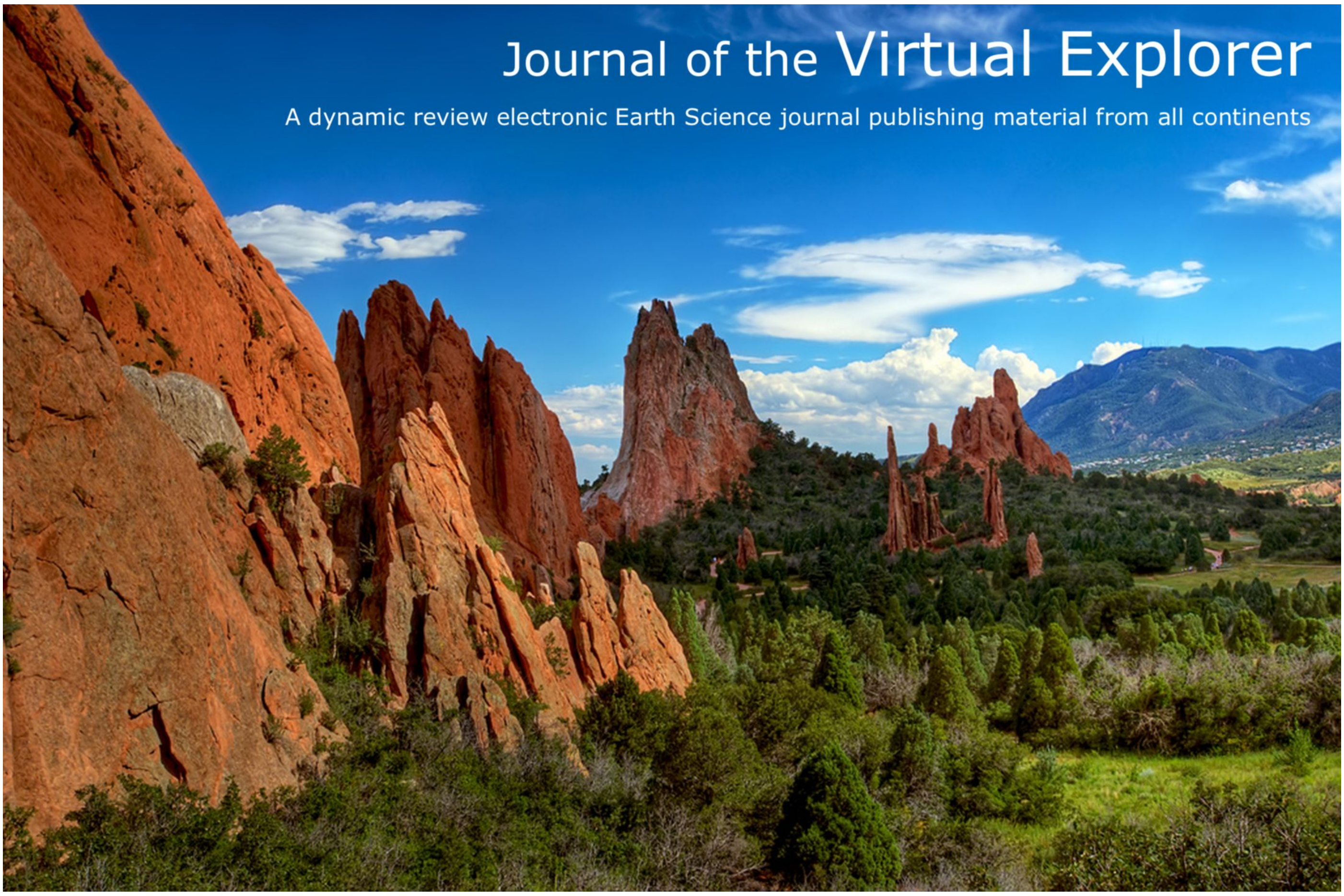

Geology of the central Apennines: a regional review

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Geology of the central Apennines: a regional review

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Abstract: The Meso-Cenozoic stratigraphical successions that crop out in central Italy are part of the sedimentary wedge developed on the southern Neotethyan passive margin. On the previous Late Triassic shallow-water carbonate platform, a basin-platform system developed in the area as a consequence of a rifting stage that affected the whole Neotethyan region during the Middle Liassic. The palaeogeography related to the basin-platform system was persistent until early Tertiary time.

During the late Miocene, the central portion of the Apennine palaeogeographical domain was involved in the evolution of a post-collisional orogenic system, consisting of a thrust-belt/foredeep couple migrating toward more external domains.

The central Apennine palaeogeographical domains were located on a peri-cratonic region, which experienced several tectonic events in response to the Neogene tectonic interaction between the European and African plates, leading to the peri-Mediterranean orogeny. In particular, during the post middle-Tortonian orogenic phases of the Apennines, the Adria microplate played a significant role. Interactions between its boundaries and the surrounding continental plates controlled the evolution of the Adria-verging orogenic system. These plate interactions caused the building of both the Apennine and of the Dinaric segments of the peri-Mediterranean chain.

The structural setting of the Apennine tectonic units is similar to other post-collisional thrust-belts, and consists of basement and cover thrust-sheets developed in an ensialic context. The geometry of the chain, the diachronism of the eastward migrating foredeep basins, and the different ages of the forethrusts are consistent with a regional foreland propagation model for the central Apennines.

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Meso-Cenozoic Stratigraphical Setting of Central Italy

Introduction

The central Apennines are a part of the peri-Mediterranean orogenic belt (Fig. 1) built up mainly in Neogene times as a consequence of the collision and the convergence between the European and African macroplates. This section summarizes stratigraphical analyses of Meso-Cenozoic carbonates and Miocene terrigenous deposits cropping out in the central Apennines.

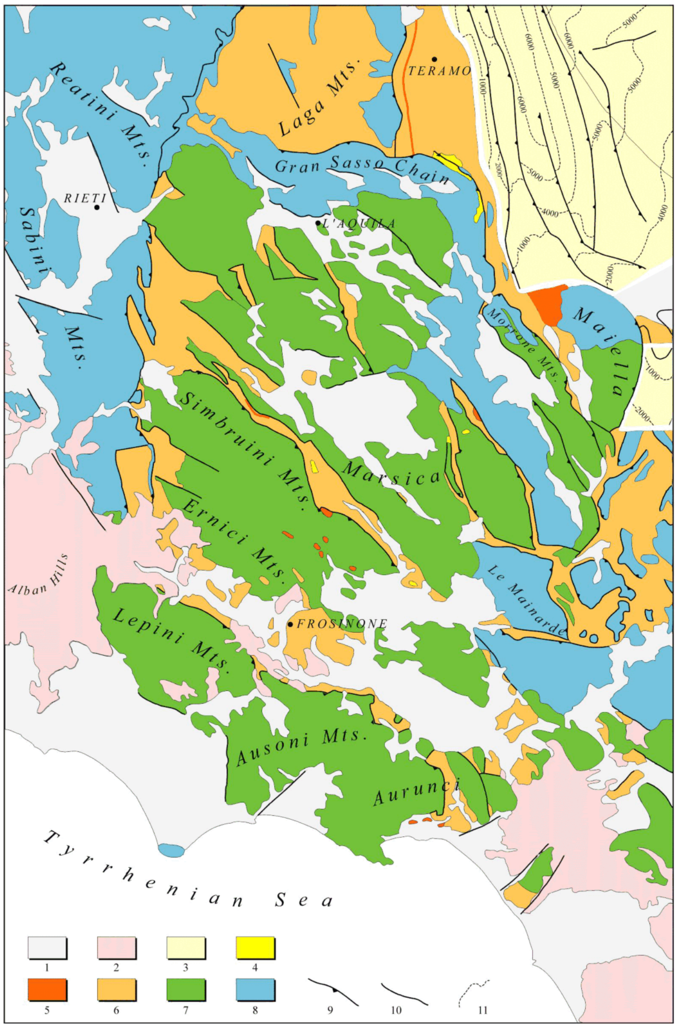
Figure 1. Peri-Mediterranean orogens and location map

Schematic map of the peri-Mediterranean orogens and location of the study area.

In the past 40 years, several studies have investigated the Meso-Cenozoic deposits of central Italy. The analytical papers on the stratigraphical features of the central Apennines, published in the 1960-70's (Accordi, 1964; Angelucci, 1966; La Monica, 1966; Accordi *et al.*, 1969; Devoto, 1969; Centamore *et al.*, 1971; Parotto, 1971; Parotto and Praturlon, 1975) have been followed, in the 1980-90"s, by the first attempts to define the geodynamical significance of the local Miocene stratigraphical record (Royden *et al.*, 1987; Patacca and Scandone, 1989; Santo and Sgrosso, 1987; Boccaletti *et al.*, 1990; Centamore *et al.*, 1991; Roure *et al.*, 1991; Patacca *et al.*, 1992a, 1992b; Casero *et al.*, 1992; Cipollari and Cosentino, 1993, 1995, 1996; Sgrosso, 1988, 1992a, 1992b; Zoetemeijer *et al.*, 1993).

The Meso-Cenozoic stratigraphical successions that crop out in central Italy (Fig. 2) are part of the sedimentary wedge developed on the southern Neotethyan passive margin. On the previous Late Triassic shallow-water carbonate platform, a basin-platform system developed in the area as a consequence of a rifting stage that affected the whole Neotethyan region during the Middle Liassic (Castellarin *et al.*, 1978, 1984; Ciarapica and Passeri, 1998, 2002). The palaeogeography related to the Middle Liassic basin-platform system was persistent until early Tertiary times.

Figure 2. Structural sketch map of the central Apennines



Structural sketch map of the central Apennines. 1) Plio-Pleistocene marine and continental deposits; 2) Pleistocene volcanics; 3) buried Pliocene marine sediments; 4) clastic deposits related to the Messinian *Lago-Mare*/Early Pliocene thrust-top basins; 5) Messinian clastic deposits and evaporites; 6) foredeep siliciclastic deposits of undifferentiated age (Upper Miocene); 7) Meso-Cenozoic shallow-water limestones; 8) Meso-Cenozoic deep-water limestones; 9) thrust; 10) undifferentiated fault; 11) isobaths in meters of the base of the Pliocene deposits.

Seafloor depth variations of Miocene sediments reflect the distribution of preexisting carbonate platforms and adjacent pelagic basins. The palaeobathymetrical differences led to sedimentation with mainly pelagic cherty limestones (*Bisciaro Fm*) and spongolitic marls (*Guadagnolo Fm*) on top of a Meso-Cenozoic pelagic sequence (Civitelli *et al.*, 1988), whereas above the earlier carbonate platforms, Middle Miocene shallow water calcarenites were deposited unconformably or paraconformably on Cretaceous limestones ("Paleogene hiatus"). This "Paleogene hiatus" is well documented in the shallow-water Meso-Cenozoic stratigraphic sequences (Selli, 1957; Accordi, 1964; Devoto, 1969; Accordi *et al.*, 1969; Parotto and Praturlon, 1975; Accordi and Carbone, 1986; Bonardi *et al.*, 1988; Bigi *et al.*, 1992; Damiani *et al.*, 1992). Damiani *et al.* (1992) proposed two alternative explanations for this hiatus: 1) subaerial erosional processes; or 2) no sedimentation in a submarine environment. However, no explanations were provided for the causes of the erosional processes and/or non-depositional events. A model suggesting an intraplate stress to explain the "Paleogene hiatus" has been proposed by Cipollari and Cosentino (1995).

During the late Miocene, the central portion of the Apennine palaeogeographical domain was involved in the evolution of a post-collisional orogenic system, consisting of a thrust-belt/foredeep couple migrating toward more external domains (Bally *et al.*, 1988; Mostardini and Merlini, 1988; Patacca and Scandone, 1989; Patacca *et al.*, 1992a; Casero *et al.*, 1992; Cipollari and Cosentino, 1995, 1996). In this geodynamical setting, tectonically-controlled sedimentary basins were developed (i.e. foredeep and piggyback basins).

Facies Distribution of the Pre-Orogenic Stratigraphical Successions

Triassic-Lower Liassic

During the late Triassic, a rifting stage affecting the southern margin of the Neotethyan domain gave rise to an intra-platform trough with deeper-water sedimentation. Upper Triassic-Lower Liassic deposits crop out in few central Apennine localities, particularly in those areas characterized by marginal platform or transitional towards pelagic Meso-Cenozoic successions. In fact, the outcrops of Triassic-Lower Liassic are rare in those areas that are characterized by Meso-Cenozoic carbonate platform facies [Simbruini Mts, Matese Mts (Plate 1)].

The majority of the Triassic outcrops in central Apennines belong to epeiric shelf or carbonate platform palaeoenvironments. The facies associated with these two sedimentary shallow-water environments are presently found in the Umbro-Sabine, Latium-Abruzzi and Matese Mts sectors. Currently, the Olevano-Antrodoco thrust brings the epeiric shelf area (W of the tectonic line) in sharp contact with the carbonate platform area. However, Triassic facies related to platform margin or euxinic basin domains are also known. Such depositional patterns have been found in the Triassic succession of Gran Sasso d''Italia (Norian-Raethian bituminous dolostones, Vradda) and, farther south, in the succession of the Simbruini Mts (Noric-Raethic bituminous dolostones of Filettino) (Plate 2). In both sectors, inside the Triassic succession, lateral facies variations occur, showing a transition from a carbonate platform environment towards an euxinic basin through carbonate platform margin facies (Adamoli *et al.*, 1990; Damiani *et al.*, 1992; Cirilli, 1992; 1993). The bituminous dolostones of Mt Prena and Vradda (Gran Sasso d''Italia) and those cropping out at Filettino (Simbruini Mts) are related to sedimentation in euxinic basins. The same heteropic trend visible in the Grand Sasso area (Bigazzi *et al.*, 1992) occurs in the Simbruini Mts. There, carbonate platform facies in the west transition eastward to euxinic basinal facies through buildups and bioclastic facies (Cirilli, 1993).

In the subsurface of central and southern Italy, Triassic facies similar to those cropping out at Filettino and in the Gran Sasso chain have been found in the Emma (Adriatic offshore) and Noto-Streppenosa (Iblean and Iblean offshore, Sicily) basins. The limited available data do not allow more than a simple comparison between the bituminous deposits of Filettino and Gran Sasso. Those deposits could be related either to the same pelagic sedimentary basin or to different intra-platform troughs. Depositional relationships are similarly ambiguous for the bituminous dolostones of Mt Prena-Vredda (Gran Sasso chain) and for those drilled in the Adriatic offshore (Emma basin) (Zappaterra, 1992). At present, there is no clear evidence that they were deposited in the same Triassic basin. Taking into account the shortening of the Apennine chain, the Triassic basin should have been considerably wide. Regardless of their precise configuration, the presence of these intra-platform troughs and/or true Triassic basins can be related to the earliest rifting phases which, during Jurassic time, lead to the formation of the Neotethys oceanic basin.

During the Early Liassic, the palaeogeography was roughly the same as in the previous time interval, with a wide domain of shallow-water platform controlling the sedimentation in this southern portion of the Neotethys margin, except for the Filettino (Simbruini Mts) and Mt Prena-Vredda (Gran Sasso chain) areas, which continued to be characterized by pelagic sedimentation [Filettino breccias and *Sant'Antonio* Fm, Hettangian-Sinemurian, in the Filettino area, *Calcari maculati* and *Corniola selcifera*, Hettangian-Sinemurian, in the Vradda sector (Damiani *et al.*, 1992)].

Middle Liassic-Lower Cretaceous

The Middle Liassic tectonic phase affected the whole Neotethyan domain, as is evident in the Mesozoic successions of central Italy. This tectonic phase, which in the study area shows a clear extensional character, is related to the Neotethys Jurassic rifting. From a more regional point of view, some authors (e.g., Abbate *et al.*, 1994; Ziegler and Roure, 1996) suppose that it was induced by the transform motion of some important tectonic elements, which should have affected and constrained the expansion of the inner Ligure-Piemontese oceanic basin.

In all the peri-Neotethyan sectors, this tectonic phase generally showed an extensional character and induced variations in the sea-floor depth. This initiated sedimentary basins characterized by different bathymetry, sedimentation, subsidence, etc.

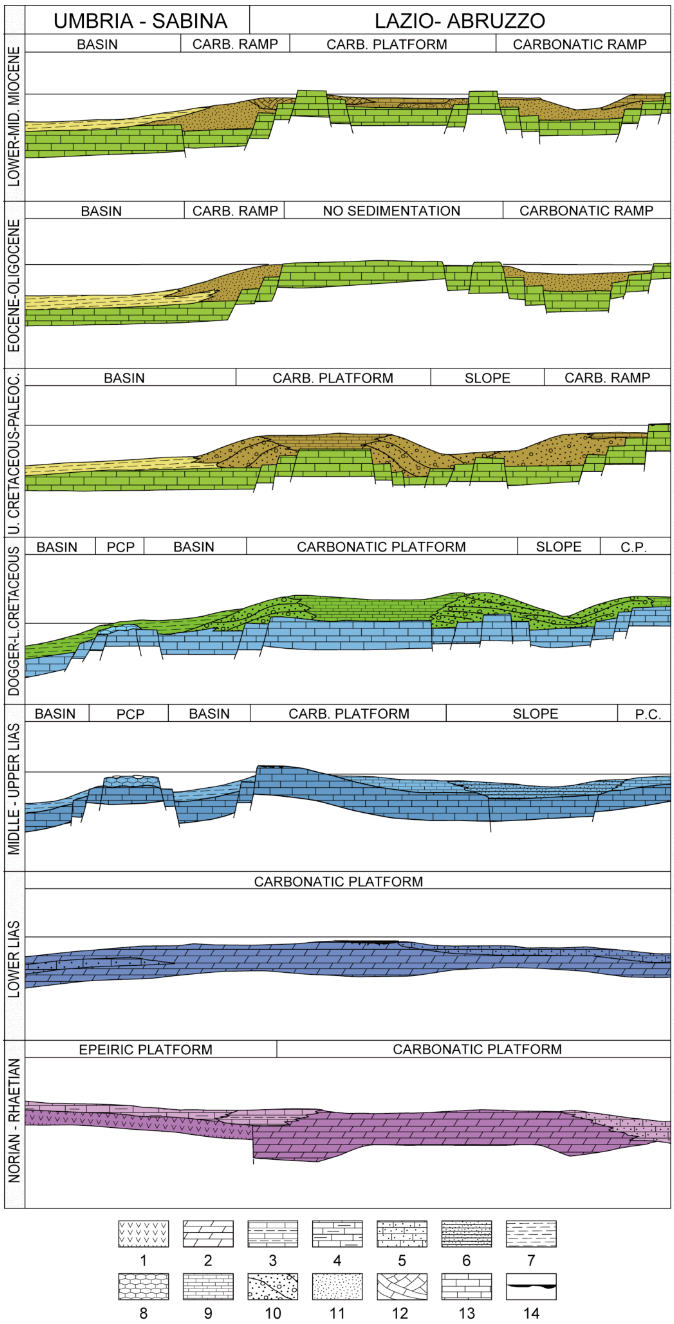
In central Italy, as well as in all those sectors that during the Early Jurassic were located along the passive continental margin of the expanding Neotethyan basin, this Middle Liassic tectonic phase broke up the shallow-water platform domain that was widespread in the whole central Italy during the Early Liassic (except for the Filettino and Vradda sectors). These extensional tectonics created platform-basin systems, characterized by downthrown sectors dominated by deeper-water sedimentation (pelagic successions) with local clastic carbonate sediment coming from the shallower areas, and upthrown sectors with shallow-water carbonate deposits related to shallow-water platform environments.

This new extensional event, which was related to the early stage of the Neotethys rifting, did not happen only along the trend of previous extensional structures, but, also along extensional fault systems perpendicular to the Late Triassic tectonic features. Following this tectonic event, the margins of the Jurassic-Cretaceous carbonate platforms were defined as well as the transitional zones between them and the downthrown areas. In addition to platform margins with N-S present orientation, the present-day distribution of the Jurassic-Cretaceous facies of central Italy shows north-south lateral facies variations in several places, including the northern margin of the Grand Sasso, the northern margin of the Maiella Mts, and the northern margin of the Morrone Mts. The presence of huge volumes of resedimented carbonate in the Middle Liassic deposits of the transitional areas (basin-to-platform) (*Corniola* Fm with megabreccias) is a further stratigraphical signal of the tectonic event responsible for creating the widespread pelagic domain.

