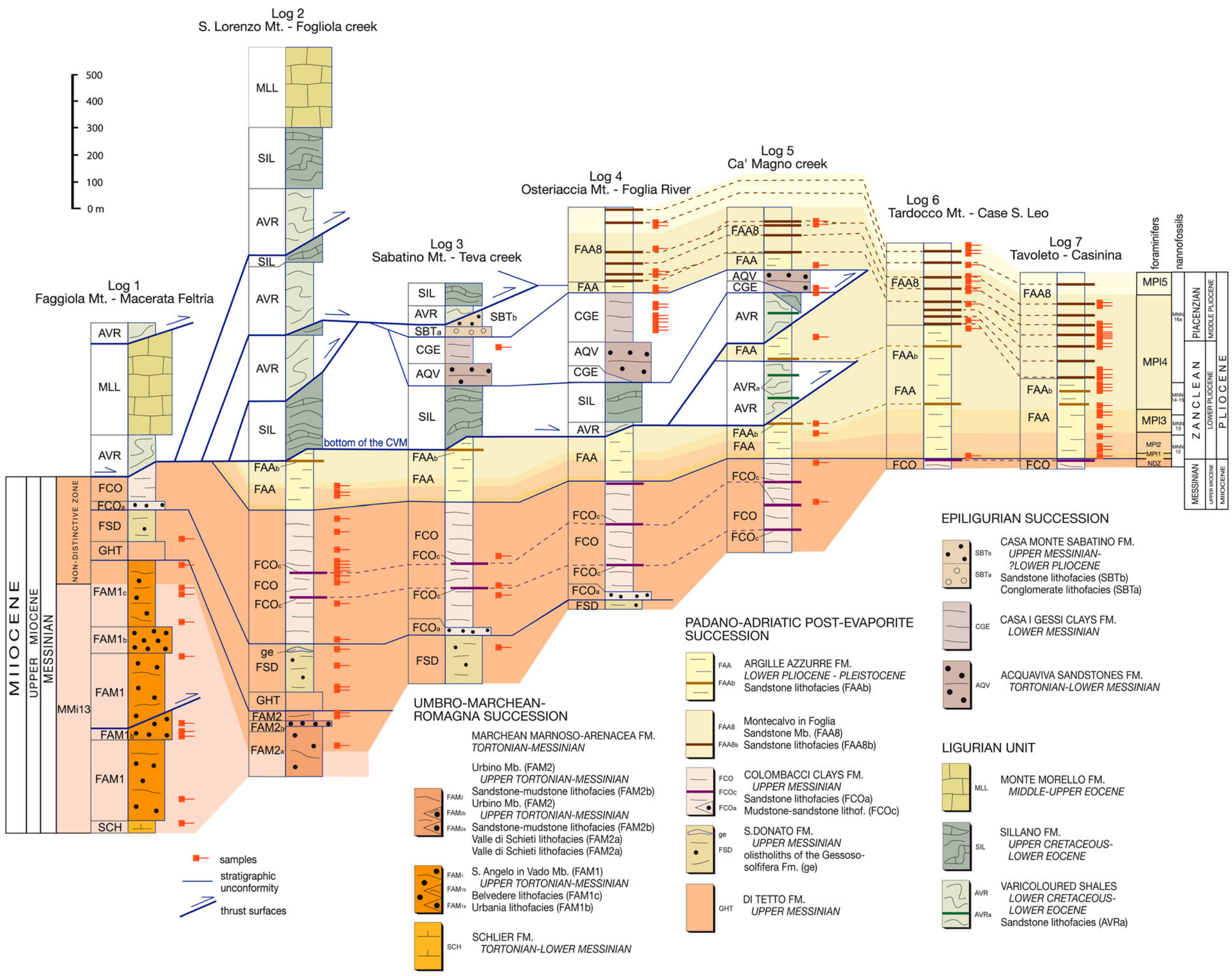

Figure 5. Detailed stratigraphic correlation scheme showing relationships among pre-and post-evaporites autochthonous foredeep deposits, Pliocene pre-and post-emplacement of the CVM, and the Ligurian and Epiligurian formations of the easternmost outcrops of the CVM (Teva Valley and Auditore area in the southeastern part of the geological map); the small red squares indicate sample used for biostratigraphy in Cornamusini, Conti, et al. (2009). Nannofossil biostratigraphic zones from Rio, Raffi, and Villa (1990), foraminifera biostratigraphic zone from Iaccarino et al. (2007).

