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ELEMENTS TO CORRELATE MARINE AND CONTINENTAL SEDIMENTARY SUCCESSIONS IN THE CONTEXT OF THE NEOTECTONIC EVOLUTION OF THE CENTRAL APENNINES

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ABSTRACT
The central Apennines show geologic and geomorphic features that report the strong influence of extensional tectonics and regional uplift on their recent evolution. The goal of this paper is to find out the time constraints of the chain uplift, focusing on the elements of correlation between marine and continental successions on both the Adriatic and Tyrrhenian sides. All along the range, the most ancient landforms are gently rolling or flat summit surfaces. On the Tyrrhenian side, the interaction between the chain uplift and the extensional tectonics related to the opening of the Tyrrhenian basin, generated several neoautoctonous basins that are older in Tuscany (since the Tortonian) and younger in the Latium-Abruzzo area (since the Pliocene). On the Adriatic side, the combined action of uplift and climatic changes, produced several depositional sequences, separated by angular unconformities. In the western basins, progressively coarsening upward sediments, corresponding to the *Globorotalia crassaformis* biozone, are found. At Valle Ricca, in the upper section of these deposits, a 2.1 Myr old volcanic layer, corresponding to the base of the *Globorotalia inflata* biozone, is present. The Valle Ricca succession is truncated by an erosion surface over which marine and brackish sandy clay (*Argille Sabbiose del Chiani-Tevere*) lay down. Similarly, in the periadriatic basin, a volcanic layer, dated 2.1 Myr, has been found at Bellante, in the upper part of a pelitic sequence. An angular unconformity separates this sequence from overlaying conglomerate and sand, recording a progressively eastward shifting of the coastline as a consequence of the uplift. Contemporaneously, extensional tectonics progressively affected the Apennine chain giving rise to a number of intermontane depressions, within which coarse breccia and lacustrine-alluvial deposits were deposited. In the Rieti and L'Aquila basins, the finding of *Equus stenonis* and *Mammuthus meridionalis* refer the basal part of these deposits to an age not older than the lower Pleistocene. Around 0.8 Myr B.P., in correspondence with a base level drop induced by a sudden increase of uplift rate, the coastline rapidly shifted seawards and littoral sandy-pebbly sediments were deposited along both sides of the Apennines. Contemporaneously, increased stream erosion rates gave rise to the present valley network, within which the interaction of river incision and climate changes generated several orders of alluvial terraces. In this contest, a hunched backward river erosion breached most of intramontane depressions, draining off the lakes and causing the erosion of the basin sedimentary sequence. In conclusion, according to all these considerations, we hypothesize that the topographic growth of the range was slow until the end of the lower Pleistocene, when a strong increase of the uplift rate affected the chain and the surrounding coastal belts.

RIASSUNTO
L'Appennino centrale presenta caratteri geologici e geomorfologici che documentano l'intensa influenza della tettonica estensionale e del sollevamento regionale sulla sua evoluzione recente. In questo lavoro si intendono evidenziare gli elementi di correlazione tra le successioni marine e continentali della fascia periadriatica abruzzese e peritirrenica laziale, al fine di proporre dei vincoli temporali all'evoluzione recente dell'Appennino. Gli elementi geomorfologici più antichi, riscontrabili lungo tutta la catena appenninica, sono rappresentati da superfici sommitali gentilmente ondulate o pianeggianti. Sul versante occidentale la tettonica distensiva legata all'apertura del Tirreno ha generato una complessa serie di bacini neoautoctoni più antichi in Toscana (dal Tortoniano) e più recenti nell'area laziale (dal Pliocene). Sul versante adriatico il sollevamento della catena ha dato origine a discordanze angolari che individuano numerose sequenze sedimentarie in assetto monoclinalico. Sul versante tirrenico della catena, si depositano sedimenti progressivamente più grossolani riferibili alla fine della biozona a Globorotalia crassaformis. *In particolare, a Valle Ricca, al tetto di questi depositi e alla base della biozona a* Globorotalia inflata*, è stato trovato un livello vulcanico datato 2.1 Ma. Su tale successione si appoggiano in discordanza le "*Argille Sabbiose del Chiani-Tevere*" di ambiente marino e salmastro. Similmente, sul versante adriatico, presso Bellante, è stato rinvenuto un livello vulcanico datato 2.1 Ma nella parte superiore di una sequenza di depositi pelitici. Questa è troncata al tetto da una discordanza angolare che la separa da sedimenti conglomeratici e sabbiosi. Contemporaneamente, la tettonica estensionale interessa progressivamente la catena generando una serie di bacini intermontani, delimitati da faglie normali. I materiali di riempimento sono costituiti alla base da sedimenti grossolani che passano verso l'alto a depositi alluvionali e fluvio-lacustri. Nelle conche di Rieti e de L'Aquila il ritrovamento di* Equus stenonis *e* Mammuthus meridionalis *consente di riferire la parte basale di questi sedimenti ad un'età non più giovane del Pleistocene inferiore. Intorno a 0.8 Ma B.P., in concomitanza con un forte abbassamento relativo del livello di base, legato ad un subitaneo incremento del tasso di sollevamento, si verifica un più marcato avanzamento delle linee di costa, accompagnato dalla messa in posto di depositi sabbioso-ciottolosi di ambiente litorale lungo i margini occidentale e orientale dell'Appennino. Contemporaneamente, un aumento del tasso di incisione fluviale dà origine all'attuale sistema di valli, all'interno delle quali, per effetto dell'interazione tra l'aumento dell'erosione fluviale e le variazioni climatiche, si sono formati più ordini di terrazzi alluvionali. In tale contesto, l'erosione regressiva dei corsi d'acqua ha profondamente inciso le soglie della maggior parte dei bacini intermontani, prosciugando i laghi ed erodendo gran parte dei depositi presenti. In conclusione, in base a queste considerazioni si può ipotizzare che la crescita topografica della catena appenninica è stata lenta fino alla fine del Pleistocene inferiore, quando si è verificato un forte incremento del tasso di sollevamento.*

Keywords: Central Apennines, Uplift, Neotectonics

Parole chiave: Appennino Centrale, Sollevamento, Neotettonica

1. INTRODUCTION

The topographic growth of the Italian Apennines was slow during the phase of major plate convergence and crustal shortening which occurred throughout the Miocene and Pliocene, but increased significantly in the Pleistocene (Ciaranfi *et al.*, 1983; Dramis, 1992; Tortorici *et al.*, 1995; Argnani *et al.*, 1997; Bertotti *et al.*, 1997; Carminati *et al.*, 1999; Calamita *et al.*, 1999; Coltorti & Pieruccini, 2000). This uplift is testified by geomorphic and geologic evidences throughout the chain.