Plates 1 and 2 show the Mesozoic successions of central Italy split into four main facies: 1) basin; 2) basin-to-platform; 3) platform edge; and 4) platform. The distribution of the platform edge facies and of the transitional one (basin-to-platform facies) shows a clear platform-basin system that controlled the Mesozoic sedimentation in the area (Fig. 3).

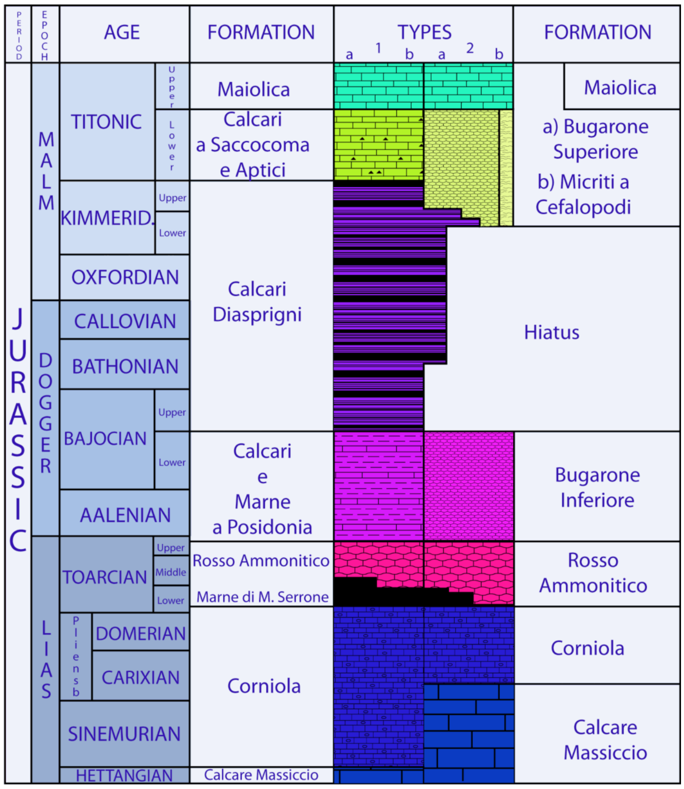
The palaeogeographical setting of this system generated the pelagic sedimentation of the northern Sibillini Mts, the inner Umbria arch, the Martani Mts, and the Narnesi-Amerini Mts. The stratigraphic succession of this domain is the Umbro-Marche Liassic basin sequence, characterized by limestones and marly pelagic limestones, without any evidence of significant carbonate re-sedimentation (Fig. 4). The rare resedimented units are linked to local morpho-structural Jurassic palaeo-highs, characterized by reduced or condensed Jurassic sequences (Pelagic Carbonate Platform - PCP, Figs. 3, 4).

Figure 3. Platform-Basin system



Main steps of the Late Triassic- Middle Miocene evolution of the platform-basin system in central Italy (modified from Accordi and Carbone, 1986). CP – carbonate platform; PCP – pelagic carbonate platform; 1) evaporites; 2) dolomites and laminated dolomitic limestones; 3) clays and marls with intercalations of oolitic and organogenous wackstone-grainstone; 4) marls; 5) bioclastic wackstone-packstone; 6) mudstone with biodetritic and microclastic intercalations ; 7) marls, clays and pelagic micrites; 8) pelagic mudstone-wackstone and hardground with nodular structures; 9) carbonate platform limestones; 10) organogenous grainstone-rudstone; 11) packstone-grainstone with intercalations of marly pelagic mudstone; 12) organogenous wackstone-grainstone; 13) carbonate basement; 14) supratidal deposits and alteration soils.

Figure 4. Jurassic stratigraphy of Umbria-Marche domain



Jurassic stratigraphy of the Umbria-Marche basin. The presence of hiatuses in the succession characterizes the stratigraphy of the Jurassic morpho-structural highs (seamounts) (after Cresta, 1989).

The early Cretaceous regional paleogeography was quite similar to that of the late Jurassic. The early Cretaceous southern margin of the Neotethyan Ocean was characterized by a persistent platform-basin system. In this time interval, to the west of this platform-basin system, the Ligurian-Piedmont oceanic basin stopped spreading. The platform-basin system led to the deposition of thick shallow- and deeper-water carbonate successions.

The low naphtagenic potential of these carbonate successions is confined to its upper portion. Lower in the stratigraphic sequence, near the stratigraphical transition between the micritic limestone with radiolarians and tintinnides pertaining to the *Maiolica* Fm and the overlying *Marne a fucoidi* Fm, the beginning of an euxinic event is recorded over the whole basin, responsible for the sedimentation of clayey horizons rich in organic matter (black-shales). The stratigraphical level that bears a particularly high concentration of these black-shales is less than a few metres thick (*Livello Selli*) and comprises also the basal part of the *Marne a fucoidi* (Erba *et al.*, 1989).

In the *Marne a fucoidi* Fm cored in the Piobbico well, 154 centimeter- and millimeter scale black-shale levels have been observed. The thickest (1-3 metres) highly C_{org}-rich black-shale occurs in the lower part of the *Marne a fucoidi* Fm ("*Livello Selli*"). In the middle portion of the *Marne a fucoidi* Fm, two thick (20 cm) and highly C_{org}-rich black-shales are recorded and named "*Livello n°113*" and "*Livello Urbino*" (Coccioni *et al.*, 1987). These three distinct anoxic events are marker-beds throughout the Umbria-Marche basin and can be correlated to coeval anoxic episodes in the Neotethys (Sicily, Gargano, Southern Alps, etc.). Generally, the total thickness of the *Marne a fucoidi* Fm is no more than 85 m.

Moving towards SE from the sectors characterized by outcrops of the pelagic facies, there is a narrow strip, extending from the southern Sibillini Mts through the Reatini and Sabini Mts, and as far as to the Tiburtini Mts, in which a carbonate basin-to-platform succession crops out. This succession is characterized by frequent re-sediments of shallow-water carbonates within pelagic calcareous and marly-calcareous deposits. Also along this strip, reduced or condensed Jurassic successions are common, and are related to pelagic carbonate platforms (PCP, Santantonio, 1993; Galluzzo and Santantonio, 2002; Cosentino *et al.*, 2006). Basin-to-platform facies, similar to those previously described, are present along the whole Gran Sasso chain, along the Mt Genzana-Mt Greco ridge, and in the Monti della Meta. Basin-to-platform facies are also exposed through drilling in the Frosolone 2 well.

The outcrops of lithofacies associated with the platform edge environment are rare and confined to the Montagna Grande ridge, Montagna del Morrone, some places in the Mt Velino-Mt Magnola-Mt Sirente region, and along the Mt Giano (Antrodoco) ridge. These lithofacies mainly consist of either organogenic grainstones with echinoderms, algae, corals and mollusks (patch reef environment), or micritic limestones that are sometimes laminated, and fossiliferous grainstones (algal-ridge environment).The carbonate facies related to shallow-water platform environments are widely distributed along the carbonate ridges of the Latium-Abruzzi region. They crop out in the Lepini Mts, Ausoni Mts, Aurunci Mts, Simbruini Mts, Ernici Mts, Mt Cairo, Matese Mts, Caserta and Benevento Mts, Mt Nuria, Mt Velino, Mt Sirente, Marsica Mts, Morrone Mts, Mt Porrara, Mt Pizzalto, Mt Rotella, and Maiella Mts. The prevailing lithofacies, associated mainly with open shallow-water platform or restricted shallow-water platform environments, are made of dolostones, dolomitic limestones and micritic limestones. In the basal portion of this interval, grainstones with oolitic intercalations are present. The upper portion (Aptian) is generally characterized by alternating micrites, marly limestones, and finely stratified marls (*Marne a Orbitolina* Fm).

Upper Cretaceous

The distribution of the different upper Cretaceous lithofacies is broadly similar to that of the previous time interval. In the lithofacies map (Plate 1), the basin and basin-to-platform successions correspond to the Upper Cretaceous-Oligocene time interval.

The successions related to a pelagic basin environment crop out widely from the northern Sibillini Mts to Mt Subasio, Martani Mts and Narni Mts. The prevailing lithotypes of this basinal succession are marly limestones, calcareous marls (*Scaglia* Fm) and, in the upper part of the stratigraphical interval, clayey marls (*Scaglia cinerea* Fm).

In the basal portion of the stratigraphic interval (Late Cenomanian) the basinal succession is characterized by an euxinic horizon ("*Livello Bonarelli*"), recognized throughout the basin as a potential source rock in this stratigraphic interval. The "*Livello Bonarelli*", ranging from 45 to 200 cm thick, consists of black limestones, argillites, gray-greenish radiolarian-rich siltstones, and black-shales rich in organic carbon. The black limestones often contain some well preserved fish remains. The "*Livello Bonarelli*" generally lies about 6-8 m below the boundary between the *Scaglia bianca* Fm and the *Scaglia rossa* Fm (Paris *et al.*, 1989). The "*Livello Bonarelli*" has been split into three segments on the basis of its lithological characteristics:

- a lower segment consisting of brown to gray radiolarian-rich silts, whose thickness varies between 30 and 100 cm;
- a middle segment consisting of laminated black-shales rich in organic matter, whose thickness varies between 30 and 100 cm;

- an upper segment consisting of radiolarian-rich silts and gray-green sapropelites, whose thickness varies between 10 and 30 cm.

The "*Livello Bonarelli*" is an important marker horizon in the whole Tethyan Basin and can be correlated with the second Oceanic Anoxic Event (OAE defined by Schlanger and Jenkins, 1976).

Towards the SE is the boundary from the basin facies to the basin-to-platform facies, which widely characterize the Sibillini Mts, Reatini Mts, Sabini Mts, and Prenestini Mts. Similar facies border the carbonate platform of Mt Nuria, Mt Ocre, Mt Sirente, and Marsica Mts from the N and E.

Basin-to-platform facies belonging to the Late Cretaceous-Oligocene have been recognized at La Meta-Mainarde, Venafro Mts, Montagnola di Frosolone, and in the northern portion of Maiella and Morrone Mts. As in the basinal facies, an anoxic level corresponding to the "*Livello Bonarelli*" occurs in the lower part of this time interval in the basin-to-platform succession. This marker-bed is easily visible in the Sibillini Mts, Reatini Mts, and Sabini Mts.

The prevailing lithologies of this basin-to-platform facies are marly limestones, calcareous marls, and clayey marls, with frequent intercalations of mainly channelized bodies of re-sedimented carbonates of different grain size. These carbonate re-sediments show grain- and debris-flow depositional mechanisms.

The Upper Cretaceous-?Paleocene facies of platform edge are very rare. These facies crop out in the Mt Giano-Mt Gabbia area, SE of Piana dell"Aquila, Montagna Grande, La Meta, and Maiella Mts. Moreover, small outcrops are present at Rocca di Cave (Prenestini Mts) and Cori (Lepini Mts).

The lithofacies pertaining to the platform edge are characterized by cyclic alternations of packstones and grainstones with subordinate wackstones. Rudists, gastropods and hydrozoan are present.

The Mt Nuria-Mt Velino, western Marsica, Simbruini Mts-Ernici Mts-Mt Cairo, Lepini Mts-Ausoni Mts-Aurunci Mts, and Matese Mts expose wide outcrops of the Upper Cretaceous-?Paleocene platform succession. This succession is characterized mainly by dolomitic limestones, dolostones and wackstone, light- or hazel-brown in color, with fragments of hippurites and benthic foraminifers that generally record a restricted shallow-water platform environment.

Cenozoic

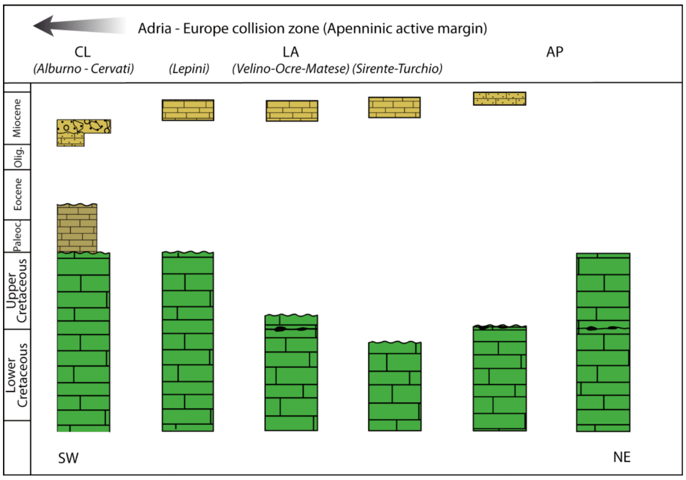
The Cenozoic pre-orogenic successions are related to a palaeogeographic framework slightly different from that of the basin-platform system that characterized the sedimentation during the Mesozoic. Whereas the basin and the basin-to-platform domains persisted throughout the Oligocene, the Mesozoic platform edge and platform domains were characterized, during Cenozoic, by a shallow ramp palaeoenvironment. Small, not mappable outcrops belonging to this shallow ramp Paleocene-Oligocene palaeoenvironment are present in Marsica, while a wider exposures characterize the southern margin of the Maiella Mts. Generally, they are made of grainstones and rudstones with corals, large foraminifers, red algae, and rudist debris.

During the Early Miocene, the lithofacies were further homogenized. In central Italy, only pelagic, transitional and shallow-water facies are present. Generally, the pelagic facies consists of marls and calcareous marls with chert and planktonic foraminifera, which laterally transition to marls and calcareous marls with frequent grain-flow or debris-flow carbonate re-sediments.

During the Middle Miocene, moving from the alignment Sibillini Mts-Reatini Mts-Sabini Mts-Prenestini Mts toward E, two lithofacies were developed: calcarenites with pelagic and displaced benthic fauna characteristic of a deeper carbonate ramp environment, and fine packstones and grainstones with essentially benthic fauna associated with a shallow carbonate ramp environment. Generally, on the Mesozoic platform domain the Middle Miocene shallow ramp deposits lie on the ?Palaeocene/Upper Cretaceous shallow-water carbonates. In contrast, in the Mt Sirente-Mt Turchio-Mt Rapanella area, the Middle Miocene shallow ramp deposits lie directly on the Lower Cretaceous shallow-water limestones of the Mesozoic platform domain, above the Paleogene hiatus (Fig. 5).

The Paleogene hiatus has been explained as due to an increase of the intraplate stress during the Middle Eocene collisional event between Adria and the European plate (Cipollari and Cosentino, 1995). This major tectonic event caused lithospheric folding and compressional deformation, and subsequent erosion in shallow-marine environments (i.e. carbonate platform domains).

Figure 5. Chronostratigraphic diagram of the Paleogene hiatus



Chronostratigraphic diagram of the Adria carbonate-platform domains along an ideal palinspastic SW-NE transect in Central-Southern Italy. The diagram shows both the maximum gap in the eastern margin of the Latium-Abruzzi carbonate platform (LA, Sirente-Turchio area) and decreasing gap towards the Adria-Europe collision zone (SW). Data from Accordi and Carbone, 1986; Bonardi *et al.*, 1988; Santo and Sgrosso, 1987; Sgrosso, 1992b.

Pre-orogenic palaeogeographical models

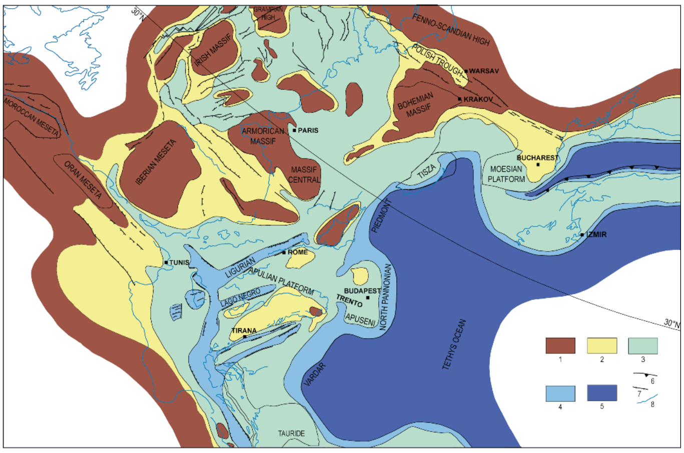
A tectonically high, active area such as the peri-Mediterranean poses many difficulties to deriving a detailed palaeogeographical model of the region. Many factors, including relatively recent orogenic processes, new oceanic basin formation, and lithospheric block rotations, impacted the evolution of the area in a number of ways that are generally not completely known.

In such a complex tectonic framework, the original relations of facies heteropy among contiguous sedimentary domains are generally obscured by tectonic activity. Reconstructing the pre-deformational palaeogeography of those areas requires unraveling its kinematic evolution and quantifying the amount of shortening and/or extension during the deformational processes. Despite uncertainties associated with these tasks, some palaeogeographical models for the western Tethyan realm have been reconstructed (Dercourt *et al.*, 1993, Ciarapica and Passeri, 1998, 2002) taking into account almost all the parameters that could influence a palaeogeographic reconstruction, including a palinspastic restoration of the area that must consider the magnitude of tectonic deformation that affected the area.

• *Late Triassic palaeogeographical model of the peri-Mediterranean area.*

During the Late Triassic the present-day peri-Mediterranean area was located between 10° and 30° N latitude and was represented by a wide area of shallow-water platform that divided two huge continental emerged areas: the Iberic-Provençal sector of the central Europe to the north and the North-African sector to the south (Fig. 6). Towards the west, this wide shallow-water platform (SWP) region was affected by evaporitic sedimentation (evaporitic platform), whereas the remaining portion of the SWP was an epeiric platform. Some stratigraphical features allow further differentiation of the shallow-water platform environment into open SWP, evaporitic SWP, and restricted SWP (Plate 1). An initial Latest Triassic rifting caused the break up of what must have been a single huge carbonate sedimentation domain during the Early and Middle Trias. Following this rifting phase, the pre-existing Lagonegro trough (trending about E-W) began to expand, giving rise to the Sicanian Basin, to the Budva Trough, and to the Pindos-Olonos Zone. Moreover, some N-S lateral branches opened, forming basins affected by pelagic sedimentation: Emma Basin and Bosnia Basin.

Figure 6. Late Triassic paleogeographic map



Late Triassic paleogeographic map of Tethys realm (modified from Yilmaz *et al.*, 1996). 1) continental; 2) coastal plain; 3) shelf deposition; basin and slope; 5) deep ocean; 6) volcanic; 7) overthrust; 8) strike-slip fault; 9) extensional fault; 10) coastline.

As described in the previous paragraphs, during the Late Triassic, pelagic facies (bituminous dolostones of Vradda and Filettino) existed in central Italy, similar to those that, in the Adriatic offshore, characterized the Emma Basin. Whereas it is possible that the bituminous dolostones of Vradda belong to the Emma Basin (mainly due to the proximity of the areas), it is more difficult to consider the bituminous dolostones of Filettino as pertaining to the same basin because the Triassic rocks that crop out at Venafro Mts and Matese Mts are related to shallow-water carbonate platform facies. The bituminous dolostones of Filettino could be the result of the tectono-sedimentary evolution of an intra-platform through, similar to the one associated with the Emma Basin but parallel to it and located in a more western sector, within the Apennine carbonate platform.

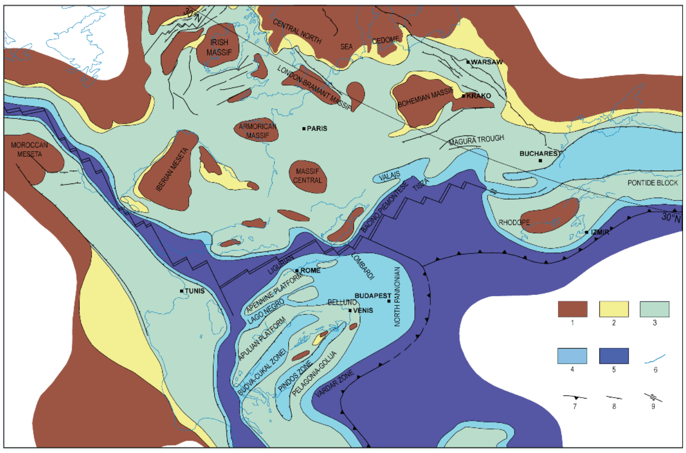
Farther north, an additional intra-platform through divided the shallow-water carbonate facies from the dolomitic domain.