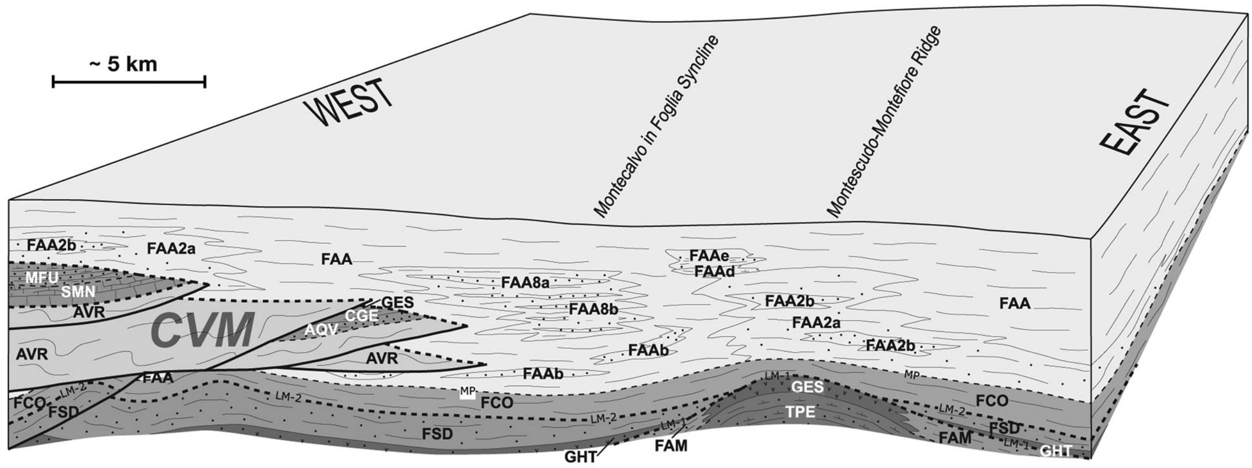

Figure 6. Sketch showing relationships between the Messinian-Pliocene deposits and the CVM in the southeastern part of the geological map. The dashed lines indicate the main stratigraphic unconformities: LM-1 and LM-2: intra-Messinian unconformities; MP: Miocene-Pliocene limit. Thickness of lithostratigraphic units are approximate.

lows, evident in the areas of Sapigno and Sant'Agata Feltria (Figure 2).

The Sant'Agata Feltria fault (FSA in Figure 2), represents one of the most important strike-slip/normal lineaments in the Marecchia Valley. Since the early Messinian, it strongly controlled the sedimentation of the foredeep and the formation of subsequent tectonic structures (i.e. similar to the strike-slip fault systems for the inner Chianti Mts in Tuscany: Bambini, Brogi, Cornamusini, Costantini, & Lazzarotto, 2009; Coltorti, Ravani, Cornamusini, Ielpi, & Verrazzani, 2009; Cornamusini et al., 2012). The fault subdivided the foredeep in to two sectors: the northern, characterized by the Sapigno syncline with mainly mudstone deposits (Ghioli di Letto Fm.), and following resedimented Messinian evaporites, coming from the structural high of the 'Vena del Gesso'; on the other side, the southern sector (south of the FSA) was characterized by a widespread and deeper basin with sedimentation of a thicker mudstone succession (Ghioli di Letto Fm.), with some slump horizons and interlayered channelized turbiditic sandstones, organized in lenticular levels (Sant'Agata Feltria Sandstones), and several ligurian-epiligurian olistostromes not belonging to the CVM, but precursors of its emplacement (see Abbate, Bortolotti, & Sagri, 1981) (Figure 2). This sedimentary succession is topped by a thick stack of Ligurian allochthonous bodies, which constitute part of the CVM.