In the central Apennines the oldest landforms, that are gentle rolling or flat summit surfaces, seem to be connected eastward, in the periadriatic basin, to the base of Pliocene marine deposits (Centamore & Nisio, 2003). On the western flank and in the chain, the extensional tectonics related to the opening of the Tyrrhenian sea generated several neoautoctonous basins that are older in Tuscany (since the Tortonian, Bossio *et al.*, 1993) and younger in Latium and Abruzzo (since the Pliocene, Ambrosetti *et al.*, 1978).

This paper examines most of the available literature data about the continental and marine successions cropping out on both sides of the central Apennines and within the intermontane basins. We focus on the sedimentary features and stratigraphic elements that could provide time constraints on the recent evolution of the study area, in the context of an uplifting mountain chain affected by extensional tectonics. Reviewing the available paleontologic and radiometric data, we point out the main stratigraphic elements that allow the correlation between the sedimentary successions cropping out in the margins of the chain and in the intermontane basins. The results are consistent with a mostly continuous and slow uplift, characterized by a strong increase of the uplift rate by the end of lower Pleistocene.

2. GEOLOGICAL SETTING

The Italian Apennines are a fold and thrust chain that, since around 15 Myr, has been affected by extensional tectonics as a consequence of the backarc opening of the Tyrrhenian basin; the formation of this basin induced the eastward-southeastward migration of the Apennines and the foredeep (Malinverno & Ryan, 1986; Patacca & Scandone, 1989; Patacca *et al.*, 1990; Mantovani *et al.*, 1996; Faccenna *et al.*, 2001). Clastic deposits shed from Mesozoic and early Cenozoic sediments have been deposited in foredeep and thrust-top basins during the late Miocene-early Pliocene, in connection with local emergence and erosion of the continental land (Centamore & Micarelli, 1991; Calamita *et al.*, 1999; Cavinato & De Celles, 1999; Cipollari *et al.,* 1999 a, b). Since late Pliocene through late early Pleistocene, a decrease in the rate of the eastward migration of the Apennine chain (Mantovani *et al.*, 1996) and minor changes in the backarc extension axis were temporally coincident with an increase of the regional emergence of the chain (Hippolyte *et al.*, 1994).

Several authors, citing different proxies among which the occurrence of low-relief summit surfaces in several high-standing parts of the Apennines, have appealed to a significant increase in the emergence of all the Apennines by the middle Pleistocene (Ambrosetti *et al.*, 1982; Ciaranfi *et al.*, 1983; Brancaccio *et al.*, 1984; Colella *et al.*, 1987; Dramis, 1992; Tortorici *et al.,* 1995; Amato & Cinque, 1999; Ascione & Cinque, 1999; Calamita *et al.*, 1999; Coltorti & Pieruccini, 2000; D'Agostino *et al.*, 2001).

The study area, located in the central Apennines (Fig. 1), is underlain by Mesozoic to early Cenozoic platform carbonate, marls and terrigenous deposits that are deformed by E-NE-verging thrusts (Parotto & Praturlon, 1975; Patacca *et al.*, 1990; Bigi *et al.*, 1991). As for the rest of the chain, the extensional tectonics, related to the opening of the Tyrrhenian basin, progressively affected the study area, generating several neoautoctonous basins on the western margin (Bossio *et al.*, 1993; Ambrosetti *et al.*, 1978) and intermontane depressions in the axial part of the range (Dramis, 1992). In the periadriatic sector, divided into minor basins by transversal tectonic structures, the uplift induced a progressive tilting of the marine sediments that generated clinoforms dipping to E-NE (Centamore *et al.*, 1990, 1991; Bigi *et al.*, 1997).

Present seismicity indicates that the modern chain continues to be affected by tectonic shortening on the Adriatic flank and extension on the Tyrrhenian flank, although most of the extensional activity is concentrated along the more elevated axial sectors of the chain (Royden *et al.,* 1987; Console *et al.,* 1988; Gasparini *et al.*, 1988; Patacca & Scandone, 1989; Patacca *et al.*, 1990; Lavecchia *et al.*, 1994; Amato *et al.*, 1997; Montone & Mariucci, 1999; Negredo *et al.*, 1999; Frepoli & Amato, 2000).

3. MARINE AND CONTINENTAL STRATIGRAPHY OF THE STUDY AREA

All the sites mentioned in the following paragraphs are reported in Fig. 1.