• *Late Jurassic palaeogeographical model of the peri-Mediterranean area*

As already discussed in the previous paragraphs devoted to the stratigraphical setting of central Italy, an important extensional tectonic phase occurred during Middle Liassic, which broke up the wide, shallow-water platform that during the infra-Liassic characterized the palaeogeographical setting of the present-day peri-Mediterranean area (Fig. 7). This extensional tectonic episode is strictly linked to the western propagation of the continental rifting that previously (Late Triassic) affected the more eastern regions of the present-day peri-Mediterranean area (Pindos-Olonos Zone).

Due to the extensional tectonics during the Late Jurassic, the platform-basin systems were widely developed and persisted throughout the Mesozoic. From the Middle Liassic, the shallow-water platforms of the peri-Tethyian area developed under epi-oceanic conditions. In this geodynamic framework, the Apulian platform became differentiated and subsequently isolated from the other Mesozoic epi-oceanic platforms, due to the development of confining pelagic basins such as the Sicily Basin, the Molise Basin and the Ionian Basin. The Molise Basin and, farther west, the Lagonegro Trough, divided the Apulian and Apennine platforms. Towards the north and west, the Apennine platform was linked, through the bacinal facies of Sabina, Tuscan Basin and Sicilide Basin, to true oceanic environments (Ligurian basin). This time interval records the maximum development of the Ligure-Piemontese oceanic basin, with the formation of sectors characterized by oceanic lithosphere.

Figure 7. Late Jurassic paleogeographic map

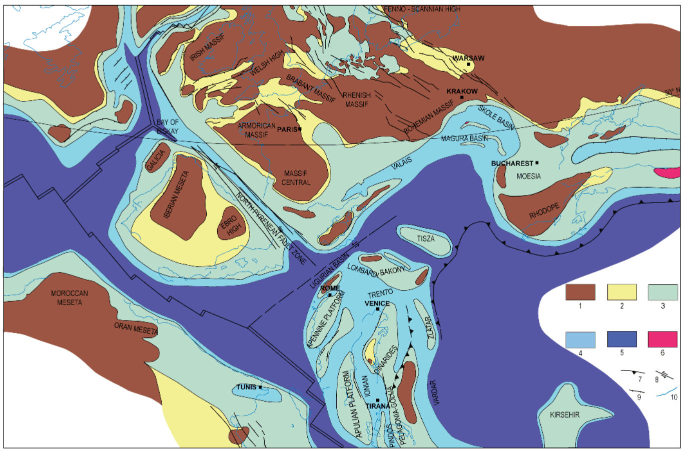


Late Jurassic paleogeographic map of Tethys realm (modified from Yilmaz *et al.*, 1996). 1) continental; 2) coastal plain; 3) shelf deposition; basin and slope; 5) deep ocean; 6) volcanic; 7) overthrust; 8) strike-slip fault; 9) extensional fault; 10) coastline.

• *Top Early Cretaceous palaeogeographical model of the peri-Mediterranean area*

During the Late Cretaceous, the geodynamic processes controlling the peri-Mediterranean area underwent drastic changes. The dominant action of the extensional tectonics, which characterized the previous time-interval, persisted only in the more eastern sector of the peri-Mediterranean area (Lybian Basin and Cyprus Basin), while the more northern one was affected by compressional tectonics (Fig. 8). In the previous period, compression had already been active only in the more eastern sector of the peri-Mediterranean area (Vardar Zone). During this time interval, a general regressive trend was recorded on the northern margin of the peri-Mediterranean area, while the central sector underwent a period of relative tectonic rest. Thus, the evolution of the platform-basin systems that were first developed during the Middle Liassic extensional tectonic phase continued in this time interval. At that moment the southern margin of the peri-Mediterranean area was affected by a general trasgressive trend, which allowed for the spread of shallow-water platform environments across the southern sectors.

Figure 8. Early Cretaceous paleogeographic map



Early Cretaceous paleogeographic map of Tethys realm (modified from Yilmaz *et al.*, 1996). 1) continental; 2) coastal plain; 3) shelf deposition; basin and slope; 5) deep ocean; 6) volcanic; 7) overthrust; 8) strike-slip fault; 9) extensional fault; 10) coastline.

Distribution of the Syn- and Post-Orogenic Cenozoic Facies

In Neogene time, during the syn-orogenic tectono-sedimentary events that affected the central Apennines, an eastward migrating foreland basin system developed. In this framework, siliciclastic turbidites filled different foredeep basins, while coarse-grained clastic deposits were deposited in various Neogene thrust-top basins. The eastward migration of this foreland basin system follows an oblique trend if compared with the Meso-Cenozoic isopic facies. In Plate 1, the syn-orogenic terrigenous deposits have not been distinguished in terms of age of deposition. Age differentiation for these deposits is provided in Plate 4.

Finally, in the post-orogenic sedimentary and volcanic covers, the Plio-Quaternary continental and marine deposits, as well as the Middle Pleistocene volcanics, have been distinguished. Plio-Quaternary deposits are widespread along both the Adriatic and the Tyrrhenian coastal plains. and also fill several intra-Apennine sedimentary basins. The Middle Pleistocene volcanics are distributed along the Tyrrhenian side of the central Apennines, generally on crustal sectors downthrown by Plio-Quaternary extensional tectonics.

Structural Setting of Central Italy

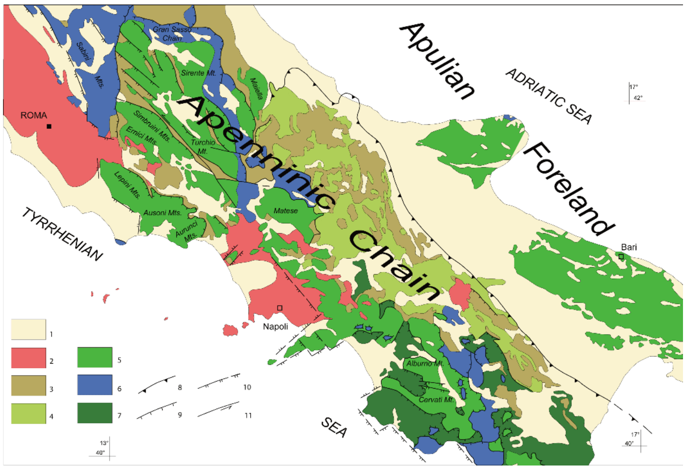
Introduction

The study area is located on a peri-cratonic region, which experienced several deformation events in response to the Neogene tectonic interaction between the European and African plates, leading to the peri-Mediterranean orogeny. In particular, during the post middle-Tortonian orogenic phases of the Apennines, the Adria microplate (D'Argenio and Horvath, 1984; Anderson, 1987) played a significant role. The boundary interaction between Adria and the surrounding continental plates controlled the evolution of the Adria-verging orogenic system. These plate interactions caused the building of both the Apennine and of the Dinaric segments of the peri-Mediterranean chain.

The post-middle Tortonian Apennine chain consists of tectonic units derived from the deformation of both Meso-Cenozoic shallow water limestones (carbonate platform domains), and Meso-Cenozoic deeper-water carbonates (slope and pelagic basin domains) (Fig. 9 and Plate 3). The structural setting of these tectonic units is similar to other post-collisional thrust-belts, and consists of basement and cover thrust-sheets developed in an ensialic context. The geometry of the chain, the diachronism of the eastward migrating foredeep basins in this area, and the different ages of the forethrusts (Fig. 10) are consistent with a regional foreland propagating model for the central Apennines (Bally *et al.*, 1988; Endignoux *et al.*, 1989; Sage *et al.*, 1991; Cipollari and Cosentino, 1992, 1995; Patacca *et al.*, 1992a; 1992b; Cavinato *et al.*, 1994; Patacca *et al.*, 2008).

Such a geodynamical setting controlled the origin and the evolution of several syntectonic sedimentary basins (foreland basin systems, sensu De Celles and Giles, 1996) which developed during the evolution of the Apennine chain (Ori and Friend, 1984; Patacca and Scandone, 1989; Boccaletti *et al.*, 1990; Cosentino *et al.*, 2003; Patacca *et al.*, 1992a; 1992b; 2008).

Figure 9. Structural sketch map of the Apenninic chain



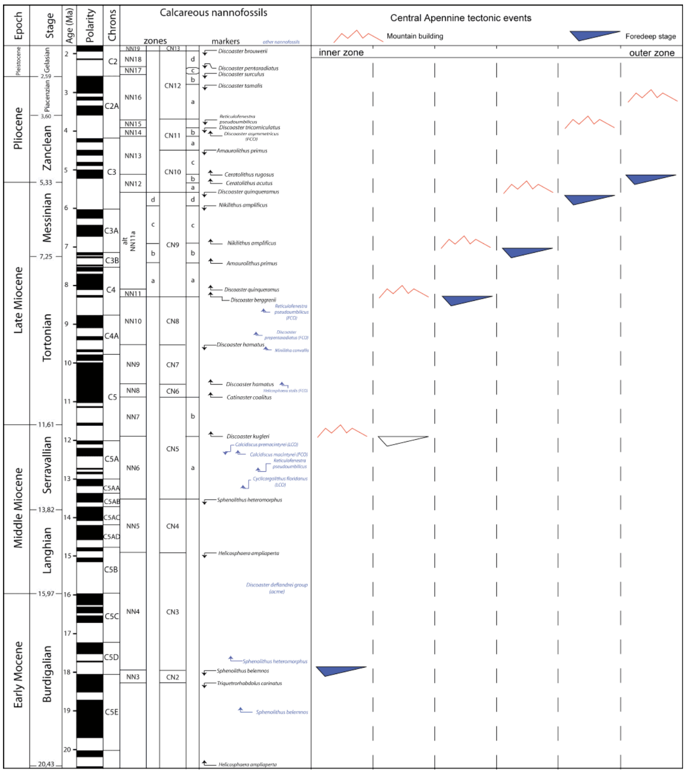
Structural sketch map of the central-southern Italy. 1) Plio-Quaternary marine and continental deposits; 2) Quaternary volcanics; 3) Post-Burdigalian fordeep siliciclastic deposits (undifferentiated ages); 4) "Flysch Rosso" belonging to the Sicilide, Lagonegro and Molise units (Oligocene-Upper Cretaceous); 5) Meso-Cenozoic carbonate platform sequences and carbonatic ramp deposits (Middle Miocene-Upper Triassic); 6) Meso-Cenozoic pelagic sequences and transitional shelf-to-basin deposits (Middle Miocene-Upper Triassic); 7) Liguride and Sicilide units, deriving from the deformation of internal domains, with Lower Miocene thrust-top basin deposits (S. Mauro, Pollica and Albidona Fms.); 8) thrust front of the Apenninic chain; 9) thrust; 10) normal fault; 11) strike-slip fault.

Structural Units of the Apennine Foreland Thrust Belt

The present structural setting of central Apennines is mainly a result of the superimposition of two tectonic processes, which affected central Italy in slightly different times. The general northeastward migration of the central Apennine orogenic system, which follows a piggyback sequence of the main thrusts, entails an out-of-sequence re-activation (out-of-sequence thrusts) of some chain sectors previously involved in the thrust belt. Generally, these compressional tectonic phases were followed by post-orogenic extensional and strike-slip tectonics.

Within this general framework, the tectonic units considered in Plate 3 are bounded by both the main thrusts activated during the different piggyback migration phases of the orogenic system, or the main out-of-sequence thrust fronts that characterize this part of the Apennines. In this context, the tectonic units distinguished in Plate 3 show a regional significance and can be considered a series of structural sub-units.

Figure 10. Chain-foredeep migration



Bio-chronostratigraphical scheme adopted for the micropaleontological analysis of the syn-tectonic terrigenous deposits of the central Apennines (zonal schemes are after Martini 1971 (modified) and Okada and Bukry, 1980). In the right half, the recognized central Apennine tectonic events are shown. For the Serravallian foredeep stage (in white) no siliciclastic deposits are recognizable in the study area.

In this paper, the description of the tectonic units that make up the central Apennines will follow the geometrical sequence, beginning with the geometrically higher units in the pile of the Apennine thrust sheets, down to the lower ones.

In a piggyback sequence of the main thrusts responsible for the growth of the Apennine chain, the geometrical criteria matches with the chronological one. In some places, where out-of-sequence thrusting plays an important role in the definition of the structural setting of the central Apennines, the geometrical criteria does not always match the timing of a forelandward piggyback propagation of the chain.

The central Apennine fold-and-thrust belt is characterized by the presence of two allochthonous units derived from the deformation of internal domains such as the external Ligurian, the Sicilide, and the Sannio domains. Generally, these allochthonous tectonic units are characterized by a chaotic complex consisting of varicoloured shales, calcareous and arenaceous turbidites. These allochthonous Apennine units were piled up during the earliest Apennine orogenic events and, subsequently, have been transported onto more external domains until Pliocene times.

• If we exclude the allochthonous portion of the external Ligurian and Sicilide units, cropping out in the northwestern and southeastern sectors of Plate 3, and those of the Sannio unit, cropping out in the southeastern sector of the area, the higher carbonate tectonic unit of the central Apennine thrust belt crops out in the northwestern sector of Plate 3. In particular, the highest tectonic unit of this thrust sheet is the Mt Soratte Tectonic Unit. This tectonic unit shows stratigraphical characteristics similar to those of the Tuscan succession and is subdivided into several tectonic sub-units. Its role as a tectonic unit should date back to the compressive Late Burdigalian event, while the foredeep of the inner *Marnoso arenacea* developed in the more outer sectors (Narni Mts and Martani Mts).

• Going towards the base of the tectonic wedge, the next tectonic unit is the Inner Umbria Tectonic Unit. This unit is bounded to the east by a right-lateral N-S strike-slip fault (southern portion of the tectonic unit) and by a thrust (Spoleto thrust), which shows multiple kinematics. This tectonic unit includes Mt Subasio, the Martani Mts, the Narni Mts, and the western Sabini Mts. Its internal structural setting is characterized by syncline and anticline macro-folds, which deform a basinal carbonate succession Lower Triassic to Lower Miocene in age. Its development should be attributed to the Serravallian compressive event, recognized in the Spoleto Mts (Cipollari and Cosentino, 1997) due to the presence of a thrust-top basin of that age (Belvedere-Vallocchia basin). Besides the presence of syn-orogenic deposits of the Belvedere-Vallocchia thrust-top basin, siliciclastic deposits are also common within this tectonic unit . These siliclastic deposits are related to sedimentation within a foredeep basin (Upper Burdigalian-Lower Serravallian), which further constraints the kinematic evolution of the area.

• The following tectonic unit is much wider than the previous one, encompassing the Sibillini Mts, the Sabini Mts, the Tiburtini Mts, and the Prenestini Mts. It derives from the deformation of shelf-to-basin and deeper-water Meso-Cenozoic limestones of the Umbria-Marche and Sabine domains. This tectonic unit (Umbria-Marche-Sabine Tectonic Unit) shows a general N-S trend with some minor thrust sheets, associated with syncline and anticline macro-folds. Generally, the orogenic transport of these structures is towards the eastern sectors. This tectonic unit is limited to east by the well-known central Apennine thrust surface: the Olevano-Antrodoco-Sibillini Mts thrust. This thrust corresponds to a very complex faulted area, characterized by multiple thrust surfaces, among which the Olevano-Antrodoco-Sibillini Mts thrust represents the more external enveloping surface (Parotto and Praturlon 1975; Salvini and Vittori, 1982; Cavinato *et al.*, 1986; Cipollari and Cosentino, 1992; Cipollari *et al.*, 1993). Because of both its timing and its oblique trend, if compared with the piggyback foreland migration of the central Apennine orogenic system, an out-of-sequence kinematic activity has been suggested for this structural element. Moreover, this tectonic unit, more than others, shows kinematic evidence that suggests multiple phases of deformation (re-folded folds, multiple slip direction on the same fault plane, folded cleavage, etc.).

In conclusion, this tectonic unit corresponds to a sector of the chain that was deformed during the Late Tortonian and Messinian Apennine compressional phases (in piggyback sequence) and subsequently was re-deformed due to the out-of-sequence thrusting of the Olevano-Antrodoco-Sibillini Mts thrust. The timing of this out-of-sequence activation corresponds to one of the main tectono-sedimentary events recorded in central Apennines: the Messinian *Lago-Mare*-Early Pliocene tectonic event.

• The Lepini-Ausoni-Aurunci Tectonic Unit derives from the deformation of the inner portion of the Apennine carbonate platform domain. It consists of Meso-Cenozoic shallow-water carbonates thrust onto Upper Tortonian terrigenous deposits related to the evolution of the Tortonian Apennine foredeep. The tectonic unit is characterized by wide homocline structures and by secondary widely open syncline structures, with a NW-SE prevailing trend.

Some small slices of the Sicilide complex are overthrust onto the carbonate of the Lepini-Ausoni-Aurunci Unit (e.g. Mt Caccume Klippe and Carpineto Romano area). At Mt Caccume, these small outcrops of Sicilide unit are tectonically overlain (sandwich-like structure) in part by a shallow-water platform succession similar to that of the Lepini-Ausoni-Aurunci Tectonic Unit.

The frontal thrust that bounded the tectonic unit on its eastern margin shows a subhorizontal geometry, as evidenced by several Klippen at its front. This thrust surface is one of the main overthrusts that lead to the build up of the central Apennine chain. In essence, the structure of the Lepini-Ausoni-Aurunci Mts represented, during Late Tortonian, the more external portion of the Apennine tectonic wedge, which was migrating with a piggyback sequence towards the Adriatic area. This conclusion is stratigraphically constrained in the Lepini Mts (Carpineto Romano area), where a sedimentary cycle unconformably overlies high deformed Meso-Cenozoic shallow-water carbonates. This unconformable sedimentary cycle (the Gorga-Gavignano unit, Cosentino *et al.*, 2003), which consists mainly of coarse-grained deposits, was sedimented in a thrust-top setting, as testified by the compressional tectonics affecting the Gorga-Gavignano unit (Cosentino *et al.*, 2003).

During the subsequent Messinian tectonic phase, the whole structure was further transported eastward, and the thrust front reached its present position.

• Moving towards the base of the central Apennine tectonic wedge, the Simbruini-Ernici-Matese Tectonic Unit rests beneath the previous tectonic unit. It is one of the wider tectonic units of the central Apennines and derives from the deformation of both shallow-water platform and platform-to-basin domains. As above mentioned, the trend of the orogenic system developed obliquely to the Meso-Cenozoic isopic facies. At its eastern end, this tectonic unit is bounded by a regional thrust surface, which allows the thrust of the Simbruini Mts, Ernici Mts, Mt Cairo, Venafro Mts, and Matese Mts carbonate successions onto the Messinian terrigenous syn-orogenic sequence. This latter sequence filled the Apennine foredeep basin that developed in this area during the Messinian.

As in other regional tectonic units recognized in the central Apennines, several minor tectonic structures are recognizable within the Simbruini-Ernici-Matese Tectonic Unit. These are linked to secondary thrusts that are probably synchronous with the main thrust at the base of this tectonic unit.

• The next tectonic unit, the Gran Sasso-western Marsica Tectonic Unit, is about 60 km wide and derives from the deformation both of Meso-Cenozoic shallow-water platform and platform-to-basin domains.

This tectonic unit has a very complex structural setting. Thrust tectonics linked to the piggyback evolution of the Apennine accretionary wedge was followed by out-of-sequence thrusting of the Gran Sasso chain. The first compressional phase that involved the area in the Apennine chain must have occurred during the Messinian *Lago-Mare*/Early Pliocene, as testified by the ages of several thrust-top basins (e.g. 1-Monte Coppe: Patacca *et al.*, 1992b; Ghisetti *et al.*, 1993; 2-Le Vicenne: Colacicchi *et al.*, 1967; Cipollari *et al.*, 1999a, 1999b; Gliozzi, 1999; 3-Monte Mezzana: Praturlon, 1968; 4-Palena: Patacca *et al.*, 1992b). This phase was characterized by piggyback migration of the Apennine compressive front, with deformation accommodated along newly-generated N-S oriented structures. Subsequently, at the end of the Early Pliocene, an out-of-sequence thrust with a W-E trend was activated (Gran Sasso Chain: Ghisetti and Vezzani, 1986; 1990; Cipollari *et al.*, 1997; Vezzani and Ghisetti, 1998), perpendicular to the previous N-S structures.

The tectonic unit of Gran Sasso-western Marsica is, thus, bounded to the north by the out-of-sequence thrust of the Gran Sasso chain, while to the east the boundary is uncertain, mainly in the zone between Mt Picca and Anversa degli Abruzzi.