4. Discussion

Analysis of the geometrical relationships among the mapped tectono-stratigraphic units draws a new regional geological framework of great interest for the interpretation of the relative chronology of the depositional and tectonic events for this sector of the Northern Apennines foredeep during the late Miocene up to the middle Pleistocene.

Based on the general and internal geometry of the CVM, on the geometry of the imbricated allochthonous and semi-allochthonous slivers, on the relationships with the underlying autochthonous units, on the different deformation styles between different tectonic slivers, on the occurrence of minor olistostromes in the autochtonous succession just below the bottom contact of the CVM, we suggest that the CVM units were emplaced within the basin as the result of mixed processes of active shearing plus gravitational sliding, similar to that proposed by Merla (1951), Elter and Trevisan (1973), Ricci Lucchi and Ori (1985), Ricci Lucchi (1986b), Roveri, Argnani, Lucente, Manzi, and Ricci Lucchi (1999) and Zattin et al. (2002), and to the mechanisms proposed for the formation of the orogenic mass wasting complexes (MWCs) of the NA (Festa, Ogata, Pini, Dilek, & Codegone, 2014; Lucente et al., 2002; Lucente & Pini, 2003, 2008). Following this interpretation, the innermost tectonically structured Ligurian Unit (Mt. Nero Thrust), through tectonic pulses, should have generated large gravitational slides, orogenic landslide sens*u* Abbate et al. (1981), flowing in the foredeep basin and interacting with the deposition (Figure 7). Furthermore, the relationships between the CVM and the underlying autochthonous succession show that the CVM superposition was onto a tectonically structured substratum (De Feyter, 1991; Zattin et al., 2002). Moreover, the WSW–ENE transversal tectonic major lineaments in the area played an important role in the emplacement of the CVM, determining morphological-structural depressions in which the CVM was accommodated. These lineaments are already known and collectively called the Arbia-Val Marecchia Line (Liotta, 1991; Pascucci, Martini, Sagri, & Sandrelli, 2007). This important structural lineament does not show strong surficial expression, but it is characterized by the presence of sets of sub-parallel faults and by alignments of paleodepressions. Depressions acted as sites of

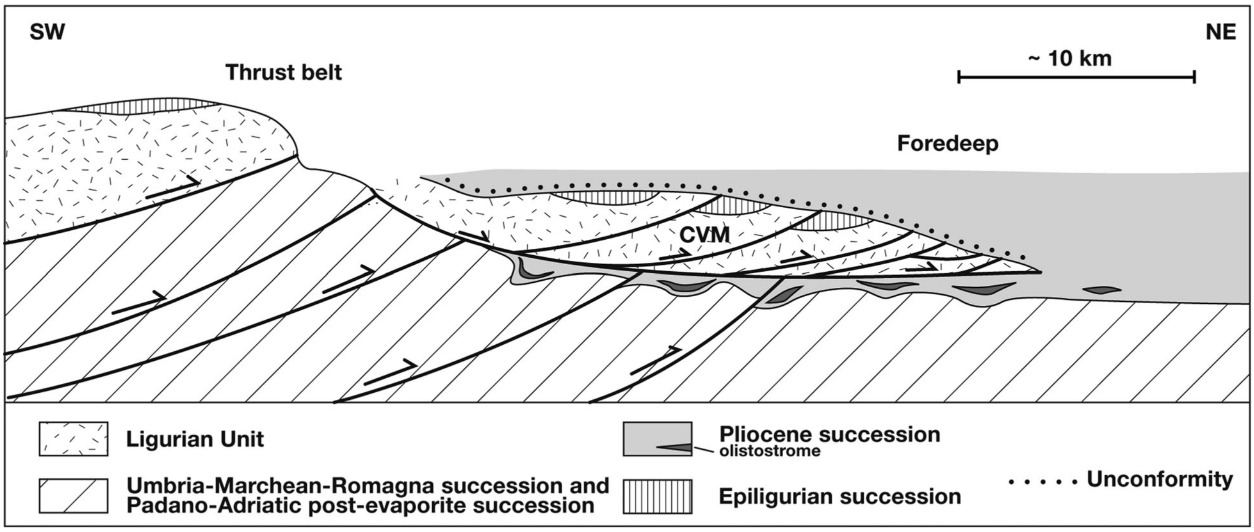

Figure 7. Sketch showing relationships between the CVM, underlying successions and contemporaneous sedimentation during emplacement.

deposition first for the turbiditic clastic sediments and the associated olistholits and olistostromes, and then for the Ligurian and Epiligurian allochthonous bodies (submarine orogenic landslides), sliding and advancing from the more internal thrust sheets.