3.1 Late Miocene - Lower Pliocene

On the western flank of the Apennines, since the Tortonian to the early Messinian, the extensional tectonics related to the opening of the Tyrrhenian sea generated several basins: here the stratigraphic sequences are characterized by the occurrence of fluvial and lacustrine deposits, gradually evolving to littoral sand and clay (Fazzini *et al.*, 1972; Bossio *et al.*, 1993; Carboni *et al.*, 1994; Testa, 1995). Subsequently, the sedimentation became evaporitic as a response to the Messinian salinity crisis (Parotto & Praturlon, 1975; Patacca *et al.*, 1990; Roveri *et al.*, 2001). After the Messinian regression, marked by an erosion surface, in the lower Pliocene, conglomerate, sandy and clayey sediments were deposited in a progressively deeper sea (Brandi *et al.*, 1970; Ambrosetti *et al.*, 1978; Buonasorte *et al.*, 1991; Barberi *et al.*, 1994; Carboni *et al.*, 1994). The change of depositional environment depended on the marine ingression as well as on the structural pattern of depressed basins with elevated and partially emerged ranges (Ambrosetti *et al.*, 1978). In the more western basins the deposition began during the *Globorotalia margaritae* biozone, whereas more to the east (Tiber basin) the so-called "Argille di Fabro" deposits may be referred to the *Globorotalia puncticulata* biozone

(Ambrosetti *et al.*, 1987; Buonasorte *et al.*, 1991; Carboni *et al.*, 1994).

In the same time interval, the foredeep migrated eastward: Valle Latina, Val Roveto, Lago del Salto-Tagliacozzo depression, Laga and Cellino basins (Cipollari & Cosentino, 1995; Centamore *et al.*, 1990; Centamore *et al.*, 1991; Bellotti, 1991; Bigi *et al.*, 1997). The turbidites lying down in the foredeep are unconformably overlain by littoral sand and fluvial-delta polygenic conglomerate (Valle del Liri, Le Vicenne, Piagge, Rigopiano, M. Coppe), deposited between late Messinian and lower Pliocene (Centamore *et al.*, 1991; Cipollari & Cosentino, 1995; Bigi *et al.*, 1997; Cipollari *et al.*, 1999a, b).

3.2 Middle – Early Upper Pliocene

On the western flank of the Apennines, in northern Latium, at the disappearing of *Globorotalia puncticulata* and at the first occurrence of *Globorotalia crassaformis*, the sediments changed from bathial clay ("*Argille di Fabro*") to littoral sand ("*Sabbie a Flabellipecten*", "*Calcare di Tarquinia*") and shoreline conglomerate ("*Conglomerato di Città della Pieve*") (Brandi *et al.*, 1970; Ambrosetti *et al.*, 1987; Barberi *et al.*, 1994; Carboni *et al.*, 1994). These sediments are finer westward, becoming coarser and coarser towards the present chain (Buonasorte *et al.*, 1991).

The general pattern of the Adriatic margin was controlled by structural elements oriented NW-SE and NE-SW that defined several basins (Teramo, Chieti, and Vasto basins) alternated with more elevated longitudinal ridges (Bigi *et al.*, 1997). In these sectors, notwithstanding marked differences in sedimentation and tectonic evolution, the deposition continued in a marine environment, producing a thick stratified succession with several minor sequences separated by angular unconformities (Bigi *et al.*, 1997). These sediments, which unconformably overlay the "*Laga Flysch*", "*Cellino Flysch*", and the "*Marne del Vomano*" formations (Cantalamessa *et al.*, 1986; Bigazzi *et al.*, 2000; Bigi *et al.*, 2000), vary from conglomerate to sand and clay; their base could be referred to the *Globorotalia crassaformis* zone (Centamore & Nisio, 2003).

3.3 Upper Pliocene – Lower Pleistocene

In the Upper Pliocene, on the western margin of the chain, sedimentation persisted with the deposition of marine clay and sandy clay in the Civitavecchia-Montalto di Castro area, in the Tiber basin, and more to south, in the Ardea basin and Pontina plain, even if the successions have been largely truncated by subsequent erosion (Carboni, 1975; Carboni *et al.,* 1993, Carboni *et al.*, 1994; Faccenna *et al.*, 1994). At Valle Ricca a volcanic layer, dated 2.1 Myr, has been reported from the upper part of these deposits (Carboni *et al.*, 1993). More in general, the upper Pliocene succession is cut by an erosion surface on which marine and brackish sandy clay lay down (Malatesta & Zarlenga, 1985; Ambrosetti *et al.*, 1987; Buonasorte *et al.*, 1991; Carboni *et al.*, 1994). These sediments ("*Argille Sabbiose del Chiani-Tevere*" in the Tiber basin sequence), referred to the lower Pleistocene because of the microfacies typical of the *Globorotalia inflata* pp. and of the *Globigerina cariacoensis* zones (Ambrosetti *et al.*, 1987; Carboni & Di Bella, 1996), are connected to ancient shorelines, presently uplifted at elevations ranging from 145 to 480 m a.s.l. (Girotti & Piccardi, 1994). In sectors closer to the mountain chain, upper Pliocene continental clay with