In the area between Mt Cappucciata and Mt Picca, a thrust surface with a N-S trend is well developed. This structural feature places the Gran Sasso-western Marsica Tectonic Unit above the syn-orogenic terrigenous deposits of the *La Queglia Flysch*, (Patacca *et al.*, 1992b; 2008) dated Messinian *Lago-Mare*/Early Pliocene. A similar structural relation is visible to the east of the Montagna Grande, where platform edge carbonates are thrust onto the terrigenous siliciclastic deposits of the foredeep. For these latter deposits, the only stratigraphical constraint is represented by the outcrop of the clays with gypsum of Anversa degli Abruzzi, which are thrust onto very fine–grained siliciclastic deposits of this foredeep. This tectonic relation implies a foredeep siliciclastic deposition post-dating the Messinian salinity crisis, thus correlative with the La Queglia foredeep (Messinian *Lago-Mare*/Early Pliocene).

As already stated, the external boundary of this tectonic unit in the Mt Picca and Anversa degli Abruzzi area is uncertain. A better definition of this boundary could result from detailed analysis of the terrigenous deposits cropping out in this sector and from a more accurate meso-structural analysis.

• The Mt Morrone-eastern Marsica Tectonic Unit is bounded to the east by several thrusts, such as the Mt Porrara thrust and the Montagna del Morrone thrust (Cosentino *et al.*, 2003). The frontal thrust is located in correspondence with the western margin of the Maiella structure and leads to the tectonic superimposition of the *La Queglia Flysch* onto the *Maiella Flysch* (Lower Pliocene) and onto the Maiella Mts pre-orogenic sustratum (Patacca *et al.*, 1992b; Patacca *et al.*, 2008).

This tectonic unit shows strong N-wards axial plunging, which allows for exposure of only the younger syn-orogenic deposits of the local stratigraphic succession (*La Queglia Flysch*) (Messinian *Lago-Mare*-Lower Pliocene). This unit, as far it has been described, should have the same geodynamic significance of the Queglia Unit of the authors (Patacca *et al.*, 1992b).

The correlation between the Mt Morrone-eastern Marsica sector and the Queglia Unit comes from a reconsideration of the stratigraphical data in the literature concerning the syn-orogenic deposits cropping out in the area (clays with gypsum of Anversa degli Abruzzi, *Rocca Pia Flysch*, gypsum-arenites of Mt Porrara). A detailed stratigraphical and structural analysis of the syn-orogenic terrigenous successions cropping out in the area is needed to confirm this hypothesis. The study of this outer sector of the Apennines is of great importance because it allows for examination of surface stratigraphical-structural features which, to the north, are buried under thousand of metres of Upper Messinian-Middle Pleistocene deposits.

• The Maiella Unit has many features in common with the previous tectonic unit. A strong axial plunging towards north causes carbonate rocks that correlate with those cropping out along the Maiella Mts ridge to be buried some thousand metres deep. The Maiella structure is characterized by a macro-anticline, overthrust towards east and cut along the backlimb by an extensional fault system (Caramanico fault *Auct.*). Another similarity with the nearby Mt Morrone-eastern Marsica Unit is the presence of a clear lateral variation of facies, from a shallow-water platform (in the south) to a platform-to-basin facies (in the north). The foredeep deposit related to the Maiella structure (Maiella flysch) was deposited during the tectono-sedimentary event of the Lower Pliocene post *Sphaeroidinellopsis seminulina* zone. In particular, recent bio-stratigraphical analyses (Cipollari *et al.*, 2003) carried out on the Maiella flysch of Fonte dei Pulcini (southern Maiella) indicated the upper part of the MPl 2 or MNN 12 zones for the onset of the siliciclastic deposition in the outermost outcropping foredeep basin (Maiella flysch).

The Maiella structure has been involved in the Apennine chain during the Middle Pliocene tectonic phase.

Finally, we describe briefly a tectonic unit that is isolated if compared with the structural framework reconstructed for this sector of the Apennines. The Molise units (Agnone, Tufillo and Daunia, Patacca *et al.*, 1992b) are characterized by thin skinned tectonics, which led to the complete detachment of the Oligocene-Middle Miocene succession from the supposed Mesozoic substratum of the Molise Basin (Calabrò *et al.*, 2003; Corrado *et al.*, 1997, 1998a, 1998b; Di Bucci *et al.*, 1999; Speranza *et al.*, 1997a). Generally, the units consist of deeper-water shales (varicoloured shales) and limestones with shallow-water carbonate resediments.

Normally, the detachment of the Oligocene-Middle Miocene succession from its substratum happens in correspondence with the varicoloured shales. At present, the authors suggest for the *Molisano* Basin a compressional activation similar to the Gran Sasso-western Marsica Tectonic Unit (Patacca *et al.*, 1992b; Cipollari *et al.*, 1999b). This interpretation is based on the age of the Agnone flysch (Messinian) and from some evidence of thrust-top basins related to the Messinian *Lago-Mare*/Lower Pliocene event (*Conglomerato di Palena*) (Patacca *et al.*, 1992b).

Post-Orogenic Tectonics (Extensional and Strike-Slip Tectonics)

In some sectors of the central Apennines, the effects of a post-orogenic strike-slip tectonics, superimposed on a complex compressional deformational history, are particularly evident (Salvini, 1991; Mattei *et al.*, 1995). One of the most prominent tectonic elements with strike-slip character is a fault system in the western sector of the study area, in the Umbro-Sabine domain. This element (Sabine lineament and Val Serra fault) shows a vertical geometry along a N-S trend and a right-lateral stike-slip kinematics (Calamita, 1990; Alfonsi *et al.*, 1991a, 1991b; Calamita and Pierantoni, 1994; Alfonsi, 1995). According to our kinematic reconstruction, this element has been active since the Tortonian.

An additionalstrike-slip element, with left-lateral strike slip motion, is the fault system that forms the eastern border of the Val Roveto. It is a tectonic feature with a regional significance [from the Venafro Mts, to the south (Cavinato and Sirna, 1988; Serafini and Vittori, 1986, 1988), to the Carseolani Mts (Serafini and Vittori, 1986; Montone and Salvini, 1990, 1993), to the north], along a NW-SE tectonic trend, which has also been activated as a normal fault. Tectonic structures related to strike-slip faults have also been recorded in the western Marsica (Corrado *et al.*, 1992) and in more outer sectors (Mattei and Miccadei, 1991; Ghisetti *et al.*, 1993; Vezzani and Ghisetti, 1995).

The present-day morpho-structural setting of central Italy is strongly influenced by the extensional tectonics that affected the study area from the Late Messinian until the Late Pleistocene and, sometimes, also until the Holocene (Barberi and Cavinato, 1993; Blumetti and Dramis, 1993; Calamita and Pizzi, 1992; Cavinato, 1993; Dramis, 1993; Cavinato *et al.*, 1994; D'Agostino *et al.*, 1994, 1998; Doglioni *et al.*, 1999; Corrado *et al.*, 1997; Calamita *et al.*, 1999; Ciccacci *et al.*, 1999; Cipollari *et al.*, 1999b; Cavinato *et al.*, 2002; Miccadei *et al.*, 2002).

A NW-SE orientation is the prevailing tectonic trend for extensional features in the central Apennines. However, normal faults with anti-Apennine trend (NE-SW) are also present in the area. Across the suite of both extensional and compressive tectonic features, a space-time migration of the deformative front from the innermost to the outermost region of the Apennines is recognizable (Cavinato and De Celles, 1999; Cipollari *et al.*, 1999b; Patacca *et al.*, 1992a). This is generally inferred from the age of the different intra-mountain sedimentary basins, initiated by the extensional tectonic activity that was affecting the emerged Apennine area since the late Messinian. Along a transect transverse to the Apennine chain, the onset of these extension-related basins becomes younger going from the Tyrrhenian to the Adriatic side of the chain (Cavinato *et al.*, 1994; Cavinato and De Celles, 1999).

Deep Structures of Central-Northern Apennines

A full revision of the geophysical and geological data available for the Central Italy in the area along the CROP 11 Profile (Crustal Seismic Profiling) can be found in Cavinato *et al.* (1994), Billi *et al.* (2006), Patacca *et al.* (2008), and Di Luzio *et al.* (2009), whereas a geodynamic scenario and a model of the Miocene tectonic evolution of the Northern Apennines have been described by Pialli *et al.* (1995; 1998), Barchi *et al.* (1998; 2001). The main information available on the deep structure of the central-northern Apennines is summarized below.

Seismic tomography (Ciaccio *et al.*, 1996; Cimini, 2004) highlights a body of high velocity material dipping steeply towards the west underneath the Marche-Umbria-Tuscan area of the northern Apennines; this body has been interpreted as a retreating subducted slab of Apulian lithosphere, which is almost completely assimilated at a depth of about 250 km. This hypothesis is supported by subcrustal seismicity in the northern Apennines: the distribution of deep-focus earthquakes delimits a 40-45 degree dipping plane reaching depths of up to 90 km from the Adriatic to the Tyrrhenian sea (Amato and Selvaggi, 1991). On the contrary, the central Apennines show neither subcrustal seismicity nor high velocity anomalies in the tomographic images (Cimini, 2004).

Digital reappraisal of seismic refraction profiles data suggest a crustal doubling, affecting lower crust and mantle, under the area of the Tiber Valley in the northern Apennines (Ponziani, 1995). These features have been recently confirmed by the results of CROP 03 deep seismic line (NVR: Near vertical reflection) (Barchi *et al.*, 1996; 1998).

In addition, Bouguer anomaly analysis (Bigi *et al.*, 1992; Tiberti *et al.*, 2005) points out positive anomalies along the Tyrrhenian Sea and in the Tuscan and the Latium sectors, whereas in the Umbria-Marche areas, negative values are recognizable. The anomaly values increase toward the east and reach positive values in the Adriatic Sea. According to Tiberti *et al.* (2005), most of the regional gravity anomalies in the central Apennines should originate within the lower crust. The transition from the western positive values and the central negatives happen across a narrow belt.

This narrow belt has been interpreted as the gravimetric expression of crustal doubling at a regional scale in the northern Apennines (Cassinis *et al.*, 1991). Taking into account the Bouguer anomalies and the results of gravimetric modelling, Bernabini *et al.* (1997) hypothesized the same crustal doubling also under the Fucino Plain. More recently, the crustal data beneath the central Apennines, coming mainly from the CROP 11 seismic profile, have been synthetized by Di Luzio *et al.* (2009). In that paper, the authors confirm a crustal doubling just beneath the Fucino Plain, where the Adriatic Moho reaches 47 km depth, whereas the Tyrrhenian Moho rests at shallower levels at about 30 km depth.

According to Billi *et al.* (2006) a mid-crustal folding affects the central Apennines just beneath the Olevano-Antrodoco out-of-sequence thrust system. A fault-bend fold-like structure has been imaged in the CROP 11 seismic profile from 5 down to 8 seconds TWTT. From surface geological data, the authors suggest that the mid-crustal antiform grew as an out-of-sequence structure since late Messinian time.

Taking into account all the reported evidence, the following geodynamic setting can be assumed for the deep crustal structures of the central Apennines:

- a western thinned crust, including the Thyrrhenian Sea, the Tuscan sectors, and the area north of Rome; it is characterized by very high heath flow (Della Vedova *et al.*, 1991; Mongelli *et al.*, 2004) due to astenospheric uplift;

- the doubling of the Moho both beneath the Tiber Valley-Gubbio area (northern Apennines) and the Fucino Plain (central Apennines) where a "Tyrrhenian Moho" has been inferred to be superposed on an "Adriatic Moho" (Morelli, 1998; Di Luzio *et al.*, 2009);

-an Adriatic lithosphere flexing down westward under the Apennine chain (Cimini, 2004).

The post Tortonian geodynamic evolution of the Apennines can be described in terms of post-collisional evolution of the chain driven by the passive sinking of the Apulian lithosphere and the progressive roll-back of the flexural hinge (Faccenna *et al.*, 2004), with Tyrrhenian mantle compensation (eastward mantle flow) (Doglioni *et al.*, 2004).

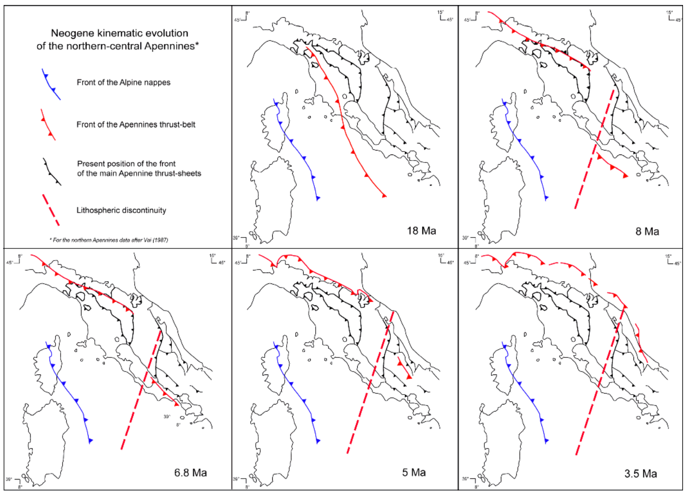
Neogene Kinematic Evolution of the Central Apennines

Neogene kinematics of the central Apennines

Taking into account the stratigraphic constraints previously described, we have attempted to reconstruct a kinematic-structural scheme for the central Apennines (Plate. 4). In this scheme, the time interval in which a particular sector has been involved in the chain is indicated in full color. This kind of data is provided by the age of the piggyback deposits recognized in the study area, which are represented in the kinematic-structural scheme with the half tone of the color used for that tectono-sedimentary event. Superimposed dots of different colors represent the relationship of the foredeep outcrops to different tectono-sedimentary events. The colored superimposed dots, which show the foredeep deposits of a particular tectono-sedimentary event, generally are drawn above a full colored area which indicates the time-interval in which that foredeep domain has been involved in the chain. In those sectors in which the stratigraphical-structural analysis has shown out-of-sequence reactivation (Olevano-Antrodoco-Sibillini Mts areas and Gran Sasso front), colored bands show the out-of-sequence reactivation age, superimposed on the full color relative to the first phase of the mountain building.

The proposed kinematic-structural map (Plate 4) prominantly displays a first order structural discontinuity with NNE-SSW trend that cuts the central Apennine chain. This discontinuity allowed the independent evolution of the northern Apennine and the central Apennine orogenic systems (Fig. 11), releasing the two sectors in which the compressive deformation migrated towards the Adriatic foreland with different rates (Vai, 1987; Cipollari and Cosentino, 1996). In this paper we wish to underline the correct displacement of the Apennine orogenic system in correspondence with this discontinuity. In the proposed scheme, this displacement is evidenced by the non-alignment of coeval sectors of the Apennine accretionary wedge.

Figure 11. Neogene kinematic evolution of the central-northern Apennines



Kinematic scheme showing the different migration between 18 and 3.5 Ma for the central and northern Apennine orogenic systems. Different velocities of propagation for the northern and central Apennine orogenic systems are guaranteed to happen for the occurrence of a lithospheric discontinuity separating northern and central Apennines.

An additional point that emerges from the analysis of this kinematic model is the prominent Adriatic foreland propagation of the Apennine compressive deformation, already evidenced by several authors (Bally *et al.*, 1988; Endignoux *et al.*, 1989; Bigi *et al.*, 1991; Sage *et al.*, 1991; Cipollari and Cosentino 1992, 1995; Patacca *et al.* 1992b; Cavinato *et al.*, 1994; Patacca *et al.*, 2008). In this paper, the timing of the propagation of the Apennine compressive front and the structures involved in the different deformational phases is more accurately shown.

Unfortunately, for the northern sector of the examined orogen, the stratigraphical constraints are insufficient to reconstruct the timing of the foreland propagation, because of the limited extent or the absence of syn-tectonic deposits linked to the evolution of the orogenic system. Deposits that do provide information are limited to the inner *Marnoso-Arenacea* outcrops (upper Burdigalian-lower Serravallian) (Valle dell'Aia, Martani Mts, Mt Subasio, etc.), the Vallocchia-Castelmonte marl outcrops, the *Belvedere* Fm. (middle-upper Serravallian) (Cipollari and Cosentino, 1997) and the terrigenous deposits of the Camerino basin (Calamita *et al.*, 1979) (Middle Tortonian-Messinian) and of the *Laga* Fm (Messinian). Owing to this, the reconstruction of the evolution of the orogenic system for this portion of the chain is not complete, as we currently lack information about the Serravallian foredeep and have scarce data concerning the Tortonian foredeep.

In contrast, in the southern sector of the study area, extensions of the syn-tectonic deposits both of the foredeep and of the piggyback basins enable us to create a more detailed reconstruction of the evolution of the Apennine orogenic system from the Late Tortonian tectono-sedimentary event.

In its outer portion, the Tortonian Apennine chain included the Volsci chain (Lepini Mts, Ausoni Mts and Aurunci Mts), at the front of which the Latina Valley foredeep basin was developed (Cipollari and Cosentino, 1995). During the building of the chain, instead of coarse clastic material being routed exclusively to the foredeep, several satellite basins received the coarse sediment (Gavignano and Gorga Units, Alberti *et al.*, 1975) (Cipollari, 1995; Cosentino *et al.*, 2003).

During the lower Messinian tectonic phase, with the migration of the orogenic system towards the Adriatic foreland, the whole Ernici-Simbruini sector was involved in the chain.

The Monti della Laga area, as far as the Val Roveto-Valle del Salto-Tagliacozzo and at least the western portion of the Marsica domain, were part of the Messinian foredeep. In the literature there are different opinions about the terrigenous deposits cropping out on the Montagna Grande area: were they deposited in the Messinian foredeep or in a younger foredeep basin? Following Patacca *et al.* (1992b), the flysch cropping out in this area is related to a younger foredeep, developed in a time interval corresponding to the Messinian *Lago-Mare*-Lower Pliocene p.p., while according to Corrado *et al.* (1995), on the basis of the optical indicators of maturity in the organic matter dispersed in the terrigenous sediments cropping out in the same area, the Montagna Grande foredeep basin should have evolved during the Messinian. This latter opinion is reported also by Ghisetti *et al.* (1993). The existence of a siliciclastic post-gypsum deposit in the Anversa degli Abruzzi sector would support the Patacca *et al.* (1992b) hypothesis, but at present the stratigraphical relation of this deposit and the Montagna Grande carbonatic succession is still under discussion.

On Plate 4 the siliciclastic deposits cropping out in the Anversa degli Abruzzi and Valle del Tasso-Sagittario sectors have been considered as belonging to a Messinian *Lago-Mare*/Early Pliocene foredeep. Then on a regional scale, along a SW-NE transect, the kinematic evolution of the Volsci chain, the Valle Latina, the Simbruini-Ernici Mts, the Val Roveto and the Marsica region, up to the Maiella more external domain, followed a piggyback sequence, with a NE-ward propagation of the Apennine frontal thrust. Except for some out-of-sequence reactivations that affected the central Apennine chain, it is possible to recognize a migration of the orogenic system towards the Adriatic foreland following the activation of thrusts in more external position. In the proposed model, the new element of the chain, which accretes the Apennine orogenic wedge during each tectono-sedimentary event, is built up simultaneously (Cipollari and Cosentino, 1992), developing a system of synchronous thrusts within the accreted wedge. Therefore, the accreted chain element is limited externally by its frontal thrust, activated for the first time during that tectono-sedimentary event, while on the inner side it is bounded by the frontal thrust of the previous tectono-sedimentary event. This inner bounding thrust generally could remain active during the younger tectonic event.

Out-of-sequence thrusting in the central Apennines

In the central Apennines, the out-of-sequence activity of regional thrust systems, such as the frontal thrust of the Olevano-Antrodoco-Sibillini Mts (Cipollari and Cosentino, 1992) and that of the Gran Sasso chain (Ghisetti and Vezzani, 1991), is superimposed on the structures of an already deformed chain. In those areas, the Olevano-Antrodoco-Sibillini Mts thrust system reactivated a chain sector already built during the previous Early Messinian tectonic phase. The thrust system that characterizes the Gran Sasso chain transversely cuts the N-S structures linked to the Acquasanta and Montagna dei Fiori-Montagnone ridge, built up during the Messinian *Lago-Mare*-Early Pliocene event. The age of the activation of the first thrust system is constrained by the age of the top of the *Laga* Fm. (Upper Messinian, post salinity crisis; Cantalamessa *et al.*, 1982; Centamore *et al.*, 1990; 1991; 1992; 1993).