On the basis of geometrical and field relationships (between CVM and autochthonous deposits, and among Epiligurian deposits), we speculate that the CVM developed in two steps. The arcuate shape and geometry of the imbricated slivers forming the CVM delineate two main WSW–ENE alignment directions, subdividing the CVM into two portions (Figure 2). A northern one between St. Agata Feltria-Perticara-San Marino and a southern one between Sasso di Simone and Mercatino Conca. The major constraints for this interpretation are (see the geological map):

(1) in the northernwestern part the CVM lies onto the lower Messinian Ghioli di Letto Fm., which is upwards richer in lenticular bodies of channelized turbidites of the Sant'Agata Feltria Sandstones and overall of the precursory olistostromes close to the CVM;
(2) the northern part of the CVM is sealed by Pliocene deposits, recording their post-CVM meaning and the end of the CVM main movement (with the exception of some late reactivations);
(3) differently, the southern part of the CVM shows a superposition onto the deformed Miocene substratum and onto Lower Pliocene deposits, whereas it is unconformably sealed by Pliocene deposits only along its southeastern termination, demonstrating its Lower Pliocene movement.

Finally, the two main flow-transport directions for the CVM have been recognized, active during four main depositional and tectonic stages (Figure 8). This allows definition of two main tectonic/gravitational flow-bodies (CVM1 and the CVM2 in Figure 8), linked with regional tectonic events and tectonic features recognizable in the field.

- *First stage* (Figure 8(a)), late Tortonian–early Messinian in age, which predate the emplacement of the CVM. The Ligurian Unit overthrusts onto the internal Marnoso-Arenacea Fm., with the formation of a NNW–SSE striking internal thrust-front (the Mt. Nero Thrust in the westernmost part of the geological map) and the closure of the innermost foredeep. The involved youngest Epiligurian sediments are Serravallian-early Tortonian in age.
- *Second stage* (Figure 8(b)), early to late Messinian in age, during which the first emplacement of the CVM1 inside the foredeep basin of the shaly/marly Ghioli di Letto Fm. occurred, following and closing the deposition of mudstones (Ghioli di Letto Fm.) and channelized turbidites (Sant'Agata Feltria Sandstones), accompanied by an increasing upward Ligurian/Epiligurian olistoliths and olistostromes precursor of the advancing allochthonous bodies. The frequency and extent of olistostromes increased in time (upper portion of the Ghioli di Letto Fm.), up to the emplacement of the large allochthonous bodies, that modified the physiography of such parts of the basin. In this area, the volumes of involved rocks strongly conditioned the sedimentary processes, up to the filling of the basinal depression and the ending of deposition. The Sant'Agata Feltria transcurrent/normal and transversal fault (FSA) was already active during this event, constraining the morphological conditions to drive the turbidite flows before and the Ligurian allochthonous bodies (CVM1) after, along the northern alignment. The foredeep basin