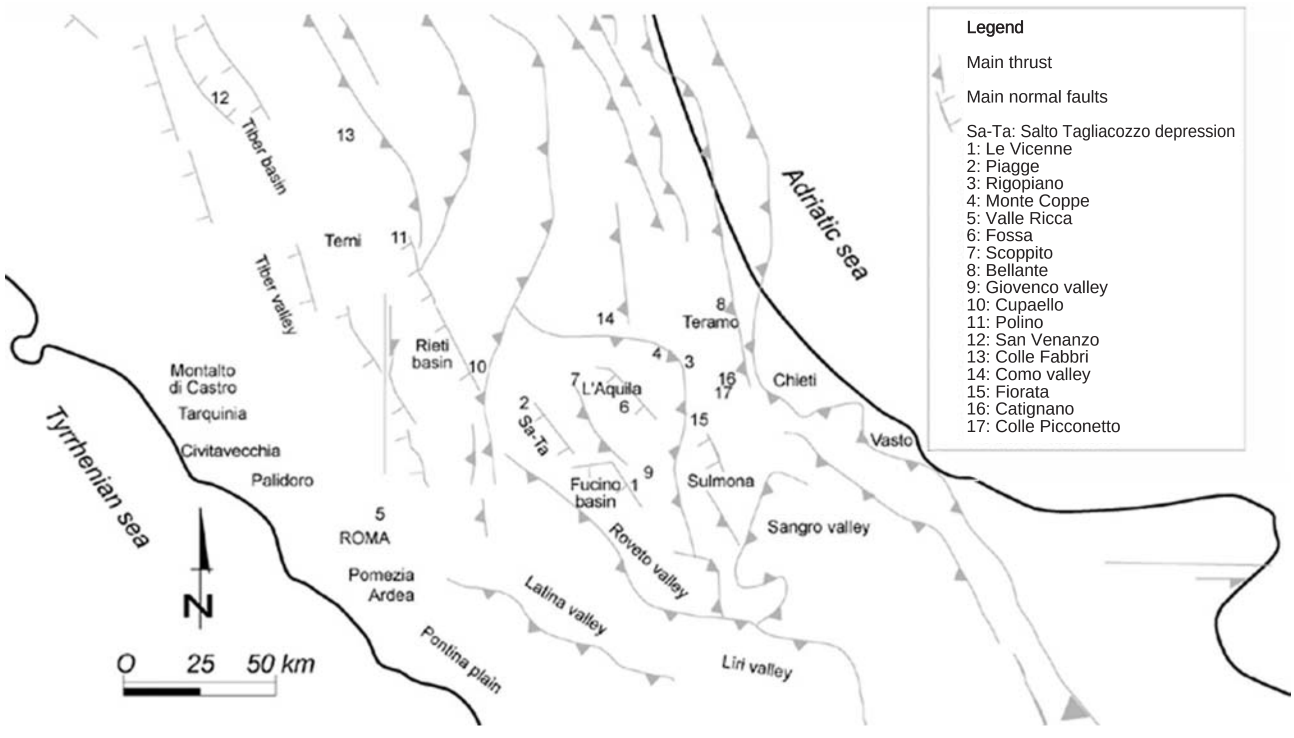

Fig. 1 - Location of the study area. The main tectonic structures and the localities mentioned in the text are reported.

peaty lens ("*Argille grigie inferiori*") crops out (Ambrosetti *et al.*, 1987). They are unconformably overlain by fluvial-lacustrine sandy clay ("*Complesso argillo-so-sabbioso*") dated lower Pleistocene according to the fossil content (Ambrosetti *et al.*, 1987; 1995). In the Tyrrhenian piedmont belt, Santernian infra-littoral sandy clay crop out (Di Bella, 1994), whereas more to the west, in the coastal sectors, circalittoral pelitic sediments with rare sand layers are dated as Emilian (Carboni, 1993).

Extensional tectonics affected the chain producing intermontane basins (Demangeot, 1972; Calamita *et al.*, 1982; Dramis, 1992). These basins are partially filled with sedimentary sequences consisting, from the bottom to the top, of coarse breccia and blocks, lacustrine clayey layers and alluvial conglomerate, gravels and sand, which locally are interfingered each other (Bertini & Bosi, 1993; Cavinato, 1993; Galadini, 1999; AA.VV., 2002). In particular, the coarse breccia and the huge blocks locally crop out several kilometers far from any slopes. In the Fucino and L'Aquila-Fossa basins, as well as in the Salto and Sangro valleys, lacustrine deposits containing huge blocks ("*megabreccia*") have been roughly referred to Pliocene (Demangeot, 1972; Bosi & Messina, 1991; Bertini & Bosi, 1993; Galadini & Messina, 1994; Galadini, 1999). In particular, in the Fucino basin, siltstone and claystone interbedded with "*megabreccia*" and characterized by no diagnostic fauna assemblages (ostracods and mollusks), constitute the "*Lower Units*" (Zarlenga, 1987; Cavinato *et al.,* 2002), that correspond to the lower part of the "*Aielli-Pescina Supersyntheme*" in AA.VV. (2002). The finding of *Equus stenonis* (late Villafranchian) in the basal part lacustrine sedimentary sequence of Rieti ("*Upper Depositional Unit*"; Cavinato *et al.*, 1987), and of *Elephas meridionalis vestinus* (late Villafranchian) in similar deposits within the L'Aquila-Scoppito basin (Esu *et al.*, 1991) refer those sediments to the lower Pleistocene, without excluding an older age for the underlying alluvial gravel and sand.

On the Adriatic margin, the marine sedimentary environment persisted with the deposition, from the bottom to the top, of neritic-littoral sand and of thick pelitic clay with lenses and layers of conglomerate (Cantalamessa *et al.*, 1986; Centamore & Micarelli, 1991; Bigi *et al.*, 1997). This sequence and the minor cycles within it are bounded by angular unconformities in the innermost and marginal sectors of the basin, while in the deeper sectors the corresponding deposits are characterized by higher thickness and depositional continuity (Cantalamessa *et al.*, 1986; Bigi *et al.*, 1997; Bigazzi *et al.*, 2000; Centamore & Nisio, 2003). At Bellante, in the upper part of the sequence, a tephra layer, dated 2.13±0.10 Myr (Bigazzi *et al.*, 2000), has been found just below a minor erosion surface (Nisio, 1997) over which neritic conglomerate and sand unconformably lay (Centamore & Micarelli, 1991; Cantalamessa *et al.*, 2002). These latter sediments are truncated by another erosion surface which records a hiatus corresponding to the upper portion of the *Globorotalia inflata* zone (late upper Pliocene); they are unconformably overlain by Sicilian sandy and gravelly sediments, deposited in a submerged and then emerged beach environment, thus recording the progressive eastward shift of the coastline (Cantalamessa *et al.*, 1986; Bigi *et al.*, 1997; Bigazzi *et al.*, 2000).

3.4 Middle Pleistocene

Around 0.8 Myr, on the Tyrrhenian flank of the Apennines the depositional environment changed laterally from marine littoral in the more depressed areas (e.g. Piana Pontina) (Casto & Zarlenga, 1997, Barbieri *et al.*, 1999) to continental/marine transitional (at Ponte Galeria, west of Rome) and continental in the area of Rome (Marra & Rosa, 1995).