These out-of-sequence re-activations were accompanied by rotation of the more superficial structural units involved in the deformation, as shown by palaeomagnetic analyses carried out in the two sectors (Ghisetti *et al.*, 1992; Mattei *et al.*, 1992; 1994; 1995; 1999; Speranza *et al.*, 1997b; Satolli and Calamita, 2008).

In the northern area of the central Apennines, this deformational event reactivated the area between the Olevano-Antrodoco-Sibillini Mts thrust system, to the east, and the more internal tectonic units of Sabini Mts and Spoleto Mts to the west. In particular, on the Spoleto Mts, signals of out-of-sequence reactivation have been observed in the Belvedere and Vallocchia areas, where low-angle thrust surfaces cause the superposition of the *Calcare massiccio* Fm onto a tectonic unit consisting of either the *Belvedere* Fm (Decandia and Giannini, 1977) or the Vallocchia marls (Cipollari, 1995), both belonging to the stratigraphical succession of a piggyback basin (sensu Ori and Friend, 1984) (Cipollari and Cosentino, 1997). Moreover, in the whole Sabine portion of the Apennine orogen, evidence of multiple phases of deformation (re-folded meso-folds, macro- and meso-folds truncated by thrust surfaces, and multiple domains of striae on the same fault plane) has been observed (Cosentino, 1988; Mattei *et al.*, 1986; Calamita *et al.*, 1987; Cosentino and Parotto, 1988; 1989; 1992; Cosentino and Montone, 1991).

In the southern area of the central Apennines, evidence for a late Messinian reactivation of some inner structures of the Apennine chain have been recently found in the southern Latina Valley (Pasquali *et al.*, 2007). In that area, thin thrust-sheets consisting of Early-Middle Miocene shallow-water carbonates are thrust onto siliciclastic deposits sedimented in a wedge-top basin. The timing of deformation can be discerned in the Monte San Giovanni Campano area, where the thrust tectonics affect clays with Messinian gypsum (Pasquali *et al.*, 2007), suggesting a tectonic event younger than the Messinian salinity crisis.

Considering a single synchronous event for the reactivation of those internal areas of the Apennine chain in the northern sector, the younger stratigraphical constraints are provided by the more ancient age of the continental deposits of the Tiberino Basin, developed in a syn-extensional post-orogenic realm. Recently, the older stratigraphic succession of the Tiberino Basin has been recognized in the Fosso Bianco Unit (Basilici, 1992; Ambrosetti and Basilici, 1994) cropping out in the south-western branch of the basin. The age of the Fosso Bianco Unit, which according to Basilici (1992) and Ambrosetti and Basilici (1994) is between the Middle Pliocene and the upper part of the Early Pliocene, seems instead to have been deposited only during the Middle Pliocene (R. Pontini *pers. comm.*).

In the southern sector, this out-of-sequence thrusting is constrained by the occurrence in the subsurface of the southernmost Latina Valley of an Early Pliocene (top Zanclean) syn-rift basin (Pasquali *et al.*, 2007).

Several geometrical and chronological constraints help pinpoint the age of the out-of-sequence thrusting in the Gran Sasso chain. The thrust tectonics are limited by the age of the siliciclastic deposits that conformably rest above the Cenozoic platform-to-basin carbonate succession in a foreland setting. These deposits show that the area was involved in a foredeep domain during the early Messinian (Ghisetti and Vezzani, 1990); Patacca *et al.*, 1992b). As a consequence, the first orogenic deformation is related to a tectonic event younger than the early Messinian tectonic phase. A further constraint on the timing of the Gran Sasso out-of-sequence thrusting is given by the age of the *Conglomerati di M. Coppe*, which lay unconformably above already deformed units. The *Conglomerati di M. Coppe* have been dubitatively referred to the Messinian (Ghisetti and Vezzani, 1990). The authors do not provide any chronological reference for these conglomerates, but instead present an age for the arenaceous-pelitic succession resting conformably above those conglomerates. In the Mt Paradiso area, this arenaceous-pelitic succession is referenced, still with uncertainty, to a generic Messinian age, while a definite infra Pliocene age (*Sphaeroidinellopsis* zone) is provided for the Mt. Coppe sector, and a top Early Pliocene age (*G. margaritae* and *G. puncticulata* zones) is provided for the Colle dei Cavatori area (Ghisetti *et al.*, 1993).

According to us, the sedimentary basin of the *Conglomerati di M. Coppe* and the overlying arenaceaous-pelitic succession was deposited in a thrust-top basin of the Apennine chain, therefore linked to the first phase in which this area was involved in the chain.

The kinematic model proposed in this paper for the Gran Sasso chain is slightly different from that suggested by Ghisetti and Vezzani (1990) and Ghisetti *et al.* (1993). The deformation of the EW Gran Sasso front should be related to a compressive event that occurred late in the Early Pliocene. We derive this conclusion after considering the Latium-Abruzzi area, containing the Gran Sasso chain, was a foredeep domain not only during early Messinian, but also up to the Late Messinian, having recorded the Messinian salinity crisis (Castorina *et al.*, 1994). It is also noteworthy that conglomerate deposits in the Latium-Abruzzi area associated with the piggyback basins active during the Messinian *Lago-Mare*-Early Pliocene event (Le Vicenne, Colacicchi *et al.*, 1967; Cipollari *et al.*, 1999a; Mt. Mezzana, Praturlon, 1980) are very similar to the *Conglomerati di M. Coppe*, unconformably overlying a deformed substratum.

To summarize, the first mountain building event of the Gran Sasso chain must be related to a tectono-sedimentary phase younger than the event which formed the foredeep basin of Laga-Valle del Salto-Tagliacozzo-Marsica (early Messinian). The out-of-sequence activation of the Gran Sasso thrust front must be related to a younger tectono-sedimentary event. Therefore, the first compressional deformation that affected the area should be referred to the Messinian *Lago-Mare*-Early Pliocene event. During this time interval, all the Latium-Abruzzi domain was involved in the chain, and the deposition of the *Conglomerati di M. Coppe* occurred in a piggyback basin coeval with those of Le Vicenne and Mt Mezzana. On the basis of these time constraints, the out-of-sequence thrusting must be related to the tectonic event that occurred in central Apennines at the top of the Early Pliocene. This event caused the accretion of the chain with the more external units.

Regional Geological Cross-Section

Introduction

We present a regional cross-section has been drawn to illustrate the structural architecture of the central Apennines. This section, SW-NE oriented, is traced from Anzio (Tyrrhenian coast) to the Adriatic Sea (offshore of Silvi Marina, about 20 km north of Pescara, Abruzzi). This section could be considered nearly parallel to the tectonic transport direction in the Lepini and Simbruini Mts, and slightly oblique to the tectonic transport direction in the Gran Sasso belt (N20° according to Ghisetti and Vezzani, 1991) and in the Marche imbricates (N70-80° according to Ghisetti *et al.*, 1993) (Plate 5).

The deep structure is extrapolated from surface data with the support of some deep wells (e.g., Fogliano 2, Acciarella 1, Latina 1, Paliano 1, and Trevi 1; Pietrarossa 1, Roccafinadamo 1, Villadegna 1, Atri 1, and Marilena 1) and, in eastern Marche domain, of the interpretation of confidential seismic data. As a consequence, the image of the deep structures is highly speculative and the cross-section should be considered only as a tentative picture of the overall general architecture of this part of the Apennine chain.

In recent years, several authors have proposed large scale interpretations of the Apennine thrust belt. The different emphasis placed on tectonic observation, surface geology, or subsurface information (mainly seismic reflection and well data) has produced conflicting models about the geometry and the kinematics of the Apennine fold-and-thrust belt (among many others, Lavecchia, 1985; Bally *et al.*, 1988; Mostardini and Merlini, 1988; Hill and Hayward 1988; Barchi, 1991b; Calamita *et al.*, 1991, 1994; Ghisetti and Vezzani, 1991; Sage *et al.*, 1991; Ghisetti *et al.*, 1993; Mazzoli *et al.*, 2000; Tozer *et al.*, 2002; Scrocca *et al.*, 2005). These interpretations differ from each other in many substantial aspects such as the thin-skinned versus basement-involved tectonics, out-of-sequence versus in-sequence thrust propagation, and the amount of extension and shortening (see Ghisetti *et al.*, 1993 and Tozer *et al.*, 2002 for a full review and bibliography therein). In the following sections these issues will be briefly discussed together with the main assumptions and constraints adopted for our cross-section.

Constraints and Assumptions

Basement

It is difficult to define the basement in the central Apennines orogen because its depth and nature cannot be clearly recognised using existing seismic reflection and well data. In our section we did not constrain the depth of the basement strictly using the presumed depth of the aeromagnetic (e.g., AGIP, 1984 and models provided by Arisi Rota and Fichera, 1987) or magnetic basement (Speranza and Chiappini, 2002) because, as also suggested by Bally *et al.* (1988), magnetic depth determination beyond 9-10 km is somewhat imprecise and should be corroborated by other data. Moreover, it should be also considered that the magnetic basement is different from the crystalline one.

At the eastern side of our cross-sections, we extrapolated the depth of the basement starting from the easily recognisable Top Messinian evaporites horizon by adding the stratigraphic thicknesses derived from a review of well data in the Adriatic. Moving west, the depth of the basement has been evaluated on the basis of structural and stratigraphical constraints, such as the thickness of the different superposed tectonic units according to the modelled structural setting. We also assumed, on the basis of the known regional flexure of the Apulian lithosphere supported by the Adriatic Moho geometry (e.g., Mele *et al.*, 2006; Di Luzio *et al.*, 2009), a gently westward dipping basement (from about 5 km to 13-14 km). The main detachment level, at the top of the supposed basement, shows the same attitude. If we assume the regional flexure of the Apulian lithosphere to be the consequence of continental subduction of the Apulian plate underneath the belt, we should then suppose that the main active detachment level cannot have remained sub-horizontal westward towards the Tyrrhenian side but must have plunged steadily to accommodate the flexure and to form an upper boundary for subducting plate (Doglioni 1993; Carminati *et al.*, 2004).

At the western side of the cross-section we have chosen to vanish with depth our structural reconstruction since in this area there are very few constraints. In this way, we intend to propose a conservative interpretation and to avoid the debate about the possible basement involvement in the Apennines (for a discussion about this issue see Ghisetti *et al.*, 1993; Tozer *et al.*, 2002; Butler *et al.* 2004; Scrocca *et al.*, 2005; Billi *et al.*, 2006; and references therein). However, it should be noted that a deep involvement of the crystalline basement in the deformation processes of the Central Apennines seems unlikely, as basement involvement has not been documented in similar orogens associated with west-directed subductions (e. g., Doglioni *et al.*, 1999; 2007).

Stratigraphy

The major structural domains traversed by our cross-section are characterised by strong variations in stratigraphy and facies. In the Upper Triassic/Lower Liassic, extensional tectonics affected the outer margin of the Africa plate (Adria microplate), leading to the development of subsiding carbonate platforms (Apenninic and Apula) and pelagic basins (Umbria-Marche, Pescara and Molise) linked by transitional domains (Sabina and Gran Sasso). Stratigraphic successions show large variations in thickness and facies of the Mesozoic formations due to the Jurassic syn-sedimentary extension that is also recorded within the basinal sequences (as documented in the Umbria-Marche domain). In the transitional and pelagic sequences, the presence (or the absence) of resedimented carbonates (turbidites and debris flow sediments) make it very difficult to have good regional estimates for primary thicknesses of these stratigraphic units.

Our sections were originally drawn at a scale of 1:100.000; therefore, the stratigraphy of the region had to be simplified and homogenised. The stratigraphic sequences of the different domains crossed by our sections have been grouped into several domains with the same average stratigraphic thickness (Lepini, Simbruini, Magnola-Velino, Sirente carbonate platform domains, Gran Sasso and Sabina-Fogliano type transitional sequences, Umbria-Marche, Pescara, and Molise pelagic sequences). Within the pelagic sequences, we have seldom shown significant thickness changes due to the Jurassic extension.

Several wells penetrate the Upper Triassic evaporites (Burano formation), revealing variable thickness that reach a maximum of about 2000 m (around 1500 m in Trevi 1, 1850 in Antrodoco 1, and 1400 in Perugia 2). The about 1800 m penetrated in Burano 1 are due to the steep dips in excess of 70° that dominate the lower half of the penetrated section, suggesting intensive deformation in the core of the Burano anticline. It is impossible to determine the original stratigraphic thickness of the Burano formation and therefore we assumed an original thickness in the range of 1200-1500 m.

In the eastern/Adriatic area, continental red sandstone (Permian?) have been drilled below the Late Triassic Burano formation (e.g., Alessandra 1 well). Furthermore, across the Adriatic domain, seismic and well data document the widespread occurrence of locally thick Permian-Middle Triassic sedimentary units (e.g., Grandić *et al.*, 2002; Franciosi and Vignolo, 2002). The thicknesses of these units may be highly variable due to the continental origin of the Permian deposits and to the syn-rift nature of the lower-middle Triassic formations. However, since no detailed information about the actual thickness of these units along the section trace is available, we have assumed an average thickness of about 500 m.

The stratigraphic horizons that have been chosen as markers in the cross-section delimit formations with the highest competence contrast within the pelagic sequences (top Burano, Calcare Massiccio, Maiolica, Scaglia and Upper Miocene). These sequences are covered by occasionally thick siliciclastic wedges that mark the progressive eastward migration of the subsiding foredeep. In the carbonate platform domains (including their marginal areas) we have used time lines corresponding to top Lower Lias, Lower Cretaceous and Upper Cretaceous as stratigraphic markers. These sequences are conformably overlain by Middle Miocene bryozoa limestone and Orbulina marls that have been grouped in another unit; on top of these sequences we separated the foredeep deposits.

In both pelagic and carbonate domains, we have used the same colour code to show the different ages of the foredeep deposits.

Detachment

The local tectonic style is controlled by ductility contrasts that occur within the stratigraphic sequences. It is generally assumed that Triassic evaporites (Burano Formation) are the main detachment level both in platform and basin domains. Secondary compressional décollement phenomena are documented for the following formations: i) *Rosso ammonitico, Marne a fucoidi, Scaglia cinerea*, and Messinian evaporites for the pelagic sequence, and ii) *Marne ad Orbitolina*, bauxite levels, and *Marne a Orbulina* for carbonate platform domains.

Furthermore, stratigraphic units around these décollement levels are often intensively deformed, suggesting disharmonious folding and intensive deformation. These processes make it very difficult to define reliable stratigraphic thicknesses. At the original 1:100.000 scale of our sections, it has proved difficult to incorporate these local details into the regional profile.

Main Structures

Our regional section crosses through distinct geological sectors. These sectors will be described from SW to NE (i.e., from the innermost to the outermost zone).

Down-faulted Tyrrhenian sector (from Anzio to the Lepini Mts)

The sequences in this area are buried underneath thick Quaternary alluvium and volcanics of the Latina Plain. This area has been dissected by NW-SE normal faults in Plio-Pleistocene time.

The wells drilled in the Latina Plain (Pianura Pontina), e.g. Fogliano 2 (Parotto and Praturlon, 1975), reveal a transitional sequence, which could be correlated with the similar outcrops of Circeo Mt to the south, or the Sabina to the north. Therefore, in the subsurface of the Latina Plain, southwest of the Lepini Mts, a stratigraphic transition from the carbonate platform facies (i.e. Lepini Mts) to a pelagic basin sequence has been inferred.

Latium-Abruzzi carbonate platform.

The pre-orogenic stratigraphy of this sector is characterized by thick and monotonous Triassic to the Upper Cretaceous-Paleocene carbonate platform sequences overlain by Middle Miocene bryozoa limestone. Thick thrust sheets piled up in Neogene time with mainly NW-SE trending structural axes. The main thrust fronts are generally located on the NE margin of the main carbonate ranges. From the inner part of the thrust (or duplex?) package towards the outer, the major thrusts are: the Lepini Mts thrust, Simbruini Mts thrust, and the Gran Sasso thrust.

According to Tallini (1994) and Cavinato *et al.* (1992) the southwest margin of the Simbruini - Ernici Mts is marked by an extensional fault system. The presence of hydrothermal fluids (sulfurous spring), and volcanic activity confirm that this fault system involves deep crustal levels, as discussed in section 2.3 (extensional fault).

The structural setting of the Simbruini range has been constrained taking into account the detailed geological map proposed by Devoto (1970), data from the deep Trevi 1 well (Dondi *et al.*, 1966), and the structural interpretation proposed by Tallini (1994). According to Tallini (1994), the main superficial thrusts (Val Roveto thrust and Fosso Fioio thrust) have been correlated with the deepest tectonic discontinuities detected in the Trevi 1 well. The proposed kinematic model shows the development of some small duplexes at the level of the upper Triassic units, followed by the main thrusting phase (from Messinian to possibly Lowermost Pliocene time). During this latter deformation phase, out-of-sequence thrusting could have occurred. We consider out-of sequence thrusting to be active thrusting in an internal position with respect to the leading edge of the thrust belt (sensu Morley, 1988). In this reconstruction, the Vallepietra-Filettino fault (a structure which has caused much debate and has been interpreted alternatively as an extensional fault, a transpressional fault, and an out-of-sequence thrust) has been represented as an extensional fault (with a low angle and linked with deep ramp). An alternative reconstruction assuming the same fault geometries could include an initial compressional phase followed by an extensional reactivation. Finally, high angle normal faults dissected the previously generated structure.

The Roveto Valley is characterized on its northeastern margin by a major left-lateral strike-slip fault (Val Roveto fault) (Serafini and Vittori, 1986; Montone and Salvini, 1993). This fault, NW-SE trending, could be interpreted as the superficial expression of a deep, crustal, tectonic discontinuity as suggested by soil-gas investigations (Ciotoli *et al.*, 1993).

Moving eastward, we represented the fault on the NE margin of Mt Sirente and the one which affected the SW border of the F. Aterno valley as thrust faults (Cavinato *et al.*, 1994).

Further east, the Gran Sasso chain is one of the main structural culminations of the Apennines, where Meso-Cenozoic carbonate units were emplaced over the Upper Miocene - Lower Pliocene foredeep deposits (Laga Flysch). Some outcropping faults have been alternatively interpreted as out-of-sequence thrusts (Ghisetti and Vezzani, 1991) or as low angle "younger-on-older" tectonic contacts (D'Agostino *et al.*, 1998).

However, we represent the overall structural setting of the Gran Sasso domain as a break-through fault-propagation-fold, later transported with significant displacement onto the footwall units.

Eastern Marche units and Adriatic offshore.

Recent foredeep deposits from upper Messinian to Pliocene or younger sedimentary covers mainly outcrop in the onshore area. The carbonate units penetrated in subsurface by several deep wells show a pelagic facies and a structural setting characterized by stacked thrust units (among many others, Bally *et al.*, 1988; Ghisetti *et al.*, 1993; Calamita *et al.*, 2002 and references therein).

In the footwall units of the main Gran Sasso overthrust we have represented two distinct foredeep basins:

- the westernmost (more internal), which is filled by the siliciclastic deposits of the Messinian Laga Flysch;

- the eastern basin, which corresponds to some turbiditic deposits of late Messinian age related to the Teramano foredeep basin (sensu Patacca *et al.*, 1992b).

We assumed also in this section the existence of a buried peripheral bulge zone, which originally separated these two foredeep basins and then deformed with a buried ramp anticline setting.

The thickness of the upper Messinian (post 5.5-Ma volcaniclastic level, Odin *et al.*, 1997) foredeep deposits on top of this unit is about 1000 m, because we consider this unit to be a northern analogue of the Queglia unit (sensu Patacca *et al.*, 1992b). We do not include the C. le Maddalena outcrop, attributed to the Gran Sasso unit, in the Queglia unit. This unit shows thick upper Messinian foredeep deposits (up to 3000 m). One possibility is that the foredeep stage in this unit started after the Messinian evaporite deposition, and had its maximum development in upper Messinian time (as suggested by Canzano 1 well some km to the north). We consider this unit to be a northern prolongation of the Morrone unit with Meso-Cenozoic pelagic facies, according to the regional transition from carbonate platform sequences to pelagic environment (also documented in the Maiella unit).

The offshore north-eastern side of this section is partly based on a geological profile published by Bally *et al.* (1988).