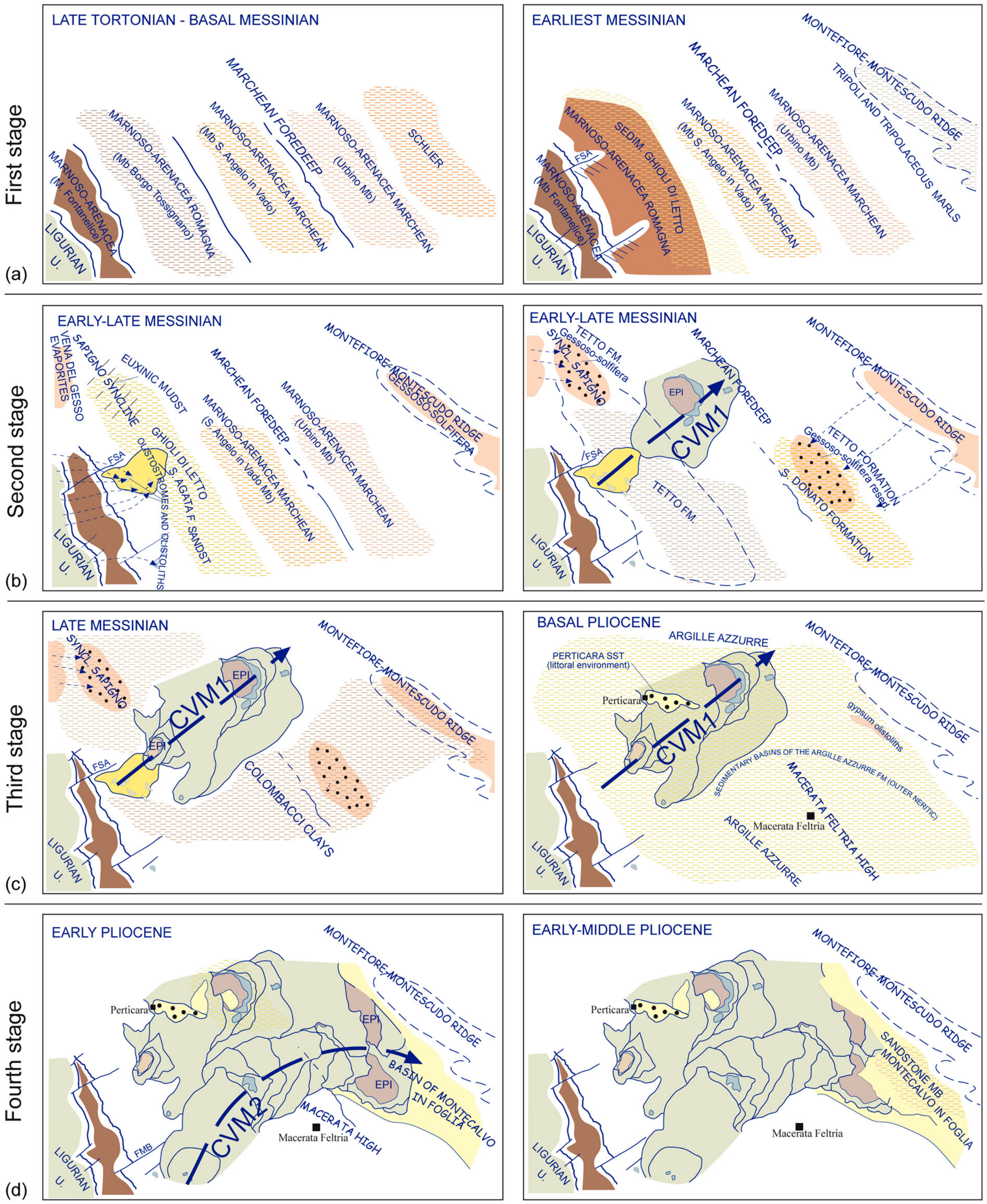

Figure 8. Proposed evolutionary model of the CVM in the foredeep basin system of the Northern Apennines (see text for explanation; FSA: Sant Agata Feltria fault; FMB: Molino di Bascio fault). The tectonic and depositional stages driving the emplacement of the CVM are represented, emphasizing the two different allochthonous bodies (CVM1 and CVM2). Dashed pattern represents areas with active deposition for each stage; large arrows show the main emplacement and transport direction of the CVM within the foredeep; small arrows indicate feeding deposit directions; EPI: Epiligurian deposits.

appears to be subdivided by the FSA in a northwestern part, which is characterized by a sedimentary succession typical of a structural/morphological high (resedimented gypsum lithofacies belonging to the Tetto Fm.) and in a southeastern part characterized by a deeper basinal succession. The two parts are separated by a depression zone coincident with the FSA direction, where the turbidites, the minor olistostrome bodies and the CVM1 flowed. The complete infilling of the northern basinal depression is also documented by the later sedimentation of the very shallow marine-littoral Monte Perticara lithofacies. unconformably onto the emplaced Ligurian Unit.