In the intermontane basins, the lower Pleistocene lacustrine clay are generally unconformably overlain by coarser sediments which record the transition to alluvial environment. These sediments are frequently entrenched within the lacustrine deposits. The finding of *Equus altidens* (lower-middle Galerian) in a buried soil at the base of coarse alluvial sediments in the Giovenco Valley allows to refer them to the middle Pleistocene (Blumetti *et al.*, 1997). In the L'Aquila-Fossa basin, lacustrine sand and clay are dated as middle Pleistocene by the occurrence of *Elephas (P.) antiquus* (Galerian) (Esu *et al.*, 1991; Bertini & Bosi, 1993).

Magma upwelling along pre-existing NW-SE trending fracture allowed the development of the intra-Apenninic volcanic vents of Cupaello, Polino, San Venanzo, and Colle Fabbri (Barberi & Innocenti, 1980; Michetti & Serva, 1990; Cavinato *et al.*, 1994). In particular, in the Rieti basin, the lava of Cupaello (dated around 0.4 Myr) flowed over a fault slope, related to the extensional tectonics that generated the present geometry of the basin itself (Barberi & Innocenti, 1980).

At least two orders of middle Pleistocene fluvial terraces are present along the main valleys (Bigi *et al.*, 1995; AA.VV., 2002). In the Corno Valley the oldest fluvial terraces, located at an elevation of 940 m a.s.l. and around 300 m above the present valley bottom, contain an ash layer dated 0.520±0.005 Myr (AA.VV., 2002). Moreover, these terrace deposits are locally interfingered with alluvial fan sediments, in which remnants of *Megaloceroides verticornis*, *Megaloceros cf. M. savini, Stephanorinus* sp, *Elephantidae* gen., *Elephas antiquus* have been found; this fossil assemblage is typical of the lower part of middle Pleistocene (AA.VV., 2002).

Reworked volcanic layers, dated 0.562±0.004 Myr, have been found in sand and carbonate silt (upper part of the "*Aielli-Pescina Supersyntheme*") around Fiorata, in the Sulmona basin (AA.VV., 2002).

In the Fucino area the older deposits of the "*Upper Units*" (Cavinato *et al.*, 2002), corresponding to the upper part of the "*Aielli-Pescina Supersyntheme*" and to the "*Catignano Syntheme*" (AA.VV., 2002), are fluvial and deltaic sand and conglomerate, interfingered with lacustrine clay and unconformably overlying the "*Lower Units*" (Cavinato *et al.*, 2002). A volcanic level found in a core drilled in the lacustrine sediments has been dated 0.541±0.009 Myr by $^{39}Ar/^{40}Ar$ method (Narcisi, 1995).

On the Adriatic margin of the central Apennines, over an erosion surface that presently reaches a maximum elevation of 470 m a. s. l., alluvial deposits lay down (Cantalamessa *et al.*, 1986; Bigi *et al.*, 1995).

At Colle Picconetto, near Catignano, a buried soil overlain by an ash layer dated 0.48±0.04 Myr, has been referred to Middle Pleistocene because of the small mammal faunas and continental molluscs assemblage (Marcolini *et al.*, 2000). A similar faunal assemblage has been found in the Valdarno basin, within alluvial gravel and sand overlain by a volcanic layer dated around 0.5

Myr (Bigazzi *et al.*, 2000).

In middle Pleistocene two cold and arid periods induced the formation of stratified slope deposits (Coltorti & Dramis, 1988). North of the study area, in the Norcia and Cascia basins, at the top of the oldest sediments some soils developed; they have been dated 0.25-0.29 Myr by K/Ar method (Coltorti *et al.*, 1987). The stratified slope deposits are often interfingered with fluvial sediments of the terraces.

3.5 Upper Pleistocene-Holocene

Along the Tyrrhenian coastal belt, several orders of marine terraces developed in the upper Pleistocene-Holocene. Terraced marine sediments containing *Strombus bubonius* (Tyrrhenian stage) are presently located at elevation ranging from 27 m (Tarquinia) to 20 m (Palidoro) and 6-12 m (southern Latium) (Blanc, 1935, 1936; Hearty & Dai Pra, 1986; Radtke, 1986; Dai Pra, 1995 and references within; Palieri & Sposato, 1988). Pebbly and gravely continental deposits, cropping out close to Pomezia, have been referred to Tyrrhenian by Malatesta & Zarlenga (1985).

In the Pontina Plain, coastal, lagoon, and eolian sediments have been dated as upper Pleistocene and Holocene (Barbieri *et al.*, 1999; Sevink *et al.*, 1984). More to the north, a 50 m thick clayey and sandy sequence, deposited in a coastal-lagoon-brackish environment, has been drilled close to Tiber River mouth (Carboni, 1993).

In the Apenninic range, the lacustrine environment, characterized by the deposition of clayey, sandy clayey and peaty sediments, persisted, where the intermontane basins like Fucino continued to be internally drained (D'Agostino *et al.*, 2001).

Moraine, loess, slope deposits, alluvial fan, and fluvio-lacustrine sediments, precisely dated by the occurrence of tephra layers, record the strong climatic changes of the upper Pleistocene-Holocene (Frezzotti & Giraudi, 1992; Giraudi, 1998 a, b, 2001). The interaction of these climatic variations with the deep stream incision caused by the regional uplift continued to form alluvial terraces (Coltorti & Dramis, 1988; Dramis, 1992). In the Velino Valley, the third order of alluvial terraces contains travertine dated 0.080-0.18 Myr by U/Th method (Carrara *et al.*, 1992).

On the Adriatic side of the range, continental deposits (alluvial fan and alluvial plain gravels) containing silty-travertine layers have been referred to the upper Pleistocene-Holocene (Cantalamessa *et al.*, 1986, Bigi *et al.*, 1997; Cantalamessa *et al.*, 2002). In particular, three orders of fluvial terraces formed in the valleys; the younger order developed in the Holocene (Calderoni *et al.*, 1996).