Open Discussions and Concluding Remarks

One of the unresolved questions in the stratigraphy of central Italy is the palaeogeographical distribution of the

Triassic facies. In particular, the surface and subsurface Triassic database is not yet sufficient to relate the Triassic bituminous dolostones that crop out in the study area to the same pelagic sedimentary basin or to a different intra-platform trough. Additional facies investigations and palaeogeographical studies must be conducted both in surface (Ernici Mts and La Meta-Mainarde-Matese Mts) and in subsurface domains (well data correlation) to resolve this question.

In the more external areas of the central Apennines, the discussion about the structural setting and the kinematic evolution of the area between the Montagna Grande and the Maiella Mts remains open. More structural-kinematic data as well as time constraints from detailed stratigraphical analysis performed on syn-orogenic terrigenous deposits are needed to resolve these problems.

Due to the northward plunging of the outermost outcropping structures of the central Apennines (La Queglia and Maiella Mts), the knowledge of the stratigraphical-structural setting of these external units is critical to resolve the deep structure of the buried Apennine chain to the east of Montagna dei Fiori thrust.

• In central Italy the Mesozoic stratigraphical setting was characterized by a platform-basin system which developed starting from Late Triassic up to Late Cretaceous time as a consequence of the Neotethyan rifting stage.

• For exploration purposes, the presence of bituminous dolostones in the Vradda (Gran Sasso chain) and in the Filettino (Simbruini Mts.) successions suggests the existence of a potential Upper Triassic source rock in central Italy.

• In the Cretaceous basinal succession of central Italy, two more organic matter-rich horizons (black-shales) deserve emphasis as potential source rocks and important stratigraphic marker horizons (Livello Selli, Aptian and Livello Bonarelli, Cenomanian).

• The central Apennine chain consists of tectonic units derived from the deformation of both Meso-Cenozoic shallow-water limestones and Meso-Cenozoic deeper-water carbonates.

• The geometry of the chain, the diachronism of the eastward migrating foredeep basins in the area, and the different ages of the forethrusts are consistent with a regional foreland propagating model for the central Apennines.

• The biostratigraphical analysis performed on the terrigenous deposits related to the evolution of the central Apennine orogenic system allow for recognition of the tectono-sedimentary events that characterized the building of the central Apennine chain. The recognized events occurred during the late Burdigalian, Serravallian, late Tortonian, early Messinian, latest Messinian-Early Pliocene, and top Early Pliocene.

• The central Apennine chain, developed as a foreland migration of the main thrusts, was subsequently affected by out-of-sequence thrusting. Specifically, out-of-sequence activity of important thrust systems such as the Olevano-Antrodoco-Sibillini Mts and the thrust front of the Gran Sasso chain is superimposed on the former deformation due to the piggyback sequence migration of the Apennine active thrust front.

• Using a shortening value of about 50%, in the central Apennines the average propagation rate of the active front of the chain is about 40 mm/yr.

• The different migration rates recorded by the orogenic systems of the northern (10 mm/yr) and central Apennines (40 mm/yr) suggest the existence of a NNE-SSW lithosphere discontinuity that has allowed an independent kinematic evolution of these two segments of the Apennine chain.

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References

Abbate, E., Bortolotti, V., Passerini, P., Principi, G., Treves, B., 1994. Oceanisation processes and sedimentary evolution of the northern Apennine ophiolite suite: a discussion. Mem. Soc. Geol. It. 48, 117-136.

Accordi, B., 1964. Lineamenti strutturali del Lazio e dell'Abruzzo meridionale. Memorie della Società Geologica Italiana 4, 595-633.

Accordi, G., Carbone, F., (Eds.), 1986. Lithofacies map of Latium-Abruzzi and neighbouring areas. Scale 1:250,000. Quaderni de 'La Ricerca Scientifica' 114 (5).

Accordi, B., Devoto, G., La Monica, G.B., Praturlon, A., Sirna, G., Zalaffi, M., 1969. Il Neogene nell'Appennino laziale-abruzzese. Giornale di Geologia, serie 2, 35 (1967), 235-265.

Adamoli, L., Bigozzi, A., Ciarapica, G., Cirilli, S., Passeri, L., Romano, A., Duranti, F., Venturi, F., 1990. Upper Triassic bituminous facies and Hettangian pelagic facies in the Gran Sasso Range. Boll. Soc. Geol. It. 109, 219-230.

AGIP Spa, 1984. Aeromagnetic Map of Italy and surrounding Seas. Boll. Geofisica Teorica Applicata. June 1984 (enclosure).

Alberti, A.U., Bergomi, C., Catenacci, V., Centamore, E., Cestari, G., Chiocchini, M., Chiocchini, U., Manganelli, V., Molinari-Paganelli, V., Panseri-Crescenzi, C., Salvati, L., Tilia-Zuccari, A., 1975. Note illustrative del Foglio 389 Anagni. Carta Geologica d'Italia, Scale 1:50.000; Servizio Geologico d'Italia.

Alfonsi, L., 1995. Wrench tectonics in central Italy, a segment of the Sabina fault. Boll. Soc. Geol. It. 114, 411-421.

Alfonsi, L., Funiciello, R., Mattei, M., Girotti, O., Maiorani, A., Martinez, M.P., Trudu, C., Turi, B., 1991a. Structural and Geochemical features on the Sabina strike-slip fault (central Apennines). Boll. Soc. Geol. It. 110, 217-230.

Alfonsi, L., Funiciello, R., Mattei, M., 1991b. Strike-slip tectonics in the Sabina area. Boll. Soc. Geol. It. 110, 481-488.

Amato, A., Selvaggi, G., 1991. Terremoti crostali e subcrostali nell'Appennino settentrionale. Studi Geologici Camerti, vol. spec., 1991/1, 75-82.

Ambrosetti, P., Basilici, G., 1994. Itinerario n° 15 - Da Perugia a Terni lungo la valle del Tevere e del Naja. In: Guide Geologiche Regionali (a cura della Società Geologica Italiana), Appennino umbro-marchigiano, 7, 275-287, BE-MA editrice, Milano.

Anderson, H., 1987. Is the Adriatic an African promontory? Geology 15, 212-215.

Angelucci, A., 1966. La serie miocenica nella media Valle Latina. Geologica Romana 5, 425-452.

Arisi Rota, F., Fichera, R., 1987. Magnetic interpretation related to geomagnetic provinces: the Italian case history. Tectonophysics 138, 179-196.

Bally, A. W., Burbi, L., Cooper, C., Ghelardoni, R., 1988. Balanced sections and seismic reflection profiles across the central Apennines. Mem. Soc. Geol. It. 35, 257-310.

Barberi, R., Cavinato, G.P., 1993. Analisi sedimentologiche ed evoluzione paleogeografica del settore meridionale del bacino di Rieti (Appennino centrale). Studi Geologici Camerti, vol. spec., 1992/1, 39-53.

Barchi, M., 1991b. Integration of seismic profile with surface and subsurface geology in a cross section through the Umbria-Marche Apennines. Boll. Soc. Geol. It. 110, 469-479.

Barchi, M., Minelli, G., Pialli, G., 1996. Tettonica dell'Appennino settentrionale alla luce dei risultati del CROP 03. Soc. Geol. It., Presentazione dei risultati del profilo sismico CROP 03, Accademia Nazionale dei Lincei, Roma, Abstract volume, 11-13.

Barchi, M.R., Minelli, G., Pialli, G., 1998. The CROP 03 profile: a synthesis of results on deep structures of the Northern Apennines. Memorie della Società Geologica Italiana 52, 383-400.

Barchi, M.R., Landuzzi, A., Minelli, G., Pialli, G., 2001. Outer northern Apennines. In: Vai G.B., Martini I.P. (Eds.), Anatomy of an Orogen: the Apennines and Adjacent Mediterranean Basins. Kluwer Academic Publishers, pp. 215-254.

Basilici, G., 1992. Il bacino continentale tiberino (Plio-Pleistocene, Umbria): analisi sedimentologica e stratigrafica. Tesi di Dottorato di Ricerca in Scienze della Terra, V ciclo. Università degli Studi di Bologna, 323 pp.

Bernabini, M., Bianchi, N., Di Bucci, D., Orlando, L., Parotto, M., Tozzi, M., 1997. Possibile struttura profonda dell'Italia centrale: 'modelling' gravimetrico lungo il profilo CROP 11. Mem. Soc. Geol. It. 51, 3-5.

Bigi, G., Castellarin, A., Catalano, R., Coli, M., Cosentino, D., Dal Piaz, G.V., Lentini, F., Parotto, M., Patacca, E., Praturlon, A., Salvini, F., Sartori, R., Scandone, P., Vai, G.B., 1991. Synthetic structural-kinematic map of Italy. Quaderni de 'La Ricerca Scientifica' 114 (3), CNR.

Bigi, G., Cosentino, D., Parotto, M., Sartori, R., Scandone, P., 1992. Structural Model of Italy. Scale 1:500,000, sheet 4. Quaderni de 'La Ricerca Scientifica' 114 (3), CNR.

Billi, A., Tiberti, M. M., Cavinato, G. P., Cosentino, D., Di Luzio, E ., Keller, J. V. A., Kluth, C., Orlando, L., Parotto, M., Praturlon, A., Romanelli, M., Storti, F., Wardell, N., 2006. First results from the CROP-11 deep seismic profile, central Apennines, Italy: evidence of mid-crustal folding. Journal of the Geological Society, London 163, 583-586.

Blumetti, A.M., Dramis, F., 1993. Il Pliocene dell'area nursina. Studi Geol. Camerti, vol. spec., 1992/1, 55-64.

Boccaletti, M., Ciaranfi, N., Cosentino, D., Deiana, G., Gelati R., Lentini, F., Massari, F., Moratti, G., Pescatore, T., Ricci Lucchi, F., Tortorici, L., 1990. Palinspastic restoration and paleogeographic reconstruction of the peri-Tyrrhenian area during the Neogene. Palaeogeogr., Palaeoclimatol., Palaeoecol. 77, 41-50.

Bonardi, G., D'Argenio, B., Perrone, V., 1988. Carta geologica dell'Appennino meridionale. Scale 1:250,000, Dip. Sc. Terra - Univ. di Napoli./ Cons. Naz. Ric.

Butler, R.W.H., Mazzoli, S., Corrado, S., De Donatis, M., Di Bucci, D., Gambini, R., Naso, G., Nicolai, C., Scrocca, D., Shiner, P., Zucconi, V., 2004. Applying thick-skinned tectonic models to the Apennine thrust belt of Italy-Limitations and implications. In: McClay K.R. (Ed.), Thrust tectonics and hydrocarbon systems: AAPG Memoir 82, 647- 667. Calabrò², R., Corrado, S., Di Bucci, D., Robustini, P., Tornaghi, M.E., 2003. Thin-skinned vs. thick-skinned tectonics in the Matese Massif, Central-Southern Apennines (Italy). Tectonophysics 377, 269-297.

Calamita, F., 1990. Thrust and fold-related structures in the Umbria-Marche Apennines (Central Italy). Annales Tectonicae 4, 83-117.

Calamita, F., Pizzi, A., 1992. Tettonica quaternaria nella dorsale appenninica umbro-marchigiana e bacini intrappenninici associati. Studi Geol. Camerti, vol. spec., 1992/1, 17-25.

Calamita, F., Pierantoni, P.P., 1994. Structural setting of the Southern Martani Mountains (Umbrian Apennines: Central Italy). Mem. Soc. Geol. It. 48, 549-557.

Calamita, F., Deiana, G., Invernizzi, C., Mastrovincenzo, S., 1987. Analisi strutturale della 'linea Ancona-Anzio Auctorum' tra Cittareale e Micigliano (Rieti). Boll. Soc. Geol. It. 106, 365-375.

Calamita, F., Centamore, E., Chiocchini, M., Deiana, G., Micarelli, A., Potetti, M., Romano, A., 1979. Analisi dell'evoluzione tettonico-sedimentaria dei 'bacini minori' torbiditici del Miocene medio-superiore dell'Appennino umbro-marchigiano e laziale-abruzzese: 7) il bacino di Camerino. Studi Geologici Camerti 5, 67-82.

Calamita, F., Cello, G., Centamore, E., Deiana, A., Micarelli, A., Paltrinieri, W., Ridolfi, M., 1991. Stile deformativo e cronologia della deformazione lungo tre sezioni bilanciate dall'Appennino umbro-marchigiano alla costa adriatica: Studi preliminari all'acquisizione dati del profilo CROP 03 Punta Ala-Gabicce. Studi Geol. Camerti, vol. spec., 1991/1, 295-314.

Calamita, F., Cello, G., Deiana, G., Paltrinieri, W., 1994. Structural styles, chronology rates of deformation, and time-space relationships in the Umbria-Marche thrust system (central Apennines, Italy). Tectonics 13, 873-881.

Calamita, F., Coltorti, M., Pieruccini, P., Pizzi, A., 1999. Evoluzione strutturale e morfogenesi plio-quaternaria dell'Appennino umbro-marchigiano tra il preappennino umbro e la costa adriatica. Boll. Soc. Geol. It. 118, 125-139.

Calamita, F., Scisciani, V., Montefalcone, R., Paltrinieri, W., Pizzi, A., 2002. L'ereditarietà del paleomargine dell'Adria nella geometria del sistema orogenico centro-appenninico: l'area abruzzese esterna. Memorie della Società Geologica Italiana 57, 355-368.

Cantalamessa, G., Centamore, E., Chiocchini, M., Micarelli, A., Potetti, M., 1982. Tectonic sedimentary evolution of the Northwestern part of the Laga Basin (Upper Miocene-Lower Pliocene, central southern Marche). Mem. Soc. Geol. It. 24, 221-232.

Carminati, E., Doglioni, C., Scrocca, D., 2004. Alps Vs. Apennines. Special Volume of the Italian Geological Society for the IGC 32 Florence 2004, 141-151.

Cassinis, R., Pialli, G., Broggi, M., Prosperi, M., (1991) - Dati gravimetrici a grande scala lungo la fascia del profilo CROP 03, interrogativi sull'assetto della crosta e del mantello. Studi Geologici Camerti, vol spec., 1991/1, 41-47.

Castellarin, A., Colacicchi, R., Praturlon, A., 1978. Fasi distensive, trascorrenze e sovrascorrimenti lungo la 'linea Ancona-Anzio', dal Lias medio al Pliocene. Geologica Romana 17, 161-189.

Castellarin, A., Colacicchi, R., Praturlon, A., Cantelli, C., 1984. The Jurassic-Lower Pliocene history of the Ancona-Anzio line (Central Italy). Mem. Soc. Geol. It. 24 (1982), 325-336.

Castorina, F., Cipollari, P., Cosentino, D., Di Biasio, E., Naso, G., Tallini, M., 1994. Testimonianza dell'evento a gessi nei depositi di avanfossa della Val Roveto (Appennino centrale): considerazioni sull'estensione spazio-temporale dell'avanfossa messiniana. Mem. Soc. Geol. It. 51, 35-47.

Cavinato, G.P., 1993. Recent tectonic evolution of the Quaternary deposits of the Rieti basin (Central Apennines, Italy): southern part. Geologica Romana 29, 411-434.

Cavinato, G.P., Sirna, M., 1988. Elementi di tettonica transpressiva lungo la linea di Atina (Lazio meridionale). Mem. Soc. Geol. It. 41, 1179-1190.

Cavinato, G.P., De Celles, P.G., 1999. Extensional basins in the tectonically bimodal central Apennines fold-thrust belt, Italy: response to corner flow above a subducting slab in retrograde motion. Geology 27 (10), 955-958.

Cavinato, G.P., Salvini, F., Tozzi, M., 1986. Evoluzione strutturale del settore centrale della linea Olévano-Antrodoco. Memorie della Società Geologica Italiana 35, 591-601.

Cavinato, G.P., Corrado, S., Sirna, M., 1992. Dati preliminari sull'assetto geologico-strutturale del settore sud-occidentale della struttura simbruino ernica. Studi Geol. Camerti, vol spec., 1991/2:, 33-42.

Cavinato, G. P., Cosentino, D., Funiciello, R., Parotto, M., Salvini, F., Tozzi, M., 1994. Constraints and problems for a geodynamical model of the Central Italy. Boll. Geof. Teor. Appl. 36 (141-144), 159-174.

Cavinato, G. P., Cosentino, D., De Rita, D., Funiciello, R., Parotto, M., 1994. Tectonic sedimentary evolution of intrapenninic basins and correlation with the volcano-tectonic activity in Central Italy. Mem. Descr. Carta. Geol. d'It. 49, 63-76.

Cavinato, G. P., Carusi, C., Dall'Asta, M., Miccadei, E., Piacentini, T., 2002. Sedimentary and tectonic evolution of Pio-Pleistocene lacustrine deposits of Fucino Basin (Central Italy). Sedimentary Geology 148, 29-59.

Centamore, E., Chiocchini, M., Deiana, G., Micarelli, A., Pieruccini, U., 1971. Contributo alla conoscenza del Giurassico dell'Appennino Umbro-Marchigiano. Studi Geologici Camerti 1, 7-89.

Centamore, E., Cantalamessa, G., Micarelli, A., Potetti, M., Ridolfi, M., 1990. I depositi terrigeni neogenici di avanfossa (Messiniano-Pliocene inferiore) dell'Abruzzo settentrionale. Mem. Soc. Geol. Ital. 45, 563-568.

Centamore, E., Cantalamessa, G., Micarelli, A., Potetti, M., Berti, D., Bigi, S., Morelli, C., Ridolfi, M., 1991. Stratigrafia e analisi di facies dei depositi del Miocene e del Pliocene inferiore dell'avanfossa marchigiano-abruzzese e delle zone limitrofe. Studi Geologici Camerti, vol. spec., 1991/2, 125-131.

Ciaccio, M.G., Cimini, G.B., Amato, A., 1996. Immagini tomografiche dell'anomalia di alta velocità nel mantello superiore dell'Appennino settentrionale. Soc. Geol. It., Presentazione dei risultati del profilo sismico CROP 03, Accademia Nazionale dei Lincei, Roma, Abstract volume, 34-35.

Ciarapica, G., Passeri, L., 1998. Evoluzione paleogeografica degli Appennini. Atti Tic. Sc. Terra 40, 233-290.

Ciarapica, G., Passeri, L., 2002. The palaeogeographic duplicity of the Apennines. Boll. Soc. Geol. It., vol. spec. n. 1, 67-75.

Ciccacci, S., D'Alessandro, L., Dramis, F., Miccadei, E., 1999. Geomorphological evolution and neotectonics of the Sulmona intramontane basin (Abruzzi, Apennine, Central Italy). Zeitschrift fur Geomorfologie 118, 27-40.

Cimini, G.B., 2004. Tomographic studies of the deep structure of the Tyrrhenian-Apennine system. Memorie Descrittive della Carta Geologica d'Italia 64, 15-28.

Ciotoli, G., Etiope, G., Lombardi, S., Naso, T., Tallini, M., 1993. Geological and soil-gas investigations for tectonic prospecting: preliminary results over the Val Roveto fault (Central Italy). Geologica Romana 29, 483-493.

Cipollari, P., 1995. Modalità e tempi di propagazione del sistema catena-avanfossa nella zona di incontro tra Appennino settentrionale e Appennino centrale. PhD thesis, University of Rome 'La Sapienza': 229 pp.

Cipollari, P., Cosentino, D., 1992. La linea Olevano-Antrodoco: contributo della biostratigrafia alla sua caratterizzazione cinematica. Studi Geologici Camerti, vol. spec., 1991/2, 143-149.

Cipollari, P., Cosentino, D., 1993. Le Arenarie di Torrice: un deposito di bacino di piggy-back del Messiniano nell'Appennino centrale. Boll. Soc. Geol. It. 112, 497-505.

Cipollari, P., Cosentino, D., 1995. Miocene unconformities in Central Apennines: geodynamic significance and sedimentary basin evolution. Tectonophysics 252, 375-389.

Cipollari, P., Cosentino, D., 1996. Miocene tectono-sedimentary events and geodynamic evolution of the central Apennines (Italy). Notes et Mém. Serv. Géol. Maroc 387, 163-176.

Cipollari, P., Cosentino, D., 1997. Il bacino di Belvedere-Vallocchia (Monti di Spoleto): un thrust-top basin dell'Appennino serravalliano. Boll. Soc. Geol. It. 116, 347-362.

Cipollari, P., Cosentino, D., Perilli, N., 1993. Analisi biostratigrafica dei depositi terrigeni a ridosso della linea Olevano-Antrodoco. Geologica Romana 29, 495-513.