- *Third stage* (Figure 8(c)), occurred at the Miocene-Pliocene boundary, during which the process of emplacement of the CVM1 underwent a further development, probably also in continuity with the previous stage. Moreover, the interaction inside the basin between the allochthonous bodies and the first Pliocene sediments, occurred during this episode. Furthermore, the very shallow marine depositional setting of these lowermost Pliocene deposits (Monte Perticara conglomerate-sandstone lithofacies), demonstrate the total filling up of the northern basinal depression.
- *Fourth stage* (Figure 8(d)), the Early Pliocene marks the emplacement of the southern bodies of the CVM2, whereas in the northern area, a minor pulse of the CVM1 toward the Adriatic foreland occurred, with slight deformation of Pliocene deposits in the Perticara area and some thrust reactivation and late movements. In the southern area, the depression between the first allochthonous body (CVM1) and the structural high of Macerata Feltria, acted as a second wider basin where a thick body of allochthonous Ligurian/Epiligurian rocks (CVM2) were emplaced. The CVM2 allochthonous bodies flowed through a more complex morphological depression, which was aligned with the Molino di Bascio transversal fault (FMB). The body of the CVM2 and its flow trajectory (Figure 8(d)) shows the removal of such a structural high, as demonstrated by the geometry and convexity of the allochthonous slivers of the CVM2. After that, during the upper part of the Early Pliocene-Middle Pliocene (MPl4–MPl5 foraminiferal Biozones of Iaccarino et al., 2007) the sediments of the 'Argille Azzurre' Fm., representing the neoautochthonous, sealed the CVM, marking the end of its movement in the foredeep basin.

5. Conclusions

A new geological framework is proposed for the Marecchia Valley and adjoining areas, based on the compilation of a new 1:50,000 scale geological map. This provides a higher rank subdivision of the geological units in autochthonous successions (Pre-Evaporite Umbro-Marchean-Romagna Succession and Padano-Adriatic Post-Evaporite Succession), in allochthonous units (Ligurian Unit) and semi-allochthonous units (Epiligurian Succession), these last two forming the so-called CVM. The relationships between the CVM and the foredeep autochthonous successions represents one of the main topics represented on the geological map. A complex stacking of allochthonous-semi-allochthonous bodies has been recognized in the CVM, showing ENE-arcuate shapes and dipping toward the WSW, producing a complicated imbricate pattern.

We propose a complex mechanism for the emplacement of the CVM, which encompasses a tectonic origin, due to the thrust activity in the inner areas (Mt. Nero Thrust), and a submarine gravitational sliding development within the foredeep basin (submarine orogenic landslides). This is based on: (a) the occurrence of increasing upward minor olistostromes, olistoliths and slumps within the foredeep deposits below the CVM bottom-boundary; (b) the tectonic structures affecting the autochthonous formations underlying the CVM are cut by the CVM bottom contact; (c) the geometry and internal setting of the CVM slivers are coherent with a gravitational emplacement, as they often have sub-horizontal or a gently west-dipping basal contact surface, that do not continue in the thrust surfaces of the thrust belt; (d) the internal tectonic structures and chaoticized setting affecting the CVM formations, particularly the Ligurian Unit, similar to the MWC of the NA, and fit well with such mechanism.

Furthermore, the relationships between the CVM and the autochthonous formations allowed recognition of two main CVM bodies, emplaced following a polyphase history. It developed at different times and in partially different areas, through continuous deformational and depositional stages, giving rise respectively to the CVM1 Messinian up to early Pliocene in age, and to the CVM2 early Pliocene in age.

The emplacement of the CVM bodies was driven by the activity of syn-sedimentary transversal-normal faults that separate the main foredeep basin in to sectors with different accommodation space, and capable of receiving the sliding bodies.

Software

All maps were digitalized using Esri ArcGIS, then redrawn using Macromedia FreeHand.

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No potential conflict of interest was reported by the authors

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