4. DISCUSSION

The results from reviewing the available literature on the continental and marine successions cropping out on both sides of central Apennines and in the intermontane basins highlight some stratigraphic elements that provide time constraints for the recent evolution of the study area, in the context of an uplifting mountain chain affected by extensional tectonics.

After the Messinian regression, in the late Miocene-lower Pliocene a marine transgression occurred in the backarc basins on the western flank of the chain, whereas to the east littoral sand and fluvial and delta conglomerate unconformably overlay turbidite deposits in the foredeep and thrust-top basins. The conglomerate were mostly supplied with locally outcropping carbonatic and flysch rocks, even if clasts were originated from very distant sources (Accordi & Carbone, 1988; Cipollari *et al.*, 1999 b). The well expressed erosion surface overlain by coarse conglomerate deposited in a continental environment suggests that the forming Apennines were partially emerged and eroded by surface processes.

In Middle Pliocene, on the western flank of the range, the depositional environment changed from bathial to littoral and shoreline (Brandi *et al.*, 1970; Ambrosetti *et al.*, 1987; Barberi *et al.*, 1994) indicating

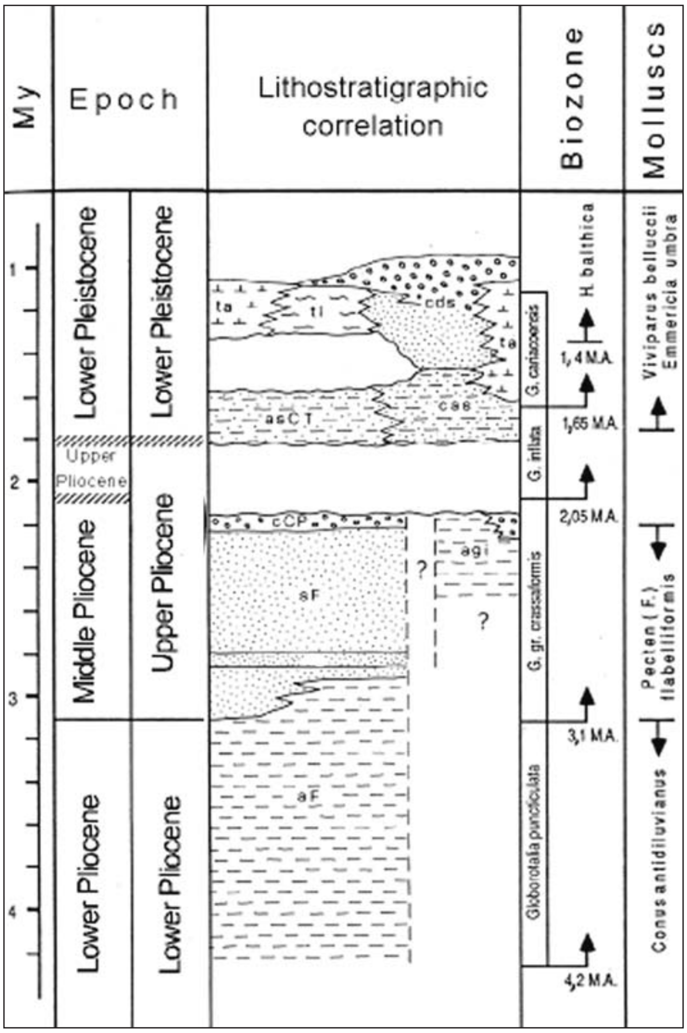

Fig. 2 - Sketch of the Tiber Basin in the southern Umbria stratigraphy (from Ambrosetti et al., 1987, modified) as an example of basin evolution on the Tyrrhenian flank of the Apennines. Marine succession: aF) "Argille di Fabro"; sF) "Sabbie a Flabellipecten"; cCP) "Conglomerato di Città della Pieve"; asCT) "Argille sabbiose del Chiani-Tevere". Continental succession: agi) "Argille grigie inferiori"; cas) "Complesso argilloso-sabbioso"; tl) peat and slime; ta) travertine; cds) thick debris deposits.

marine regression. A depositional hiatus after 2.1 Myr followed (Fig. 2), corresponding to at least a portion of the *Globorotalia inflata* zone (upper Pliocene). This relatively strong sea level lowering occurred regionally, as suggested by the erosion surface above a 2.1 Myr old volcanic layer at Bellante, in the periadriatic basin (Fig. 4). The presence of angular unconformities within the sedimentary sequence testifies the progressive tilting of the periadriatic basin as a consequence of the interaction of the slow emersion of the chain and the sea level changes.

The middle-upper Pliocene marine deposits are coarser close to the flanks of the present chain indicating that the axial part of the Apennine had already emerged (Fig. 3). Here, geomorphic processes shaped a low relief landscape whose fragmented relics are presently visible in the summit portion of the chain.

In the emerged Apenninic range, between the upper Pliocene and lower Pleistocene, extensional tectonics gave rise to NW-SE trending normal faults that, displacing the previous low relief landscape, generated several intermontane depressions (Fig.3). The first deposits associated to the formation of these basins are coarse breccia and blocks, that are interfingered and overlaid by lacustrine sediments. The coarse breccia have been probably generated on bare slopes in cold-dry conditions during the upper Pliocene (Shackleton *et al.*, 1984; Horowits, 1989). Gravitational processes, probably triggered by high magnitude earthquakes, mobilized this weathering material together with the huge blocks and transported them up to some kilometers far from the feeding areas (Demangeot, 1965; AA.VV., 2002). Unfortunately, there are no precise chronological data for this event, but since the breccias are overlain