Cipollari, P., Cosentino, D., Parotto, M., 1997. Modello cinematico-strutturale dell'Italia centrale. Studi Geologici Camerti, vol. spec., 1995/2, 135-143.

Cipollari, P., Cosentino, D., Esu, D., Girotti, O., Gliozzi, E., Praturlon, A., 1999a. Thrust-top lacustrine-lagoonal basin development in accretionary wedges: late Messinian (Lago-Mare) episode in the central Apennines (Italy). Palaeogeogr., Palaeoclimatol., Palaeoecol. 151, 146-166.

Cipollari, P., Cosentino, D., Gliozzi, E., 1999b. Extension- and compression-related basins in central Italy during the Messinian Lago-Mare event. Tectonophysics 315, 163-185.

Cipollari, P., Cosentino, D., Di Bella, L., Gliozzi, E., Pipponzi, G., 2003. Inizio della sedimentazione d'avanfossa nella Maiella meridionale: la sezione di Fonte dei Pulcini (Taranta Peligna). Studi Geologici Camerti, Num. Spec. 2003, 63-71.

Cirilli, S., 1992. Facies euxiniche nel Trias superiore dei Monti Simbruini (Appennino centrale). Studi Geologici Camerti, vol. spec., 1991/2, 157-159.

Cirilli, S., 1993. Il Trias di Filettino-Vallepietra (Monti Simbruini, Appennino centrale). Boll. Soc. Geol. It. 112, 371-394.

Civitelli, G., Corda, L., Mariotti, G., 1988. Il Bacino Sabino: 2) sedimentologia e stratigrafia della serie calcarea e marnosa-spongolitica (Paleogene-Miocene). Mem. Soc. Geol. It. 35 (1986), 33-47.

Coccioni, R., Nesci, O., Tramontana, M., Wezel, C. F., Moretti, E., 1987. Descrizione di un livello guida 'radiolaritico-bituminoso-ittiolitico' alla base delle Marne a Fucoidi nell'Appennino umbro-marchigiano. Boll. Soc. Geol. Ital. 106, 183-192.

Colacicchi, R., Devoto, G., Praturlon, A., 1967. Depositi messiniani oligoalini al bordo orientale del Fucino e descrizione di Tyrrhenocythere ruggieri DEVOTO, nuova specie di ostracode. Boll. Soc. Geol. It. 86, 21-37.

Corrado, S., Cosentino, D., Gioia, C., 1992. Sistema di retroscorrimenti nella Marsica orientale (Abruzzo, Appennino centrale). Mem. Soc. Geol. It. 45, 591-603.

Corrado, S., Cosentino, D., Parotto, M., Vecchia, P., 1995. Verifica delle compatibilità geometriche e cinematiche del thrust-belt sabino (Appennino centrale). Convegno scientifico 'Geodinamica e tettonica attiva del sistema Tirreno-Appennino', Camerino, 9-10 febbraio 1995. Riassunti, 290-292.

Corrado, S., Di Bucci, D., Naso, G., Butler, R.W.H., 1997. Thrusting and strike-slip tectonics in the Alto Molise region (Italy): implications to the Neogene-Quaternary evolution of the Central Apennines orogenic system. J. Geol. Soc. London 154, 679-688.

Corrado, S., Di Bucci, D., Naso, G., Damiani, A.V., 1998a. Rapporti tra le grandi unità stratigrafico-strutturali delle aree esterne dell'Appennino centrale: evoluzione geologica dell'Alto Molise. Boll. Soc. Geol. It. 117, 761-776.

Corrado, S., Di Bucci, D., Naso, G., Faccenna, C., 1998b. Influence of paleogeography on thrust system geometries: an analogue modeling approach for the Abruzzi-Molise (Italy) case history. Tectonophysics 296, 437-453.

Cosentino, D., 1988. Nuovi dati sull'assetto stratigrafico-strutturale dell'area di Roccagiovine (Monti Lucretili). Mem. Soc. Geol. It. 35 (1986), 407-416.

Cosentino, D., Montone, P., 1991. Tectonics in the tiburtino-lucretile sector of the Central Apennine (Latium, Central Italy). Boll. Soc. Geol. It. 110, 707-716.

Cosentino, D., Parotto, M., 1988. Assetto strutturale dei Monti Lucretili settentrionali (Sabina): nuovi dati e schema tettonico preliminare. Geologica Romana 25 (1986), 73-90.

Cosentino, D., Parotto, M., 1989. Sabine thrust belt (Central Apennine, Italy). 28th IGC Abstracts, Washington D. C., 1-331.

Cosentino, D., Parotto, M., 1992. La struttura a falde della sabina (Appennino centrale). Studi Geologici Camerti, vol. spec., 1991/2, 381-387.

Cosentino, D., Cipollari, P., Pipponzi, G., 2003. Il sistema orogenico dell'Appennino centrale: vincoli stratigrafici e cronologia della migrazione. Studi Geologici Camerti, num. spec. 2003, 87-101.

Cosentino, D., Cipollari, P., Pasquali, V., 2006. The Jurassic Pelagic Carbonate Platform of the Cornicolani Mts. (Latium, central Italy). In: G. Pasquarè and C. Venturini, Mapping geology in Italy, APAT - SELCA. IGC Florence, 2004.

Cresta, S., 1989. Stratigrafia del Triassico-Giurassico. Mem. descr. Carta Geol. d'It. 39, 14-22.

D'Agostino, N., Funiciello, R., Speranza, F., Tozzi, M., 1994. Caratteri della tettonica distensiva nell'Appennino Centrale. Boll. Soc. Geol. It. 113, 37-53.

D'Agostino, N., Chamot-Rooke, N., Funiciello, R., Jolivet, L., Speranza, F., 1998. The role of pre-existing thrust faults and topography on the styles of extension in the Gran Sasso range (central Italy). Tectonophysics 292, 229-254,.

D'Argenio, B., Horvath, F., 1984. Some remarks on the deformation history of Adria, from the Mesozoic to the Tertiary. Annales Geophysicae 2, 143-146.

Damiani, A.V., Chiocchini, M., Colacicchi, R., Mariotti, G., Parotto, M., Passeri, L., Praturlon, A., 1992. Elementi litostratigrafici per una sintesi delle facies carbonatiche meso-cenozoiche dell'Appennino centrale. Studi Geologici Camerti, vol. spec., 1991/2, 187-213.

Decandia, F.A., Giannini, E., 1977. Studi geologici nell'Appennino umbro-marchigiano. 1-evidenze di due fasi tettoniche terziarie a SE di Spoleto (Prov. di Perugia). Boll. Soc. Geol. It. 96, 713-722.

Dercourt, J., Ricou, L.E., Vrielynck, B., eds., 1993. Atlas Tethys Palaeoenvironmental Maps. Gauthier-Villars, Paris, 307 p., 14 maps, 1 pl.

Devoto, G., 1969. Alcune considerazioni sul Miocene terminale laziale-abruzzese. Atti Acc. Gioenia Sc. Nat. 1, 17-24.

Devoto, G., 1970. Sguardo geologico dei Monti Simbruini (Lazio nord-orientale). Geologica Romana 9, 127-136.

Di Bucci, D., Corrado, S., Naso, G., Parotto, M., Praturlon, A., 1999. Evoluzione tettonica neogenico-quaternaria dell'area molisana. Boll. Soc. Geol. Ital. 118, 13-30.

Di Luzio, E., Mele, G., Tiberti, M.M., Cavinato, G.P., Parotto, M., 2009. Moho deepening and shallow upper crustal delamination beneath the central Apennines. Earth and Planetary Science Letters 280, 1-12.

Doglioni, C., 1993. Some remarks on the origin of foredeeps. Tectonophysics 228, 1-20.

Doglioni, C., Harabaglia, P., Merlin, S., Monelli, F., Peccerillo, A., Piromallo, C., 1999. Orogens and slabs vs. their direction of subduction. Earth Science Review 45, 167-208.

Doglioni, C., Innocenti, F., Morellato, C., Procaccianti, D., Scrocca, D., 2004. On the Tyrrhenian Sea opening. Memorie Descrittive della Carta Geologica d'Italia 64, 147-164.

Doglioni, C., Carminati, E., Cuffaro, M., Scrocca, D., 2007. Subduction kinematics and dynamic constraints. Earth Science Review 83, 125-175.

Dondi, L., Papetti, I., Tedeschi, D., 1966. Stratigrafia del Pozzo Trevi 1 (Lazio). Geologica Romana 5, 249-262.

Dramis, F., 1993. Il ruolo dei sollevamenti tettonici a lungo raggio nella genesi del rilievo appenninico. Studi Geologici Camerti, vol. spec., 1992/1, 9-15.

Endignoux, L., Moretti, I., Roure, F., 1989. Forward modeling of the southern Apennines. Tectonics 8, 1095-1104.

Erba, E., Coccioni, R., Premoli Silva, I., 1989. Gli scisti a fucoidi nell'area umbro-marchigiana: le sezioni della s.s. Apecchiese. Mem. descr. Carta Geol. d'It. 39, 146-164.

Franciosi, R., Vignolo, A., 2002. Northern Adriatic foreland a promising setting for the southalpine midtriassic petroleum system. EAGE 64th Conference and Exibition-Florence, Italy, Abstracts volume.

Galluzzo, F., Santantonio, M., 2002. The Sabina Plateau: a new element in the Mesozoic palaeogeography of Central Apennines. Boll. Soc. Geol. It., vol. spec. n. 1, 561-588.

Ghisetti, F., Vezzani, L., 1986. Carta geologica del gruppo del M. Siella-M. Camicia-M. Prena-M. Brancastello (Gran Sasso d'Italia, Abruzzo). S.EL.CA., Firenze.

Ghisetti, F., Vezzani, L., 1990. Stili strutturali nei sistemi di sovrascorrimento della Catena del Gran Sasso (Appennino centrale). In: (M. Boccaletti, G. Deiana and G. Papani Ed.), Atti del Convegno 'Neogene Thrust Tectonics - Esempi da Alpi meridionali, Appennino e Sicilia', (Parma, 8-9 giugno 1990), Studi Geologici Camerti, vol. spec. 1990, 37-50.

Ghisetti, F., Vezzani, L., 1991. Thrust belt development in the central Apennines: northward po-¬larity of thrusting and out-of-sequence deformations in the Gran Sasso chain (Italy). Tectonics 10, 904-919.

Ghisetti, F., Follador, U., Lanza, R., Vezzani, L., 1992. La zona di taglio Rigopiano-Bussi-Rivisondoli: svincolo transpressivo al margine nord-orientale della piattaforma laziale-abruzzese. Studi Geologici Camerti, vol. spec., 1991/2, 215-220.

Ghisetti, F., Vezzani, L., Follador, U., 1993. Transpressioni destre nelle zone esterne dell'Appennino centrale. Geologica Romana 29, 73-95.

Gliozzi, E., 1999. A late Messinian brackish water ostracod fauna of Paratethyan aspect from Le Vicenne (Abruzzi, central Apennines, Italy). Palaeogeogr., Palaeoclimatol., Palaeoecol. 151, 191-208.

GrandiÄ, S., Biancone, M., Samarzija, J., 2002. Geophysical and Stratigraphic Evidence of the Adriatic Triassic Rift Structures. Memorie della Società Geologica Italiana 57, 315-325.

Hill, K.C., Hayward, A.B., 1988. Structural constraints on the Tertiary plate tectonic evolution of Italy. Marine and Petroleum Geology 5 (1), 2-16.

La Monica, G.B., 1966. Caratteristiche granulometriche e sedimentologiche delle arenarie di Torrice (Frosinone - Lazio meridionale). Atti Acc. Gioenia Sc. Nat. 18, 285-312.

Lavecchia, G., 1985. Il sovrascorrimento dei Monti Sibillini: analisi cinematica e strutturale. Boll. Soc. Geol. It. 104, 161-194.

Mattei, M., Miccadei, E., 1991. Strike-slip tectonics between the Marsica range and the Molisan basin in the Sangro Valley (Abruzzo, central Italy). Boll. Soc. Geol. It. 110, 735-747.

Mattei, M., Montone, P., Salvini, F., 1986. Analisi strutturale dei rilievi appenninici intorno a Tivoli (Roma). Mem. Soc. Geol. It. 35, 579-589.

Mattei, M., Funiciello, R., Kissel, C., Laj, C., 1992. Rotazioni di blocchi crostali neogenici nell'Appennino centrale: analisi paleomagnetiche e di anisotropia della suscettività magnetica (AMS). Studi Geologici Camerti, vol. spec., 1991/2, 221-229.

Mattei, M., Funiciello, R., Kissel, C., Laj, C., 1994. Strike-slip tectonics and Neogene block rotation in Central Italy. Mem. Soc. Geol. It. 48, 485-497.

Mattei, M., Funiciello, R., Kissel, C., 1995. Paleomagnetic and structural evidence of Neogene block rotation in the Central Apennines, Italy. Journal Geophysical Research 100, 17863-17883.

Mattei, M., Speranza, F., Sagnotti, L., Funiciello, R., Faccenna, C., 1999. Paleomagnetic constraints to the tectonic evolution of the northern Italian peninsula. Mem. Soc. Geol. It. 52, 469-478.

Martini, E., 1971. Standard Tertiary and Quaternary calcareous nannoplankton zonation. Proceedings of the Second International Conference on Planktonic Microfossils, Rome: 739-785, Ediz. Tecnoscienza.

Mazzoli, S., Corrado, S., De Donatis, M., Scrocca, D., Butler, R.W.H., Di Bucci, D., Naso, G., Nicolai, C., Zucconi, V., 2000. Time and space variability of --thin-skinned'' and --thick-skinned'' thrust tectonics in the Apennines (Italy). Rendiconti dei Lincei, Scienze Fisiche e Naturali 11, 5-39.

Mele, G., Sandvol, E., Cavinato, G.P., 2006. Evidence of crustal thickening beneath the central Apennines (Italy) from teleseismic receiver functions. Earth and Planetary Science Letters 249, 425-435.

Miccadei, E., Piacentini, T., Barberi, R., 2002. Uplift and local tectonic subsidence in the evolution of intramontane basins: the example of the Sulmona Basin (central Apennines, Italy). Studi Geologici Camerti, num. spec., 2002, 119-133.

Mongelli, F., Zito, G., De Lorenzo, S., Doglioni, C., 2004. Geodynamic interpretation of the heat flow in the Tyrrhenian Sea. Memorie Descrittive della Carta Geologica d'Italia 64, 71-82.

Montone, P., Salvini, F., 1990. Carta geologico-strutturale dei rilievi tra Colli di Monte Bove (Carsoli) e Tagliacozzo, Abruzzo. Scala 1:25.000, Stabil. L. Salomone, Roma.

Montone, P., Salvini, F., 1993. Geologia strutturale dei rilievi tra Colli di Monte Bove (Carsoli) e Tagliacozzo, Abruzzo. Geologica Romana 29, 15-29.

Morley, C.K., 1988. Out-of-sequence thrusts. Tectonics 7: 539-561.

Mostardini, F., Merlini, S., 1988. Appennino centro-meridionale. Sezioni geologiche e proposta di modello strutturale. Mem. Soc. Geol. It., 35 (1986), 177-202.

Odin, G.S., Ricci Lucchi, F., Tateo, F., Cosca, M., Hunziker, J.C., 1997. Integrated stratigraphy of the Maccarone section, late Messinian (Marche Region, Italy). In: Montanari A., Odin G.S., Coccioni R. (Eds.), Miocene Stratigraphy: An Integrated Approach, Elsevier Science B.V., Amsterdam, 531-545.

Okada, H., Bukry, D., 1980. Supplementary modification and introduction of code numbers to the low-latitude coccolith biostratigraphic zonation (Bukry, 1973; 1975). Mar. Micropaleontol. 5 (3), 5-321.

Ori, G.G., Friend, P.F., 1984. Sedimentary basins formed and carried piggyback on active thrust sheets. Geology 12, 475-478.

Parotto, M. 1971. Stratigraphy and tectonics of the eastern Simbruini and western Marsica Ranges (Central Apennines-Italy). Acc. Naz. Lincei 9, 93-170.

Parotto, M., Praturlon, A., 1975. Geological summary of the Central Apennines. Quaderni de 'La Ricerca Scientifica' 90, 257-311.

Pasquali, V., Castorina, F., Cipollari, P., Cosentino, D., Lo Mastro, S., 2007. I depositi tardo-orogenici della Valle Latina meridionale: stratigrafia e implicazioni cinematiche per l'evoluzione dell'Appennino centrale. Bollettino della Società Geologica Italiana (Ital. J. Geosci.) 126 (1), 101-118.

Patacca, E., Scandone, P., 1989. Post-Tortonian mountain building in the Apennines. The role of the passive sinking of a relic lithospheric slab. In: The Lithosphere in Italy, Eds. Boriani A., Bonafede M., Piccardo G.B. and Vai G.B. Atti dei Convegni Lincei 80, 157-176.

Patacca, E., Sartori, R., Scandone P., 1992a. Tyrrhenian basin and Apenninic arcs: kinematic relations since late Tortonian times. Mem. Soc. Geol. It. 45 (1990), 425-451.

Patacca, E., Scandone, P., Bellatalla, M., Perilli, N., Santini, U., 1992b. La zona di giunzione tra l'arco appenninico settentrionale e l'arco appenninico meridionale nell'Abruzzo e nel Molise. Studi Geologici Camerti, vol. spec., 1991/2, 417-441.

Patacca, E., Scandone, P., Di Luzio, E., Cavinato, G.P., Parotto, M., 2008. Structural architecture of the central Apennines: Interpretation of the CROP 11 seismic profile from the Adriatic coast to the orographic divide. Tectonics 27, TC3006, 10.1029/2005TC001917.

Pialli, G., Alwarez, W., Minelli, G., 1995. Geodinamica dell'Appennino settentrionale e sue ripercussioni nella evoluzione tettonica miocenica. Studi Geologici Camerti, vol. spec., 1995/1, 523-536.

Pialli, G., Barchi, M.R., Minelli, G., Eds. 1998. Results of the Crop 03 Deep Seismic Reflection Profile. Memorie della Società Geologica Italiana 52, 654 pp.

Ponziani, F., 1995. Nuova interpretazione di dati di sismica a rifrazione profonda negli Appennini settentrionali. Studi Geologici Camerti, vol. spec., 1995/1, 551-565.

Praturlon, A., 1968. Note illustrative della Carta Geologica d'Italia alla scala 1:100.000, Foglio 152 (Sora). Servizio Geologico d'Italia, 76 pp.

Praturlon, A., 1980. Le cadre géologique génèral de l'Italie. Sa place dans le cadre européen et méditerranéen. In: 26-° Congr. Géol. Inter. - Introduction à la géologie générale d'Italie et guide à l'excursion 122A, 3-14.

Roure, F., Casero, P., Vially, R., 1991. Growth processes and melange formation in the southern Apennines accretionary wedge. Earth and Planetary Science Letters 102, 395-412.

Royden, L., Patacca, E., Scandone, P., 1987. Segmentation and configuration of subducted lithosphere in Italy: An important control on thrust-belt and foredeep-basin evolution. Geology 15, 714-717.

Sage, L., Mosconi, A., Moretti, I., Riva, E., Roure, F., 1991. Cross section balancing in the Central Apennines: an application of LOCACE. AAPG Bull. 75, 832-844.

Satolli, S., Calamita, F., 2008. Differences and similarities between the central and the southern Apennines (Italy): Examining the Gran Sasso versus the Matese-frosolone salients using paleomagnetic, geological, and structural data. J. Geophys. Res., 113, B10101, 10.1029/2008JB005699.

Salvini, F. 1991. Tettonica a blocchi in settori crostali superficiali: modellizzazione ed esempi da dati strutturali in Appennino centrale. Studi Geologici Camerti, vol. spec., 1991/2, 237-247.

Salvini, F., Vittori, E., 1982. Analisi strutturale della linea Olévano-Antrodoco-Posta (Ancona-Anzio Auct.): metodologia di studio delle deformazioni fragili e presentazione del tratto meridionale. Memorie della Società Geologica Italiana 24, 337-355.

Santantonio, M., 1993. Facies associations and evolution of pelagic carbonate platform/basin systems: examples from the Italian Jurassic. Sedimentology 40, 1039-1067.

Santo, A., Sgrosso, I., 1987. Alcune precisazioni sulle 'trasgressioni' mioceniche nell'Appennino meridionale. Mem. Soc. Geol. It. 38, 225-240.