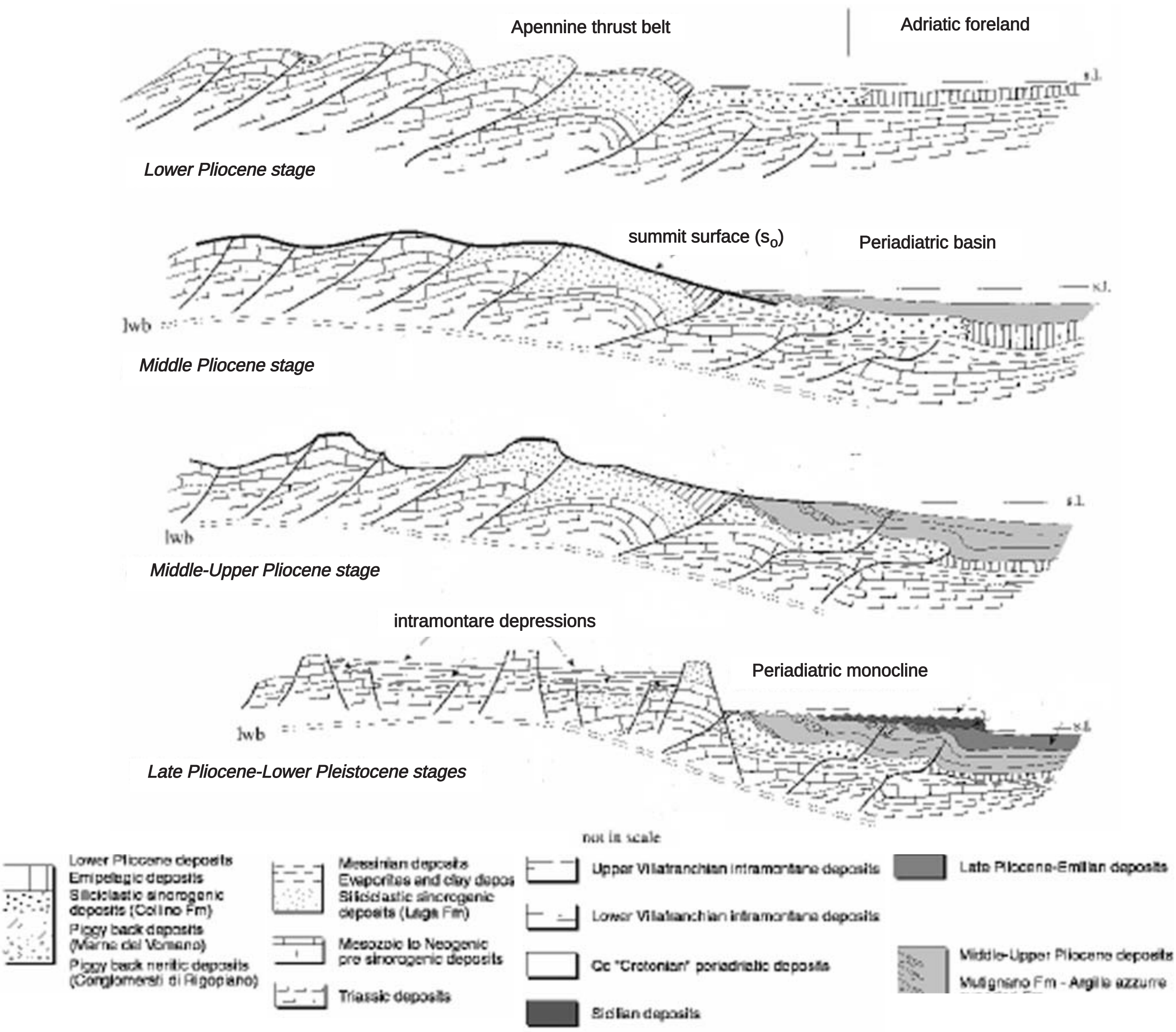

Fig. 3 – Sketch of the Lowe Pliocene-Lower Pleistocene evolution of the eastern Apennine flank and of the adjacent Periadriatic basin (from Centamore & Nisio, 2003, modified). Whereas the Apennines were uplifting, being affected by extensional tectonics and shaped by surface processes, in the Periadriatic basin several cycles of marine deposits lay down and successively were tilted and emerged as e result of the uplift and of the progressive eastward shifting of the coastline.

by lower Pleistocene deposits, we could hypothesize that they could be referred to the same cold and dry climatic phase that induced marine regression after 2.1 Myr, in correspondence with the *Globorotalia inflata* biozone.

During lower Pleistocene, as a consequence of more humid and warm climatic conditions (Shackleton *et al.*, 1984; Horowits, 1989) in the intermontane basins, the sedimentation became coarser, but the persistence of lacustrine or low gradient fluvial environment suggests that the basins were internally drained (D'Agostino *et al.*, 2001). In the Santernian, marine transgression occured in both the Adriatic and Tyrrhenian margins (Figg. 2, 4).

Around 0.8 Myr B.P., on both flanks of the range, the marine regression relative to the isotopic stage 22 induced backward coastline shifting and the deposition of transitional marine/continental and continental deposits. Contemporaneously a marked increase in the uplift rate of the Apenninic range occurred; this strong uplift, reported all along the Italian peninsula (Ambrosetti *et al.*, 1982; Ciaranfi *et al.*, 1983; Dramis, 1992; Moretti, 1993; Tortorici *et al.*, 1995; Calamita *et al.*, 1999; Coltorti & Pieruccini, 2000; D'Agostino *et al.*, 2001), induced widespread deep fluvial erosion (Fig. 3). Therefore, most intermontane depressions were reached by the headward river erosion which breached the basin thresholds, draining off the lakes and cutting the filling sediments. The interaction between the uplift and the strong climatic changes of the middle-upper Pleistocene generated several orders of fluvial and marine terraces along the Tyrrhenian coast. The formation of the fluvial and marine terraces was alternate because during cold periods, the sea level drop induced rivers to incise downstream, whereas large amounts of sediments from poorly vegetated valley slopes were washed in the rivers upstream. Conversely, during warm periods, the sea level rise induced aggradation towards the mouth and incision upstream.

On the Adriatic flank, the lower Pleistocene coastal deposits, uplifted and tilted to the NE, were isolated on the interfluves by the strong stream incision, whereas five orders of fluvial terraces formed along the valleys until the Holocene.

On the basis of the reviewed data and of their discussion we could point out that the topographic growth of the Apennines began at least in the Miocene when the extension was affecting only the western portions of the deforming thrustbelt. No data suggest that strong changes of the uplift rate occurred until the end of lower Pleistocene, when a long-wave uplift affected the Apennines and the Tyrrhenian and Adriatic coastal belts. This is confirmed by the present maximum elevation (470-480 m) of the lower Pleistocene shorelines and relative deposits on both flanks of the chain (Girotti & Piccardi, 1994; Bigi *et al.*, 1995). On the Latium coastal belt, the maximum elevation of the Tyrrhenian marine terrace is around 27 m (Palieri & Sposato, 1988). According to these data and their discussion, we could roughly calculate an uplift rate of around 0.5 mm/yr in the last ~1 Myr.

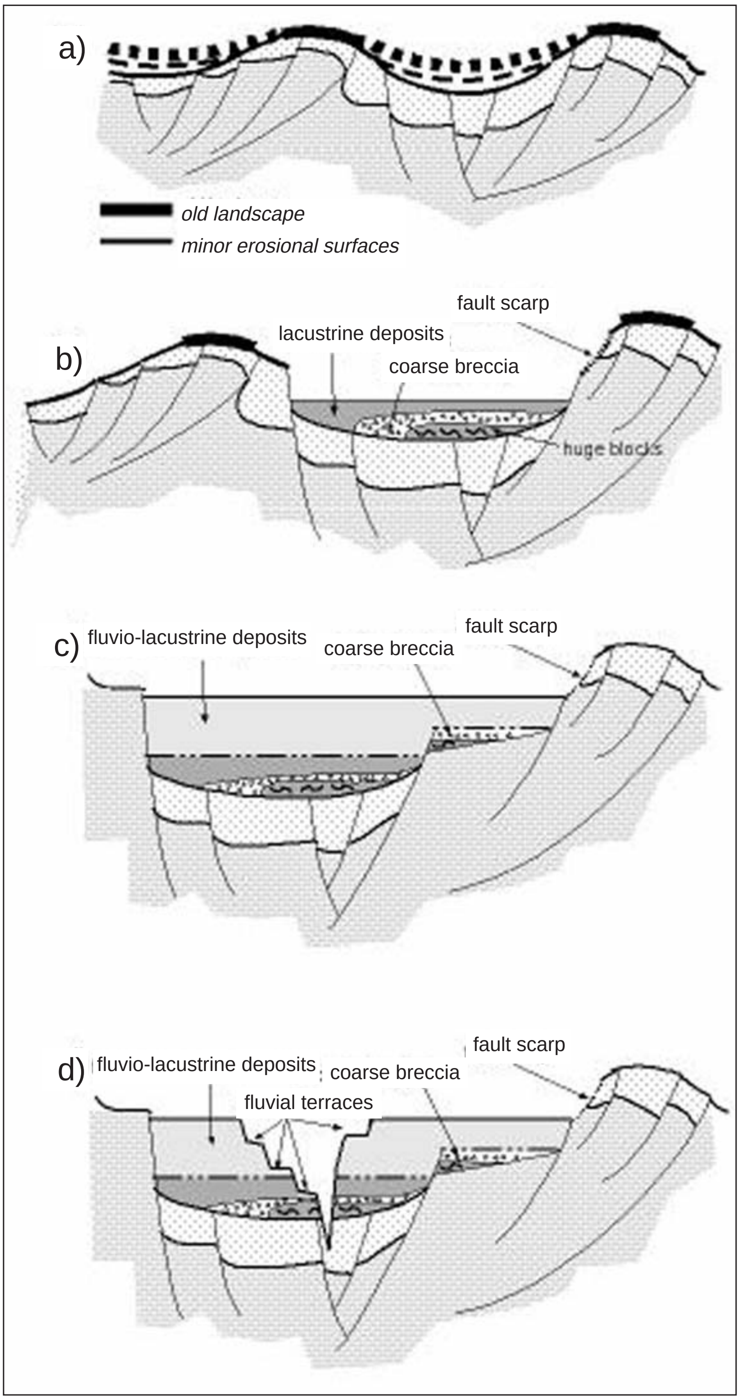

Fig. 4 - Sketch of the Pliocene-Middle Pleistocene evolution of an intermontane depression (from Centamore & Nisio, 2003, modified). a) In the Pliocene, the forming Apennines were partially emerged and surface processes shaped a low relief landscape presently located on the summit portion of the chain. b) In the Upper Pliocene-Lower Pleistocene the intermontame depressions were filled mostly by coarse breccia and lacustrine deposits. c) At the end of the Lower Pleistocene the lacustrine and/or low gradient fluvial deposits suggest that the basins were internally drained. d) In the middle Pleistocene, a marked increase in the uplift rate induced the headward stream erosion to enter in the intermontane basins and to incise their deposits.

5. CONCLUSION

In this paper we examine most of the available literature data on the continental and marine successions cropping out on both sides of the central Apennines and within the intermontane basins. We focus on the sedimentary features and stratigraphic elements that could provide time constraints on the recent evolution of the study area in the context of an uplifting mountain chain affected by extensional tectonics. The obtained results are consistent with a mostly continuous and slow uplift, started in the upper Miocene-lower Pliocene and followed by a phase of higher uplift rate by the end of lower Pleistocene. This uplift increase induced an equally strong change in the landscape of the Apennines, as suggested by the geomorphological and stratigraphical evidences of the intermontane basins, not only in the Latium-Abruzzo area, but also all along the central Apennines (for example Norcia, Colfiorito, Terni basins). They indicate that the general drainage system changed from internally drained fluvial-lacustrine basins to open river systems, delivering their sediments from the intermontane basins to the Adriatic and Tyrrhenian seas.

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