Schlanger, S.O., Jenkins, H.C., 1976. Cretaceous oceanic anoxic events: causes and consequences. Geologie en Mijnbouw 55, 179-184.

Scrocca, D., Carminati, E., Doglioni, C., 2005. Deep structure of the southern Apennines, Italy: Thin-skinned or thick-skinned?, Tectonics 24, TC3005, 10.1029/2004TC001634.

Selli, R. 1957. Sulla trasgressione del Miocene nell'Italia meridionale. Giorn. Geol., serie 2, 26, 1-54.

Serafini, S., Vittori, E., 1986. Primi risultati di uno studio statistico delle mesostrutture della Val Roveto e dell'area di Sora (Lazio meridionale). Mem. Soc. Geol. It. 35, 631-646.

Serafini, S., Vittori, E., 1988. Caratteri tettonici desunti da dati mesostrutturali nell'area compresa tra Sora e le gole di Atina (Lazio meridionale). Mem. Soc. Geol. It. 41, 1191-1199.

Sgrosso, I., 1988. Criteri ed elementi per una ricostruzione paleogeografica delle zone esterne dell'Appennino centro-meridionale. Mem. Soc. Geol. It. 35 (1986), 203-219. Sgrosso, I., 1992a. Nuovi elementi per un pià¹ articolato modello paleogeografico nell'Appennino centro meridionale. Mem. Soc. Geol. It. 41 (1988), 225-242.

Sgrosso, I., 1992b. Sedimenti miocenici discordanti nell'Appennino centro-meridionale. Mem. Soc. Geol. It. 45 (1990), 613-615.

Speranza, F., Mattei, M., Naso, G., Di Bucci, D., Corrado, S., 1997a. Neogene-Quaternary evolution of the central Apennine orogenic system (Italy): a structural and paleomagnetic approach in the Molise region. Tectonophysics 299, 143-157.

Speranza, F., Sagnotti, L., Mattei, M., 1997b. Tectonics of the Umbria-Marche-Romagna Arc (central-northern Apennines, Italy): new paleomagnetic approach. Journal Geophysical Research 102, 3153-3166.

Speranza, F., Chiappini, M., 2002. Thick-skinned tectonics in the external Apennines, Italy: New evidence from magnetic anomaly analysis, Journal of Geophysical Research 107, 2290, 10.1029/2000JB000027.

Tallini, M., 1994. Deformazioni compressive e distensive nelle unità di tetto dei fronti della Valle Latina e della Val Roveto: Analisi geometrica, cinematica ed interpretazione strutturale. PhD thesis, University of Roma La Sapienza, 269 pp.

Tiberti, M.M., Orlando, L., Di Bucci, D., Bernabini, M., Parotto, M., 2005. Regional gravity anomaly map and crustal model of the Central-Southern Apennines (Italy). Journal of Geodynamics 40, 73-91.

Tozer, R.S.J., Butler, R.W.H., Corrado, S., 2002. Comparing thin- and thick-skinned thrust tectonic models of the Central Apennines, Italy. EGU Stephan Mueller Special Publication Series 1, 181-194.

Vai, G. B., 1987. Migrazione complessa del sistema fronte deformativo avanfossa-cercine periferico: il caso dell'Appennino settentrionale. Mem. Soc. Geol. It. 38, 95-105.

Vezzani, L., Ghisetti, F., 1995. Domini in compressione ed in distensione al retro dei fronti del Gran Sasso-M. Picca e del M. Morrone: il ruolo della zona di taglio Avezzano-Bussi (Appennino centrale). Studi Geologici Camerti, vol. spec., 1995/2, 475-490.

Vezzani, L., Ghisetti, F., 1998. Carta Geologica dell'Abruzzo, scala 1:100.000. Regione Abruzzo, settore urbanistica-beni ambientali e cultura. S.EL.CA., Firenze.

Yilmaz, P.O., Norton, I.O., Leary, D., Chuchla, R.J., 1996. Tectonic evolution and paleogeography of Europe. In: Ziegler, P.A., Horvà th, F. (eds), Peri-Tethys Memoir 2: Structure and Prospects of Alpine Basins and Forelands. Mém. Mus. natn. Hist. nat. 170, 15-45. Paris. ISBN: 2-85653507-0

Zappaterra, E., 1992. Regional distribution models of source rocks in the Periadriatic region. Mem. Soc. Geol. It. 45, 817-822.

Ziegler, P.A., Roure, F., 1996. Architecture and petroleum systems of the Alpine orogen and associated basins. In: Ziegler, P.A., Horvà th, F., (eds), Peri-Tethys Memoir 2: 'Structure and Prospects of Alpine Basins and Forelands. Mém. Mus. natn. Hist. nat. 170, 47-60. Paris. ISBN: 2-85653507-0

Zoetemeijer R., Cloetingh, S., Sassi, W., Roure, F., 1993. Modelling of piggyback-basin stratigraphy: record of tectonic evolution.

A. Plates

Figure - Plate 1. Lithofacies Map of the Central Apennines

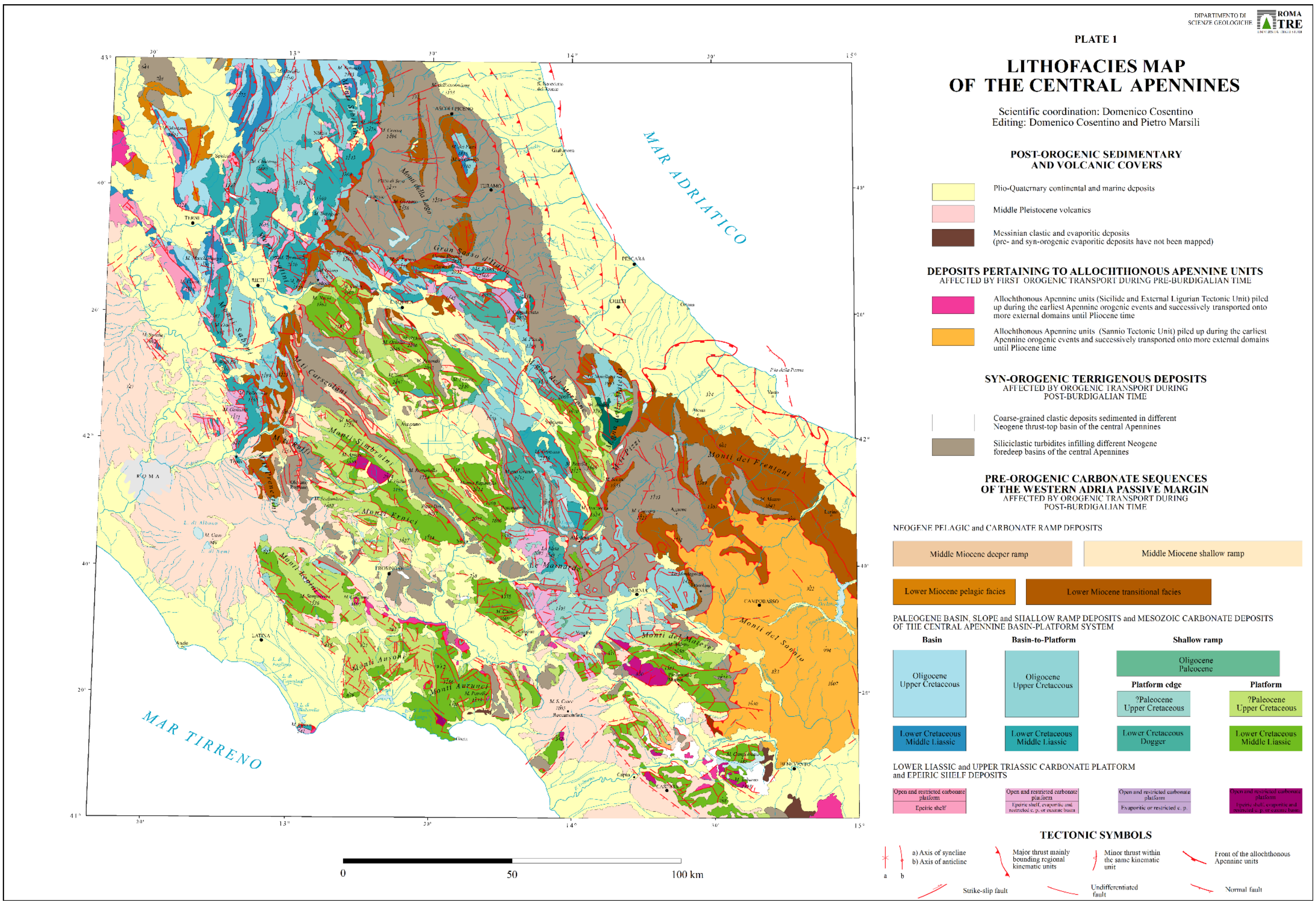

Figure - Plate 2. Stratigraphical Logs of the Major Central Apennine Tectonic Units

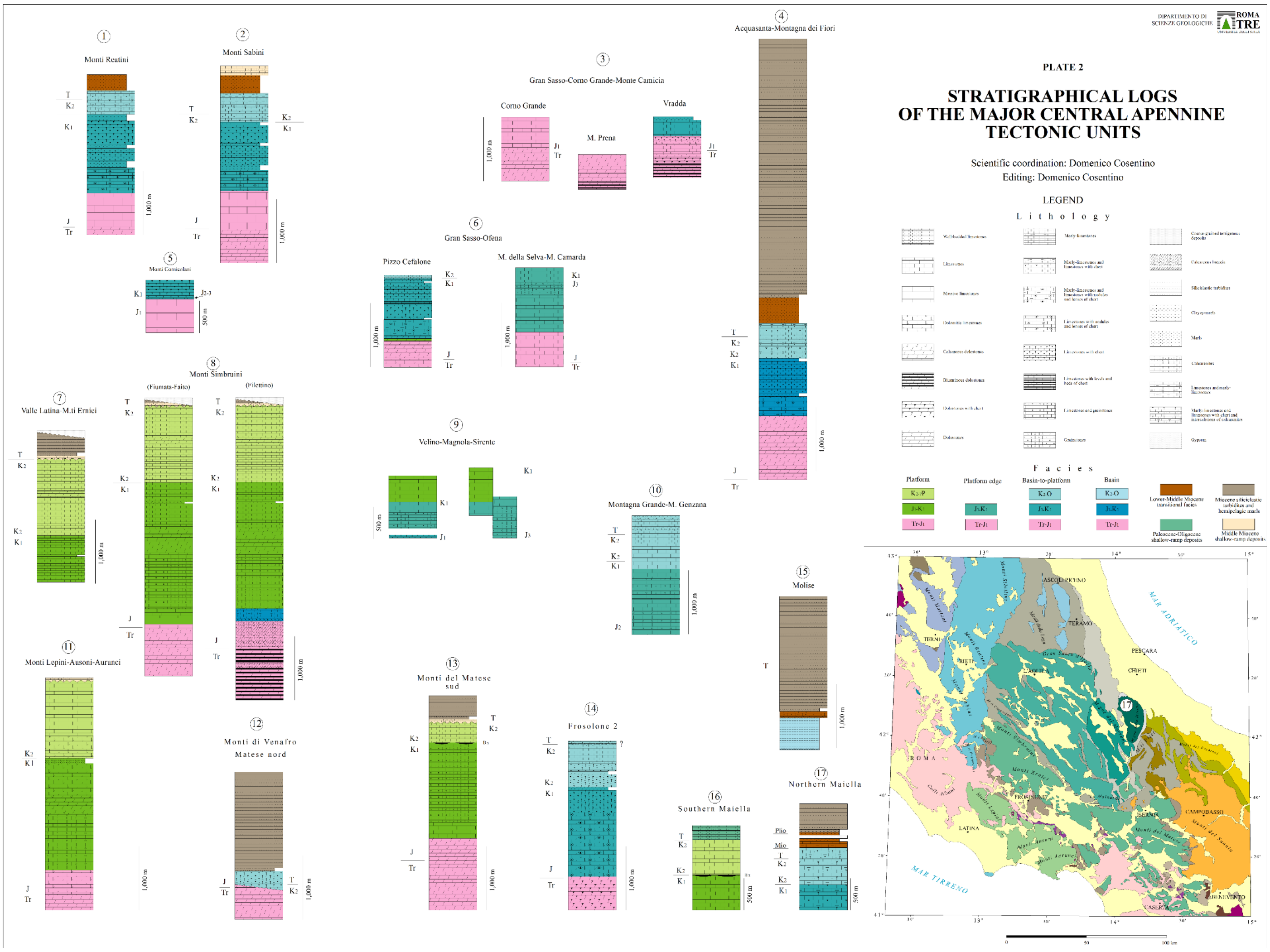

Figure - Plate 3. Structural Map of the Central Apennines

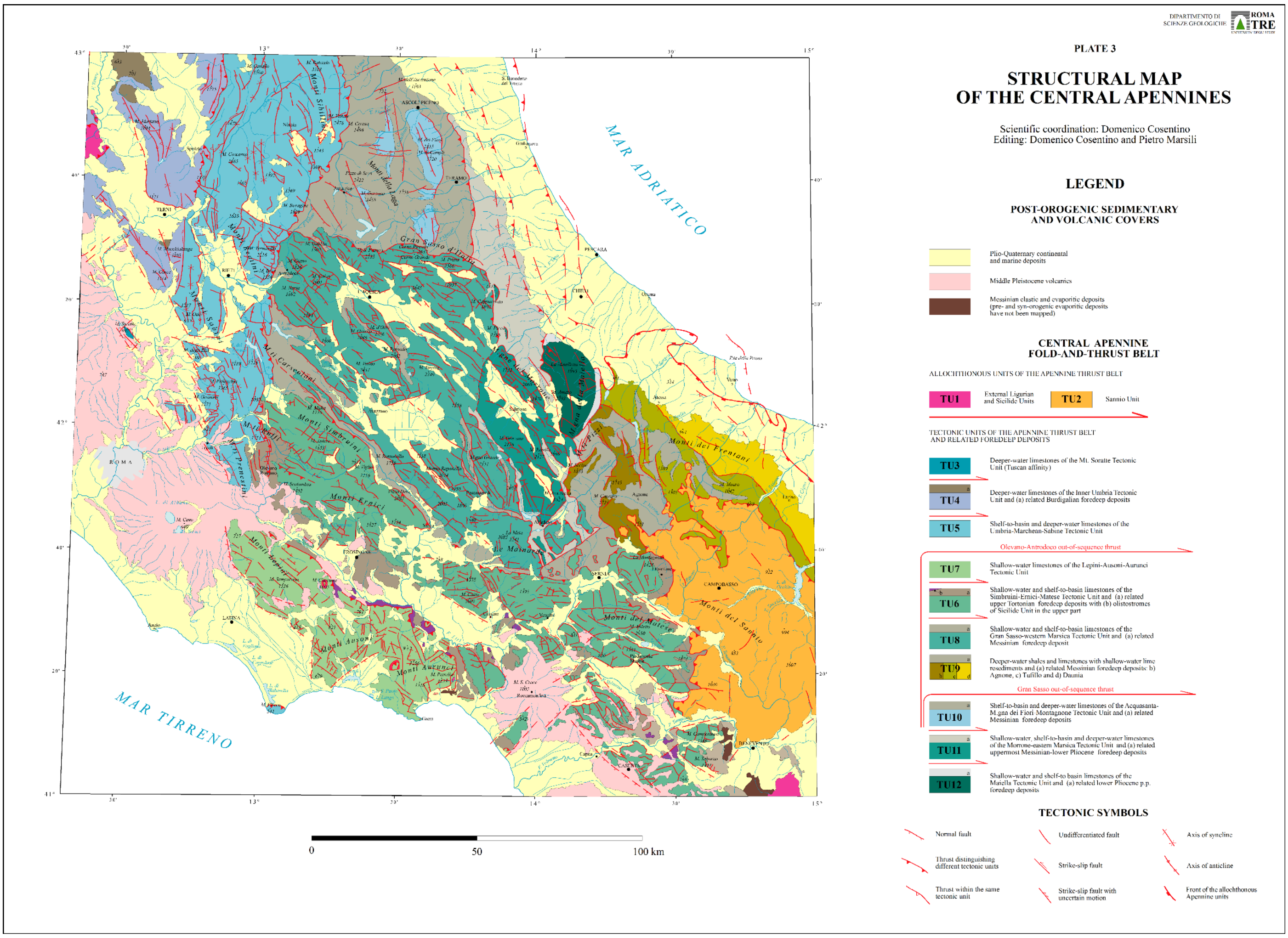

Figure - Plate 4. Kinematic Map of the Central Apennines

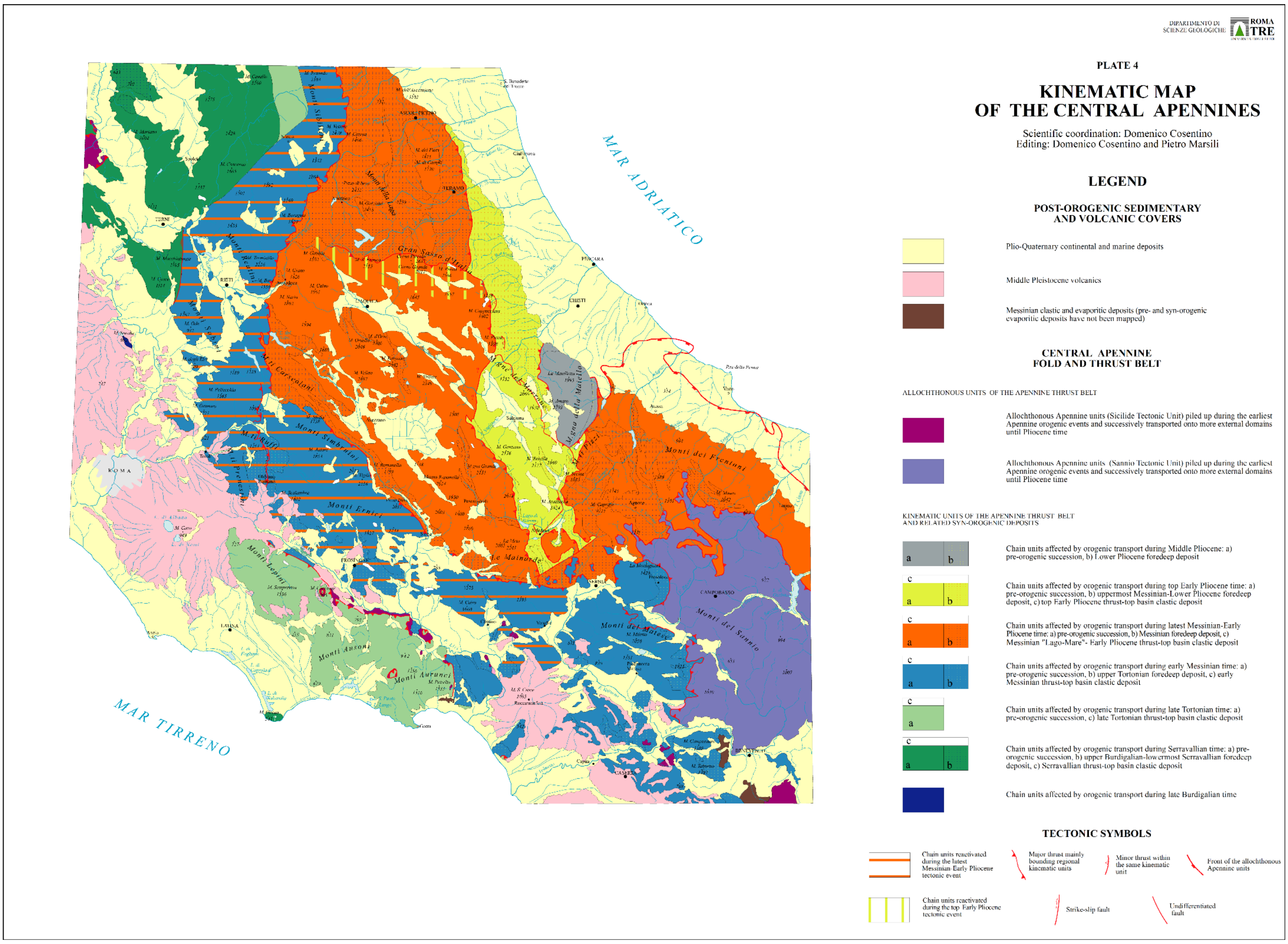

Figure - Plate 5. Cross-section